New Seismic Hazard Research Capabilities and Software Improvements in OpenSHA v25.4

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New tools and improvements for Seismic Hazard Analysis

- NSHM23 Western US Branch Averaged ERF
- WGCEP UCERF3 Epistemic List ERF
- Support for Generalized Conditional Intensity Measures (GCIM)

1. Background

OpenSHA (https://opensha.org) is an open-source, Java-based platform for Seismic Hazard Analysis (SHA). It provides a framework for implementing earthquake rupture forecasts (ERFs) and combining them with ground-motion models to compute hazard curves, maps, and related products while exploring epistemic uncertainties.

The most recent software release supports community models such as the NSHM23 Western U.S. Branch Averaged ERF and the UCERF3 Epistemic List ERF, distributed through the GetFile framework for validated, versioned data. OpenSHA also adds features like a Generalized Conditional Intensity Measure (GCIM) option within the hazard-curve workflow for conditional ground-motion selection.

The platform is used both on local workstations and in large-scale environments, including HPC systems and the Quakeworx science gateway, improving accessibility, reproducibility, and community use in seismic hazard and risk research.

2. New and updated ERFs

An Earthquake Rupture Forecast (ERF) gives the probability of all damaging earthquakes throughout a region, over a specified time span, and at some level of discretization. In OpenSHA, ERFs are implemented as modular components and, together with ground-motion models, drive hazard calculations that produce hazard curves, maps, and related products for sites of interest.

The following ERFs are now available for use across OpenSHA applications,
- NSHM23 Western US Branch Averaged ERF
- WGCEP UCERF3 Epistemic List ERF

The NSHM23 model provides probabilistic forecasts of earthquake shaking across the U.S., combining the latest rupture, fault, and ground-motion data to estimate the likelihood of exceeding different levels of ground motion at specific locations.
The WUS Branch Averaged ERF is specific to the crustal only Western United States excluding the Cascadia subduction zone. This branch averaged ERF acts as a weighted average of all branches from an epistemic list ERF. Think of this like taking the average of a week's weather forecast.

The WGCEP Uniform California v3 Epistemic List ERF leverages the best available science to forecast earthquake shaking across California. An epistemic list ERF is actually a collection of ERFs with plausible alternative models weighted to account for epistemic uncertainty. Specific to this UCERF3 ERF is support for the plotting of fractiles and curves, which is not universally supported amongst all epistemic list ERFs.

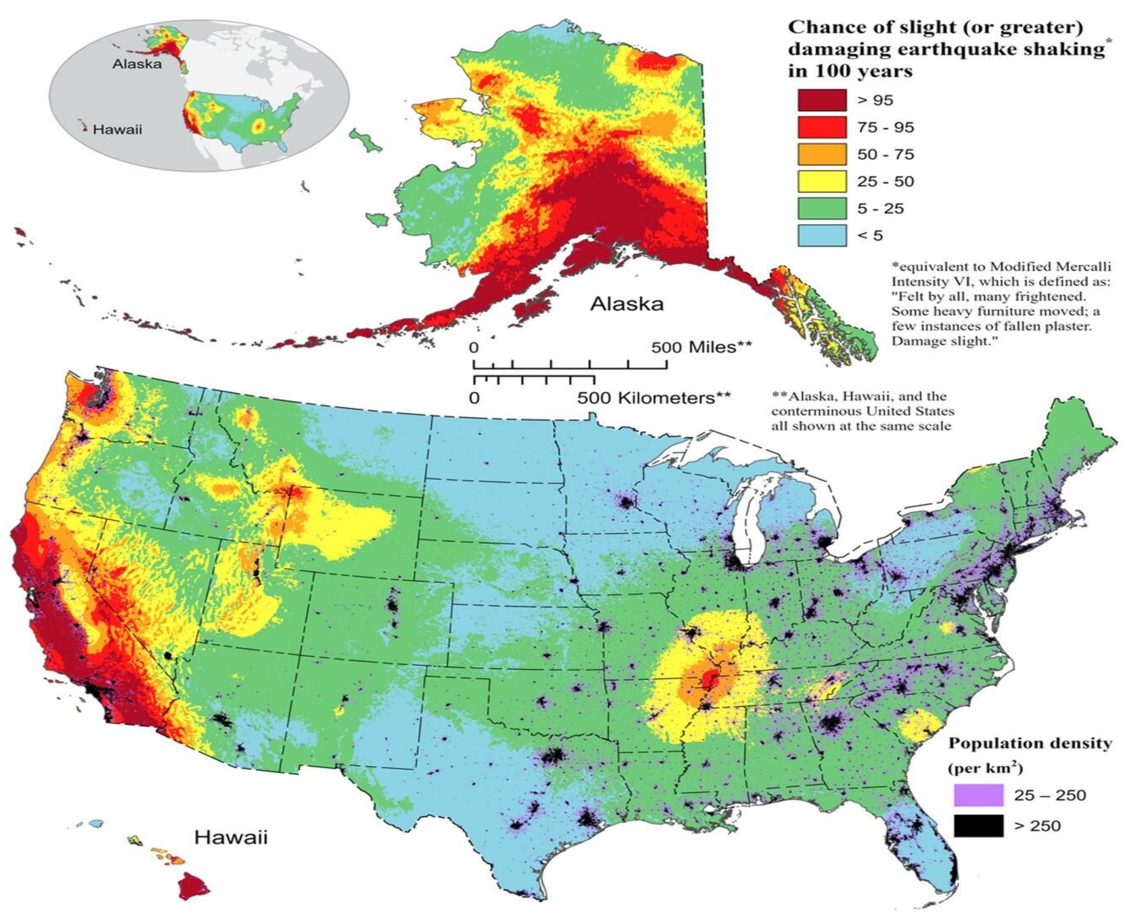

Fig 1. NSHM23 map displays likelihood of damaging earthquake shaking in the United States over the next 100 years. (USGS, Jan 11 2024)

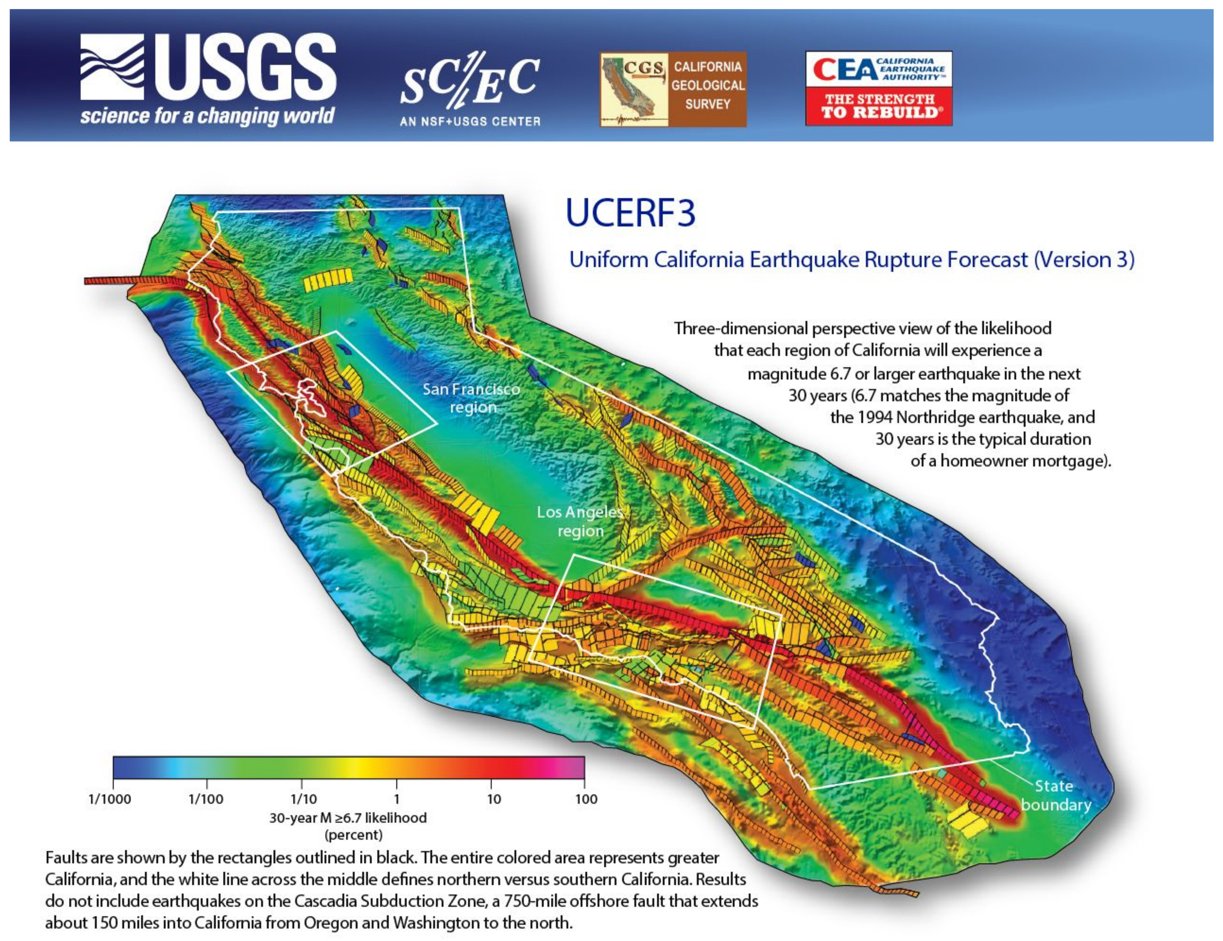

Fig 2. UCERF3 Probabilistic Seismic Hazard Map (WGCEP, n.d.)

3. GCIM Control Panel

The Generalized Conditional Intensity Measure (GCIM) approach provides a rigorous probabilistic framework for ground motion selection. It characterizes the joint distribution of a vector of intensity measures, including their marginal distributions and correlations, moving beyond the limitations of the simplified Uniform Hazard Spectrum (UHS). This results in a more holistic and physically realistic representation of ground motion characteristics for a given seismic scenario.

Implemented within the OpenSHA Hazard Curve Application, the GCIM method offers an accessible and powerful tool for practitioners. This integration allows users to generate GCIM distributions directly from seismic hazard curves, facilitating the selection of ground motions that preserve the natural correlations between intensity measures. This leads to more reliable and accurate seismic response analysis compared to traditional UHS-based procedures.

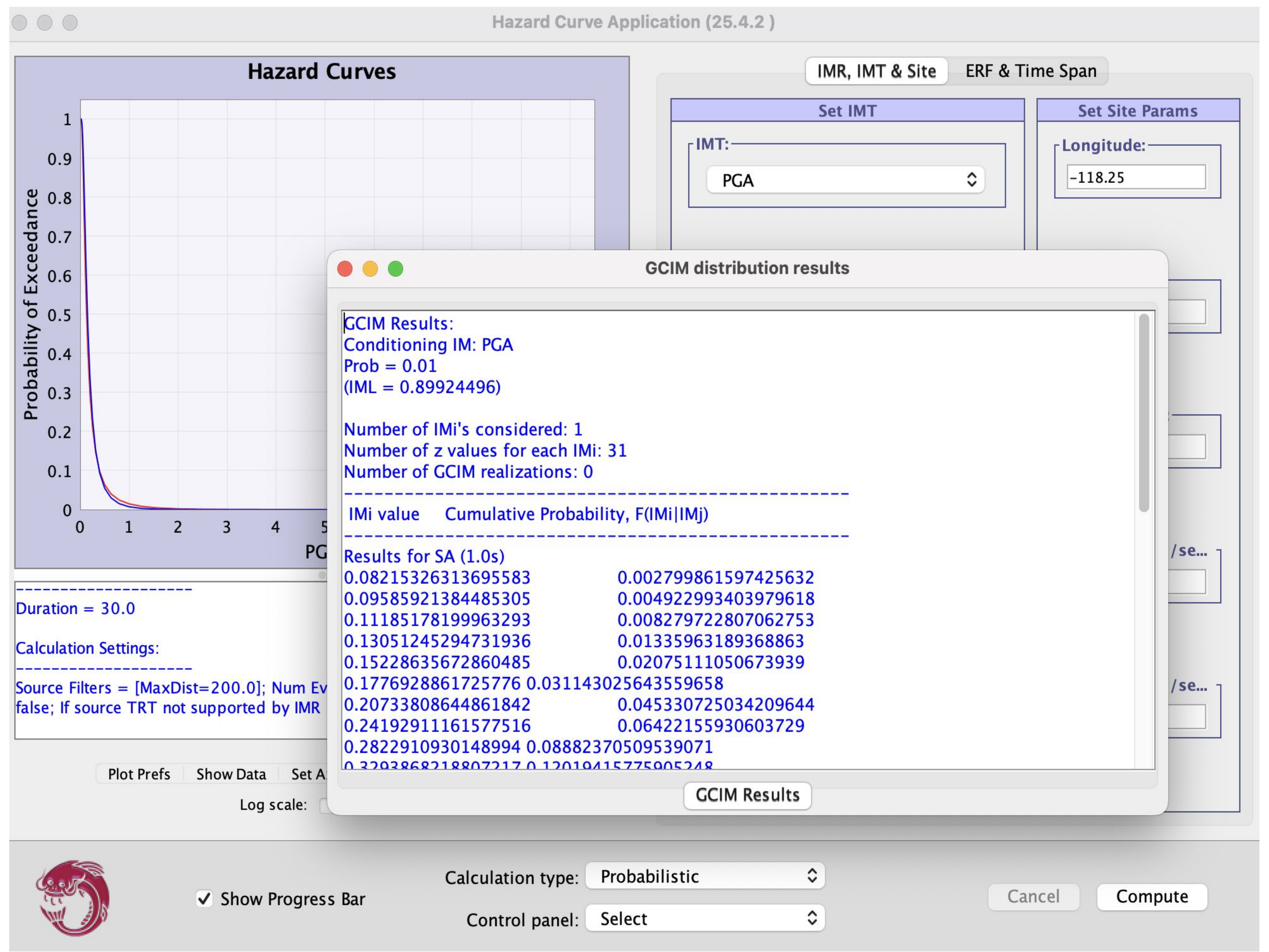

Fig 3. GCIM in Hazard Curve Application

4. New GetFile Framework

The increasing size of geospatial datasets for earthquake models is rapidly exceeding the 100 MB file-size limits imposed by GitHub. To support the 2023 update of the National Seismic Hazard Model, ERF data must now be distributed separately from OpenSHA code. The GetFile framework provides a robust mechanism for retrieving hazard models directly from USC servers, ensuring reliable access to the datasets required for OpenSHA analyses.

In the current OpenSHA release, GetFile's primary role is data validation. It efficiently detects corrupted ERF files using precomputed checksums and ensures that downloads match verified versions. By lazily downloading and caching data on demand, GetFile reduces initial application download times, gracefully handles network interruptions, and allows users to continue working with previously retrieved datasets when servers are temporarily unavailable.

Beyond validation, GetFile was designed for flexible versioning, enabling snapshots, rollbacks, and the potential to manage multiple server backends for georedundancy. Future releases of OpenSHA will integrate GetFile more deeply, leveraging these capabilities to streamline data distribution and reproducibility. As an open-source Java framework, GetFile also has potential for broader adoption in scientific software outside of the OpenSHA ecosystem.

Learn more about GetFile, its use in OpenSHA, and see video demonstrations at https://strike.scec.org/scecpedia/GetFile.

5. UCERF3-ETAS in High Performance Computing

UCERF3-ETAS combines the long-term UCERF3 earthquake rupture forecast with the Epidemic-Type Aftershock Sequence (ETAS) statistical model, which describes how earthquakes trigger their own aftershocks in space and time. Implemented in OpenSHA, it produces large ensembles of stochastic catalogs that can be used to generate multiple outputs, including hazard curves, aftershock rate forecasts, and gridded nucleation maps. The gridded nucleation map summarizes the average spatial distribution of earthquake starting points across all simulations, highlighting regions where earthquakes are statistically more likely to begin based on historical and spontaneous seismicity. Larger ensembles, such as 10,000, 20,000, or 100,000 simulations, reduce stochastic noise and reveal robust spatial patterns, including clustering along major faults and high-seismicity regions.

To deliver timely forecasts after significant earthquakes, UCERF3-ETAS is run on multiple high-performance computing (HPC) systems — including USC CARC Discovery, SDSC Expanse, and TACC Stampede3 and Frontera. If one system is unavailable, others can generate results without delay, which is critical for rapid aftershock forecasting and hazard assessment. The Quakeworx science gateway currently automates job submission and report generation on SDSC Expanse, with plans to support additional HPC backends in the future. This distributed infrastructure ensures both reliability and speed, helping the scientific community and emergency managers access actionable forecasts quickly.

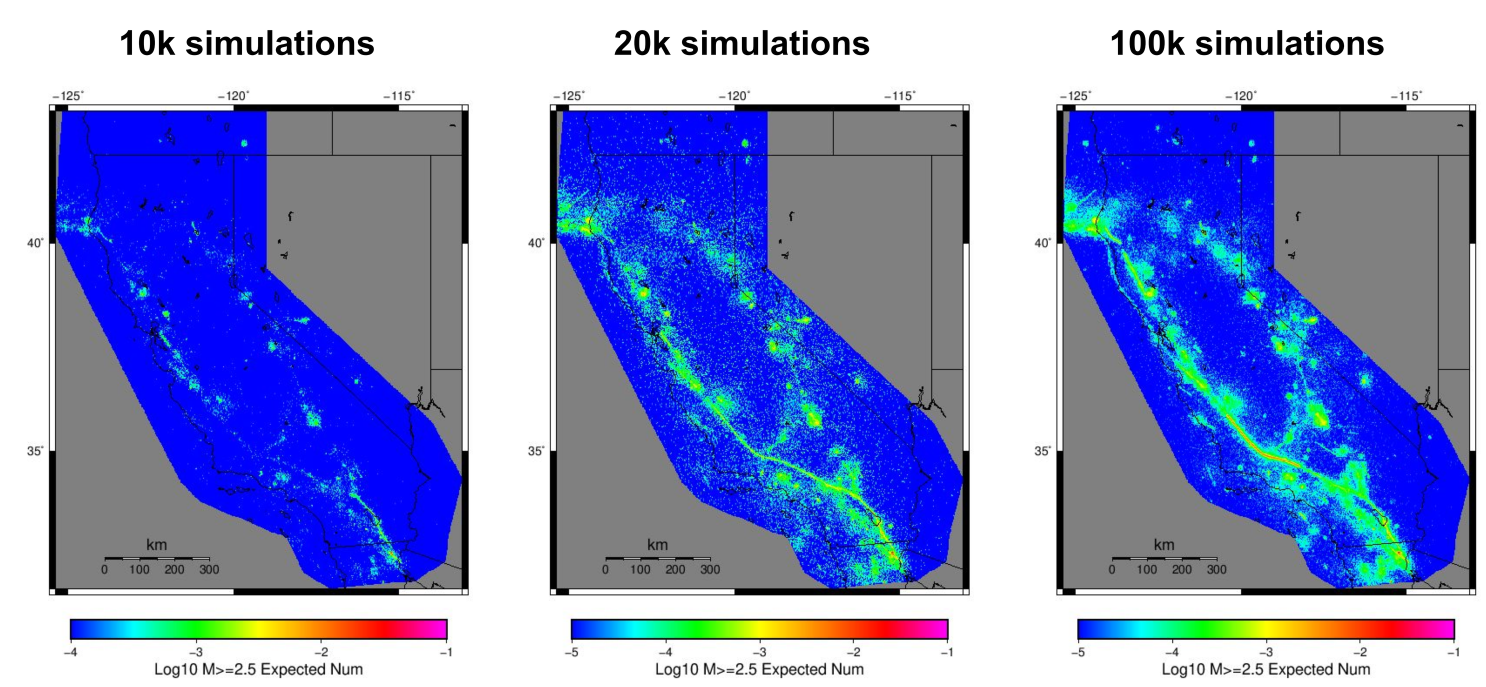

Fig 4. UCERF3-ETAS Gridded Nucleation complete catalog including spontaneous M ≥ 2.5

6. Next Steps

Upcoming OpenSHA releases will introduce new tools such as an Intensity Measure Event Set Calculator, a Loss Estimation Application, and time-dependent earthquake forecast utilities, alongside improvements to software distribution, documentation, and the user interface. These enhancements will streamline workflows, improve reproducibility, and make advanced seismic hazard analyses more accessible to the research community.

Efforts are also underway to migrate computations from traditional servers to cloud-based hyperscalers like AWS, while expanding access through the Quakeworx science gateway. This will allow scalable, flexible simulations without requiring command-line expertise. Together, these developments ensure OpenSHA continues to deliver state-of-the-art science efficiently, transparently, and reliably to the seismic hazard and risk communities.

7. Acknowledgements and References

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URLs: http://www.tacc.utexas.edu https://carc.usc.edu https://www.sdsc.edu

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Try it out: Scan the QR code on the left or navigate to the following link in a web browser to access the code as well as documentation for installing and using OpenSHA applications.

https://opensha.org