Developing Smoothed Seismicity Forecasts for U.S. National Seismic Hazard Models

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Smoothed background seismicity models are a critical component of probabilistic seismic hazard analyses such as the U.S. National Seismic Hazard Models (NSHMs), accounting for off-fault and smaller-magnitude seismicity. They are typically developed by declustering (i.e., removing aftershocks from) and then spatially smoothing an earthquake catalog to estimate a long-term independent background seismicity rate that can be used to forecast future seismicity. In this presentation, we will describe the updated methodology that is now used to compute these smoothed seismicity forecasts for U.S. NSHMs, including the 2023 50-state NSHM (Petersen et al., Earthquake Spectra, 2024; Field et al., BSSA, 2023) and the 2025 Puerto Rico and U.S. Virgin Islands (PRVI) NSHM.

Earthquake catalogs are the fundamental basis of the smoothed seismicity forecasts. The NSHM catalogs are developed by merging preexisting input catalogs (including historical and instrumental source catalogs), removing duplicates, explosions, and mining-related seismicity, and calculating a uniform moment magnitude (Mueller, SRL, 2019). Catalogs are developed separately for the Central and Eastern US, the Western US, Alaska, Hawai‘i, and PRVI. Additionally, in regions along subduction zones (e.g., Alaska and PRVI), catalogs are also subdivided into crustal, subduction interface, and intraslab seismicity based on probabilistic methods and Slab2 subduction zone geometry models (Hayes et al., Science, 2018), because different sets of ground motion models are used for different tectonic classes of seismicity (Powers et al., Earthquake Spectra, 2024).

A significant update of the smoothed seismicity methodology involves splitting the model into two main components: a spatial kernel that describes the relative distribution of seismicity in a region, and a total earthquake rate model defined by a Gutenberg-Richter (GR) *b*-value and the Poisson rate of earthquakes with magnitudes above the minimum magnitude used to compute hazard. This decoupling allows us to better account for uncertainty in the two components separately.

The spatial kernel is constructed by declustering and spatially smoothing the earthquake catalog in each region. While past versions of the NSHM primarily used a single declustering method (Gardner and Knopoff, BSSA, 1974), our new methodology uses three declustering methods, adding the Reasenberg (JGR, 1985) and nearest-neighbor (Zaliapin and Ben-Zion, JGR, 2020) methods. Declustering is a non-unique process because aftershocks are not physically distinguishable from mainshocks, and so different methods can produce different results from the same catalog, depending on how clusters are defined. Including multiple declustering methods therefore better accounts for epistemic uncertainty in the forecast of the spatial distribution of seismicity. The declustered catalogs are then spatially smoothed using twodimensional Gaussian kernels of either fixed or adaptive (variable) bandwidth (Frankel, SRL, 1995; Helmstetter et al., SRL, 2007; Moschetti, BSSA, 2015).

Another change is that the absolute rates are determined from the full catalog rather than the declustered catalog. Using the full catalog to provide a Poisson rate includes the hazard from aftershocks and provides a more accurate assessment of the hazard at low probabilities of a single exceedance (e.g. ≤10% in 50 years) (Field et al., SRL, 2003, Marzocchi and Taroni, BSSA, 2014, Michael and Llenos, BSSA, 2022). Using the full catalog allows us to determine the Gutenberg-Richter *b*-values without the biases introduced by declustering methods (e.g. Llenos and Michael, BSSA, 2020). The total earthquake rate model is constructed from the catalog by computing the joint distribution of the Poisson rate of earthquakes and the GR *b*-value. First, the *b*-value is determined along with its uncertainty. Then the joint distribution is determined by using Monte Carlo sampling. This approach allows us to account for uncertainties in *b*-value, the Poisson rate given an observed number of events, magnitudes, and magnitude of completeness. The joint distribution can then be used to define high, low, and mean rate branches parameterized by Gutenberg-Richter *a*- and *b*-values. Those branches are combined with the spatial kernels to produce a full smoothed seismicity forecast. This new methodology improves the representation of epistemic uncertainty compared to previous NSHM models.