Active deformation of the Los Humeros geothermal field (Mexico) based on InSAR persistent scatterers

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Introduction and geological settings

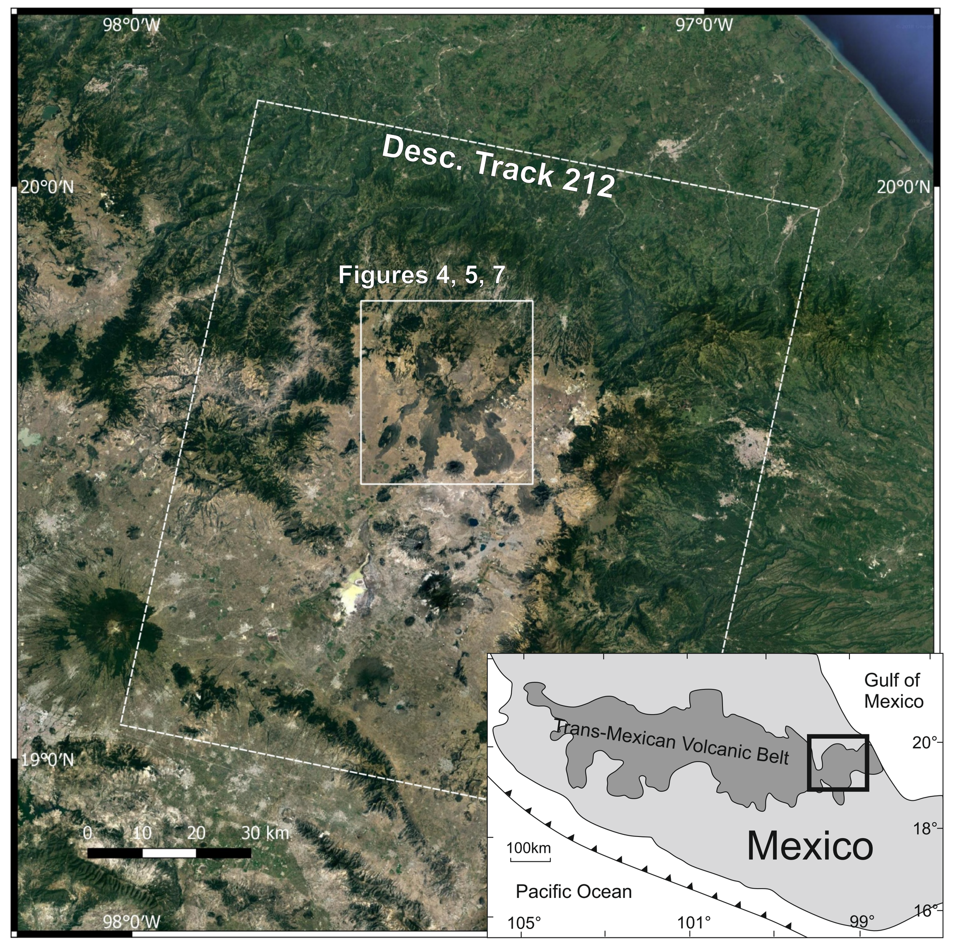


Figure 1. Map showing the location of the study area and the footprint of the SAR data (descending track 212).

Los Humeros is one of the largest geothermal fields in Mexico connected to a caldera system that has been active from 0.46 Ma until recent. Production of the field started in the early 80's. Since then more then 50 wells were drilled and the current operating capacity is ~68 MW (NREL, 2017).

We performed PS-InSAR (Persistent Scatterer by Synthetic Aperture Radar Interferometry) time-series analysis to resolve ongoing ground deformation. We used C-band Envisat ASAR images acquired between April 2003 and March 2007 (Figure 1). The LosHumeros geothermal field is located in a complex tectonic environment and influenced by Quaternary volcanism resulting in large-wavelength background movements. Our main goal was to isolate and identify local displacements due to geothermal exploration activities.

Los Humeros is a Pleistocene volcanic caldera complex built up by basalt, andesite, and rhyolite in the eastern sector of the Trans-Mexican Volcanic Belt. The volcanics overlie thick Mesozoic carbonates (Figure 2). ~10.5-1.5 Ma andesitic rocks provide the main reservoir formation of the geothermal field. The caldera complex was formed by at least two major eruptions, and multiple minor to medium eruptions and lava flows. The explosive, rhyolitic eruption that produced the Los Humeros caldera took place at ~450 ky followed by the Los Potreros-eruption ~140ky ago. Recent andesitic and basaltic volcanism is poorly dated, but considered to be <20-40 ky old (e.g. Carrasco-Nunez et al., 2017).

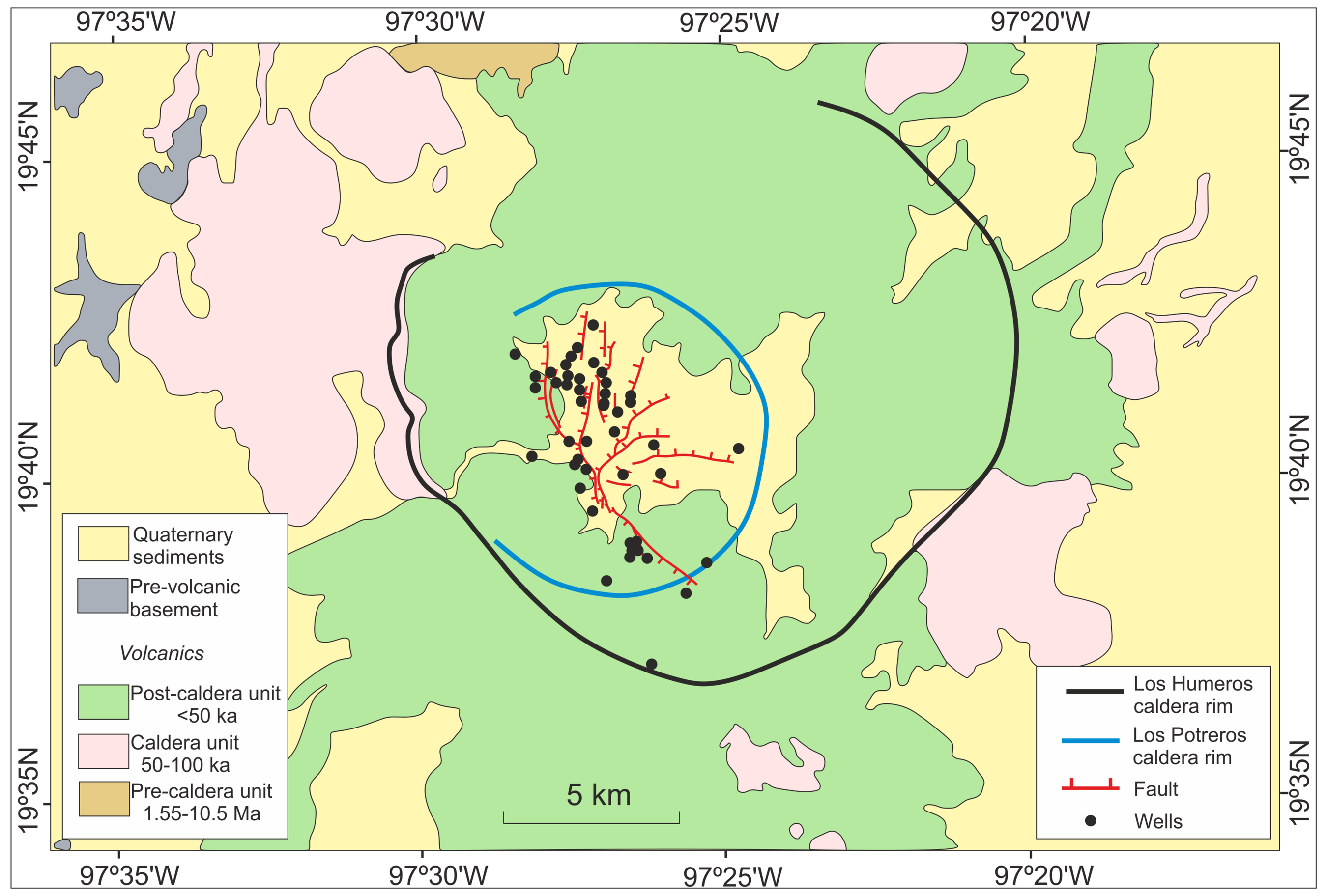


Figure 2. Geological map of the Los Humeros geothermal field and it surroundings, highlighting major faults, the caldera rims, and the location of the wells. Modified after Norini et al. (2015) and Carrasco-Nunez et al. (2017).

Interferometric Synthetic Aperture Radar data

PS-InSAR processing was performed on 13 Envisat images with descending orbits using the StaMPS method (Hooper et al, 2007). We selected a singe master image based on criteria for perpendicular and temporal baselines (Figure 3). During the processing the interferograms were investigated and the ones with no visible coherence and perpendicular baselines above 500 m were discarded.

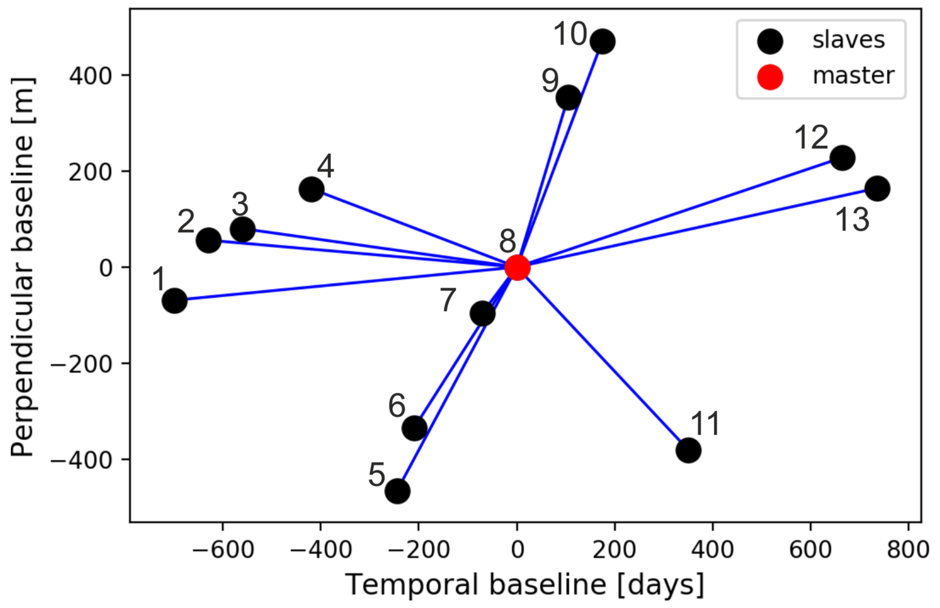


Figure 3. Perpendicular versus temporal baseline plot of the Envisat data. Numbers refer to the images listed in **Table 1**.

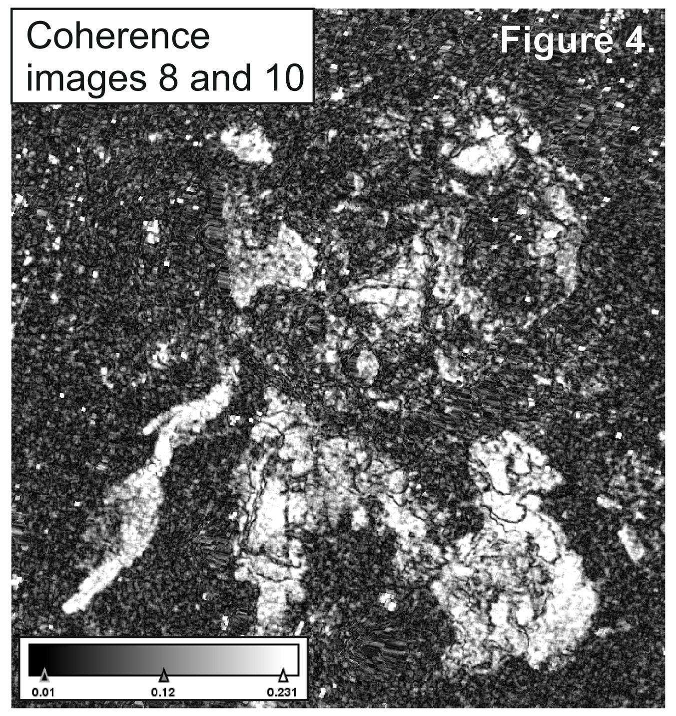


Image number	Acquisition date
1	08-Apr-2003
3	17-Jun-2003
3	26-Aug-2003
4	13-Jan-2004
5	06-Jul-2004
6	10-Aug-2004
7	28-Dec-2004
8	*08-Mar-2005*
9	21-Jun-2005
10	30-Aug-2005
11	21-Feb-2006
12	02-Jan-2007
13	13-Mar-2007

Table 1. Aquisition dated of Envisat images used for processing. The details of the master image is in *italic.*

Correction of the stratified tropospheric artifacts

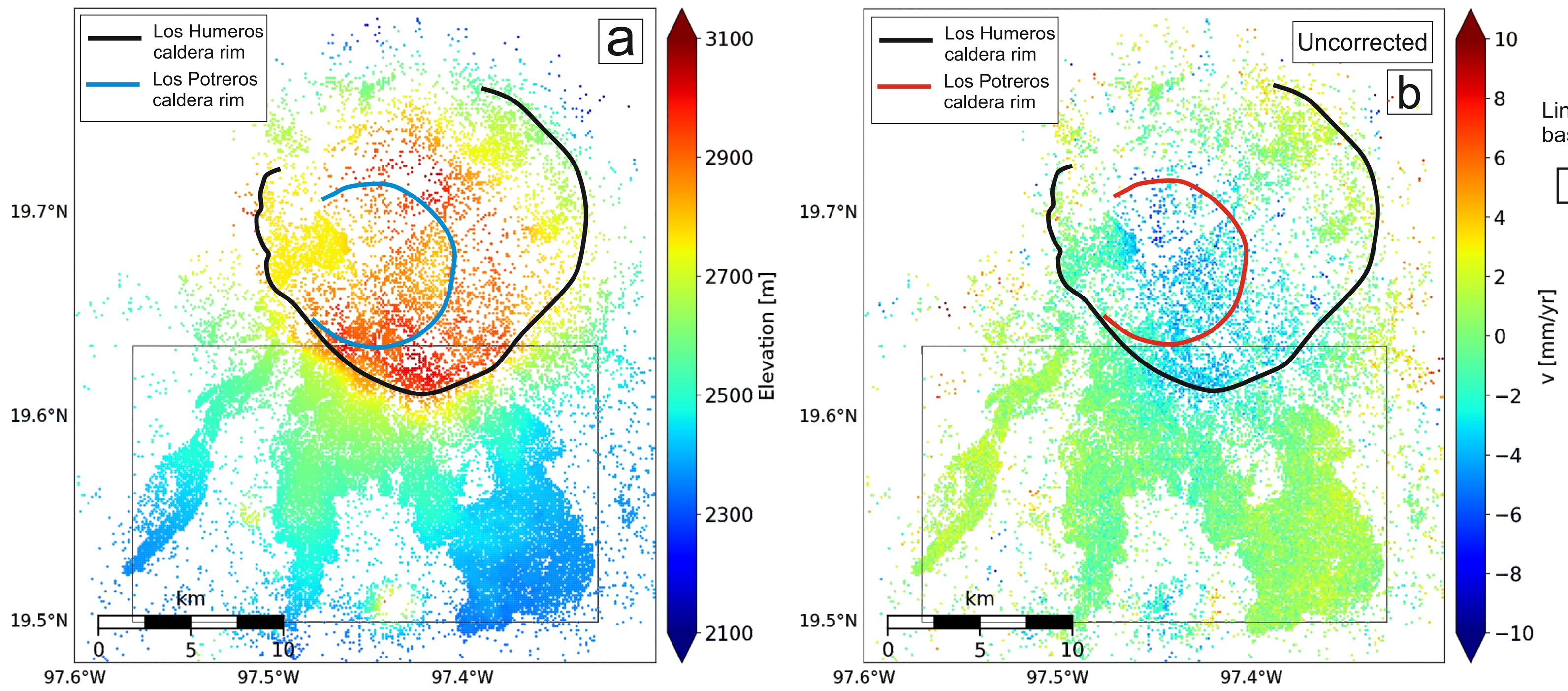


Figure 5. a: Elevation of the PS points. **b:** Deformation map showing the velocities in the satellite line of sight (LOS). Movements are relative to the mean of the whole area. Standard deviations are below 4 mm/year. Black rectangle highlights the region used for tropospheric correction.

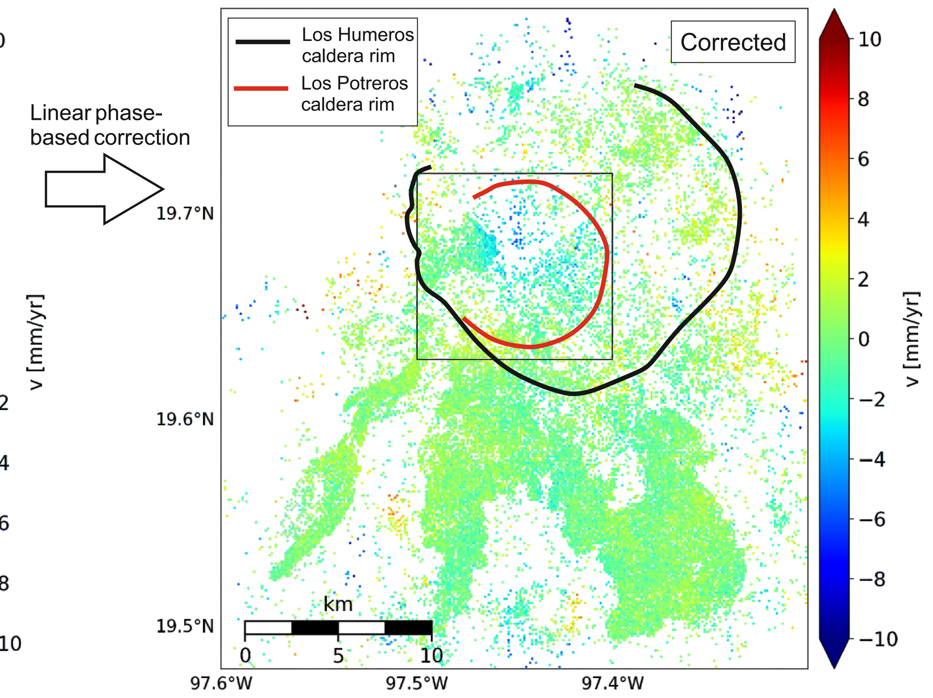
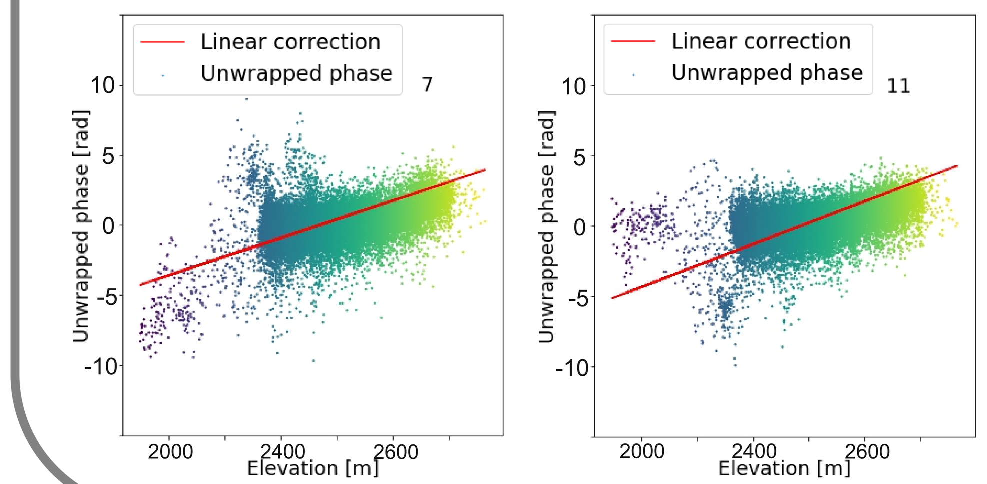


Figure 7. Deformation map corrected for topography-related atmospheric phase delays.



The individual interferograms are of good quality with high coherence even on long time scales in the vicinity of the Los Humeros geothermal field. On the other hand, dense vegetation especially in the norther part of the study area induces low signal coherence (Figure 4).
Most parts of the study area are located at high altitudes with strong relief. As a result, the interferograms seem to be influenced by topography-related atmospheric phase delays. We corrected these artifacts based on a linear relationship between phase and elevation. We selected a region outside the geothermal field (Figure 5, black boxes) to estimate the tropospheric contribution and removed them from the interferograms.

Figure 6. Phase-elevation plots of the 7th and 11th interferograms.

Monitoring the geothermal field

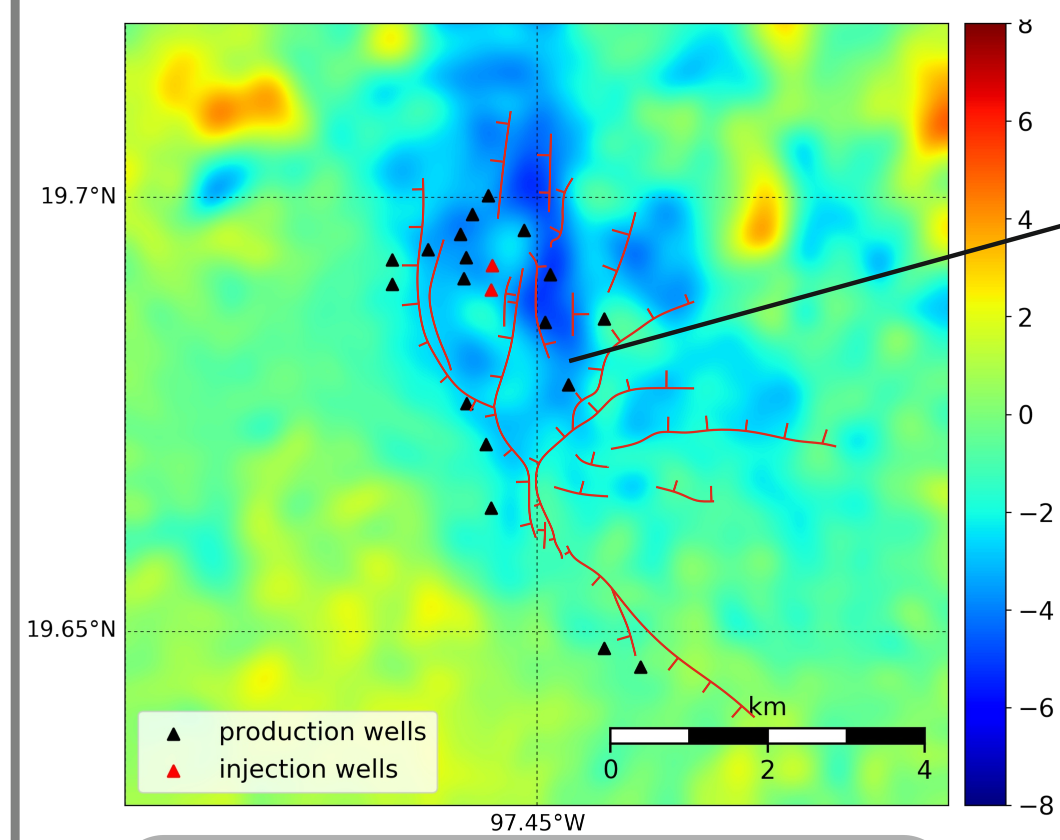


Figure 8. Interpolated deformation map over the geothermal field. Negative values indicate movement away from the satellite (~subsidence) and positive values indicate movement towards the satellite (~uplift).

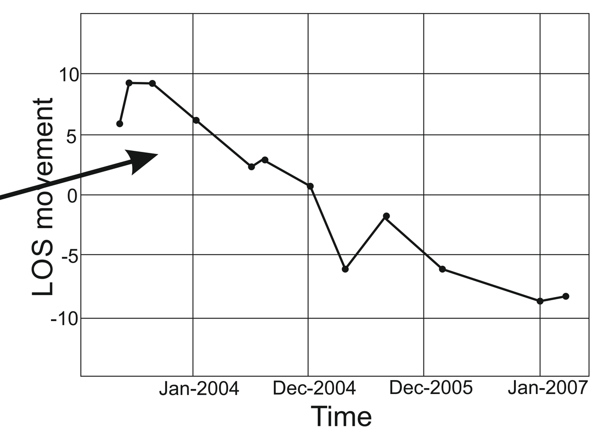


Figure 9. Movement of a single PS point.

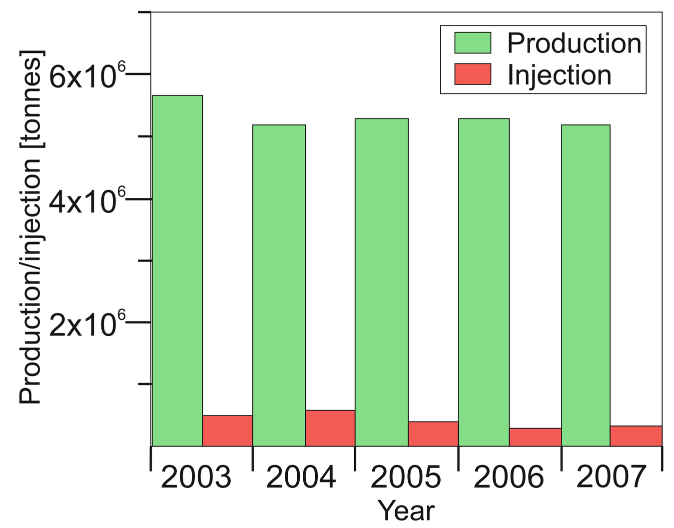


Figure 10. Production/injection history during the period of InSAR monitoring.

Concluding remarks:

- Interferograms are influenced by strong topography-related atmospheric signal which requires correction.
- The geothermal field is characterized by about 4-8 mm/year of surface subsidence.
- The lagrest subsidence is observed in the northern part of the field.
- We correlate the deformation over the Los Humeros geothermal field with geothermal production and fluid flow and displacement along the main structures.

We plan to extend the analysis with an inverse study to learn more about the geothermal field characteristics.

References

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