Improving Earthquake Rate Models for 1-Year Hazard Forecasts from Induced Seismicity in the Central and Eastern US

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Injection-induced earthquake rates can vary rapidly in space and time, presenting significant challenges to traditional probabilistic seismic hazard assessment (PSHA) methodologies that are based on a time-independent model of mainshock occurrence. To address the rapid changes in seismicity that have recently been observed in the central and eastern US (CEUS), the U.S. Geological Survey (USGS) has developed 1-year seismic hazard forecasts from both natural and induced seismicity (Petersen et al., 2016, 2017, 2018). These 1-year forecasts represent a significant step in quantifying the hazard from induced seismicity, but they are based largely on methods that were developed for the long-term (50-year) US National Seismic Hazard Models. This presentation will focus on some of the efforts that are in development to improve the earthquake rate models that are used in these short-term hazard assessments.

The current 1-year hazard forecasts rely on earthquake rate models based on declustered catalogs (i.e., catalogs with foreshocks and aftershocks removed), as is common practice in PSHA. However, standard declustering (e.g., Gardner and Knopoff, 1974) can remove over 90% of some induced sequences in the CEUS, and the choices of whether and how to decluster can lead to seismicity rate estimates that vary by up to factors of 10-20 (Llenos and Michael, 2016). Declustering was a source of concern in the development of the 2018 hazard forecast, which was largely based on declustered 2017 seismicity (Petersen et al., 2018). While the total number of earthquakes decreased from 2016 to 2017, the declustered rate actually increased, although this behavior is not seen if an alternative declustering algorithm such as Reasenberg (1985) is used. This indicates that the 1-year model is highly dependent on the choice of declustering method.

Moreover, the current 1-year models are based solely on earthquake catalog data and do not incorporate any information about fluid injection, which is a significant contributor to the seismicity increase in the CEUS (Ellsworth, 2013). Recent models (e.g., Langenbruch and Zoback, 2016; Norbeck and Rubinstein, 2018) have had some success at forecasting seismicity rate changes based on fluid injection changes. In order to improve the accuracy of the 1-year hazard assessments, we are exploring ways to make forecasts that are based on the full, rather than declustered, catalogs and that can be informed by fluid injection data.

We focus on southern Kansas, where the USGS has operated a seismic network since 2014, following the sharp increase in seismicity that began in 2013. We develop earthquake rate models using the space-time Epidemic-Type Aftershock Sequence (ETAS) model (Ogata, 1998; Zhuang et al., 2002), which characterizes both the background seismicity rate as well as aftershock triggering. After the model parameters are fit to the seismicity data from a given year, forecasts of the full catalog for the following year are then made using a suite of 100,000 simulated catalogs based on those parameters. We also explore

the use of an earthquake nucleation hydromechanical model (Norbeck and Rubinstein, 2018) to forecast changes in the background seismicity rate based on fluid injection data. Results suggest that the ETAS model is a useful framework for combining background rate changes informed by fluid-injection data with spatiotemporal earthquake interactions to produce more accurate one-year forecasts.

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