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## High-resolution spatio-temporal fault slip using InSAR observations: insights on seismic and aseismic slip during a shallow crust earthquake swarm

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How earthquakes initiate and run-away into major ruptures is still a challenging research topic, that will benefit from increasing our capability to observe processes from the seismogenic source regions. In recent years, two models for earthquake nucleation have been proposed to explain earthquake sequences, a slow-slipping model and a cascade model, based mostly on the analysing seismic data. Here we use geodetic data to contribute to the study of seismogenic source regions during earthquake sequences. Earthquake swarms are unusual as they do not obey observational physics laws, e.g., Gutenberg-Richter law. This deviation might be to a disproportioned contribution of aseismic processes, and hence provide an opportunity to investigate the role of aseismic behaviour in the nucleation and propagation of earthquakes.

Here, we study a shallow seismic swarm in Nevada, USA, in 2011. We process satellite radar images to form differential interferograms and to quantify the surface displacements. From the interferograms, we observe a clear surface displacement signal (~4 cm in line-of-sight direction) consistent with slip along a N-S striking normal fault, before the largest magnitude event (M4.6) in the swarm. We also find that interferograms across the M4.6 are dominated by slip on a NE-SW striking fault. Thus, we consider slip along a fault system with a geometry consisting of two fault planes. To interpret the surface displacement, we invert for its optimal geometry directly using the interferometric wrapped phase. Based on the fault geometry together with inferred surface ruptures, we construct a smooth fault plane with triangular dislocations. Then, we extend our previous method to obtain distributed fault slip models from the wrapped phase. We implement a physics-based linear elastic crack model with no stress singularities, coupled with a linear time inversion with optimal regularization method to estimate the temporal evolution of fault slip. We apply this method to the 2011 Hawthorne swarm geodetic data to test the two conceptual earthquake nucleation and propagation models. The inversion reveals (1) two slip maxima; a narrow (1km<sup>2</sup>) slip area on the southern fault with high average slip (0.8m) occurring before the M4.6 event; and a wider (40km<sup>2</sup>) slip area on the northern fault which ruptured during and after the M4.6 event and with lower average slip (0.1m); (2) our results are more consistent with a cascade model of discrete slip patches, rather than a slow-slipping model thought as a growing

elliptical crack; (3) the aseismic (geodetic) moment ratio is variable from 100% before the M4.6 event, but remains larger than 60% after it.

The study of the 2011 Hawthorne swarm allows us to illuminate fault slip in much greater detail than usually possible. We conclude that there were significant aseismic fault processes, most likely slow-slip or localized fluid-enhanced fault slip, along with discrete segments of the fault plane active before and after the largest earthquake in this swarm. This study contributes to highlighting the importance of using geodetic data to understand the role of aseismic processes during swarms. An important step towards improving our understanding of the nucleation and propagation of earthquakes.