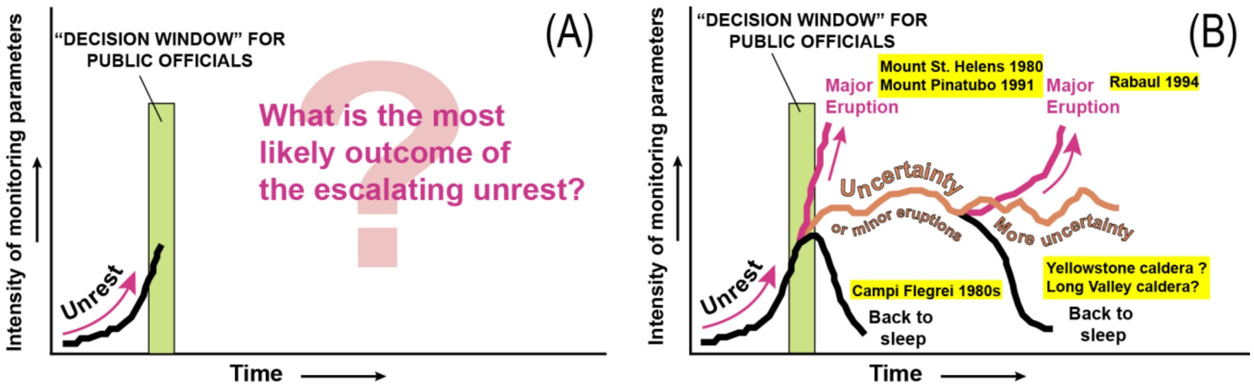
Under the radar: New activity beneath the “Roof of Patagonia”, Domuyo volcano, Argentina

Paul Lundgren[1], Társilo Girona[1], Sergey Samsinov[2], Vincent Realmuto[1], and Cunren Liang[3]

[1]Jet Propulsion Laboratory, California Institute of Technology
[2]Canada Centre for Mapping and Earth Observation, Natural Resources Canada
[3]Seismological Laboratory, California Institute of Technology

Motivation: 1

Forecasting system evolution during unrest



(from Tilling, 2008)

Research Questions:

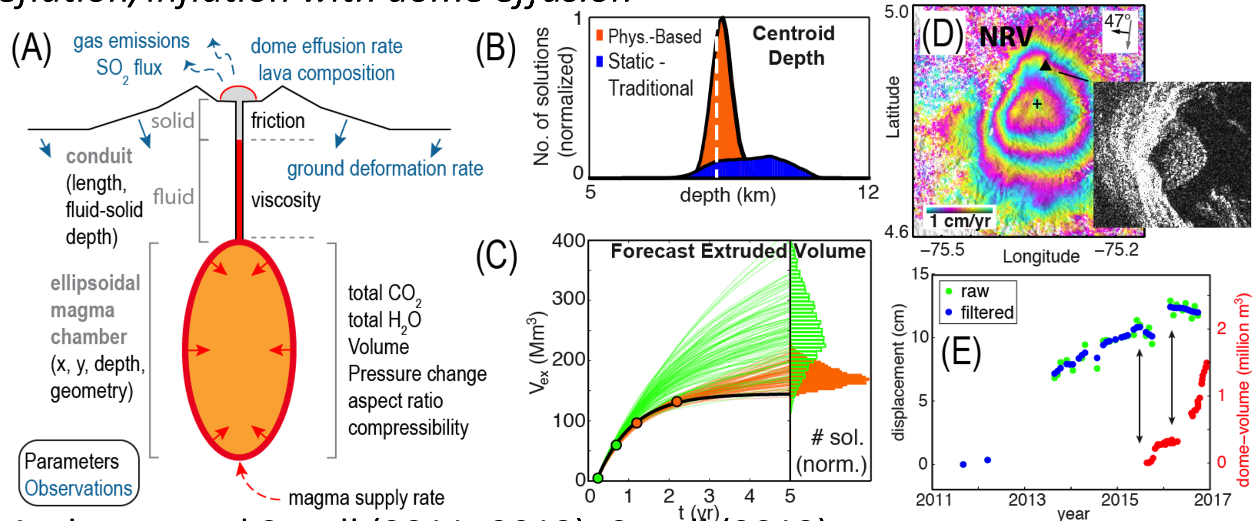
1. Does caldera inflation unrest imply future eruption?

2. How is caldera breathing related to magma ascent and volcanic outgassing?

Motivation: 2

Understanding and forecasting require **physics-based** models

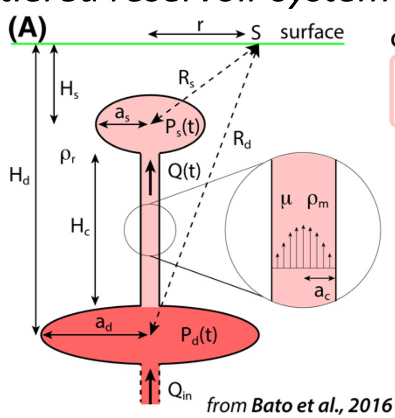
Deflation/inflation with dome effusion



Anderson and Segall (2011, 2013), Segall (2013)

Source geometry and pressure/volume change are important constraints on physics-based volcano models.

Two-tiered reservoir system



Chamber Overpressures

$$\frac{\Delta P_{st_{i+1}} - \Delta P_{st_i}}{t_{i+1}-t_i} = \frac{G a_c^4}{8\mu\gamma_s H_c a_s^3}\left((\rho_r-\rho_m)gH_c + \Delta P_{dt_i} - \Delta P_{st_i}\right)$$

$$\frac{\Delta P_{dt_{i+1}} - \Delta P_{dt_i}}{t_{i+1}-t_i} = \frac{G}{\pi\gamma_d a_d^3}Q_{in} - \frac{\gamma_s a_s^3}{\gamma_d a_d^3}\frac{\Delta P_{st_{i+1}}-\Delta P_{st_i}}{t_{i+1}-t_i}$$

Surface disaplacements

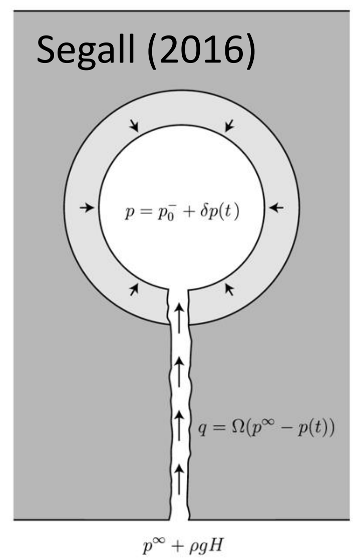
$$u_R(r,t_i) = \frac{(1-\nu)}{G} r \left(\frac{\alpha_s a_s^3 \Delta P_{st_i}}{R_s^3} + \frac{\alpha_d a_d^3 \Delta P_{dt_i}}{R_d^3}\right)$$

$$u_z(r,t_i) = \frac{(1-\nu)}{G}\left(\frac{H_s\alpha_s a_s^3\Delta P_{st_i}}{R_s^3} + \frac{H_d\alpha_d a_d^3\Delta P_{dt_i}}{R_d^3}\right)$$

Reverso et al. (2012), Bato et al. (2017)

Physics-based models use **deformation time series** (among other information) to constrain a few types of mass conservation continuum and fluid mechanical models.

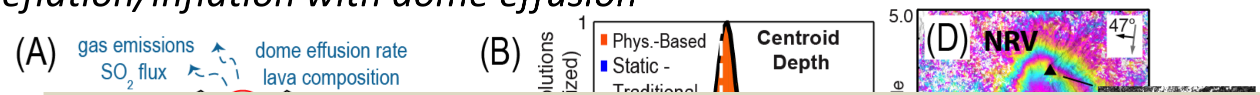
Single reservoir with viscoelastic shell



Motivation: 2

Understanding and forecasting require **physics-based** models

Deflation/inflation with dome effusion



Source geometry and

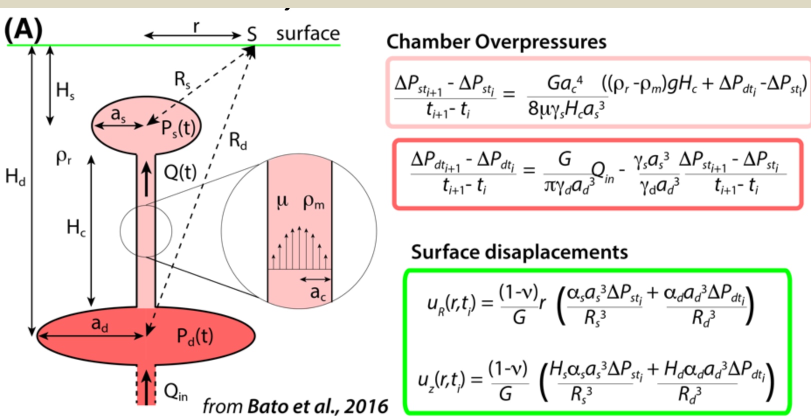
nt

h

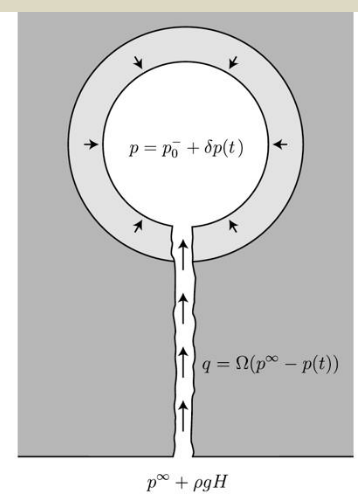
Ar

Two

But models based on fitting geodetic observations are often for single events and may lack assessment of longer term system behavior



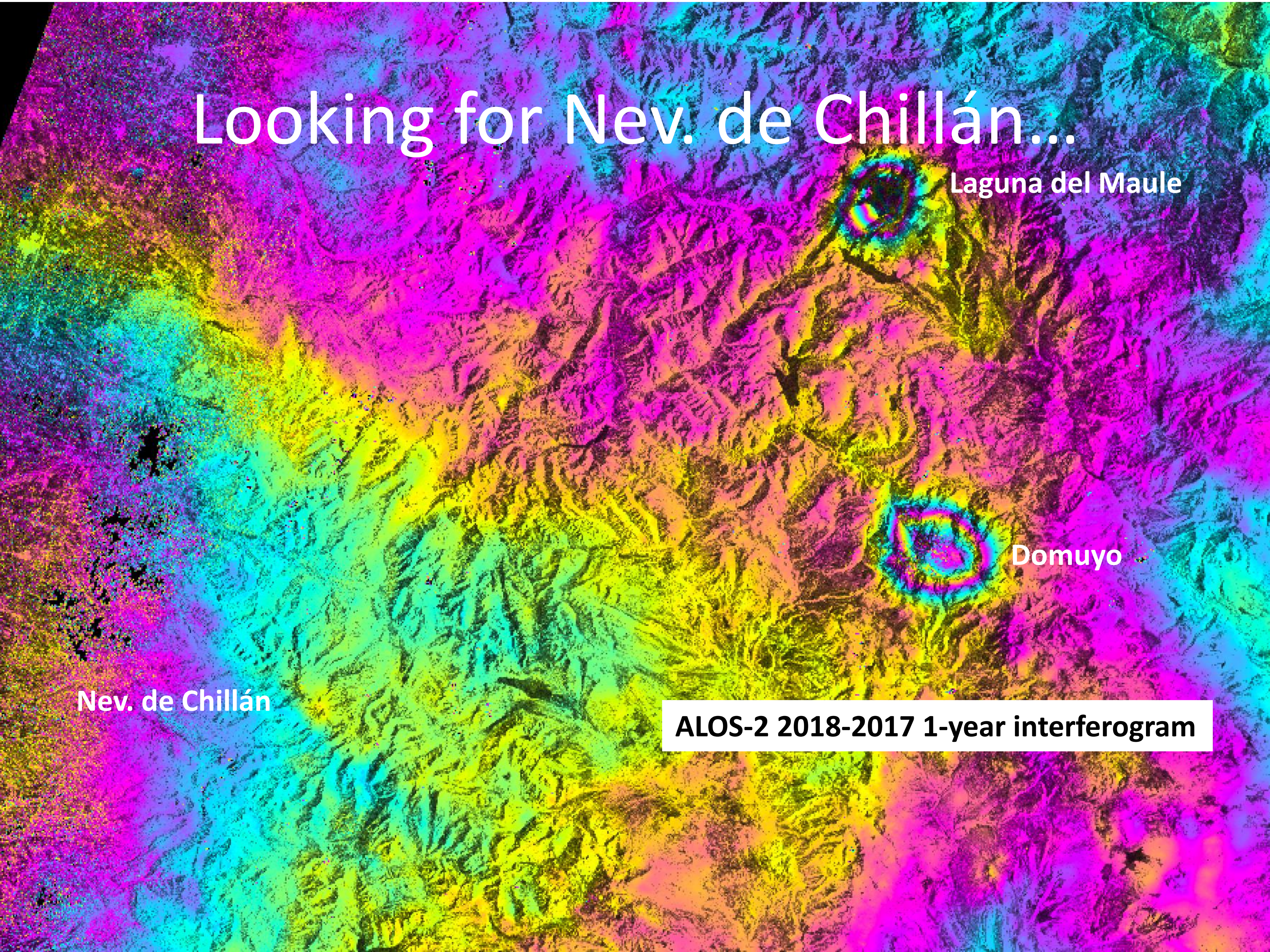
use **deformation time series** (among other information) to constrain a few types of mass conservation continuum and fluid mechanical models.



Reverso et al. (2012), Bato et al. (2017)

Outline

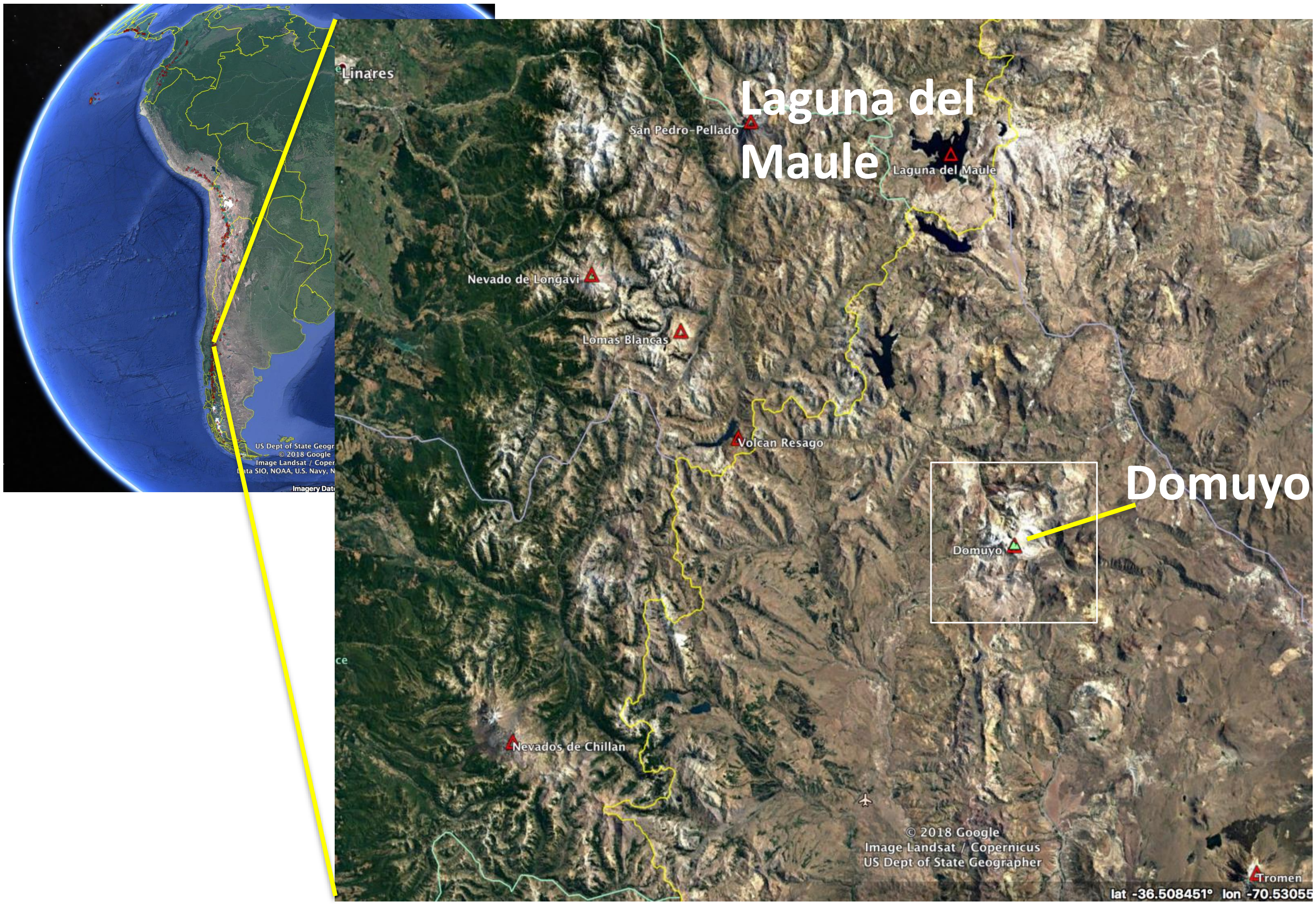
- ✓ Motivation
- Domuyo background
- Domuyo volcano InSAR deformation
- Domuyo TIR time series
- Conceptual physics-based model


Looking for Nev. de Chillán...
Laguna del Maule
Domuyo
Nev. de Chillán
ALOS-2 2018-2017 1-year interferogram

Domuyo volcano

Located in the Southern Andes of Argentina

Domuyo volcano



Domuyo volcano

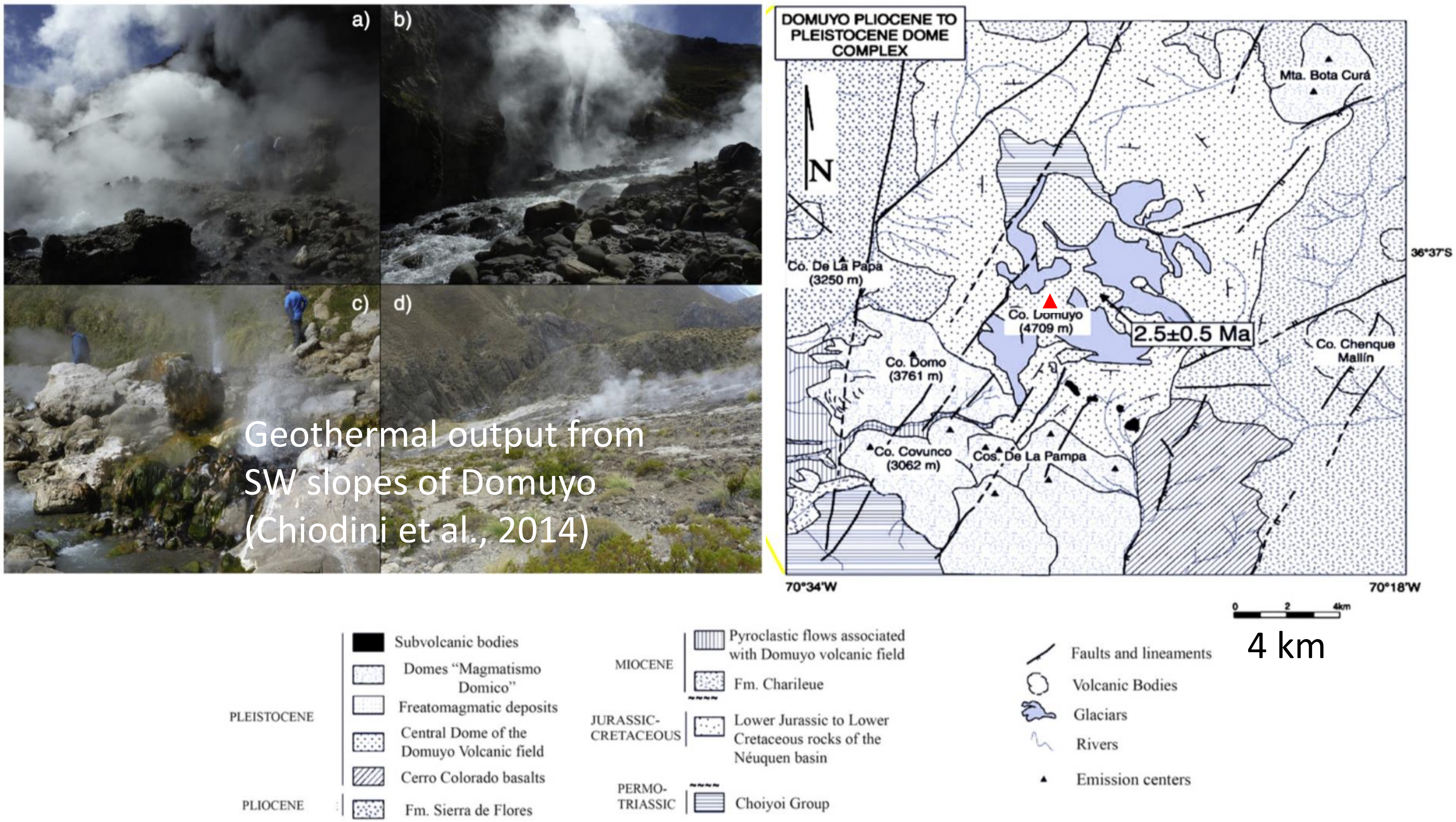


Fig. 1. (Left panel) The Domuyo volcanic complex, north of the Cordillera del Viento chain, and (right panel) geological map showing the distribution of Permian–Triassic to Pleistocene rocks; the arrow points to a K-Ar dating location (modified from Miranda et al., 2006).

Domuyo volcano

Chiodini et al. (2014):

- Second largest energy hydrothermal energy release measured in the world after Yellowstone (1.1 GW)
- High heat flux hard to explain from 0.1 Ma most recent activity, and may suggest more recent magma intrusion.

Tassi et al. (2016):

- Silicic (rhyolitic to dacitic) domes
- Geothermal chemistry suggests water from two different reservoirs (600m and 2-3 km depth)
- Actively degassing magmatic gasses evident above 3000m

F. Tassi et al. / Journal of Volcanology and Geothermal Research 328 (2016) 198–209

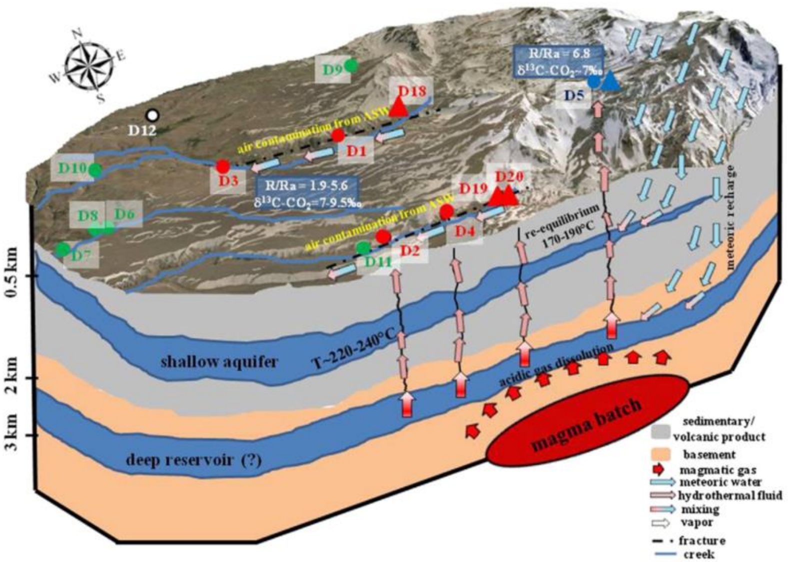
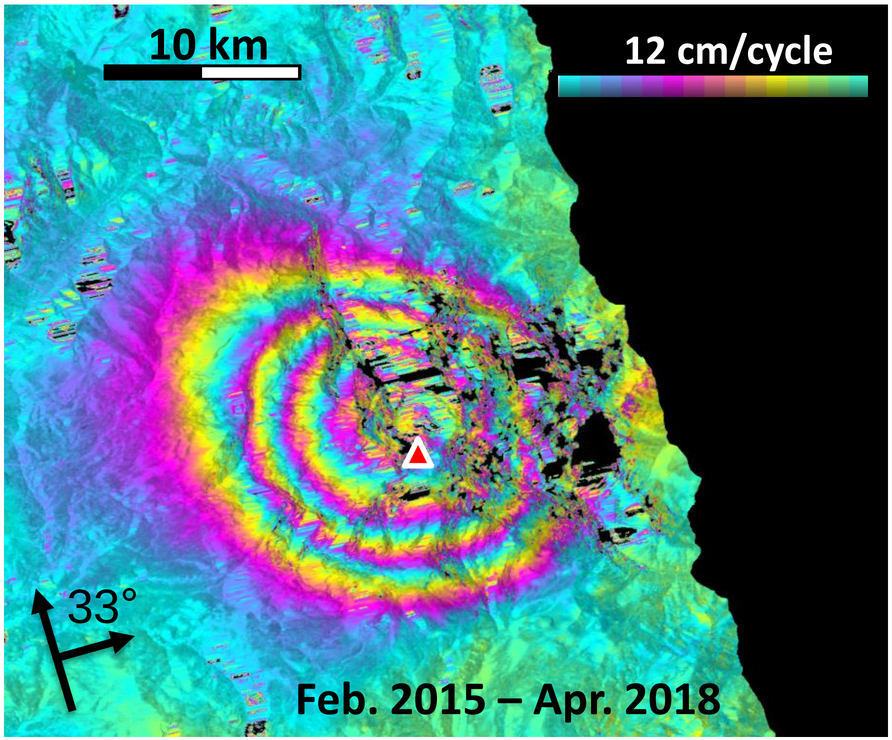
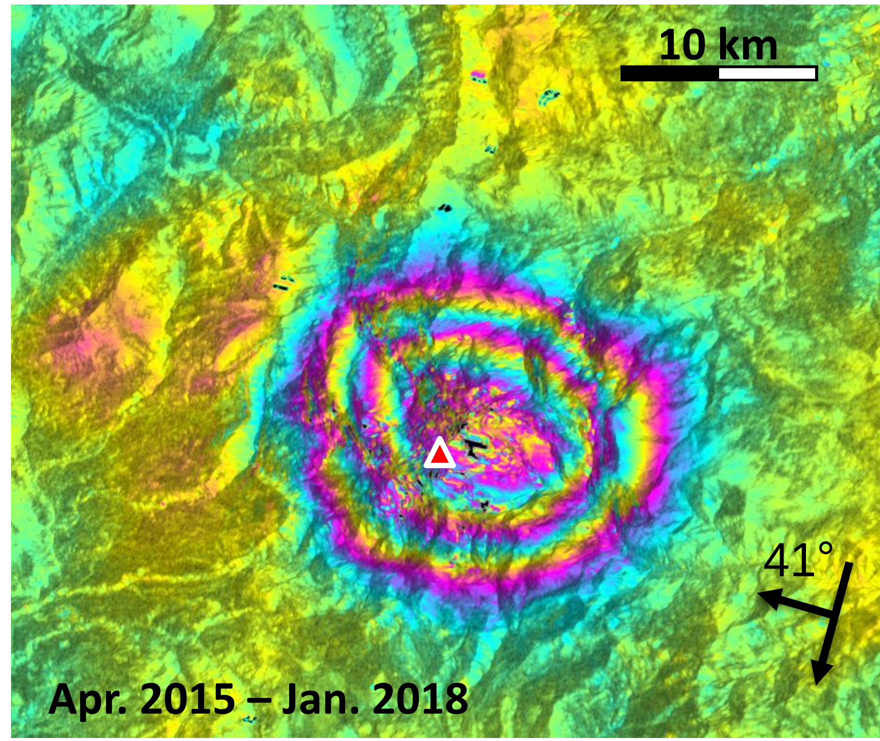


Fig. 12. Three-dimensional geochemical conceptual model of the hydrothermal system of the Domuyo volcanic complex.

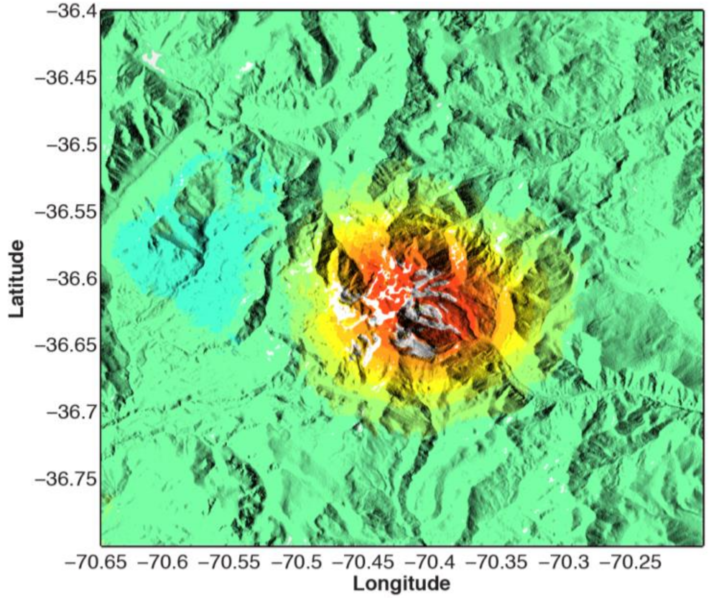
Tassi et al., 2016

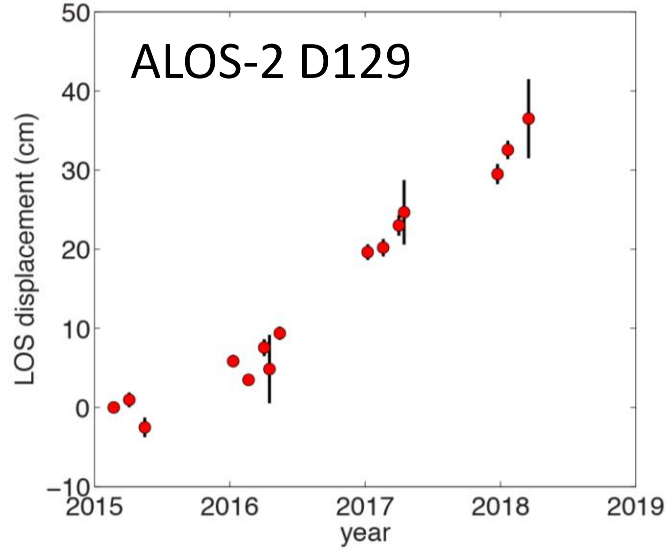
ALOS-2 2015-2018 interferograms

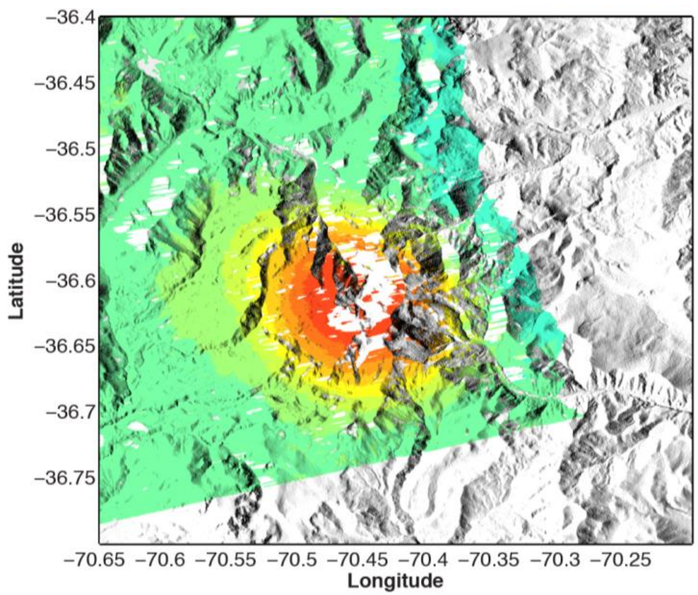


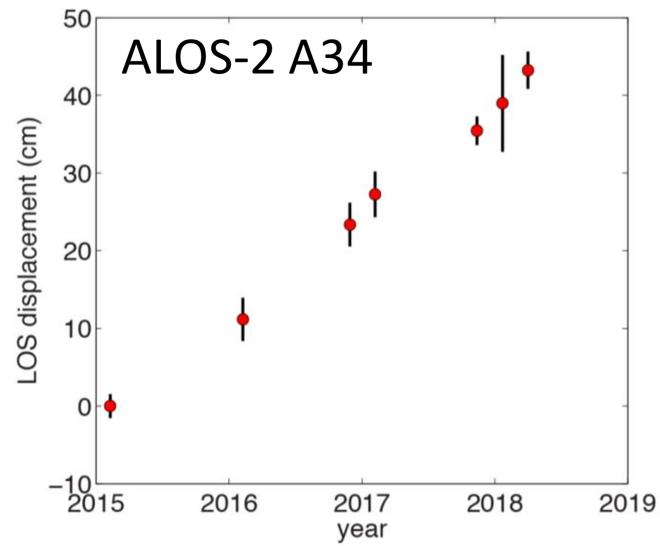


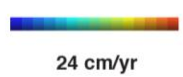
37°


Latitude
Longitude
−36.4
−36.45
−36.5
−36.55
−36.6
−36.65
−36.7
−36.75
−70.65 −70.6 −70.55 −70.5 −70.45 −70.4 −70.35 −70.3 −70.25


ALOS-2 D129
LOS displacement (cm)
year
50
40
30
20
10
0
−10
2015
2016
2017
2018
2019

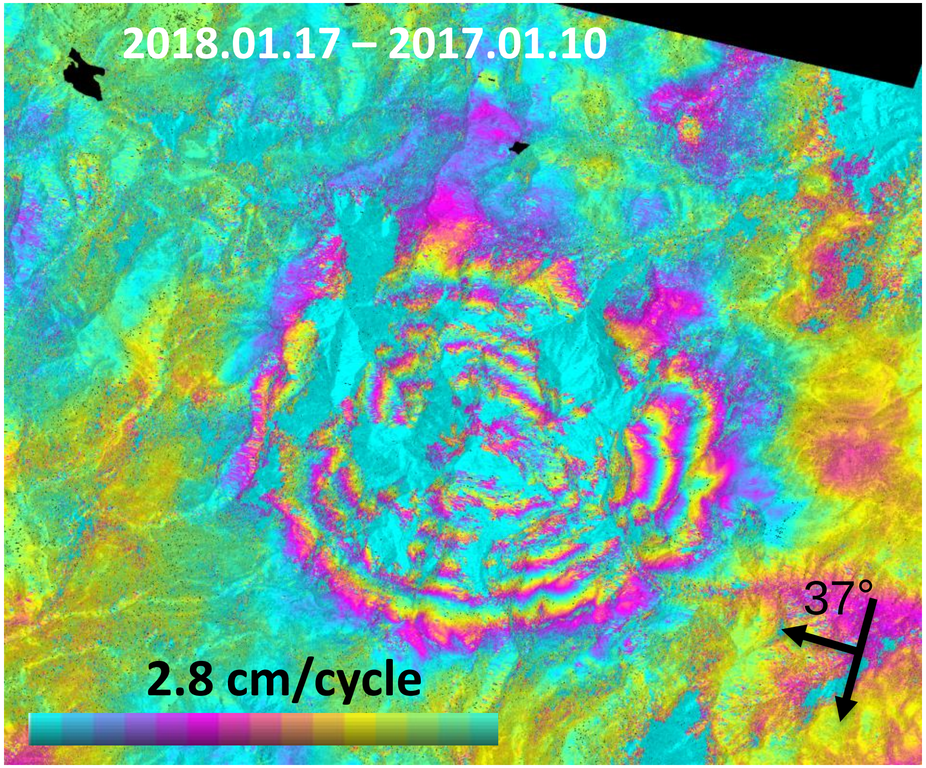

Latitude
Longitude
−36.4
−36.45
−36.5
−36.55
−36.6
−36.65
−36.7
−36.75
−70.65 −70.6 −70.55 −70.5 −70.45 −70.4 −70.35 −70.3 −70.25

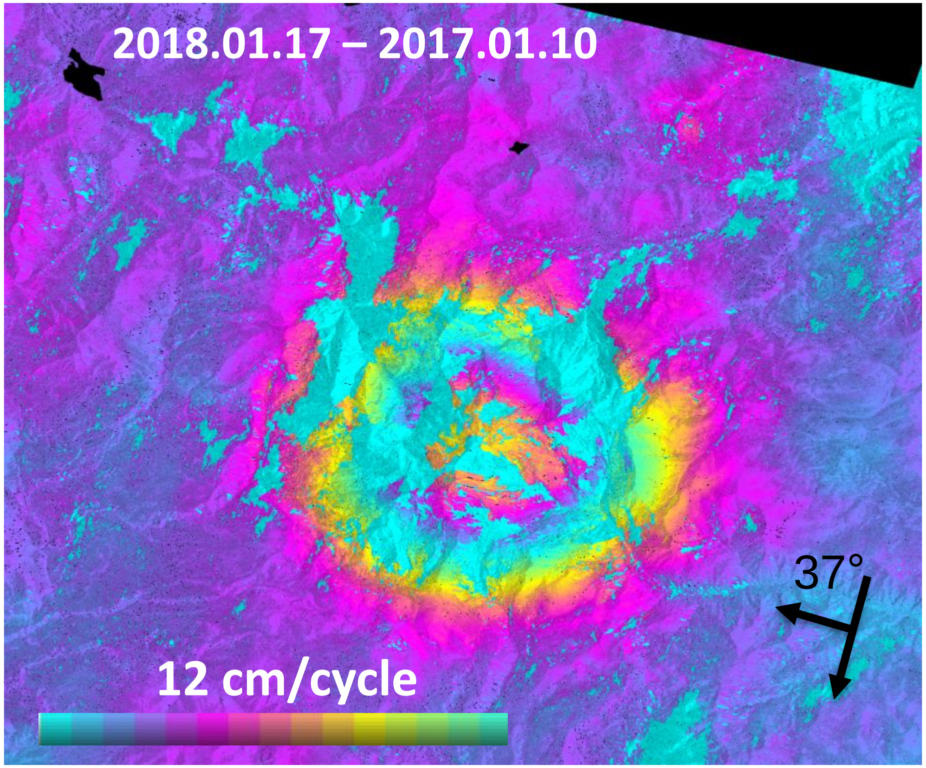

ALOS-2 A34
LOS displacement (cm)
year
50
40
30
20
10
0
−10
2015
2016
2017
2018
2019


24 cm/yr

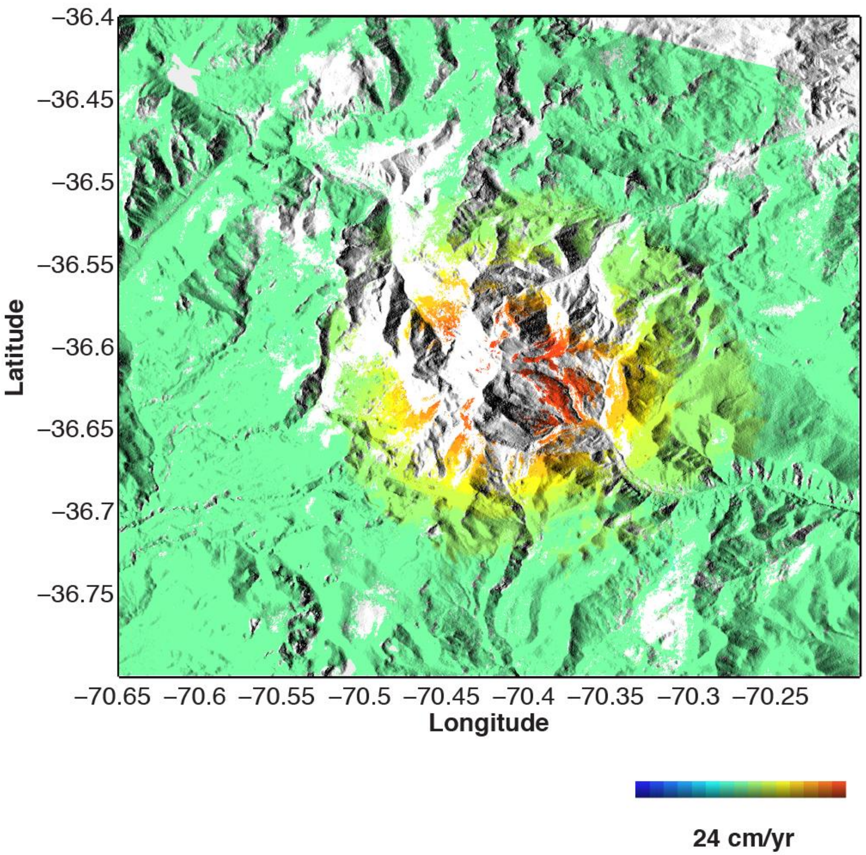
Sentinel-1 D83 1-year interferogram

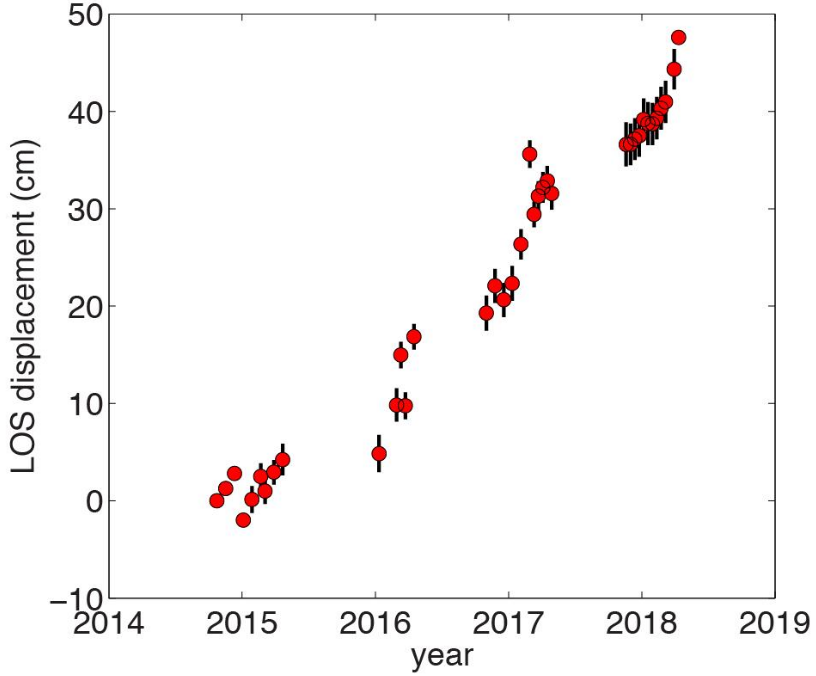
ARIA project performed a rapid response to request for data. Within a few days interferograms spanning 3 years confirmed the ALOS-2 results (special thanks to Hook Hua and Lan Dang at JPL)



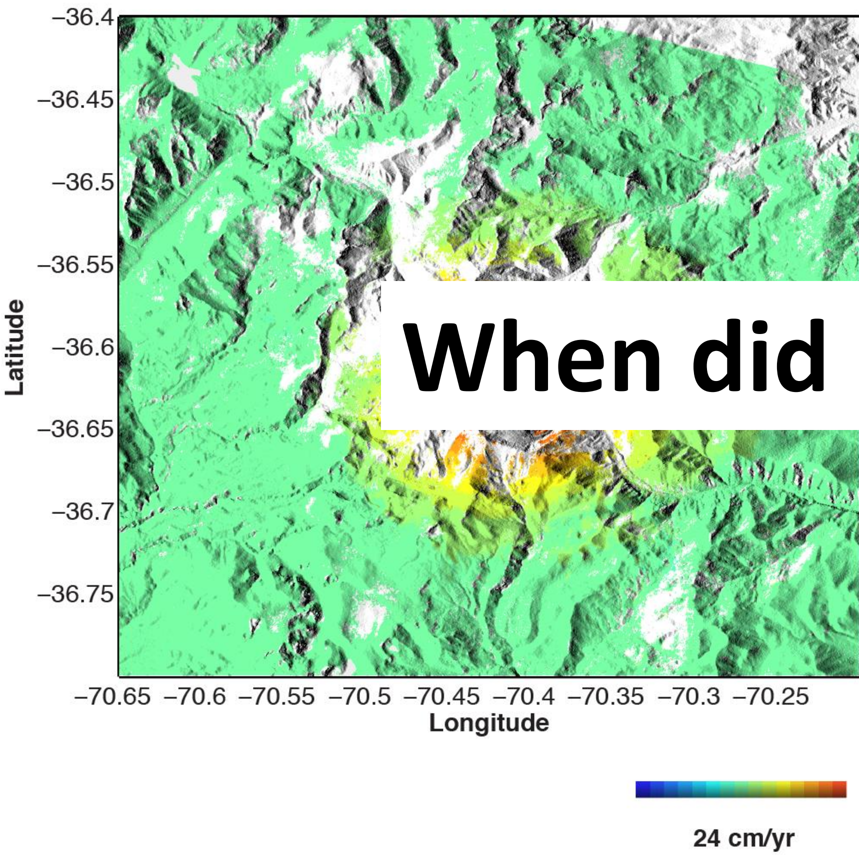


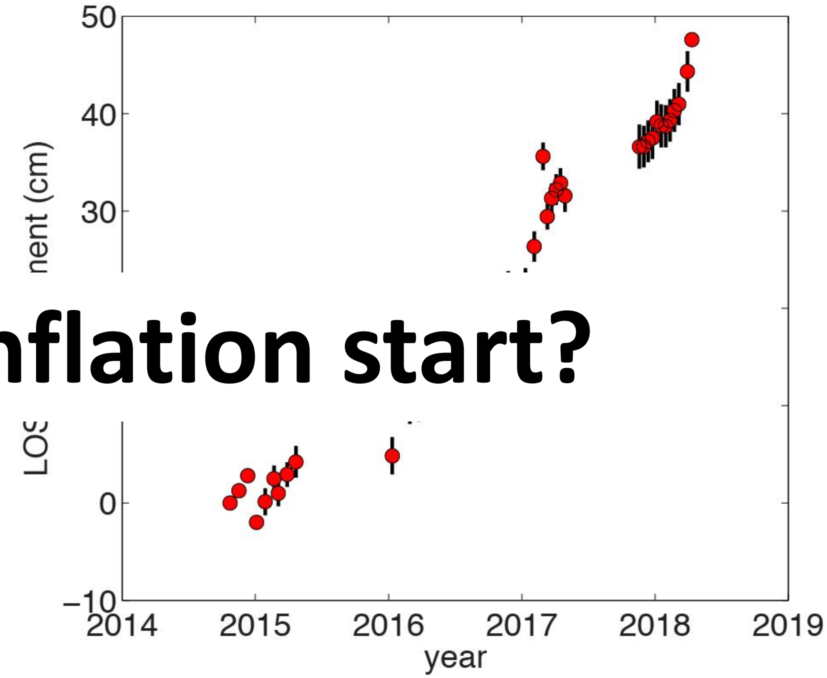
Sentinel-1 D83





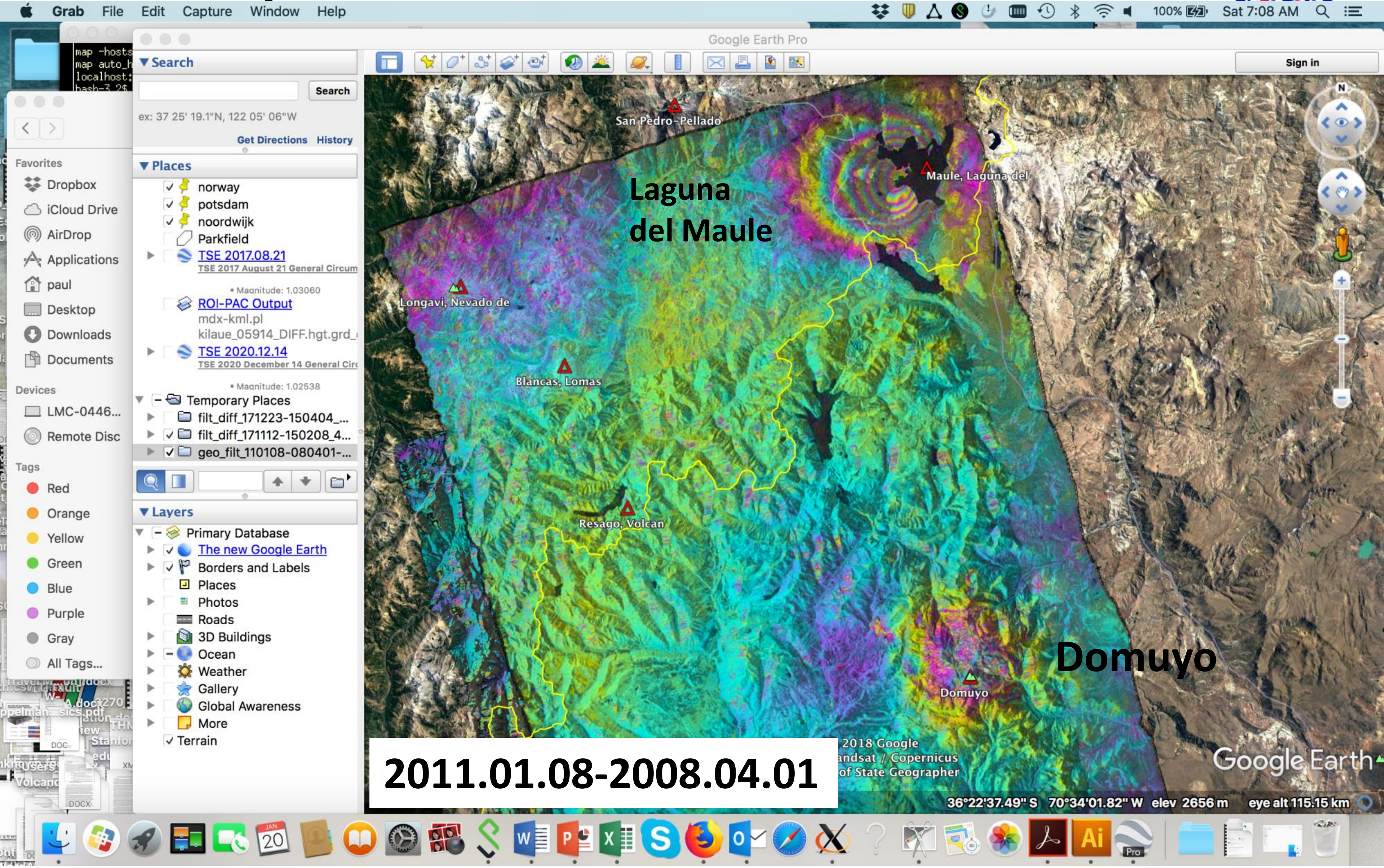
Sentinel-1 D83



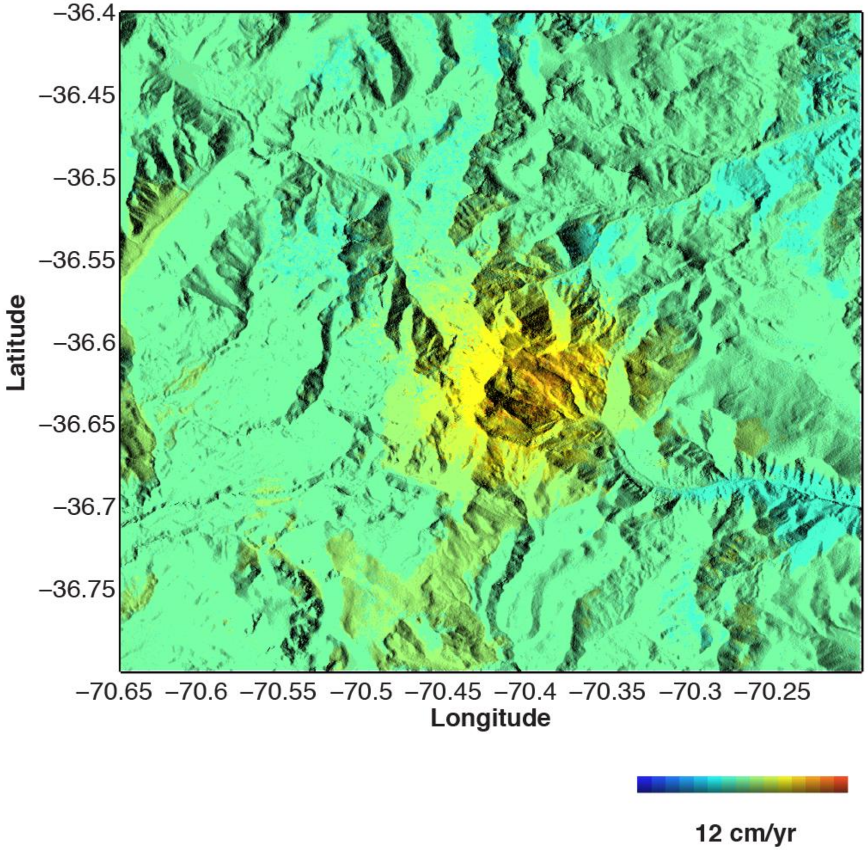


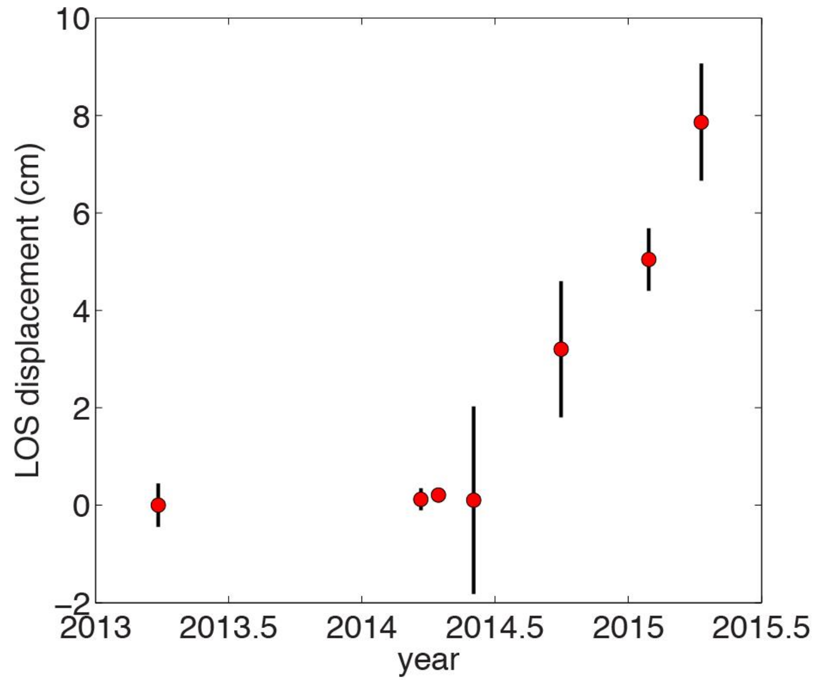
When did inflation start?

Domuyo: ALOS results 2008 - 2011



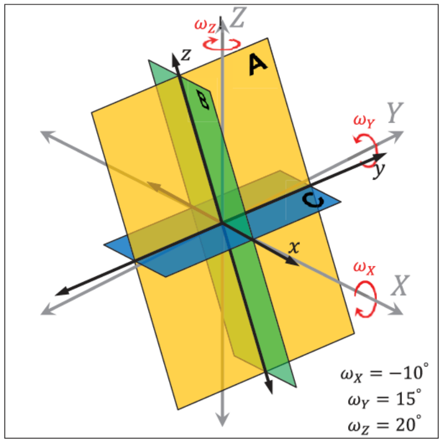
RADARSAT-2 F0W2





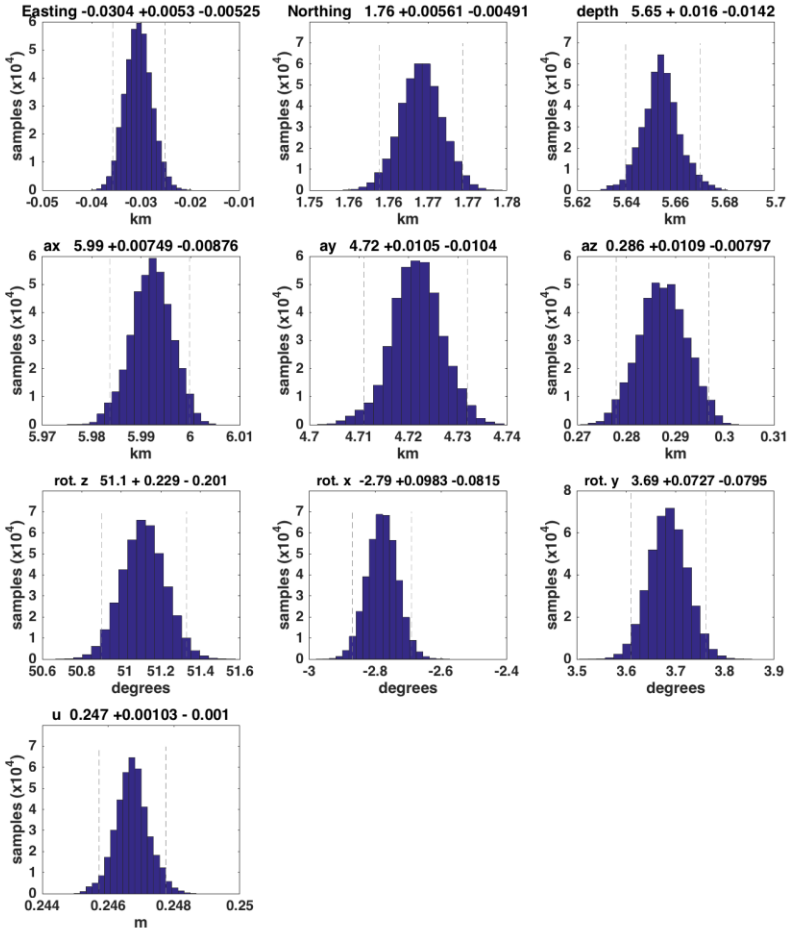
Domuyo preliminary model results

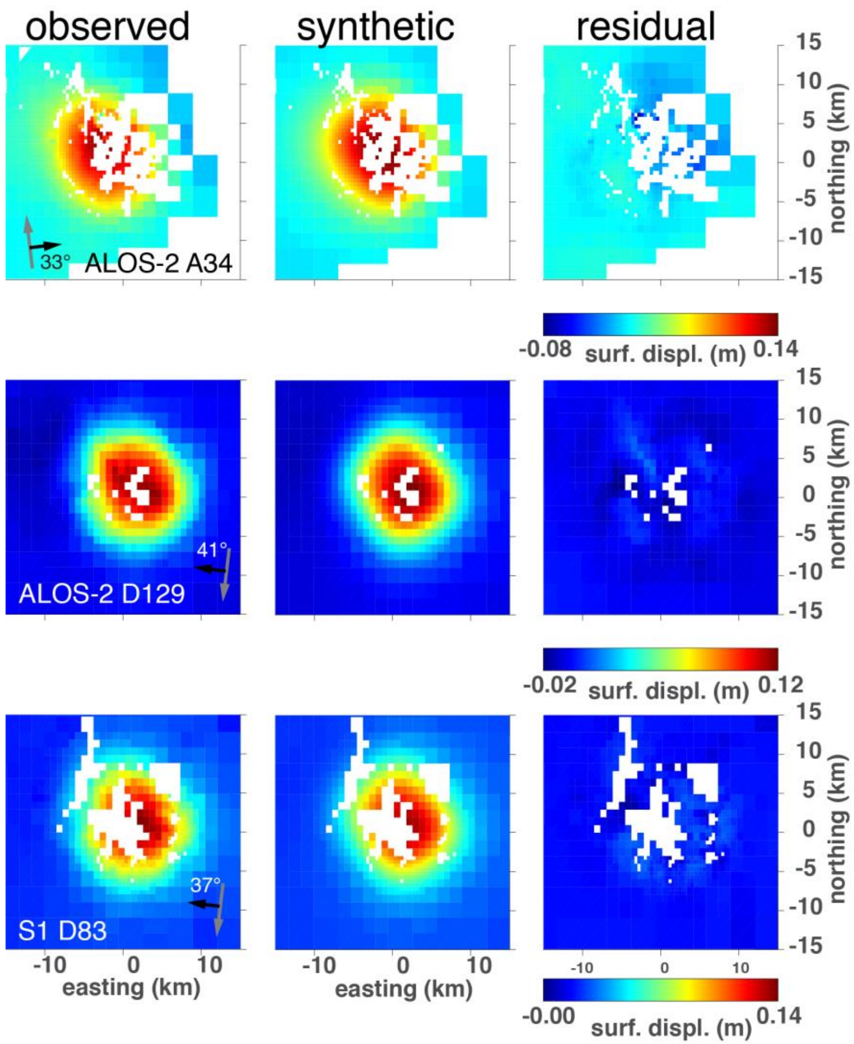
- Bayesian inference MCMC CDM source model solution
- Based on ALOS-2 and Sentinel-1 asc and desc TS linear rates

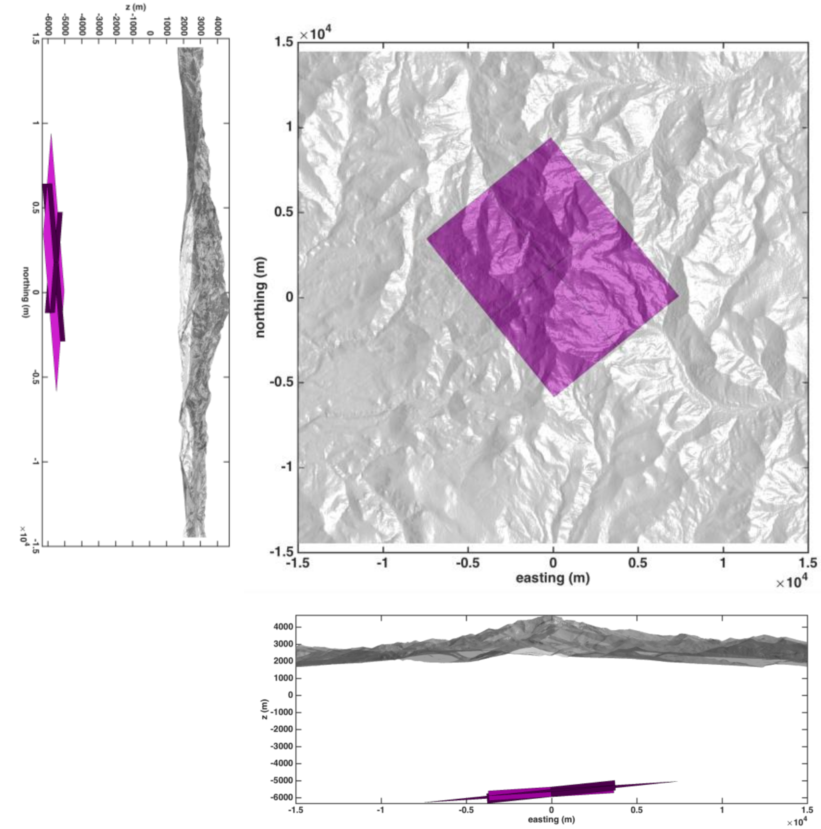


We model ellipsoidal cavity volume change of arbitrary geometry using the compound dislocation model (CDM) of Nikkhoo et al. (2017)

Source parameters are estimated using a Bayesian Markov chain Monte Carlo approach (e.g. Lundgren et al., 2017).

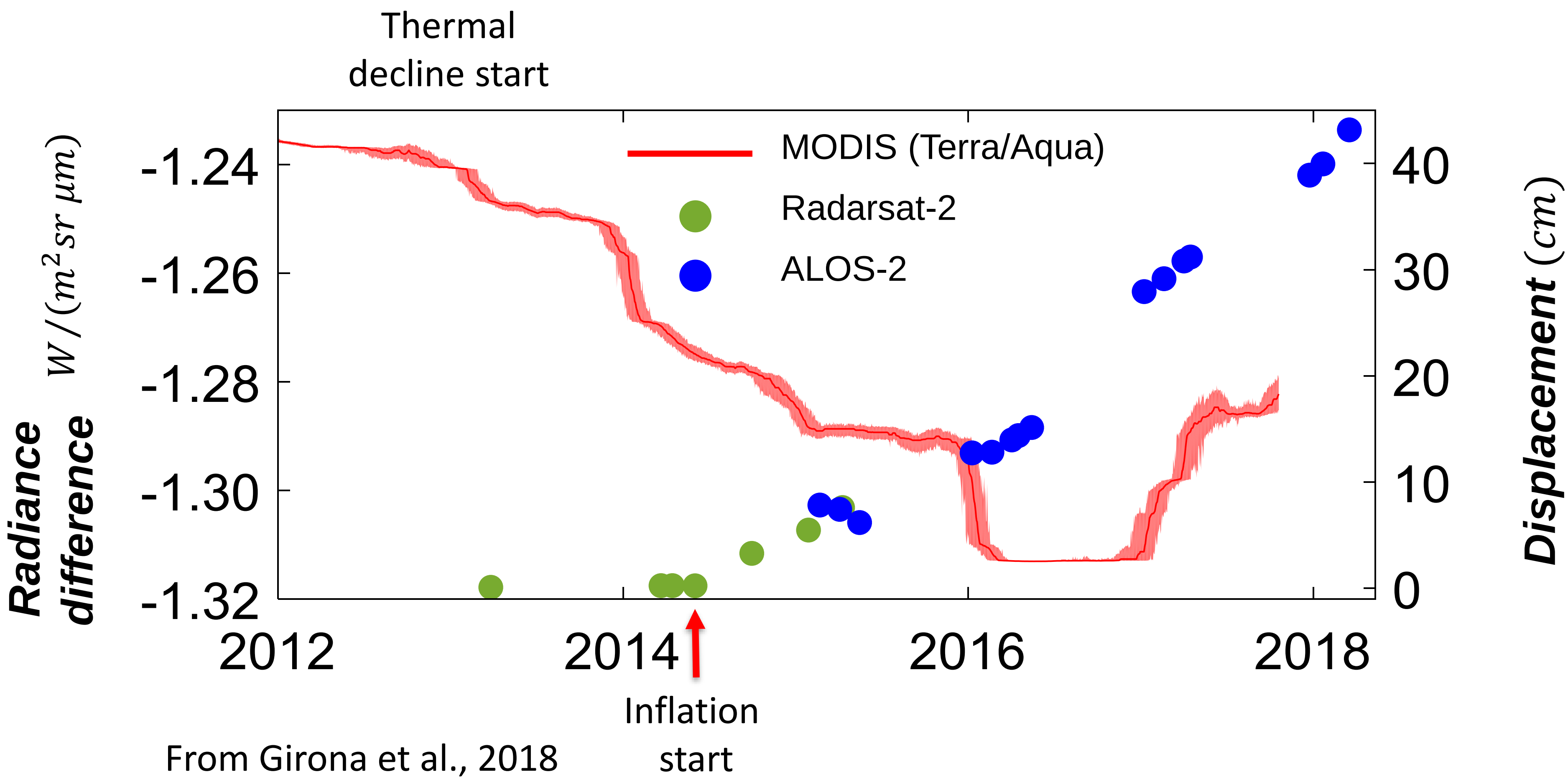






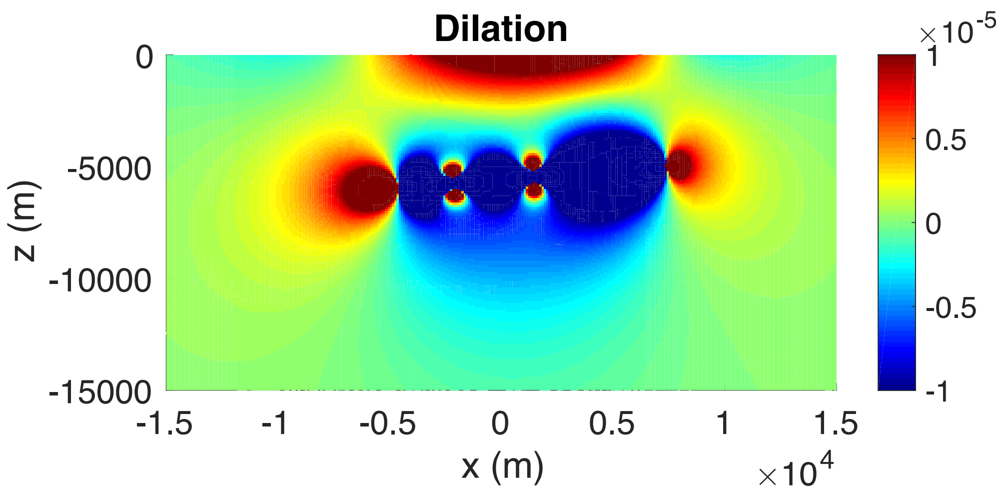
- CDM solution represents a near horizontal pancake-like ellipsoidal magma body
- Depth ~5.5 - 6 km , too deep for a hydrothermal system

Thermal time series



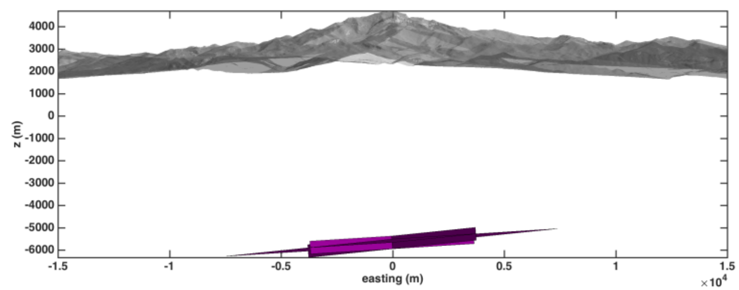
From Girona et al., 2018

Domuyo source inversion results



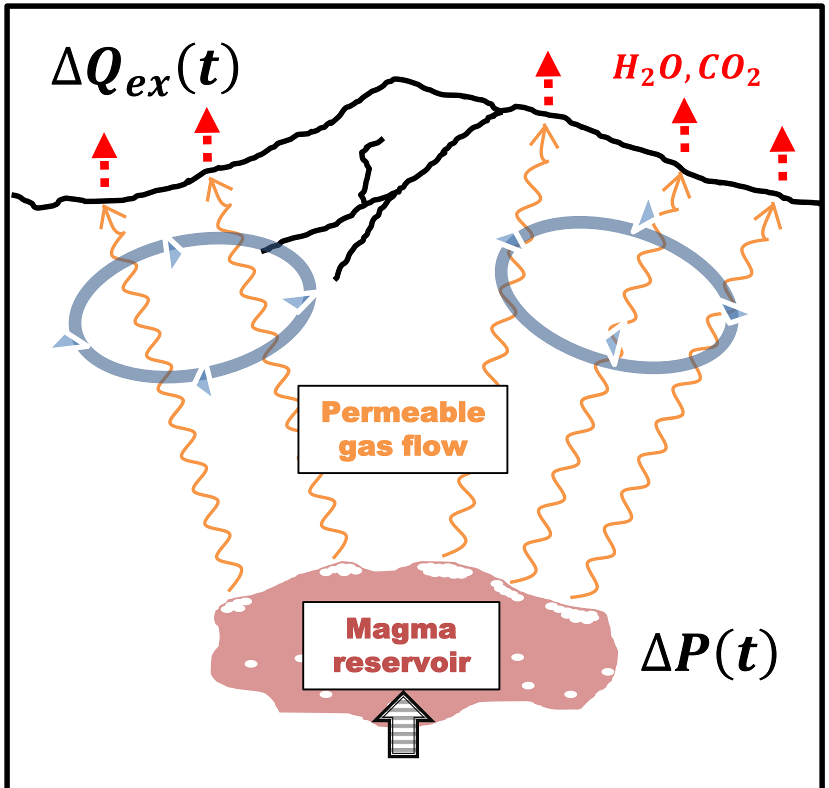
0

6 km



- Negative dilation immediately above the source might be expected to reduce fluid flux from magma body (e.g. Zhang et al., 2008)

What can explain the phase-shift between deformation-thermal time series?



HYPOTHESIS:

deformation ⟷ pressure
thermal evolution ⟷ outgassing

AIM:

Understand the pressure – outgassing coupling

PHYSICAL APPROACH/ASSUMPTIONS:

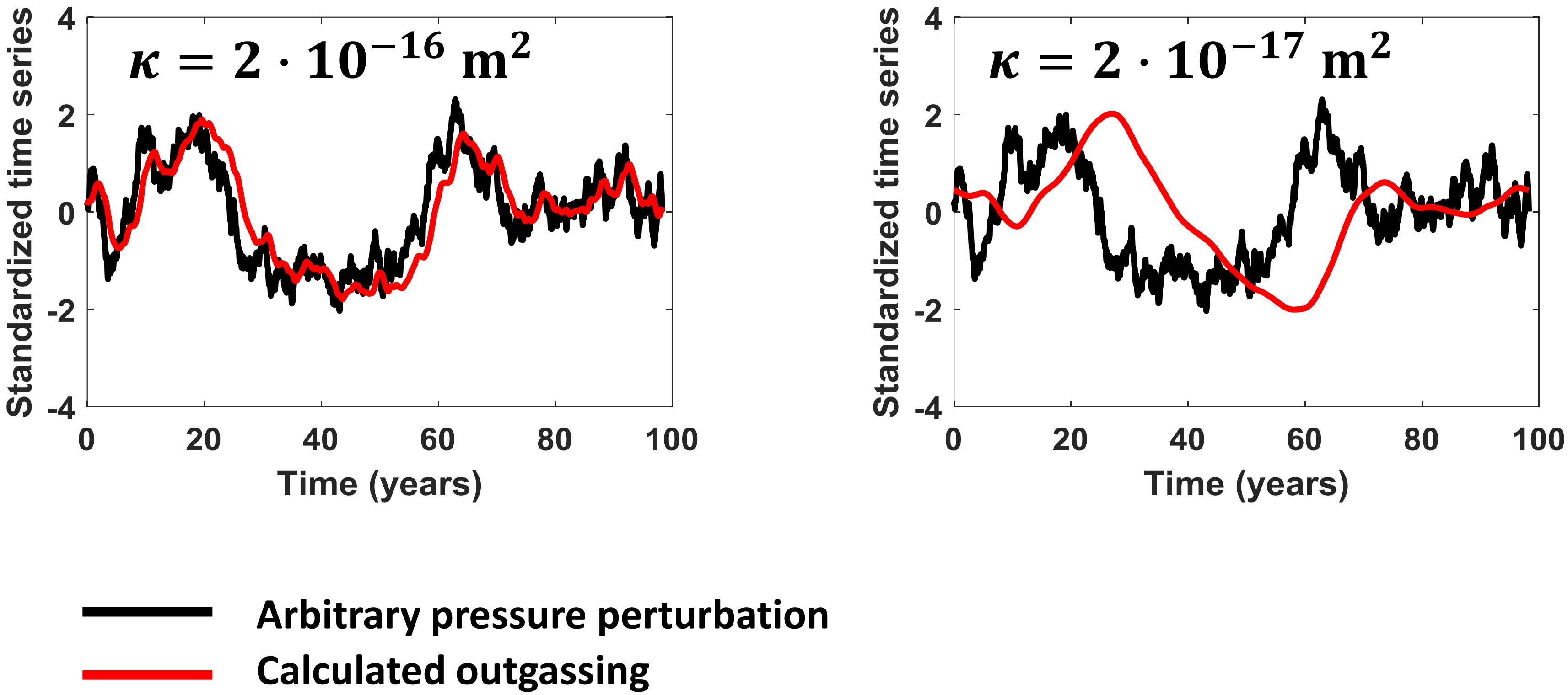
Linearized **momentum** and **mass** conservation equations + Ideal gas law + Infinite permeable medium approximation

FIRST-ORDER ANALYTICAL SOLUTION (IN FREQUENCY DOMAIN):

$$\mathcal{F}\{\Delta Q_{ex}(t)\} = \frac{\mathcal{F}\{\Delta P(t)\}}{\left[\frac{\beta_b + j\beta_c\omega}{\beta_a}\frac{\lambda_\omega - jk_\omega}{k_\omega^2 + \lambda_\omega^2} - \frac{\beta_d}{\beta_a}\right]\left(e^{\lambda_\omega L}e^{jk_\omega L} - 1\right)}$$

Model under development by Társilo Girona, JPL

The phase-shift between pressure-outgassing (deformation-thermal) is governed by the crustal permeability.



Summary

- **Domuyo Volcano** is another example of **abrupt** shallow crustal **inflation** from a volcano with **no historical eruption record**. Rapid, **12 cm/year inflation started by mid-2014** and is on-going.
- Source is sub-horizontal **tabular body at ~6 km** below the surface using an elastic half-space
- The **combination** of **geodetic** data and **long-wavelength thermal infrared** data can help to constrain the processes governing the evolution of volcanic calderas.
- Caldera breathing may be controlled by **the transfer of gases through the shallow crust**, which **produces spontaneous pressure oscillations in magma reservoirs**.
- The **phase shift** observed **in** the **geodetic-thermal time series** of Domuyo **may be consistent with gas-controlled breathing and low crust permeability**.
- **Long-term Inflation does not necessarily mean continuous magma ascent**.
- **Future work** includes to: solve numerically the full momentum equation (without linearizing and using the infinite permeable medium approximation); account for the crust viscoelasticity; incorporate thermal evolution of the magma reservoir; and link pressure and outgassing with deformation and thermal infrared emissions.

Acknowledgements: Thanks to JAXA for ALOS, and ALOS-2 data, ESA for Copernicus Sentinel-1 data, and CSA for RADARSAT-2 data