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Monitoring unrest in a subglacial volcano by combining thermal, meltwater conductivity and seismic signals: The Katla caldera, Iceland

Magnus T. Gudmundsson (1), Þórdís Hognadóttir (1), Kristín Vogfjord (2), Eyjólfur Magnusson (1), Hanna I. Reynolds (1), and Matthew Roberts (2)

(1) University of Iceland, Nordvulk, Institute of Earth Sciences, Reykjavik, Iceland (mtg@hi.is, 354 5528911), (2) Icelandic Meteorological Office, Iceland

Highly active ice-covered volcanoes pose problems for some of the methods used for monitoring unrest associated with magma movements in the crust. Glacier surfaces are subjected to meteorological and seasonal fluctuations in elevation at time scales ranging from hours/days to years. Such fluctuations limit the applicability of inSAR and GPS, and in general the detection of crustal deformation signals. Nunataks provide sites for GPS bench marks but the seasonal fluctuations in ice cover elevation and subglacial water pressure generate associated fluctuations in observed ground deformation. The Katla caldera in south Iceland is filled with 400-700 m thick ice, has seasonal variations in surface elevation of $\sim$10 m and basal water pressure variations suspected to be of the order of 1 MPa. Geothermal activity within the caldera is manifested as 15-20 depressions in the ice surface, typically 500-1000 m wide and 15-50 m deep. The depressions, also called ice cauldrons, are formed by geothermal melting at the base of the glacier. At some of these cauldrons meltwater collects at the glacier base and stored for some weeks or months before being drained in small outburst floods. At other cauldrons the meltwater at the base is drained away continuously, releasing geothermal waters into the rivers draining the glacier. The size and depth of the ice cauldrons in Katla has been monitored by regular overflights with a radar that measures surface elveation profiles along the flight lines. A time series of cauldron variations has been obtained since 1999. Over the same period semi-continuous records of electrical conductivity in rivers draining from the outlet glaciers from the caldera have been obtained. The data show variations in geothermal output and conductivity that broadly correlate with seismic activity. Most of the seismicity occurs at less than 2-3 km depth, in swarms consisting mostly of earthquakes of sizes <2.5-3. On a time scale of months- to-years, increases in seismicity are associated with increased geothermal activity. Two events (1999 and 2011) have occurred where cauldrons grew significantly or new were formed, leading to the release of significant amounts of meltwater from the glacier in larger outburst floods (peak discharge of few thousand m3/s). The 2011 flood swept away the bridge on the main road, causing disruption to transport along the south coast of Iceland. These events have not been properly explained, but they are clearly associated with increases in geothermal heat output and increased seismicity in the caldera. The association of these events with shallow magma migration is at present unclear but is one of the tasks FUTUREVOLC in 2012-2016 is to study these geothermal-seismicity-unrest linkages.