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Pore fluid pressure evolution in volcanic environments: the role of rainfall

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There is mounting evidence that rainfall can be instrumental in triggering or otherwise modulating primary volcanic activity. Individual case studies have revealed a link between rainfall and volcanism at Piton de la Fournaise (La Réunion), Mount St. Helens, Kīlauea (both USA), Las Pilas volcano (Nicaragua), and Soufrière Hills volcano (Montserrat), among others. Additionally, there exists a wealth of anecdotal evidence of rainfall-induced volcanism around the world. Do these discrete examples reflect a prevalent underlying link between rainfall and volcanic activity?

We extract and analyse multi-decadal rainfall timeseries from satellite data to assess whether the duration and timing of annual rainfall plays a role in modulating eruption frequency at different volcanoes. By comparing observed eruption distributions over time with the theoretical probability of those distributions, we identify around three dozen volcanic systems—~15 % of the volcanoes in our pre-filtered catalogue—where the eruption record appears to be strongly correlated with the wettest parts of the year. Our analyses reconfirm previous observations at several volcanoes and suggests that they are indeed symptomatic of a broader link between volcanism and the hydrological cycle.

Shallow-seated physical explanations often involve either the thermal contraction of recently-emplaced lava, fluid-induced pressurisation of the interior of a dome, or a combination of both. Deeper-seated mechanisms include rainfall perturbing the regional stress within or applied by the volcanic edifice in one of two primary different ways: (a) by changing the load overlying the magma chamber, or (b) by changing the threshold for mechanical failure (either prompting opportunistic dyke propagation or directly facilitating magma chamber rupture).These mechanisms are underpinned by a single common process: the infiltration of meteoric water into the edifice.

We demonstrate that pressure transfer models yield pressure fluctuations at magma-relevant depths in line with previously theorised trigger stresses. Infiltration-induced quasistatic stresses can bring about a long-lived increase of pore pressure above hydrostatic, in contrast to the short-lived dynamic stress pulses observed at shallow depths. Assuming realistic fluid transport properties, we model pressure perturbations of order 10 kPa in the immediate subsurface, attenuating rapidly in the uppermost couple of kilometers. These pressure changes are a non-negligible fraction of the tensile strength of material thought to be important in dyke propagation, highlighting that the potential for time-variant fluid pressure within the edifice is an important consideration.

We anticipate that satellite-derived precipitation data will prove invaluable in integrating rainfall into future quantitative studies, volcano monitoring programs, and probabilistic hazard assessment. Aside from the possibility for initiation of primary volcanic activity, rainfall is a demonstrable driver of many secondary hazards, such as lahars, debris flows, mass movement, acid rain. As ongoing climate change is projected to result in increasingly extreme rainfall patterns over the coming century, the potential for rainfall-triggered volcanic activity may be set to increase in the future. Rainfall is both measurable and, to a degree, forecastable: the inclusion of continuous ground- and satellite-based meteorological monitoring—in tandem with simple models of pressure transfer—could prove invaluable in providing some advance warning of these hazards.