What's Causing Asymmetric Deformation at Tungurahua Volcano, Ecuador?

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1. Motivation

Background:

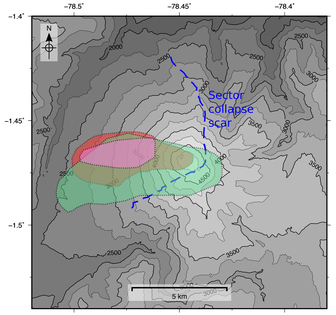
- Steep stratovolcano in Ecuadorian Andes; persistently active since 1999.
- Historic collapses of west flank; most recent 3000 ka.
- Highest volcano deformation rates observed within collapse scar from 3000 ka event.

Questions:

- What is causing the asymmetric deformation?
- How does asymmetric deformation relate to flank collapse hazard?

2. History of Asymmetry

Highly asymmetric surface deformation footprints.



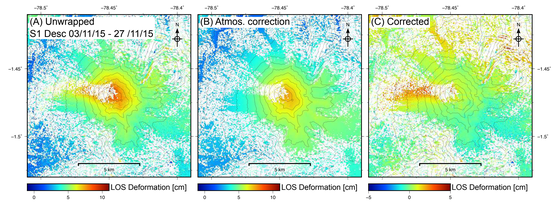
Green (2007 - 2008): Fournier et al., 2010, G[3]

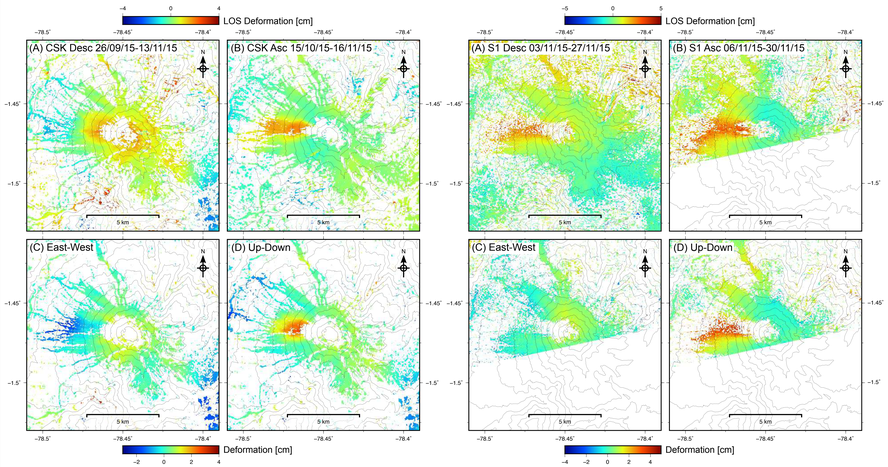
Pink (2007 - 2011): Morales-Rivera et al., 2016, G[3]

Red (2007-2008): Biggs et al., 2010, GRL

3. Nov 2015 Flank Deformation

- November 2015 deformation event detected with CSK (asc. & desc.), Sentinel-1 (asc. & desc.) & ALOS-2 (desc.; *not shown*) satellites.
- Individual interferograms corrected for atmospheric effects using TRAIN (Bekaert et al., 2015c) → example (right) for Sentinel-1.
- Consistent LOS uplift on W flank: ~ 3-4 cm.





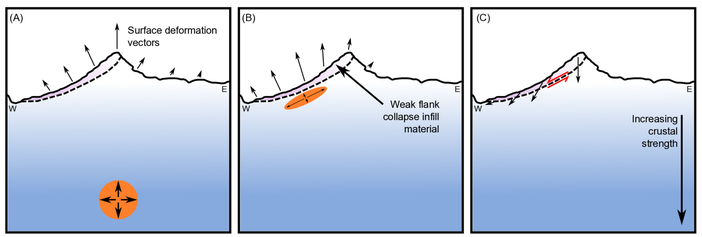
- Asc. & desc. viewing angles used to calculate east-west & up-down deformation maps.
- Majority of LOS uplift explained by vertical deformation.
- East-west deformation considered to be negligible.

4. Conceptual Models

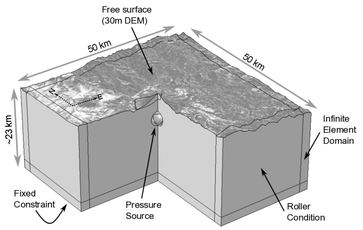
Possible mechanisms to produce asymmetric deformation:

(A): Asymmetric material properties.
(B): Asymmetric / inclined intrusion.
(C): Localised fault slip

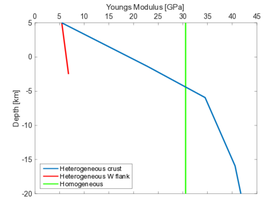
+ combinations of the 3…

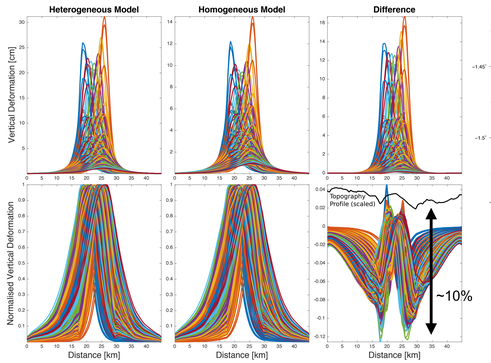


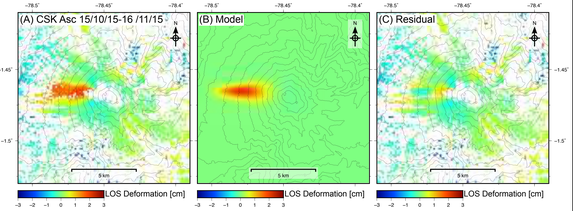
5. FE Model Results



- 3D Finite Element Models with COMSOL Multiphysics.
- Material properties informed by seismic V_P study; shown →
- West flank has separate model domain with individual material properties.
- Test mechanisms A & B.

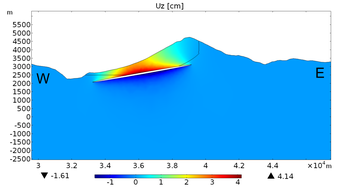






- Observed deformation pattern requires narrow & (likely) dipping deformation source.
- Cigar-shaped sources & high-aspect-ratio-sills tested.
- Model results displayed (above & below) are for current best-fit result: inclined sill shape source beneath W flank.

- Deformation X-sections (N-S) through W flank.
- Homogeneous & heterogeneous models compared with 294 different source combinations.
- Normalised comparison only shows ~10% difference in profile shape around W flank → not significant compared to observed signals.



- Other model results show that topography causes slight asymmetry in deformation footprint; small magnitude compared to observed signals.

6. Take-Home Messages

- Vertical uplift & negligible westward motion indicate a fault-slip mechanism (C) is unlikely.
- Asymmetric flank material properties (mechanism A) can not explain the full magnitude & spatial footprint of observed west flank deformation; neither can topography.
- West flank deformation likely to be caused by asymmetric / inclined magmatic intrusion / pathway (mechanism B).
- Inclined magma pressurisation presents greatest threat for flank collapse / lateral blast hazard.