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Red-flag! Automated detection of migrating seismicity leading to intrusive or eruptive events

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Volcanic eruptions are often heralded by magma movement, thus it is important for observatories to detect such motion, and as early as possible. Tracking the magma per se is challenging, but a good proxy for it is to track the seismicity that is reflecting the stress perturbations induced by the migrating magma. This can be done using Seismic Amplitude Ratio Analysis (SARA), a simple method which tracks the time evolution of the ratios of seismic amplitudes recorded at different seismic stations in a network in real time. Changes in amplitude ratios signify changes in location of the seismic activity, implying magma movement.

To quantitatively determine whether amplitude ratios are changing, we use the Mann-Kendall trend test which is based on Kendall's correlation coefficient. Using this method, we are able to accurately? pick up subtle amplitude ratio changes across different time scales.

We tested the method using synthetic seismograms simulating seismic migration. Using synthetics not only provides a controlled environment for us to observe how changes in different parameters affect the amplitude ratios, but also the means to examine a variety of scenarios, including migration in different directions, and migration amidst various degrees and spread of background events. Our results show that we are able to clearly pick up the start and end of a migration episode, as well as distinguish between the magma gushing out at the surface and the magmatic injection stalling at depth in a failed attempt to reach the surface. We also used real seismic data from Piton de la Fournaise, with episodes of known magma intrusion and migration leading to eruption, to validate our methodology. Following the success of these examples, we applied SARA on recent seismic data from Gede volcano, a volcano in western Java, in an effort to shed light on the driving forces behind the seismic swarms frequently happening there, which neither culminate in eruptions nor detectable inflation. Preliminary results suggest that these swarms do not involve magma migration, but more techniques need to be tested to completely rule out the involvement of magma.