Credit: K. Anderson (*USGS*)

Dynamics of Large Effusive Eruptions Driven by Caldera Collapse

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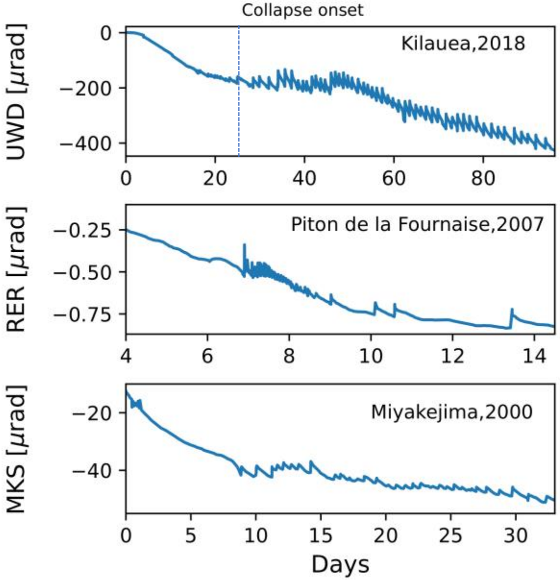
Abstract

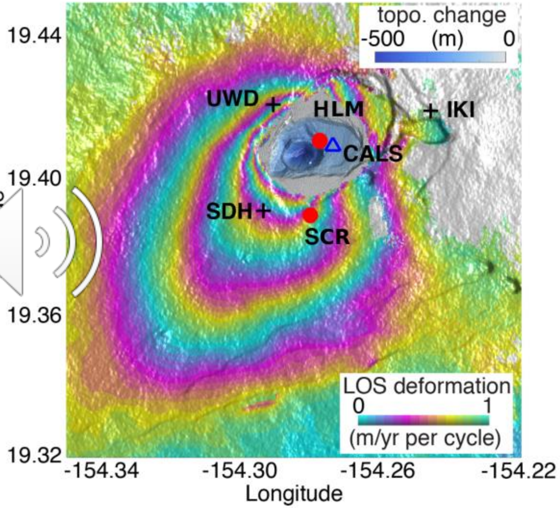
The largest effusive basaltic eruptions are associated with caldera collapse and are manifest through quasi-periodic ground displacements and moderate sized yet the mechanism governing their dynamics remains elusive. In this work we provide a new physical model to understand these processes, which accounts for both the quasi-periodic stick-slip collapse of the caldera roof and the long term eruptive behaviour. We show that it is the caldera collapse itself that sustains large effusive eruptions, and that triggering caldera collapse requires, in turn, topography generated pressures. The model is consistent with data for the 2018 Kilauea eruption and allows us to estimate for the first time, the properties of the plumbing system. The results reveal that two reservoirs were active during [illegible] eruption and constrain their connectivity. Compared to the model, the Kilauea eruption stopped after producing slightly more than 60% of its potential collapses, possibly due to the presence of the second reservoir. Finally, we show that this physical framework is generally applicable to the largest instrumented caldera collapse eruptions of the past fifty years.

Caldera Forming Eruptions: Surface Deformation

Deformation in time (Tilt)



Deformation in space

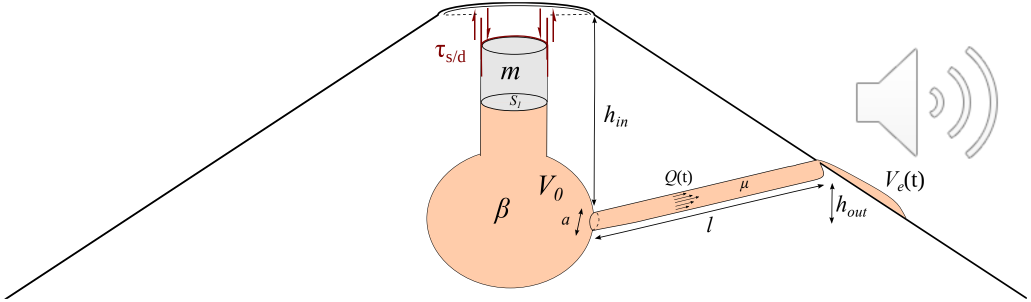


- Caldera collapse proceeds with stick-slip behavior along annular faults. During slip of the caldera block the edifice inflates. During stick the edifice deflates.
- On average deflation exceeds inflation producing a long-term overall deflation of the edifice (as seen from InSAR and tilt data)
- Eruptions resulting in caldera collapse have vent located at low altitude
- These observations are common to all instrumented caldera collapses

Model of caldera collapse

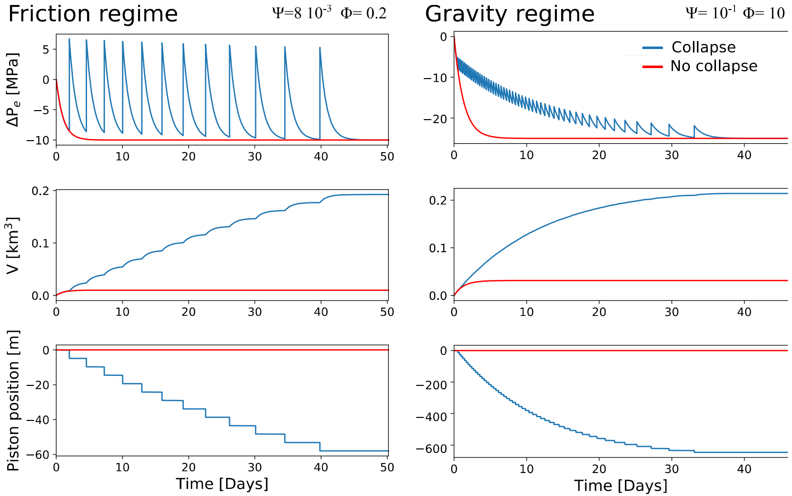
- The cause of caldera collapse is poorly understood, and so it is the link between the collapse and the large erupted volumes or the origin of the inflation-deflation cycles in the tilt time series. We develop a theoretical framework to elucidate these processes.

Model set-up



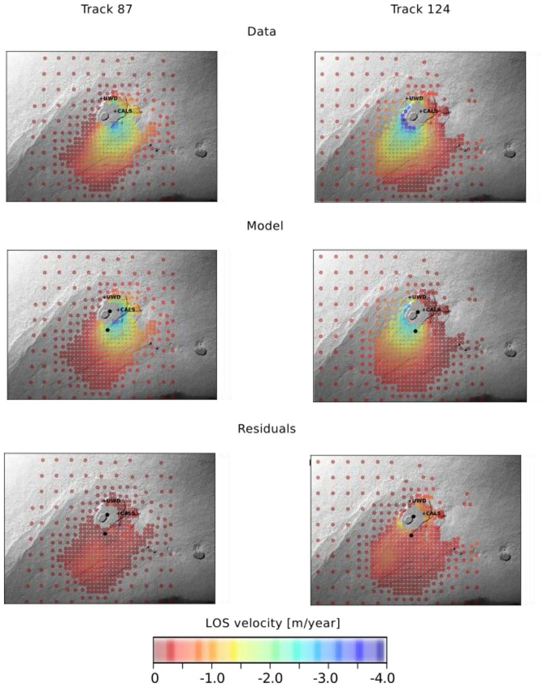
We solve analytically mass and momentum conservation for a coupled piston-elastic reservoir. We find that the system can be described by two regimes: friction dominated and gravity dominated (on the right).

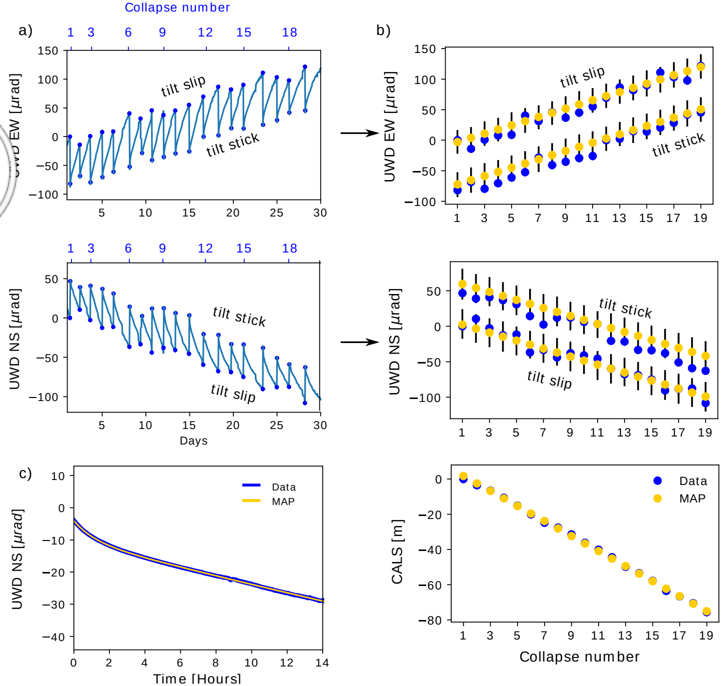
Friction vs Gravity driven eruptions



Application of the Model to the 2018 Kilauea Eruption

- We use the theoretical model of caldera collapse to the 2018 Kilauea eruption. We use a Bayesian inversion implemented with Monte Carlo Markov Chain (MCMC) to estimate the parameters of the volcanic plumbing system feeding the eruption. We invert InSAR (Sentinel-1), tiltmeter and GNSS data.





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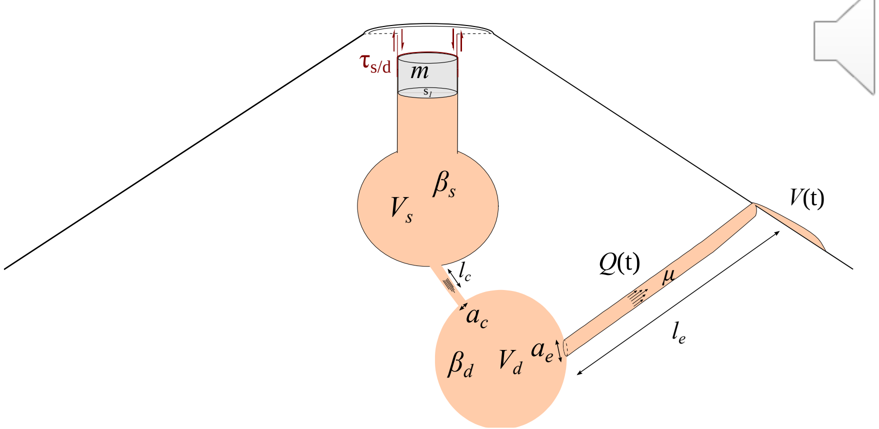

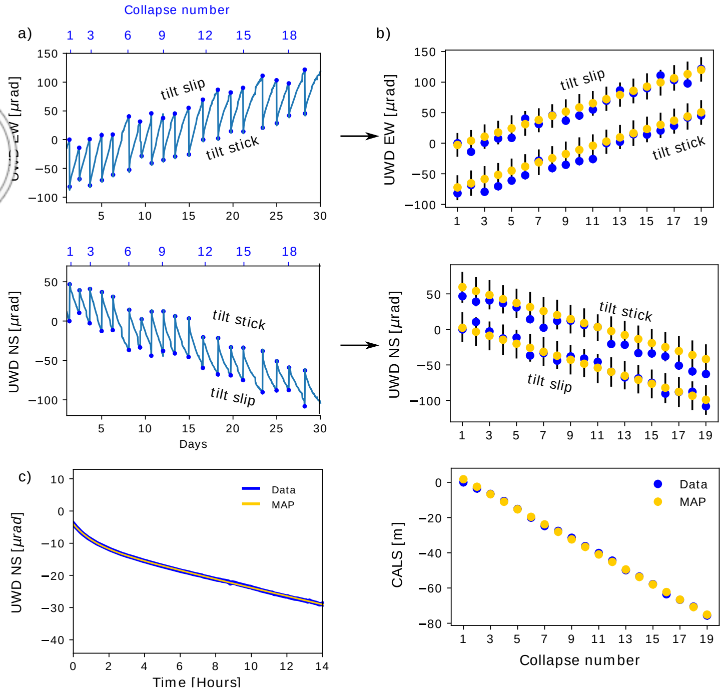

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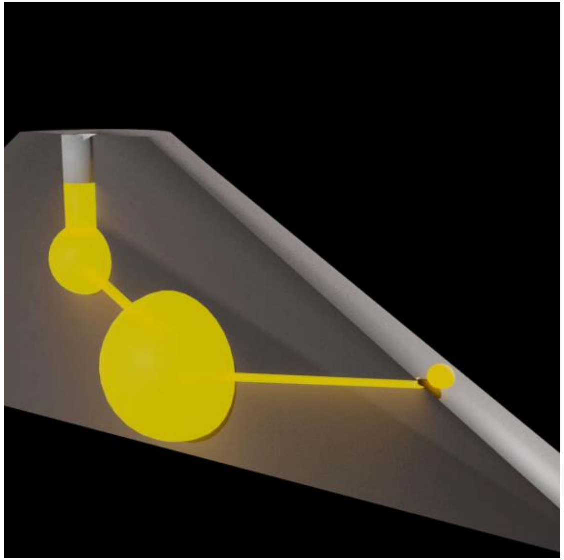
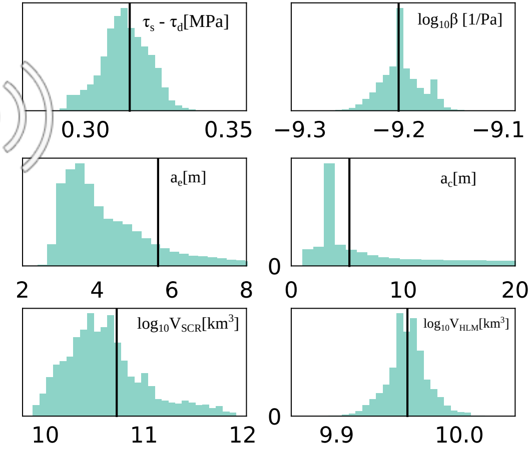




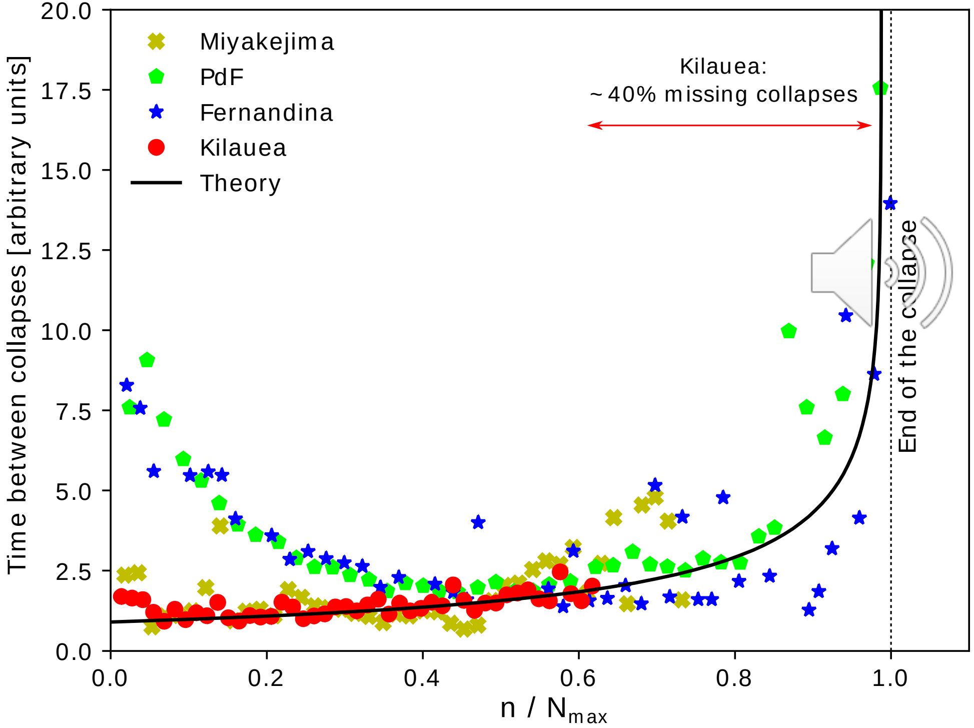
Volume HLM : 8-9 km^3

Volume SCR : 8-50 km^3

Conduit Eruption : 3-6 m

Conduit Connection: 1-10 m

Comparison with other eruptions



Theory

$$\Delta t_{stick}(n) = \frac{8\bar{\beta}V_0\mu l}{\pi a^4} \ln\left[\frac{N_{max}(1+\epsilon)-n}{N_{max}-n}\right]$$

- Transient initial phase not accounted by the model (more evident for Piton de la Fournaise (PDF) and Fernandina)
- Presence of volatiles in the magma at the beginning of the eruption
- Kilauea 40% of collapses (about 20 events) are missing. Shut down the connection between the reservoirs

Acknowledgements

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Publications

A. Roman and P. R. Lundgren, Dynamics of Large Effusive Eruptions Driven by Caldera Collapse, Nature, Under Review

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