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# Dynamics of caldera collapse during effusive eruptions constrained by geodetic data

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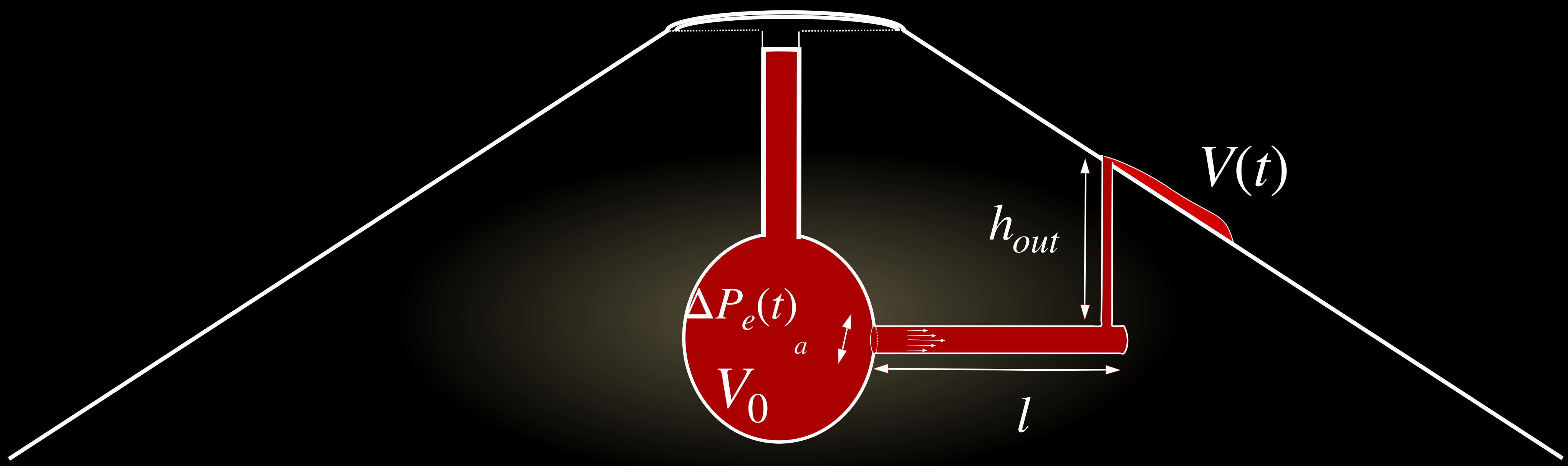
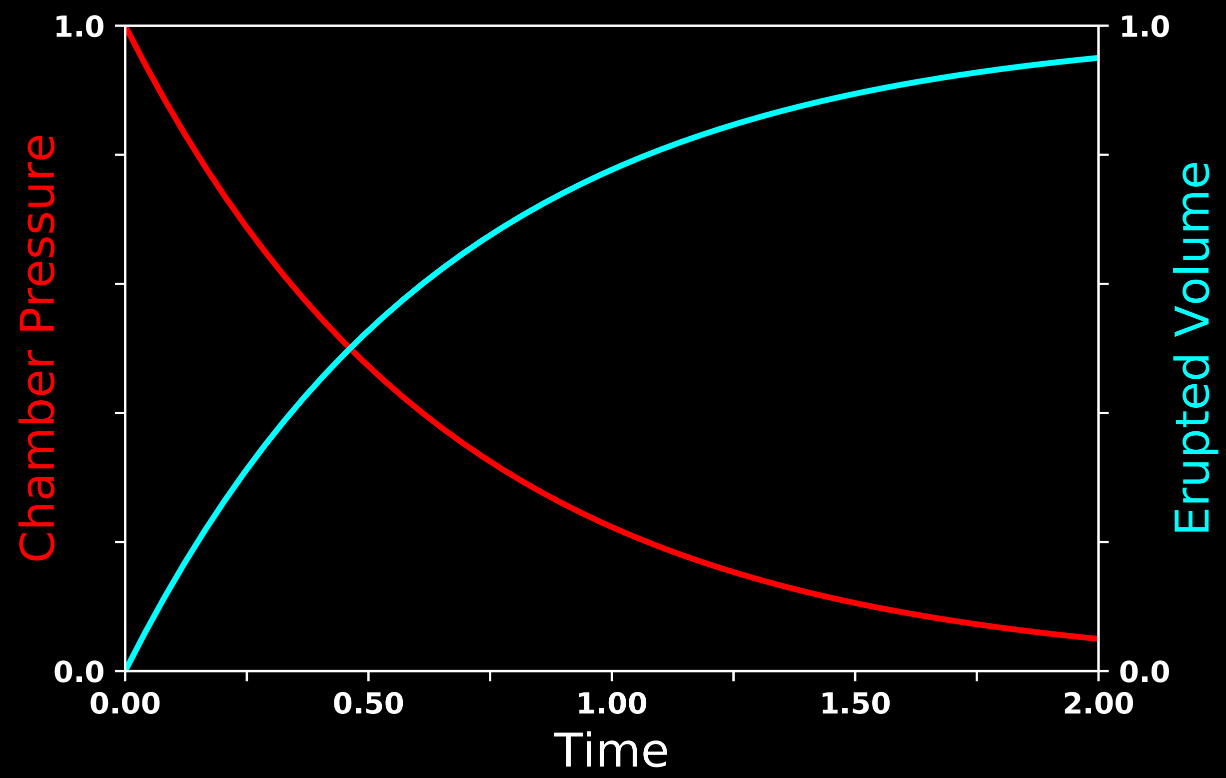
# Small effusive eruptions




Volumes and Pressures (Deformation) have exponential forms

e.g. *Wadge*, 1981
*Anderson and Segall*, 2011

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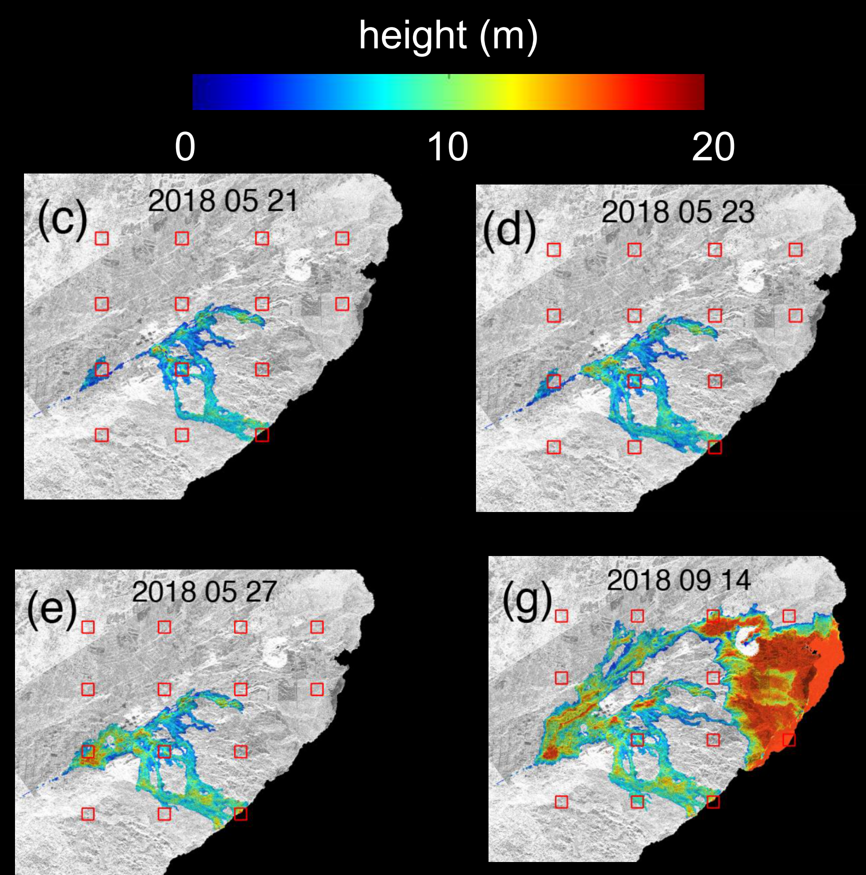
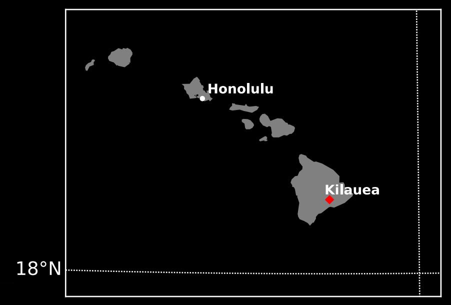
# LARGE effusive eruptions (0.2-1.0 km$^3$)

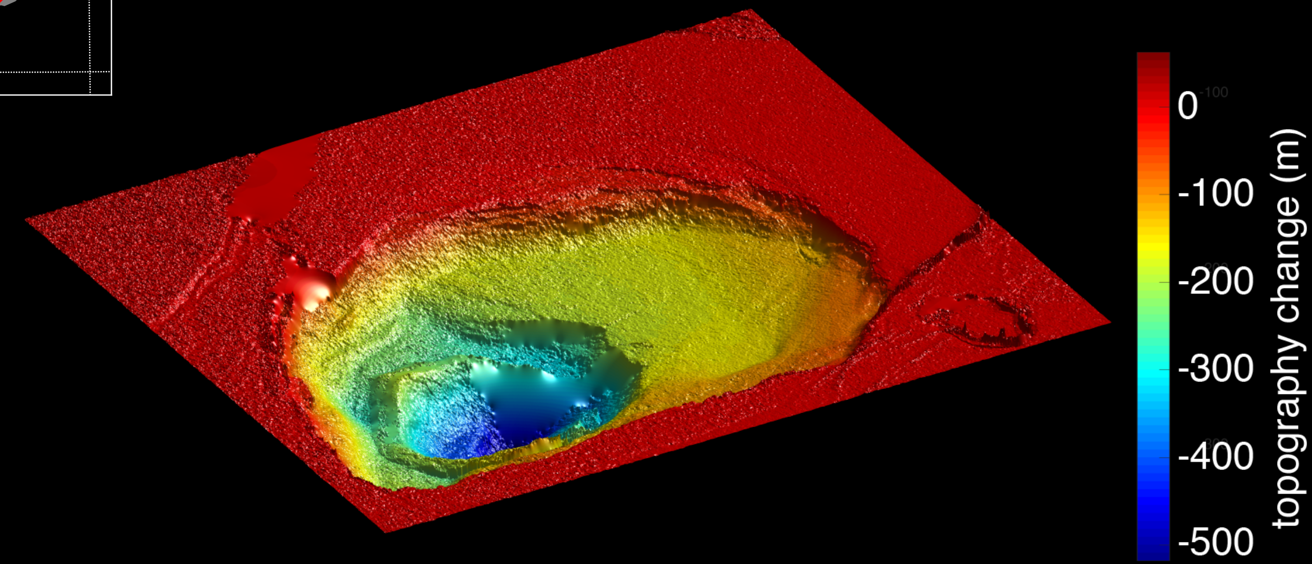
## Miyakejima (2001), Réunion (2007), Bardarbunga (2014), Kilauea (2018)

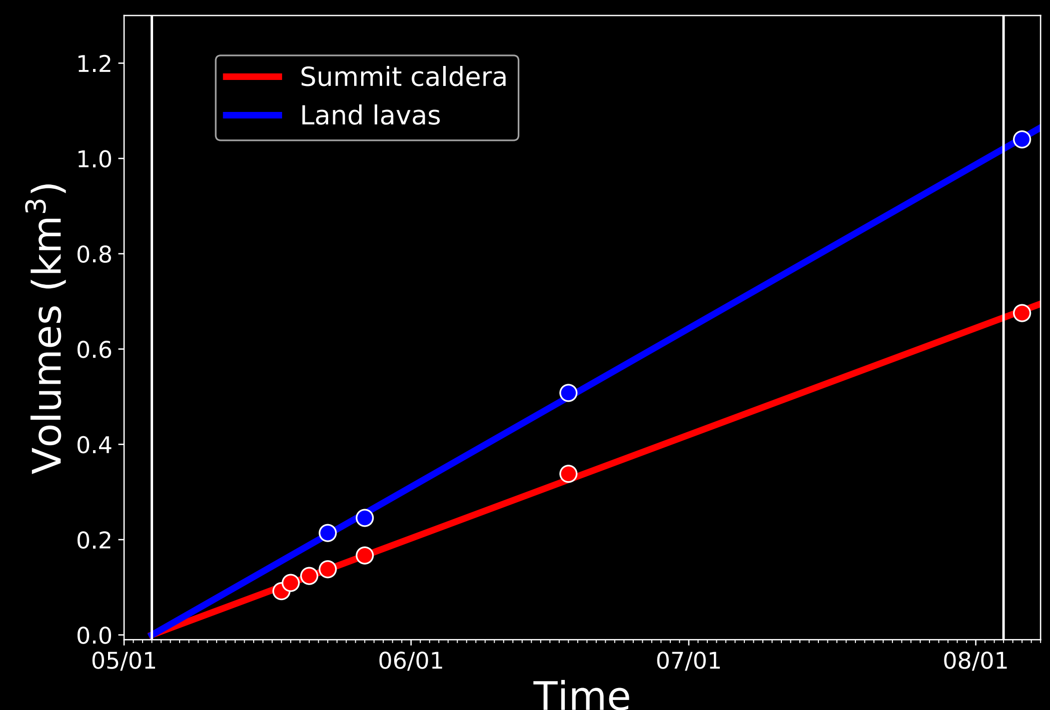
## Erupted lavas




## Caldera collapse




1)Erupted volume ~ caldera collapse

2) High fluxes ~130 m$^3$s$^{-1}$

*Lundgren et al*, 2019

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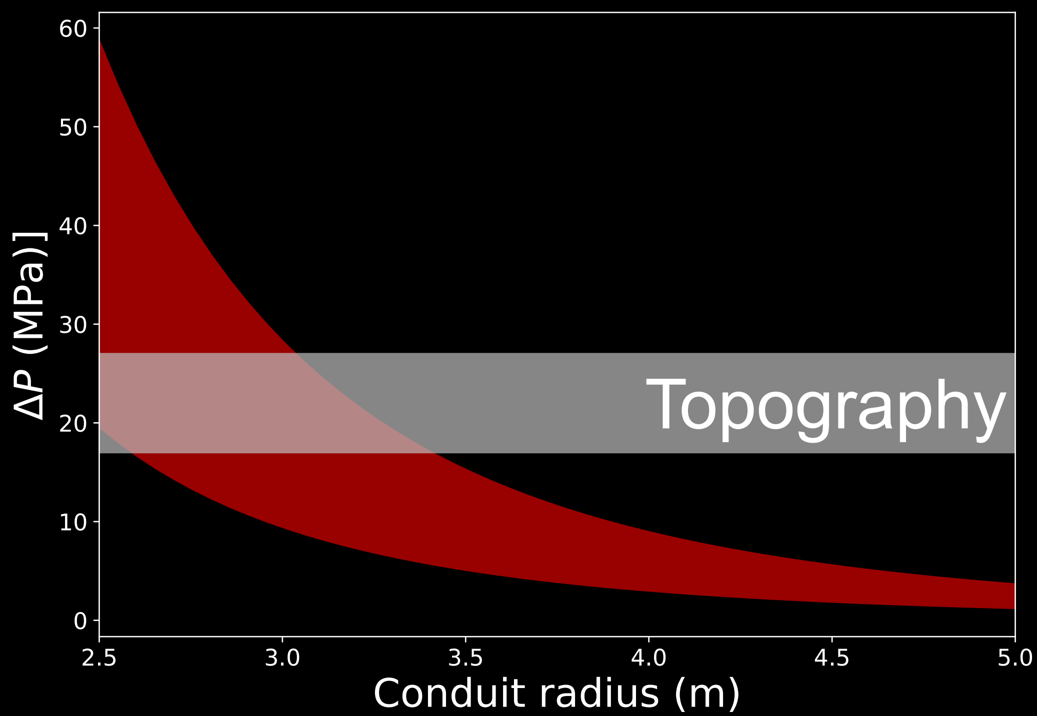
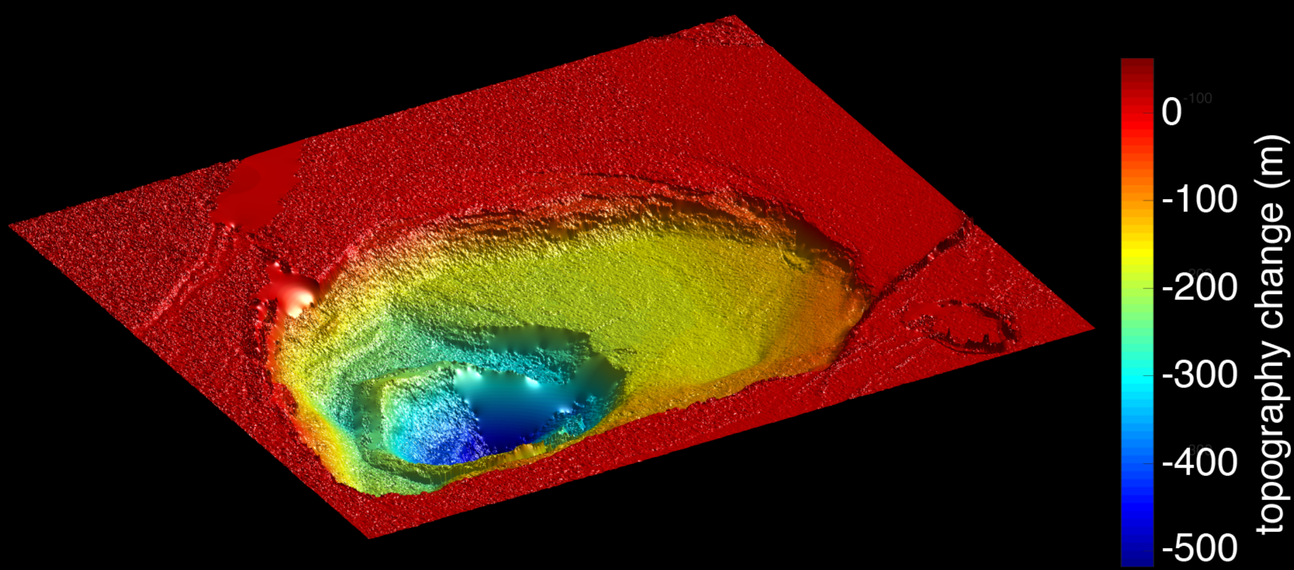
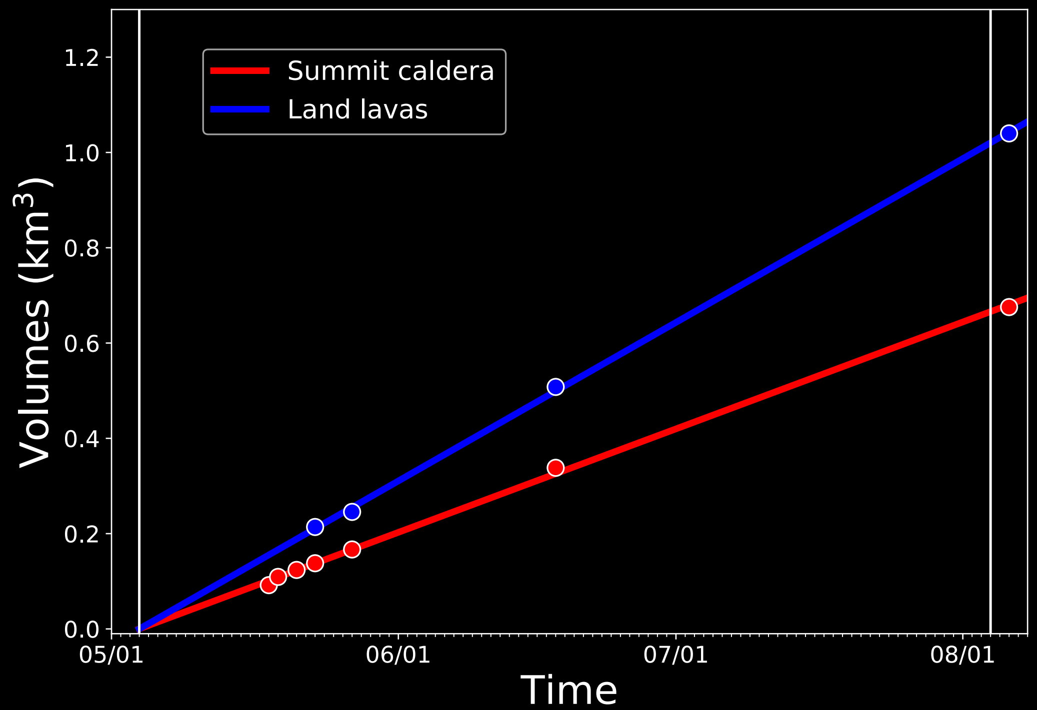
# LARGE effusive eruptions




1)Erupted volume ~ caldera collapse
2) Flux ~130 - 150 $m^3s^{-1}$

*Lundgren et al*, 2019

# LARGE effusive eruptions

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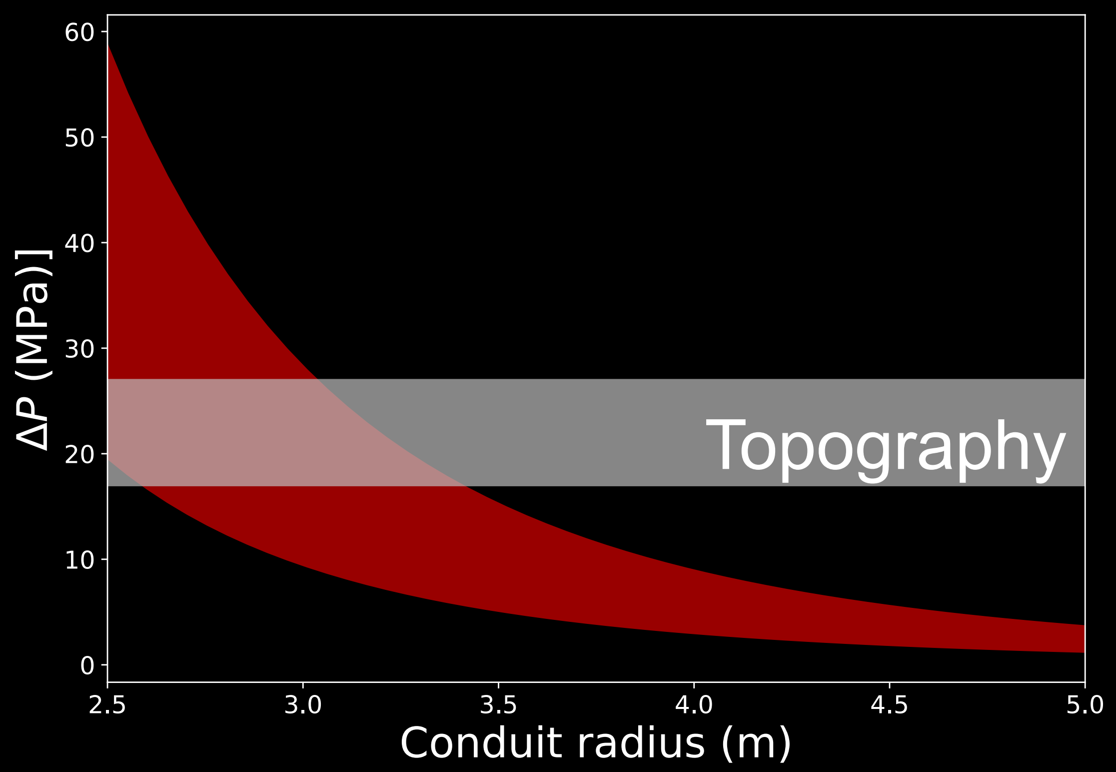



**Paradox:**

1) High driving pressures for open conduit systems (lithostatic baseline)
2) Pressure drops below lithostatic values

**Observation:**

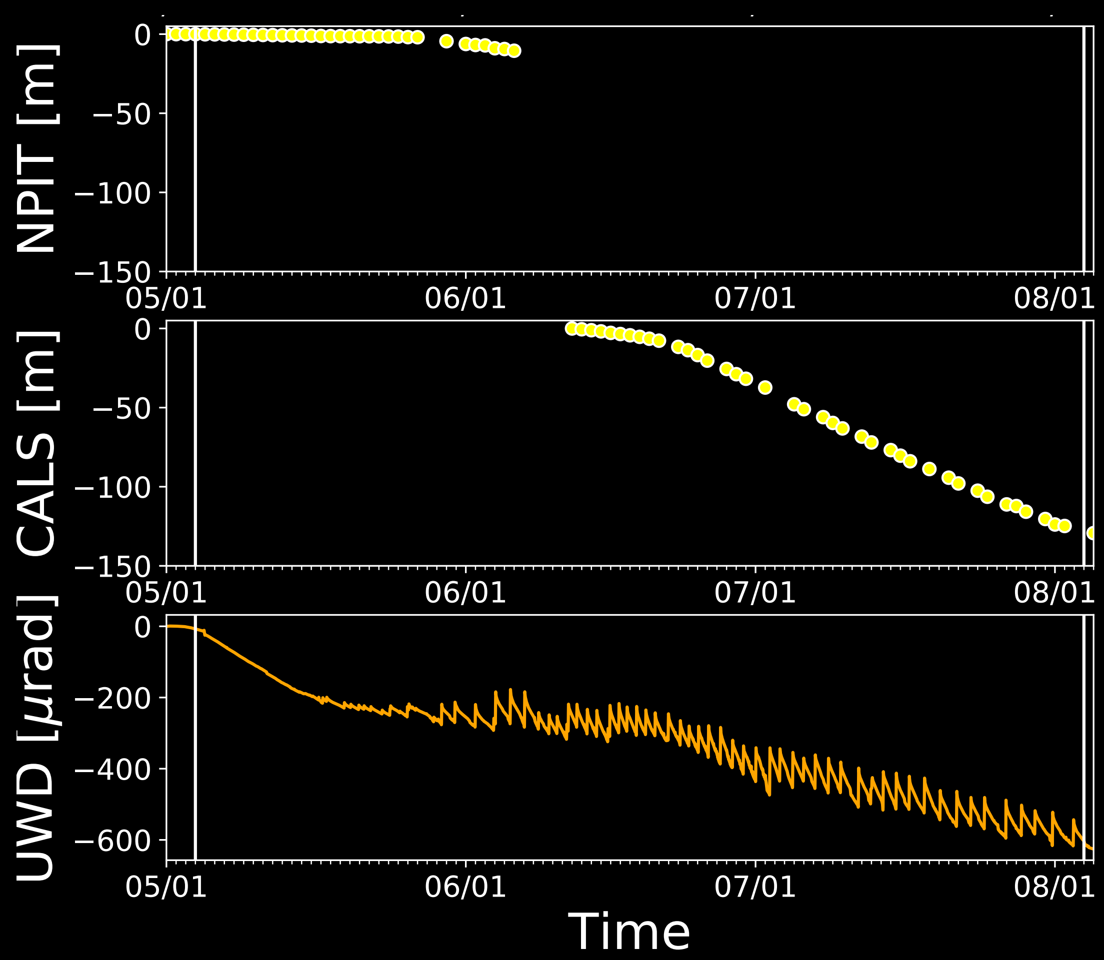
Caldera collapse corresponds to low altitude, distal vents

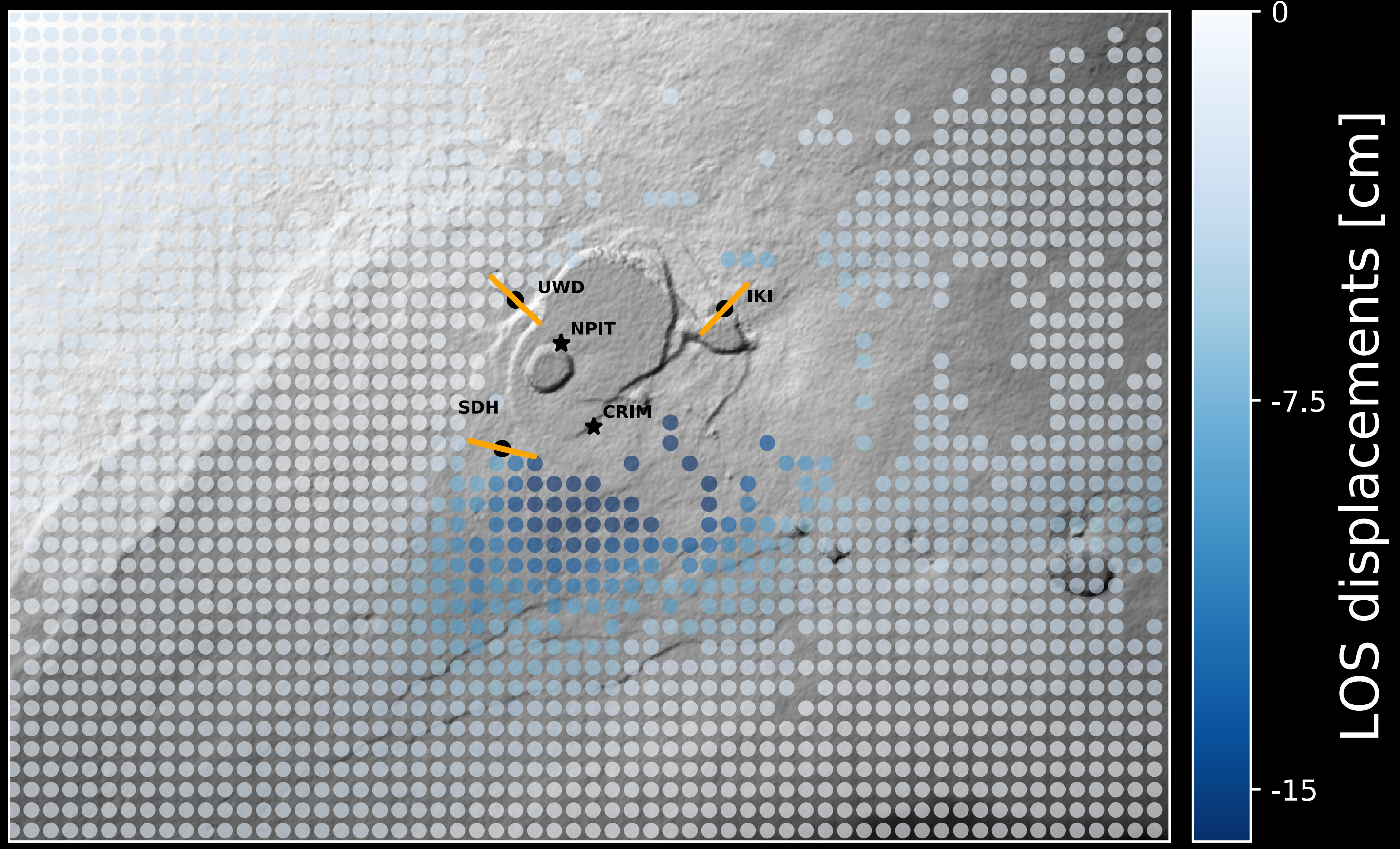
**Importance of topographic gradient**

The higher the horizontal extent of the feeder dike, the larger the contribution of pressure generated by topography

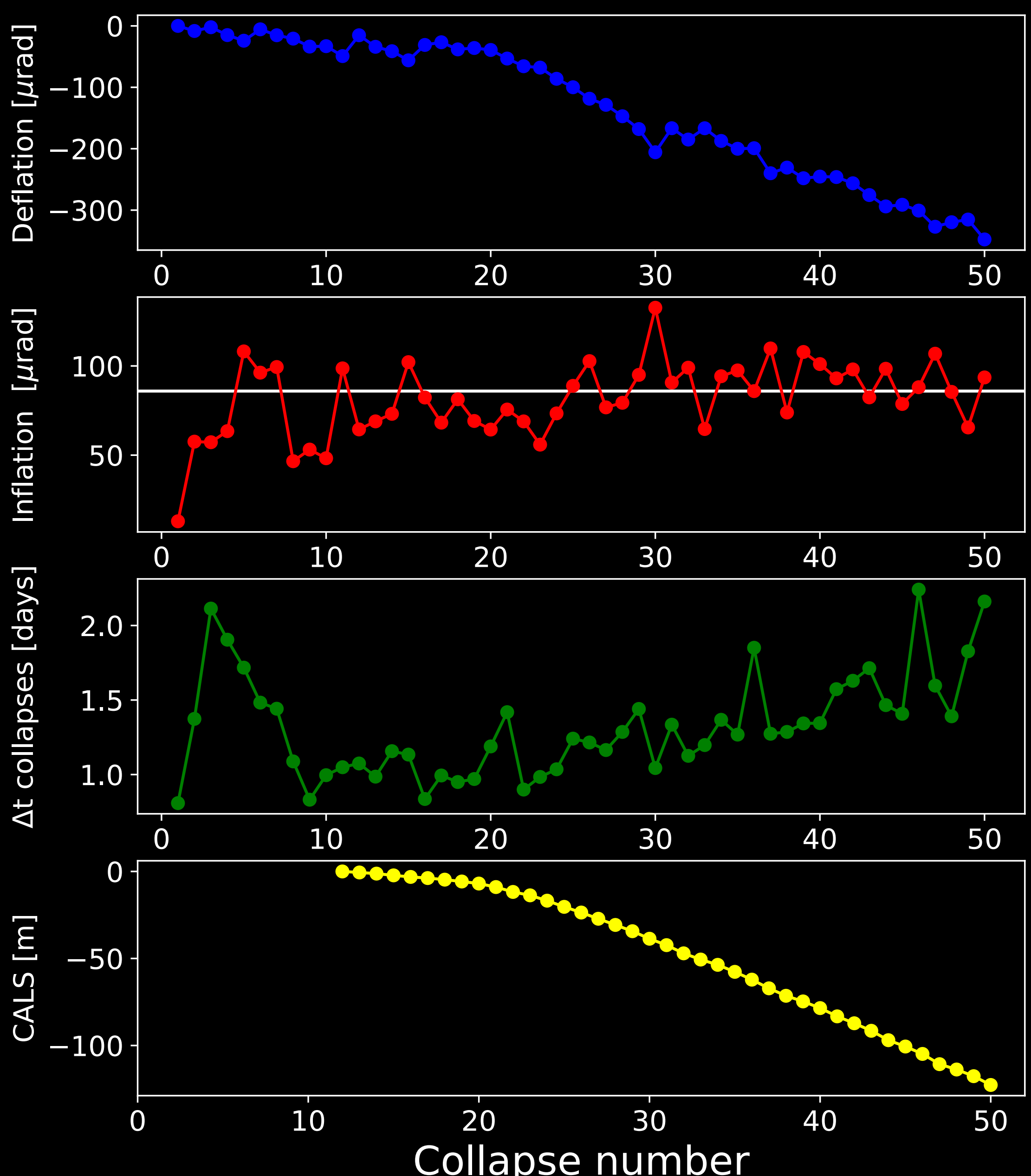
*Fialko and Rubin, 1999*
*Pinel and Jaupart, 2004*

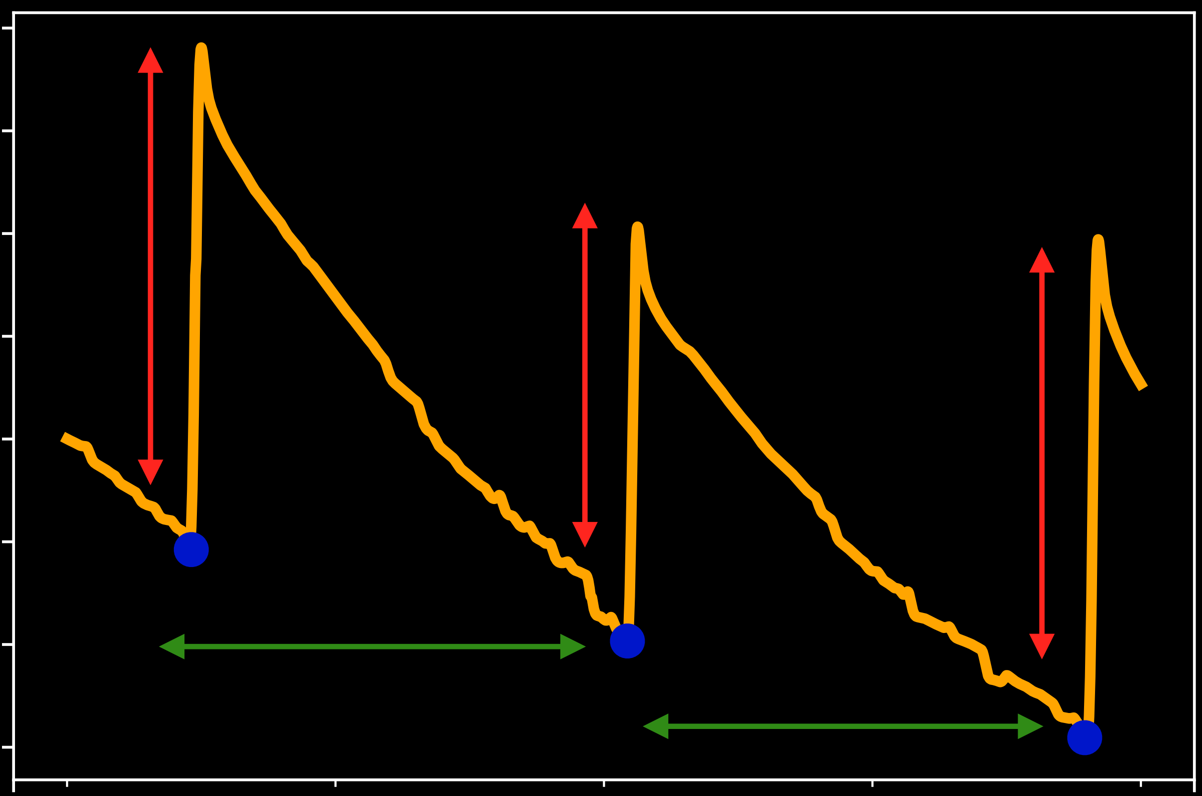
# Ground deformation



# Observables



Tilt inflation ~ 90 microrad

Net deflation between collapses ~ 10 microrad

Time interval between collapses increases

**How much inflation/deflation?**

**How much slip?**

**How many collapses?**

**...**

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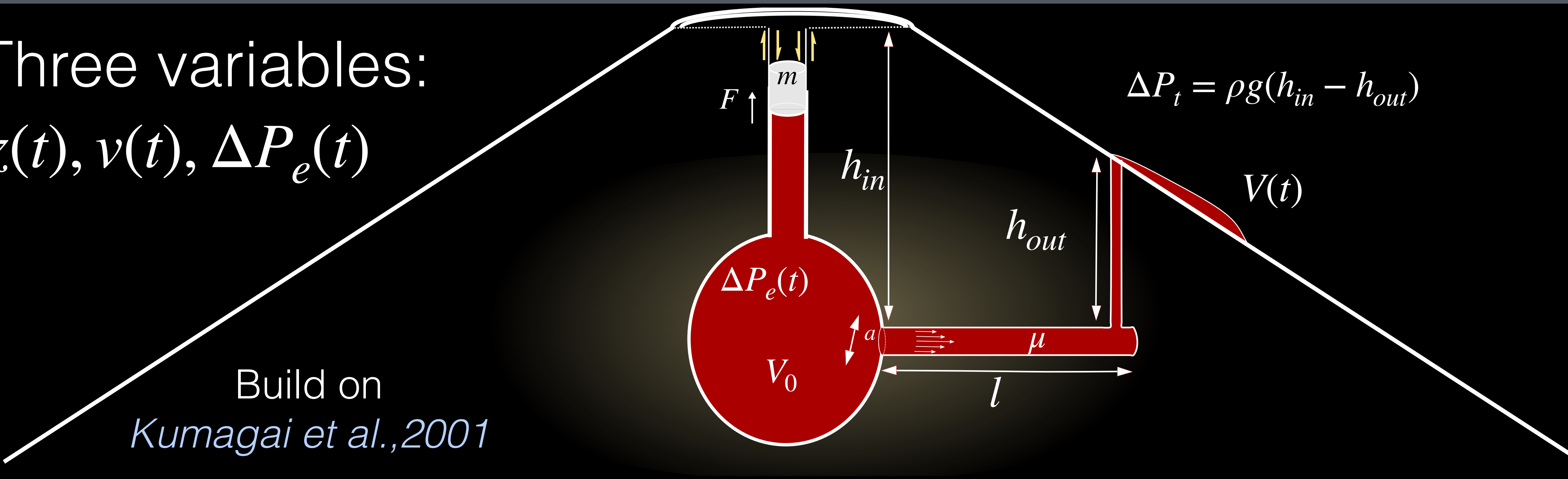
# Physical model for stick-slip collapse

Three variables:

$z(t), v(t), \Delta P_e(t)$




Build on *Kumagai et al.,2001*

**During slip:**

$$\frac{dz}{dt} = v$$

$$m\frac{dv}{dt} = -F_d - \rho g S z - \Delta P_e S$$

$$\frac{d\Delta P_e}{dt} = \frac{S}{\beta V_0}v - \frac{\pi a^4}{8\beta V_0 \mu l}(\Delta P_e + \Delta P_t)$$

**Slip starts when:**

$$\Delta P_e S = -F_s - \rho g z S$$

**And stops when:**

$$v = 0$$

**During stick:**

$$\frac{d\Delta P_e}{dt} = -\frac{\pi a^4}{8\beta V_0 \mu l}(\Delta P_e + \Delta P_t)$$

**The initial condition for pressure:**

$$\Delta P_e(t_{stick}) = \Delta P_e(v = 0)$$

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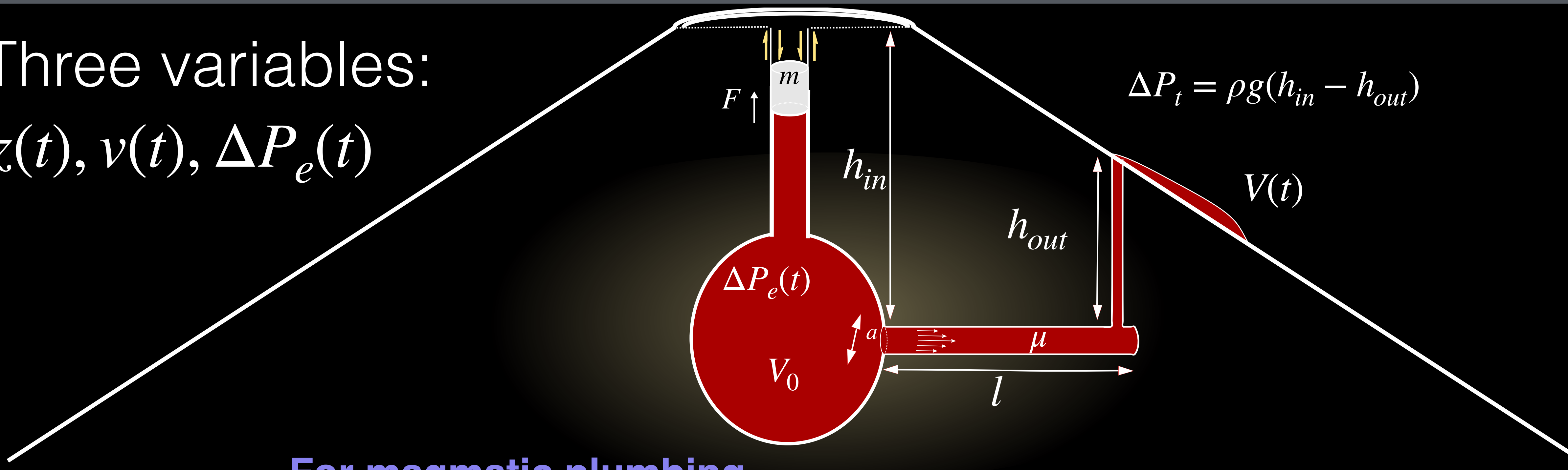
# Physical model for stick-slip collapse

Three variables:

$z(t), v(t), \Delta P_e(t)$




For magmatic plumbing systems

**During slip:**

$$\frac{dz}{dt} = v$$

$$m\frac{dv}{dt} = -F_d - \rho g S z - \Delta P_e S$$

$$\frac{d\Delta P_e}{dt} = \frac{S}{\beta V_0}v - \cancel{\frac{\pi a^4}{8\beta V_0 \mu l}(\Delta P_e + \Delta P_t)}$$

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# Physical model for stick-slip collapse

$$\Delta x_{slip} = \frac{\Psi}{\rho g}\frac{P_s - P_d}{1+\Psi}$$

$$\Delta P_{slip} = 2\frac{P_s - P_d}{1+\Psi}$$

$$\Delta t(n) = -\tau \log\left[\frac{(1+\Psi)\Phi - 2\Psi n}{(1+\Psi)\Phi - 2\Psi n + 2\Psi + 2}\right]$$

$$N = \frac{1+\Psi}{2\Psi}\Phi$$

The control parameters are:

$$\Psi = \frac{\beta \rho g V_0}{S}$$ Lithostatic vs Elastic

$$\Phi = \frac{P_l - P_s}{P_s - P_d}$$ Topographic vs Frictional

$$\tau = \frac{\pi a^4}{8\mu\beta V_0 l}$$ Characteristic timescale: Hydraulic properties, volume, compressibility

1) The time interval between collapses increases with the collapse number
2) There are a finite number of collapses

# Pressure, collapse and erupted volumes

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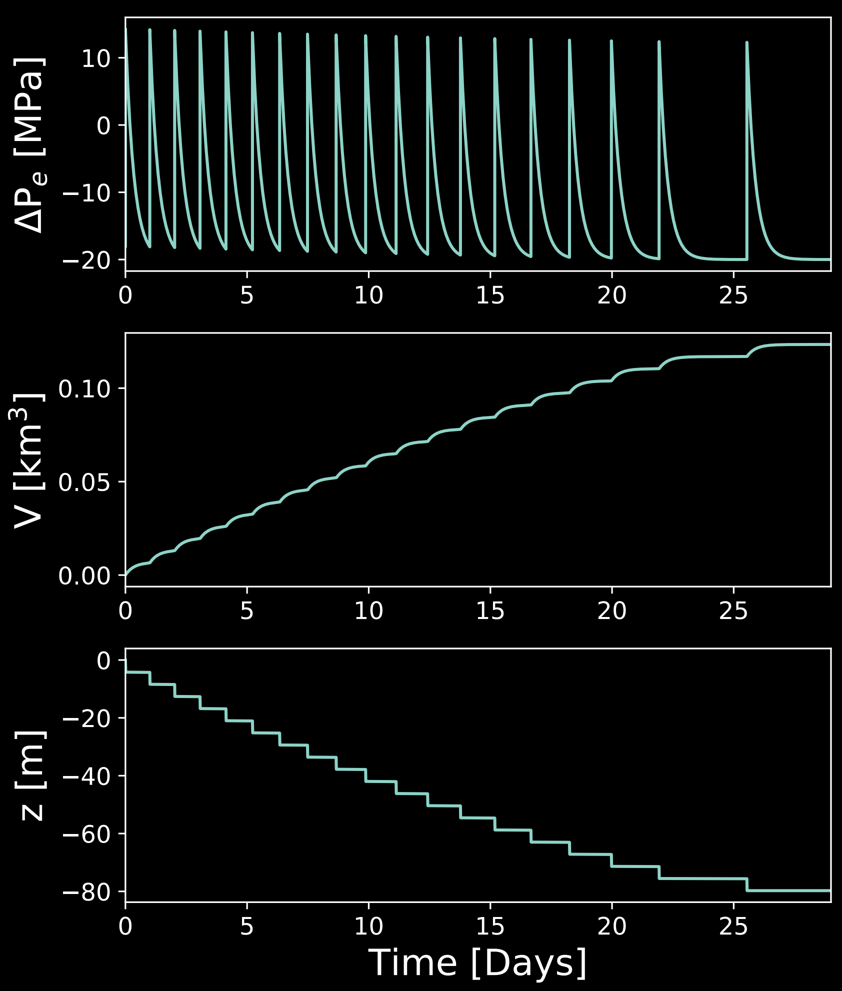
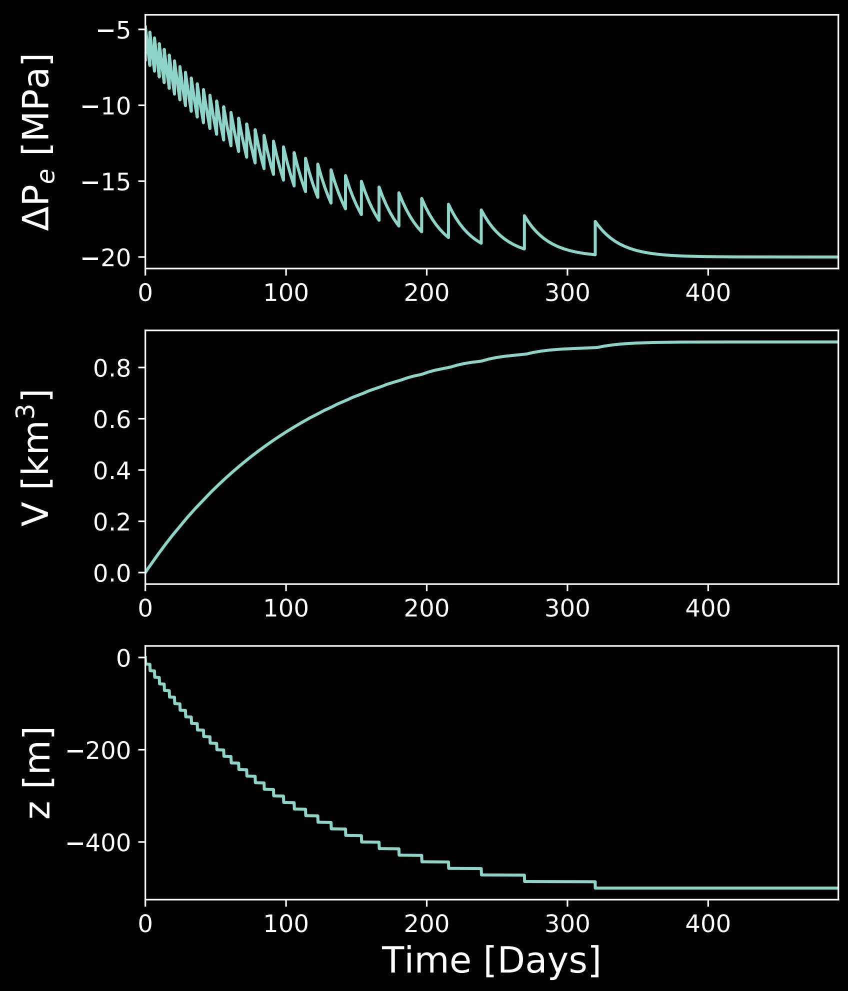
$$\Phi = \frac{P_t - P_s}{P_s - P_d}$$

Interplay between topographic pressure gradient and frictional properties

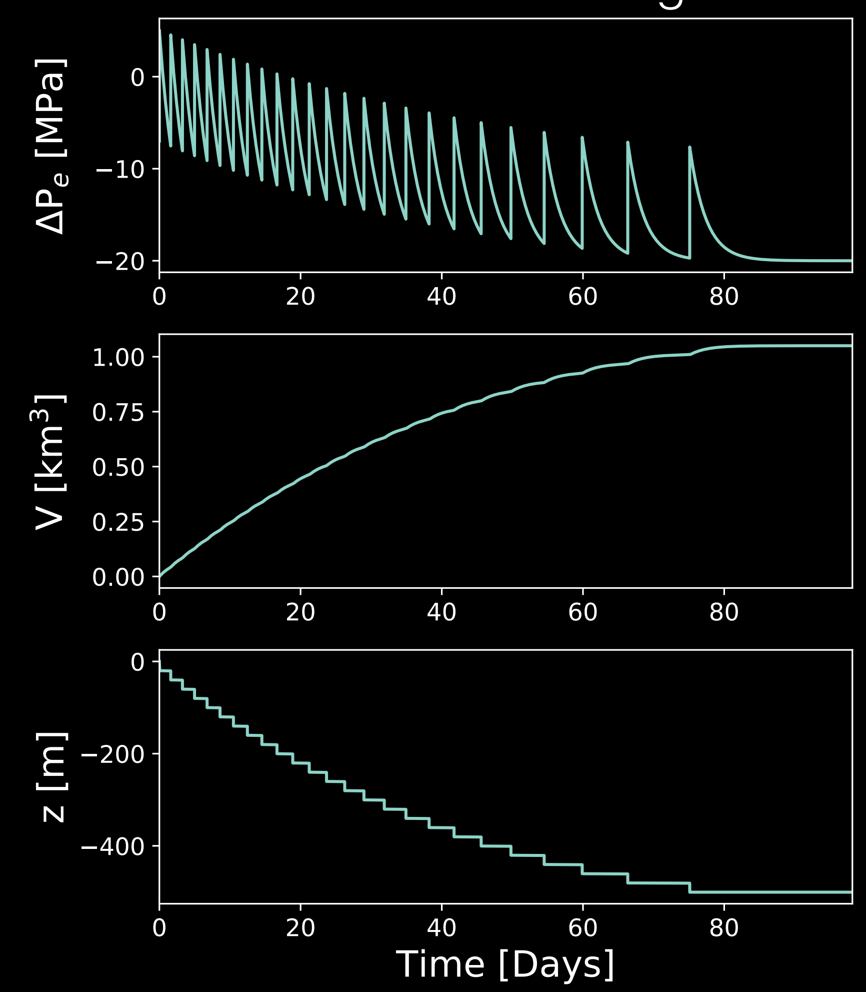
$\Phi = 0.1$ Friction Controlled




$\Phi = 10$ Topography Controlled




$\Phi = 2$ Intermediate regime



# Maintaining high eruptive flux through caldera collapse

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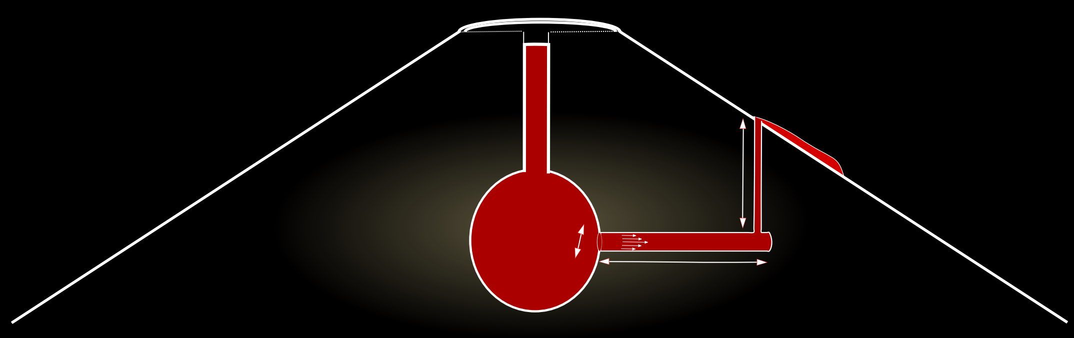
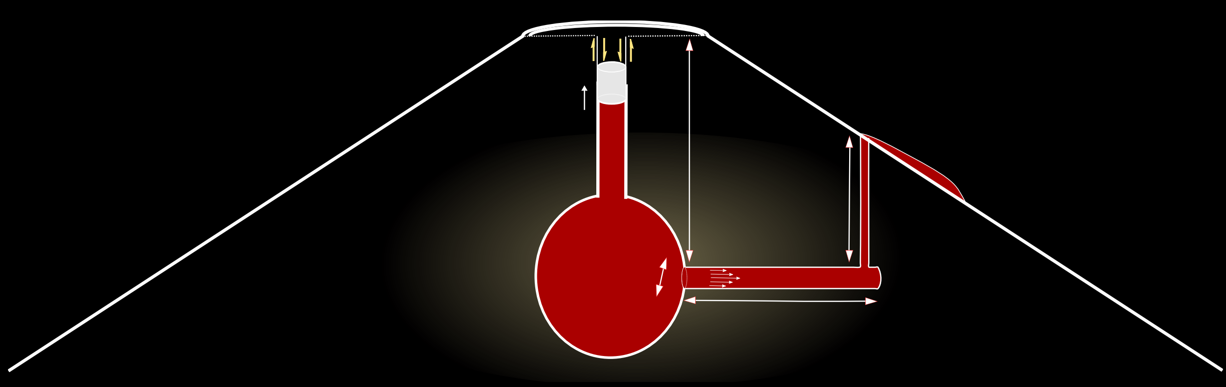
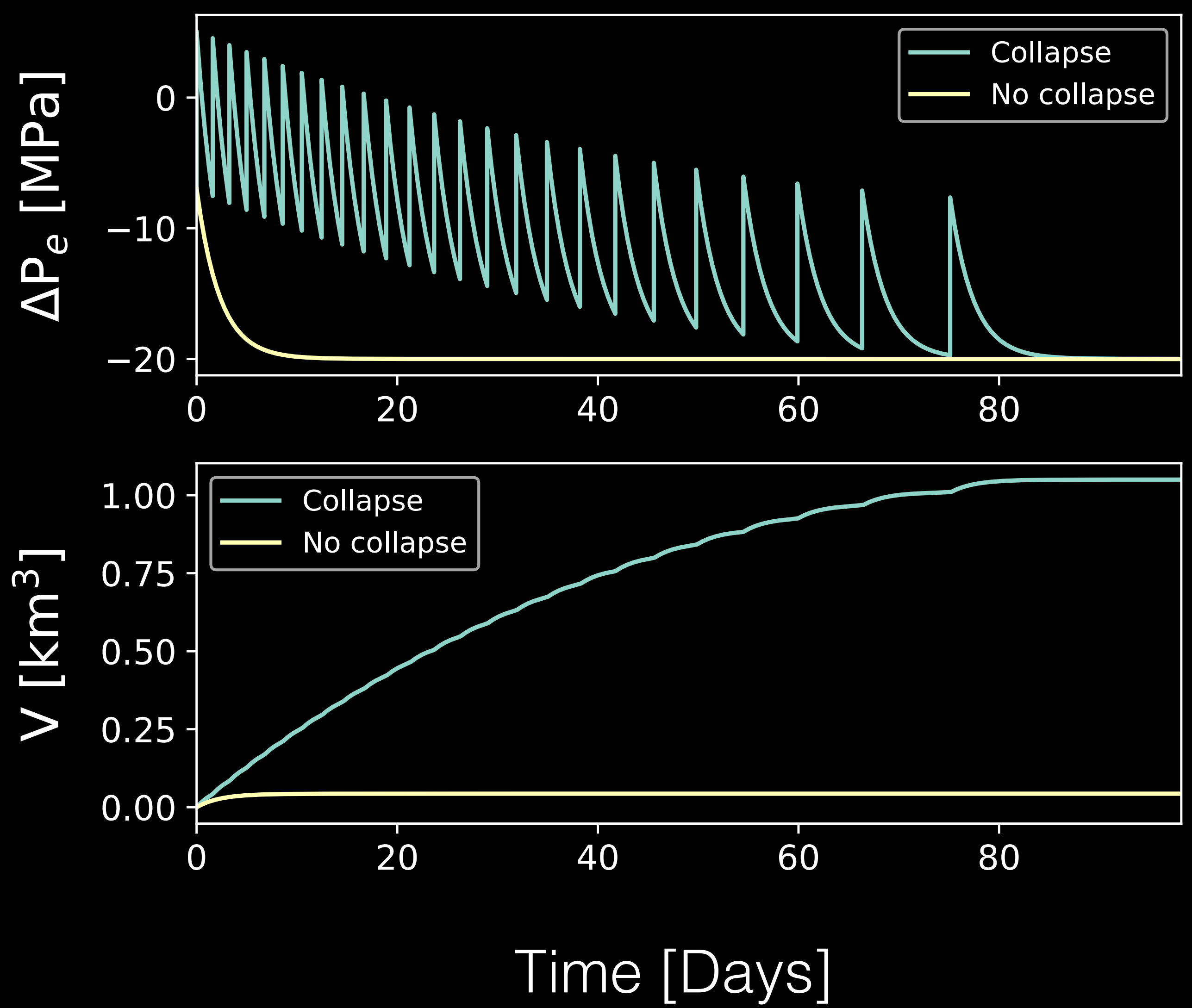
## No collapse



## Collapse






The duration and the total erupted volume of caldera forming eruption are much larger than normal ones

# Ground deformation location inversion

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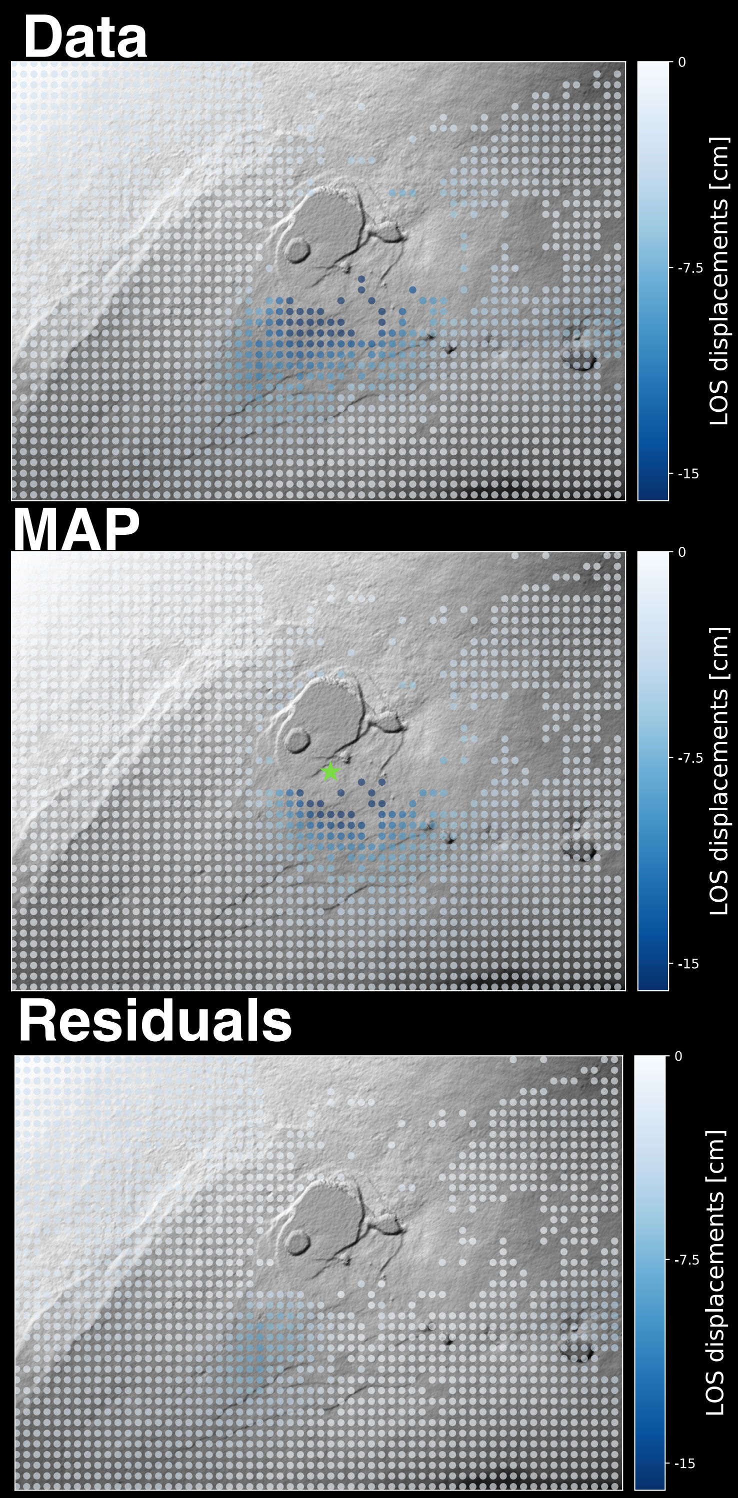


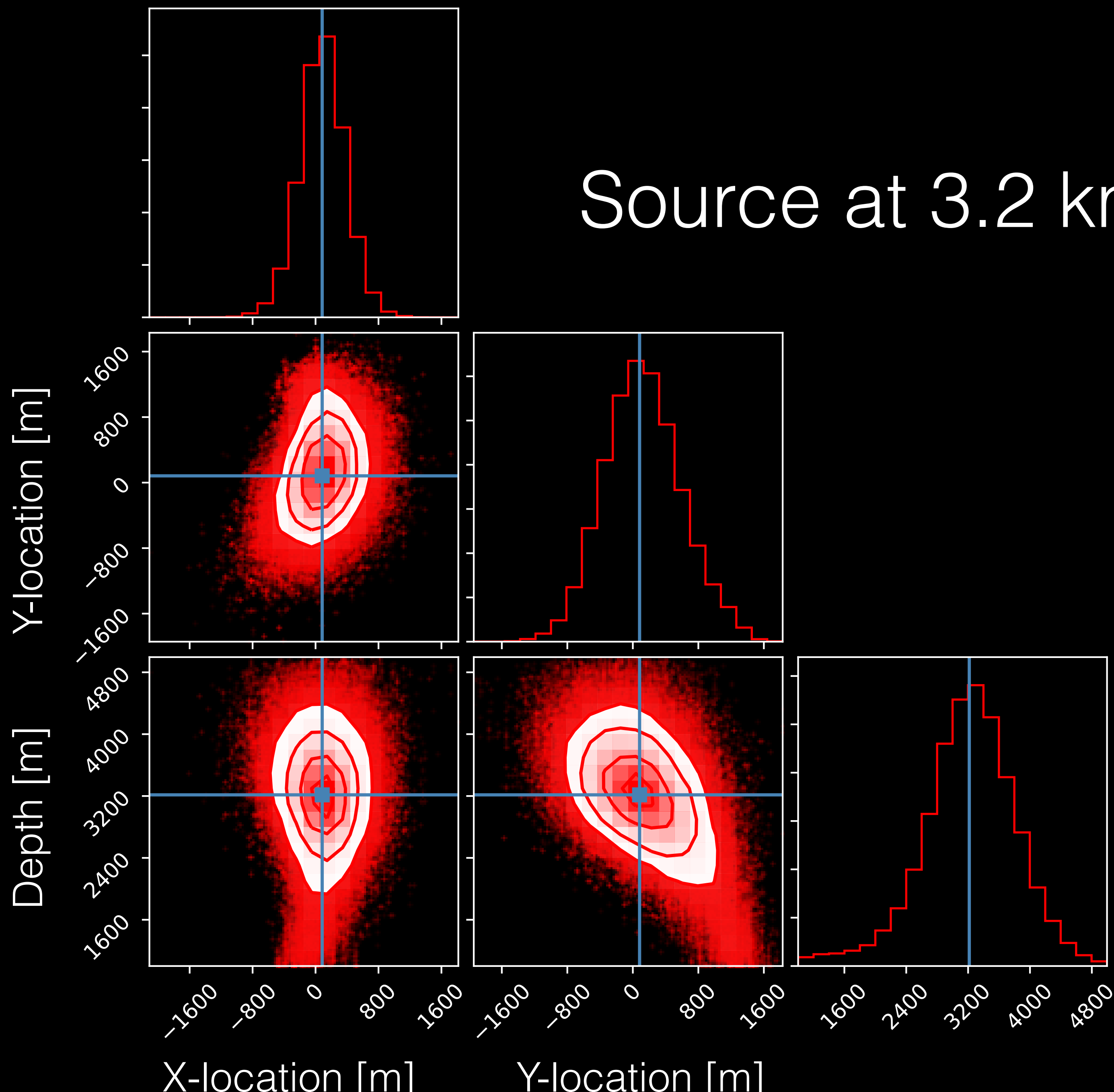


Source at 3.2 km

# Bayesian inversion of piston collapse model

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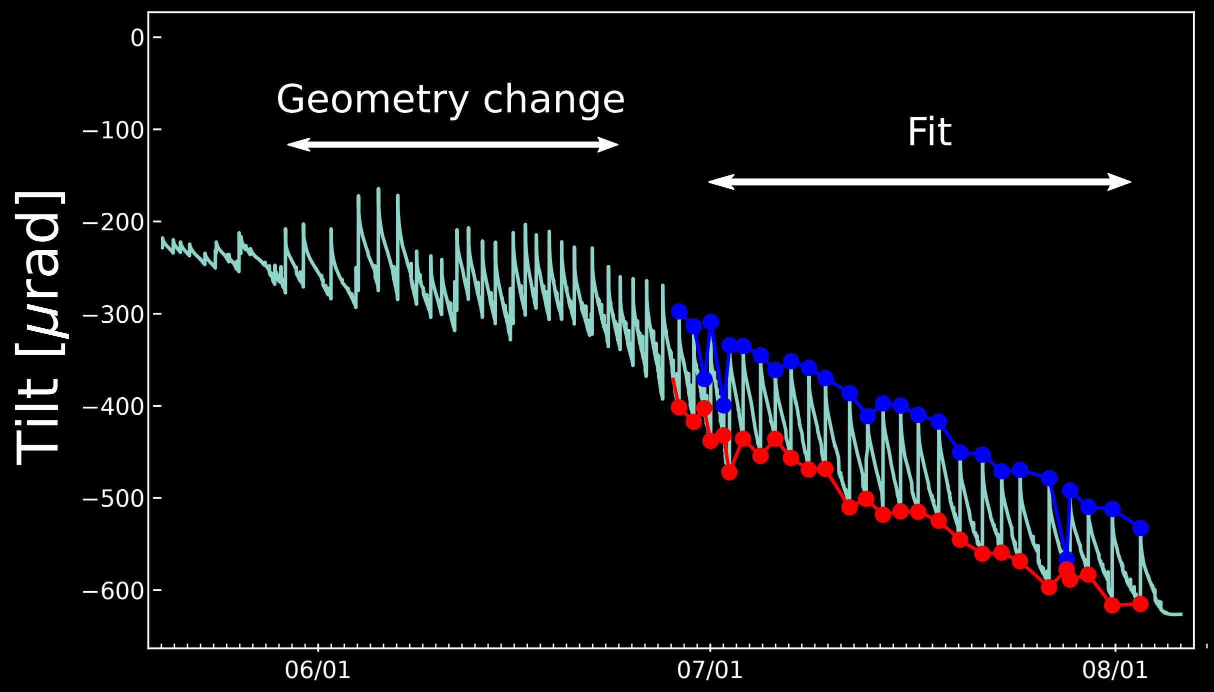
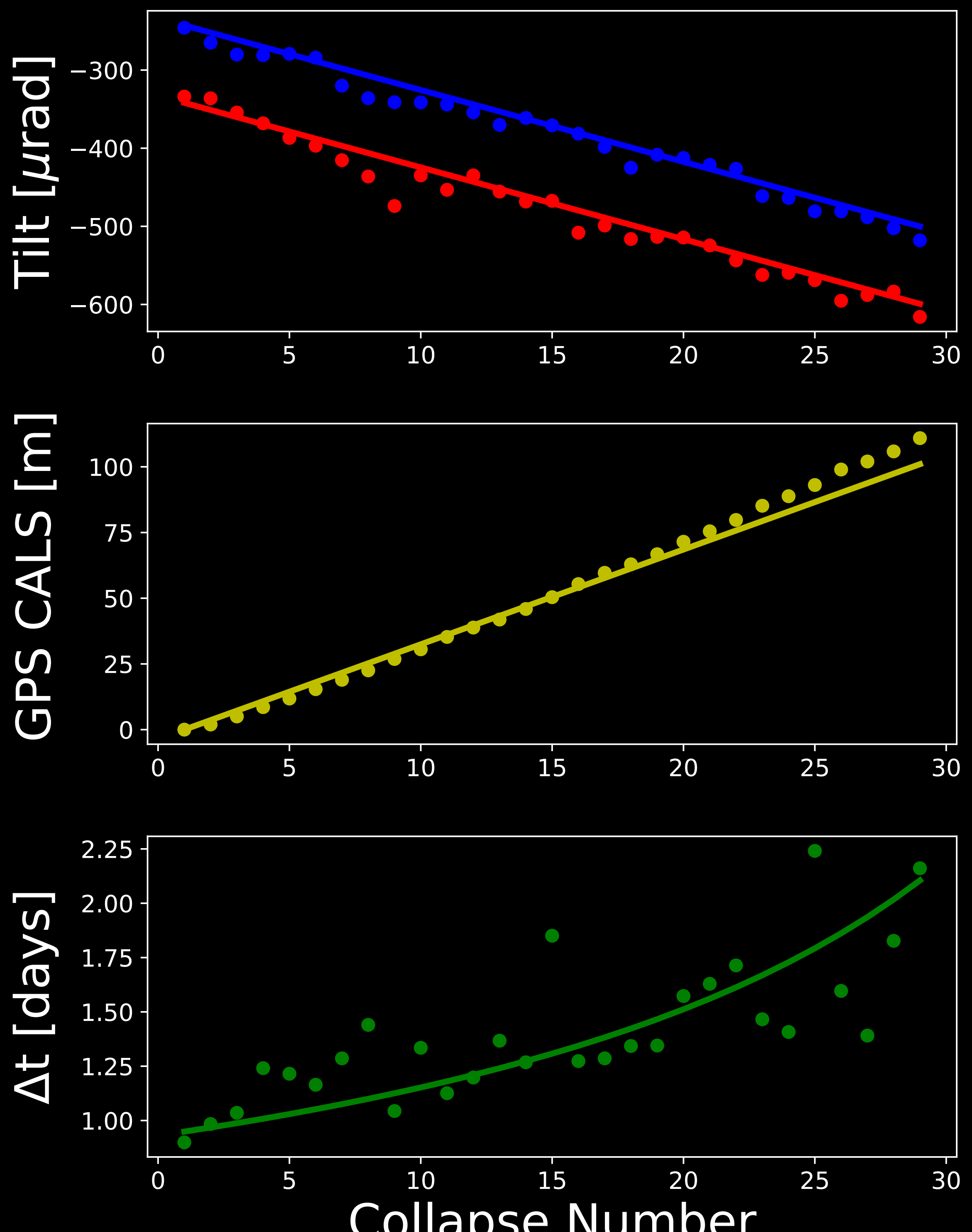



Fit period July 2018 : **29 collapses**

- Tilt at the onset of each collapse
- Tilt at the end of each collapse
- Time interval between collapses



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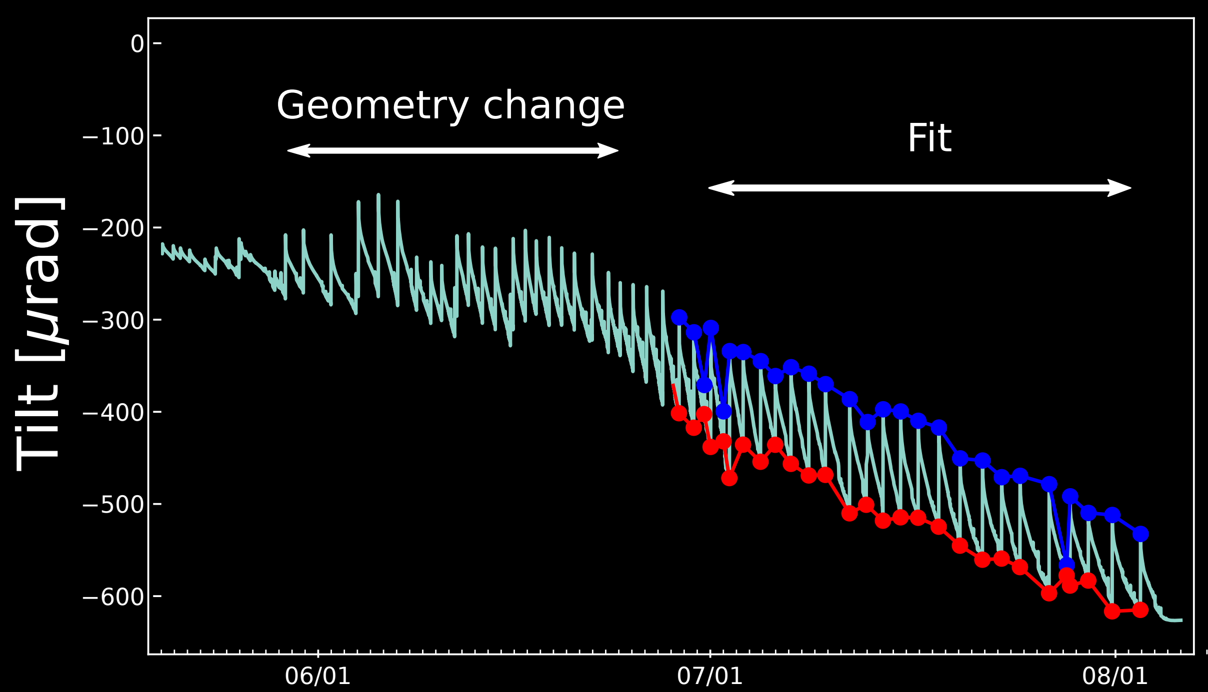
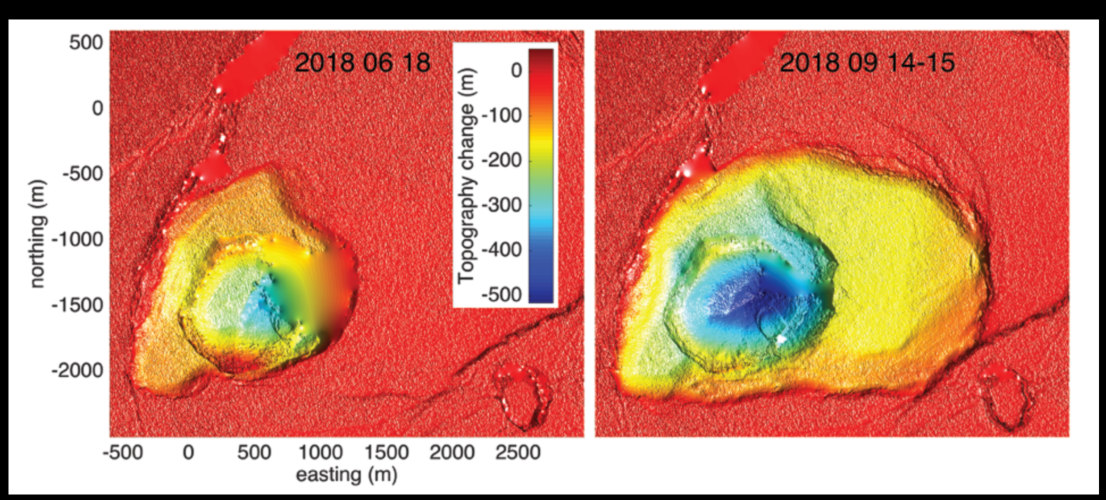
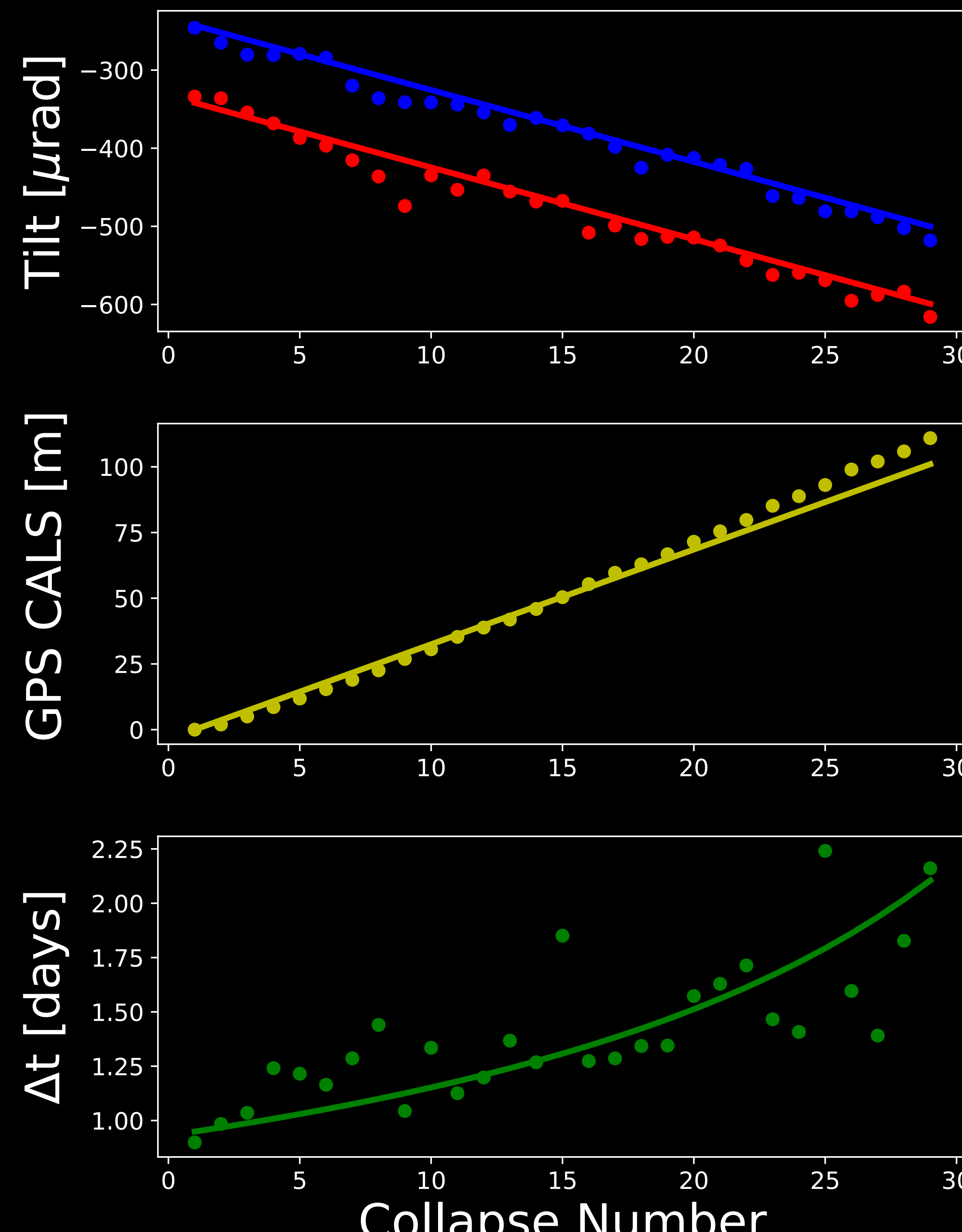
# Bayesian inversion of piston collapse model



# Bayesian inversion of piston collapse model

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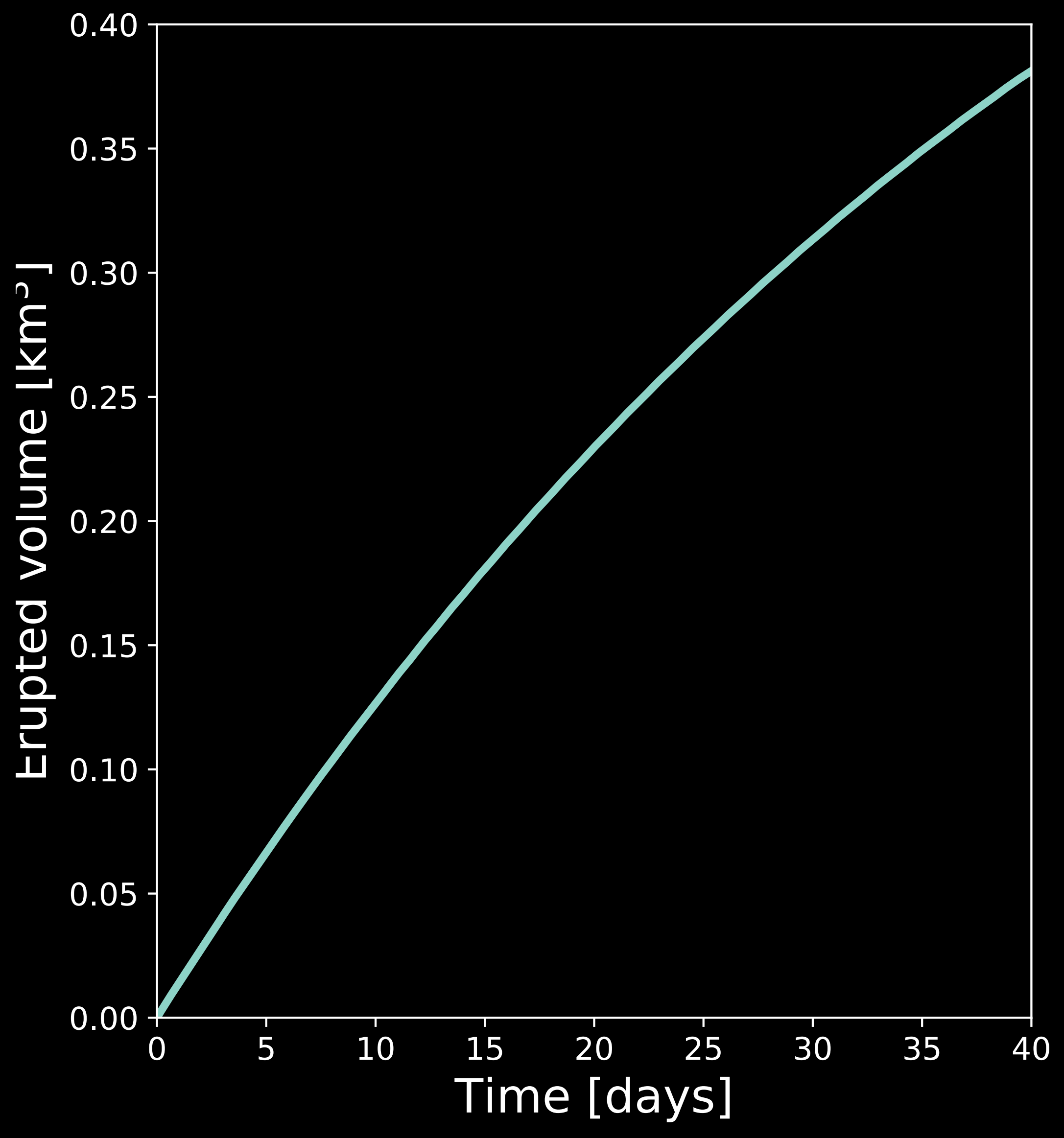
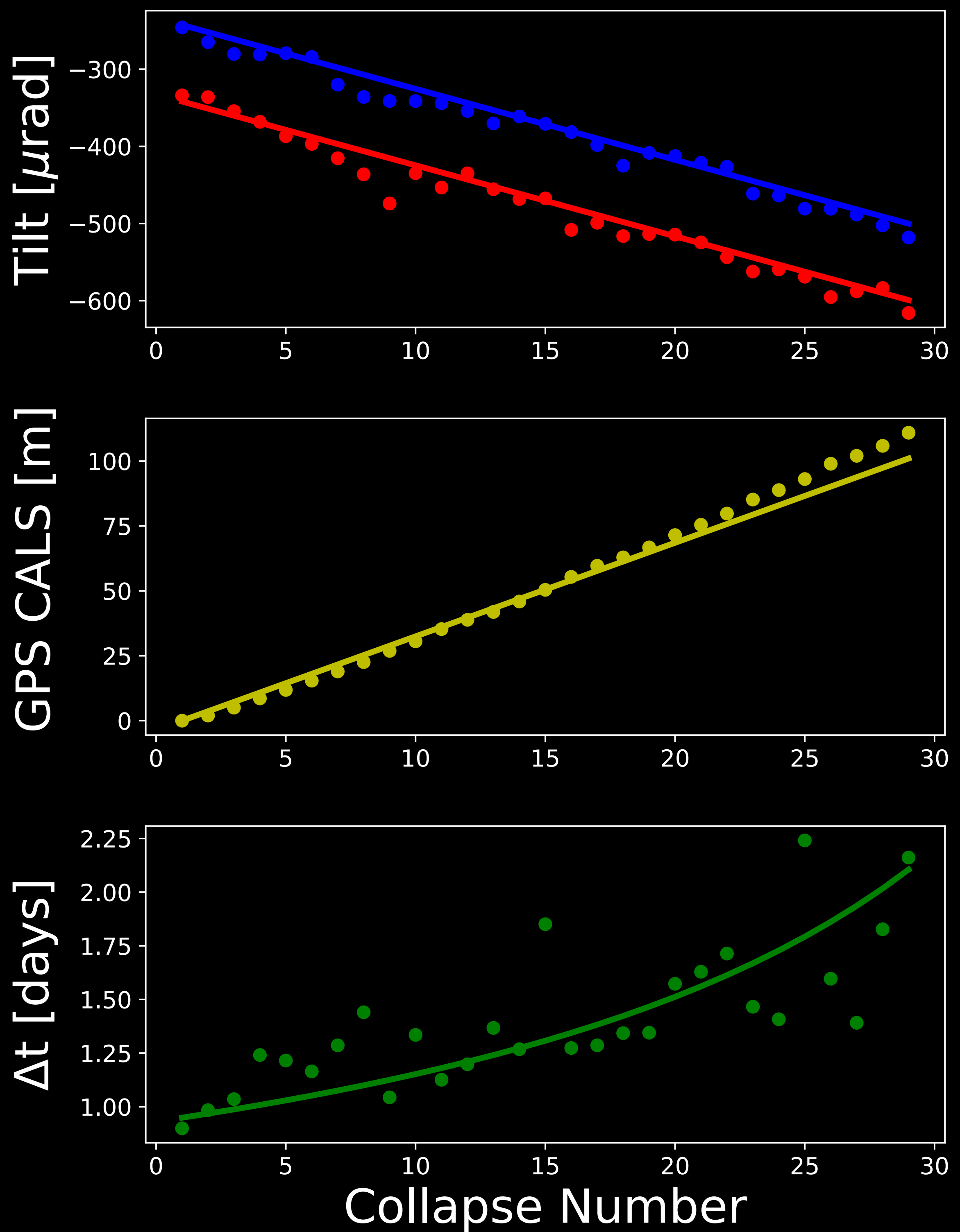
Erupted volumes prediction



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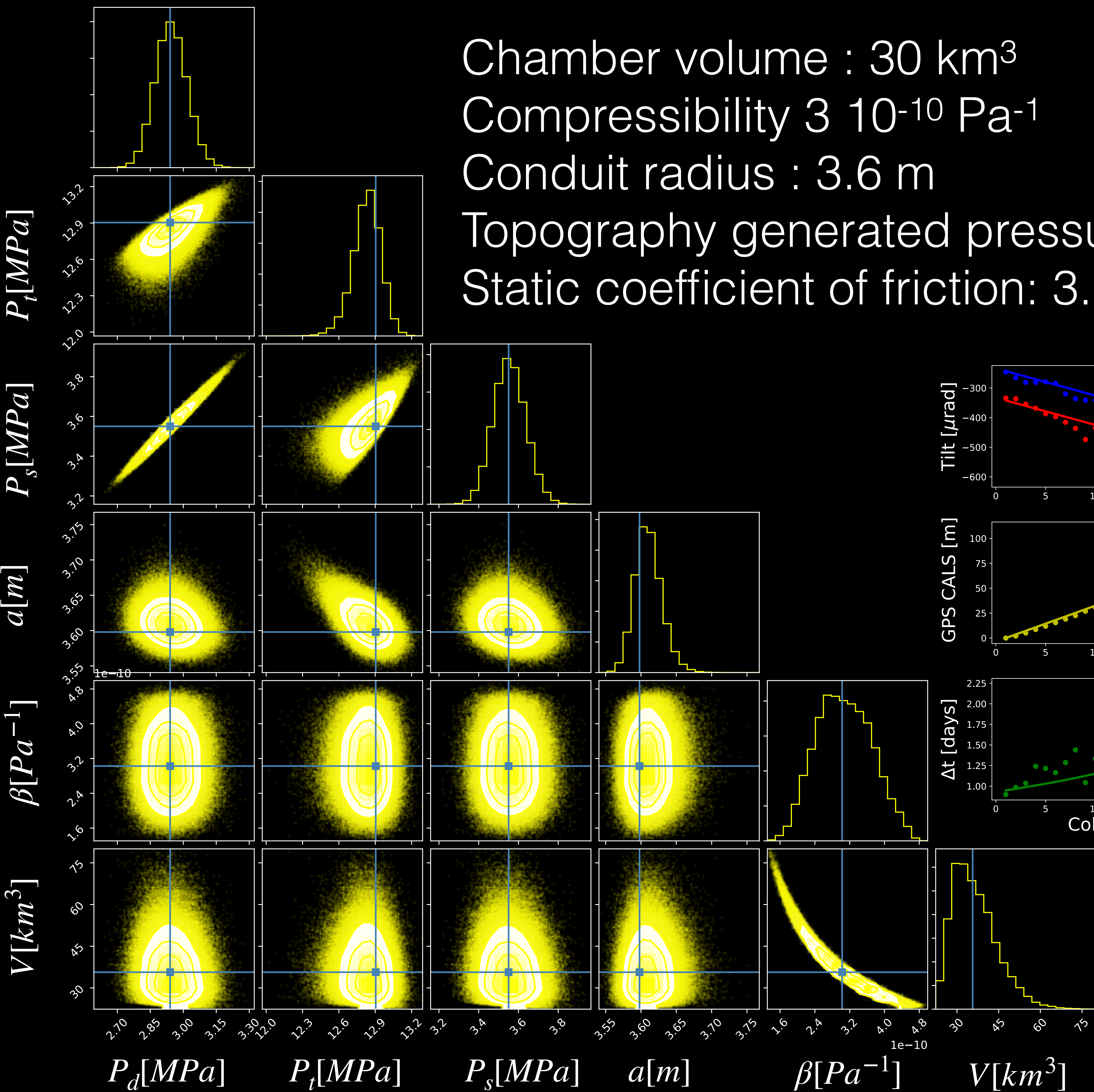
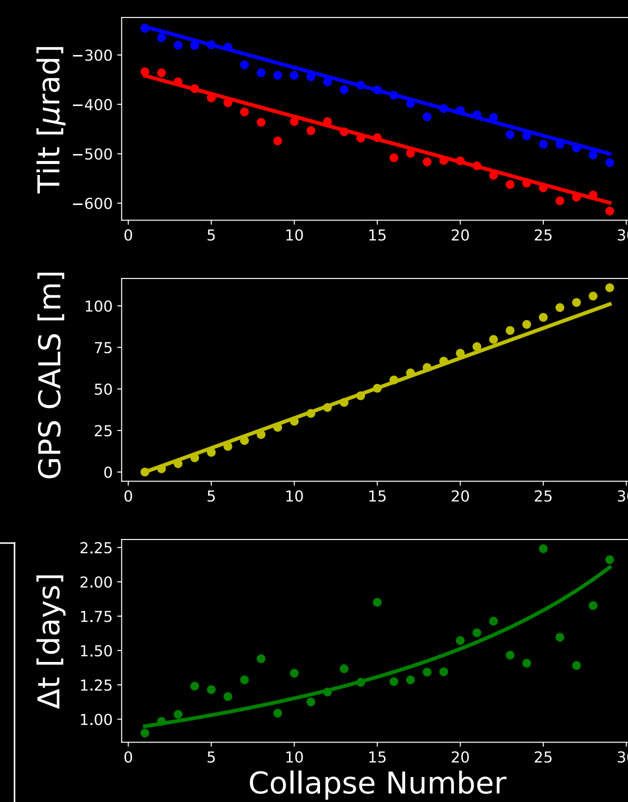
Chamber volume : 30 km$^3$
Compressibility 3 10$^{-10}$ Pa$^{-1}$
Conduit radius : 3.6 m
Topography generated pressure: 13 MPa
Static coefficient of friction: 3.6 MPa



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# Conclusions

- LARGE basaltic eruptions require:
  - Continuous pressurization of the chamber to maintain high eruptive fluxes
  - Topography generated pressure gradients to drive chamber pressure below lithostatic values
- A dynamical model consisting of a piston collapsing in an elastic reservoir suggests a reservoir volume of ~ 30 $km^3$, bulk compressibility of 3 $10^{-10}$ $Pa^{-1}$, conduit radius of 3.5 m, and constrain the frictional properties of the faults along which slip occurs
- The role of complexities in the summit plumbing system are yet to be explored

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