Understanding Ground Deformation Close to Growing Lava Domes: High-Resolution InSAR Observations and Numerical Modelling

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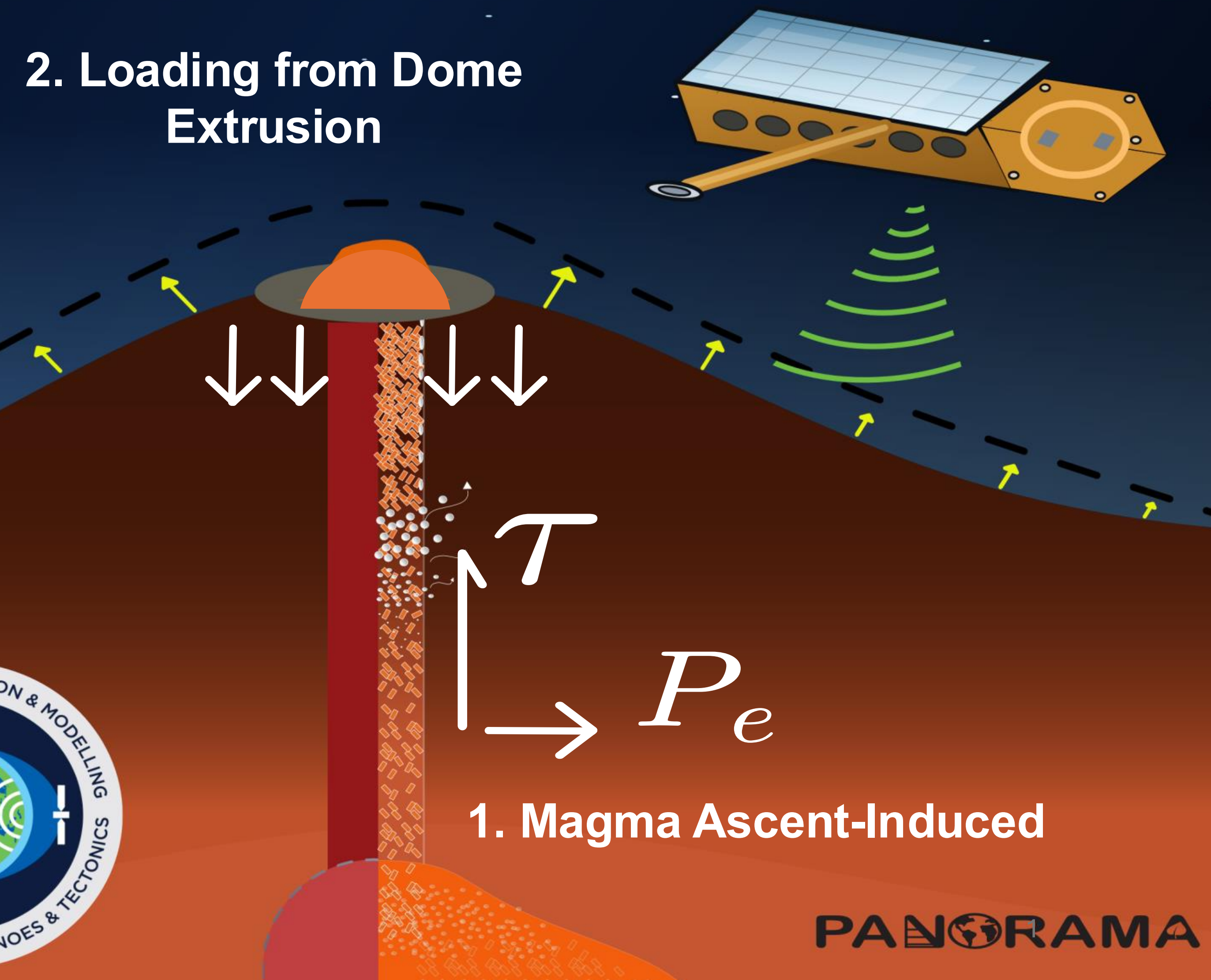


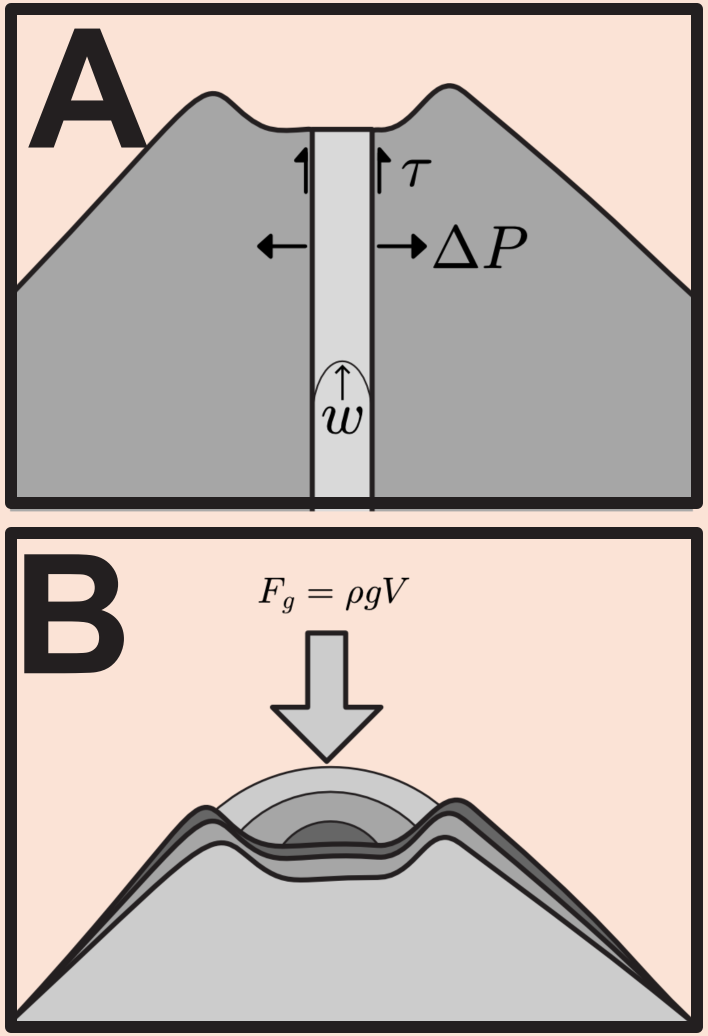
UNIVERSITY OF LEEDS

CENTRE FOR OBSERVATION & MODELLING OF EARTHQUAKES, VOLCANOES & TECTONICS

PANORAMA

Talk Overview:

- Monitoring Challenge: Lava dome-building volcanoes
- Methods – SAR, InSAR, Modelling
- 3 Lava Dome-Building Examples
- Implications: Volcanic Processes & Monitoring



Monitoring Lava Dome-Building Eruptions

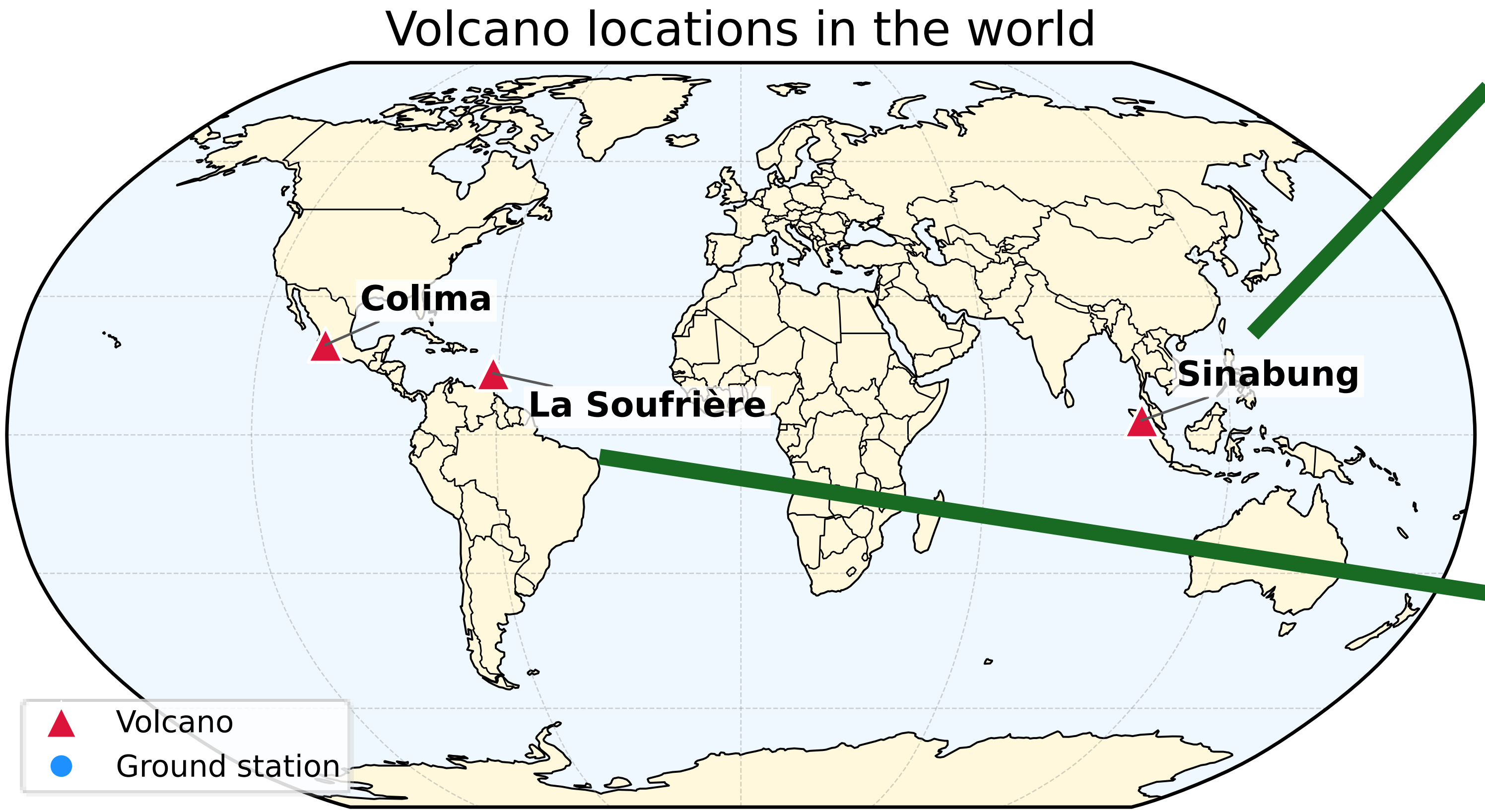
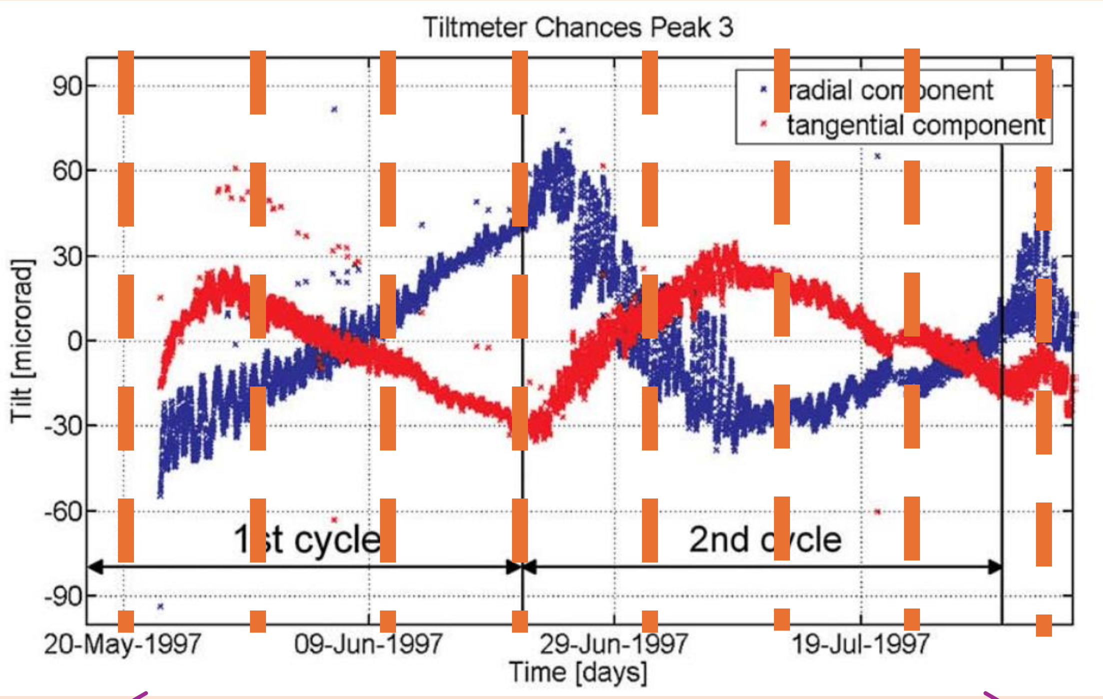


Image Credit: Kemron Alexander, SMU, UWI-SRC.

Challenge: Ground-based monitoring near active domes

Example: Soufrière Hills Volcano, Montserrat 1995-onwards

Tiltmeter was approximately 400 m from the centre of the dome



3 Months of Data

InSAR every 12 days

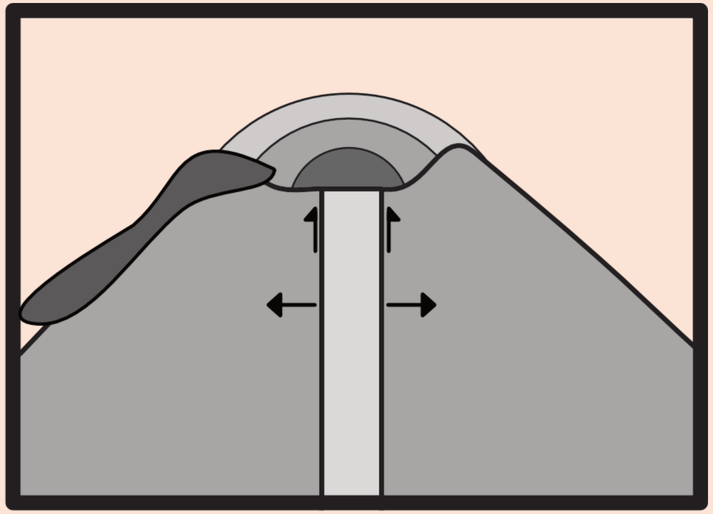
Figure from Hautmann et al. (2009)

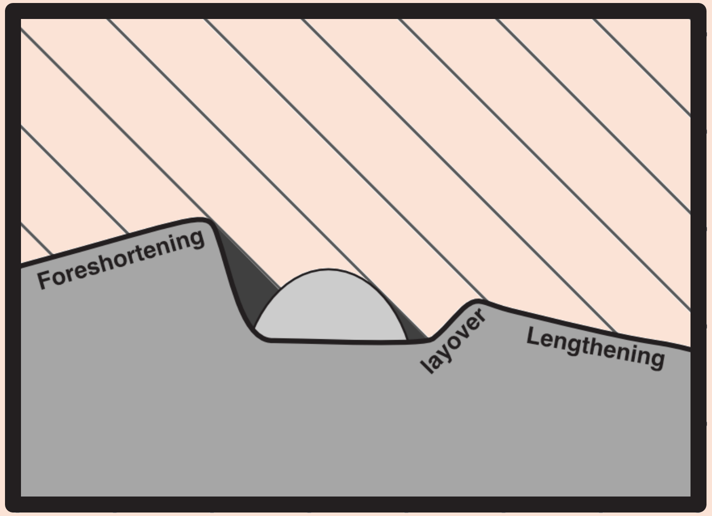
Sparks and Young (2002)

Challenge: Lava domes are difficult InSAR targets

- **Small and Proximal** — close to the active vent
- **Transient** — hours – days – weeks
- **Hard to observe** — Radar viewing geometry interacting with steep topography
- **Hard to preserve** — coherence is lost due to new lava, PDCs, ash, rockfall

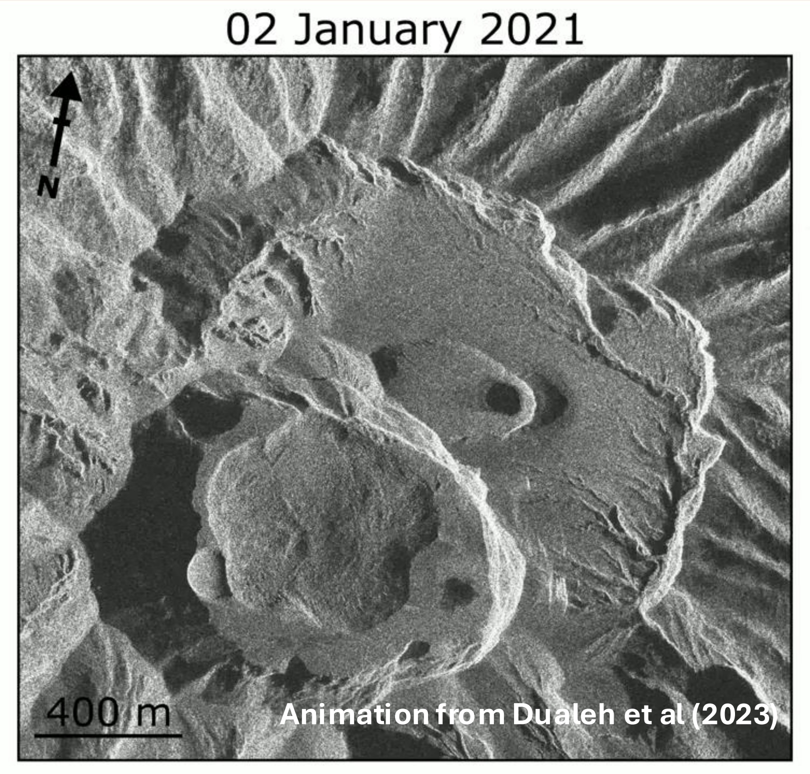
Result: C/L band SAR can miss the short-wavelength deformation most relevant to dome processes.





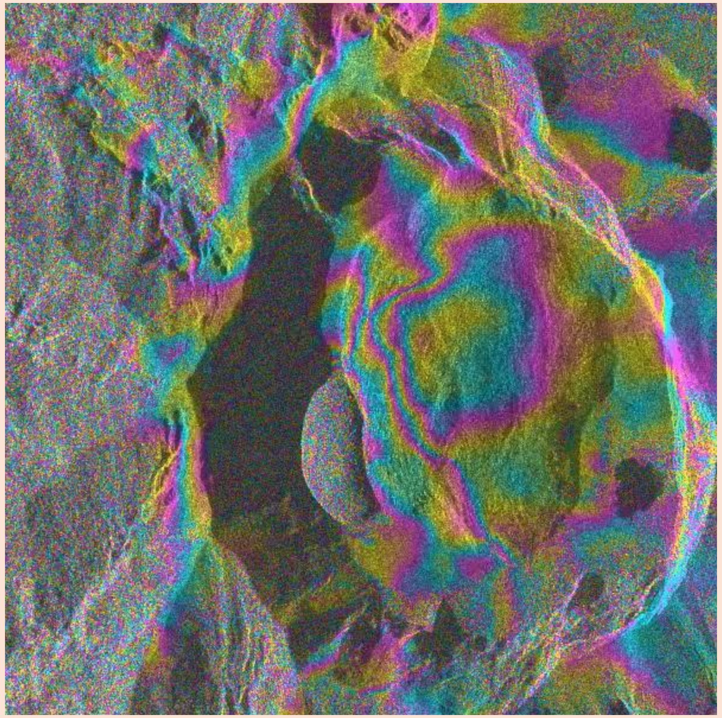
Methods: SAR, InSAR, Modelling

SAR



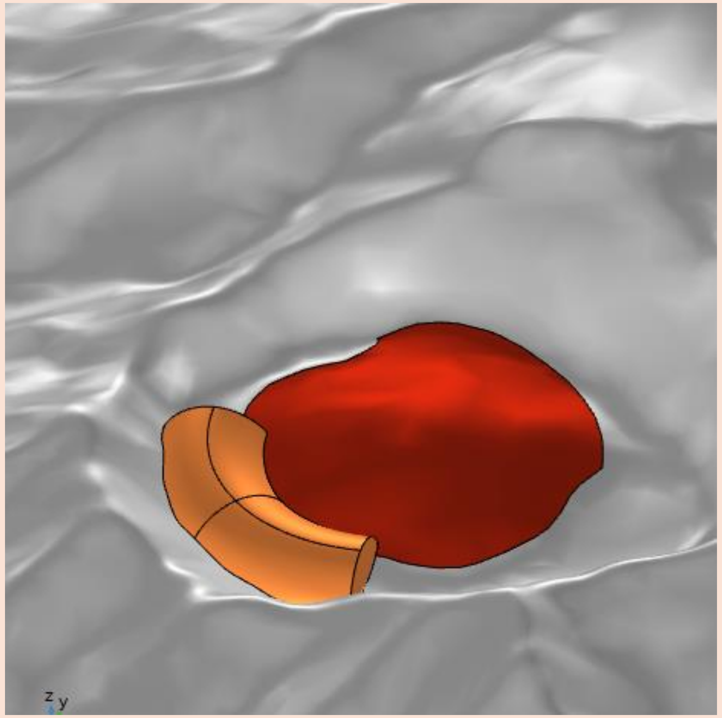
What changed at the vent?

InSAR



Where did the edifice respond to stress?

Modelling



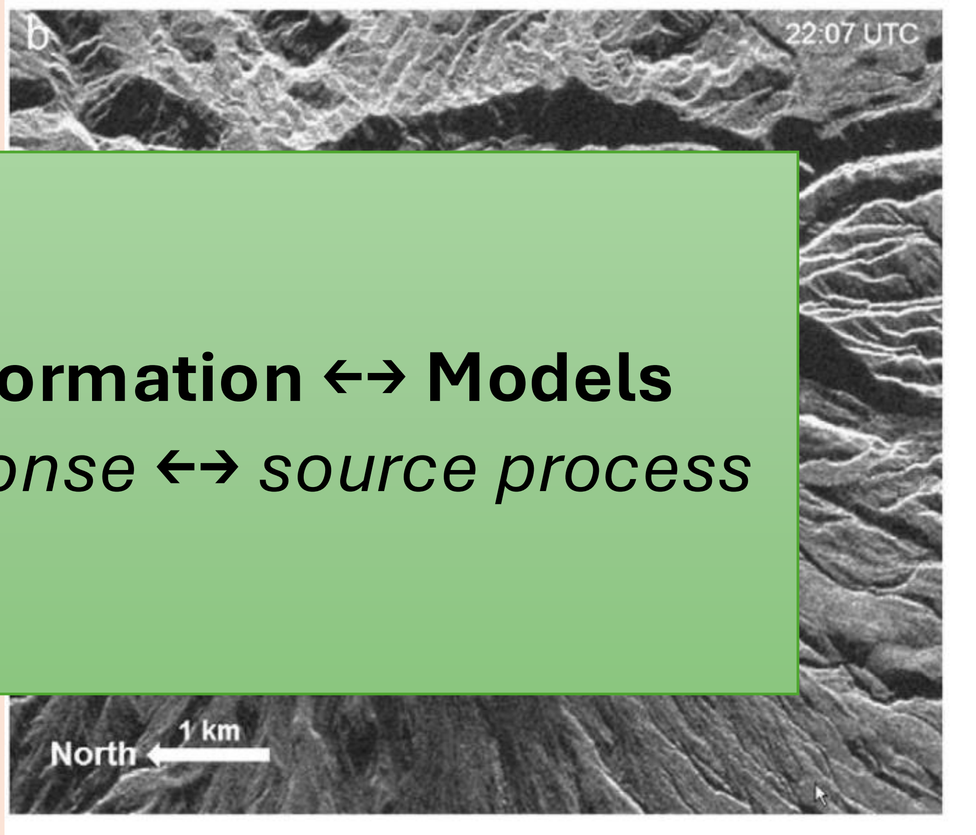
What source process caused it?

SAR intensity images show rapid dome change

- At Merapi in 2010, SAR observations
  captu
  dome
  corre
  disch
  et al.
- Cont
  supported timely evacuations.

SAR intensity ↔ InSAR deformation ↔ Models

surface change ↔ edifice response ↔ source process



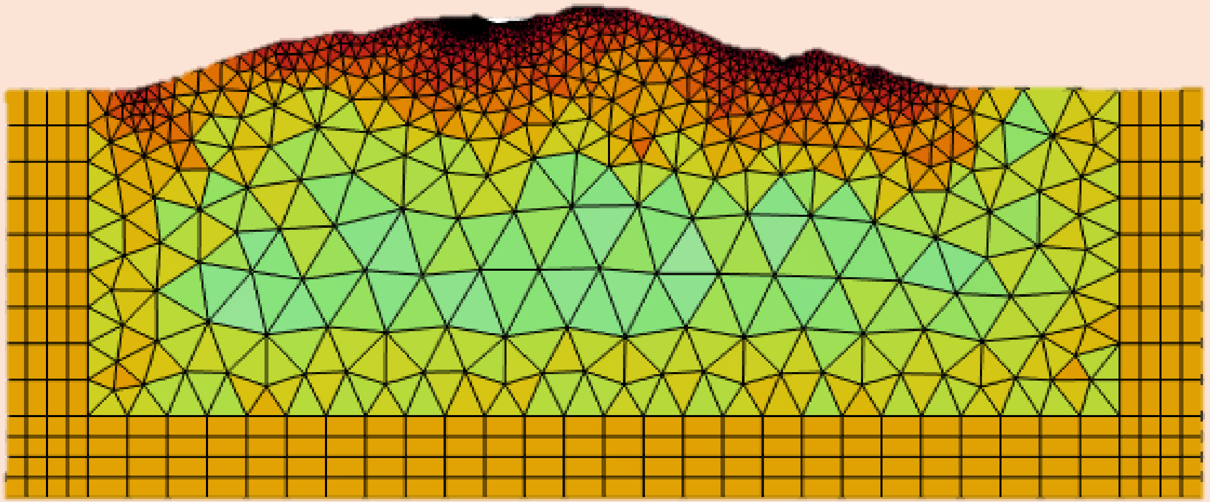
Warnings provided by Indonesian Geological Agency's Center for Volcanology and Geologic Hazard Mitigation (CVGHM) . SAR Image from Pallister et al. (2013)

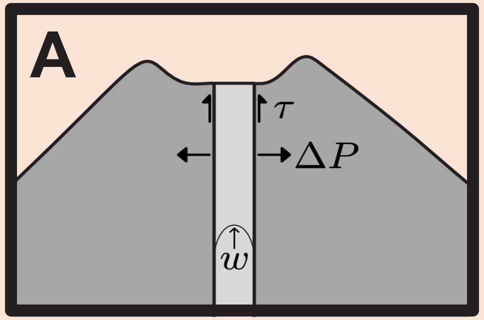
Key point: SAR intensity images help identify surface changes

Finite Element Modelling: Physics of dome growth

Why use FEM?

- Shallow sources relative to source size
- Complex sources e.g Fluid Flow
- Significant topography



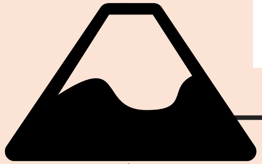


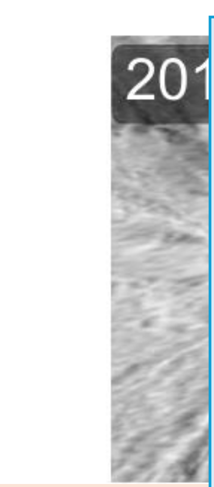
Volcan de Colima, Mexico

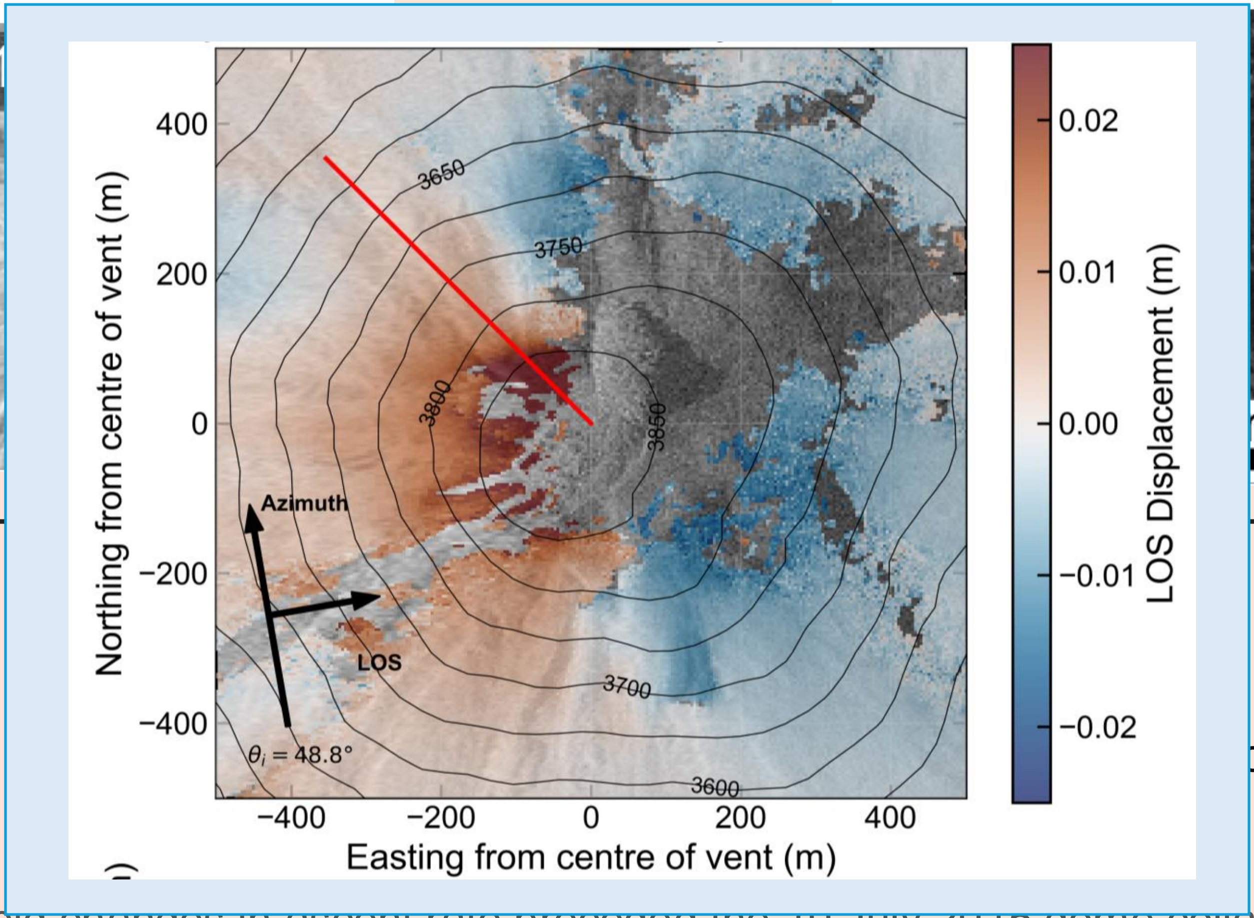
Image from Faculty of Science, Colima University.

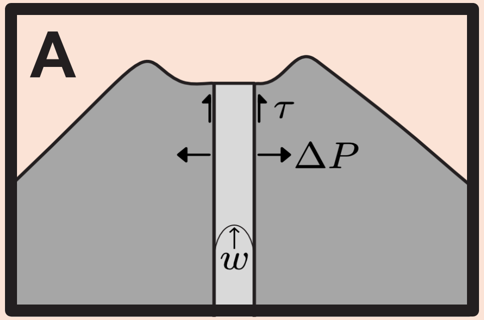
Image from Eliot Eaton (2018)

Volcan de Colima: localised deformation linked to changing ascent rate









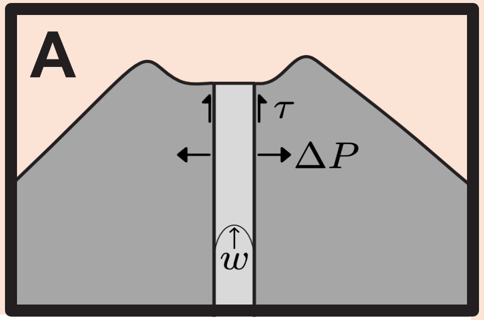
Early May
New phase of slow dome growth

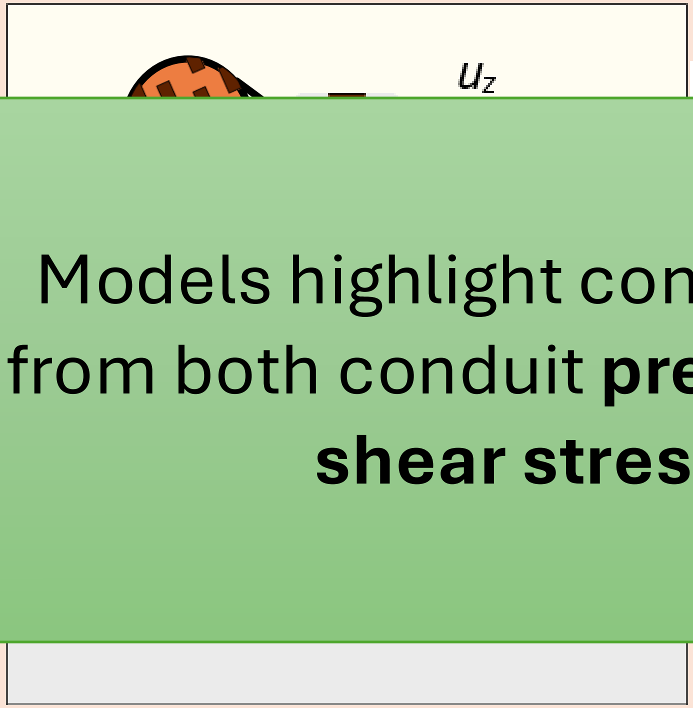
...on

10 July
Collapse event

Rapid changes in ascent rate preceded the 10 July 2015 dome collapse.

Volcan de Colima: modelling deformation from magma ascent

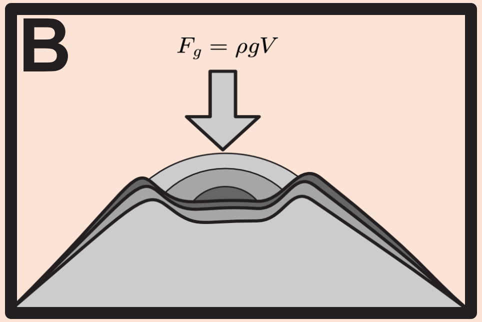




Models highlight contributions from both conduit **pressure** and **shear stress**

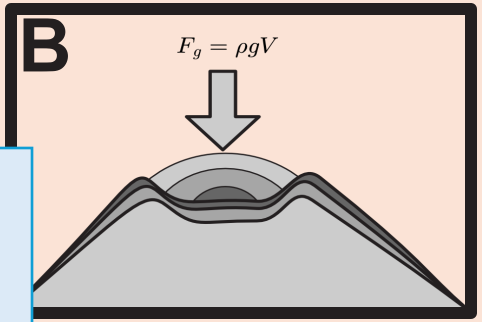
A poorly constrained parameter is an edifice scale **Young's Modulus**

Mount Sinabung, Indonesia (2010-)



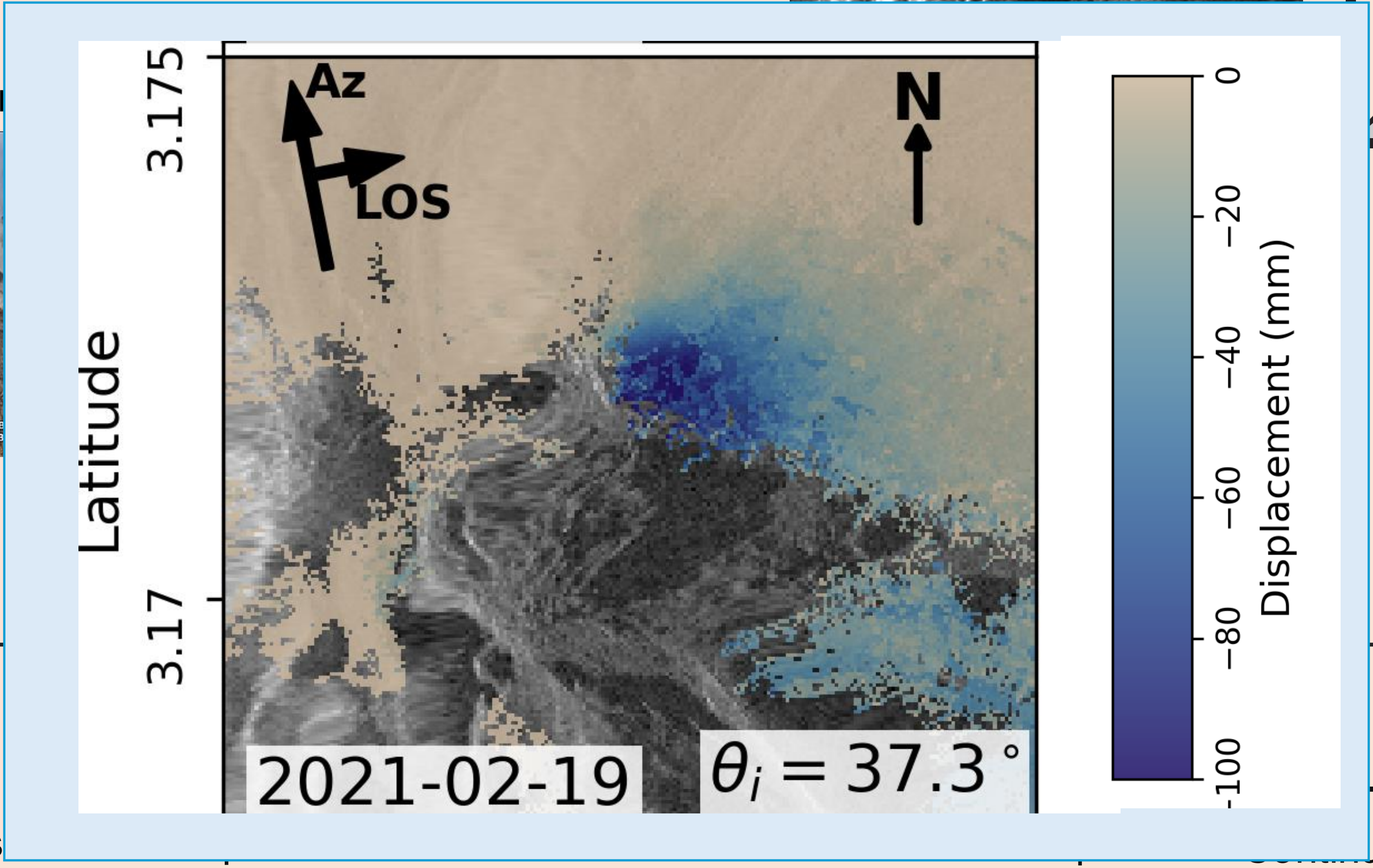
- Dome growth and collapse cycles lasted for over a decade with varying intensity
- 14,000 people who live within 10 km of the volcano (Pallister et al., 2019)
- Changes in behaviour occur rapidly

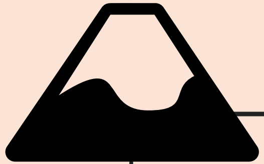
Loading at Mount Sinabung



Photos taken by Fi

Photos taken by Firdaus Surbakti





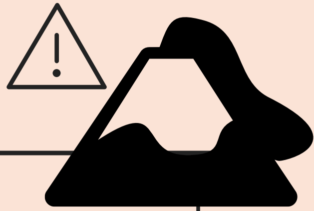
August 2020
Phreatic explos

Dome

Dome growth

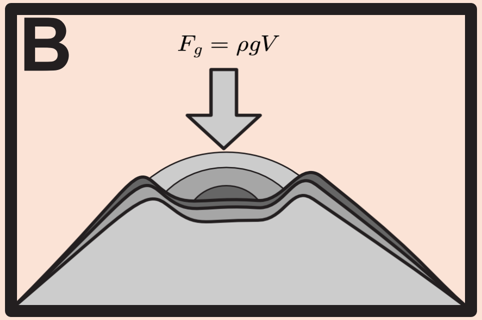
events + PDCs

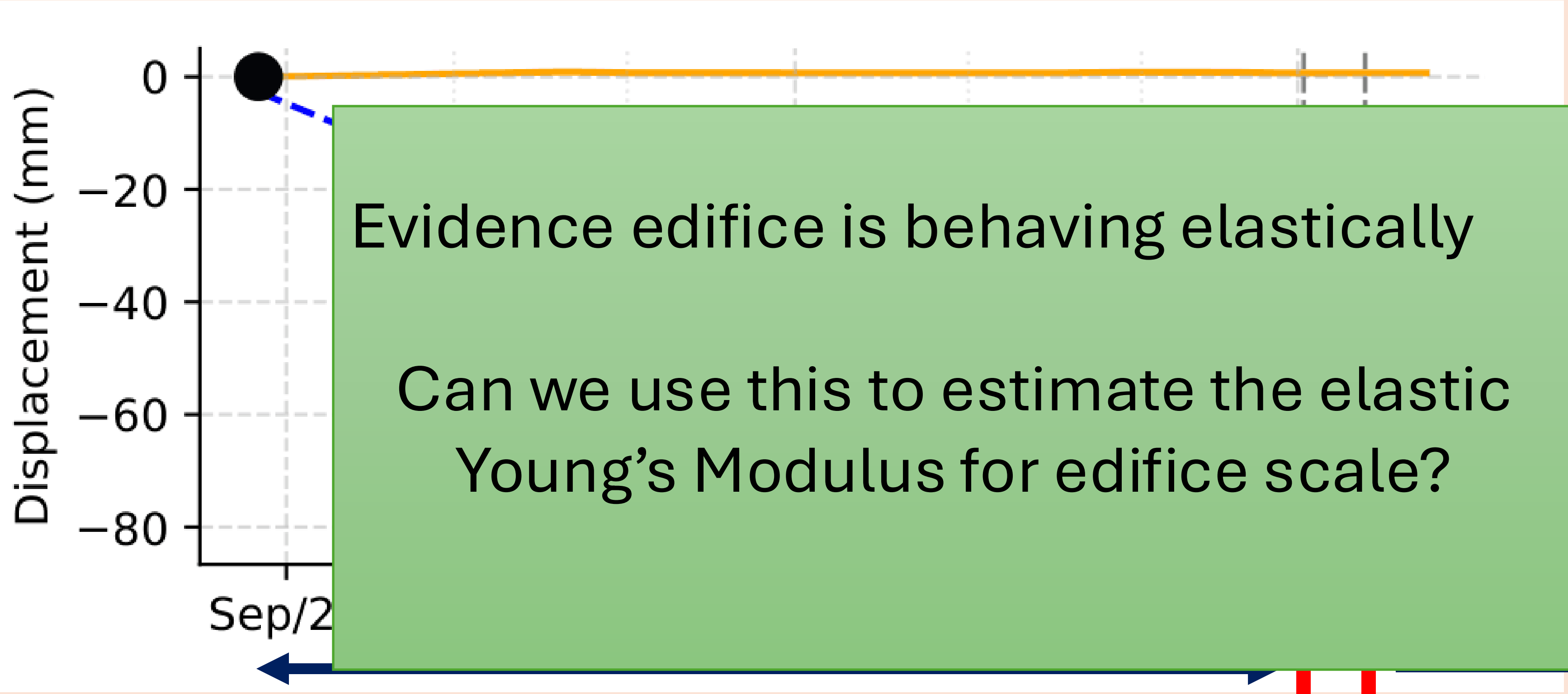
-April
ued
dome growth



May
Series of collapse

Mt Sinabung: Elastic response following dome collapse and PDCs





Evidence edifice is behaving elastically

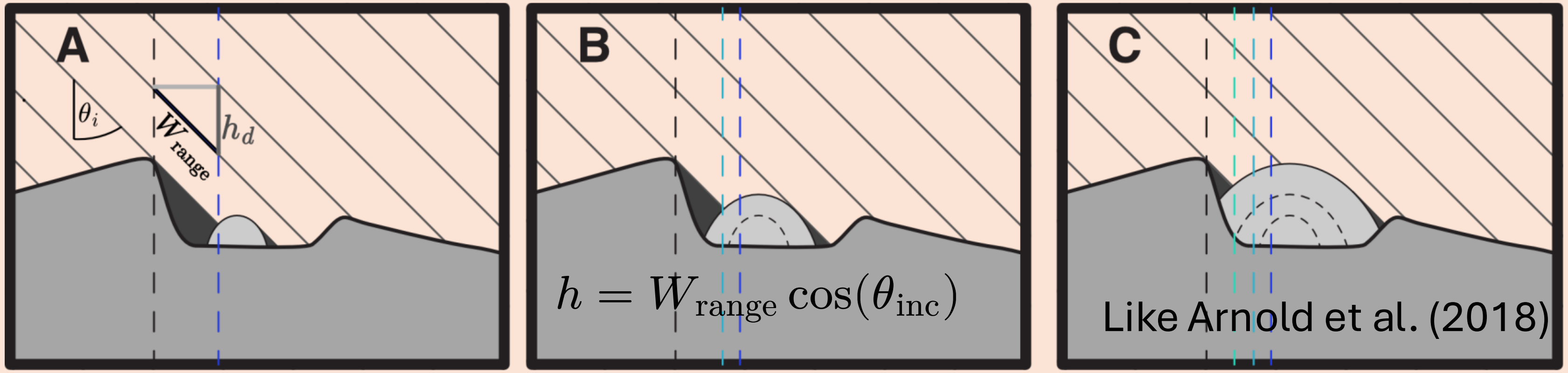
Can we use this to estimate the elastic Young's Modulus for edifice scale?

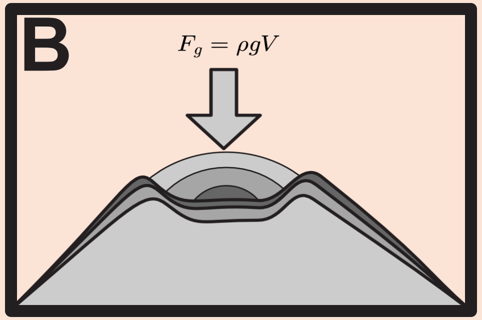
tic Response

Dome Extrusion

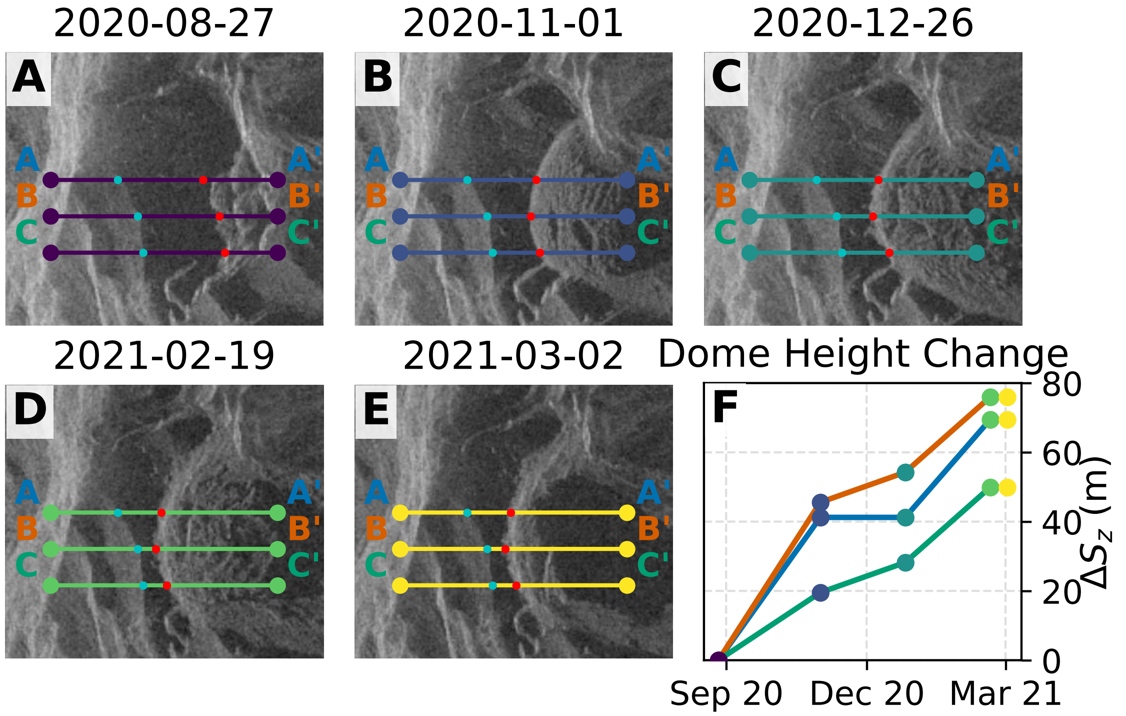
Dome Collapse events

Continued Extrusion

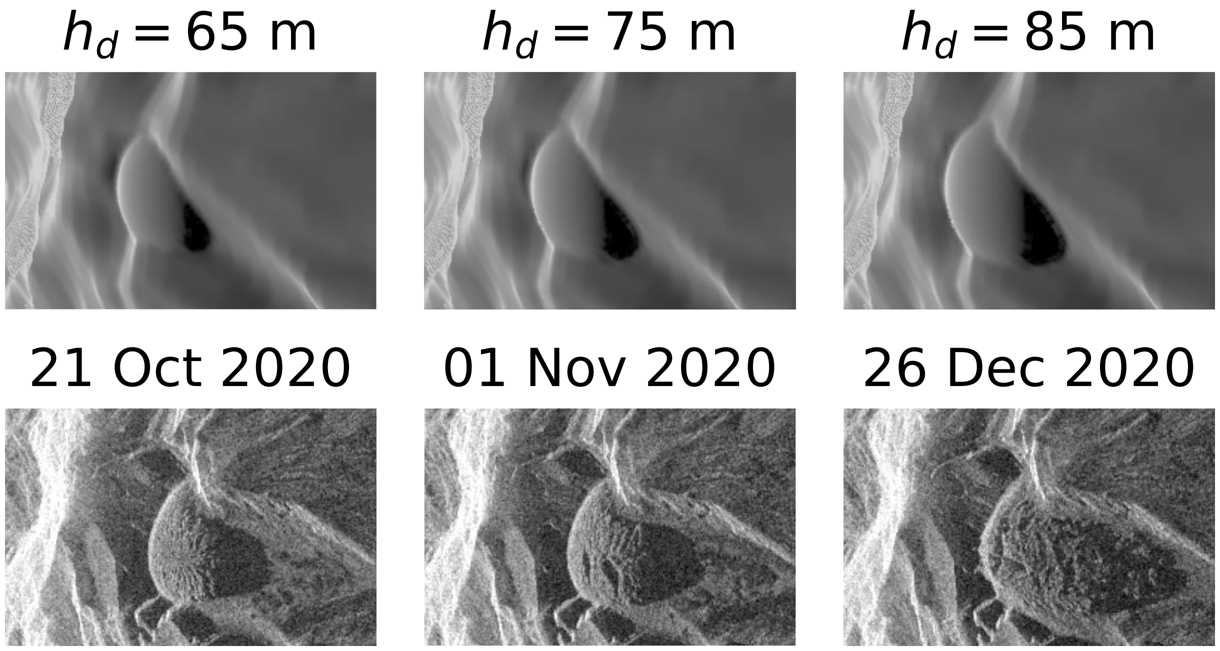




Use Change in Radar Shadow

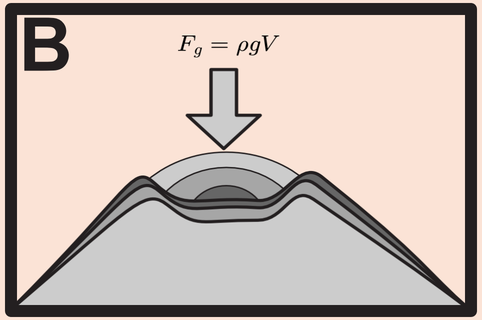


Create Dome + DEM and simulate SAR image



similar approach to Ozawa and Kozono (2013)

Mt Sinabung: Constraining Edifice Modulus from loading models



Model de

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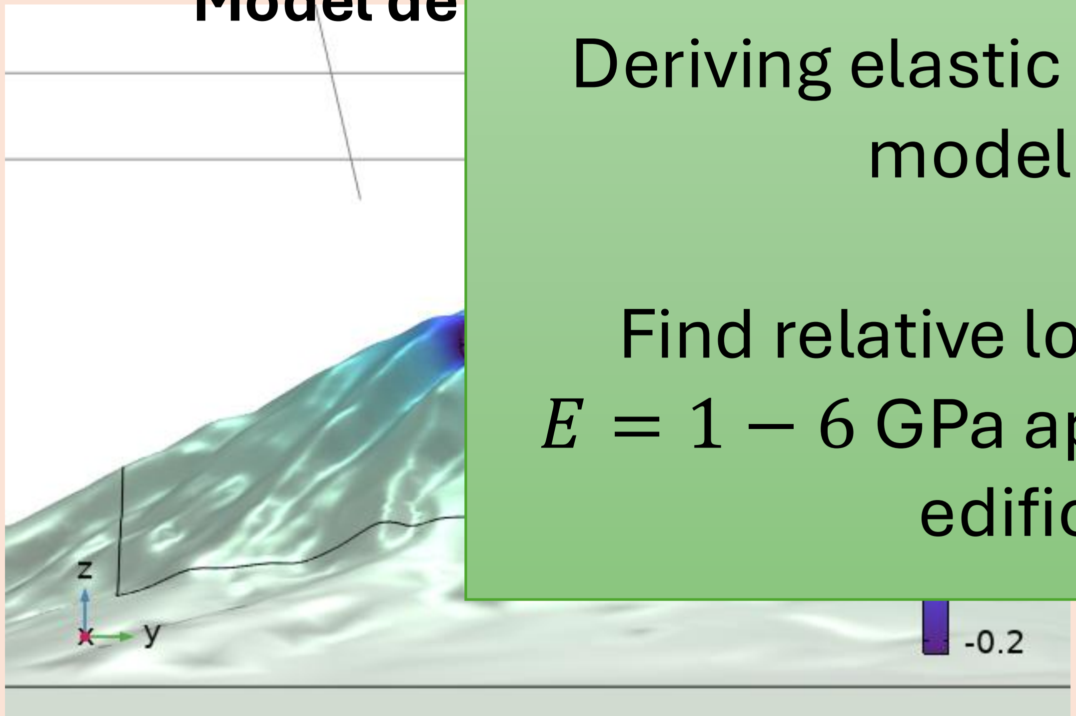
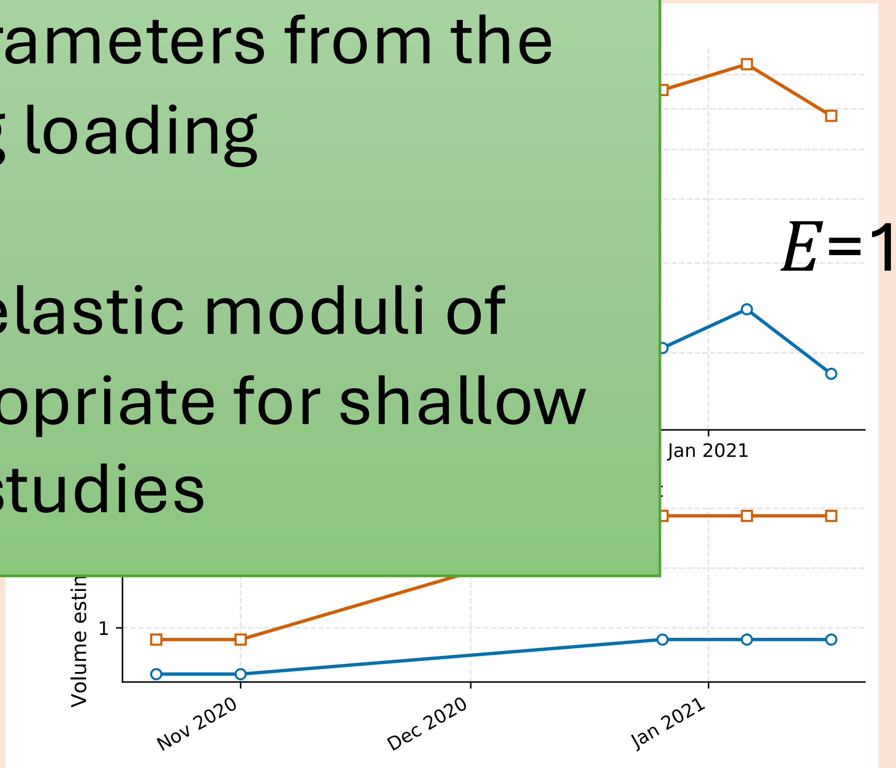


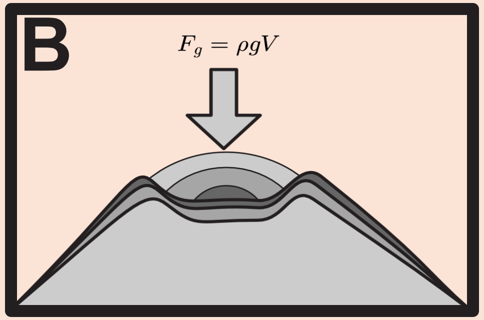


E=1–6 GPa

Deriving elastic parameters from the modelling loading

Find relative low elastic moduli of $E = 1 - 6$ GPa appropriate for shallow edifice studies

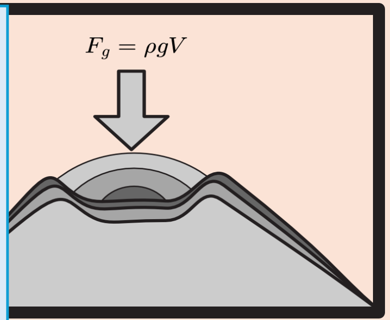
La Soufrière, St Vincent & the Grenadines



1979 Dome Growth

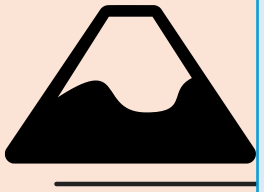
2021 Dome Growth

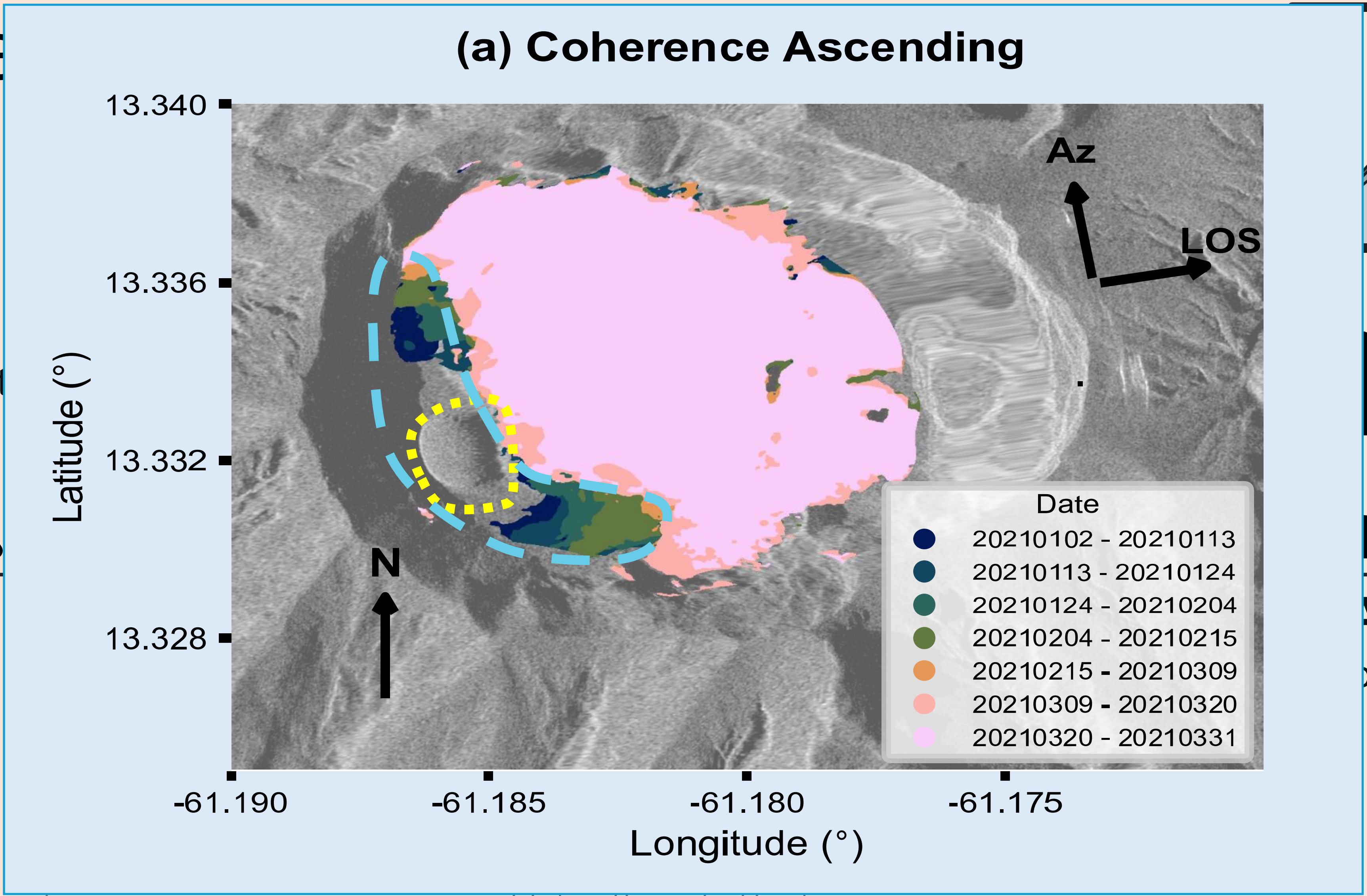
La Soufrière: coherence close to the growing dome

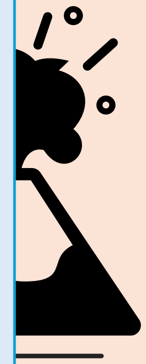


Late Dec

New phase
dome growt





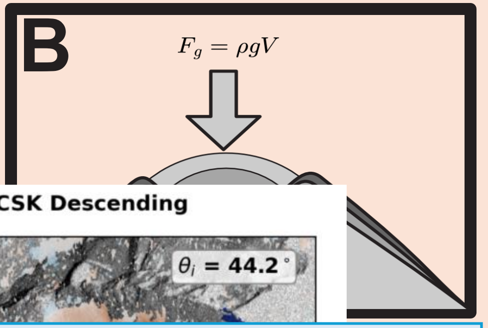


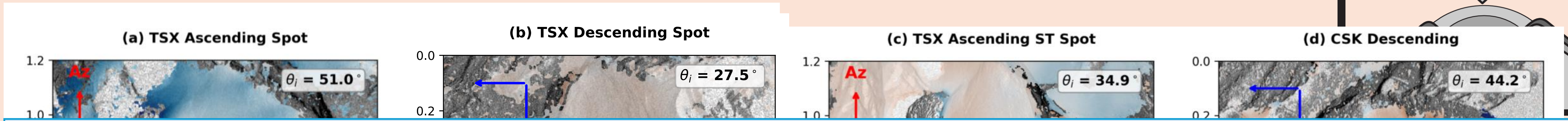
April

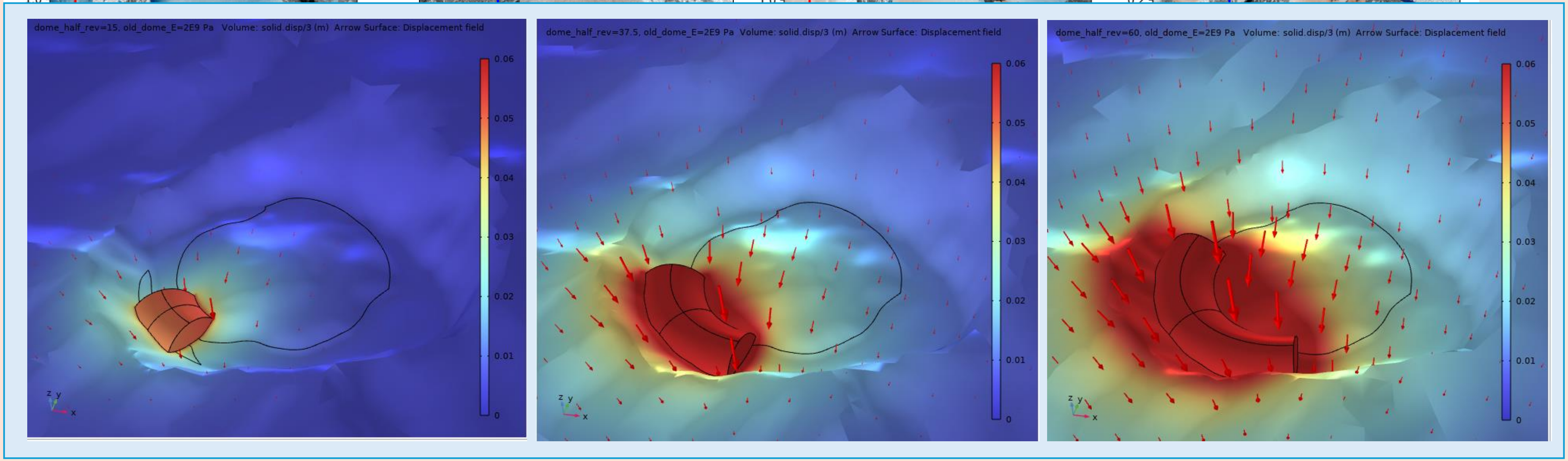
osive phase

Dome growth rates from Dualeh et al (2023)

La Soufrière, St Vincent:







Implications for volcanic processes

Magma conduit-induced:

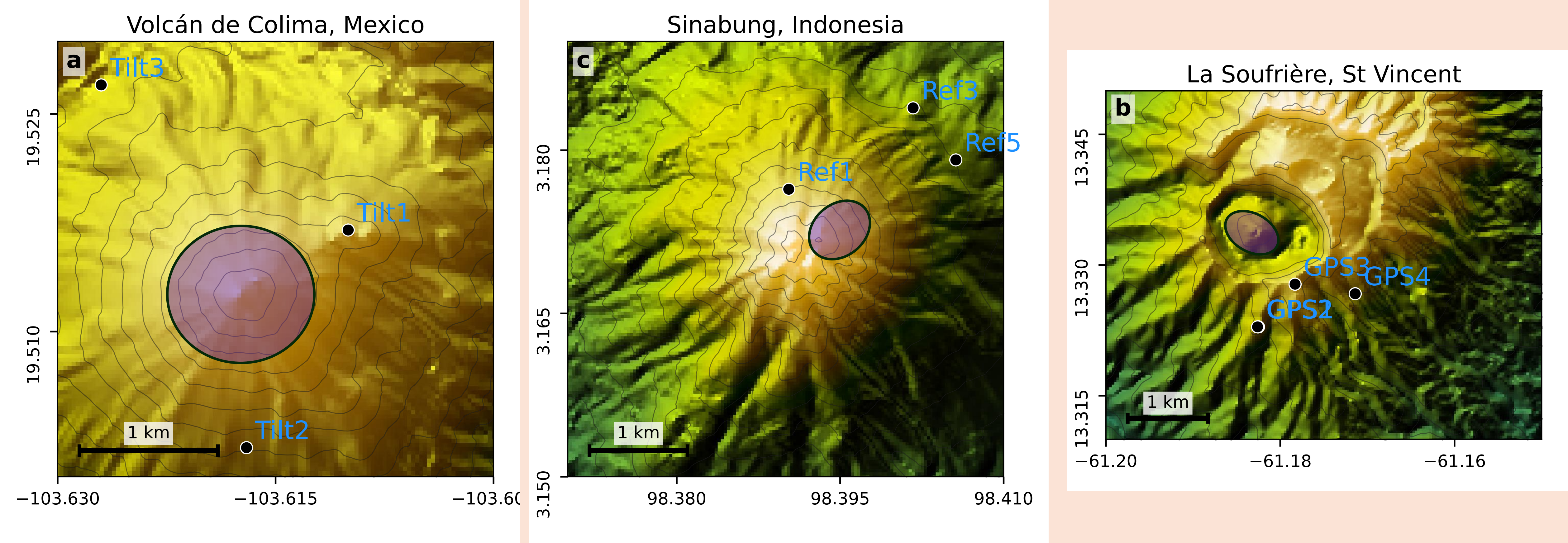
- Highly localised, transient deformation close to the vent occurring on timescales of **change in magma ascent rate**
- Modelling highlights both shear stress and pressure source

Loading due to dome extrusion:

- Cumulative deformation due to dome volume/mass
- Reversal after dome collapse suggests elastic edifice
- Constrain elastic modulus of edifice to 1-6 GPa – Significantly lower than individual rock samples

Implications for monitoring:

Comparison to Ground-Based



Implications for monitoring

High-resolution SAR can identify **spatial distribution of deformation**

- Guide future deployment of proximal instruments such as GNSS, tiltmeters

Satellite observations **cannot replace continuous ground-based monitoring**.

Rapid changes in ascent rate, pressurisation, extrusion, or collapse **may occur between acquisitions**

Best monitoring strategy: combine frequent **X-band SAR** from multiple viewing geometries with continuous ground-based geodetic and seismic data.

Currently **small baseline X-Band** is critical for lava-dome building eruptions

Data Availability - G-VEWERS

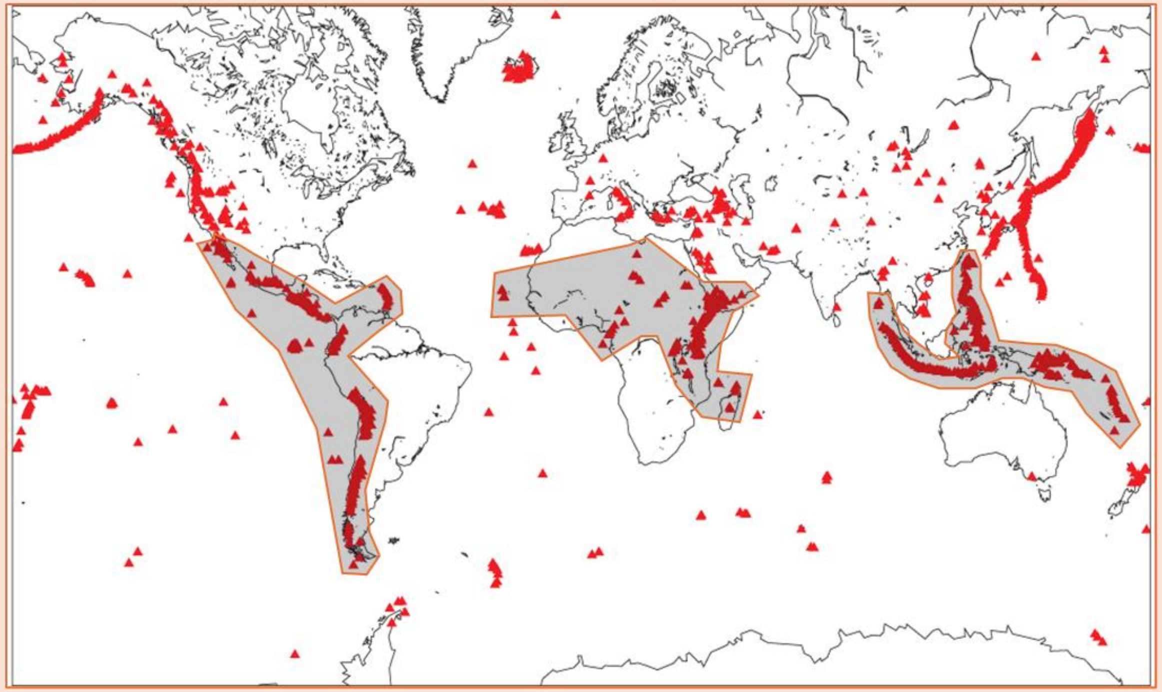
Global Volcano Early Warning and Eruption Response from Space
Successor to CEOS Volcano Pilot (2014-2017) and Volcano Demonstrator (2019-2023)

Permanent partnership between:

- space agencies
- researchers at academic institutions
- volcano observatories

Goal: Coordinating the acquisition, access, and utilization of satellite data to support volcano monitoring and early warning at volcano observatories worldwide

Contact: Susanna Ebmeier (S.K.Ebmeier@leeds.ac.uk)



TerraSAR-X
CEOS Geohazard Supersites