Development of a drone-based GPR system for alpine glacier surveying

Bastien Ruols[1], Ludovic Baron[1], and James Irving[1]
[1] Institute of Earth Sciences, University of Lausanne, Switzerland

Ground-penetrating radar (GPR) has served as a key tool in the field of glaciology for more than 50 years thanks to the excellent propagation characteristics of radar waves in ice. In alpine glacier environments, the GPR method has been successfully used to (i) determine ice thickness and monitor the nature of the glacier bed; (ii) locate internal layering; (iii) identify shear zones and crevasses; (iv) map internal water bodies; (v) estimate ice water content; (vi) distinguish between cold and temperate ice; and (vii) identify and characterize englacial and subglacial channels. Typically, alpine glacier GPR surveys are carried out directly on the surface of the ice (e.g., by walking, skiing, or with snowmobiles), or via helicopter several tens of meters above the glacier. An advantage of helicopter-based acquisitions is that they permit the coverage of large areas; however, this comes at the expenses of reduced resolution of glacier internal structure, in particular in the context of 3D surveys. With ice-based acquisitions, on the other hand, detailed 3D imaging is possible, but it is extremely time consuming to cover large areas. Further, surface features such as crevasses and moulins can make such surveys extremely dangerous and render many regions of the glacier inaccessible. Recent advances in the development of uncrewed aerial vehicles (UAV) open new data acquisition possibilities for glacier GPR data, which combine the advantages of these surveys.

We are in the process of developing a drone-based GPR system that allows for safe and efficient high-resolution 3D and 4D data acquisition on alpine glaciers. Our custom-built GPR instrument uses real-time sampling to record traces of length 2800 ns, which corresponds to a depth of over 200 m in glacier ice. Each trace is stacked over 5000 times and acquired using a sampling frequency of 320 MHz, the latter of which is just enough to avoid aliasing with our lightweight, 70-MHz-center-frequency antenna. Traces are recorded at a rate of 14 Hz, meaning that a drone speed of at least 4 m/s can be considered while maintaining a sufficiently high trace density for high-resolution studies. This is at least four times faster than a conventional survey on foot. The total weight of our GPR system plus single transmit/receive antenna is around 2 kg. The drone used in our work has a maximum payload capacity of about 6 kg, and is equipped with a radar-based ground sensor which enables us to follow the glacier surface topography during the flights at a minimum height of 1.5 m. An independent differential GPS allows us to locate each recorded GPR trace with decimeter precision.

We performed initial tests with the above-described system in August 2021 on the Otemma Glacier in the Swiss Alps. This glacier has been previously studied in detail by our group with multiple foot-based GPR surveys, and thus provides an excellent opportunity for comparison in terms of data quality. Around one-hundred-line kilometers of GPR data were recorded over a 10-days period. The recorded data include dense 3D grids as well as numerous 2D survey lines that cover a large portion of the glacier, including some profiles across the entire valley. These first field results show the concrete benefit of drone-based GPR surveys and motivate further development towards 3D and 4D studies.