In May 2002, almost two decades after its last eruption, Mauna Loa, Hawai’i, began to inflate rapidly. Six months prior a similar inflation at Mauna Loa in 2002, relative to Kilauea.

Dynamic coupling of Kilauea and Mauna Loa, Hawai’i
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Summary

In May 2002, almost two decades after its last eruption, Mauna Loa, Hawai’i, began to inflate rapidly. Six months prior a similar inflation began at neighboring Kilauea. A numerical model that integrates GPS measurements of volcano deformation with asthenospheric and crustal magma flow demonstrates that Mauna Loa and Kilauea may be dynamically linked through an asthenospheric porous melt zone extending beneath both volcanoes. At each volcano shallow crustal magma storage reservoirs are connected to the asthenosphere by a lithospheric magma plumbing system through which changes in magma pressure are transmitted. In the asthenospheric melt zone pore pressure can diffuse between both volcanoes, resulting in the six-month delay in inflation of Mauna Loa relative to Kilauea. Since 2002, the magma added to Mauna Loa’s crustal reservoir is comparable in volume to historical eruptions of Mauna Loa.

Conceptual model

Oblique northeastward view of the Island of Hawaii’i underlain by modeled reduced pore pressure (pressure above magma-static) in an asthenospheric melt zone of high permeability, the consequence of melt accumulation by compaction (McKenzie, 1984). Magma inflow, , is based on the model of DePaolo & Stolper (1996). Streamlines (thin red arrows) show that Mauna Loa and Kilauea capture different parts of the melt source. Thick red arrows above the porous zone schematically represent vertical magma flow through Mauna Loa’s and Kilauea’s lithospheric plumbing system. Inserts show aerial view of Mauna Loa’s (left) and Kilauea’s (right) summit. Blue dots with labels indicate the locations of continuous GPS stations used to calibrate the model. Location and size of modeled deformation sources are indicated by black circles for spherical (Mogi) sources and a line for a dike beneath Mauna Loa’s summit (Amelung et al., 2007). Magma rising through Kilauea’s lithospheric plumbing system is mostly stored in the deep rift zone (DRZ) or erupts at the east rift zone (ERZ), with the remainder stored in shallow crustal reservoirs, modeled as Mogi sources labeled Halema’uma’u and South Caldera (Cervelli & Miklius, 2003). The porous flow model is coupled to kinematic deformation models through pressure dependent magma flow rates and conservation of mass.

A finite difference & lumped element model

The governing equation for the finite difference model of the asthenospheric high-permeability zone:

\[ \frac{\partial p(x,t)}{\partial t} = c^2 \nabla^2 p(x,t) + q(x,t) \]

Here p(x,t) is reduced pore pressure, t is time and x is the two-dimensional cartesian coordinate, c=10^2 m^2 s^-1 is pore-pressure diffusivity (Wang, 2000) and corresponds to a permeability within the range of empirical predictions for partially molten mantle (Holtzman et al., 2003). q(x,t) accounts for the local change in pore pressure associated with the volumetric melt flux in or out of the porous layer. Boundary conditions are no flow along the perimeter and magma supply from below, Q, modeled as a Gaussian distribution of 30 km diameter southwest of Kilauea (e.g., DePaolo & Stolper,1996; Farnetani & Hofmann, 2010). Q and Q are outflow from the porous layer. They are calculated using a conductance formulation \[ Q(t) = \alpha \left( \Phi(x,t) - P(t) \right) \] and \[ Q(t) = \alpha \left( \Phi(x,t) - P(t) \right) \], respectively, where \( \alpha = 0.018 \text{ km}^2 \text{ m} \text{ yr}^{-1} \) and denotes the spatial distribution of the source. Magma flux to the south-caldera reservoir is given by \( Q(t) = \beta \left( P(t) - P(t) \right) \), where \( \beta \) depends on P to account for the opening of magma pathways. The value of P and P depend on the change in volume of the Mogi source due to magma flux Q. The values of P and P depend on the change in volume of the Mogi source as a result of the difference in magma influx and outflux.

Inflow, Q

Deep rift zone storage, Q

Lithospheric plumbing systems

Modeled streamline

Prescribed flow rate

Calculated flow rate

The governing equation for the finite difference model of the asthenospheric high-permeability zone:

\[ \frac{\partial p(x,t)}{\partial t} = c^2 \nabla^2 p(x,t) + q(x,t) \]

Model results

Modeled time series (left). a. Prescribed rate of flow into the porous zone (Q, black), to the east rift zone (Q, red) and into the deep rift zone (Q, red dashed). Changes of Q and Q, relative to the pre-2002 steady state are determined by model calibration. b. Modeled change in pressure of Mauna Loa’s summit reservoir (blue) and Kilauea’s Halema’uma’u reservoir (red solid) and south-caldera reservoir (red dashed). c. Modeled change in volume of magma stored in Mauna Loa’s (blue) and Kilauea’s (red) summit reservoirs. d. Long period earthquakes at 45 km beneath Mauna Loa. e. Measured (blue dots) and modeled (blue line) change in distance between GPS stations MOKP and ELEP on either side of Mauna Loa’s summit, as well as measured (red dots) and modeled (red line) change in distance between GPS stations AHUP and UWEV on either side of Kilauea’s summit.

Observed and modeled GPS displacements (right). a. Measured (blue) and modeled (red) horizontal change in the position of Mauna Loa GPS stations MOKP, MLSP, and ELEP (small black circles) during the time period between 2001 and 2011. The black line shows the orientation and length of the dike modeled as a rectangular dislocation source. The black circle indicates the location and diameter of the magma chamber modeled as a Mogi source. b-d. Measured (blue) and modeled (red) horizontal change in the position of Kilauea GPS stations UWEV, KOSM, and AHUP (small black circles). The large black circle indicates the location and diameter of the south-caldera Mogi source, whereas the medium-size black circle indicates the location and diameter of the Halema’uma’u Mogi source. The modeled displacements at UWEV, KOSM, and AHUP include a component due to slip on the decollement beneath Kilauea’s south flank. GPS displacements during the time interval magma flow to the east rift zone is thought to have been blocked, resulting in a backup and inflation of the Halema’uma’u reservoir. e. GPS displacements when magma was entering the south-caldera reservoir. A better fit to GPS displacements at station KOSM would require a more complex deformation source beneath the southern caldera and upper southwest rift zone. d. GPS displacements during the deflation of Kilauea’s summit. During this time there was additional magma flow into the east rift zone from the south-caldera reservoir.

Conclusions

A much simplified representation of a complex natural system demonstrates the feasibility of an asthenospheric partial melt zone that dynamically links Kilauea and Mauna Loa volcanoes.

Modeled pore pressure diffusions between both volcanoes occurs in dynamical coupling on time scales of 1/2 year. The results are consistent with compositionally distinct magma supplied to each volcano. Deformation at Kilauea and Mauna Loa can be explained simultaneously, including the perplexing 1/2 year delay in the onset of inflation at Mauna Loa in 2002, relative to Kilauea.

References