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Seismicity in Central Oklahoma shows spatio-temporal signatures of reservoir-induced seismicity

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Starting in 2009, the seismicity rate in Oklahoma, U.S., has significantly increased. Evidences suggest that the earthquakes are clearly linked to the disposal of large volumes of waste water which are directly injected into the highly permeable Arbuckle aquifer. This formation is in hydraulic conncection with the underlying crystalline basement where most of the seismicity occurs. In response to the high number of earthquakes, the Oklahoma Corporation Commission called for a reduction of the injection volume in Central and Western Oklahoma to 40% of the 2014 amount in 2016. This reduced the seismicity rate even though the seismic hazard remains elevated.

To date, many works have been published to evaluate spatio-temporal features of the observed seismicity. Yet, it remains difficult to find an appropriate model which describes the seismicity controlling physical mechanisms. That is because these deviate from the ones leading to high-pressure injection-induced earthquakes, such as at geothermal exploration or hydraulic fracturing for shale gas production. Not only are seismically active regions in many cases far from high-volume injectors, but most of the events occur also much deeper in the basement.

Considering the filling of artificial surface reservoirs and using that knowledge, we here propose a new model for the case of large volume fluid injection-induced seismicity which we call Underground Reservoir-Induced Seismicity (URIS). Assuming that the high amount of fluid injected into the Arbuckle formation corresponds to the filling of an underground reservoir, pressure and stress changes in the underlying, poroelastic basement are induced due to a combination of different mechanisms. These are the direct effect of the fluid mass added to the injection formation and acting on the basement top, pore-fluid pressure diffusion in the basement as well as poroelastic coupling.

We derived an analytical solution for such a problem and developed a numerical finite-element model. Using hydraulic and elastic parameters for Oklahoma as well as a constant boundary condition, we demonstrate that the URIS model is sensitive to the tectonic stress regime which is a direct consequence of the poroelastic effects. Moving one step further, we defined a boundary condition for the analytic solution given by injection volumes for the region under consideration between 2009 and 2016, extrapolated to a constant value until the end of 2018. Using obtained pressure and stress values we generated synthetic event catalogs for a strike-slip regime.

Our results suggest that the evolution in time and at depth of observed earthquakes is well captured by the URIS model. Thus, such an approach should be considered in future works to reduce the seismic hazard caused by large-volume injection-induced events.