Modelling Ground Deformation Induced by Dome-Feeding Magma Conduits

Eliot Eaton[1], Jurgen Neuberg[1], Susanna Ebmeier[1], University of Leeds, UK
Contact email: ee16eme@leeds.ac.uk

UNIVERSITY OF LEEDS

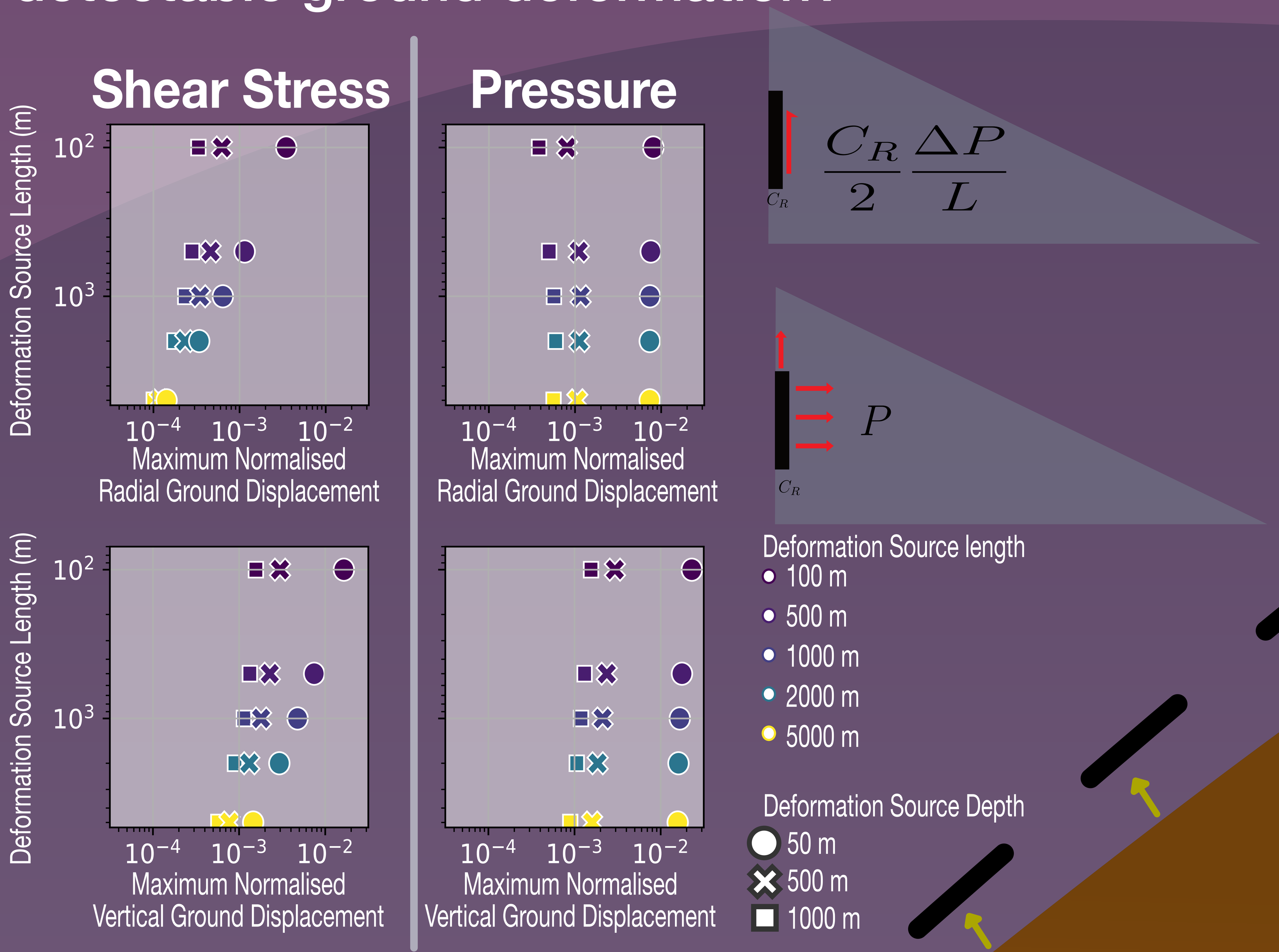
Why investigate ground deformation caused by a magma conduit?

During active volcanic crises at stratovolcanoes, multi-disciplinary monitoring often relies on near-conduit indicators of unrest that occur on the timescale of hours to days, e.g. increased seismicity, changes in gas emissions, or ground deformation [1,2].

Typically, deformation observed at the conduits of active volcanoes is small in magnitude, highly transient, and associated with gas expansion in the upper conduit acting as a localised pressure source, the ascent of highly viscous magma, or sliding along a magmatic fault [3,4]. Therefore, open-conduit processes typically require near-conduit, ground-based measurements for detection [5,6].

Here, we aim to establish the detectability of dome growth scenarios using COMSOL Multiphysics to model both magma ascent and the resulting ground deformation.

Which lava dome growth scenarios cause detectable ground deformation?

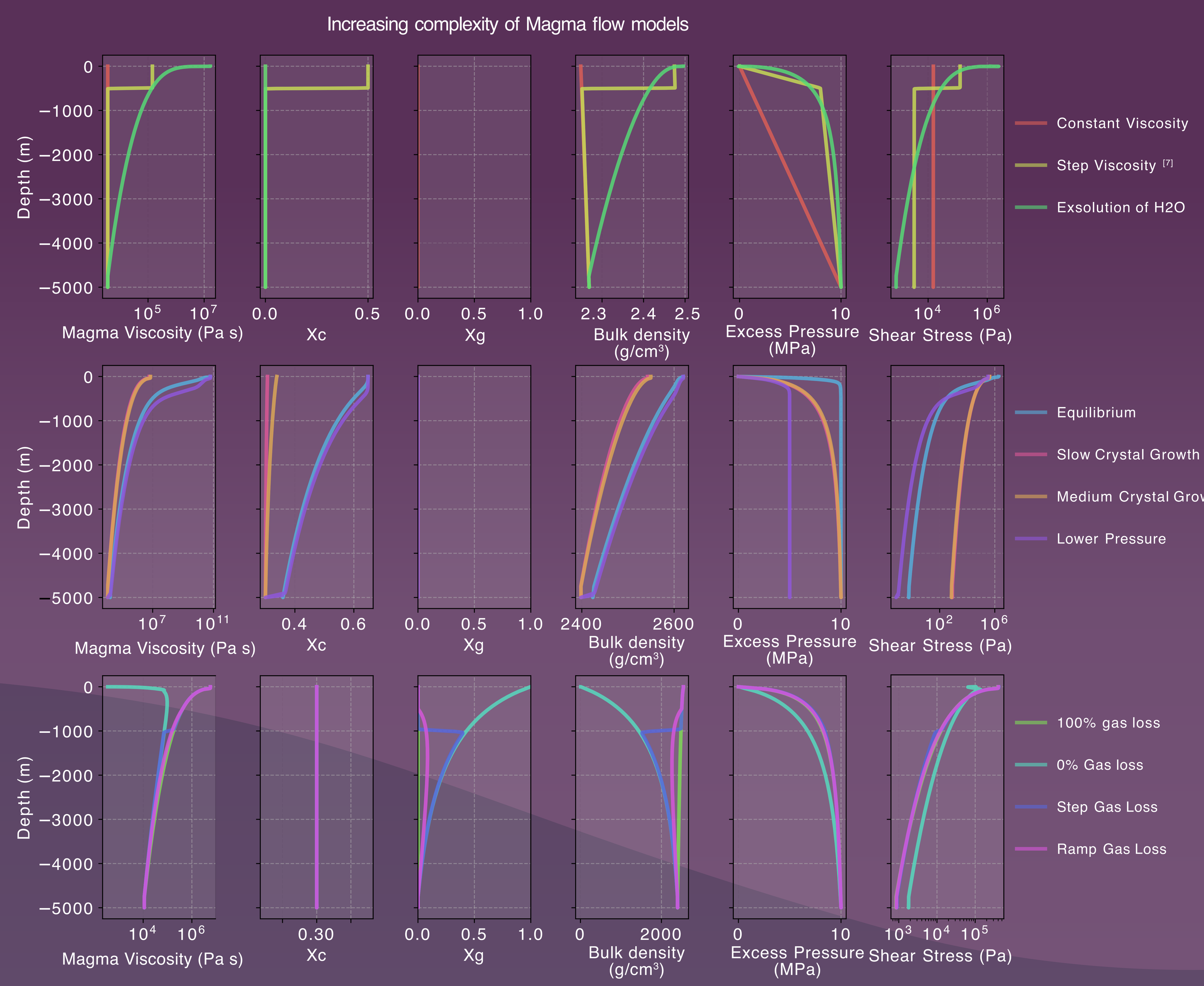


How is ground displacement normalised?

- Excess Pressure - 10 MPa
- Conduit Radius - 10 m
- Young's Modulus - 1e9

$$\frac{P_E C_R^2}{E}$$

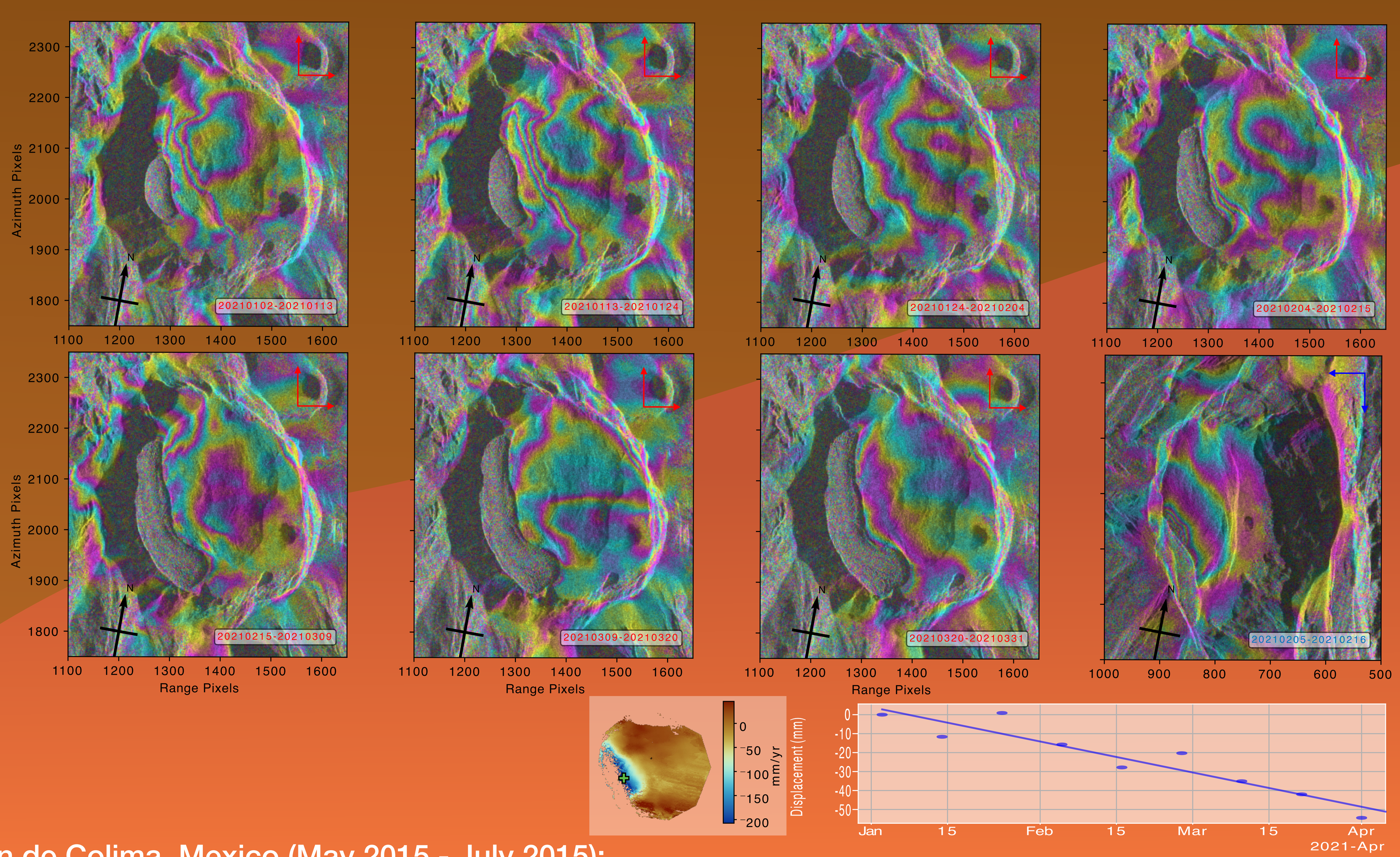
How can numerical models of magma ascent be used as a deformation source?



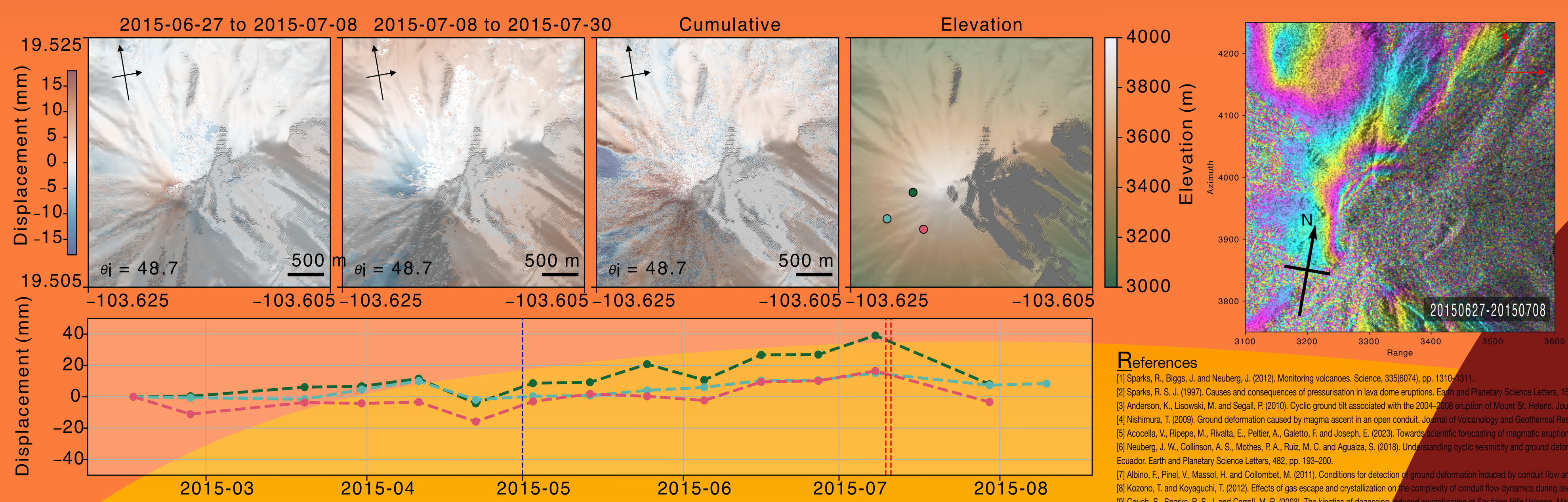
Next steps

Using high resolution InSAR to understand ground motion during lava dome growth episodes.

La Soufrière, St Vincent & the Grenadines (Dec 20 - March 21): Loading of new growing dome on the old dome



Volcán de Colima, Mexico (May 2015 - July 2015): Localised deformation during fast-growing lava dome growth prior to July 10th & 11th dome collapse



What goes into a magma flow model? [11,12]

How do crystals and bubbles affect magma viscosity? [14]

$$\eta_{magma} = \eta_{melt} \cdot \mu_{crystals} \cdot \mu_{bubbles}$$

Crystal volume fraction (Xc) during ascent

1. No crystal growth $X_c = X_{c,i}$

2. Intermediate case determined by the crystal growth rate constant [8] τ $X_c(X_{c,i}, \tau, \text{Pressure})$

3. Equilibrium crystal growth [9,13] $X_c(X_{c,i}, \text{Pressure})$ (Applying a fudge factor close to Xc = Xc,max)

Gas loss from the conduit using a sink term

Very efficient gas loss (e.g. no bubbles)

$$Q_{exsolved} = -\frac{\partial n^{H_2O}_{dissolved}}{\partial z} M_{H_2O} U_{av}(z)$$

Intermediate case

$$Q_{loss} = \frac{\partial\left((S_0 - 1)\ n^{H_2O}_{dissolved}\right)}{\partial z} M_{H_2O} U_{av}(z)$$

Inefficient gas loss (e.g. all exsolved gas remains in bubbles)

$$Q_{bubbles} = -\frac{\partial\left(S_0\ n^{H_2O}_{dissolved}\right)}{\partial z} M_{H_2O} U_{av}(z)$$

Exsolution of volatiles

Only modelling the exsolution of H_2O, using wt% in melt determined by the exsolution law of Zhang et al. (2007) [10]. η_{melt}(Pressure, Temperature, Composition)

Growth of bubbles due to decompression following the ideal gas law

Assumptions:

- Bubbles ascend on a similar timescale to the magma
- Isothermal ascent
- Magma behaves as a Newtonian fluid
- And more...!!

References

[1] Sparks, R., Biggs, J. and Neuberg, J. (2012). Monitoring volcanoes. Science, 335(6074), pp. 1310–1311.
[2] Sparks, R. S. J. (1997). Causes and consequences of pressurisation in lava dome eruptions. Earth and Planetary Science Letters, 150(3–4), pp. 177–189.
[3] Anderson, K., Lisowski, M. and Segall, P. (2010). Cyclic ground tilt associated with the 2004–2008 eruption of Mount St. Helens. Journal of Geophysical Research: Solid Earth, 115(B11).
[4] Nishimura, T. (2009). Ground deformation caused by magma ascent in an open conduit. Journal of Volcanology and Geothermal Research, 187(3–4), pp. 178–192.
[5] Acocella, V., Ripepe, M., Rivalta, E., Peltier, A., Galetto, F. and Joseph, E. (2023). Towards scientific forecasting of magmatic eruptions. Nature Reviews Earth & Environment, pp. 1–18.
[6] Neuberg, J. W., Collinson, A. S., Mothes, P. A., Ruiz, M. C. and Aguaiza, S. (2018). Understanding cyclic seismicity and ground deformation patterns at volcanoes: intriguing lessons from Tungurahua volcano, Ecuador. Earth and Planetary Science Letters, 482, pp. 193–200.
[7] Albino, F., Pinel, V., Massol, H. and Collombet, M. (2011). Conditions for detection of ground deformation induced by conduit flow and evolution. Journal of Geophysical Research: Solid Earth, 116(B6).
[8] Kozono, T. and Koyaguchi, T. (2012). Effects of gas escape and crystallization on the complexity of conduit flow dynamics during lava dome eruptions. Journal of Geophysical Research: Solid Earth, 117(B8).
[9] Couch, S., Sparks, R. S. J. and Carroll, M. R. (2003). The kinetics of degassing-induced crystallization at Soufrière Hills Volcano, Montserrat. Journal of Petrology, 44(8), pp. 1477–1502.
[10] Zhang, Y., Xu, Z., Zhu, M. and Wang, H., 2007. Silicate melt properties and volcanic eruptions. Reviews of Geophysics, 45(4).
[13] Melnik, O. and Sparks, R. (2005). Controls on conduit magma flow dynamics during lava dome building eruptions. Journal of Geophysical Research: Solid Earth, 110(B2).
[11] Thomas, M. E. and Neuberg, J. (2012). What makes a volcano tick—a first explanation of deep multiple seismic sources in ascending magma. Geology, 40(4), pp. 351–354.
[12] Marsden, L. H., Neuberg, J. W., Thomas, M. E., Mothes, P. A. and Ruiz, M. C. (2019b). Combining magma flow and deformation modeling to explain observed changes in tilt. Frontiers in Earth Science, 7, p. 219.
[13] Melnik, O. and Sparks, R. (2005). Controls on conduit magma flow dynamics during lava dome building eruptions. Journal of Geophysical Research: Solid Earth, 110(B2).
[14] Hess, K.U. and Dingwell, D.D., 1996. Viscosities of hydrous leucogranitic melts: A non-Arrhenian model. American Mineralogist, 81(9-10), pp.1297-1300.

UKRI Natural Environment Research Council
PANORAMA