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Observing and interpreting signals of unrest in high-latitude, remote, glacier-covered volanoes

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Volcanoes located at high latitudes are often partially or completely covered by ice, with limited or no access for observation except through remote sensing from satellite or airborne radar or Lidar. The environment is often controlled by harsh climate conditions, heavy snow accumulation and darkness, restricting possibilities for observations even further. Extracting definitive information on the volcanoes' activity status from processing of scantily distributed observations proves quite difficult, often providing limited constraints on the parameters of interest. Microseismicity and seismic tremor is a robust monitoring tool of volcanic activity, but for adequate sensitivity the instruments must be sited near the volcanoes, for which rock outcrops are required or long-term stable vaults in the ice. Observations of surface deformation through GPS or InSAR processing also require rock outcrops for stable station locations or coherence on satellite images over time. Signs of increased degassing can be indicators of magmatic intrusions, but these are difficult to observe through the ice and snow. Observations of dissolved chemicals in glacial rivers sourced from the volcanoes may reveal changes in degassing, but can be highly diluted and are not always sensitive to changes. Changes in heat output due to increased geothermal activity at the glacier bed may be revealed as changes on the ice surface and cause formation or deepening of ice cauldrons, which can then be monitored with airborne radar measurements and continuous GPS stations placed in the cauldrons.

All the above observations are to some degree applied to monitor volcanoes in Iceland, where some of the country's most active volcanoes are located within or at the margin of Europe's largest glacier, Vatnajökull; in harsh environmental conditions where placement and continuous operation of in-situ observational instruments is very limited. Development and testing on Icelandic volcanoes of new or improved instrumentation and techniques include: (i) permanent, real-time seismic stations in the Vatnajökull glacier and on nunataks within the glacier, which significantly increased sensitivity to microseismicity in the subglacial volcanoes, Grímsvötn, Bárdarbunga, Kverkfjöll and to some degree Öræfajökull. (ii) Real-time operation of cGPS stations on the ice surface, which enabled monitoring of a major, slow caldera collapse at Bárdarbunga and of ice cauldron elevation and draining, forewarning of a subglacial flood, (iii) a continuous gas-in-snow monitoring instrument containing CO_2, H2S, and SO_2 sensors, which gives gas ratios consistent with other methods, and a continuous DOAS instrument for monitoring SO_2 emission, also tested on Beerenberg volcano on Jan Mayen island.

Interpretation of multidisciplinary observations and analysis from the unrest in Bárdarbunga 2014-2015 and Öræfajökull 2017 will be presented. With seismic data and analysis results at the center, we will focus on their joint interpretation with other data types. In particular we will focus on uncertainties in earthquake locations and how to obtain support and constraints from the other observations, and on how the seismic data can support interpretation of other types of small signals like weak deformation signals at the glacier margin of similar order as the glacial isostatic correction.