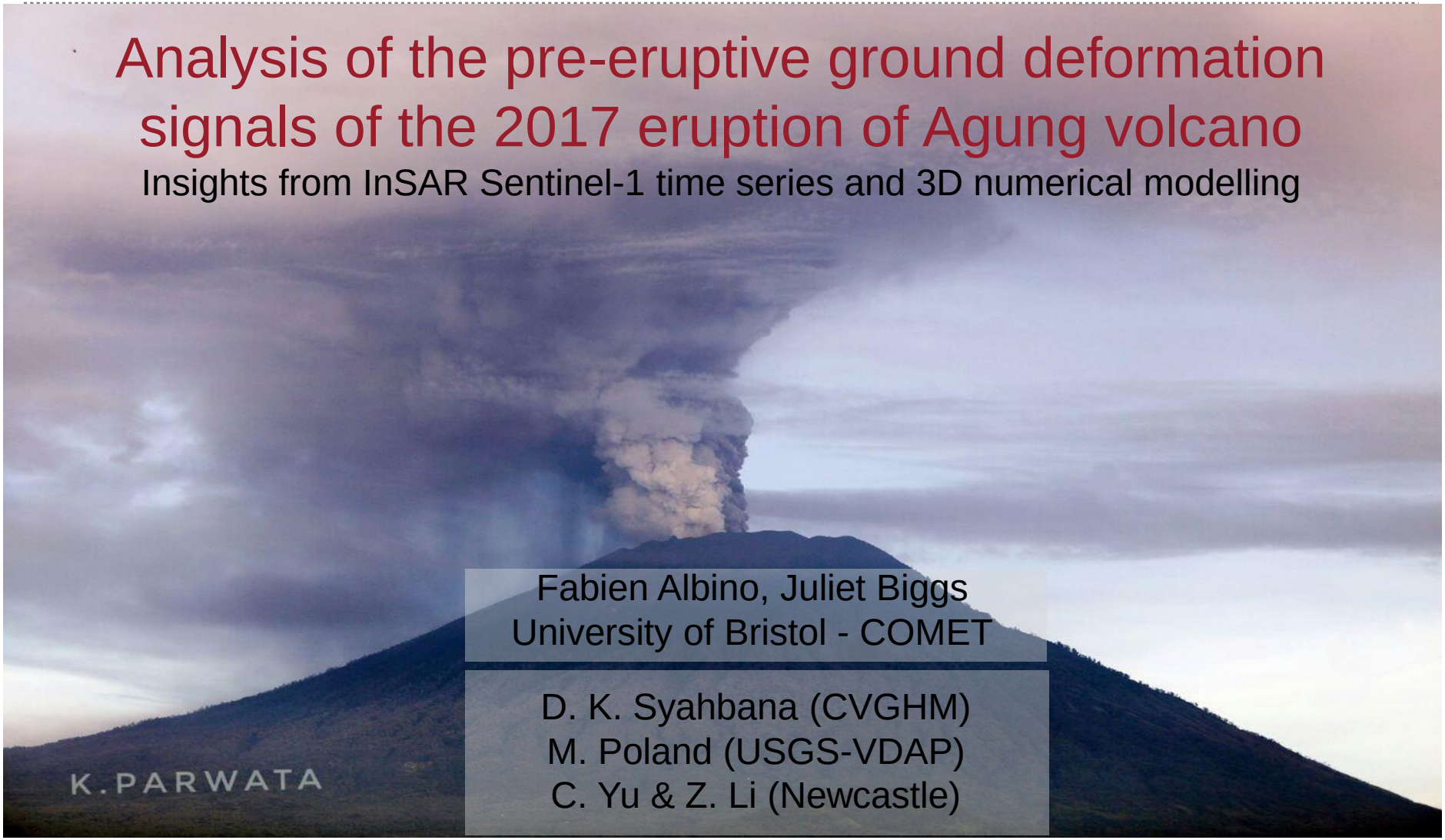
Analysis of the pre-eruptive ground deformation signals of the 2017 eruption of Agung volcano

Insights from InSAR Sentinel-1 time series and 3D numerical modelling

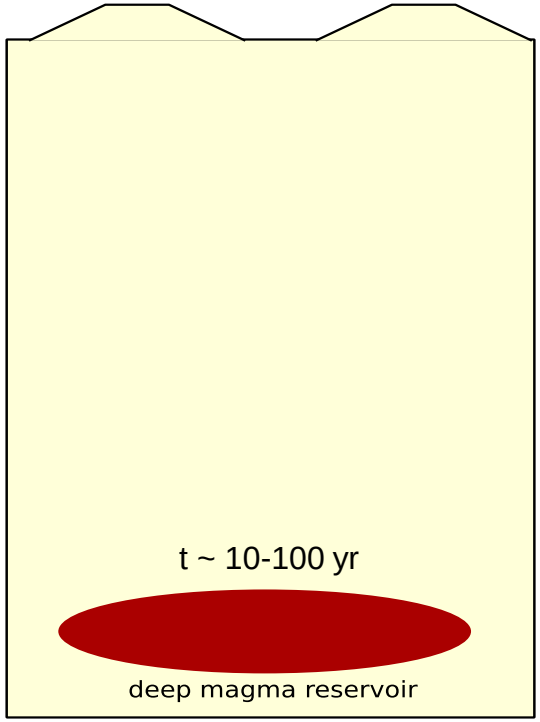


Fabien Albino, Juliet Biggs
University of Bristol - COMET

D. K. Syahbana (CVGHM)
M. Poland (USGS-VDAP)
C. Yu & Z. Li (Newcastle)

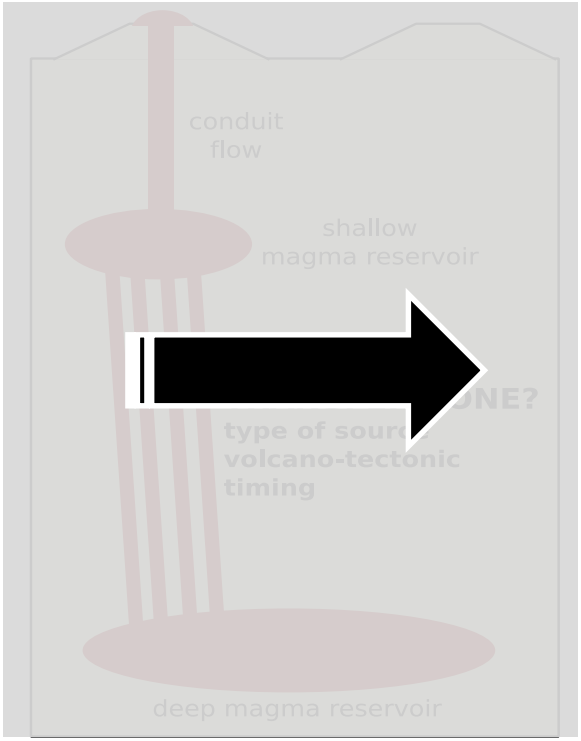
Magmatic systems beneath arc-volcanoes

1) long period of unrest
ex: Uturuncu, Cordon del Azufre

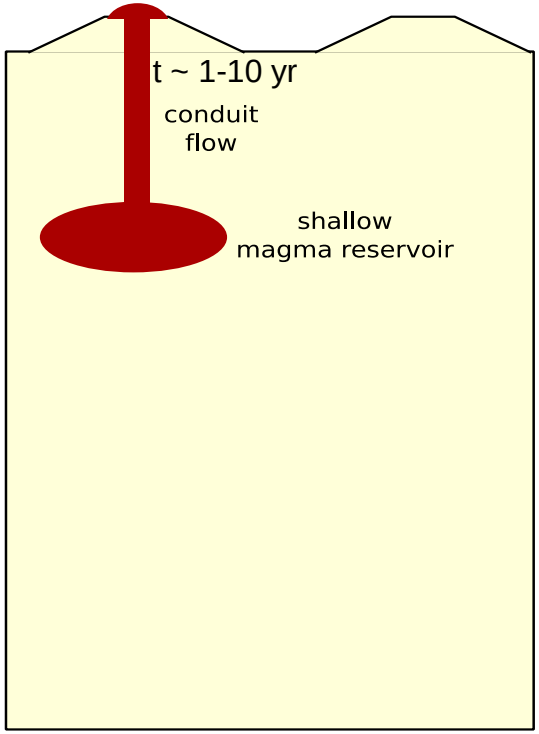


Fialko and Pearce, 2012
Froger et al., 2007

2) prior to eruption



3) continuous eruption
ex: Merapi, Colima



Voight et al., 1999
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Magmatic systems beneath arc-volcanoes

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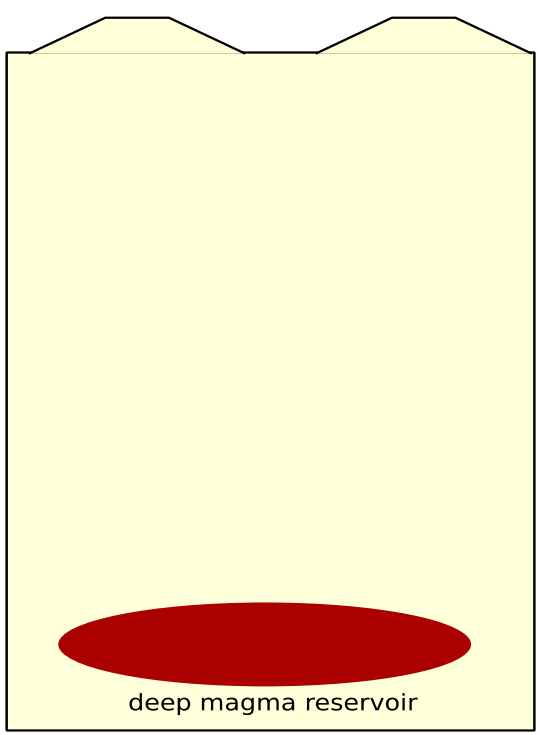

Fialko and Pearce, 2012
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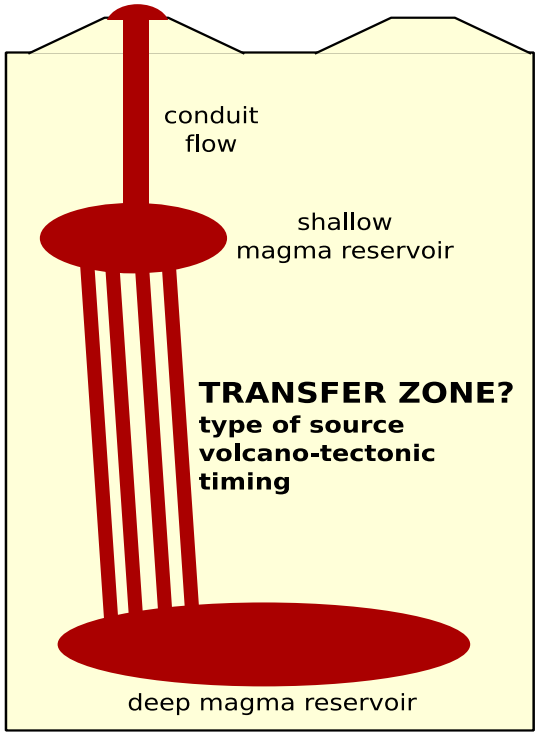

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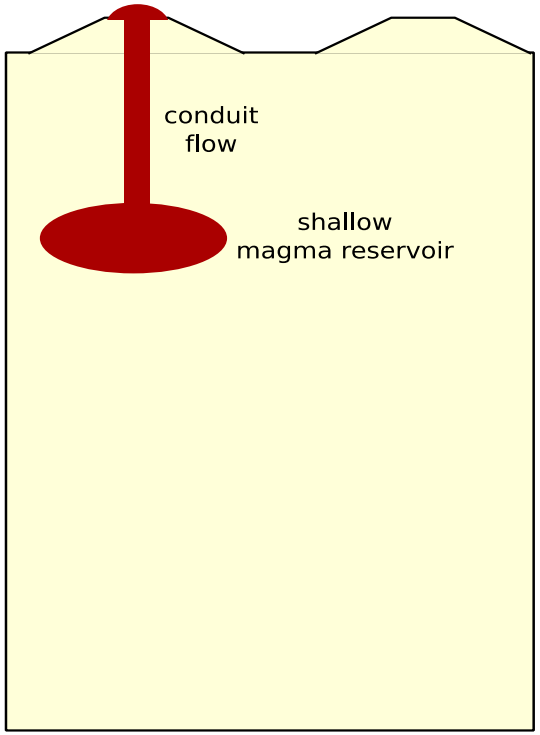


Voight et al., 1999
Bonaccorso et al., 1999

Can we use Agung 2017 eruption to learn about magmatic systems below arc-volcanoes ?

- To identify ground deformation signals

InSAR techniques (Sentinel-1 data)

- To constrain the location and orientation of magmatic sources

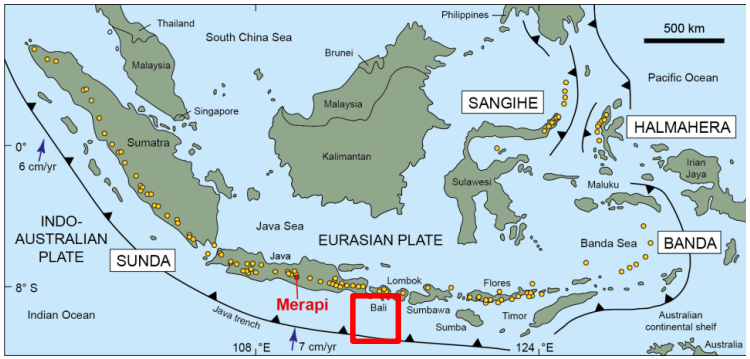
FEM modelling (ground deformation and stress)

- To build a conceptual model for the 2017 eruption

Historical observations

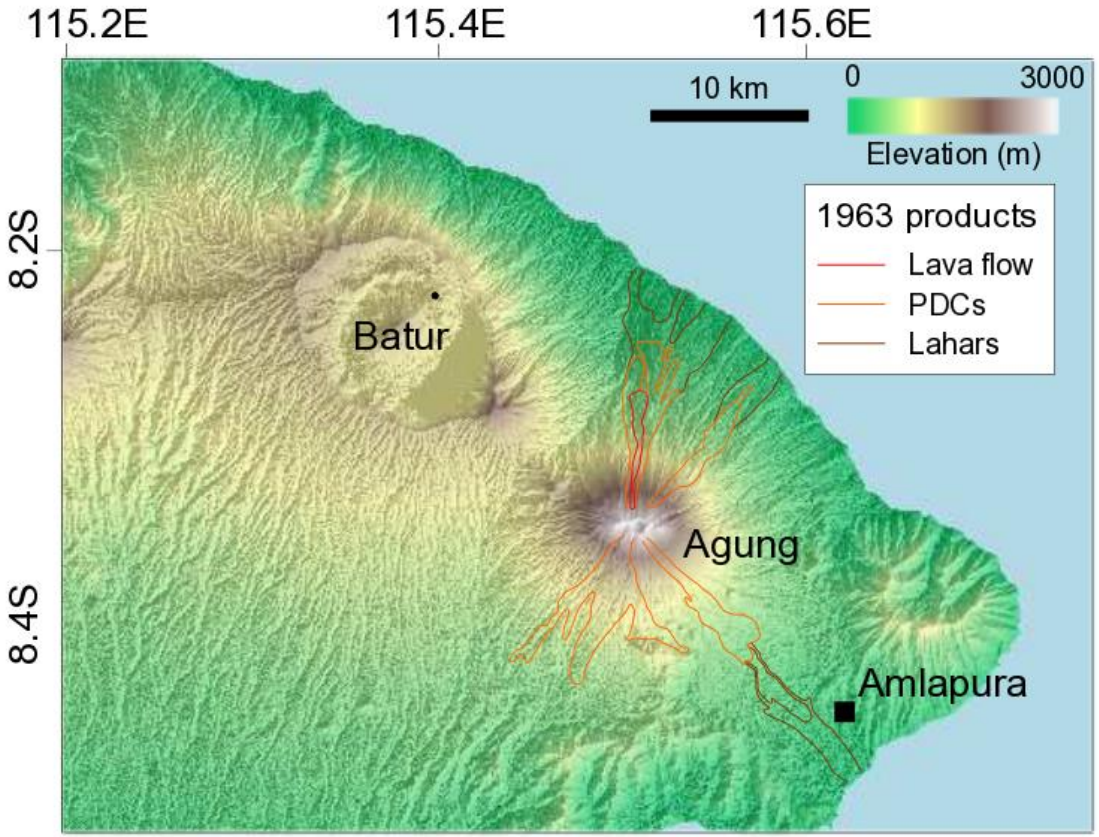
Geodesy/Seismology - Degassing - Geochemistry/Petrology

Context



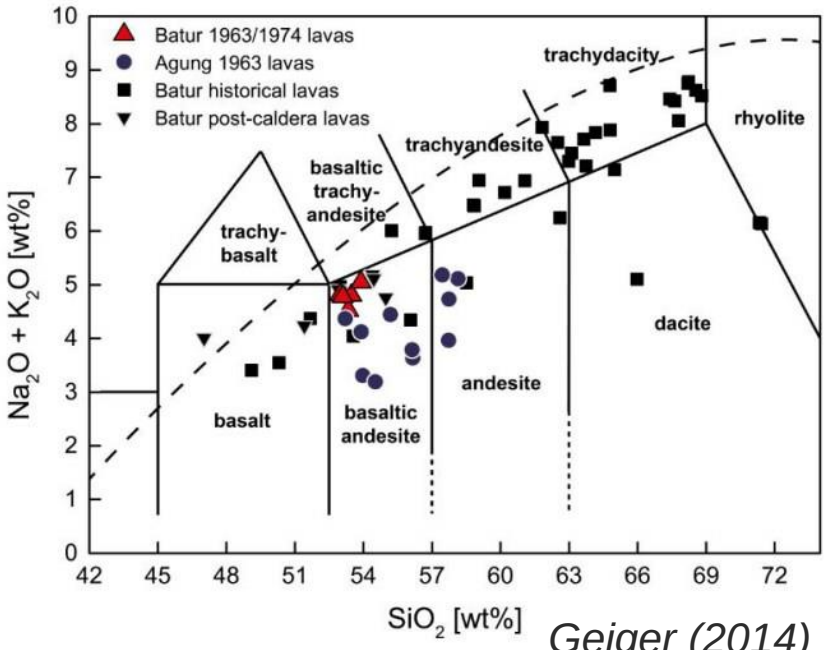
Modified after Gertisser & Keller (2003)

- Sunda Subduction arc
- Andesitic Stratovolcano
- Historical eruptions in 1808,1843 and1963



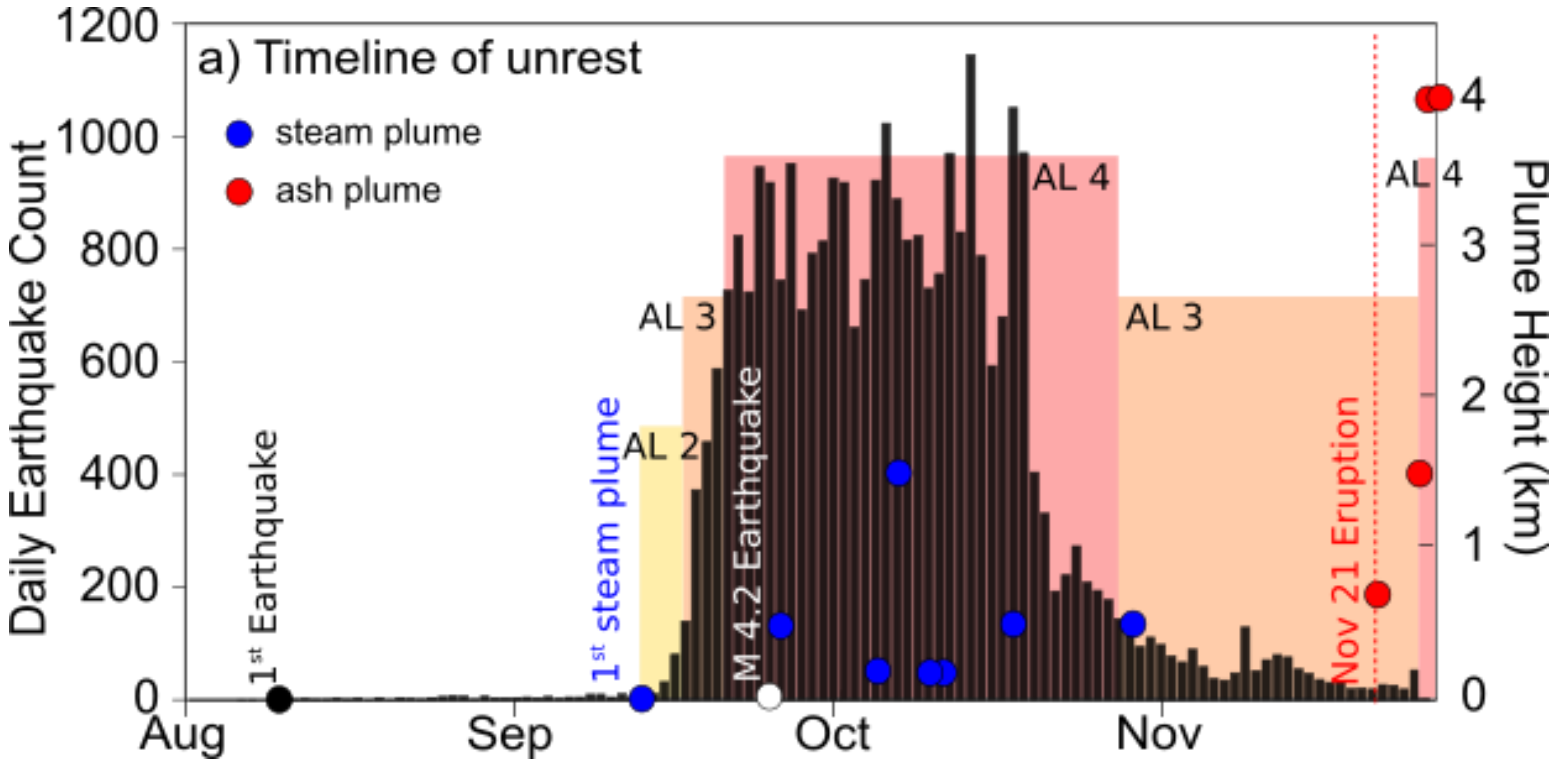
The 1963 eruption

- Agung eruption (VEI 5): **February 18**
- Batur eruption: **September 5**
- Petrology similar between erupted products
- Mixing between basaltic and andesitic magmas

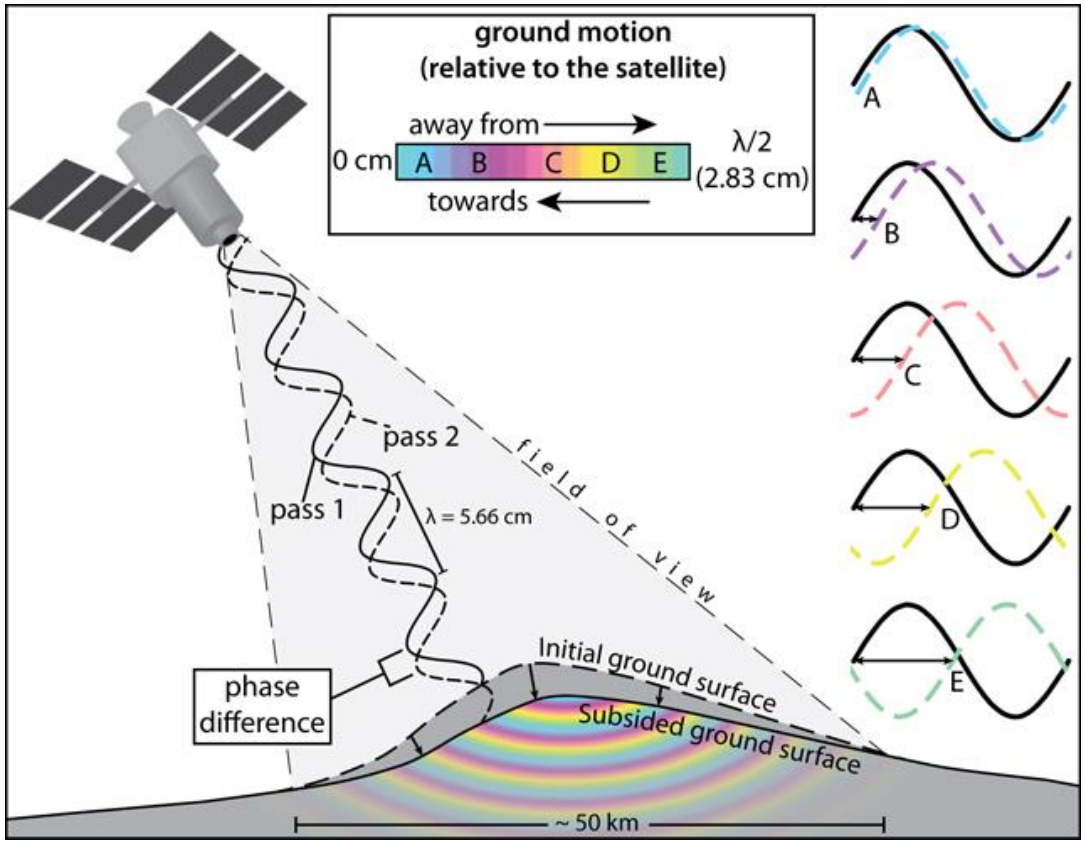


Geiger (2014)

2017: Timeline of unrest (from ground observations)



InSAR principles



$$\varphi_{\text{int}} = \varphi_f + \varphi_{topo} + \varphi_{displ} + \varphi_{atm} + \varphi_{err}$$

φ_f **flat Earth**

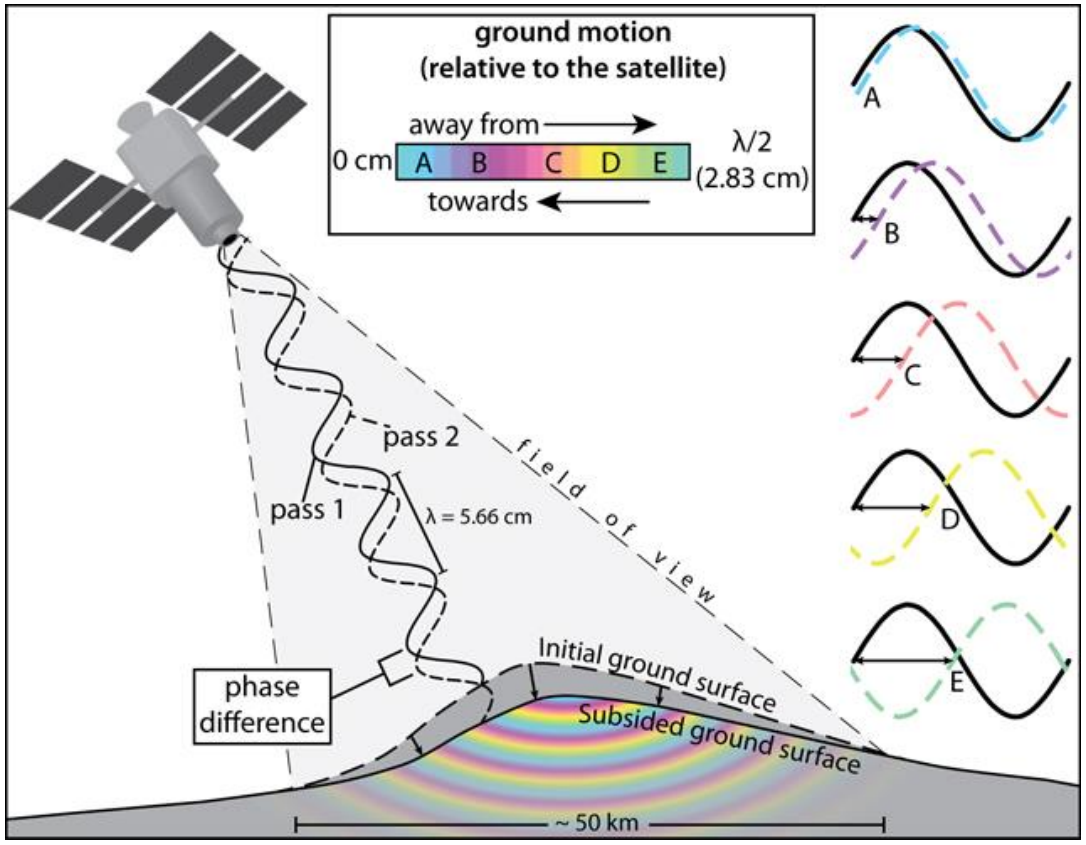
φ_{topo} **topographic phase**

φ_{displ} **deformation phase**

φ_{atm} **atmospheric phase**

φ_{err} **noise (error phase)**

InSAR principles



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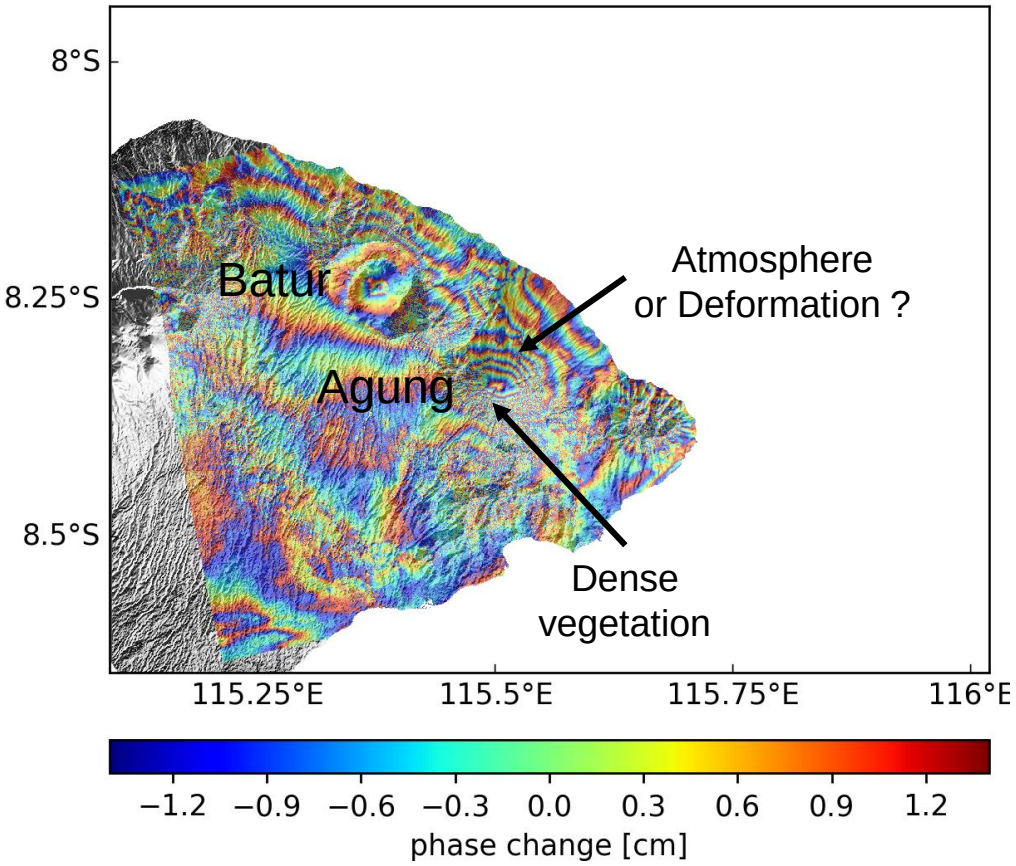
Challenge of InSAR in tropical volcanoes

Variation of water vapor

Dense vegetation

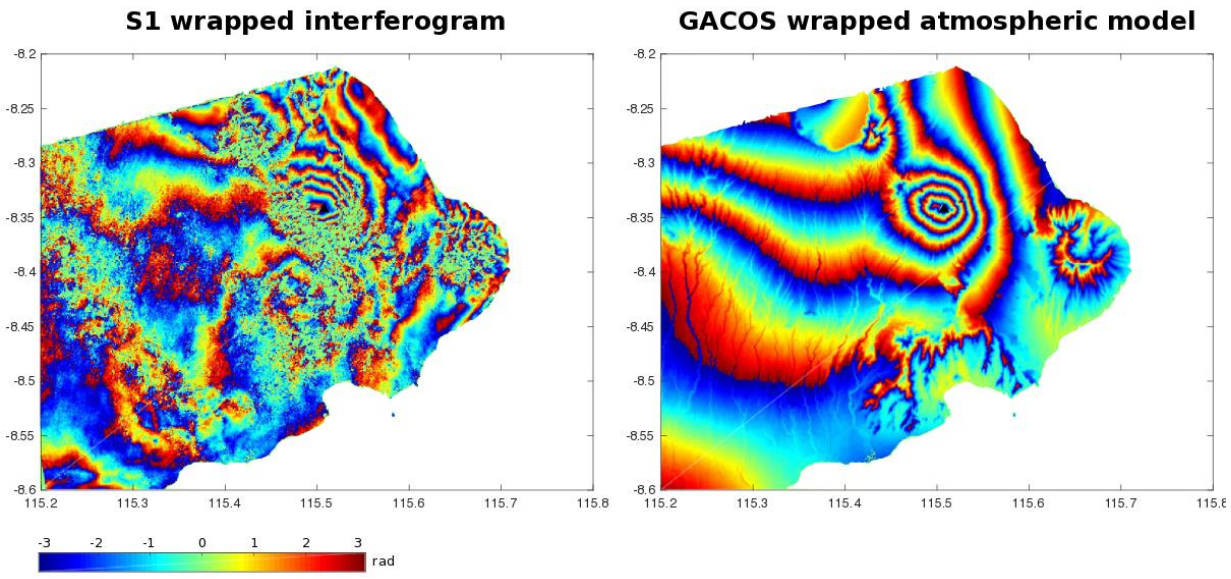
Challenge of InSAR in tropical volcanoes



12-days Sentinel Interferograms
18 Sept – 30 Sept 2017

- Good coherence
- Several fringes on Agung summit

Correction of atmospheric phase delays

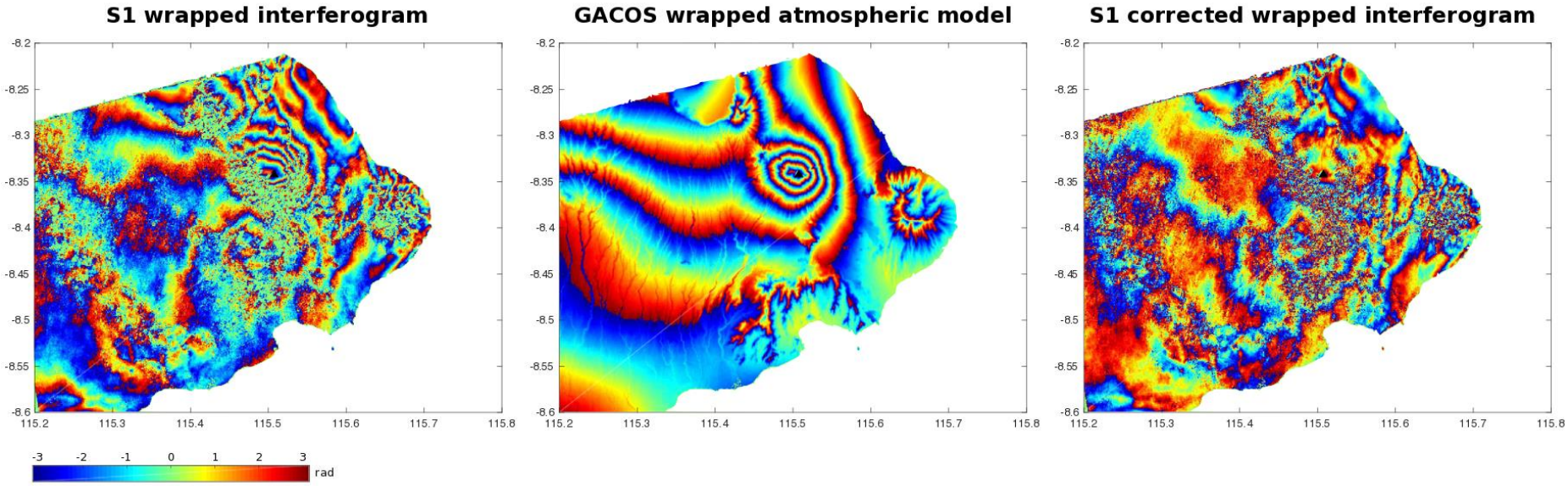


GACOS Atmospheric corrections
http://ceg-research.ncl.ac.uk/v2/gacos/

- ECMWF weather model (0.125º and 6h)
- SRTM DEM (90 m)

Thursday keynote – ***Zhenhong Li***
GACOS-Assisted InSAR Time Series Technique

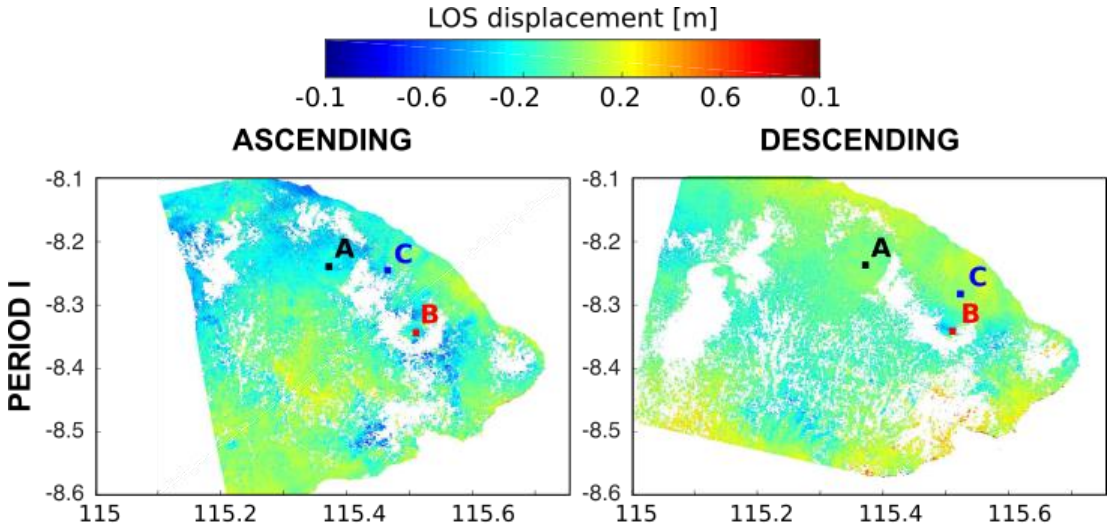
Correction of atmospheric phase delays



Open-access data are great!!! But we need to be responsible with it.

- Diffusion of wrong information during the seismic crisis (social media)
- Need to develop/improve path of communication from the community to the public

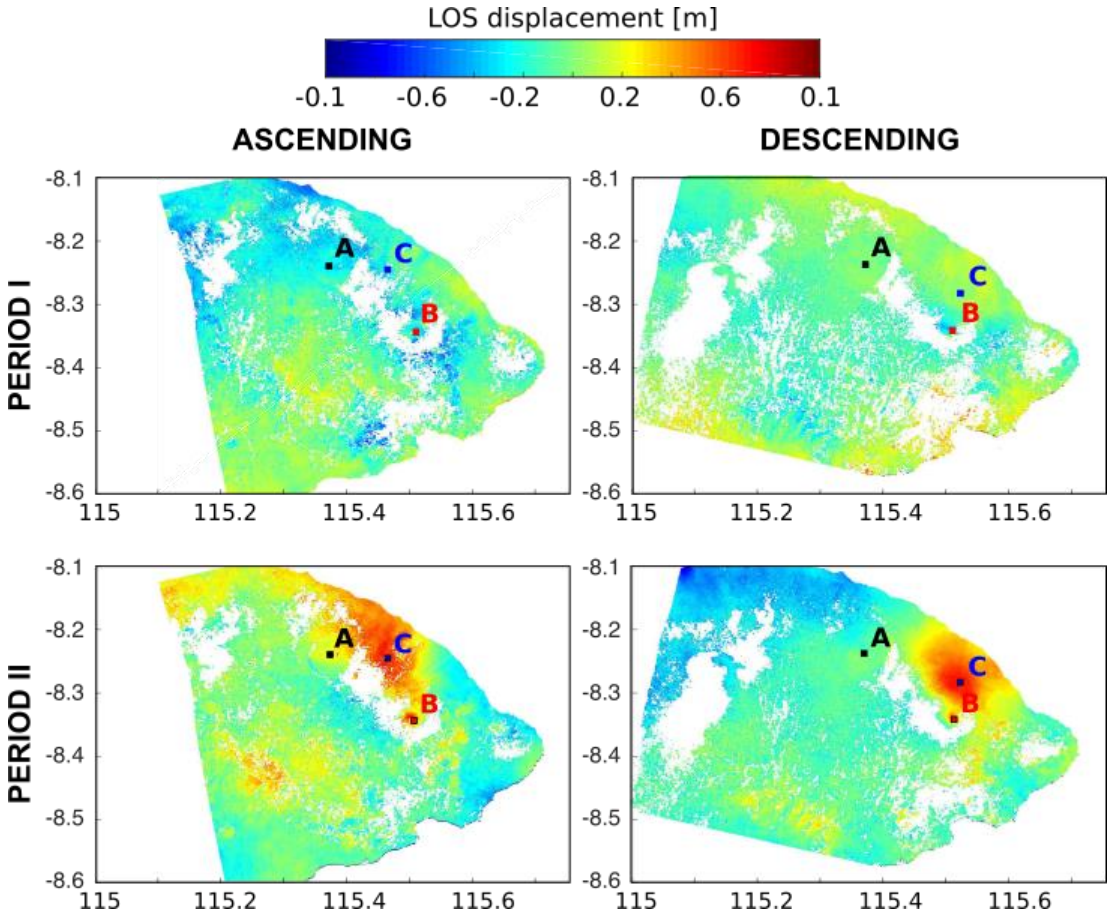
InSAR stacking



Period I:
From mid April to August 1st

No significant ground deformation

InSAR stacking



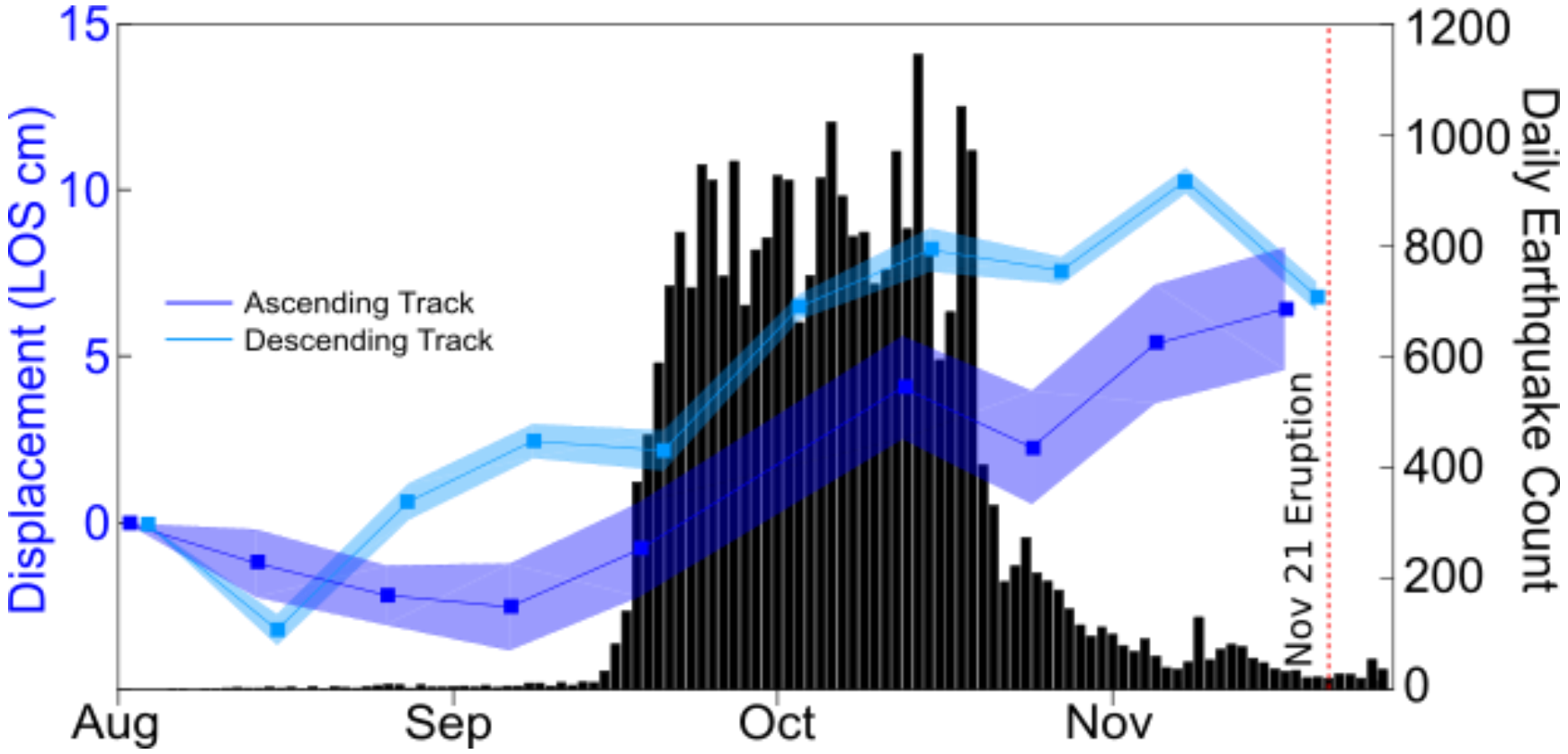
Period I:
From mid April to August 1st

No significant ground deformation

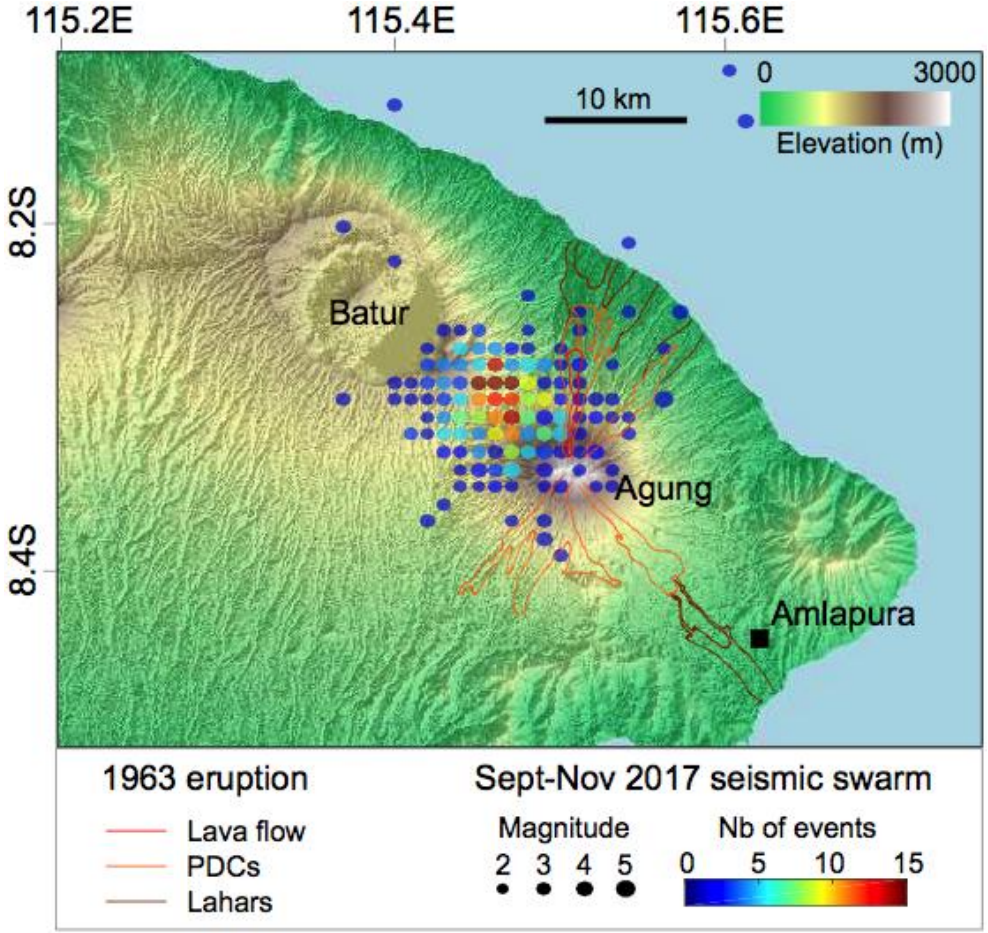
Period II:
August 1st to November 21st

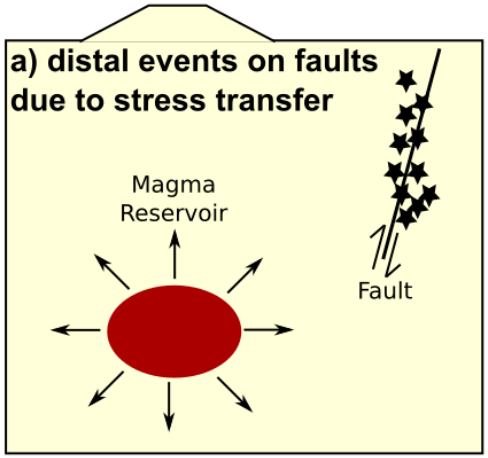
Wide uplift (8-10 cm) in the northern flank of Agung

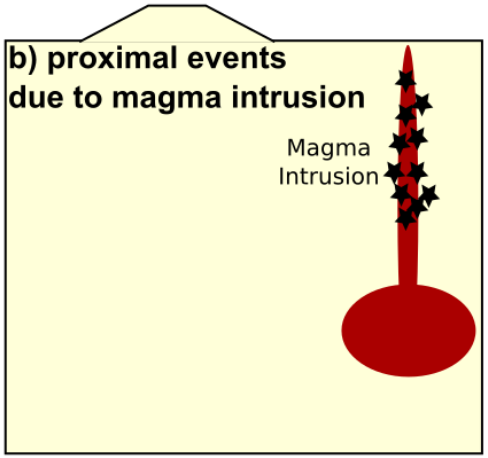
Timeline of unrest (seismicity + InSAR)



Offset of seismicity

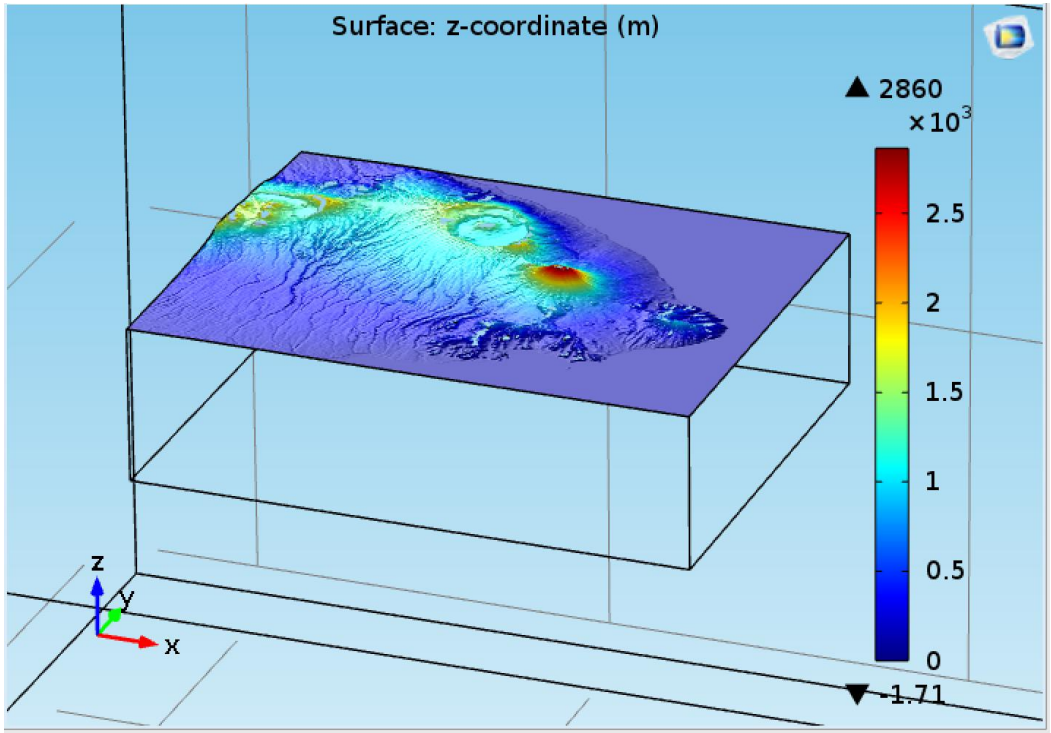




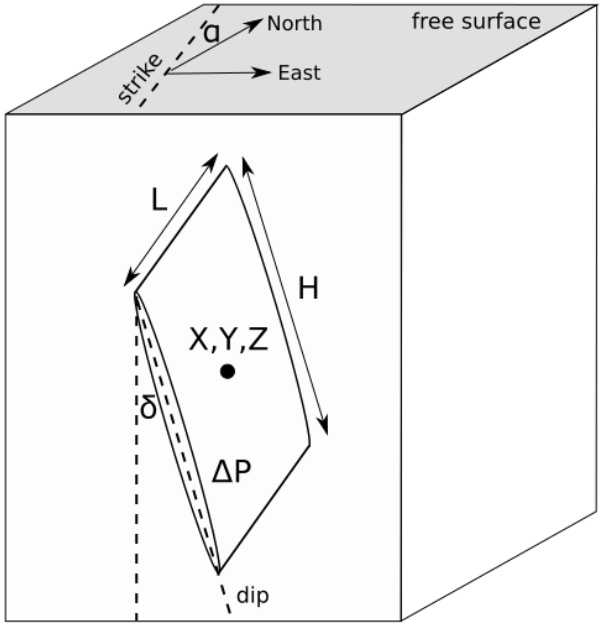


FEM modelling (COMSOL)

3D Topography

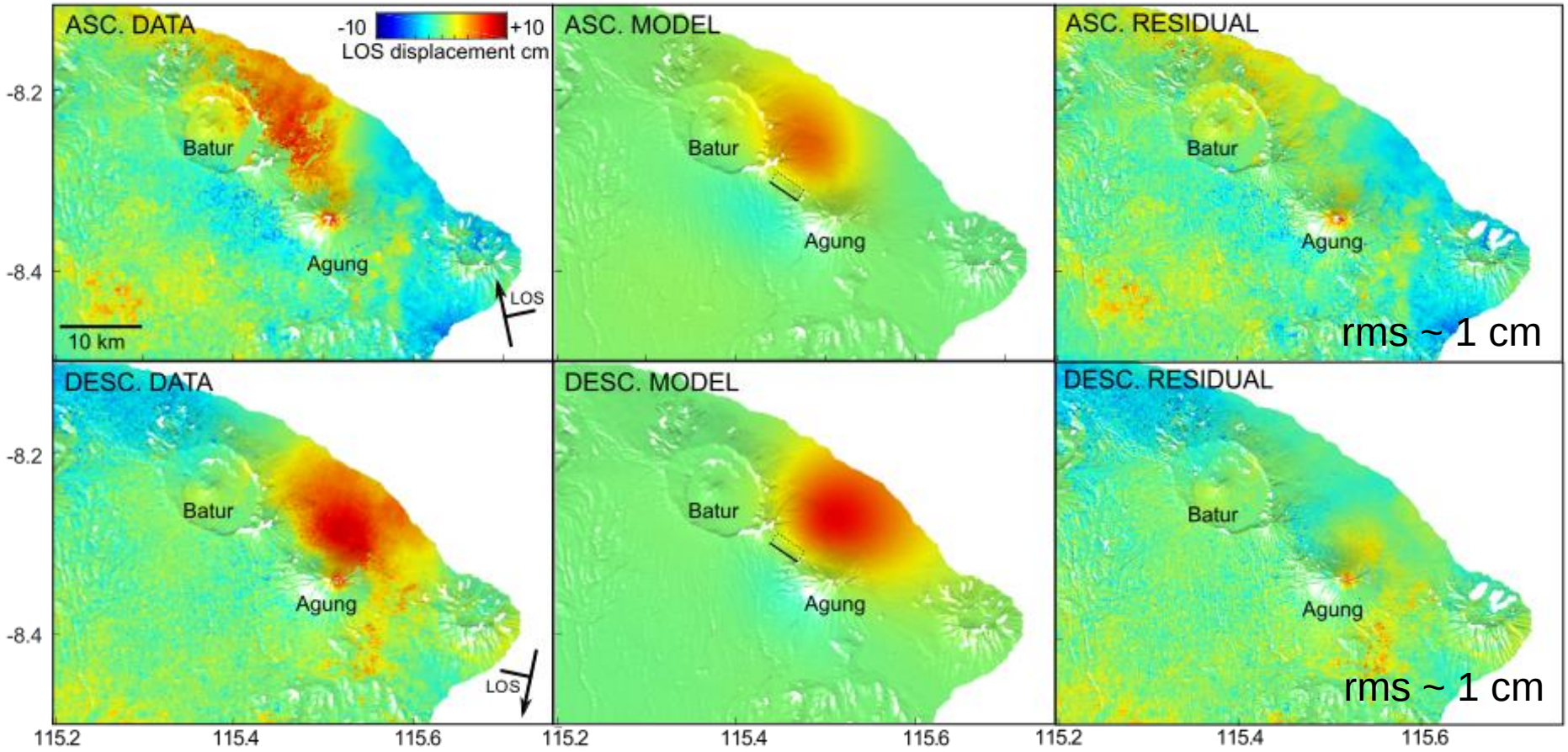


Magma Intrusion
(8 parameters)

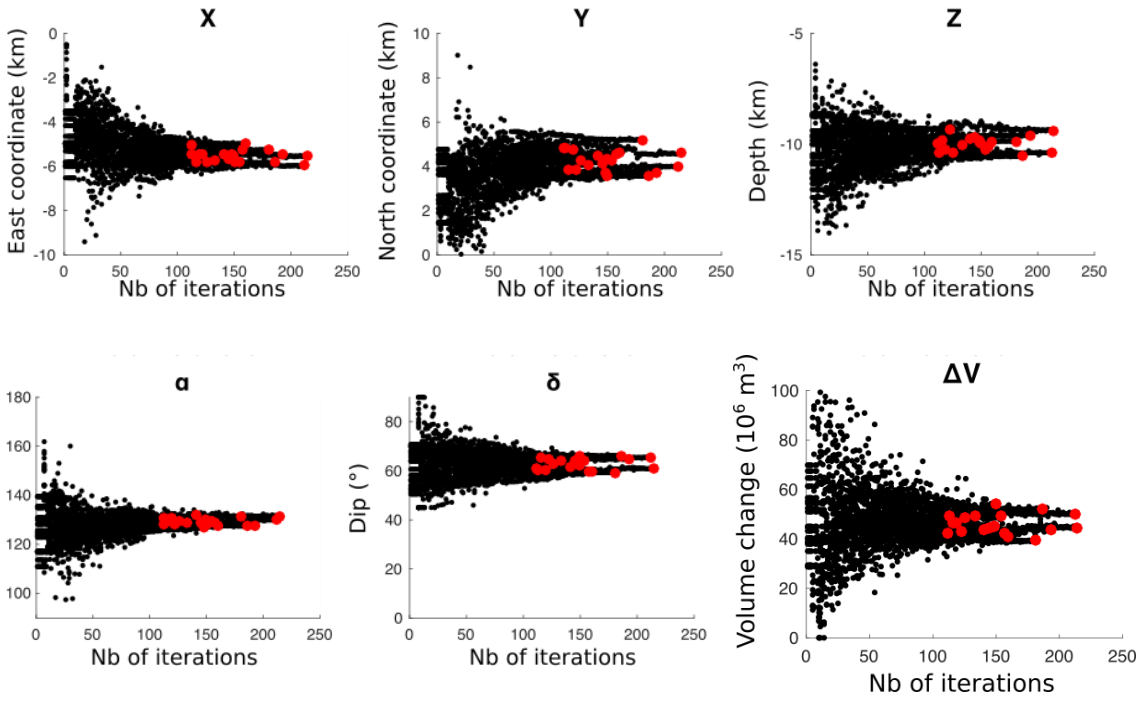


(X,Y,Z) : coordinates of the centre
(L,H) : Length and Height
(α, θ) : Azimuth and Dip
ΔP : Magma Overpressure

Modelling of the large uplift signal



Inversion: Monte-Carlo + Nelder-Mead

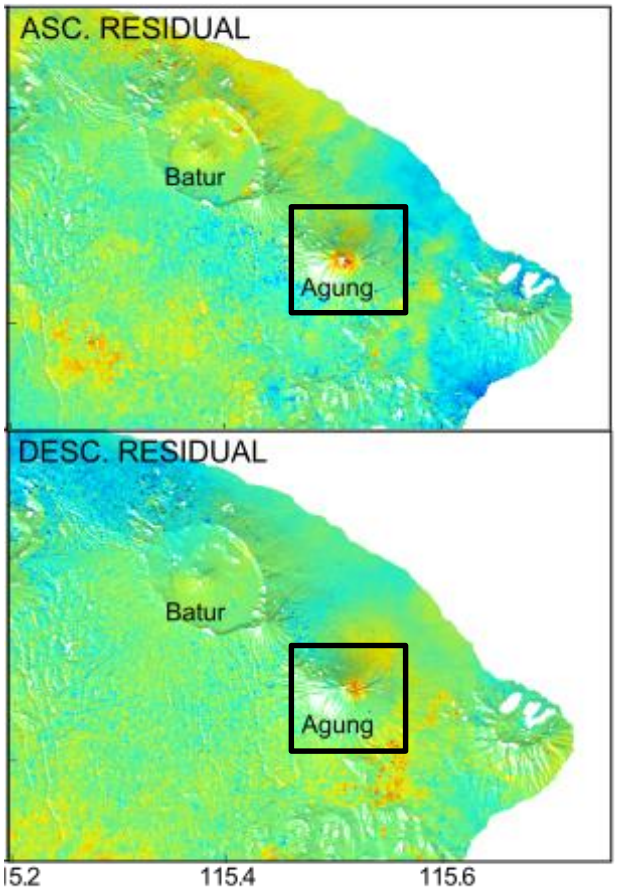


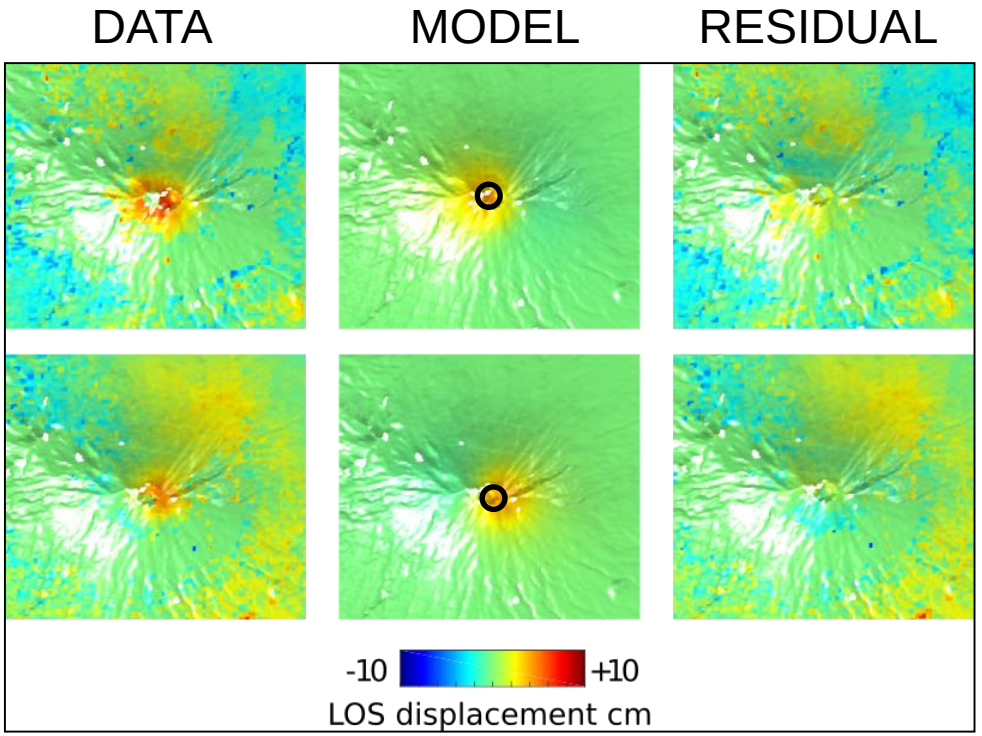
X = -5.5 km (±0.3)
Y = +4.3 km (±0.5)
Z = -10.0 km (±0.3)

α = -50.8° (±1.5)
δ = 62.9° (±2.3)

ΔV = 47.6x10^6 m^3 (±3.6)

Modelling of the small summit signal





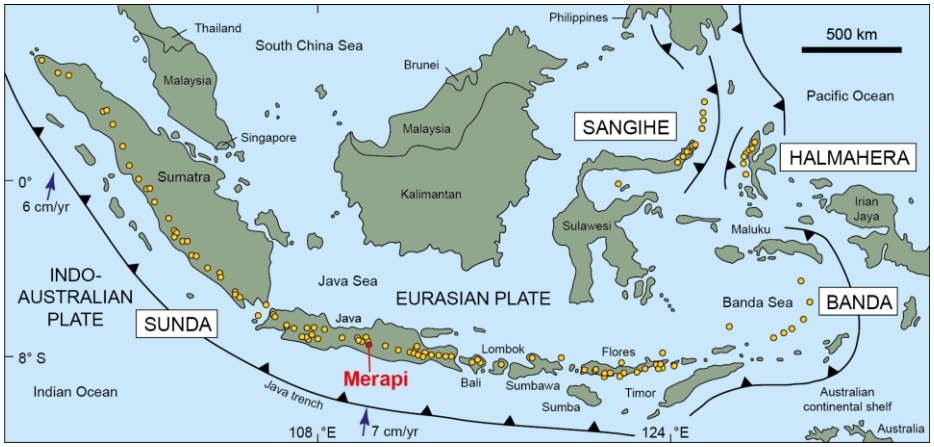
Zc = 600-700 m (below summit)

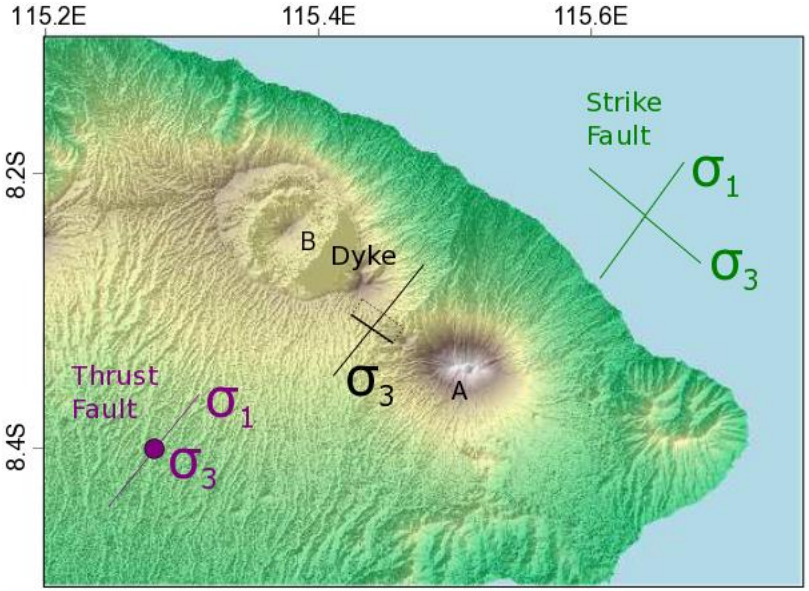
$\Delta Vc = 3.6\ 10^6\ m^3$

How can we explain the orientation of the intrusion ?

Dyke Opening along σ_3 (azimuth 39º) Propagation along σ_1 (plunge 63º)

Hyp. 1 Tectonic stress around Bali





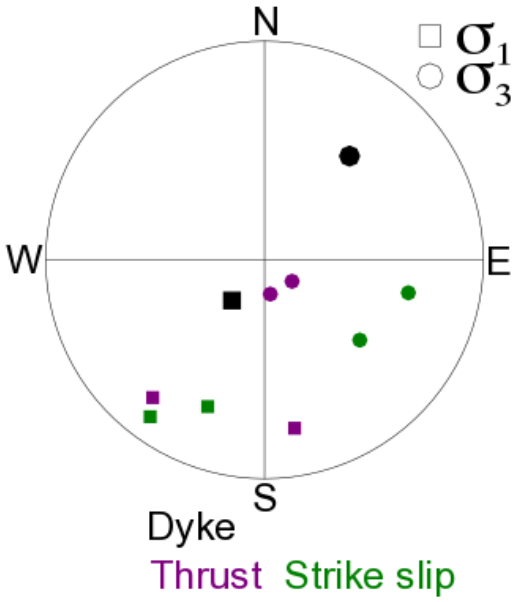
World Stress Map, 2016

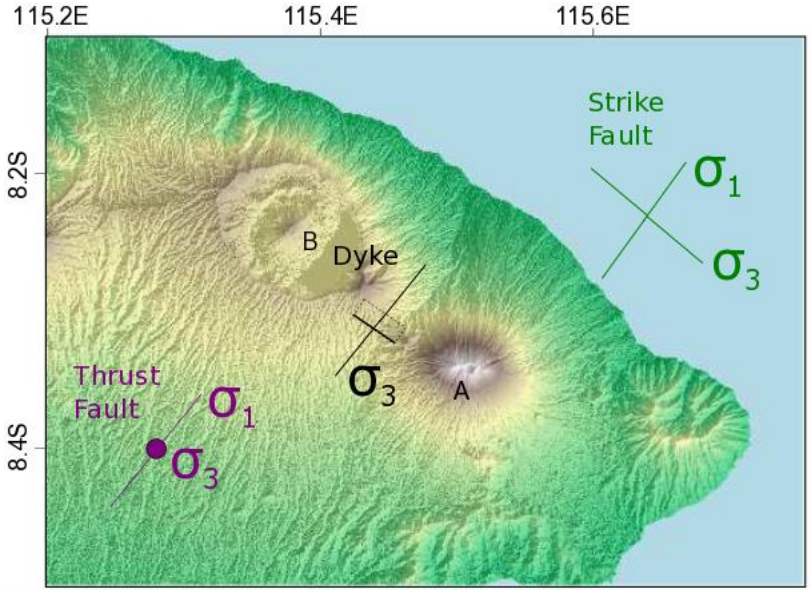
How can we explain the orientation of the intrusion ?

Dyke σ_3 azimuth: 39º σ_1 plunge: 63º

Hyp. 1 Tectonic stress around Bali

σ_3 azimuth: 103-171º σ_1 plunge: 7-18º

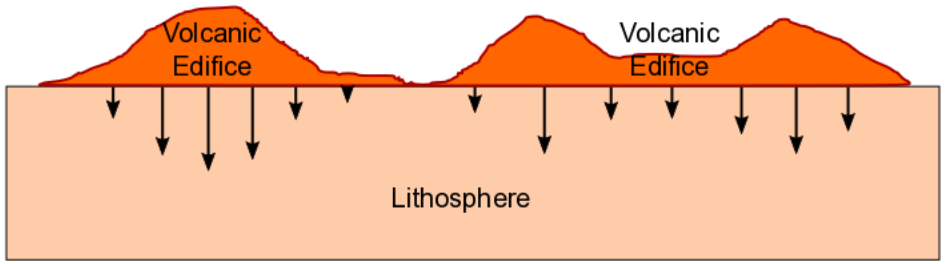


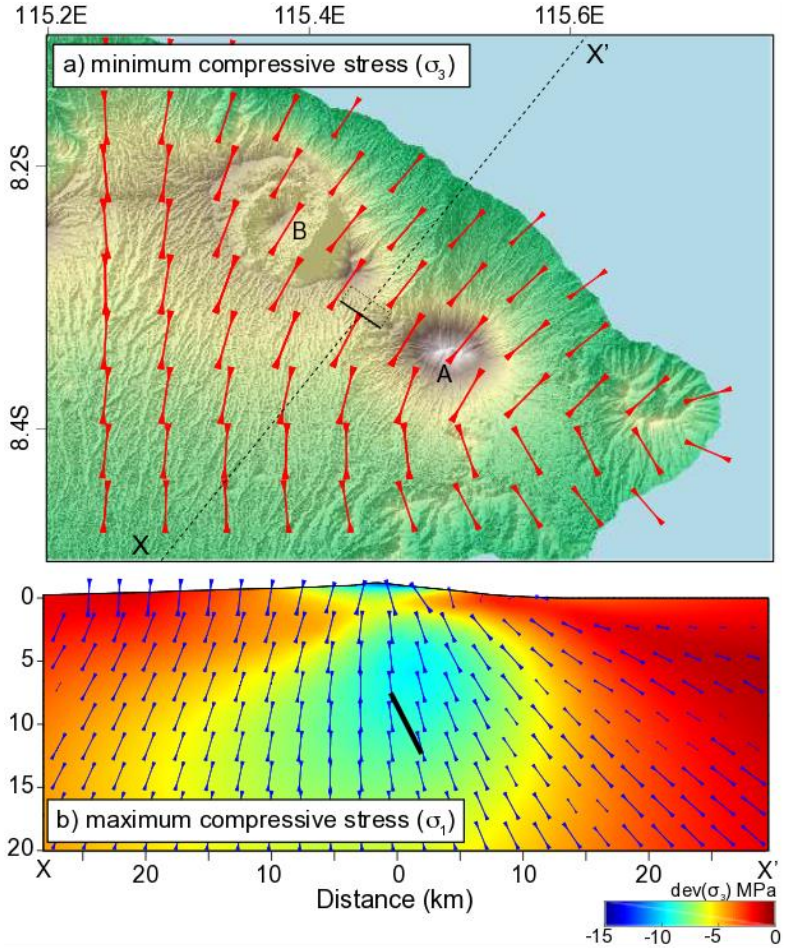


How can we explain the orientation of the intrusion ?

Dyke σ_3 azimuth: 39º σ_1 plunge: 63º

Hyp. 2 Topographic loading stress



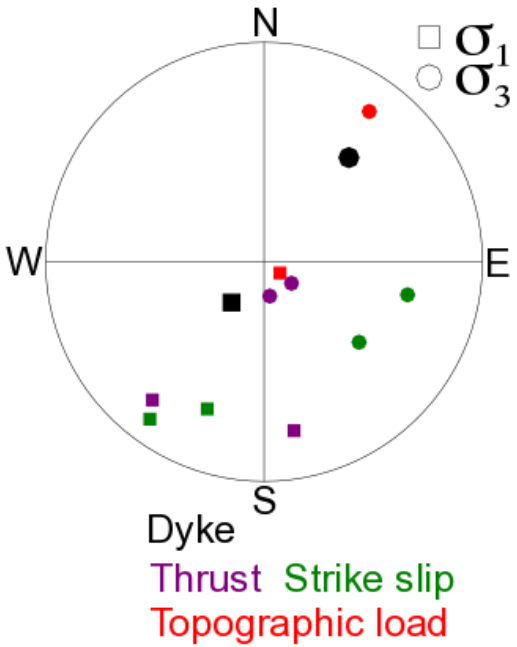


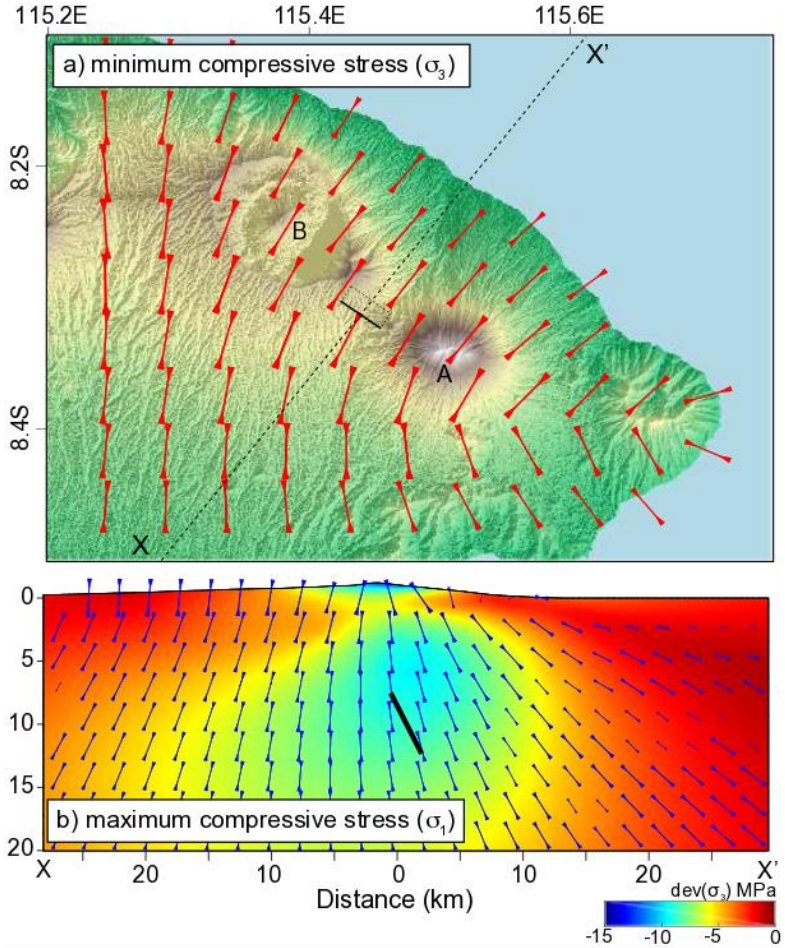
How can we explain the orientation of the intrusion ?

Dyke σ_3 azimuth: 39º σ_1 plunge: 63º

Hyp. 2 Topographic loading stress

σ_3 azimuth: 35º σ_1 plunge: 80º





What did we learn?

- How magma is transferred below Agung before the eruption ?

A deep and large dyke intrusion located midway between Agung and Batur

- Which mechanism is controlling the propagation of the magma ?

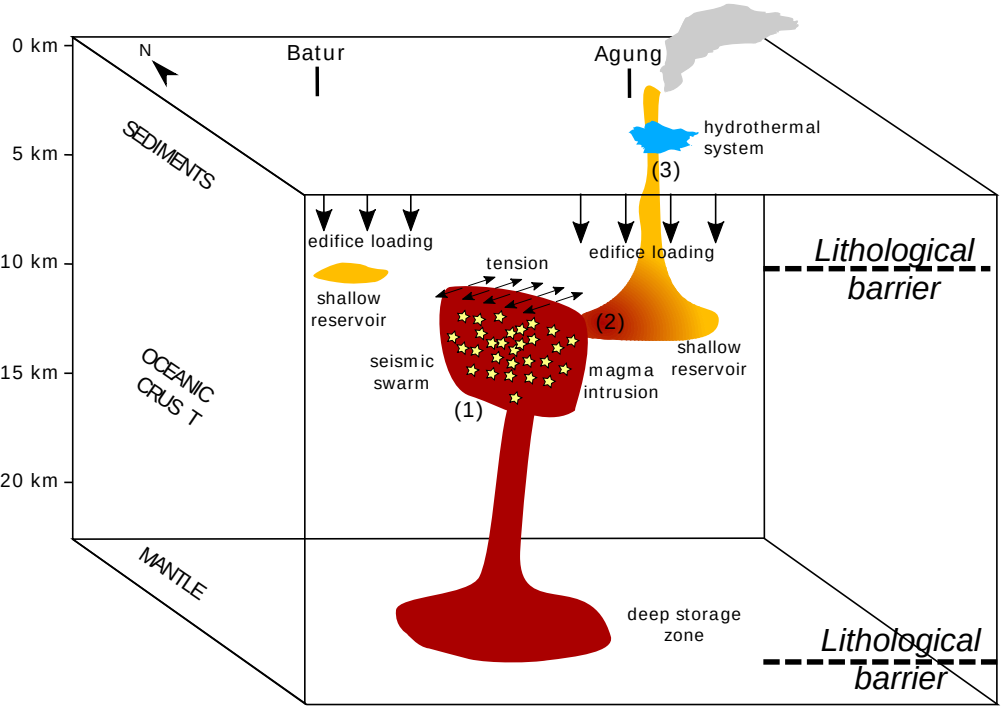
Not regional stresses. But local stress induced by the loading of the volcanic edifices.

This is the first geodetic evidence of a magmatic connection between the two volcanoes.

These results have a strong implication to understand how simultaneous eruptions occurred at Agung and Batur (e.g. 1963).

Conceptual model of Agung magmatic system

Albino et al., 2018 (in review) [geodesy]
Geiger et al., 2018 [thermo-barometry]
Fontijn et al., 2015 [petrology]

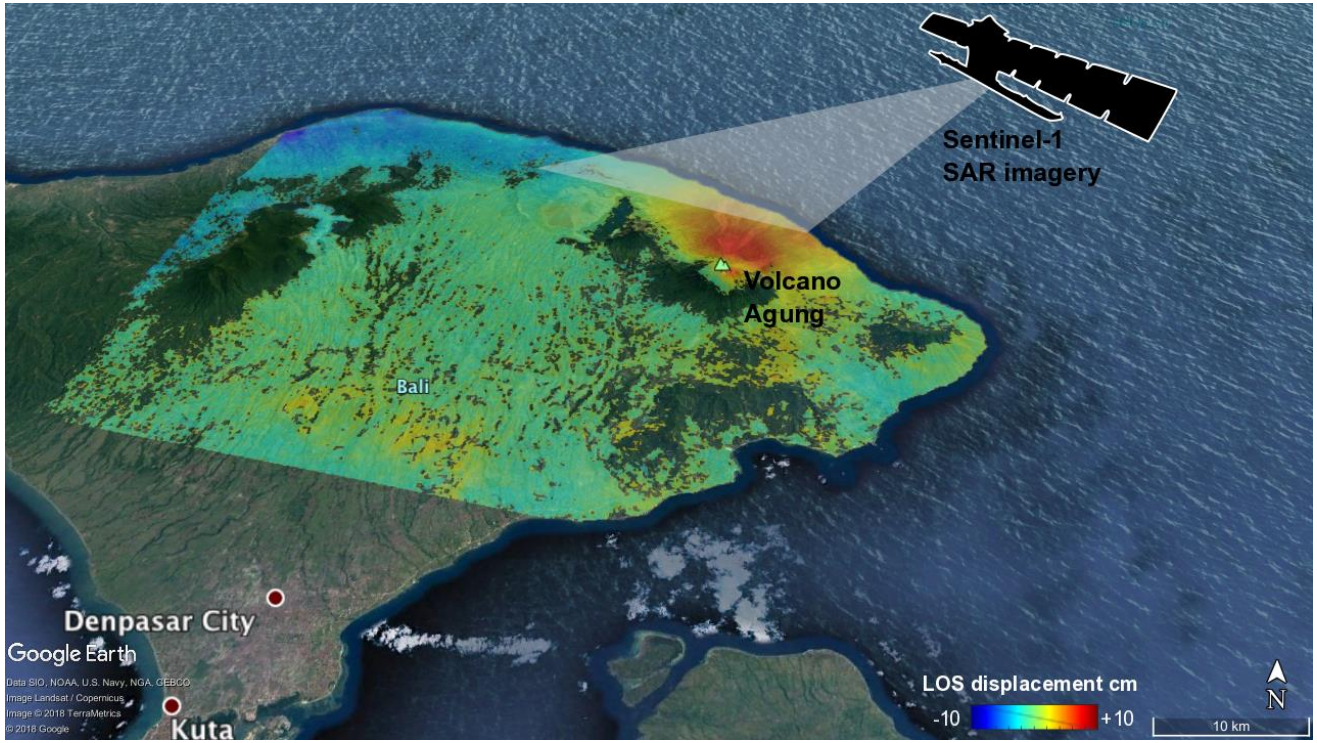


(1) Sept. - Oct. 2017
Magma transfer from deep source (15-20 km)
Ground uplift- Seismic swarm

(2) Mid-October 2017
Arrest of magma vertical propagation (5-7 km)
Small deformation - Drop of seismicity

(3) November 2017
Mixing between intrusion and shallow source
Increase of degassing (SO_2)
P^o of the hydrothermal system

(4) 21st November
ERUPTION



Dyke intrusion between neighbouring arc volcanoes responsible for 2017 pre-eruptive seismic swarm at Agung, Bali

F. Albino, J. Biggs and D. K. Syahbana

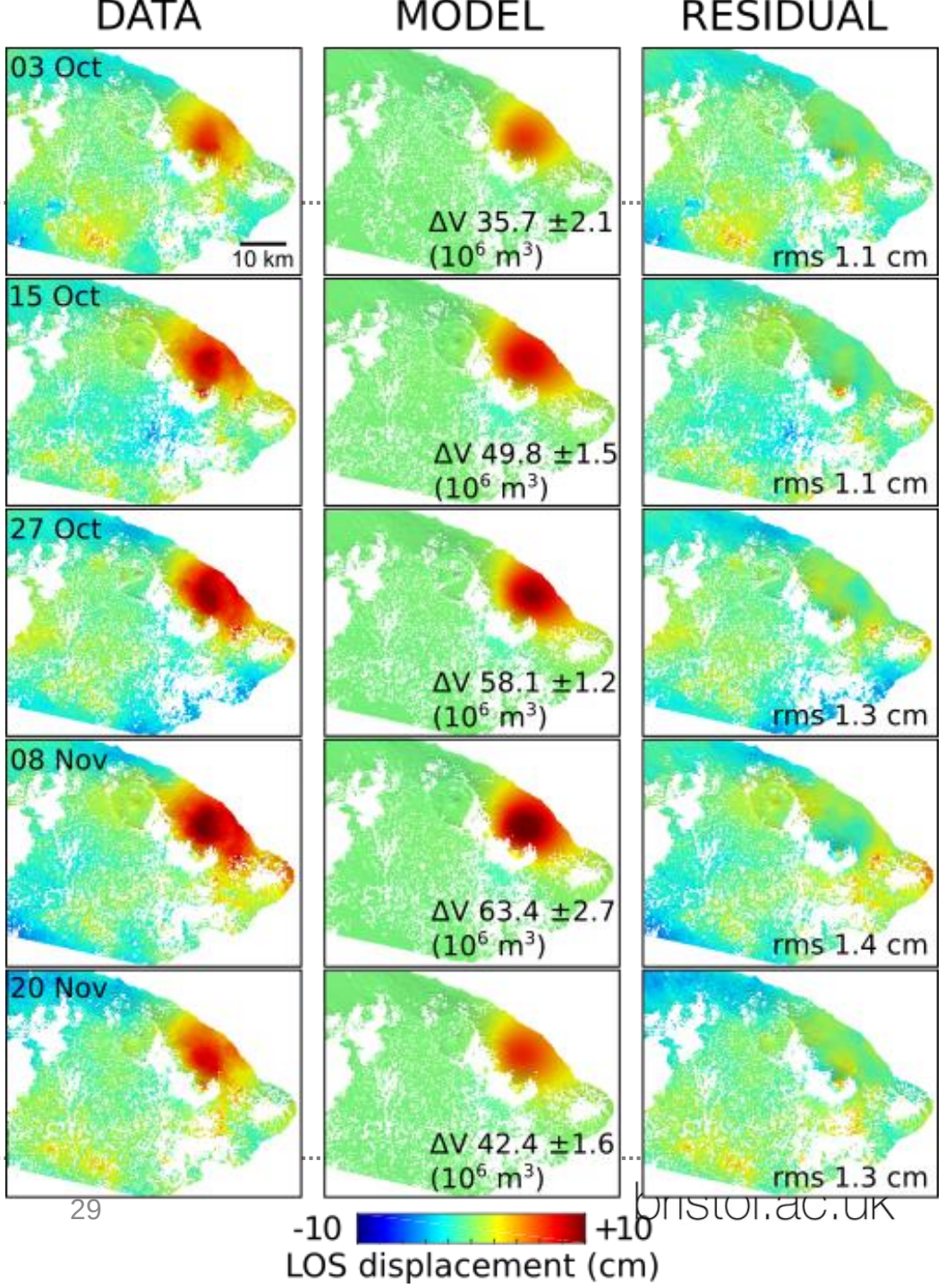
in review, Nature Communications

fa17101@bristol.ac.uk

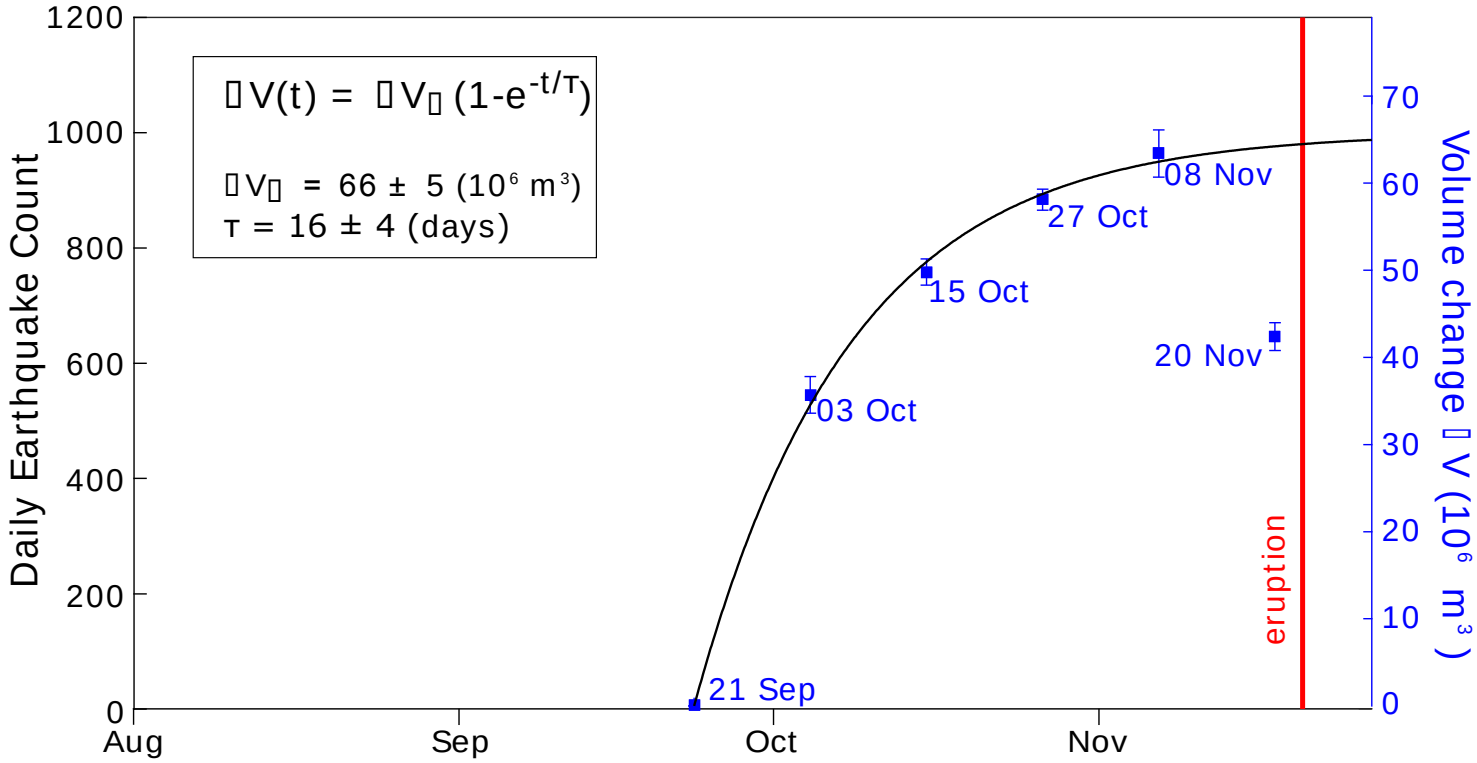
@FabienAlbino

University of BRISTOL

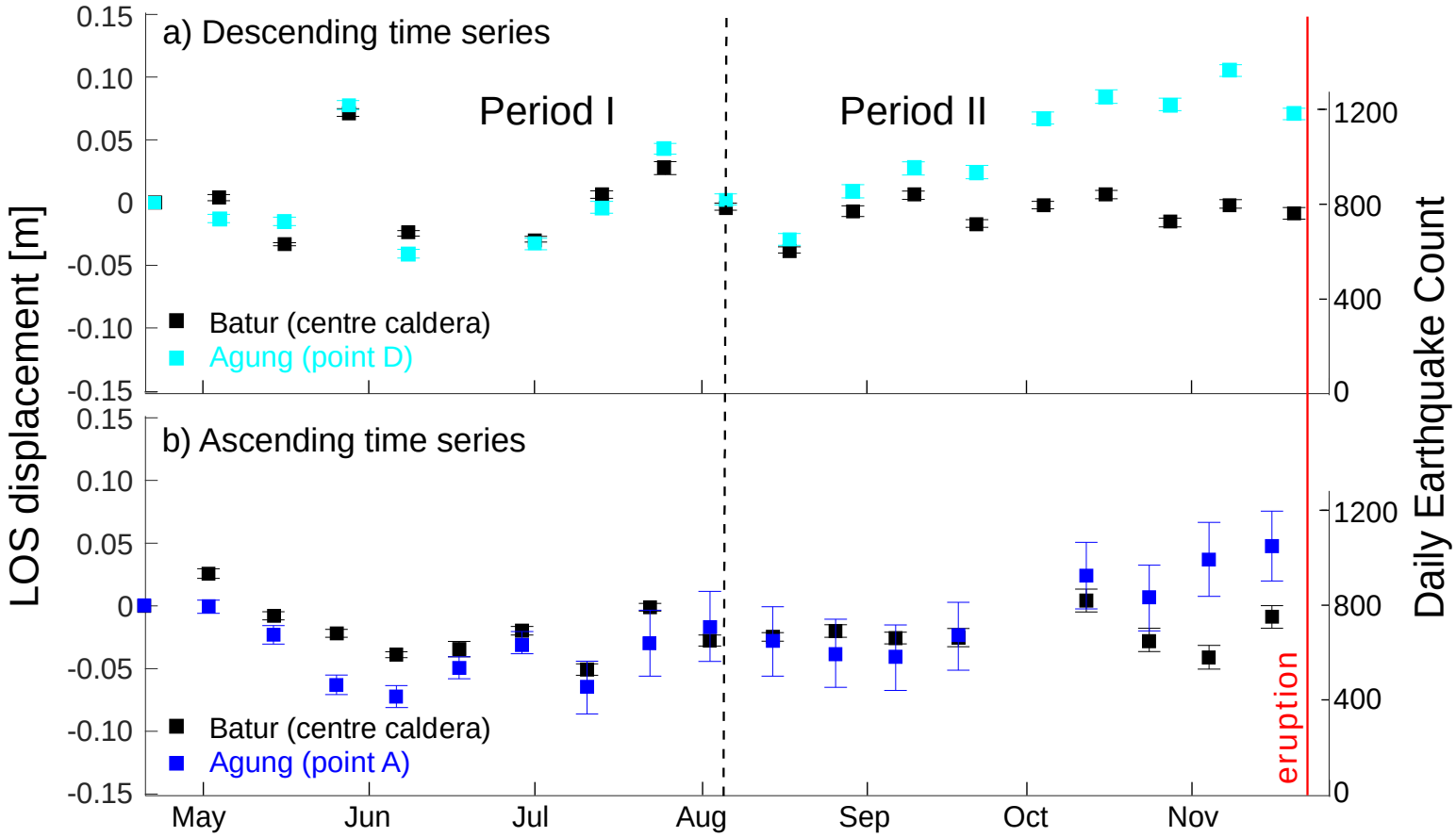
Time-step inversion



Volume history



Full time series



Trade-off between parameters