Abstract

Glaciers and proglacial areas are rapidly changing due to the climate crisis, therefore, their characterization and monitoring are necessary to assess the risks of water shortage, landslides, glacial lake outburst floods, and other impacts on natural and anthropic environments. Glaciers and proglacial areas are complex systems that have been historically studied from several perspectives and disciplines, such as mathematics, geophysics, glaciology, geomorphology, geomatics, hydraulics, etc. Only multidisciplinary approaches can view those systems considering all the variables in play.

Geophysics, and in particular the Ground Penetrating Radar (GPR) technique, have been the preferred tool to investigate the thickness of a glacier. It may also reveal cavities, hydraulic networks, bedrock features, crevasses, and other elements. In proglacial areas, it may be employed to study proglacial lakes or permafrost, for example. However, being an indirect exploration method (i.e. it displays the subsurface geometries and properties without physical access to the subsurface itself), other ground-proof data are needed to correctly interpret GPR data. Moreover, various sources of interference can be present, and the survey resolution is hampered by the logistical issues of harsh environments.

Employing the GPR as the primary tool, three methodologies were developed, which integrate other disciplines to overcome some of the GPR downsides, in three typical study sites: a glacier, a proglacial lake, and a snow field.

The first methodology employs ice-thickness algorithms to help the interpretation of GPR surveys of glaciers, to enhance the survey resolution, and to contrast the meltwater-induced signal scattering, which is often enough to hide the correct bedrock detection. Three algorithms were used that, starting from the surface topography of a glacier, employ ice-flux dynamics equations and produce models of the ice thickness. The results were interpreted jointly with the GPR scattered

radargrams to obtain a more reliable estimation of the inner geometry of the studied glacier.

The second methodology integrates geophysical and geotechnical techniques to assess the sedimentation in a proglacial lake. A 200 MHz GPR antenna was able to display the bathymetry of a 10-m-deep lake and the thickness of its fine sediment layer. A Time-Domain Reflectometer estimated the electrical permittivity and conductivity of the sediments. The permittivity was needed to understand the propagation velocity of the GPR signal in the sediments, to convert travel times to sediment thickness. The conductivity evidenced spatial variations: it was lower near the inflows, where the sediment layer was also thickest. The grain-size distribution analysis proved that the spatial variations in conductivity were linked to different kinds of sediments. This link was exploited to speculate that the geotechnical properties of the sediments, measured on a few samples, can be representative of the sediments deposited throughout the lake (except the inflows), after observing their homogeneous geoelectrical/electromagnetic properties.

The third methodology is a drone prototype that can carry a GPR antenna over inaccessible or dangerous areas: the logistics and safety issues are central in mountain fieldwork. A prototype was built using materials that do not interfere with the GPR signals, and tuned to carry a heavy payload at high altitudes, to make it possible to use different GPR antennas (tested from 70 to 900 MHz) on the same vehicle. Interestingly, the test on a snow field to simulate a snow-water equivalent measurement, also revealed that some sensors used for flight purposes can be used to better interpret the GPR data.

In all three tested methodologies, the integration with other disciplines was key to facing the challenges of GPR surveys in glacial and proglacial environments. The presented approaches contain a certain degree of site-specificness because they were developed for the specific needs of researching the Rutor basin (Aosta Valley, European Alps). However, those methodologies can be adjusted for the surveying needs of other glaciers and proglacial areas.