Active deformation of the Los Humeros caldera floor inferred from Envisat and Sentinel-1 InSAR

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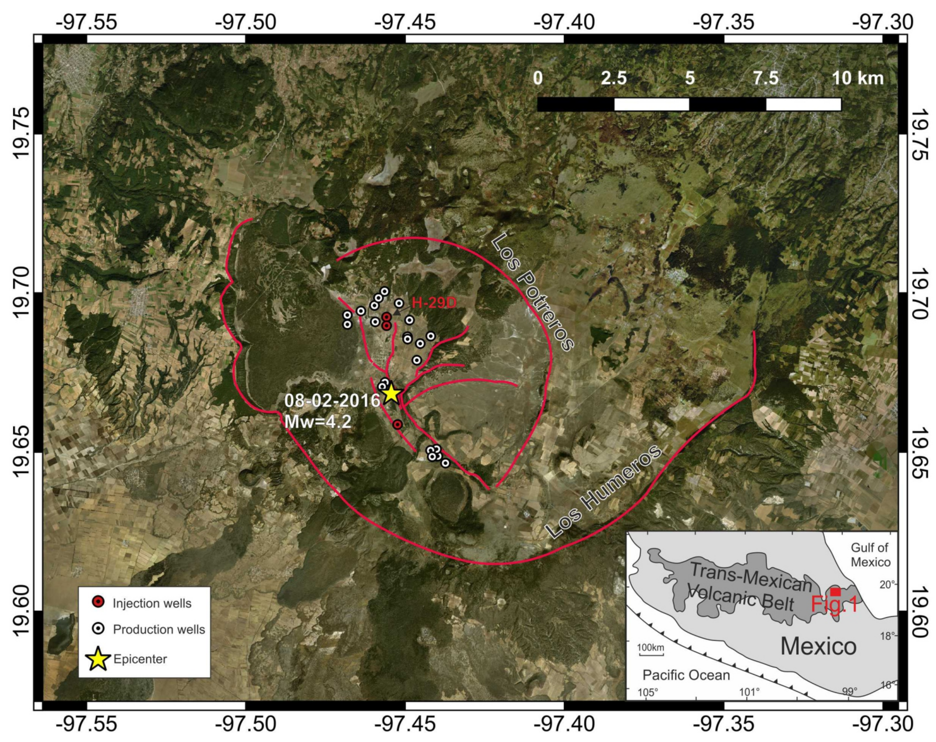
Introduction

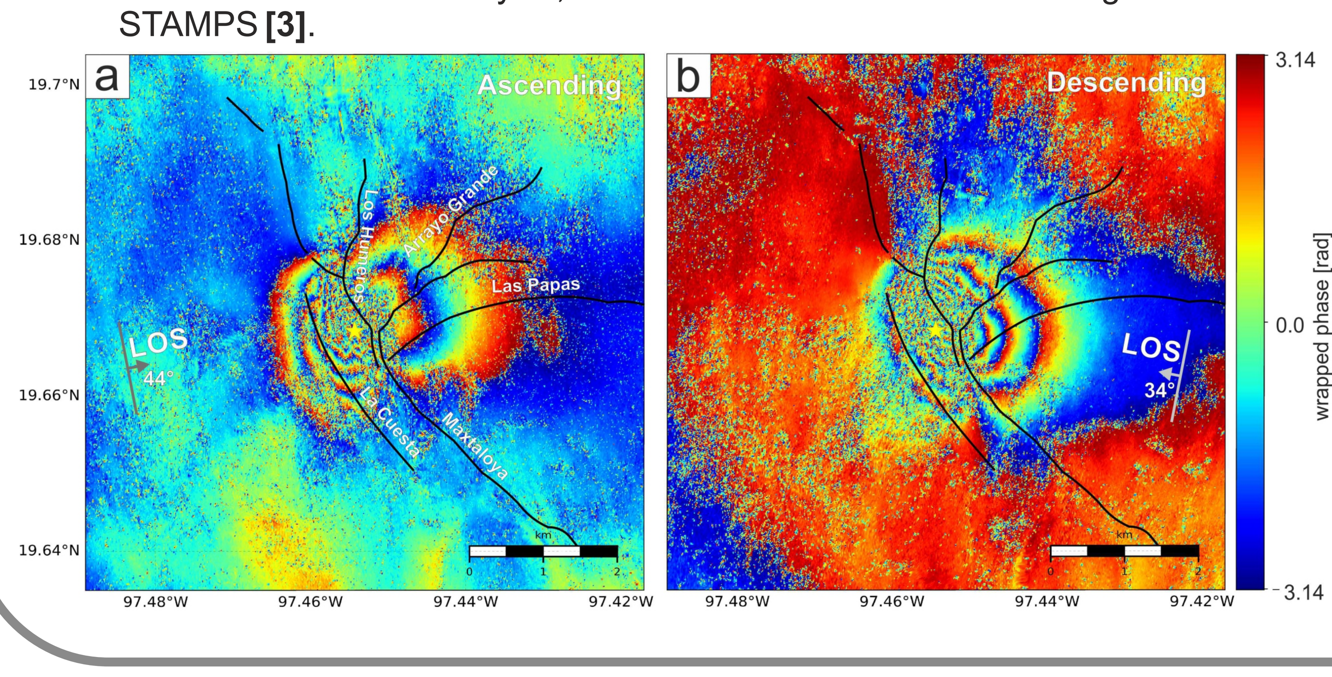
- We estimate ground motions at the Los Humeros Geothermal Field, Mexico by Envisat and Sentinel-1 interferometry to infer for reservoir processes and properties.
- We map and model the long-term deformation between 2003-2007 and 2015-2019 by Persistent Scatterer Interferometry (PSI).
- We investigate the coseismic deformation due to the 8 February 2016, Mw=4.2 earthquake that occurred seven days after a sharp increase in the injection rate in the H-29D well.
- The focal mechanism solution by **[1]** shows a reverse movement with a minor left-lateral component: Mw=4.2, depth=1500m, strike=169°, dip=61°, rake=42°.
- We apply elastic dislocation models on a rectangle with uniform slip to reproduce the coseismic deformation pattern. We test singel fault inverse models and also a more complex fault geometry with a segmented fault.



Major faults, caldera rims, and the location of the wells at the Los Humeros Geothermal Field. The yellow star indicates the epicentre of the 8 February 2016, Mw 4.2 earthquake after [1].

InSAR data processing

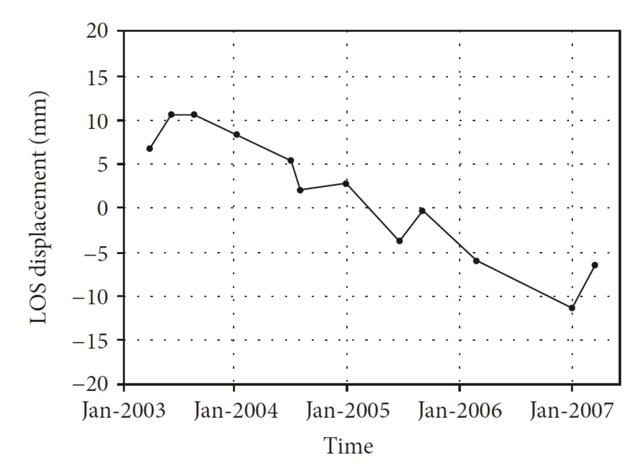
- We performed PSI time series analysis of 13 Envisat images between April 2003 and March 2007, and 20 Sentinel-1 images between February 2016 and May 2019 to map the long-term deformation.
- To map the coseismic deformation due to the February 8, 2016 earthquake, we used ascending and descending image pairs with acquisition dates of 29 January 2016 - 10 February 2016 and 7 February 2016 - 19 February 2016.
- The GAMMA software was used for the processing of the individual interferograms **[2]**.
- For the time series analysis, we followed the PSI method using the MATLAB-based workflow of STAMPS **[3]**.

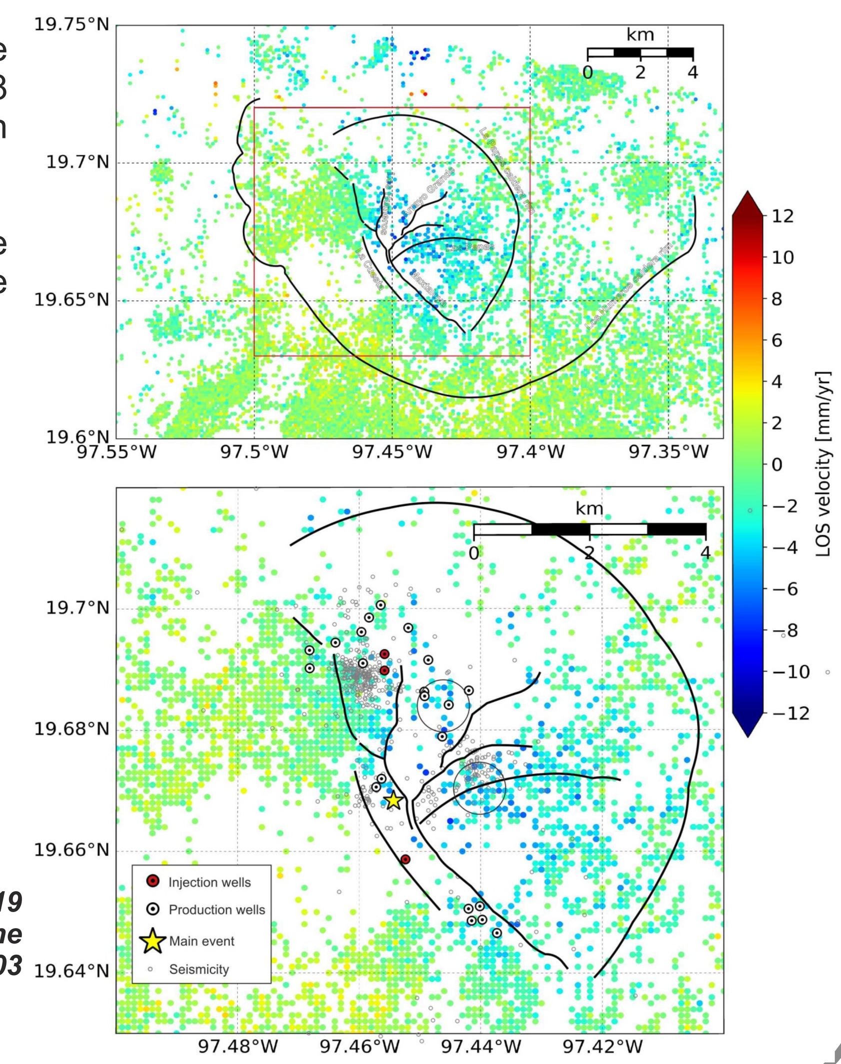


Wrapped phases of the ascending (left) and descending (right) interferograms showing the coseismic deformation.

Long-term deformation

- Movements away from the satellite (~subsidence) are concentrated to the Los Potreros caldera with up to 8 mm/year near the inner-caldera structures for both time series datasets.
- The Los Humeros fault in the North, and the Maxtaloya fault in the South appear to constrain the western boundary of the deforming area.

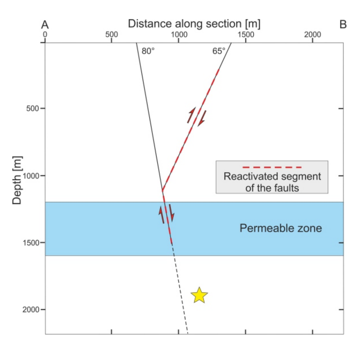


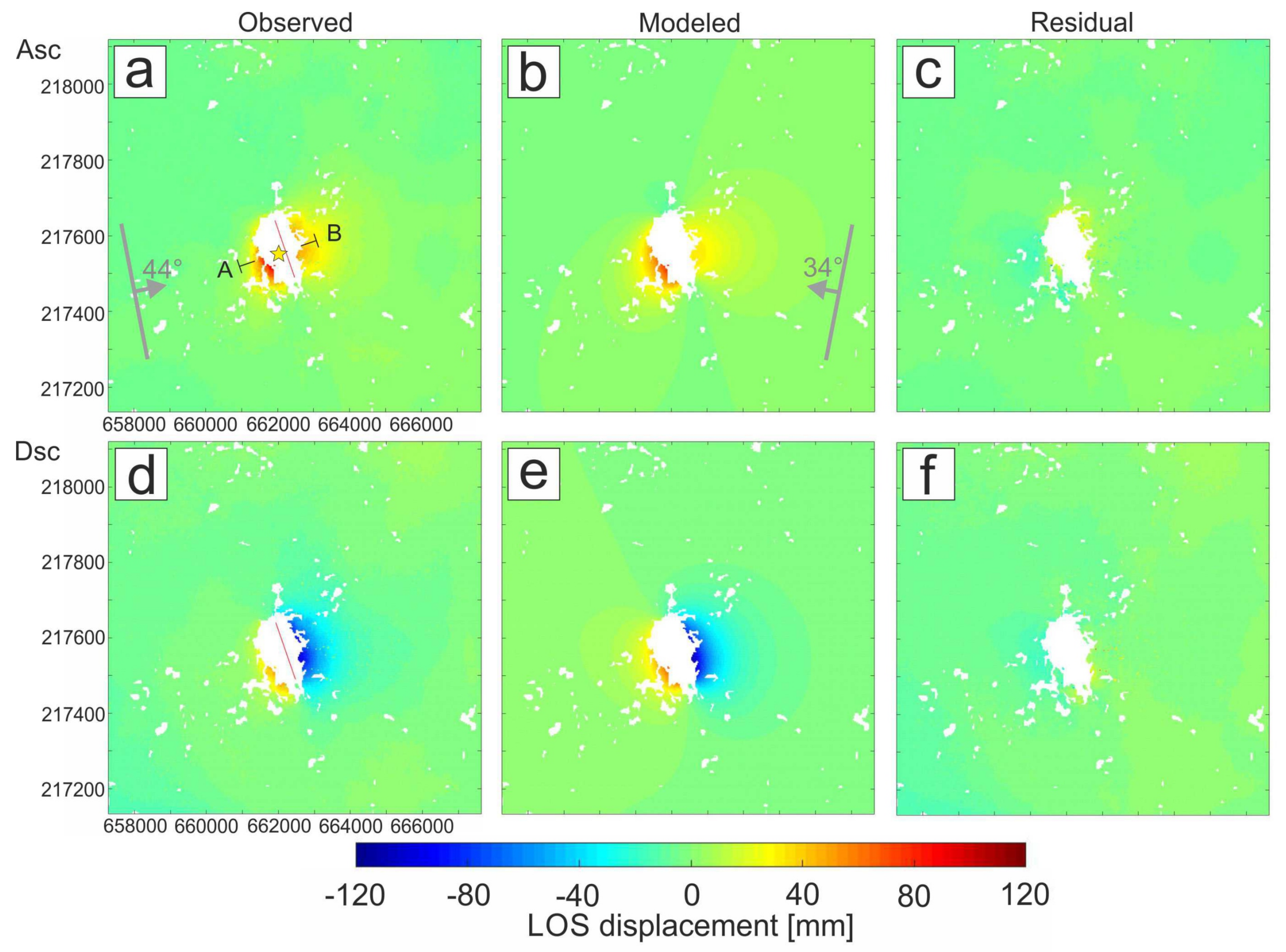


Mean PS velocities in the LOS direction between 2016-2019 (lright) and the time series of the LOS velocities (left) from the area where the largest subsidence is observed between 2003 and 2007 after [8].

Models for the coseismic deformation

- The InSAR data were subsampled using an adaptive quadtree sampling algorithm **[4]**.
- First, we modeled the coseismic deformation by a single fault. The Bayesian **[5]** inversion targeted a forward model for a rectangular dislocation in an elastic half-space **[6]** with nine adjustable parameters.
- The observed surface movements could not be reproduced by the joint inversion of the two interferograms, the models have errors up to 100 % **[7]**.
- We constructed a forward model describing a segmented fault with two fault planes, fitting in the structural framework of the area, and consistent with the surface rupture.
- Our two fault model shows a very good fit with the InSAR data, with RMS misfits of 4 mm with the ascending, and 5 mm with the descending data.





Observed (a, d), modeled (b, e), and residual (c, f) displacements in the LOS direction for ascending (top) and descending (bottom) satellite passes.

	One fault model	Two fault model		Focal mechanism
		fault 1	fault 2	solution after[1]
Strike [°]	160	160	340	169
Dip [°]	59	65	80	61
Rake [°]	74	75	-75	42
Length [m]	1655	1600	1600	-
Width [m]	1301	1000	400	-
Depth* [m]	0.89	200	926	1900
X position** [m]	662240	662200	661802	662280
Y position** [m]	2175600	2175650	2175505	2177864
Slip [m]	0.188	0.31	0.31	-
Mw	-	-	-	4.2

*In case of our model, it marks the depth of the top edge of the rectangular plane, which is different from the focal depth by [1].
**In case of our models, these are the X and Y UTM coordinates of the center of the top edge of the rectangular plane.

Discussion and conclusions

- Persistent Scatterer Interferometry (PSI) time series analysis for the period of 2003-2007 and 2016-2019 shows that the **local ground deformation of up to 8 mm/year** correlates with the exploitation area.
- **Deformation of the center of the Los Potreros caldera** floor is also observed near the Las Papas fault, where no production wells are drilled. This area is also marked by natural seismicity, suggesing that **neotectonic deformations** connected to volcano-tectonic activity may exist.
- Despite the single fault inverse dislocation models for the coseismic deformation of the **8 February, 2016 earthquake**, we manage to resolve the observed ground deformation pattern by taking into consideration the complexity in the subsurface having a **segmented fault** with two fault planes.
- The InSAR observations are in good agreement with the coseismic deformation mapped by **[9]**. However, their forward model shows misfits up to ~50 mm.
- The observed surface movements together with the modeling results indicate the **reverse kinematics of the Los Humeros fault and the normal kinematics** of the deeper segment **of the eastward dipping La Cuesta fault**.
- Despite focal mechanism solutions, coseismic deformation mapped with high-resolution **satellite data facilitate to infer for more complex fault geometry**.
- Our study demonstrates that ground movements mapped with **InSAR** and interpreted by **taking into account other geological and geophysical observations** can significantly contribute to our **understanding of the** geological features that control the **geothermal reservoir**.

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