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Muon tomography of the La Soufrière de Guadeloupe hydrothermal system: 3-D structure and dynamics

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Muon imaging has recently emerged as a powerful method to complement standard geophysical methods in volcanology. Muon measurements yield a radiography of the average density along the muon path, allowing to image large volumes of a geological body from a single observation point. When multiple muon detectors surrounding the volcano are available, it is possible to invert these data to retrieve the 3-D density distribution in the volcano. Long-term measurements of the muon flux allow to infer density changes in the system. In the context of volcanic hydrothermal systems, this approach helps to characterize zones of steam formation, condensation, water infiltration and storage. We present the results of imaging the La Soufrière de Guadeloupe shallow active hydrothermal system with a network of muon detectors scanning the lava dome from different positions around its base. First, we jointly invert the muon data from three different detectors with gravity data to obtain a three-dimensional density model of the lava dome. The model reveals an extensive low-density region where the hydrothermal system is most active. We then analyze the dynamics of the hydrothermal system from long-term measurements (more than 2 years of almost non-interrupted acquisition), acquired by 2 simultaneous muon detectors. Shallow regions seem to evidence smaller density changes than deeper parts of the hydrothermal system (200-300 m below the summit). Among the most active regions, periods of relative calm can follow periods of quasi-periodical changes. Our simultaneous muon detector strategy provides constraints on the three-dimensional location of the density changes and an improved quantification of the associated mass changes. This works characterizes for the first time the dynamic behavior of an active hydrothermal system, at a volcano undergoing thermal and degassing unrest, at a large spatial scale and for a relatively long term (1.5 - 2 years), with a temporal resolution of $\sim$1 month.