Geodetic Observations of Human Induced Seismicity and Deformation: The 2011 M_w5.3 Trinidad, Colorado Earthquake

Barnhart, W.D., Rubinstein J.L., Hayes, G.P., Benz, H.

Geodetic observations are a powerful tool for identifying, quantifying, modeling, and monitoring solid earth deformation, including human induced deformation. Although induced earthquakes are a seismological phenomenon, they are driven by complex interactions between anthropogenic processes, hydrological systems, local geology, and pre-existing faults. To gain a more complete image of the dynamics of these systems, observations of ongoing surface deformation, both seismic and aseismic, can compliment and enhance ongoing seismological studies. Here, we present interferometric synthetic aperture radar (InSAR) analysis of ground deformation in the Raton Basin of southern Colorado and northern New Mexico, including displacements from the suspected wastewater injection induced 2011 M_w5.3 Trinidad earthquake.

Using Envisat observations from the WInSAR archive spanning the Raton Basin, we image co-seismic surface displacements of the 2011 Trinidad earthquake. From these displacements, we invert for the location and geometry of the source fault and the finite distribution of slip through an iterative resampling algorithm. We find that the earthquake slipped within the crystalline basement underlying basin sedimentary rocks and in the vicinity of high-volume wastewater injection wells. The spatial and temporal separation between the location and onset of wastewater injection and the earthquake itself suggests a pore pressure migration triggering mechanism is present. The finite slip distributions, along with seismically recorded aftershocks, further highlight the location and orientation of previously unmapped, seismogenic faults. Lastly, the precise earthquake location afforded by InSAR observations provides a well-located earthquake source that can be used to calibrate other regional earthquakes locations.

Additionally, we derive InSAR time series observations from ALOS imagery acquired from 2007-2011. These results highlight ongoing regions of surface subsidence within the basin, presumably from shallow withdrawal of fluids. We infer that the displacements arise from extraction of coal-bed methane and water that is later reinjected. While it is not clear if there is a causative relationship between regions of co-located surface subsidence and recorded earthquakes, the time series permits us to exclude several other hypotheses for the causes of increased seismicity in the Raton Basin, including volcanic activity related to the Rio Grande Rift. Furthermore, the InSAR time series analysis provides observations of time variable surface deformation that may be used to inform hydrological models which assess subsurface stress changes from the removal and injection of fluids.

Generally, the capability of InSAR to capture sub-centimeter scale surface displacements over broad spatial areas opens many new opportunities to further assess the dynamic behavior of regions experiencing induced seismicity. While few to no InSAR observations have been available over Oklahoma and Kansas until recently, ongoing acquisitions and future InSAR missions such as NISAR will provide a valuable tool to supplement seismological observations in the quantification and monitoring of active deformation in these regions.