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Fibre-optic observation of volcanic tremor through floating ice sheet resonance

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We report on the indirect observation of low-frequency tremor at Grimsvötn, Iceland, via resonance of an ice sheet, floating atop a volcanically heated subglacial lake.

Entirely covered by Europe's largest glacier, Vatnajökull, Grimsvötn is among Iceland's largest and most active volcanoes. In addition to flood hazards, ash clouds pose a threat to settlements and air traffic, as direct interactions between magma and meltwater cause Grímsvötn to erupt explosively. To study the seismicity and structure of Grimsvötn in detail, we deployed a 12.5 km long fibre-optic cable around and inside the caldera, which we used for Distributed Acoustic Sensing (DAS) measurements in May 2021.

The experiment revealed a previously unknown level of seismicity, with nearly 2'000 earthquake detections in less than one month. Furthermore, the cable segment within the caldera recorded continuous and nearly monochromatic oscillations at 0.23 Hz. This corresponds to the expected fundamental-mode resonance frequency of flexural waves within the floating ice sheet, which effectively acts as a damped harmonic oscillator with Q around 15.

In spite of the ice sheet being affected by ambient noise at slightly lower frequencies, the resonance amplitude does not generally correlate with the level of ambient noise throughout southern Iceland. It follows that an additional and spatially localised forcing term is required to explain the observations. A linear inversion reveals that the forcing acts continuously, with periods of higher or lower activity alternating over time scales of a few days.

A plausible explanation for the additional resonance forcing is volcanic tremor, most likely related to geothermal activity, that shows surface expressions in the form of cauldrons and fumaroles along the caldera rim. Being largely below the instrument noise at channels outside the caldera, the ice sheet resonance acts as a magnifying glass that increases tremor amplitudes to an observable level, thereby providing a new and unconventional form of seismic volcano monitoring.