InSAR Observations of Long-Term Extension in the Build-Up to the January 2017 Eruption of Erta ‘Ale volcano, Afar, Ethiopia.

Chris Moore[1] | Tim Wright[1] | Andy Hooper[1] | Juliet Biggs[2]

1 - School of Earth and Environment, University of Leeds | 2 - School of Earth Sciences, University of Bristol

1. Introduction

The Afar region lies over the triple junction of the Red Sea Rift (RSR), the Main Ethiopian Rift (MER), and the Gulf of Aden (GoA) (Figure 1).

The Erta ‘Ale volcanic ridge segment in northern Afar represents the on-land portion of the RSR, gradually accommodating the full spreading rate of ~ 2 cm/yr.

The Erta ‘Ale ridge is highly active with ground deformation recorded in 1993-1996 at Gada ‘Ale (Amelung et al., 2000), 2004 at Dallol (Nobile et al., 2012), 2004-2005 at Erta ‘Ale (Barnie et al., 2016) and 2008 at Alu-Dalafilla (Pagli et al., 2012).

Erta ‘Ale is a basaltic shield volcano with a summit caldera which has hosted an active lava lake for > 90 years (Barberi and Varet, 1970).

Previously recorded eruptions at Erta ‘Ale include small lava lake overflows, contained within the caldera walls (Feild et al., 2012).

On January 21st 2017 Erta ‘Ale erupted with a large flank intrusion producing large ground deformation and extensive lava flows that remain active to present, ~ 18 months later.

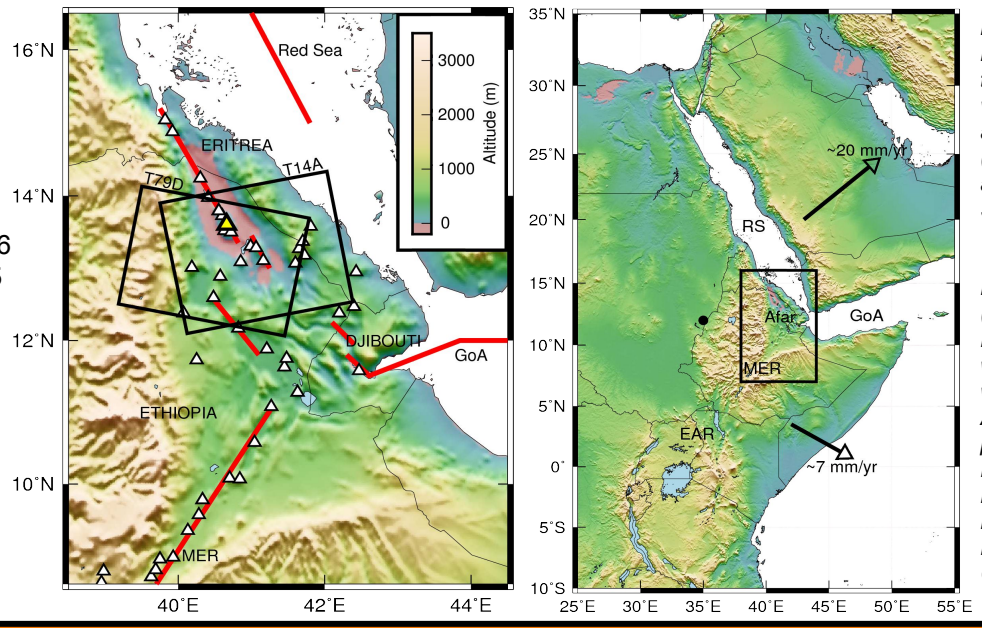


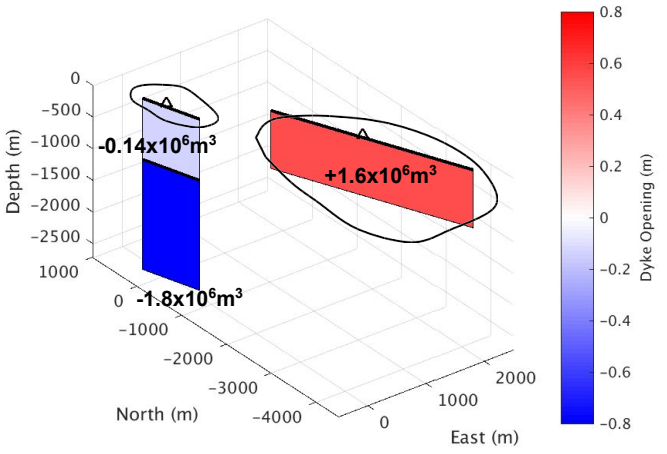
Figure 1. *Left - Topography of the Afar region with volcanoes (triangles), and ridge segments (red lines) identifies as well as Sentinel-1 SAR coverage (tracks 14 (ascending), and 79 (descending)) over Erta ‘Ale volcano (yellow triangle). Right - Map of the wider rift system in with velocities of the Arabian and Somalian plates relative to the Nubian plate. EAR - East African Rift, MER - Main Ethiopian Rift, RS - Red Sea, GoA - Gulf of Aden.*

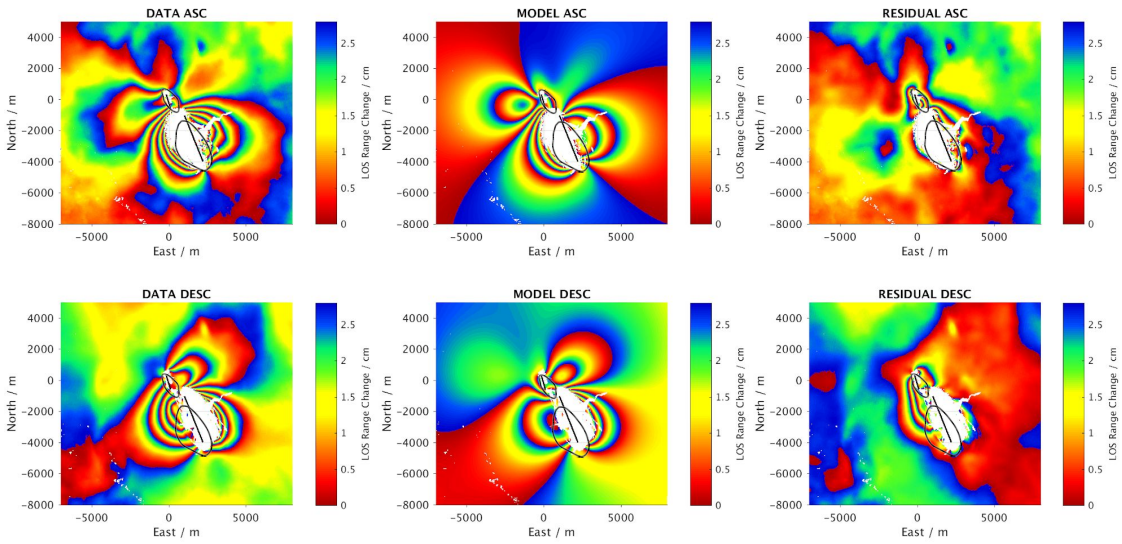
2. Jan 2017 Eruption | Deformation Modelling

There is large deformation associated with the Jan 21st 2017 intrusion with extension of ~ 45 cm, with ~ 5 cm uplift, around the flank eruption site, and ~ 12 cm of contraction, with ~ 7 cm subsidence, around the lava lake (Figure 3).

We model this using GBIS (Geodetic Bayesian Inversion Software) (Bagnardi and Hooper, 2018), with 2 dykes, one below the lava lake being split into two sections, and one below the eruption site (Figure 2).

Figure 2. *Below - Wrapped Sentinel-1 syn-eruption ascending (top) and descending (bottom) interferograms, with GBIS model, and residual with model parameters. Right - 3D visualisation of model dykes with volumes.*





TRID_model	
d1 x	-30.7
d1 y	-145
d2 x	-30.7
d2 y	-145
d3 x	1610
d3 y	-2510
d1 length	965
d2 length	965
d3 length	3200
d1 width	965
d2 width	1740
d3 width	915
d1 depth	10.9
d2 depth	975.9
d3 depth	3.55
d1 opening	-0.14
d2 opening	-1.08
d3 opening	0.558
d1 strike	344
d2 strike	344
d3 strike	338
dip	-89.99
RMSE ASC	1.031
RMSE DESC	0.89472
RMSE MEAN	0.96288

3. 3D Deformation Maps

We can resolve true deformation in the vertical and ridge-perpendicular horizontal using the ascending and descending line of sight observations due to the different look geometries.

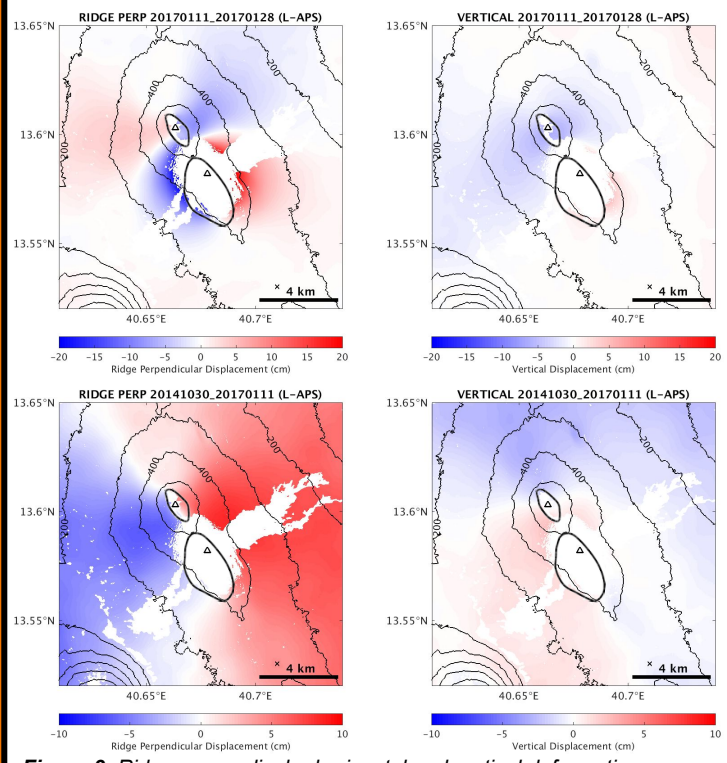


Figure 3. *Ridge perpendicular horizontal and vertical deformation maps for syn-eruption (top) and pre-eruption (bottom) periods.*

4. Pre-eruption Extension | InSAR Time Series

We use the whole catalogue of Sentinel-1 observations at Erta ‘Ale to create a time series of deformation from October 2014 to March 2018 (a gap in ascending data immediately after the eruption means any post-eruption trends are currently hard to resolve).

By correcting for atmospheric errors and filtering a local non-deforming region, we can estimate the variance of each time series step as equal to the mean of the residuals in this region, which we then use in the full time series inversion to give error estimates.

Figure 4 shows the maximum ridge-perpendicular horizontal deformation at Erta ‘Ale with a gradual, consistent build-up of extension at ~ 6 cm/yr to ~ 16 cm in the > 2 years before the eruption (~ 3 x higher than plate spreading rate).

By modelling the total pre-eruption deformation for a single dyke using GBIS, we can invert the pre-eruption time series for step dyke opening (Figure 4 inset), which reaches a maximum of ~ 0.25 m (volume roughly equivalent to the syn-eruption dykes of ~ 10^6 m^3).

These long term trends at Erta ‘Ale have not previously been observed and may give insight into the shallow magma storage on the ridge.

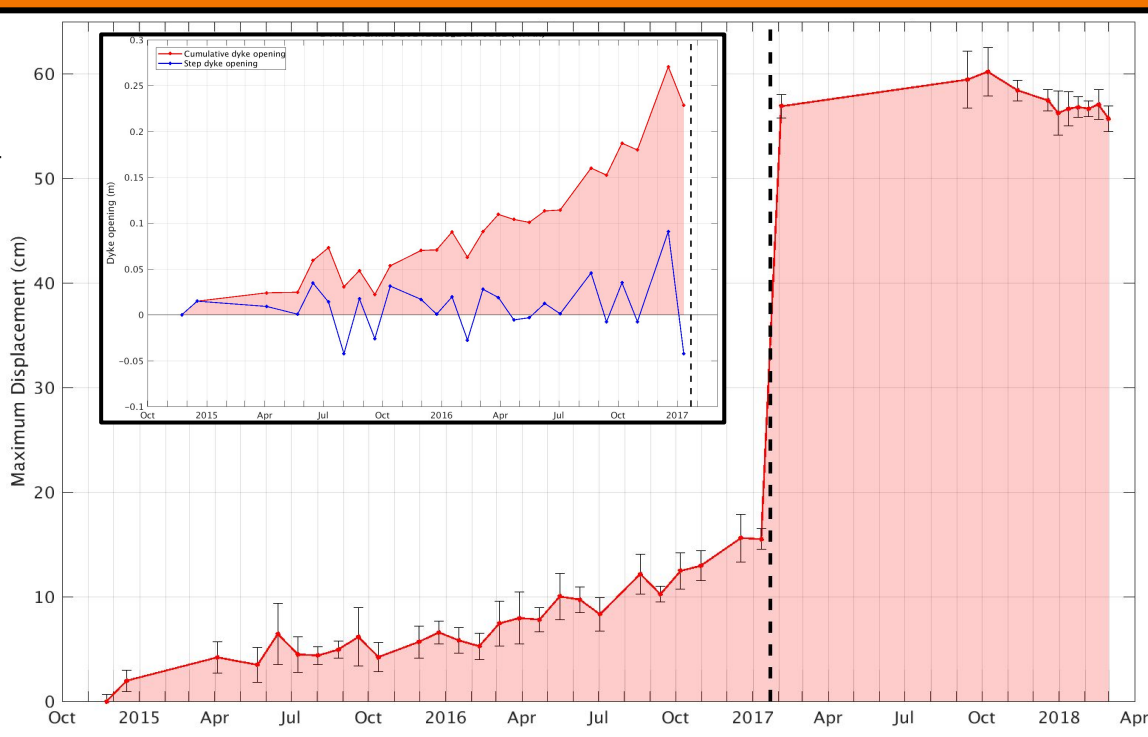


Figure 4. *Main - Maximum ridge perpendicular deformation time series for all Sentinel-1 observations, with errors calculated from variance of a local non-deforming area. Inset - Pre-eruption cumulative (red) and step (blue) dyke opening time series for a fixed dyke geometry found from modelling total pre-eruption deformation.*

5. Summary

Erta ‘Ale volcano lies on the Erta ‘Ale ridge in northern Afar, which represents the on-land portion of the RSR and is characterised by highly active basaltic volcanism.

In Jan 2017 a dyke intrusion erupted on the south flank of the volcano producing large amounts of surface deformation, previously unobserved at Erta ‘Ale volcano, which can be modelled using 2 dykes.

Time series analysis of Sentinel-1 InSAR observations show a long-term gradual build-up of extension over the ridge axis in the > 2 years previous to the eruption, associated with the slow opening of a dyke of similar geometry to one observed at Erta ‘Ale in 2004-2005 (Barnie et al., 2016).

References

Amelung, F., Oppenheimer, C., Segall, P. and Zebker, H., 2000. Ground deformation near Gada ‘Ale volcano, Afar, observed by radar interferometry. Geophysical Research Letters, 27, 19, 3093–3096.

Bagnardi, M. and Hooper, A., 2018. Inversion of surface deformation data for rapid estimates of source parameters and uncertainties: A Bayesian approach. Geochemistry, Geophysics, Geosystems.

Barberi, F. and Varet, J., 1970. The Erta Ale volcanic range (Danakil depression, northern afar, ethiopia). Bulletin Volcanologique, 34, 4, 848–917.

Barnie, T. D., Oppenheimer, C. and Pagli, C., 2016. Does the lava lake of Erta Ale volcano respond to regional magmatic and tectonic events? An investigation using Earth Observation data. Geological Society, London, Special Publications, 420, 181–208.

Field, L., Barnie, T., Blundy, J., Brooker, R. A., Keir, D., Lewi, E. and Saunders, K., 2012. Integrated field, satellite and petrological observations of the November 2010 eruption of Erta Ale. Bulletin of Volcanology, 74, 2251–2271.

Nobile, A., Pagli, C., Keir, D., Wright, T. J., Ayele, A., Ruch, J. and Acocella, V., 2012. Dike-fault interaction during the 2004 Dallol intrusion at the northern edge of the Erta Ale Ridge (Afar, Ethiopia). Geophysical Research Letters, 39, L19305.

Pagli, C., Wright, T. J., Ebinger, C. J., Yun, S. H., Cann, J. R., Barnie, T. and Ayele, A., 2012. Shallow axial magma chamber at the slow-spreading Erta Ale Ridge. Nature Geoscience, 5, 4, 284–288.