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Aquifers as indicators of volcanic unrest - models of hydrological responses to magmatic activity and their geophysical signals

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Aquifers respond to and modify the surface expressions of magmatic activity, and they can also become agents of unrest themselves. Therefore, monitoring the hydrology can provide a valuable window into subsurface processes in volcanic areas. Interpretations of unrest signals as groundwater responses to changes in the magmatic system can be found for many volcanoes. Changes in temperature and strain conditions, seismic excitation or the injection of magmatic fluids into hydrothermal systems are just a few of the proposed processes induced by magmatic activity that affect the local hydrology. Aquifer responses are described to include changes in water table levels, changes in temperature or composition of hydrothermal waters and pore pressure-induced ground deformation. We can observe these effects at the surface via geophysical and geochemical signals. To fully to utilise these indicators as monitoring and forecasting tools, however, it is necessary to improve our still poor understanding of the ongoing mechanisms in the interactions of hydrological and magmatic systems.
An extensive literature research provided an overview on reported effects, which we investigate in detail using numerical modelling. The hydrogeophysical study uses finite element analysis to quantitatively test proposed mechanisms of aquifer excitation and the resultant geophysical signals. We present a set of generic models for two typical volcanic landforms – a stratovolcano and a caldera - that simulate the interaction between deeper magmatic systems with shallow-seated aquifers, focusing on strain and temperature effects. They predict pore pressure induced hydraulic head changes in the aquifer as well as changing groundwater temperatures and strain induced fluid migration. Volcano observatories can track these hydrological effects for example with potential field investigations or the monitoring of wells. The models allow us to explore the parameter space, contributing to a better understanding of the coupling of these two highly complex systems. Our results provide further insight into the subsurface processes at volcanic systems and will aid the evaluation of unrest signals with potential for improved eruption forecasting.