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Seismic Network in Greenland Monitors Earth and Ice System

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Some of the most dramatic effects of climate change have been observed in the Earth's polar regions. In Greenland, ice loss from the Greenland ice sheet has accelerated in recent years [*Shepherd et al.,* 2012]. Outlet glaciers are changing their behavior rapidly, with many thinning, retreating, and accelerating [*Joughin et al.,* 2004]. The loss of ice weighing on the crust and mantle below has allowed both to rebound, resulting in high rock uplift rates [*Bevis et al.,* 2012]. Changes in ice cover and meltwater production influence sea level and climate feedbacks; they are expected to contribute to increasing vulnerability to geohazards such as landslides, flooding, and extreme weather.

Recent investigations of the causes and consequences of changes in the Greenland ice sheet have highlighted the links between the ice–ocean–atmosphere–solid Earth system and the need for better observations of all four parts of the system. Advancements in seismic and geodetic technology are now being harnessed to observe and document the rapid changes occurring in the ice sheet and to illuminate interactions between multiple Earth systems.

The Greenland Ice Sheet Monitoring Network (GLISN) project—a collaboration between Canada, Denmark, France, Germany, Italy, Japan, Norway, Poland, South Korea, Switzerland, and the United States—provides real-time broadband seismological observations to help address critical, poorly understood aspects of the Arctic system (Figure 1). Geodetic observations are also included at selected stations. Seismic data from GLISN record changes at high temporal resolution and reflect deformation and structures internal to the ice and solid Earth. These data complement existing observations from satellite and airborne remote sensing, ice-penetrating radar, and GPS geodesy.

GLISN Objectives and Network Description

Historically, seismology in the Arctic has been limited by the sparsity of available data, a result of the harsh climate and remoteness of most areas of Greenland. GLISN aims to change this by developing a high-quality broadband seismic network in Greenland with uniform station spacing, delivering open data in near-real time.

Launched in 2009, the GLISN project completed installation of all 33 initially planned seismic stations in August 2013. Most GLISN stations in Greenland are installed on bedrock along the ice-free coast at sparsely populated settlements to take advantage of existing power and communications infrastructure. Four stations are installed in the ice. Additional stations surrounding Greenland—in Canada, Iceland, and on several Norwegian islands—allow scientists to gain a broad view

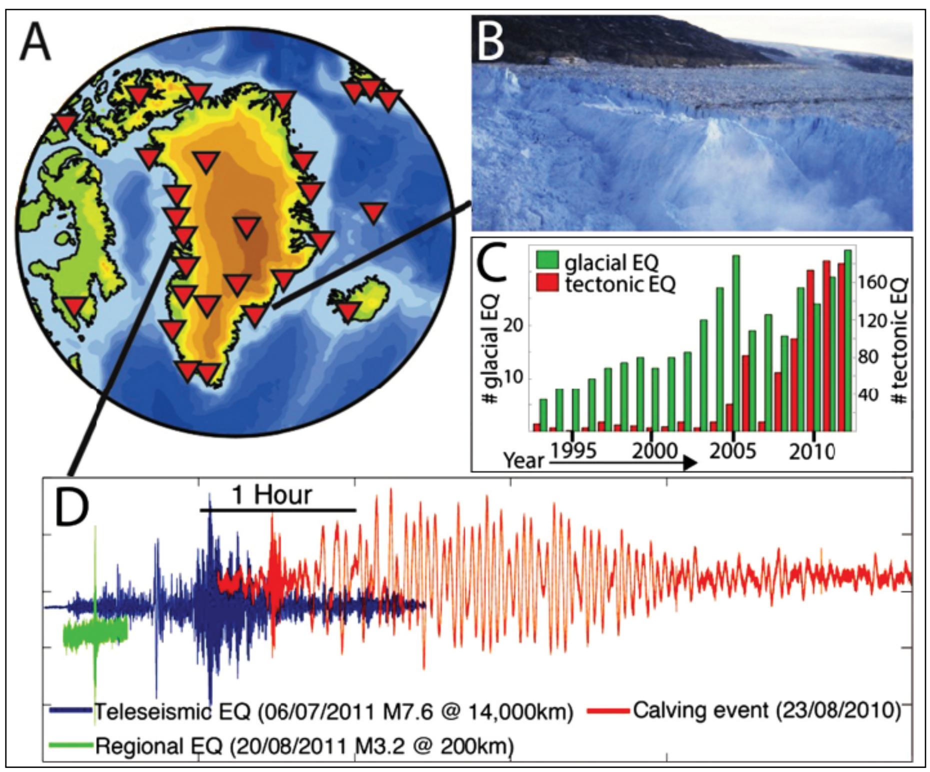

Fig. 1. (a) Locations of seismometers (red triangles) in the Greenland Ice Sheet Monitoring Network (GLISN). Contours indicate bathymetry and topography. (b) Detachment of a large iceberg from Helheim Glacier near GLISN station ANGG causes a glacial earthquake [after Nettles and Ekström, *2010]. (c) Number of recent glacial (green) and tectonic (red) earthquake detections in Greenland. The increase in glacial earthquake detections reflects the retreat of glacier margins around Greenland; the increase in tectonic earthquake detections results from better seismometer coverage. (d) Seismograms recorded at GLISN station NUUG [*Walter et al., *2013] (reprinted from* Journal of Glaciology *with permission of the International Glaciological Society).*

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of Greenland's structure and changes in the ice.

Three of the ice sheet stations include geodetic-quality GPS, and many stations on rock are loosely co-located with Greenland GPS Network (GNET) stations [*Bevis et al.,* 2012]. High-fidelity continuous broadband data collected at a rate of 100 samples per second (sps) are now recorded year round, even at remote sites with little or no winter sunlight. In the most remote regions, data sampled at 1 sps are retrieved using Iridium satellite modems, with the complete data set retrieved during maintenance visits. Elsewhere, the full data stream is transmitted in near-real time. Data return rates average more than 95%.

Quality-controlled data from all 33 GLISN seismic stations are openly available from the Data Management Center of the Incorporated Research Institutions for Seismology (http://www.iris.edu/dms) and the European Integrated Data Archive (http://www.orfeus-eu.org/eida); GPS data are available from UNAVCO (http://www.unavco.org).

Data Usage

The GLISN project has already provided valuable data for multiple studies. Data from the network (Figure 1) have been used to improve analysis of glacial earthquakes [*Veitch and Nettles,* 2012], which result from calving events of about 1 cubic kilometer each. GLISN stations have also been used in automatic detection of calving events by measurement of tilt associated with seiches (standing waves) in the fjords where many glaciers terminate [*Walter et al.,* 2013].

In addition, the new data have dramatically improved the detection capability for tectonic earthquakes (http://seis.geus.net/projects/glisn/geus-eqlist.html), which may respond to changes in ice loading. The data will also allow detailed mapping of crustal structures under the ice as well as mantle structure, both of which are needed for separation of elastic and viscous contributions to surface uplift—and hence for improved prediction of changes in sea level. The use of GLISN as a fiduciary reference network for targeted local seismic and geodetic studies is expected to aid in the estimation of ice sheet basal properties and fluid flow pathways through the ice.

Scientific Guidance and Opportunities

The development of the GLISN geophysical network has been made possible by a high level of international cooperation. GLISN welcomes new partners and encourages active communication with the scientific community. Scientific and technical guidance for the GLISN effort is provided by the GLISN International Steering Committee and through national organizations. More information, including contact information for all steering committee members, is available at http://www.glisn.info.

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