Inversion of coseismic deformation due to the 8th February 2016, Mw 4.2 earthquake at Los Humeros (Mexico) inferred from DInSAR

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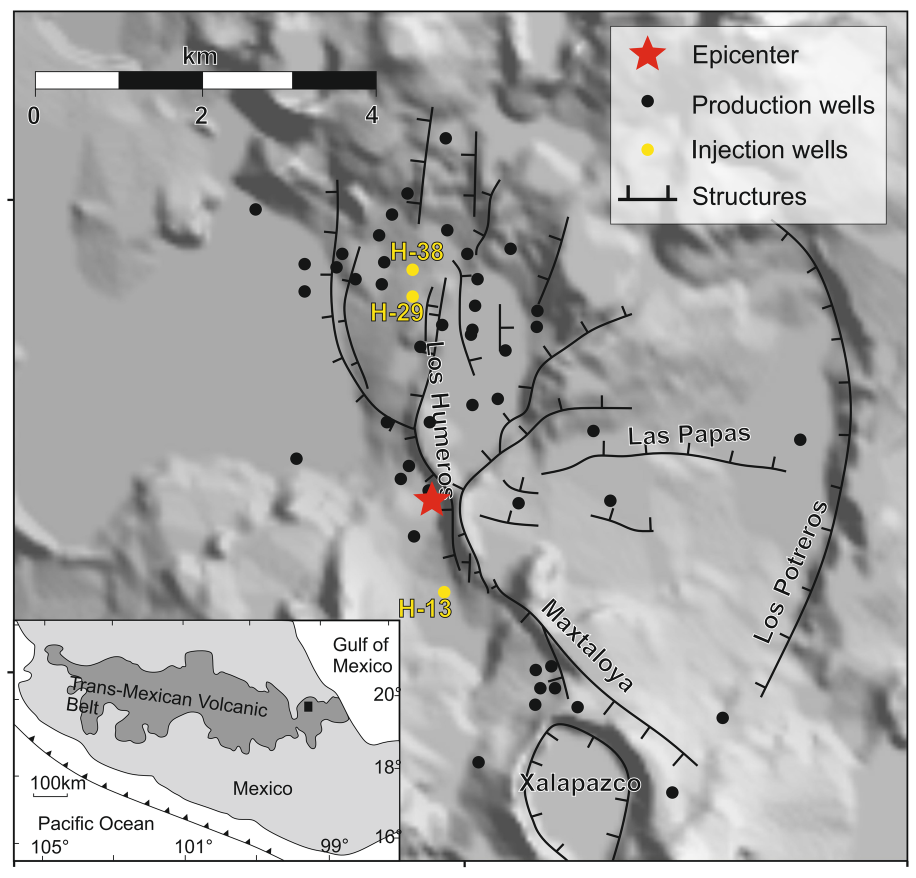
Introduction

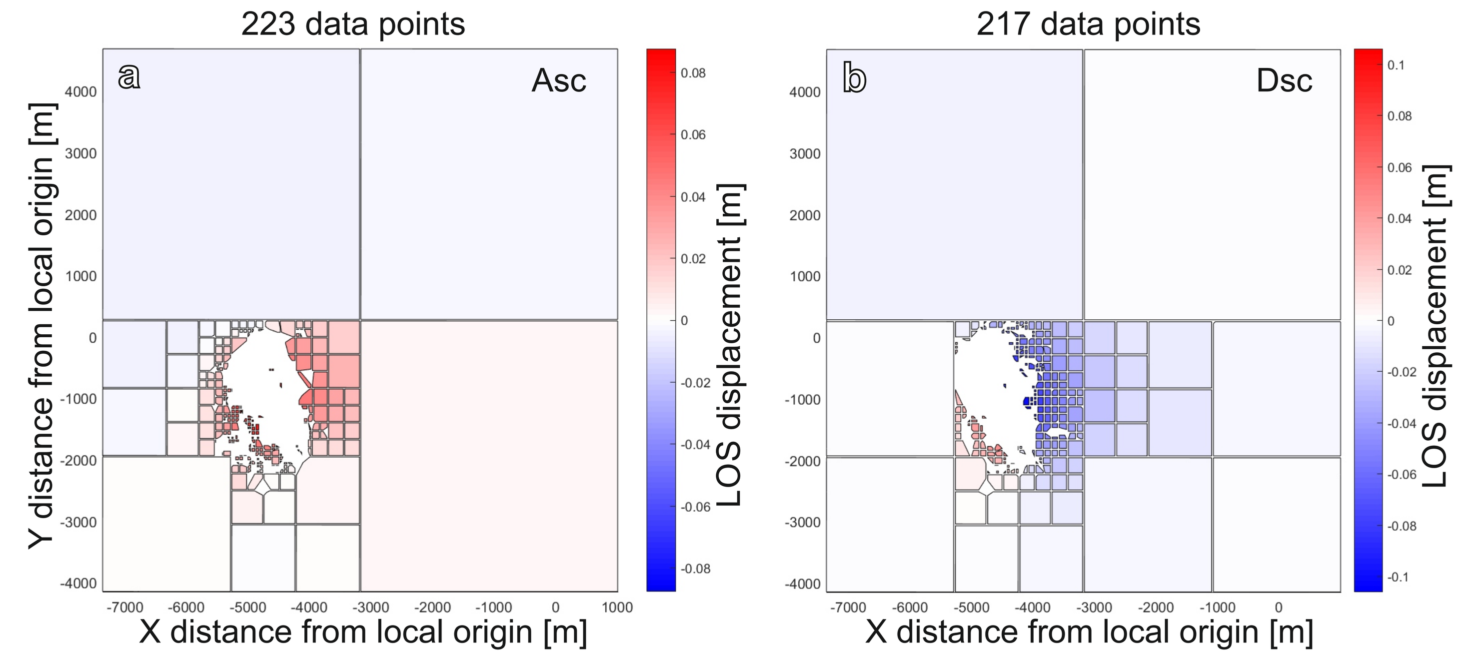
- The Los Humeros Geothermal field (LHGF) is among the largest geothermal fields in Mexico with an installed capacity of ~93.6 MW.
- The geothermal reservoir is built up by pre-caldera andesites of Miocene age [1], situated at ~1500 m depth, with an average thickness of ~1000 m [2].
- The geothermal activity is controlled by NNW-SSE to E-W striking structures located inside the caldera.
- On the 8th February 2016, an earthquake originated along the trace of the Los Humeros fault.
- The focal mechanism solution by [3] shows a reverse movement with a minor left-lateral component: Mw=4.2, depth=1500m, strike=169°, dip=61°, rake=42°.
- The event occurred after a sharp increase in the injection rate at the H-29 well.



Major faults, caldera rims, and the location of the wells at the Los Humeros Geothermal Field modified after [4] and [2]. The red star indicates the epicentre of the 8 February 2016, Mw 4.2 earthquake after [3].

InSAR data and geoetic modeling

- We have attempted to resolve the source parameters of the earthquake to explain the observed ground deformation pattern.
- We used Sentinel-1 images of 29 January 2016 and 10 February 2016 for the ascending interferogram. The descending interferogram was processed using the SAR images acquired on 7 February 2016 and on 19 February 2016. The interferometric processing was performed using the GAMMA software [5].
- We inverted the interferograms for a fault solution with uniform slip using the Okada model [6]. We used the freely available MATLAB-based Geodetic Bayesian Inversion Software (GBIS, [7]) for the parameter estimation procedure.

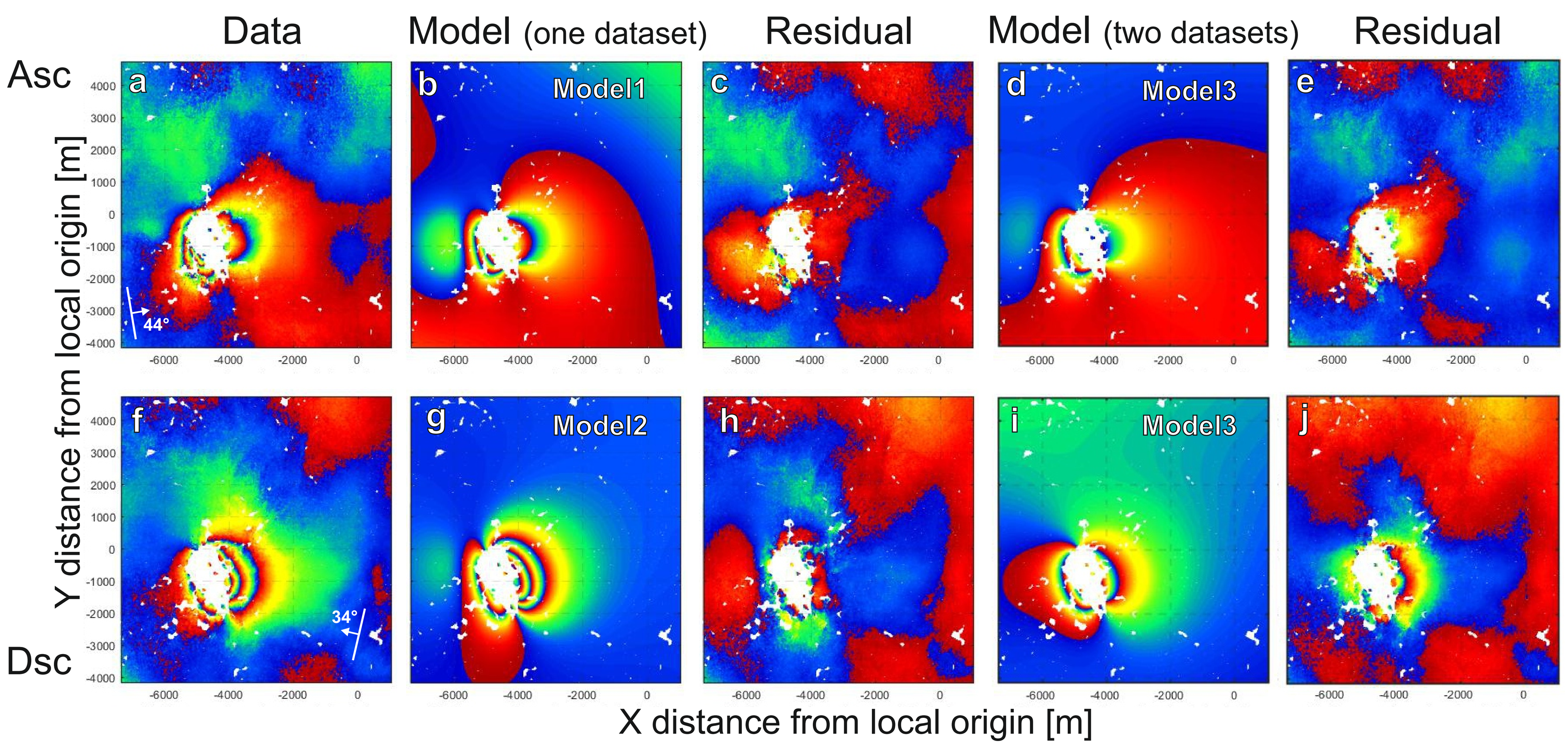


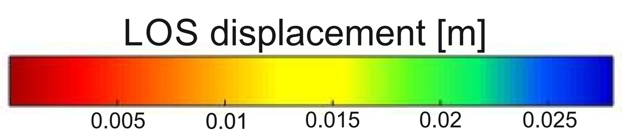
Subsampled unwrapped InSAR datasets for ascending (a) and descending (b) satellite passes. The colouring corresponds to displacements relative to the satellite LOS (positive values: movements towards the satellite, negative values: movement away from the satellite.

	Total Range	Mo	Model 1	Model 2	Model 3
	Lowe	Uppe	Optima (2.5%–97.5%)	Optima (2.5%–97.5%)	Optimal (2.5% – 97.5%)
Top Depth [m]	0	2000	2.08 (0.034–3.82)	485.03 (485.03 – 485.03)	0.89 (0.26 – 3.86)
Dip [°	-90	-45	-52.57 (-54.09 – -51.40)	-90.00 (-90.00 – -90.00)	-58.92 (-60.67 – -58.08)
Strike [°]	270	360	341.74 (341.14 – 341.89)	334.72 (334.72 – 334.72)	339.74 (339.66 – 340.48)
Lengtl [m]	1000	2500	1489.1 (1455.1 – 1512.77)	1814.51 (1814.5 – 1814.51)	1655.46 (1632.21 – 1678.68)
Width [m]	500	2000	1141.7 (1108.3 – 1185.52)	517.35 (517.35 – 517.35)	1301.08 (1249.40 – 1372.38)
X center [m]	-4650	-4450	-4534.5 (-4538.58 – -4533.69)	-4631.7 (-4631.75 – -4631.75)	-4529.56 (-4535.18 – -4529.14)
Y center [m]	-1000	-800	-865.54 (-867.06 – -853.84)	-992.72 (-992.72 – -992.71)	-844.09 (-844.73 – -839.78)
Strike slip [m]	-0.5	0.5	-0.055 (-0.072 – -0.052)	0.0720 (0.035 – 0.128)	-0.052 (-0.062 – -0.045)
Dip slip [m]	-2.0	2.0	-0.284 (-0.296 – -0.271)	-0.638 (-0.652 – -0.614)	-0.180 (-0.184 – -0.173)

- InSAR data were subsampled using an adaptive quadtree sampling algorithm [8].
- We performed the modelling using the ascending and descending interferograms separately (Model 1 and Model 2, respectively) and with the combination of the two datasets (Model 3).
- The inversion targeted a forward model for a rectangular dislocation with nine adjustable parameters.
- We selected lower and upper bounds for the source parameters according to prior information about the activated fault based on the observed ground movement pattern and previous studies including geological mapping [4] and seismological data [3].

Results





Observed (a, f), modeled (b, d, g, i), and residual (c, e, h, j) displacements in the LOS direction for ascending (top) and descending (bottom) satellite passes. Model 1 and Model 2 are obtained by the inversion of the ascending and descending interferograms separately. For Model 3 the two interferograms were used simultaneously.

- Surface movements predicted by the three models are consistent with a NNW-SSE-strike, westward dipping reverse fault with minor strike-slip component.
- The geometry of the fault varies for each model.
- The geothermal activity is controlled by NNW-SSE to E-W striking structures located inside the caldera.
- The models calibrated with a single dataset (Model 1 and Model 2) show very good fit with the ascending and descending interferograms separately.
- In case of the two datasets inverted simultaneously (Model 3), misfits increase, especially with the descending data.

Discussion and conclusions

- Our model calibrated jointly with the two interferograms (Model 3) shows misfits up to 30 mm with the descending data, suggesting that the models are inaccurate. We think the source of the inaccuracy is in the assumption of a single fault plane with uniform slip.
- The InSAR observations are in good agreement with the coseismic deformation mapped by [9]. However, their forward model shows misfits up to two times larger than in our Model 3.
- The fault orientation and event rake are in good agreement with the seismological data, but the difference in depth is large (Model3: depth of the center of the fault plane=558m, strike=160°, dip=59°, rake=75°; seismological data: Mw=4.2, depth=1500m, strike=169°, dip=61°, rake=42°, [3]).
- Considering the uncertainties of our models, we conclude that they are not entirely capable of explaining the observed ground deformation pattern.
- The joint deployment of ascending and descending InSAR data has shown that further research, taking into account the complexity in the subsurface, is crucial for a quantitative understanding of the source parameters. Suchunderstanding can reveal the connection between geothermal operations and induced seismicity.

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