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Drone-based GPR system for 4D glacier data acquisition

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Thanks to the excellent propagation characteristics of radar waves in ice, ground-penetrating radar (GPR) has been one of the key geophysical methods used in the field of glaciology over the last 50 years. Alpine glacier GPR surveys are typically performed either directly on the glacier surface (e.g., on foot, skis, or with snowmobiles), or by helicopter several tens of meters above the surface. Helicopter-based surveys allow the coverage of large areas safely and efficiently, but this comes at the expense of reduced resolution of glacier internal structures, particularly in the context of 3D surveys. On the other hand, ice-based acquisitions offer high-resolution opportunities, but are very time-consuming, often risky, and can be physically exhausting to perform. Recent advances in the development of drone technologies open new data acquisition possibilities for glacier GPR data, combining the advantages of both ice and air-based methods.

We have developed 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 single 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. An independent differential GPS allows us to locate each recorded GPR trace with decimeter precision.

We performed initial testing of the above-described system in August 2021 on the Otemma glacier and successfully acquired around 70-line kilometers of 3D GPR data, over an 8-day period, covering a large portion of the glacier. In September 2021, we undertook additional fieldwork on the Tsanfleuron and Sex-Rouge glaciers and recorded 30-line kilometers of 3D GPR data in less than 3 days. We could then determine and model with high-precision the ice-thickness distribution over the Tsanfleuron pass. These first field results show the concrete benefit of drone-based GPR glacier surveys and motivate further development towards 3D and 4D studies.