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Detecting anisotropy using Distributed Acoustic Sensing and fibre-optic seismology in a fast-flowing glacier in Greenland

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Material anisotropy within a glacier both influences and is influenced by its internal flow regime. Anisotropy can be measured from surface seismic recordings, using either active sources or natural seismic emissions. In the past decade, Distributed Acoustic Sensing (DAS) has emerged as a new, and potentially transformative, seismic acquisition technology, involving determining seismic responses from the deformation of optical fibres. Although DAS has shown great potential within engineering and resources sectors, it has not yet been widely deployed in studies of glaciers and ice masses.

Here, we present results from a glaciological deployment of a DAS system. In July 2019, a Solifos BRUsens fibre optic cable was installed in a 1050 m borehole drilled on Store Glacier in West Greenland. Vertical seismic profiles (VSPs) were recorded using a Silixa iDAS interrogation unit, with seismic energy generated with a 7 kg sledgehammer striking a polyethene (UHMWPE) impact plate. A three-day sequence of zero-offset VSPs (with the source located ~1 m from the borehole top) were recorded to monitor the freezing of the cable, combined with offset-VSPs in along- and cross-flow directions, and radially at 300 m offset.

P-wave energy (frequency ~200 Hz) is detectable through the whole ice thickness, sampled at 1 m depth increments. The zero-offset reflectivity of the glacier bed is low, but reflections are detected from the apparent base of a subglacial sediment layer. S-wave energy is also detectable in the offset VSP records. The zero-offset VSPs show a mean vertical P-wave velocity of 3800 ± 140 m/s for the upper 800 m of the glacier, rising to 4080 ± 140 m/s between 900-950 m. In the deepest 50 m, velocity reduces to 3890 ± 80 m/s. This variation in vertical velocity is consistent with the development of an anisotropic ice fabric in the lowermost 10% of the glacier. The full dataset also contains natural seismic emissions, highlighting the potential of DAS as both an active and passive seismic monitoring tool.

DAS offers transformative potential for understanding the seismic properties of glaciers and ice sheets. The simplicity of the typical VSP geometry makes the interpretation of seismic travel-times less vulnerable to approximations, and thus the derivation of seismic properties more robust, than

in conventional surface seismic surveys. As an addition, DAS facilitates VSP recording with unprecedented vertical and temporal resolution. Furthermore, the sensitivity of the optical-fibre to both P- and S-wave particle motion means that a comprehensive suite of acoustic and elastic properties can be inferred.