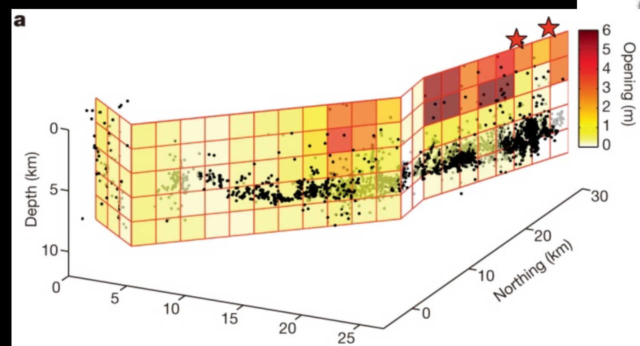
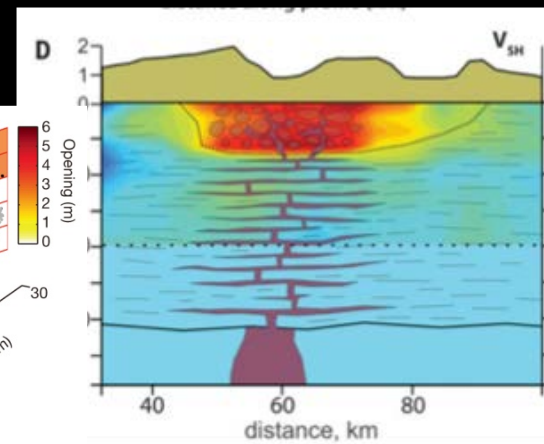
Magmatic Processes

Paul Segall (Stanford)

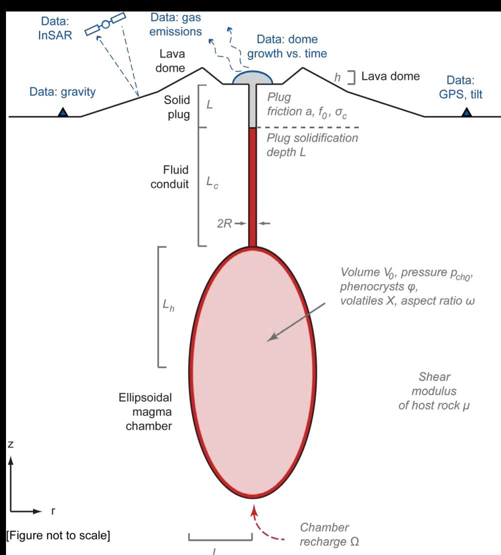
Seismic Imaging

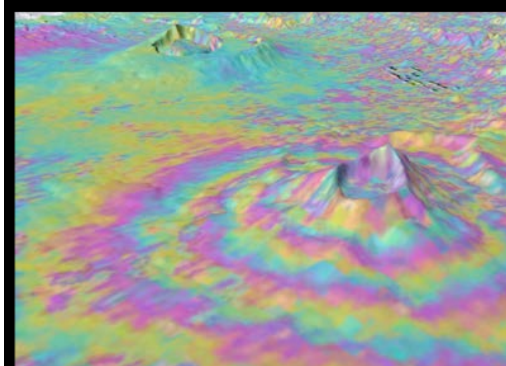
Volcano Seismicity and Tremor

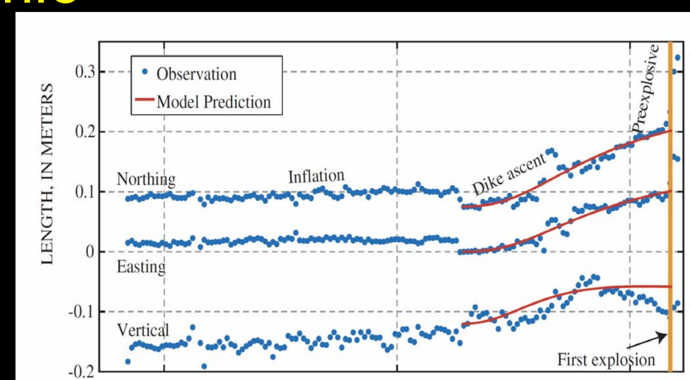




Geodetic + Seismic







Model based joint inversion

Geodetic Monitoring

Key Scientific Questions

- How is magma stored in the crust? geometry, volume and physical state of crustal melts.

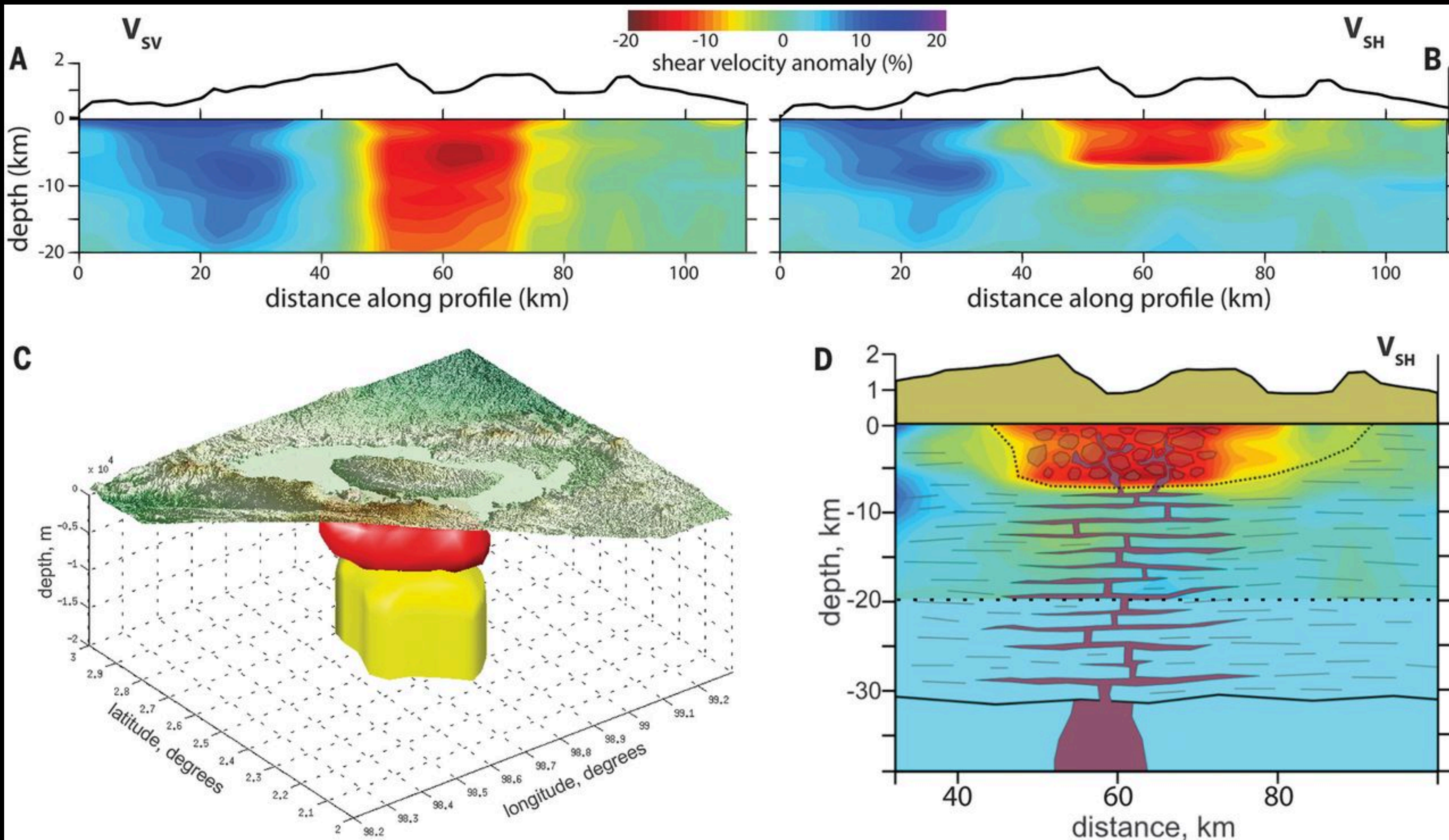
- Can we move from empirical to physics-based eruption forecasting?

- How to predict not only that an eruption is likely, but also eruptive style?

- Can we predict the duration and size of an eruption once its underway?

- Link different data types: deformation, seismic, gravity, gas, petrology, tomography, …

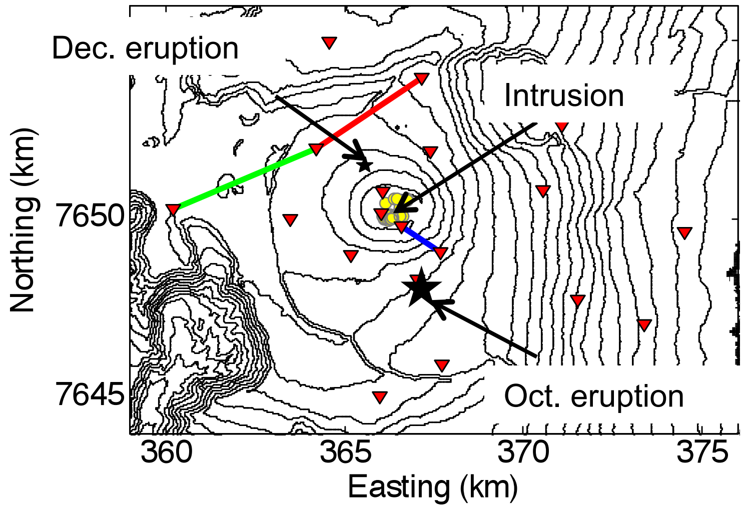
Imaging a Magmatic Sill Complex Beneath Toba

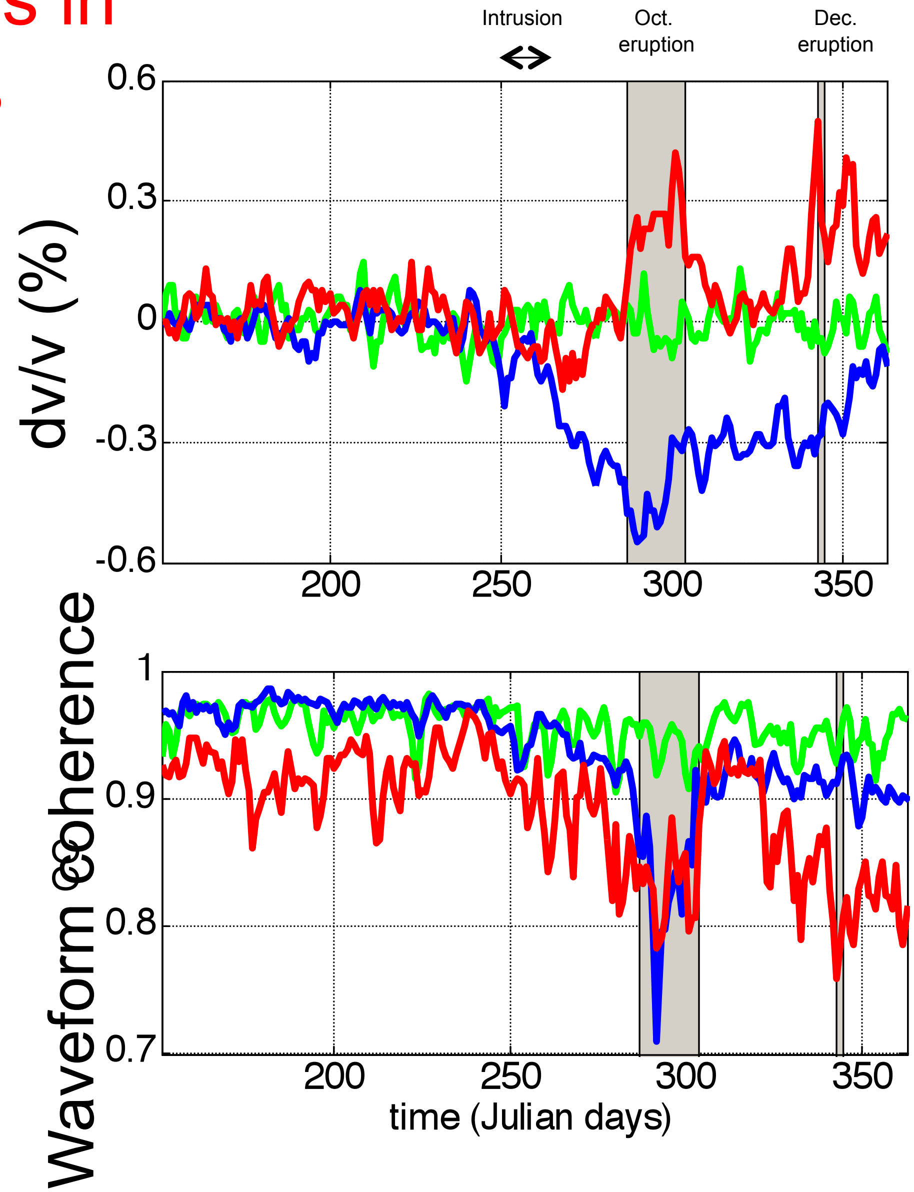


K. Jaxybulatov et al. 2014, **A large magmatic sill complex beneath the Toba caldera,** Science

Science AAAS

Imaging temporal changes in mechanical properties

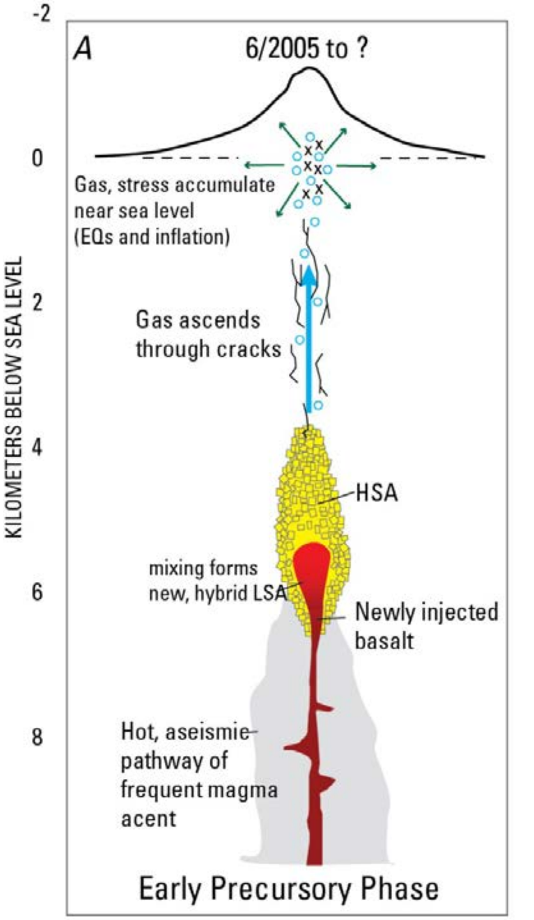


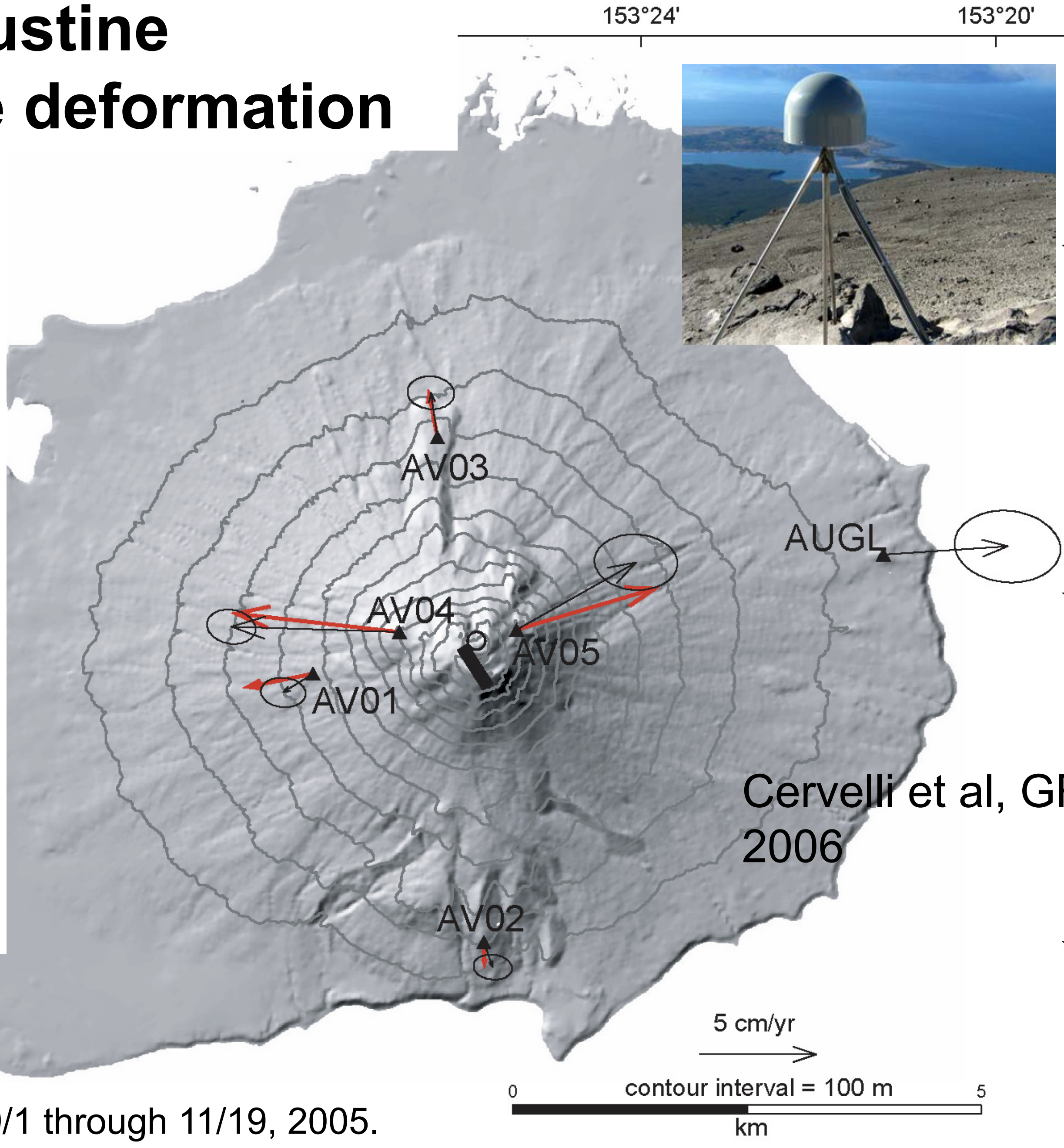


Obermann et al, JGR 2013

Also work extracting
body waves from ambient noise
Nori Nakata

Augustine
Pre-eruptive deformation

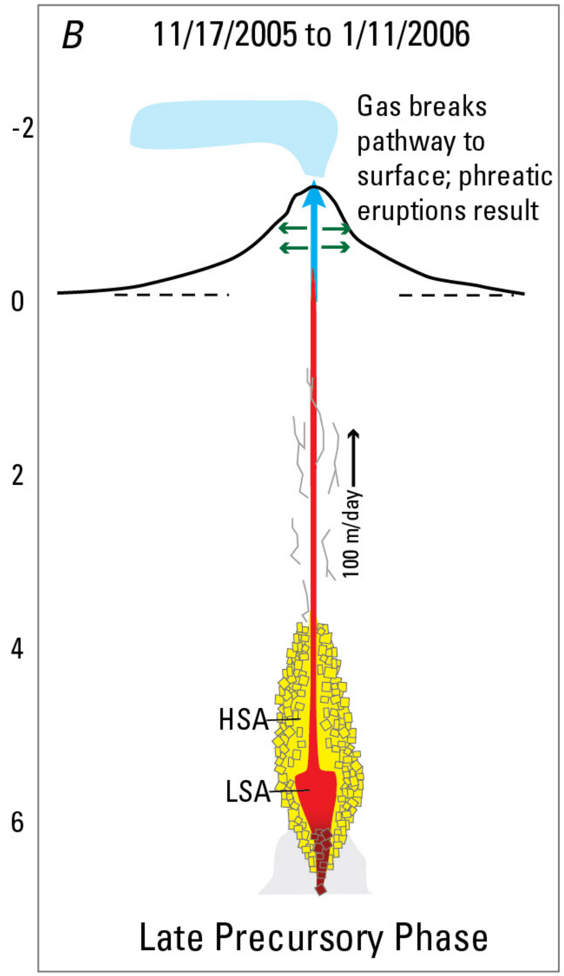


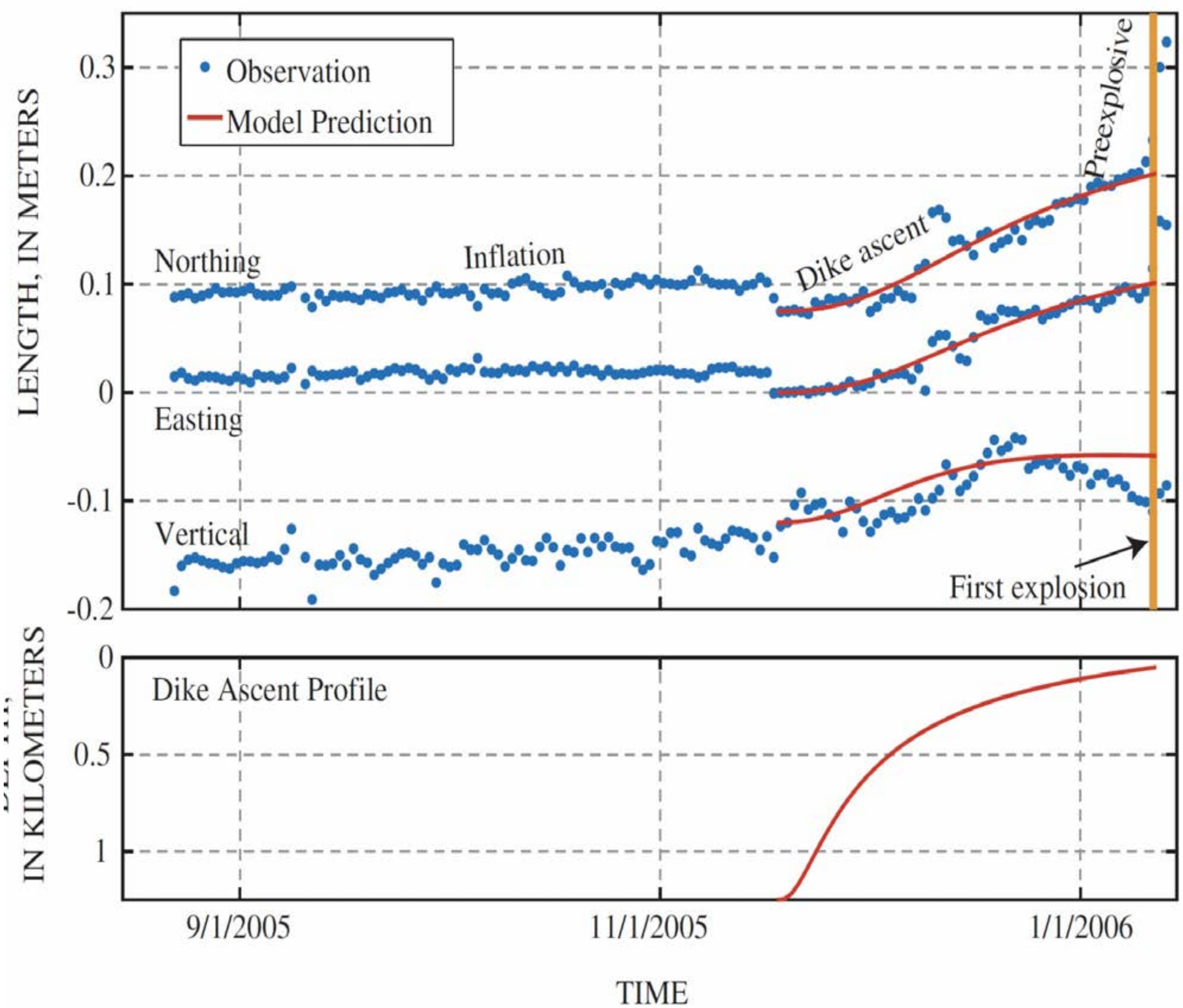


Cervelli et al, GRL 2006

Velocities from 9/1 through 11/19, 2005.

Augustine: Dike Propagation

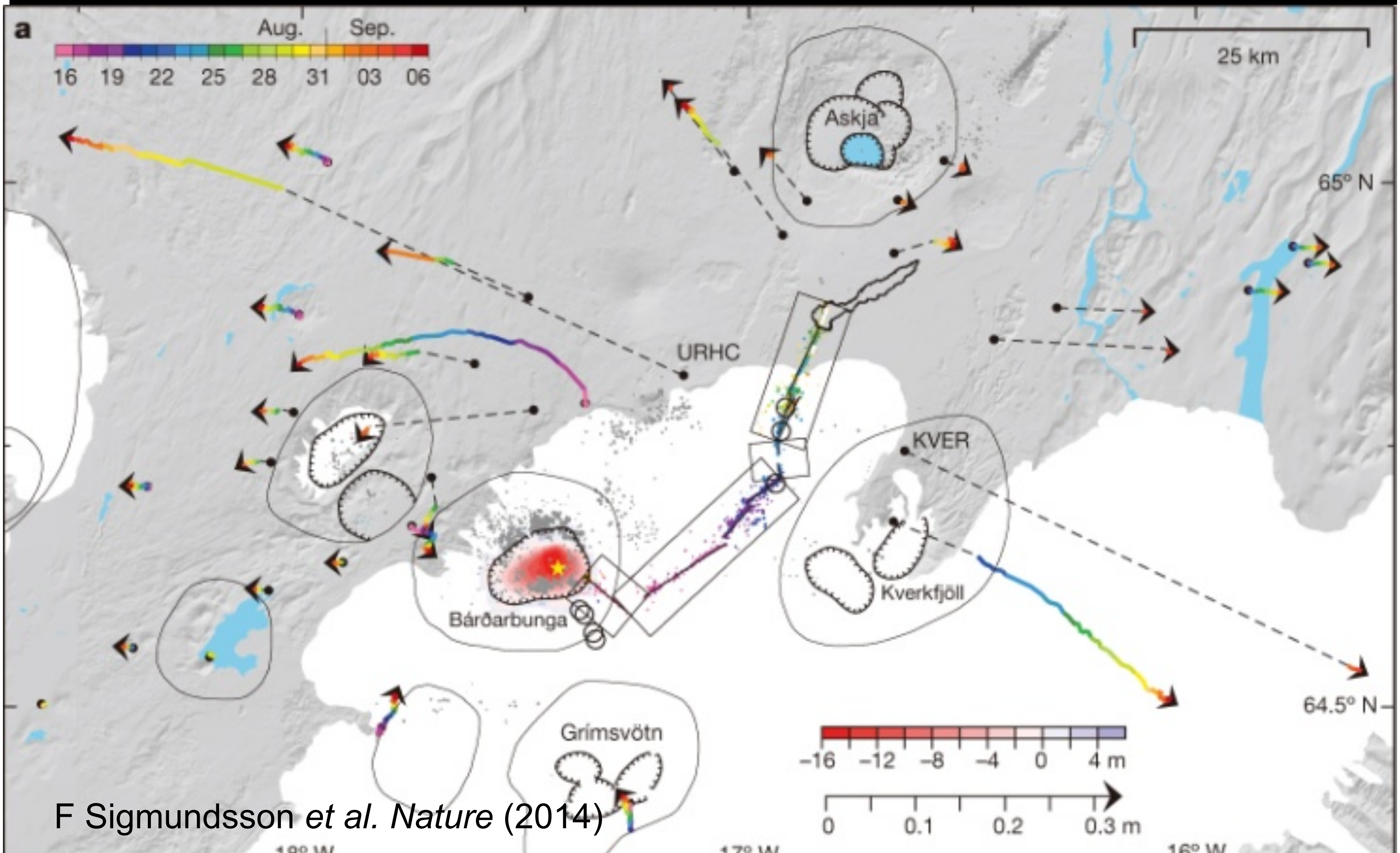




Extension continued following first explosion, forecasting that eruption would continue

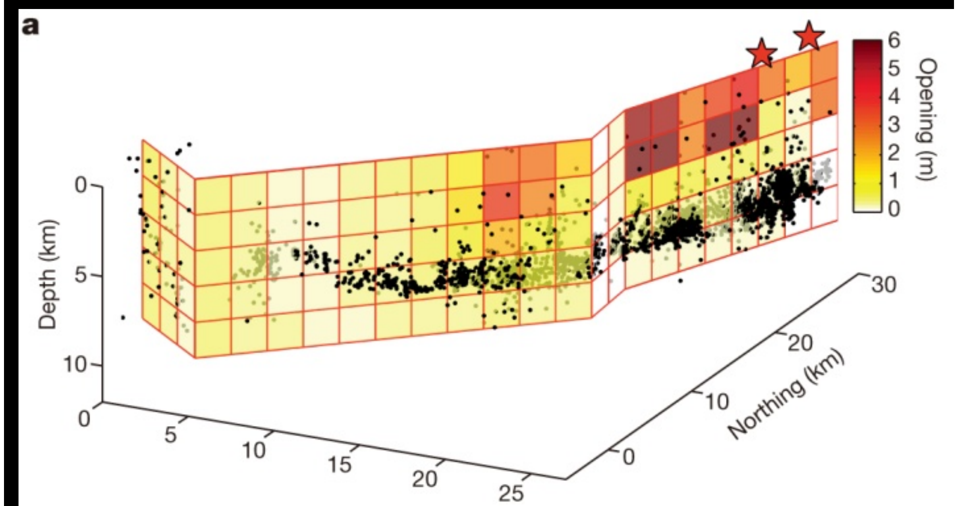
Cervelli et al, GRL 2006

40 km Long Dike Intrusion in Iceland

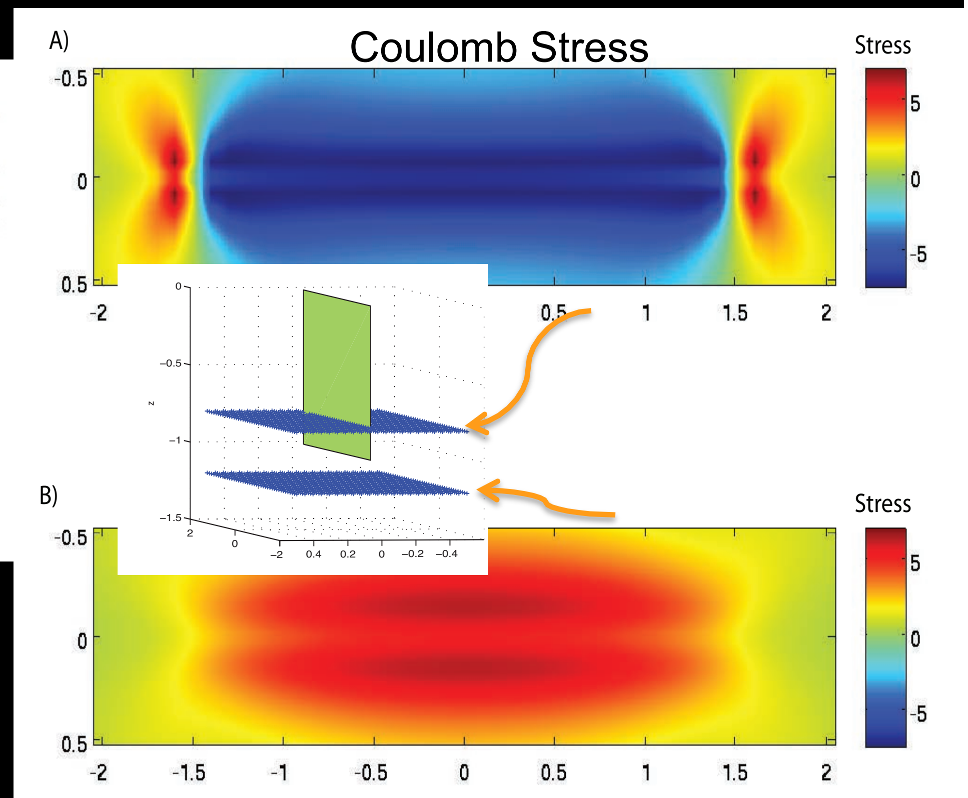


F Sigmundsson *et al. Nature* (2014)

Dike Deformation and Seismicity

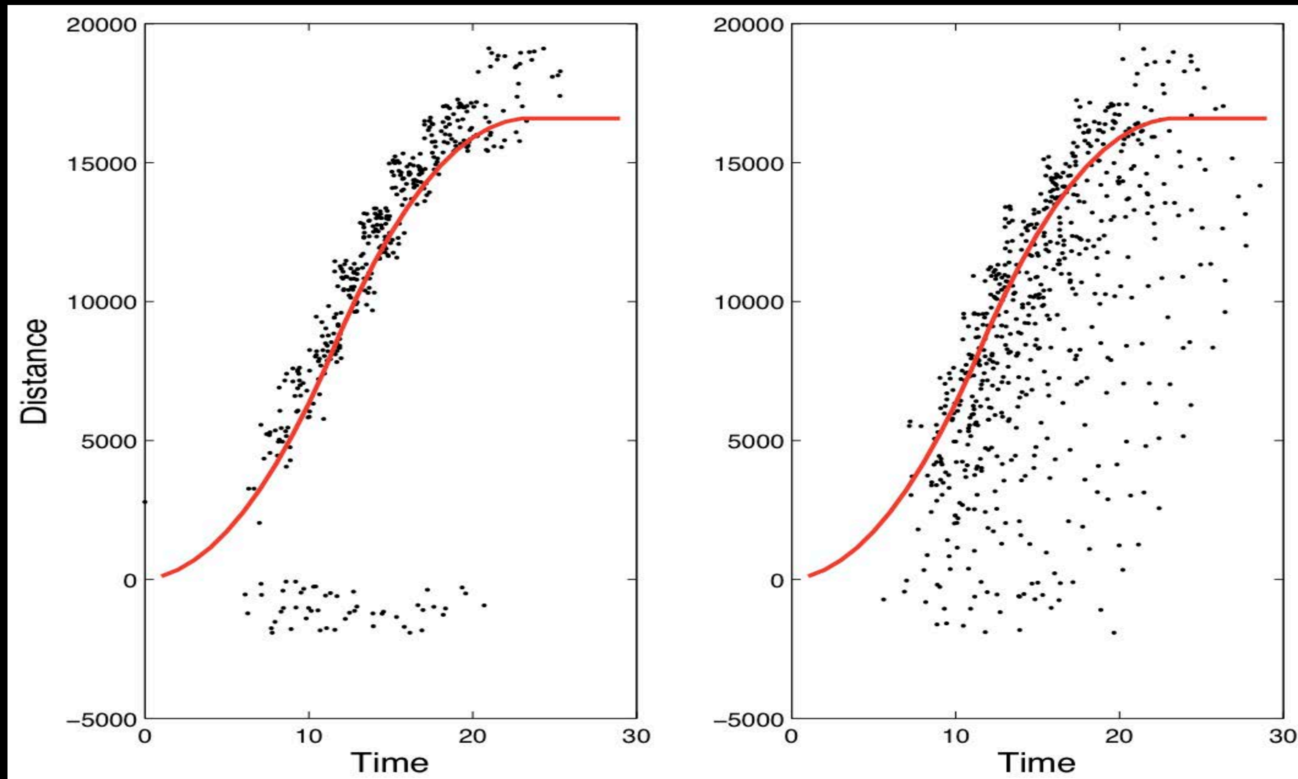


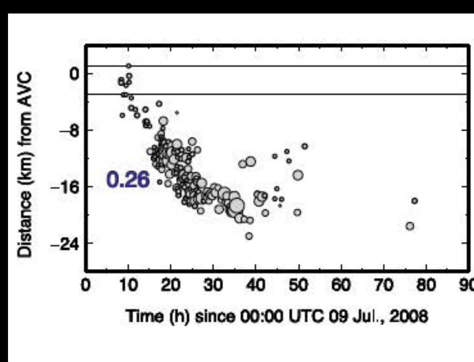
F Sigmundsson *et al. Nature* (2014)

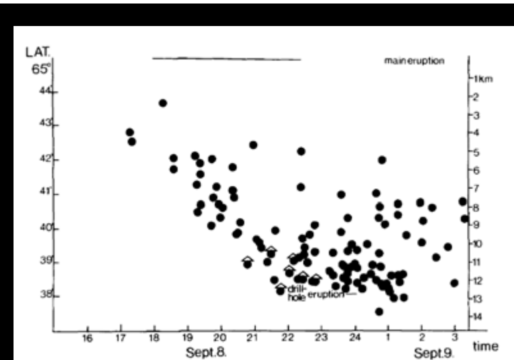


Segall et al, JGR (2013)

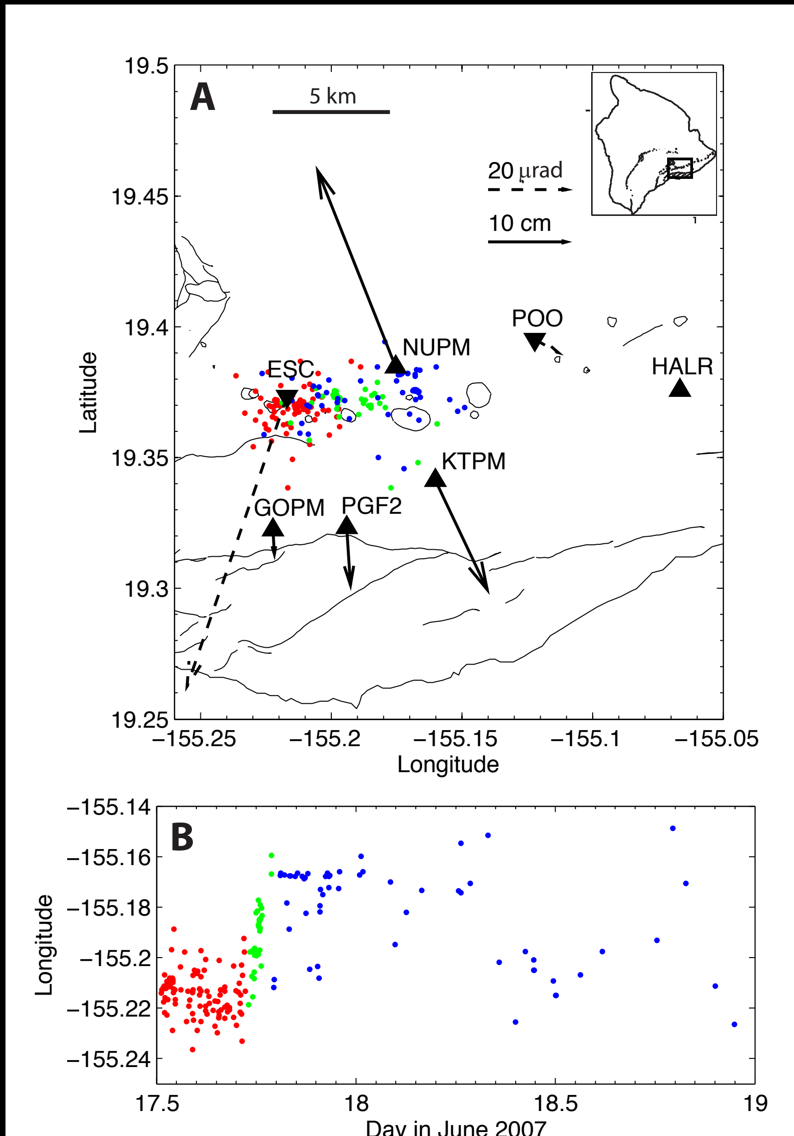
Seismicity Patterns

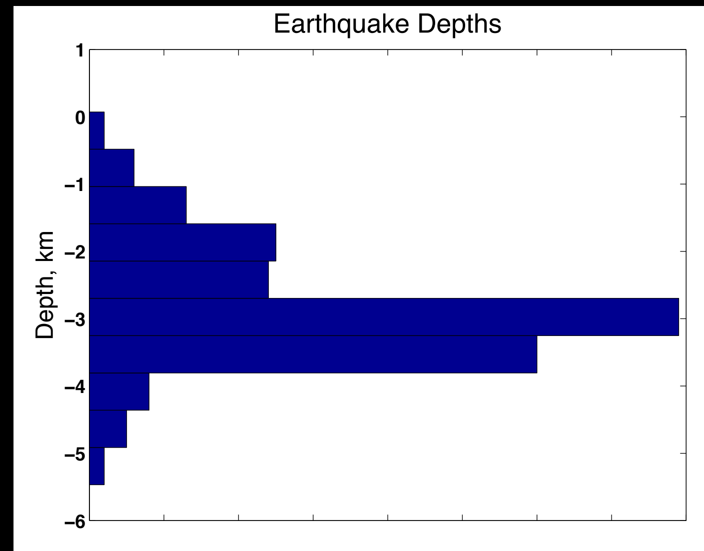


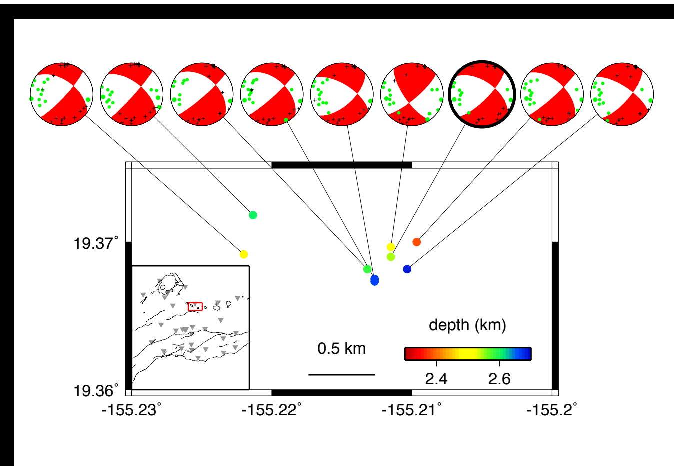




June 2007 "Fathers Day" Kilauea Intrusion

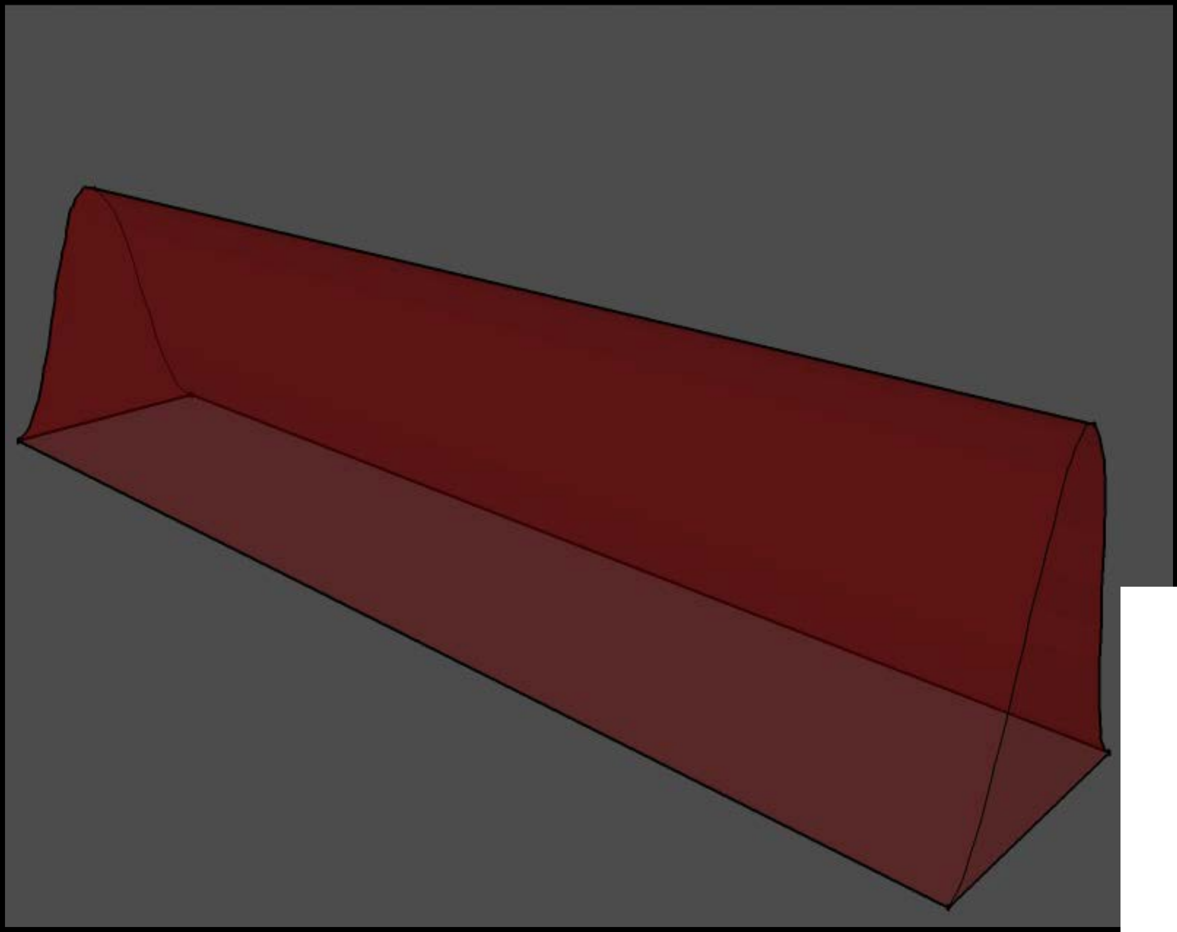


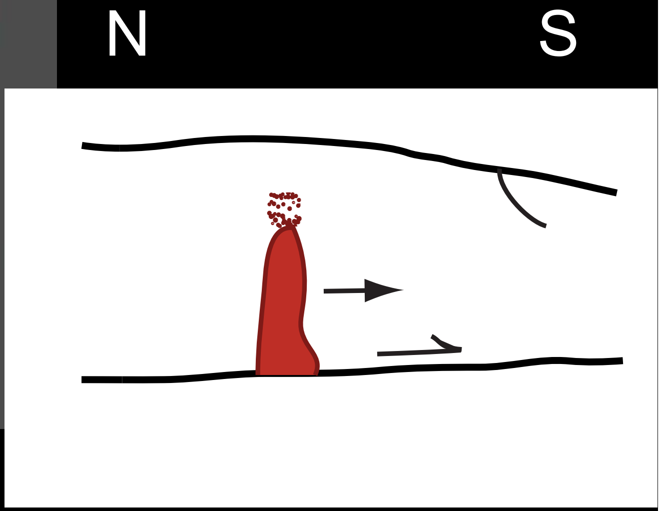




Segall et al, JGR (2013)

Intrusion into Rift Zone





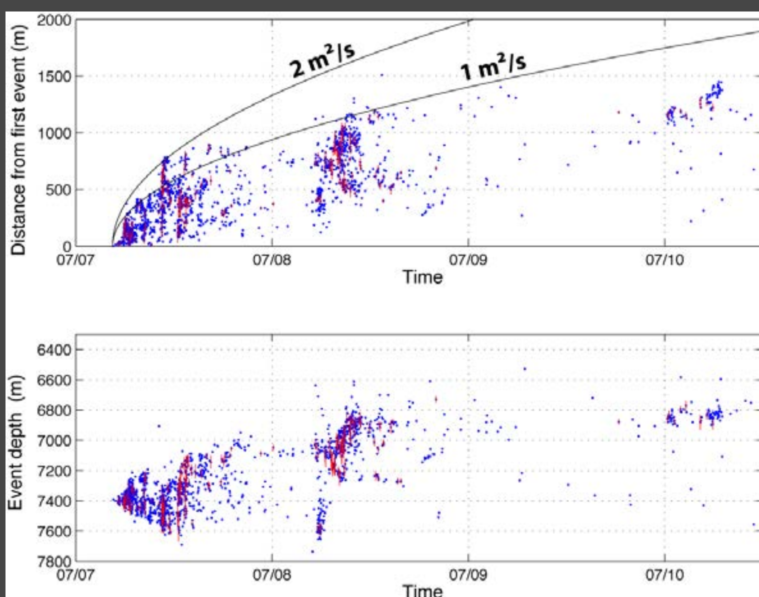
Long Valley 2014 swarm

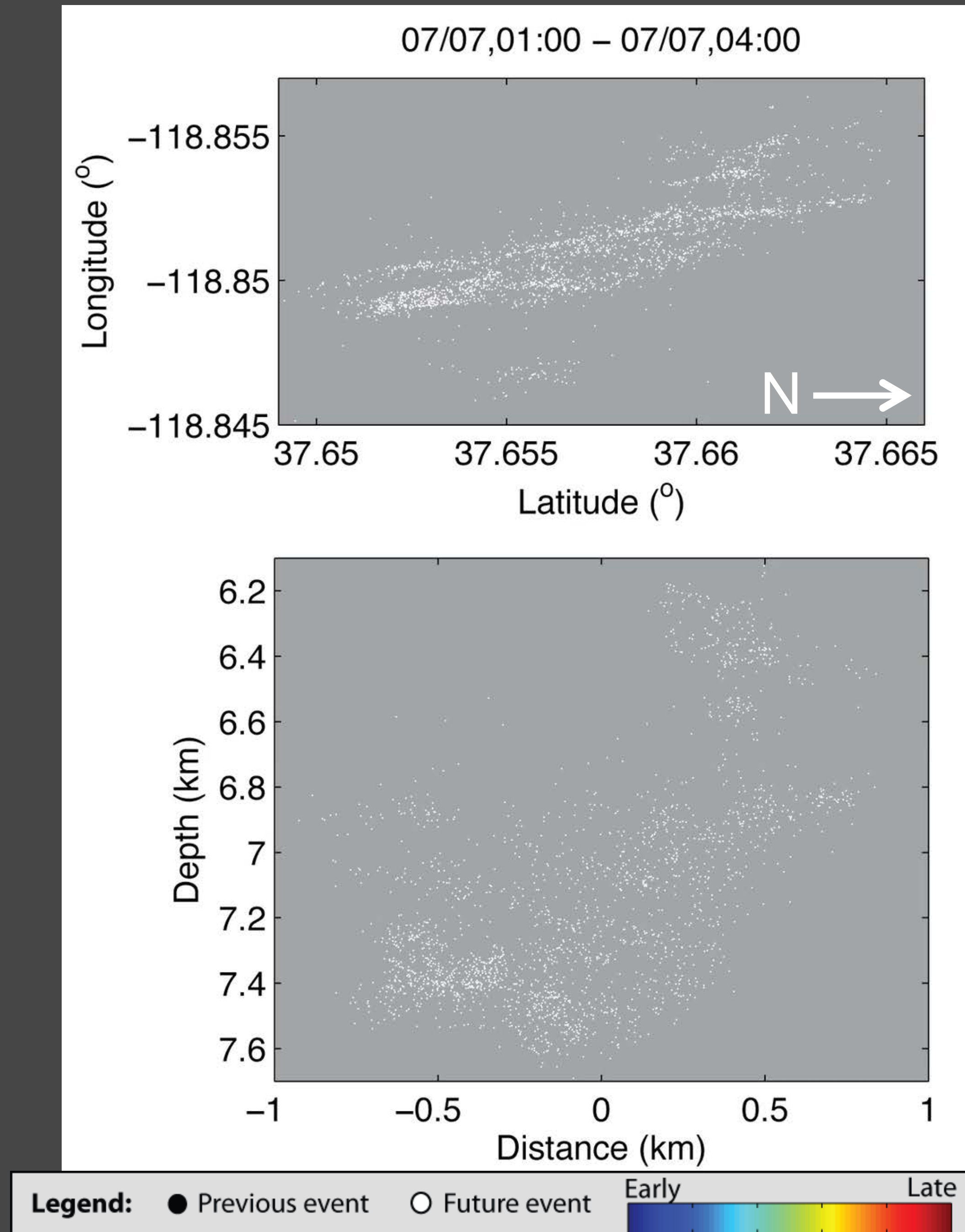
- Max magnitude: 2.8

468 catalog earthquakes

-> 2468 precisely located events after processing

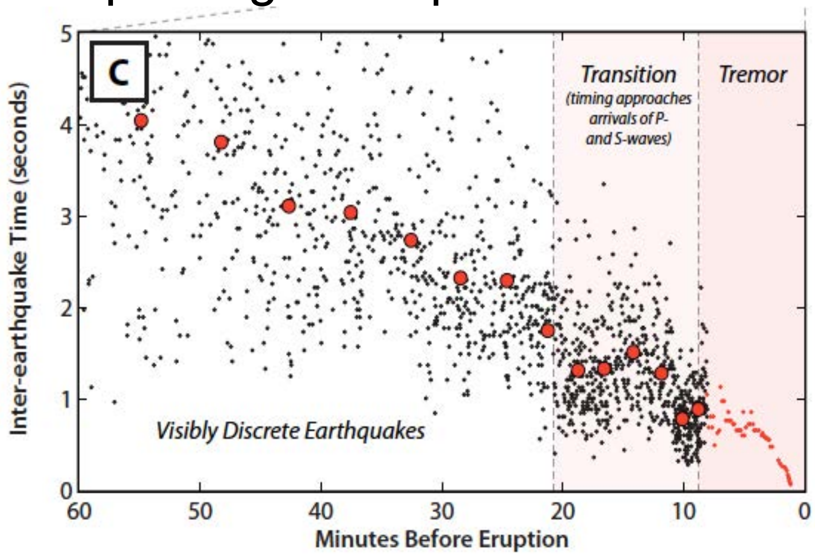
Dave Shelly, AGU 2014





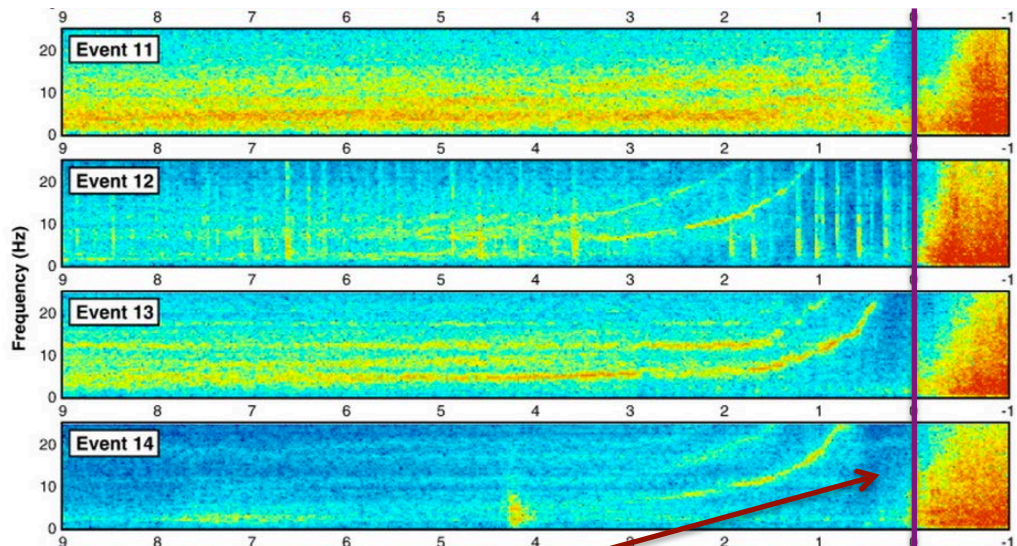
Repeating Quakes and Gliding Tremor

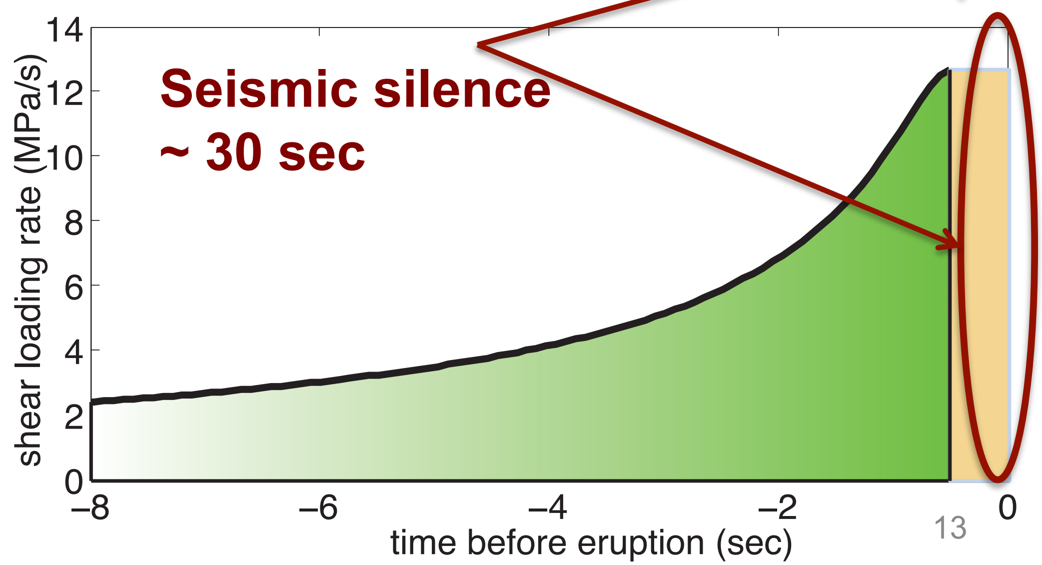
- repeating earthquakes M ~ 1

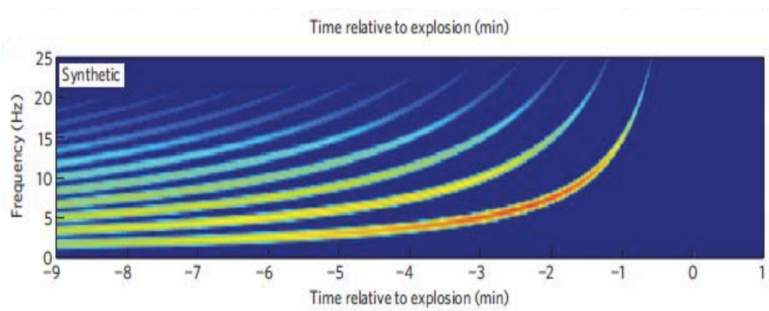


Hotovec et al., 2012

Gliding Harmonic Tremor eruption

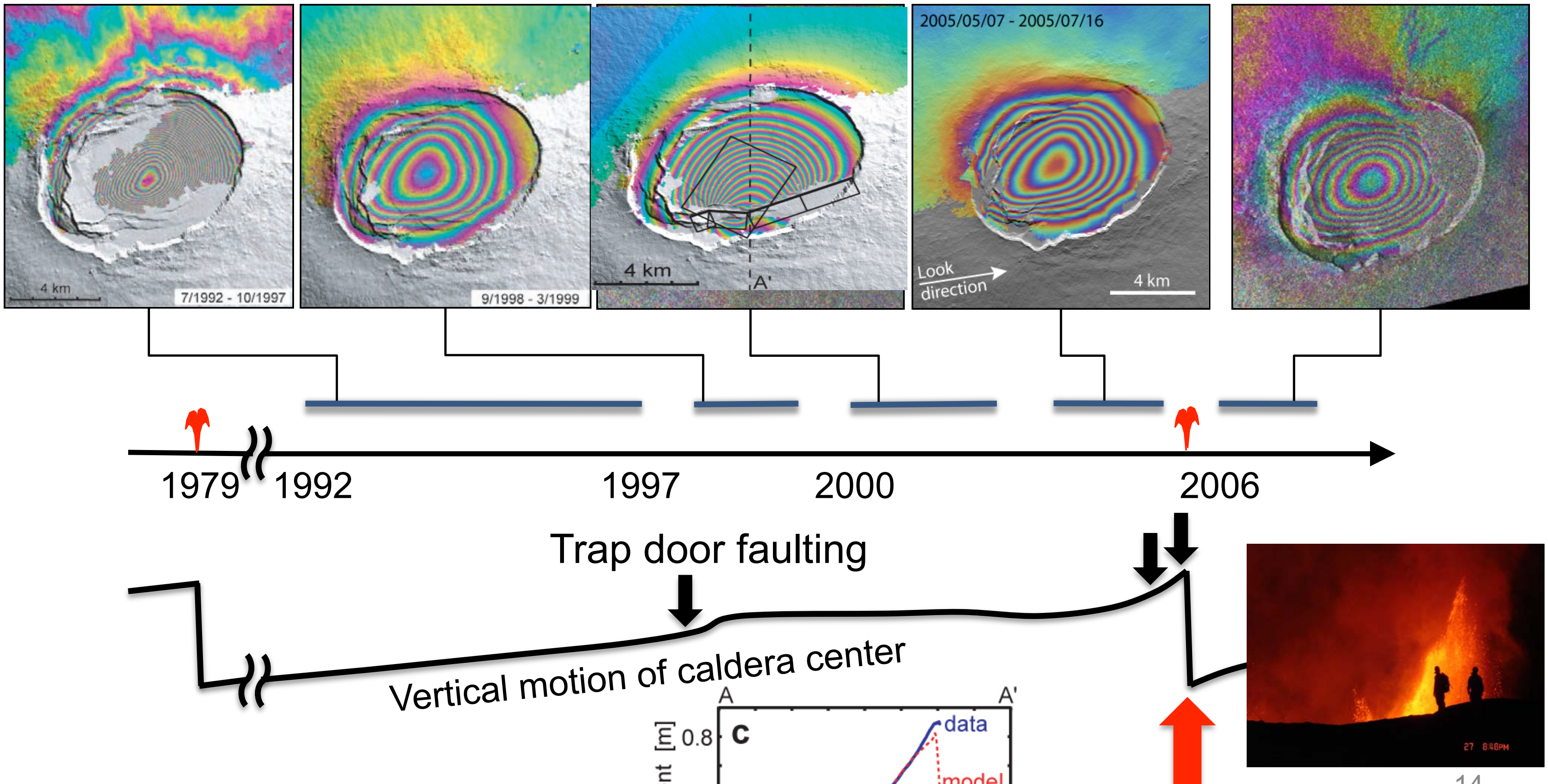


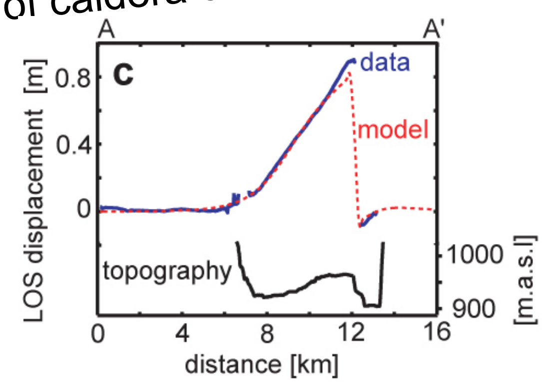




Model: Dmitrieva etal, 2013 NatGeo

Galapagos Uplift, Trapdoor Faulting, & Eruption



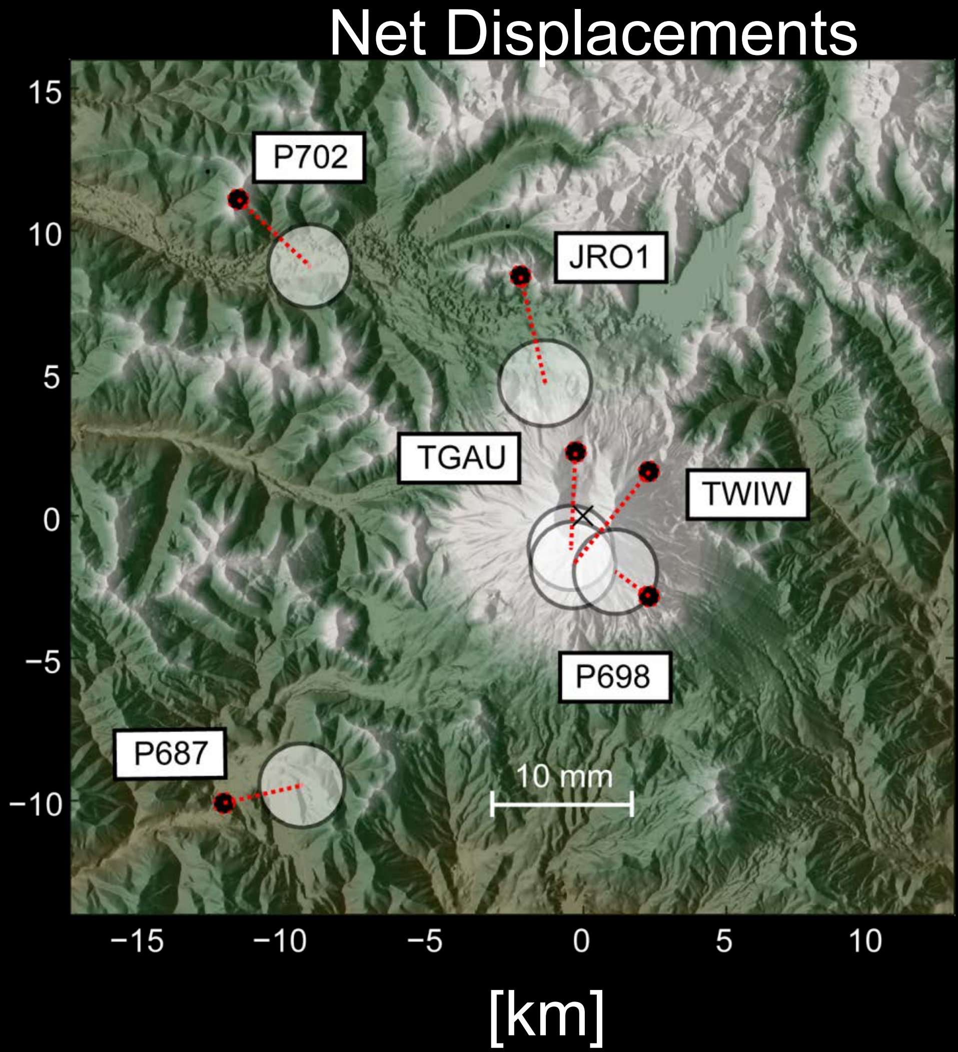


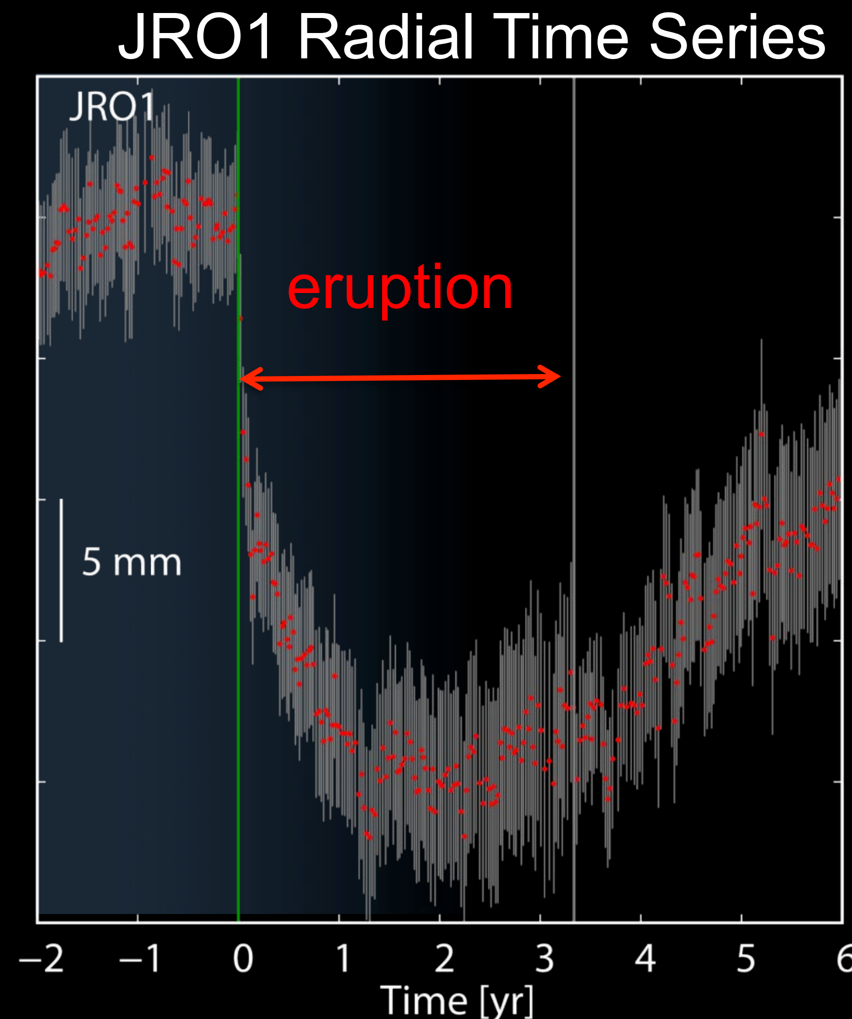
Global monitoring feasible

(Amelung et el. 2000; Chadwick et al. 2006; Geist et al. 2008).

Mount St. Helens: 2004-2008

Mount St Helens Dome Forming Eruption 2004-2008





Lisowski et al. [2008]

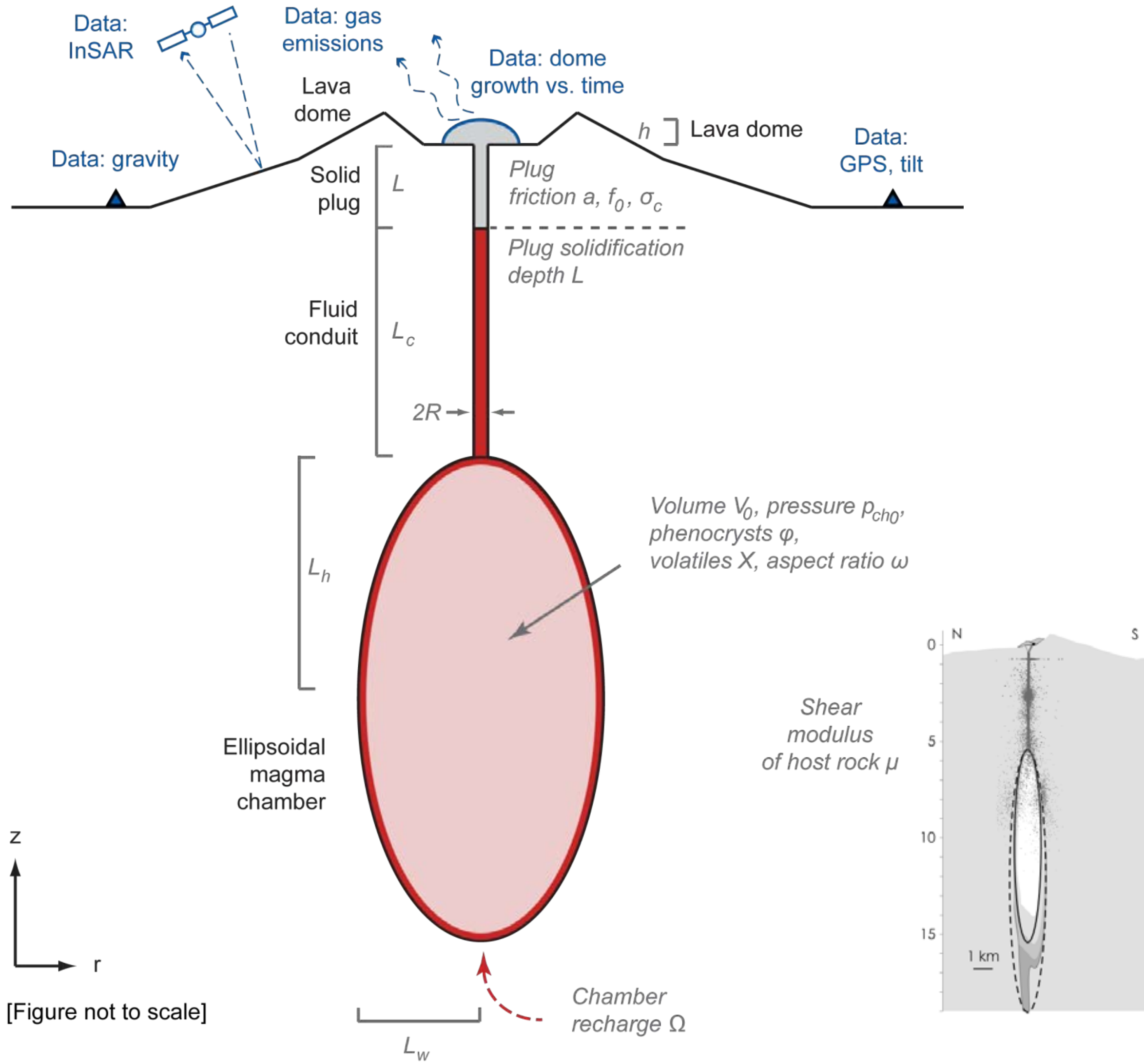
Physics-based Volcano Deformation

<u>Key model parameters</u>

- Chamber volume, initial overpressure, aspect ratio, volatile content, conduit length, chamber influx, and frictional plug parameters

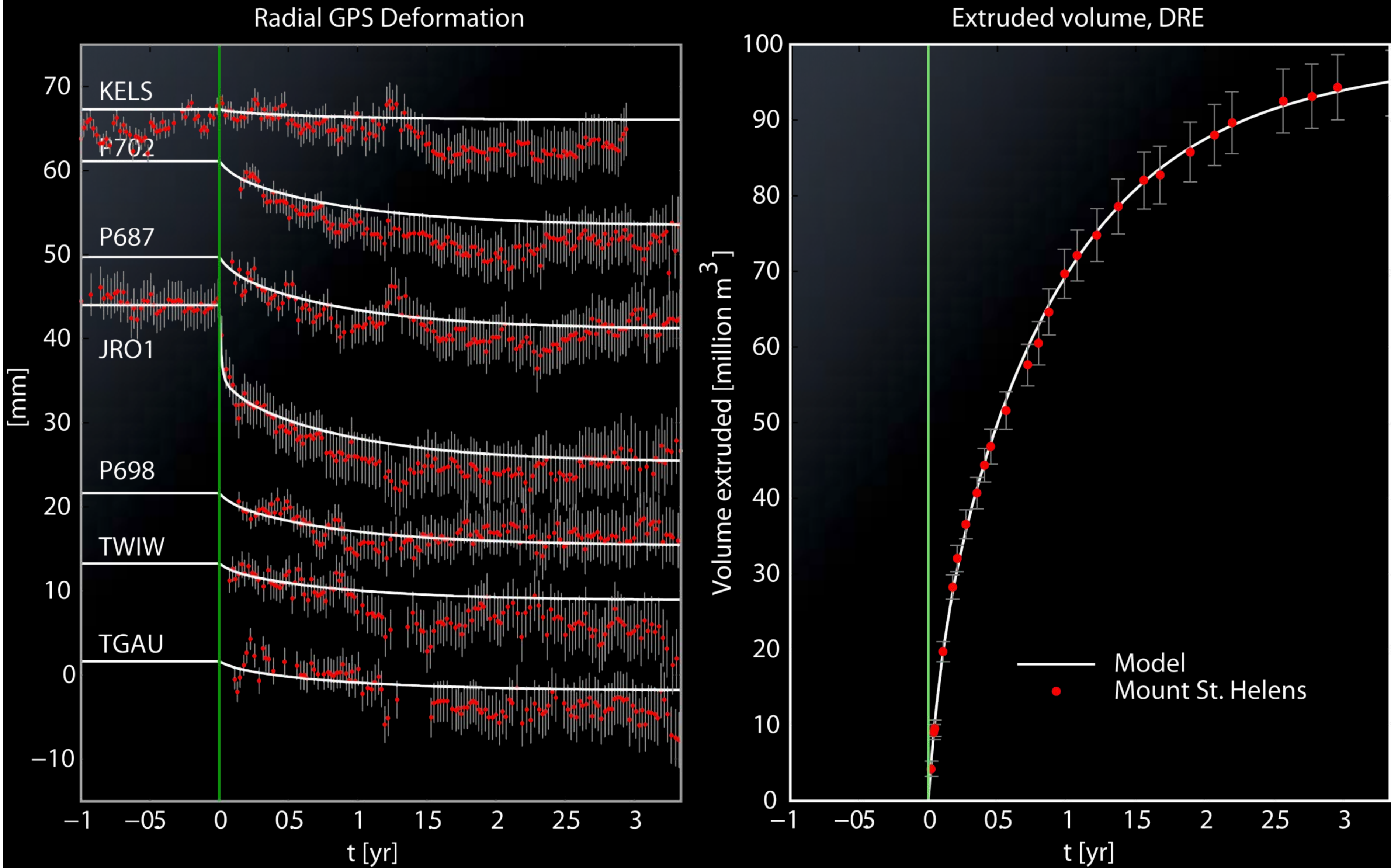
<u>Key assumptions</u>

- Radial symmetry, 1D conduit
- Newtonian rheology
- No gas loss from fluid conduit
- Fixed crystallization depth

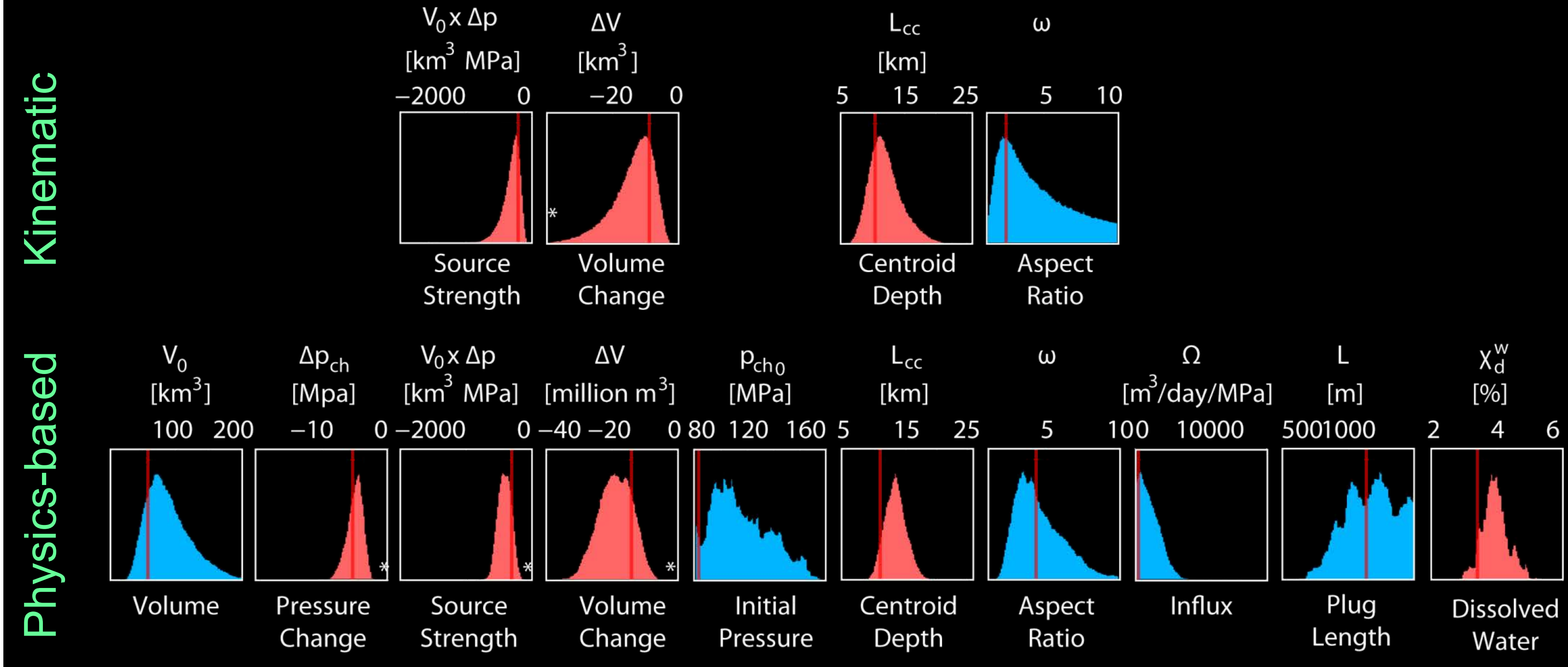


Anderson and Segall, Physics−based models of ground deformation and extrusion rate at effusively erupting volcanoes: Model development and analysis JGR 2011

Model Fits both GPS and Extrusion Data



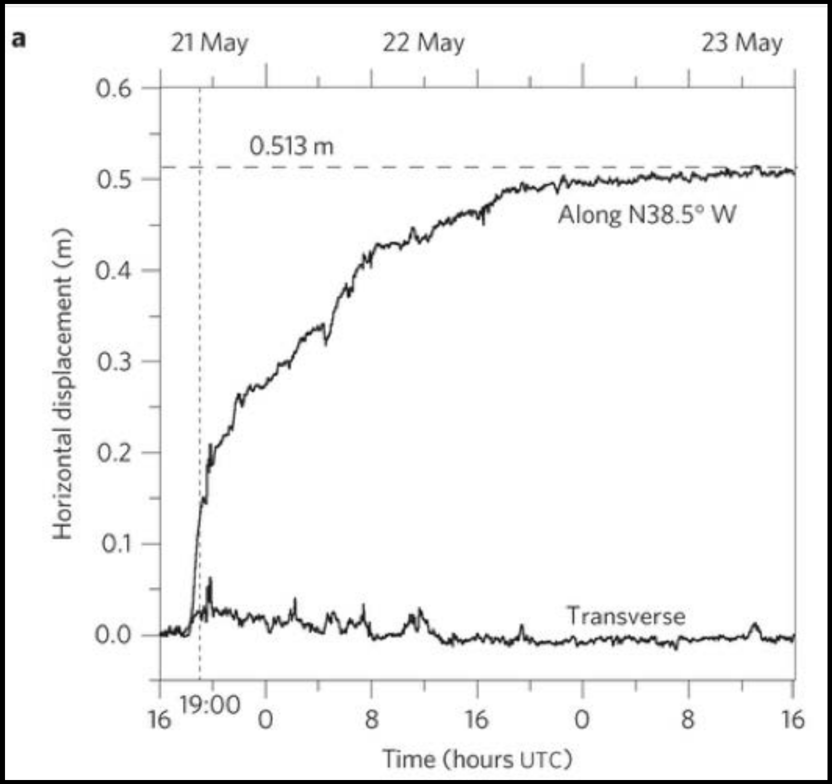
Kinematic vs. Physics-Based Inversion



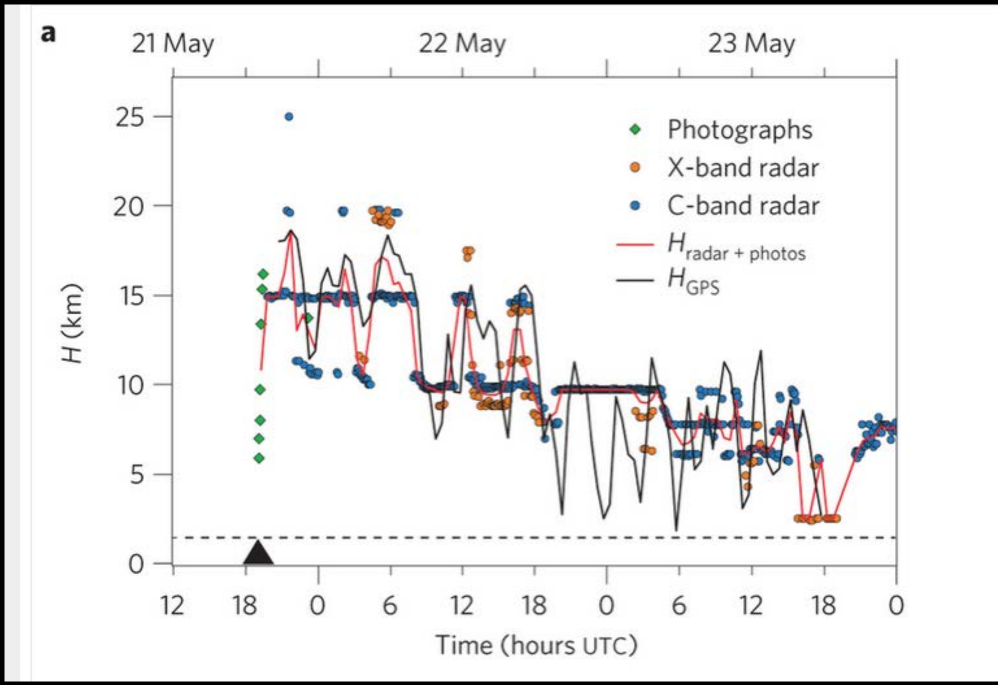
Anderson and Segall, JGR 2013

Grimsvotn GPS and Erupted Flux from Plume Height

GPS Displacements

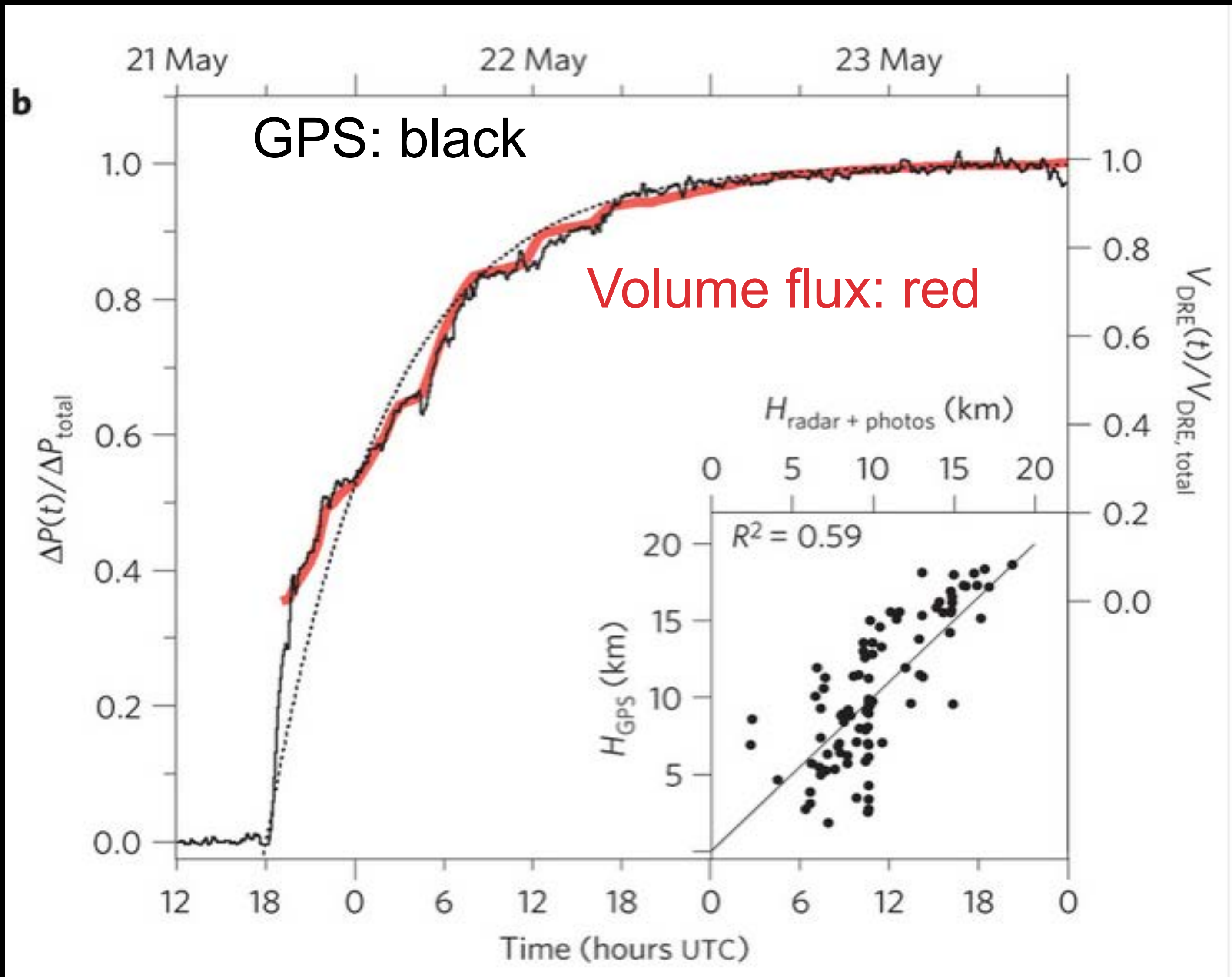


Plume Height from Radar



Hreinsdóttir et al, Volcanic plume height correlated with magma-pressure change at Grímsvötn Volcano, Iceland; 2014 Nature

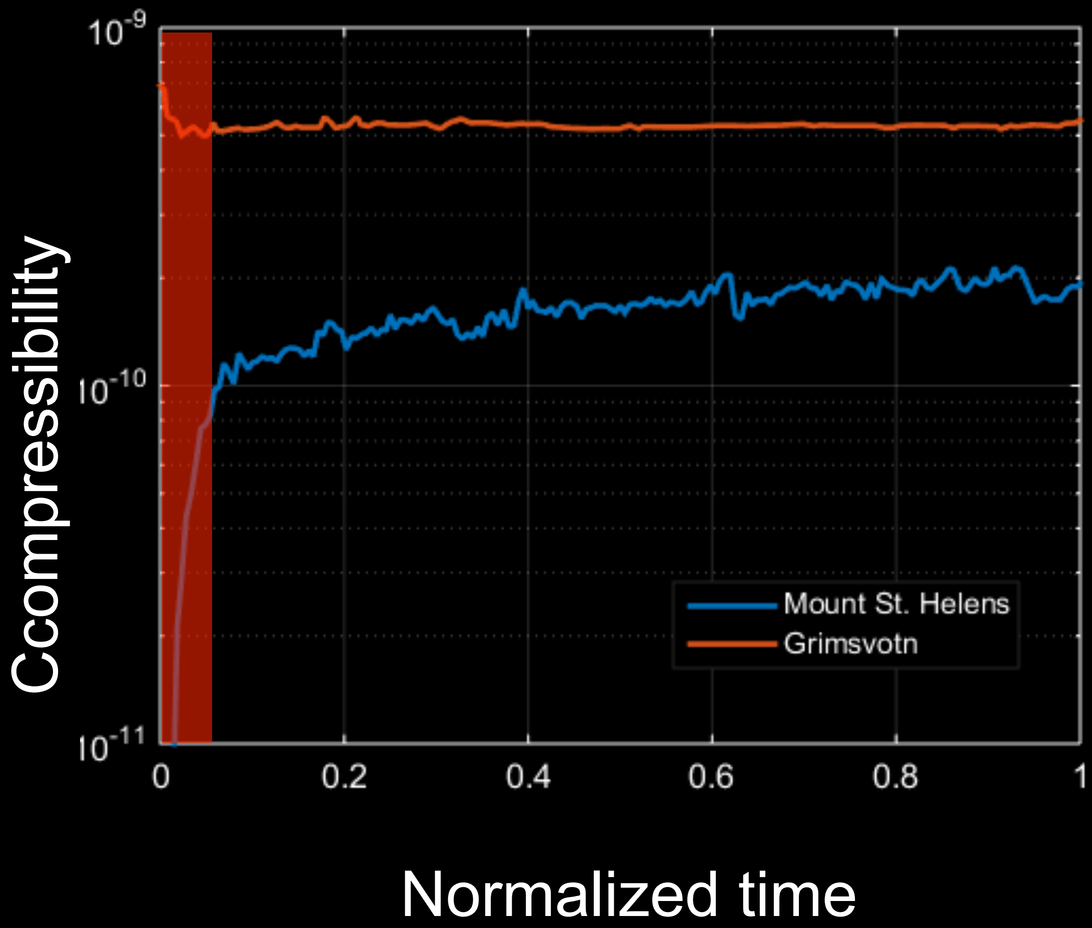
Grimsvotn GPS and Inferred Flux



Hreinsdóttir et al, 2014

Assessing Physical Properties in Magma Chamber

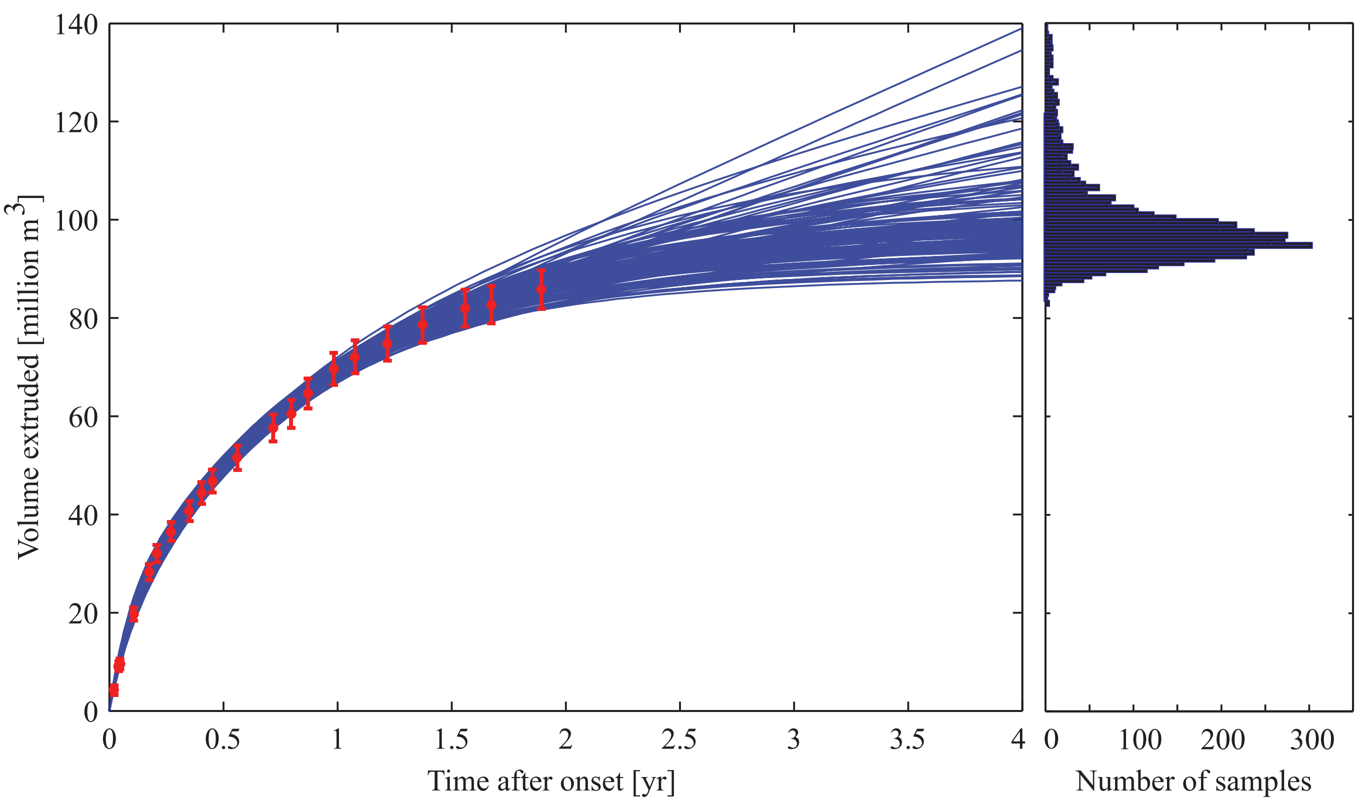
$$\underbrace{\frac{q_{out}}{\dot{u}(r)}}_{flux\ to\ GPS\ velocity} \underbrace{\frac{f(\mathrm{r/d}, a/b, \ldots)}{d^2\mu}}_{chamber\ geometry} = \underbrace{\bar{\beta}}_{compressibility}$$



Segall 2013

Calculations:
Kyle Anderson

Forecasting Eruption Extent ?

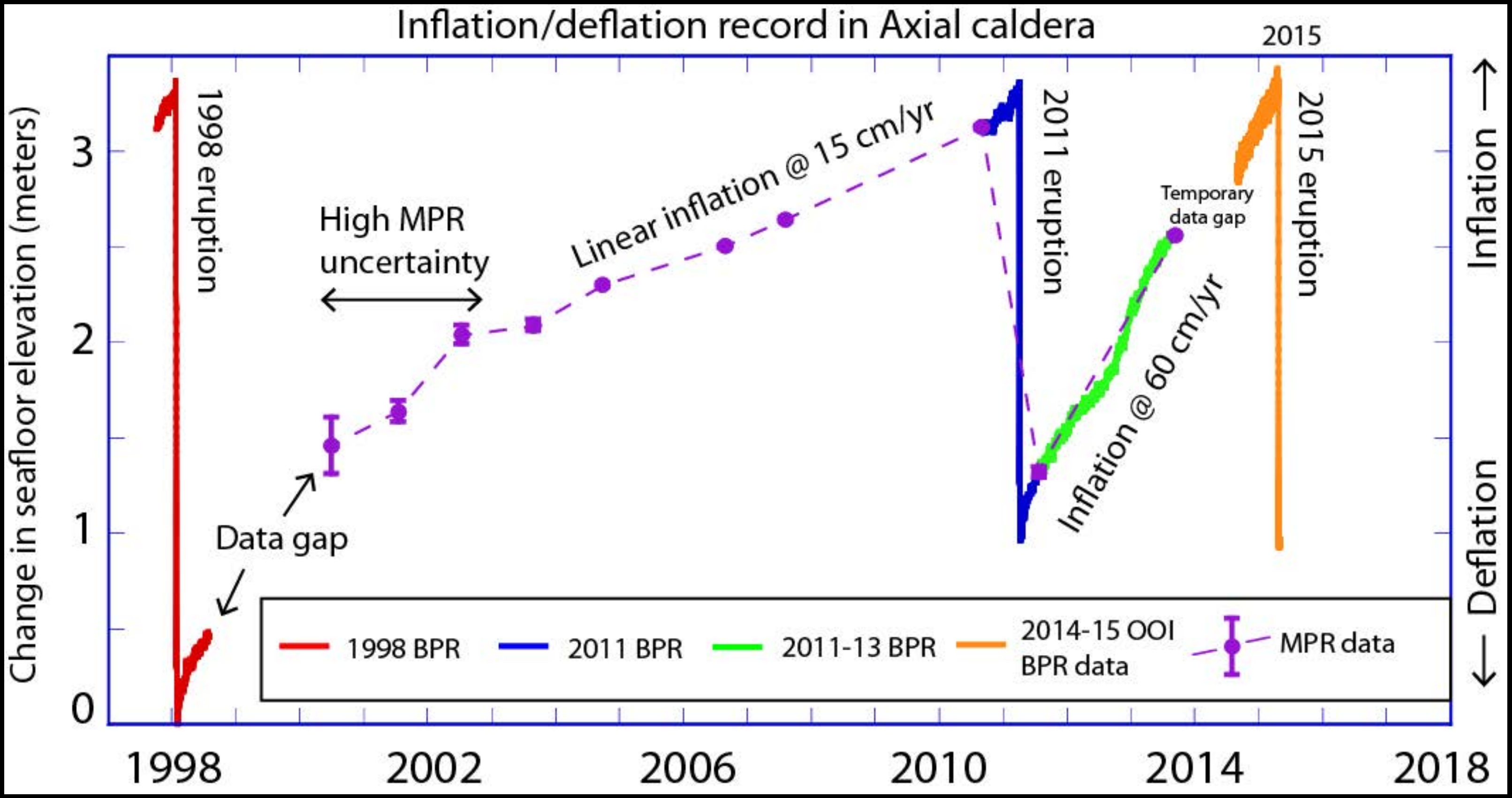


- Physics-based Monte Carlo Forecasting

- Forecast based on knowledge of the system and all existing data.

Axial Volcano

2.4 meter subsidence
April 2015



Bill Chadwick

Recommendations

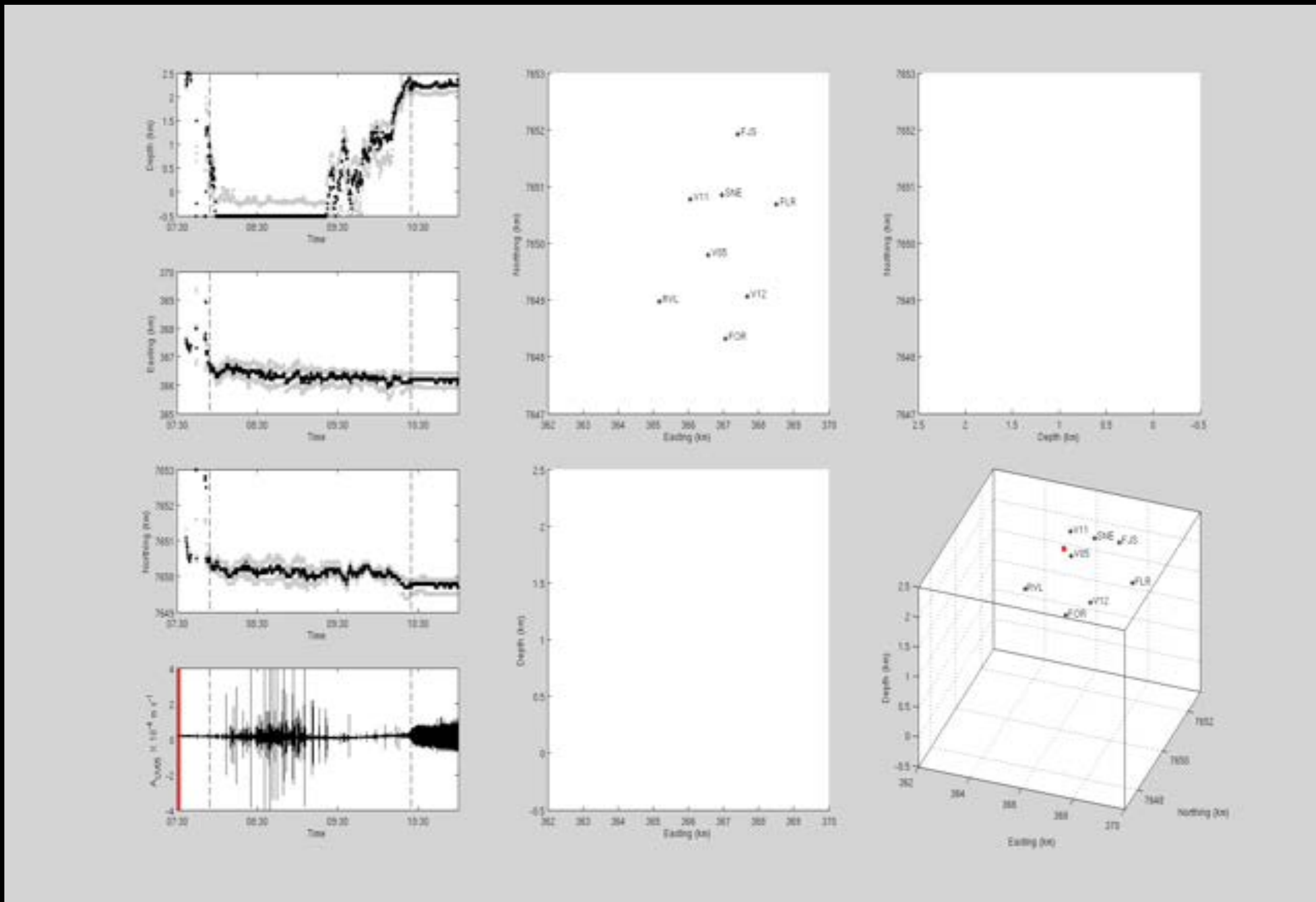
• Long term monitoring of volcanic systems required to record intrusive and eruptive processes.

• Advances in methodology (e.g. ambient noise imaging, precise event location, 4D inversion) require spatially and temporally dense data sets.

• Joint inversion of seismicity and deformation is feasible and potentially powerful in forecasting eruptions.

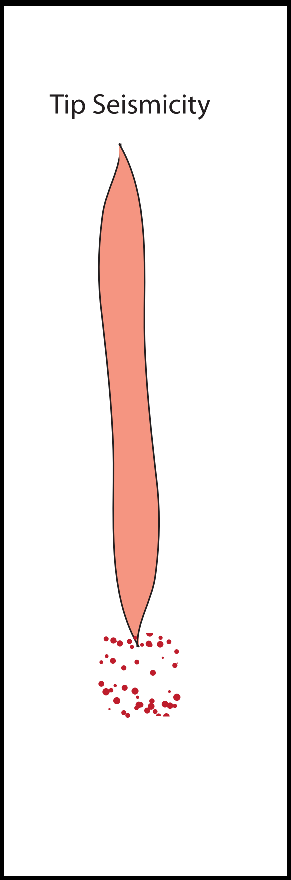
• Physics based models provide key links between different data types and *may* allow for dynamical forecasts.

Continuous Amplitude Imaging

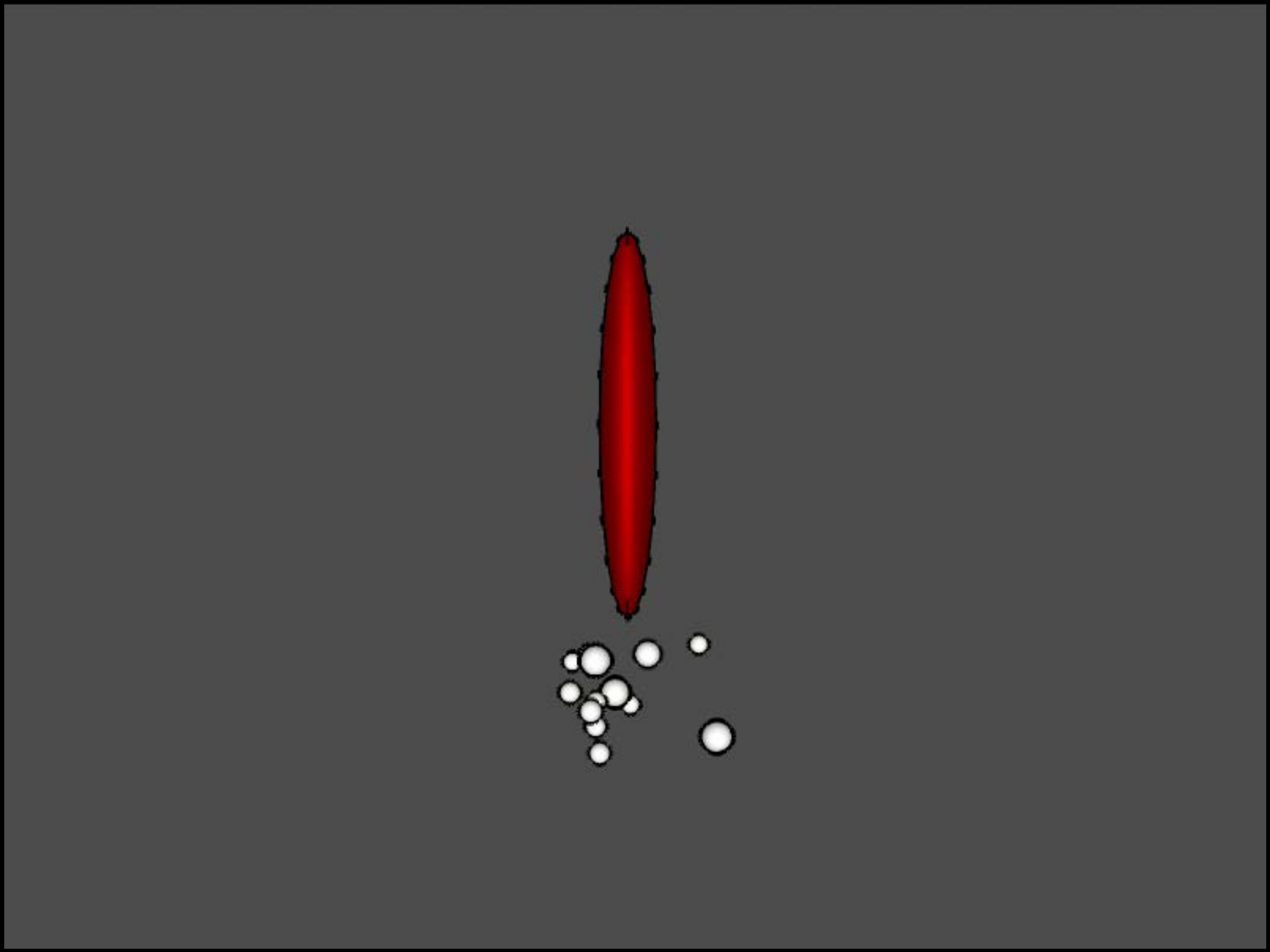


Taisne et al, Imaging the dynamics of magma propagation using radiated seismic intensity, GRL, 2011

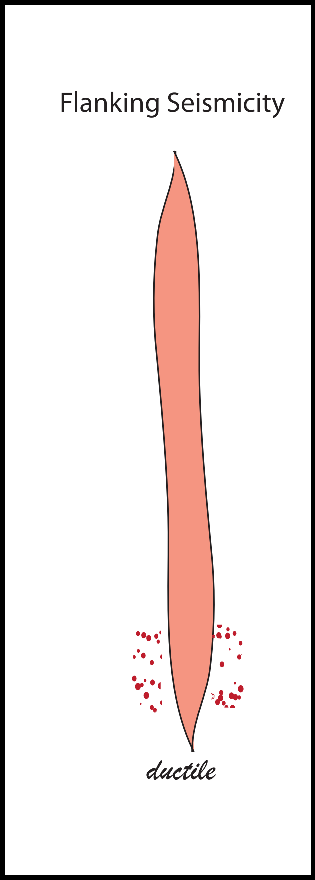
Dike Seismicity



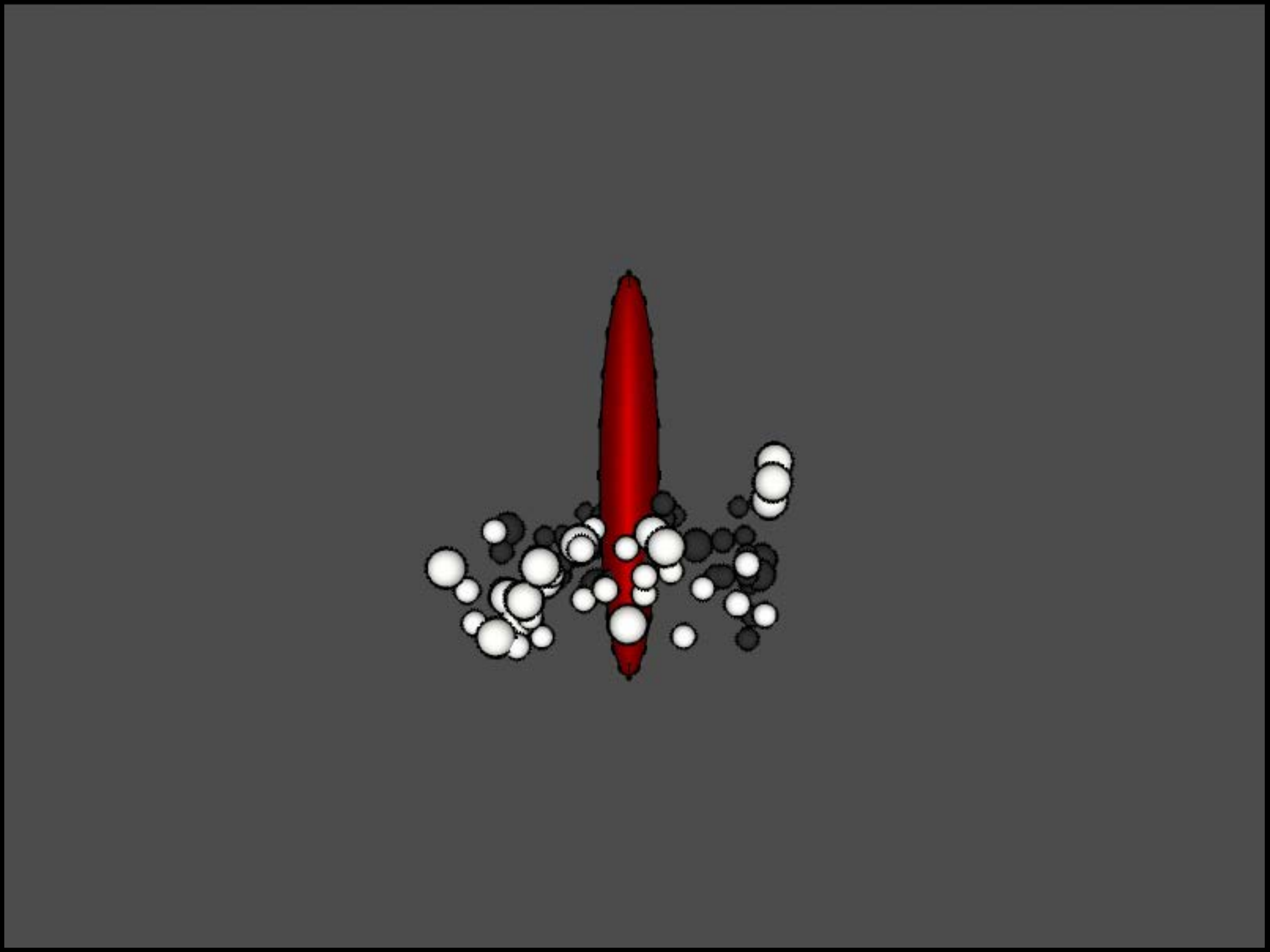
Cross section



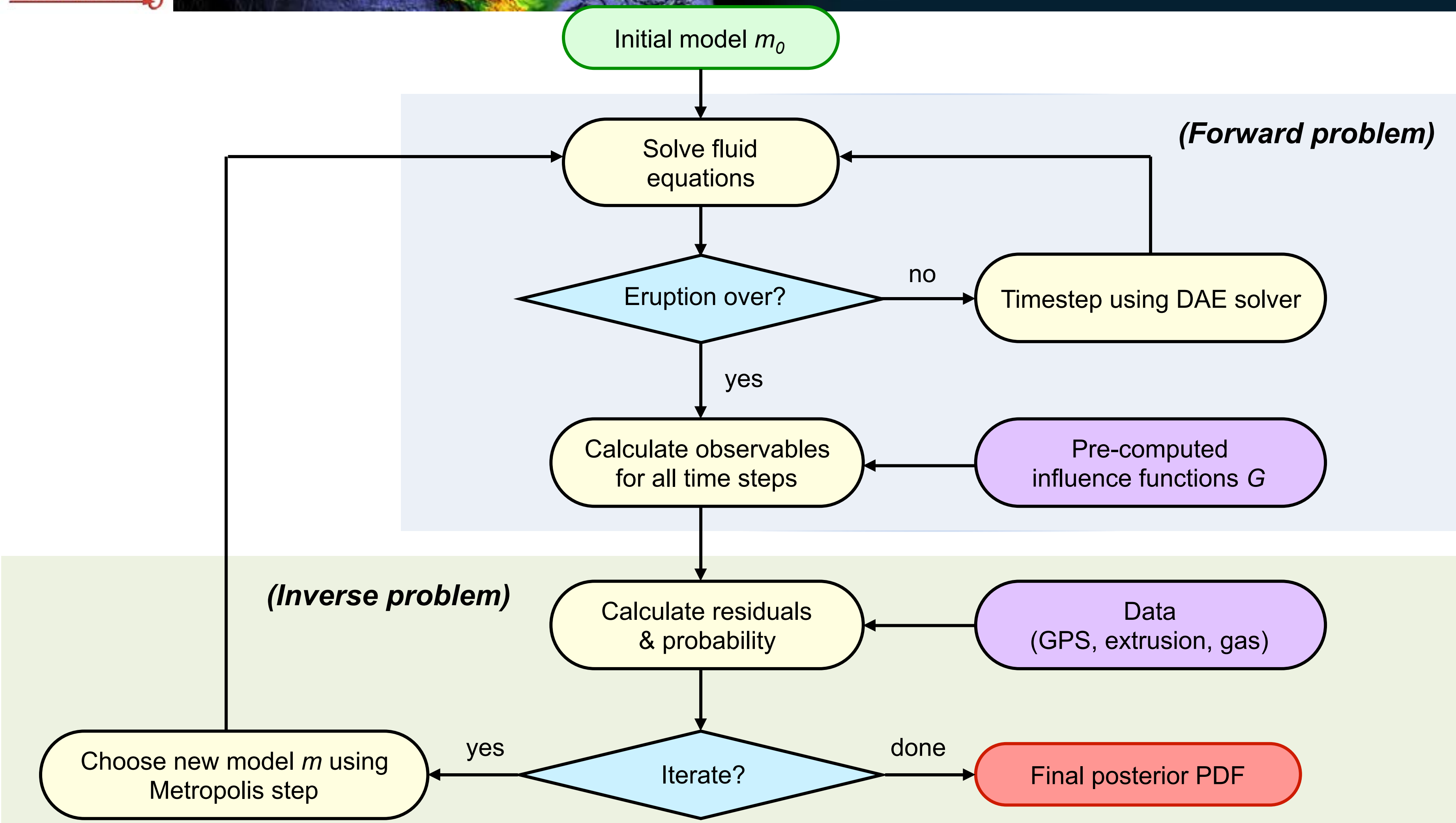
Dike Seismicity



Cross section



Monte Carlo inversion



$$P\left(\mathbf{d_1}, \mathbf{d_2}, ..., \mathbf{d_K} | \mathbf{m}\right) =$$
$$\prod_{k=1}^{K} \left\{ \left(2\pi\gamma_k^2\right)^{-N_k/2} \left|\Sigma_k\right|^{-1/2} \exp\left(-\frac{1}{2\gamma_k^2} \mathbf{r_k^T} \Sigma_k^{-1} \mathbf{r_k} \right) \right\}$$