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Volcano shapes, entropies, and eruption probabilities

Agust Gudmundsson (1) and Nahid Mohajeri (2)

(1) Royal Holloway University of London, Department of Earth Sciences, Egham, United Kingdom (rock.fractures@googlemail.com), (2) Solar Energy and Building Physics Laboratory (LESO-PB), Ecole Polytechnique Federale de Lausanne (EPFL), 1015 Lausanne, Switzerland (nahid.mohajeri@epfl.ch)

We propose that the shapes of polygenetic volcanic edifices reflect the shapes of the associated probability distributions of eruptions. In this view, the peak of a given volcanic edifice coincides roughly with the peak of the probability (or frequency) distribution of its eruptions. The broadness and slopes of the edifices vary widely, however. The shapes of volcanic edifices can be approximated by various distributions, either discrete (binning or histogram approximation) or continuous. For a volcano shape (profile) approximated by a normal curve, for example, the broadness would be reflected in its standard deviation (spread).

Entropy (S) of a discrete probability distribution is a measure of the absolute uncertainty as to the next outcome/message: in this case, the uncertainty as to time and place of the next eruption. A uniform discrete distribution (all bins of equal height), representing a flat volcanic field or zone, has the largest entropy or uncertainty. For continuous distributions, we use differential entropy, which is a measure of relative uncertainty, or uncertainty change, rather than absolute uncertainty.

Volcano shapes can be approximated by various distributions, from which the entropies and thus the uncertainties as regards future eruptions can be calculated. We use the Gibbs-Shannon formula for the discrete entropies and the analogues general formula for the differential entropies and compare their usefulness for assessing the probabilities of eruptions in volcanoes. We relate the entropies to the work done by the volcano during an eruption using the Helmholtz free energy.

Many factors other than the frequency of eruptions determine the shape of a volcano. These include erosion, landslides, and the properties of the erupted materials (including their angle of repose). The exact functional relation between the volcano shape and the eruption probability distribution must be explored for individual volcanoes but, once established, can be used to assess the probability of eruptions in relation to the shape of the volcano.

These methods can also be applied to the probability of injected dykes reaching the surface in a volcano. We show how the thickness distributions of dykes can be used to estimated their height (dip-dimension) distributions and, for a given magma source and volcano geometry, their probability of erupting. From the calculated energy (mainly elastic and thermal) of the host volcano, and other constraints, the maximum-entropy method can be used to improve the reliability of the assessment of the likelihood of eruption during an unrest period.

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