

## **USGS Earthquake Hazards Program Research Priorities for FY2023**

### **1. Introduction**

The USGS Earthquake Hazards Program (EHP) Research Priorities presented here reflect its mission within the National Earthquake Hazards Reduction Program (NEHRP) to reduce loss of lives and property from earthquakes and improve public safety and community resilience in the Nation.

Applicants should review the four major program elements and common research priorities described in section 3, as well as priority research targets listed below that are specific to each region or topic. Proposed work should advance the science that underlies EHP products by posing and testing new hypotheses and/or developing novel data acquisition tools, analysis methods, and products. Proposed work can also improve information dissemination and make research results more effective in mitigating losses from earthquakes. While proposed projects may involve collection of data and/or application of existing analysis methods, such activities should be in support of clearly stated research goals. Proposals focused on development of new products must demonstrate strong collaboration with intended users. Across all program elements, proposals focused on research targeting earthquake hazard mitigation and risk reduction in underserved communities, and in populations whose vulnerability may be directly related to socioeconomic factors, are strongly encouraged.

The EHP produces data and information on earthquakes and related hazards, but the production of data and reports alone is not sufficient to reduce earthquake risk; the Program also takes an active role with the user community in the application and interpretation of Program results. Active engagement with our user community provides opportunities for dialogues on modifications to our existing products and new products that make our work and results more relevant and applicable. The EHP supports opportunities for engaging the user community at both the national and regional levels.

### **2. Regional and topical areas**

These elements are integrated into ten Research Areas—five regional and four topical areas plus a National category:

- Central and Eastern United States (CEUS): The United States east of the Rocky Mountains, including Puerto Rico and the U.S. Virgin Islands;
- Intermountain West (IMW): From the Cascade Range and eastern flank of the Sierra Nevada to the front ranges of the Rocky Mountains, including Idaho, Nevada, Utah, and Arizona, and portions of Washington, Oregon, California, Montana, Wyoming, Colorado, New Mexico, and Texas.
- Northern California (NC): From Cape Mendocino to the central creeping section of the San Andreas fault and the adjacent Coast Ranges, with particular emphasis on the greater San Francisco Bay Area;
- Pacific Northwest and Alaska (PNA): western Washington and Oregon, California north of Cape Mendocino (Cascadia), and Alaska;
- Southern California (SC): From the Carrizo Plain south to the international border with Mexico.
- Earthquake Early Warning (EEW): Basic and applied research to improve the accuracy, reliability, and timeliness of earthquake early warning alerts generated by ShakeAlert;
- Earthquake Physics (EP): Basic and applied, geographically broad research on the physics of earthquakes;
- Engineering Seismology and Impacts (ESI): Basic and applied, geographically broad research on the

natural macroseismic effects of earthquakes including ground failure, and their impacts to the built environment; geotechnical and structural studies; connecting USGS hazard data and products to losses and risk; and research and development tied to the National Earthquake Information Center (NEIC) and the National Seismic Hazard Modeling Project (NSHMP);

- Induced Seismicity (IS): A sub-topic of Earthquake Physics (EP), basic and applied research on the physics of induced earthquakes;
- National (NAT): Research applicable nationally, especially activities related to the National Seismic Hazard Model;

### 3. Common Priority Topics and Data for all Research Areas (CEUS, ESI, EP, IS, EEW, IMW, NAT, NC, PNA, SC)

Following are priority tasks and data for the EHP Program Elements common to multiple regional and topical areas. We emphasize that this is not an exhaustive list of all potential research topics, nor intended to discourage submission of proposals to accomplish other important tasks. Examples tailored to specific topical or regional needs are noted in respective sections. Common priorities for the EHP are included in section 3.2. Although these priorities are relevant to multiple research areas, related proposals must be submitted to a single regional or topical panel, and PIs are encouraged to reach out to Coordinators to discuss the most appropriate area for submission.

Applicants are encouraged to use seismic monitoring data, including structural monitoring data, from the USGS Advanced National Seismic System (ANSS). Specific ANSS coordination priorities are included in several of the regional and topical priority areas.

#### 3.1 USGS Science Plans

Please note that the EHP encourages research proposals responsive to two USGS Science Plans in addition to priorities specified below. The first is a blueprint for advancing science and resilience from subduction zone hazards entitled *Reducing Risk Where Tectonic Plates Collide – A Plan to Advance Subduction Zone Science*. This Subduction Zone Science plan emphasizes scientific and technological developments, improved hazard assessments, addressing stakeholder needs and maximizing capabilities through partnerships to reduce the risks posed by subduction zone events. The Plan focuses on three themes: (1) advancing observations and models of subduction zone processes, (2) quantifying natural hazards and risk and (3) hazard forecasting and situational awareness. For each of these themes, the Plan describes USGS accomplishments and current capabilities, discusses specific knowledge and capability gaps, describes scientific frontiers, and summarizes key questions, needed research, required investments, and resulting products. The EHP encourages research proposals responsive to these themes.

*Science for a Risky World: a USGS Plan for Risk Research and Applications* (hereafter “**Risk Plan**”) is a roadmap to ensure that USGS hazards information is delivered and incorporated into risk assessments and other products that can be used by decision makers to reduce loss. The Risk Plan includes 23 recommendations focused on building institutional capacity in partnerships, project funding, professional staff and capabilities, product delivery, and expanding information technology capabilities. Seventeen case studies highlight USGS risk work already underway. The Plan notes that collaboration with partners from the beginning of research and product development through to message delivery and continuing during product evaluation is necessary to provide partners with information that can support actionable decisions for risk reduction.

### 3.2 Program Elements and Common Priorities.

#### Element I. **National and regional earthquake hazards assessments.**

The EHP publishes national and regional assessments of the expected degree of ground deformation and shaking, and their impacts over various time periods. These products, developed from research on earthquake locations, magnitudes, recurrence, and ground motions, are the basis of the seismic safety elements of building codes affecting construction nationwide. The EHP also prepares long-term forecasts of earthquake probabilities, as well as scenario ground motion maps of the expected shaking and ground deformation. These products support the development of cost-effective mitigation measures and practices in structure design, construction, and land use planning.

The USGS is particularly interested in research that results in improvements to the National Seismic Hazard Model (NSHM), and the assessment of earthquake hazards in large metropolitan areas. Models of seismic source, recurrence, ground motions, and site effects that may be directly incorporated into the NSHM are sought.

Common Priorities include:

- Use geodetic data to improve maps of crustal deformation and better constrain fault slip rates.
- Improve estimates of the timing, size, and effects of prehistoric or early historic earthquakes.
- Conduct geologic, geomorphic, and paleoseismic studies to estimate the timing, recurrence, rupture lengths, and magnitudes of prehistoric earthquakes on Quaternary faults.
- Use geologic data to quantify long-term (e.g., millennial scale) to short-term (e.g., earthquake-cycle scale) slip rates for Quaternary active faults and explore spatial and/or temporal slip rate variability.
- Characterize the factors that result in amplification of earthquake ground motions, such as in sedimentary basins, or where geologic structures or topography may enhance them.
- Develop ground-motion models applicable to hazards assessments.
- Improve existing 3D seismic velocity models of Earth structure onshore and offshore, particularly for sedimentary basins beneath or near urban areas, with application to earthquake source and ground motion characterization.

#### Element II. **Earthquake information, monitoring, and notification.**

The EHP supports efforts to improve the accuracy of algorithms and processes that provide information about earthquakes in near-real-time, including early warning, improved detection and location techniques, estimation of finite fault rupture extent, and refined seismic moment determinations.

However, routine monitoring activities are evaluated and funded under a separate solicitation for seismic and geodetic network operations.

Common priorities include:

- Develop and test new approaches to integrating seismic, geodetic, and other data and *a priori* information in monitoring operations, applicable to earthquake early warning, aftershock forecasting, routine earthquake monitoring, and slow slip detection and characterization.
- Advance machine learning/artificial intelligence methods for earthquake and deformation monitoring.

#### Element III. **Research on earthquake occurrence, physics, effects, impacts, and risks.**

Earthquake impact and risk assessments help emergency managers, planners, and the public prepare for future earthquakes. With the goal of improving hazard assessments, earthquake forecasts, and earthquake monitoring products, the EHP supports applied research on earthquake processes and effects. This work is focused on multi-disciplinary observations, theory, experiments, and development of testable models of

earthquake and tectonic processes and of earthquake effects (e.g., macroseismic intensities, ground shaking, ground failure, and structural response).

Common priorities include:

- Conduct research on earthquake recurrence and interactions that underpin operational earthquake and aftershock forecasting, including improved approaches for characterizing earthquake swarms.
- Conduct geologic, geomorphic, and/or paleoseismic studies to address fault segmentation, multi-fault ruptures, long-term paleoseismic records, fault length and displacement scaling relations, and empirical regressions on moment magnitude.
- Improve our understanding of the surface and subsurface rupture extent and displacement of notable historical earthquakes.
- Collect geological and geophysical data that will help characterize shear-wave and community velocity models as well as the effects of basin geometry, near-surface geology, and structure on strong ground motions and site amplification.
- Collect data and refine physical models of fragile geologic features to constrain past ground motions

#### **Element IV. Earthquake resilience, safety policy, communication, and user engagement**

The EHP produces data and information on earthquakes and related hazards, but the production of data and reports alone is not sufficient to reduce earthquake risk; the Program also takes an active role with the user community in the application and interpretation of Program results. Active engagement with our user community provides opportunities for dialogues on modifications to our existing products and new products that make our work and results more relevant and applicable. The EHP supports opportunities for engaging the user community at both the national and regional levels. As discussed above, proposals targeting earthquake hazard mitigation and risk reduction in underserved communities, and in populations whose vulnerability may be directly related to socioeconomic factors, are strongly encouraged.

- Provide collaborative engagement opportunities (workshops, etc.) for specialists and practitioners that facilitate addressing important challenges in regional and local urban areas, such as: earthquake hazard mitigation, response, preparedness, resilience; community velocity models; defining priority faults within a region for further study; fault setback planning, or similar.
- Advancing better coordination of messages across multiple agencies by examining resources for education, crowdsourcing, and emergency management tools, for disseminating earthquake information, earthquake hazard products, and post- earthquake information.
- Engage user communities to assess the efficacy of existing earthquake products and elicit their suggestions for improvements and new products.
- Develop new tools and products for increasing awareness of seismic hazard and within the general public and targeted user groups, such as emergency responders, public utilities, risk managers, decision makers, developers, and engineers.
- Develop approaches to provide earthquake hazard information needed for risk assessments, and earthquake mitigation and response planning to decision makers, emergency responders, and the public, particularly that cross local, state, and national boundaries and various levels of government.

#### 4. Proposal preparation guidance

Proposals submitted in response to this Program Announcement must indicate the Regional or Topical Research Area (CEUS, ESI, EP, IS, EEW, IMW, NAT, NC, PNA, or SC) that the proposed research addresses. Only **one** Research Area may be selected per proposal. The specific priorities noted in this attachment and addressed in the proposal must also be indicated. **Proposals applicable to a specific area in which an underserved community resides should be submitted to the relevant regional Research Area.** Although it is required to indicate the Regional or Topical Research Area when submitting a proposal, upon initial review, the regional and topical coordinators reserve the right to move proposals to the most suitable Regional or Topical Research Area.

Proposals addressing earthquake research that is national in scope and is in support of the National Seismic Hazard Model, should be directed to the National (NAT) panel. Proposals for research on foreign earthquakes should be directed to the panel for the U.S. region or topic that will most benefit from the study's knowledge or to where new techniques would be most transferable. In all instances, **if uncertain about which panel is most appropriate, please contact one or more of the coordinators for guidance.** Coordinators may also assist applicants by describing related work being done internally within the USGS, identifying existing relevant data sets, and helping applicants establish contacts with USGS researchers working in similar areas. Coordinators are listed below in the descriptions of the priorities for each panel.

Examples of past or currently funded projects in each Research Area may be found at <https://www.usgs.gov/natural-hazards/earthquake-hazards/external-grants>.

Descriptions of some USGS internal projects can be found at: <http://earthquake.usgs.gov/research>. It is strongly recommended that the applicant contact the appropriate coordinator and other USGS points of contact to learn whether the proposed work duplicates work being done internally, and how their proposed work can complement and help support the goals and objectives of internal efforts. We encourage discussions with the regional and topical coordinators before proposing work outside of goals and priorities noted in this document.

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Priority Topics for Research in the Central and Eastern U.S. (CEUS) Coordinator: Thomas Pratt, [tpratt@usgs.gov](mailto:tpratt@usgs.gov)

A major priority for research in the CEUS is to refine seismic hazard estimates encapsulated in the National Seismic Hazard Model, which is used in the development of building codes and for emergency planning. Hazard assessments for the CEUS are based largely on the historical earthquake catalog and a small number of specific fault sources with a known history of earthquakes. Identifying and characterizing active faults and the frequency of large earthquakes on them are priorities. A second major priority is improving and reducing uncertainties in estimates of strong ground motion for the National Seismic Hazard Model, and in particular for areas with extensive sediment layers such as the Atlantic Coastal Plain, the Mississippi Embayment region, and the large sedimentary basins elsewhere in the CEUS. A third major priority is to understand the causes of seismicity in this intraplate setting. Priority for all these topics will be given to studies that affect multi-state regions such as characterizing major seismic source zones, estimating ground motion effects from widespread geologic units, improving our understanding of processes causing CEUS earthquakes, or improving our knowledge about important large earthquakes in the region.

Contact the CEUS Coordinator to learn more about the status of internally supported projects or to discuss potential proposals. Studies of CEUS earthquakes resulting from human activities such as wastewater injection should be directed to the **EP** panel (see Section 4).

In addition to the common priorities listed in section 3.3, the following priority tasks are identified under each element:

#### **CEUS Element I. National and regional earthquake hazards assessments.**

- Assess the seismic potential of earthquake source zones and active faults in the CEUS. Emphasis should be on areas where studies could have the greatest impact, either due to a lack of knowledge about a source fault or zone or because complementary data provide a high chance of a significant change in our assessment of the hazard.
- Improve assessments of the earthquake potential of Puerto Rico and surrounding offshore faults, the Antilles subduction zone as pertains to hazards in U.S. territories, ground motions in the region, an associated hazards (landslides, tsunamis, ground failure) to the U.S. Caribbean territories and Atlantic seaboard. This topic is of special relevance given the ongoing seismic activity in southern Puerto Rico, and we encourage studies that analyze data from that sequence, or complementary studies to help understand the tectonic setting and causes of the seismicity.
- Conduct reconnaissance paleoseismic studies of CEUS regions outside of known source zones to assess whether there is a history of strong ground shaking, or to determine the frequency of strong shaking. Examples might include studies of fragile geologic structures (stalactites, balanced rocks), mapping and analyses of paleoliquefaction features, or constraints from possible earthquake- or shaking-induced slope failures such as landslides, turbidites or rockfalls.
- Improve estimates of site response and liquefaction potential using field experiments, existing instrumental recordings or modeling studies, with an emphasis on geologic units that underlie large areas of the CEUS.

#### **CEUS Element II: Earthquake information, monitoring and notification.**

- Estimate earthquake source characteristics, calibrate seismic magnitude scales, and characterize wave propagation and attenuation in the CEUS including basin effects.
- Systematically evaluate the temporal and spatial distributions of foreshocks and aftershocks of

intraplate earthquakes to improve declustering of seismic catalogs and understanding of earthquake processes. Determine whether seismic activity in an area represents aftershocks of larger prehistoric earthquakes.

- Reduce earthquake location errors using improved regional velocity models or location methodologies.
- Improve detection capabilities for current monitoring or enhancement of catalogs using machine learning/artificial intelligence methods to reduce detection thresholds.

**CEUS Element III. Research on earthquake occurrence, physics, effects, impacts, and risks.**

- Develop physical models of long-term deformation in intraplate areas including both onshore and offshore areas of the CEUS. Proposals may address topics such as the causes of large earthquakes, regional migration of seismicity, and earthquake clustering.
- Determine the tectonic processes that cause earthquakes in specific areas of the CEUS but not in adjacent, less seismically active areas.
- Reduce uncertainties in the interpretation of GPS data in regions with low rates of seismic strain accumulation and use geodynamic modeling for assessment of earthquake-generation processes.

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Priority Topics for Research in the Intermountain West (IMW) Coordinator:  
Christopher DuRoss, [cduross@usgs.gov](mailto:cduross@usgs.gov)

Priorities for research in the IMW focus on the collection of data that directly contribute to regional seismic hazard assessments such as the USGS National Seismic Hazard Model (NSHM). High priority issues to be addressed in proposed work are listed below for each EHP program element, although other proposal topics will be considered.

In addition to the common priorities listed in section 3.3, the following priority tasks are identified under each element:

**IMW Element I. National and regional earthquake hazards assessments.**

- Improve source models for IMW faults deemed priorities by each State (below). These studies could include investigations that determine late Quaternary slip rates, paleoseismic chronologies, earthquake recurrence, and segmentation of fault sources.
  - **Nevada:** A list of fault studies recommended by the Nevada Bureau of Mines and Geology is available at: [http://www.nbmng.unr.edu/docs/Earthquakes/NBMG\\_priorities\\_NEHRP.pdf](http://www.nbmng.unr.edu/docs/Earthquakes/NBMG_priorities_NEHRP.pdf)
  - **Utah:** Priority faults deemed to need further study have been identified by the Utah Quaternary Fault Parameters Working Group (UQFPWG). An updated list of these priorities as defined by the UQFPWG is available at: <https://geology.utah.gov/hazards/earthquakes-faults/utah-earthquake-working-groups/>
  - **Elsewhere in the IMW:** Priority faults are summarized in a workshop report at [http://ugspub.nr.utah.gov/publications/misc\\_pubs/mp-15-5/mp-15-5\\_workshop.pdf](http://ugspub.nr.utah.gov/publications/misc_pubs/mp-15-5/mp-15-5_workshop.pdf)
- Compile and/or update regional information on Quaternary fault geometry and source parameters (e.g., paleoseismic history and fault slip rate) to support the USGS NSHM.

**IMW Element II. Earthquake information, monitoring, and notification.**

- Use seismic data to improve determinations of IMW earthquake source characteristics, crustal structure, subsurface fault geometry, and fault rupture extent.

**IMW Element III. Research on earthquake occurrence, physics, effects, impacts, and risks.**

- Conduct studies that address scientific issues that are particularly important for understanding the potential hazard and its uncertainty posed by IMW faults, including: (1) prehistoric earthquake identification and correlation to determine fault rupture length, (2) fault segmentation and multi-fault ruptures, (3) long-term paleoseismic data and slip histories, (4) lacustrine paleoseismic data and tsunami hazard, (5) fault scaling relations (e.g., between fault length and displacement) and empirical regressions on moment magnitude, (6) relations between subsurface fault geometry (e.g., planar versus listric) and surface rupture, and (7) fault creep and afterslip.
- Conduct studies that will improve our understanding of large historical earthquakes in the IMW, such as the M5.7 Magna, Utah, M6.5 Monte Cristo Range, Nevada, and M6.5 Stanley, Idaho earthquakes. Research topics could include surface displacement along fault strike, rupture length and termination at structural complexities, distributed or off-fault deformation, and evidence of strong shaking in epicentral regions.
- Collect geological, geophysical, and geotechnical data that develop and refine community velocity models in urban areas of the IMW region. Appropriate data sets could include shear-wave velocities,



density of near-surface units, attenuation measurements, basin geometry and structure, and mapping of subsurface faults and folds.

- Conduct research on the development and integration of seismic shear-wave velocities from multiple scales throughout the region, particularly the joint analysis of multi-scale datasets in urbanized sedimentary basins.
- Develop geological, geophysical, and geotechnical models to characterize the effects of basin geometry, near-surface geology, and structure on strong ground motions and site amplification.
- Conduct studies to develop or improve deformational and seismotectonic models in the IMW region, for example, to characterize regions of distributed tectonic deformation and explore connections between subsurface structures and surface observations of faulting.
- Conduct earthquake hazards research that targets regions of high hazard and risk. Specific areas of interest include, but are not limited to, the Wasatch Front and southwestern (e.g., St. George) regions of Utah, the Reno-Carson City urban corridor, Las Vegas and surrounding urban areas of Nevada, northern Basin and Range cities (e.g., in Idaho, Montana, Wyoming, and Oregon), and lacustrine basins such as the Great Salt Lake and Lake Tahoe.

#### **IMW Element IV. Earthquake resilience, safety policy, communication, and user engagement.**

In addition to Section 1, IMW focused priorities are:

- Collaboration (e.g., State or regional working groups) and community outreach on important problems in IMW urban areas and risk reduction in underserved and/or vulnerable communities.

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Priority Topics for Research in Northern California (NC) Coordinator: Keith Knudsen,  
kknudsen@usgs.gov

The Northern California component of the EHP is charged with characterizing seismic hazard throughout Northern California. The primary area of concern is the urbanized San Francisco Bay region, extending from Monterey to Willits, and from the Central Valley to the Pacific Coast: this region bears more than 25% of the nation's annualized seismic risk. Research in Northern California outside this urbanized region may also be supported, with appropriate justification, to understand this plate boundary system and/or to evaluate hazards to critical infrastructure. Please feel free to contact the NC Coordinator to learn more about coordination with internally supported projects and/or to discuss potential proposals.

In addition to the common priorities listed in section 3.3, the following priority tasks are identified under each element:

**NC Element I. National and regional earthquake hazards assessments.**

- Conduct geologic, geomorphic and paleoseismic investigations to estimate the timing, recurrence, rupture lengths, estimates of slip in historical and prehistoric earthquakes, and magnitudes of prehistoric earthquakes on hazardous faults in Northern California;
- Improve source models for Northern California faults and compile and/or update regional information on fault geometry and source parameters to support the USGS National Seismic Hazard Model;
- Use crustal deformation measurements and geologic studies to constrain and document regional deformation rates, fault slip rates, fault creep, fault mechanics, strain transients, and stress evolution;
- Develop methods to forecast coseismic and post-earthquake slip on faults that produce surface-rupturing earthquakes in Northern California;
- Validate and improve community regional 3D geologic and seismic velocity models for the Bay Area and Northern California, with emphasis on basins;
- Characterize shallow shear wave velocity structure throughout Northern California, particularly at stations that have recorded strong ground motion.

**NC Element II. Earthquake information, monitoring, and notification.**

- Use seismic data to improve characterization fault source characteristics, subsurface geometry and fault rupture extent;
- Integrate and improve seismic and geodetic monitoring efforts in Northern California, in particular to enable recognition of anomalous or precursory behavior;
- Assess creep rates and locations to identify fault coupling, frictional properties, and transient aseismic events, and also identify locations/faults that do not creep;
- Measure crustal strain at a variety of scales from site to regional scale using creep meters, borehole strain meters, GPS, InSAR, etc.;
- Identify and catalogue repeating earthquakes to understand fault frictional behavior and asperities.

**NC Element III. Research on earthquake occurrence, physics, effects, impacts, and risks.**

- Develop, refine, and test probabilistic models for earthquake rupture in Northern California, in coordination with USGS efforts;
- Evaluate models for strain transfer along fault systems, especially systems in the East and North Bay;
- Identify and apply methods to address the “connectedness” of faults and fault segments, and identify

data that might be used to constrain the lengths of ruptures in future rupture forecasts and probabilistic hazard assessments;

- Evaluate inputs, and improve methods and input data needed to characterize regional landslide, liquefaction and lateral spread potential, and apply these new methods to hazard mapping in Northern California.

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## Priority Topics for Research in the Pacific Northwest and Alaska (PNA)

Research priorities for the Pacific Northwest and Alaska are considered by a combined panel, but priorities specific to each region are listed separately below. PI's are encouraged to contact the coordinators listed below, for coordination with internally supported projects and/or to discuss potential proposals.

### *9.1 Priority Topics for Research in the Pacific Northwest (PNA-Pacific Northwest)*

*Pacific Northwest Coordinator for External Research: Joan Gomberg, gomberg@usgs.gov*

Research proposed should advance understanding of earthquake-related processes by stating and testing new hypotheses and/or developing and employing novel data sets and analyses. Use of the following existing data sources is encouraged: 1) Advanced National Seismic System and Canadian National Seismographic Network and strong motion networks in Cascadia; 2) the NSF-sponsored Cascadia Initiative onshore-offshore deployments; 3) Network of the Americas GPS sites, strainmeters, tiltmeters, and strong motion sensors; 4) high-resolution LiDAR, InSAR, potential field, and other remote sensing data; 5) the Pacific Northwest Geodetic Array (PANGA) GPS stations and tiltmeters; and 6) the Ocean Networks Canada and Oceans Observatory Initiative off-shore cabled networks. Research that leverages relevant activities sponsored by other agencies and institutions also is encouraged, such those that support development of the SZ4D Initiative (see <https://www.sz4d.org>), and outcomes of the 2021 NSF-supported collaborative amphibious controlled source seismic experiment to image Cascadia's megathrust and the subducting and overriding plates. Topics noted below should focus on the Cascadia subduction zone region, although research elsewhere with clear relevance may also be proposed. Product development activities should demonstrate user involvement in product conception, implementation, and evaluation.

In addition to the common priorities listed in section 3.3, the following priority tasks are identified under each element:

#### **PNA-Pacific Northwest Element I. National and regional earthquake hazards assessments.**

- Clarify the distribution and stationarity of locking along the plate-boundary (megathrust), particularly offshore.
- Develop numerical, observationally validated, ground motion models that include complex wave propagation effects for Cascadia M8-9 plate-interface earthquakes, in-slab and upper-plate earthquakes.
- Characterize heterogeneities on the plate interface that may affect seismic radiation, particularly those likely to generate high-frequency strong ground motions.
- Develop approaches and observational inputs for temporal and spatial earthquake and aftershock forecasting, which account for potential differences among upper-plate, interplate and intraplate settings.
- Improve estimates of the sizes, recurrence intervals, and effects of past, late Quaternary earthquakes in the regions of the Puget Sound, Olympic Mountains, Yakima fold and thrust belt, the Columbia Plateau, and Portland and Tualatin basins and vicinity. Augment seismic intensity data for historical earthquakes.
- For the Cascadia megathrust, improve estimates of its earthquake recurrence intervals, magnitudes, and rupture lengths, particularly that probe discrepancies between onshore and offshore evidence. Test potential links between megathrust and upper-plate faulting.

- Evaluate earthquake-induced ground failure potential (*i.e.*, landslides and liquefaction), particularly in populated areas, transit corridors, and near bodies of water where landslides could generate hazardous local tsunamis or form hazardous temporary dams.
- For plausible earthquake scenarios, model tsunami generation and inundation, collect data on and/or compare with paleo-tsunami deposits for model validation, and evaluate likely tsunami hazard variability.
- Quantify maximum magnitudes and occurrence probabilities of outer-rise and intraplate Cascadia earthquakes.

**PNA-Pacific Northwest Element II. Earthquake information, monitoring, and notification.**

- Develop and apply new approaches and technologies for measuring seismic and aseismic geodetic deformation offshore.

**PNA-Pacific Northwest Element III. Research on earthquake occurrence, physics, effects, impacts, and risks.**

- Improve estimates of fault-zone properties that may influence rupture area and fault slip. Quantify the relationship between slow slip events and earthquake potential.
- Evaluate potential interactions between interplate, intraplate, and upper-plate faults.
- Conduct studies of the transition from strike-slip to convergent boundaries (e.g., at the Mendocino Triple Junction).
- Develop computer models applicable to Cascadia that simulate multiple earthquake cycles, and that link rupture-related phenomena (e.g., tsunami, ground failure, turbidity current generation).

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USGS needs basic information to characterize the active earthquake sources in Alaska for use in updating the seismic hazard maps of Alaska and for informing the tsunami hazard of Alaska. The EHP encourages proposals for studies that take advantage of the Alaska Amphibious Community Seismic Experiment (AACSE) and EarthScope's Transportable Array deployment. High priority issues to be addressed in proposed work are listed below for each program element, although other proposal topics will be considered. Contact the Alaska Coordinator to learn more about internally supported projects or to discuss potential proposals.

In addition to the common priorities listed in section 3.3, the following priority tasks are identified under each element:

**PNA-Alaska Element I. National and regional earthquake hazards assessments.**

- Improve the paleoseismic and paleogeodetic record of large to great earthquakes and tsunamis along the Alaska-Aleutian megathrust, including assessing the persistence, or non-persistence of rupture boundaries, recurrence intervals, and whether or not presently creeping sections of the megathrust have produced past great earthquakes.
- Perform lacustrine paleoseismology research to assess the record of strong ground motions along the subduction zone from megathrust, intraslab, and crustal earthquakes. Evaluate if lake sediments record historical earthquakes and events identified by other paleoseismology and paleotsunami records.
- Conduct geodetic field studies and/or modeling of geodetic data to resolve plate coupling and the role of aseismic slip on the potential for, and/or recurrence time of, large earthquakes along the Alaska-Aleutian megathrust, or the Queen Charlotte Fault and across southeastern Alaska.
- Examine large intraslab earthquakes, including the October 2020 Shumagin Islands, 2018 Anchorage and the 2016 Iniskin earthquakes, in order to better define the hazard, ground motions, and potential of these events along the subduction zone.
- Examine the Alaska Amphibious Community Seismic Experiment (AACSE) seismic data to better understand earthquake hazards along the megathrust in the region from Kodiak to Sanak Island.
- Evaluate the location, length, and nature of slow-slip events in Alaska, and particularly their relationship to down-dip and up-dip limits of co-seismic slip, or earthquake potential, along the Alaska-Aleutian megathrust.
- Develop methods and utilize geodetic data to estimate slip rates along faults or across regions that can be applied to seismic hazard analyses. Construct self-consistent models of crustal deformation that integrate seismic, geologic, and geodetic data from which hazard estimates can be derived.
- Improve the understanding of active faulting, historical seismicity, and the paleoseismic record of large earthquakes on major crustal faults in Alaska, including the Denali, Totschunda, Fairweather, Queen Charlotte, Castle Mountain, Tintina, and Kaltag faults, and on subsidiary and related faults such as the Northern Alaska Range Thrust System. In particular, increase knowledge of the Queen Charlotte-Fairweather fault system and its geologic structure and tsunami potential.
- Use high-precision hypocenter location methods and/or high-resolution topographic datasets to identify the extent and geometry of unmapped faults in so-called seismic zones.
- Conduct studies to map active faults, define their earthquake history, and seismic potential on and near major crustal faults in Alaska.
- Investigate megathrust splay faults in the accretionary prism of the Alaska-Aleutian subduction zone to better define where they occur, their slip histories, and potential implications to tsunami hazard.

## **PNA-Alaska Element II. Earthquake information, monitoring, and notification.**

- Develop region-specific relationships for inferring seismic wave velocities from seismic or rock type data. Develop 3-D community seismic velocity models for Alaska that are validated against earthquake catalog data to support improving earthquake locations, simulating ground motions, determining source mechanisms, evaluating sedimentary basin ground motion amplification and the calculation of probabilistic hazard maps.
- Develop and test new approaches to integrating seismic, geodetic, and other data and a priori information in monitoring operations, applicable to earthquake early warning, routine earthquake monitoring, and slow slip detection and characterization.
- Advance machine learning/artificial intelligence methods for earthquake and deformation monitoring.

## **PNA-Alaska Element III. Research on earthquake occurrence, physics, effects, impacts, and risks.**

- Evaluate the potential interactions among subduction-zone faults, intraslab faults, splay faults, and crustal faults and the impacts of such interactions on seismic hazard.
- Develop physical and statistical models that may be used in earthquake hazard and risk assessments for the range of source types and seismicity patterns in Alaska.
- Develop empirical or simulation-based ground motion models that incorporate three-dimensional seismic structure and consider a range of earthquake source scenarios and complexity.
- Improve ground motion models for subduction interface and deep intra-slab earthquakes for use in the Alaska update of the National Seismic Hazard Model (see NAT priorities).
- Characterize site conditions at Advanced National Seismic System (ANSS) National Strong Motion Network stations outside of the Anchorage bowl for developing statewide ground motion prediction equations.
- Improve understanding of co-seismic ground failure by better accounting for ground displacements that were neither classic liquefaction nor proper landslides. Advance models for estimates of liquefaction and landslides, which are currently rather crude both in terms of the underlying empirical framework and input data. Assess the potential for large volume/high mobility co-seismic rock avalanches in Alaska.

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Priority Topics for Research in Southern California (SC), Coordinator: Katherine Scharer,  
kscharer@usgs.gov

Southern California is a region of complex geology containing large mountain ranges, deep sedimentary basins, and numerous active faults. To better quantify the hazard from future earthquakes in this region, it is necessary to improve our understanding of fault characterization, earthquake rupture properties, and seismic wave propagation at local and regional distances using a combination of field observations, analysis of monitoring data, and modeling approaches. Contact the SC Coordinator to learn more about internally supported projects or to discuss potential proposals.

In addition to the common priorities listed in section 3.3, the following priority tasks are identified under each element:

**SC Element I. National and regional earthquake hazards assessments.**

- Refine models of relative or absolute activity of offshore faults system using geophysical data and chronostratigraphic constraints from sediment cores.
- Investigate the surface deformation field from past buried or distributed faulting, and model potential future effects on the built environment.
- Develop methods or facilitate use of machine learning techniques in investigations of large spatial and/or temporal datasets in seismology, geodesy and earthquake geology.
- Refine estimates of the interseismic deformation field including vertical deformation and post-seismic transients from historic ruptures.
- Improve information on basin structure and methods to integrate basin models of varying resolution.
- Develop and test ground motion simulation models with application to addressing seismic hazards in Southern California.
- Advance the use of ground motion records (natural or synthetic) to constrain ground motion simulation models.
- Develop new, improved, or alternative models of 3D fault, seismic velocity, and seismic attenuation structures. Integration of these models within the existing SCEC Community Fault and Velocity Models is strongly encouraged.
- Develop methods to improve the treatment of site and path effects into existing models, including ergodic and non-ergodic models, and linear and non-linear site effects.
- Develop, refine, and test probabilistic models for earthquake rupture using or advancing the approach provided by the Uniform California Earthquake Rupture Forecast-3 (UCERF3) Report.

**SC Element II. Earthquake information, monitoring, and notification.**

- Use seismic data to determine earthquake source parameters, fault and crustal structure and the state of stress in the crust, including further development and testing of 3-D structural models. Integration of results with the existing SCEC Community Fault and Stress Models is strongly encouraged.
- Develop methodology to improve the characterization of instrumentally-recorded notable earthquakes and earthquake sequences, including interactions between events.

**SC Element III. Research on earthquake occurrence, physics, effects, impacts, and risks.**

- Test earthquake recurrence models and address contemporaneity of ruptures along major faults through development of long or spatially targeted paleoseismic records.
- Develop methods to distinguish or characterize rates of past earthquakes vs. creep events.



- Develop methods to assess rupture directivity and speed from past earthquakes.
- Improve characterization of the processes that drive earthquake occurrence, including tectonic loading, short-term static and dynamic stresses, fluids, and aseismic slip.
- Investigate characteristics, causal mechanisms, and interactions between fluid-driven and tectonic swarms.
- Develop methods to estimate variations in expected ground motions, accounting for local geological structure, topography, and soil-structure interaction.
- Develop methodologies to characterize earthquake ruptures for use in ground motion simulations. Approaches including multi-segment ruptures and/or complex fault geometries are encouraged.
- Use ground motion simulations and/or recordings of past earthquakes to quantify the expected level and distribution of shaking over a broad frequency range (e.g., 0-20 Hz) for future large earthquakes.

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Priority Topics for Research on Earthquake Early Warning (EEW) Coordinator:  
Jeffrey McGuire, [jmcguire@usgs.gov](mailto:jmcguire@usgs.gov)

Earthquake early warning (EEW) systems aim to provide advance warning of specified earthquake ground motion levels to populations in order to mitigate losses. The USGS operates the ShakeAlert Earthquake Early Warning System for the United States West Coast (<https://earthquake.usgs.gov/research/earlywarning>). The EHP encourages proposals for studies that clearly demonstrate how the proposed research can be applied to improve the accuracy, reliability, and timeliness of ShakeAlert Messages issued by the USGS which in turn are used by distribution providers (e.g., apps, transportation agencies, etc.) for the development and delivery of alerts to people and automated systems.

The EHP supports efforts focused on scientific research on the topics identified below. However, all other monitoring and notification activities are evaluated and funded under a separate solicitation for seismic and geodetic network operations. Furthermore, operationalization, testing and upkeep of current ShakeAlert algorithms are not supported under this Program Announcement.

Proposers are strongly encouraged to contact the EEW Research Coordinator to learn more about internally supported projects or to discuss potential proposals.

In addition to the common priorities listed in section 3.3, the following priority tasks are identified under each element:

## EEW Element II. **Earthquake information, monitoring and notification.**

- Advance existing algorithms and processes, or develop novel techniques, to improve the timeliness and accuracy of predicted ground motions used to issue earthquake early warning alerts. Examples include algorithms that identify the finite fault extent, improve early magnitude or location estimates, improve estimates of parameter uncertainty, estimate expected ground motions directly from observed ground motions, methods that incorporate directivity into predicted ground motions, or real-time methods to estimate the probability that a fault rupture will continue or terminate.
- Improve methods used to combine source and/or ground motion information from multiple algorithms in order to generate a single, high-quality alert stream.
- Improve methods for using seismic algorithm output as prior information for geodetic algorithms or for algorithms that combine seismic and geodetic data to improve source parameter or predicted ground motion estimates.
- Identify and assess novel instrumentation for use in earthquake early warning systems, including lower-cost sensors and fiber-optic based methods. Any proposal to use new instrumentation should clearly demonstrate its value in terms of improved (e.g. faster, more reliable) alerts, augmentation of existing network-based systems, or other considerations relative to existing real-time data streams used by ShakeAlert.
- Proposals to develop continuous, open test datasets of either seismic waveforms or derived parametric data from low-cost sensors and/or Internet of Things and/or fiber-optic based methods are encouraged, particularly from geographic areas covered by ShakeAlert and time intervals that are long enough to include earthquakes of sufficient shaking intensity to issue alerts as well as a representative sampling of possible noise sources.
- Investigate if ShakeAlert's use of the internet for data telemetry and alert delivery is sufficiently resilient to be effective during large earthquakes including quantification of likely telemetry delays and/or outages in such events.
- Evaluation and prototyping the use of artificial intelligence, machine learning, edge computing and

cloud computing to improve the ShakeAlert system.

- Evaluation of near-fault arrays for resolving rupture propagation and improved ground motion forecasts.
- Evaluation of the algorithms, data streams, and telemetry methods that would allow efficient use of offshore instrumentation in Cascadia to improve ShakeAlert warnings for large offshore earthquakes, particularly the evaluation of distributed acoustic sensing systems utilizing submarine cables and also telemetered buoys.
- Improve performance evaluation metrics used to assess the accuracy and timeliness of predicted ground motions issued by earthquake early warning systems, and assess the cost benefit for end-users in threshold-based applications.
- Holistic comparative assessment of earthquake early warning algorithm performance, in a theoretical and empirical framework.
- Improve the identification and classification of seismic phases in real-time to better discriminate earthquake signals versus noise, P-wave versus S-wave phases, local versus teleseismic earthquakes.
- Improved EEW algorithms for forecasting shaking in tall buildings and evaluation of user experiences in tall buildings to determine appropriate alerting criteria.
- Investigation of ShakeAlert technical partner alerting needs (e.g., assessing who needs alerts at high MMI values).

### **EEW Element III. Research on earthquake occurrence, physics, effects, impacts, and risks.**

- Reduce uncertainties in ground motion predictions that demonstrates improved accuracy of earthquake early warning alerts, particularly in high-risk urban areas. This could include incorporation of real-time site response at ShakeAlert seismic stations, rapid source characterization (including stress drop), calibration of seismic magnitude scales, new approaches to using finite fault information to predict ground motions, and characterization of wave propagation and attenuation, including basin effects.
- Evaluate suitability of existing broadband synthetics for use in testing EEW systems, or develop new synthetics if appropriate ones do not exist. Synthetics of particular interest are scenarios for which there are no available ground motion recordings along the west coast of the US, including: isolated, large-magnitude scenario events, especially at close distances to population centers; and complex sequences of events including doublets, mainshock-aftershock sequences, and/or swarms.
- Develop uncertainty measures that are consistent across EEW algorithms. Develop methods that consider both the uncertainty in parameter estimates (shaking intensity) and the likelihood that an alert is a true earthquake.
- Evaluation of user experiences in tall buildings, including the identification of useful alert metrics and strategies.

### **EEW Element IV. Earthquake resilience, safety policy, communication, and user engagement.**

#### **In addition to Section 1, ShakeAlert focused priorities are:**

- Advance messaging, communication, and education strategies for critical ShakeAlert topics such as use of countdowns for alert delivery to wireless devices like cell phones, the late alert zone, complex earthquake sequences, and other topics that communicate appropriate expectations from and the limitations of the ShakeAlert System.
- Support the implementation of drills and exercises via social science research to determine ideal formats, timing, drill cues (e.g., sounds, messages, accommodation(s) for those with access and functional needs), as well as the evaluation of these activities.

- Explore new and emergent communication technologies to increase the reach of ShakeAlert to diverse audiences.
- Advance ShakeAlert education and training in multiple languages while accounting for linguistic, social, and cultural differences and/or limited written or oral proficiency.
- Explore how to improve ShakeAlert to be inclusive and accessible to diverse populations including those with access and functional needs.
- Research channels to provide access to ShakeAlert for people without access to technologies due to disabilities, socioeconomic variances, and/or other factors.
- Analyze education materials (e.g. text books, curriculum guides, videos, posters, brochures, and other ephemera), to determine key themes and gaps about EEW systems, protective actions, and earthquake behavior.
- Explore potential iconography, images, sounds, or other cognitive tools that can improve various communities understanding and use of ShakeAlert and protective actions.
- Analyze human behavior and responses to people receiving a ShakeAlert-powered alert.
- Compare and contrast ShakeAlert public performance to other EEW systems.
- Advance understanding of how ShakeAlert can catalyze discourse about retrofitting and improving building codes.
- Study integration of ShakeAlert into educational environments (e.g., K-12 schools, daycare and early childhood learning environments, libraries, museums, etc.) and how they are utilizing this technology for the benefit of learners, educators, and staff.
- Exploring counter narratives of technical partners regarding ShakeAlert responses.
- Communication, education, and outreach projects specific to ShakeAlert including but not limited to building awareness, education and training, and the integration of earthquake early warning with other tools for earthquake risk reduction.
- Examine issues of trust in channel providers for warnings e.g., app providers, IPAWS, and others.
- Social media analysis of how people responded online to various alerts sent by ShakeAlert alert providers, as well as better understand sentiment and discourse online about the system.
- Assess the limits of over-alerting from a social science perspective (e.g., What forms of over alerting will cause users to not act when they receive future ShakeAlert-powered alerts?).
- Research on how ShakeAlert education can be incorporated into supporting school programs like afterschool programs, museum experiences, displays, curriculum units, either by schools or through not-for-profit organizations.
- Examine potential risks of over-alerting with the addition of ShakeAlert to the Integrated Public Alerts and Warning Systems (IPAWS) portal, which is being used for multiple purposes, e.g., to distribute Wireless Emergency Alerts (WEAs), including AMBER alerts, Blue and Silver alerts, Weather warnings, and other types of alerts.

Priority Topics for Research on Earthquake Physics and Occurrence (EP) Coordinator:  
Nick Beeler, nbeeler@usgs.gov

In addition to the common priorities listed in section 3.3, the following priority tasks are identified:

**EP Element III. Research on earthquake occurrence, physics, effects, impacts, and risks.**

- Refine and evaluate existing physical and statistical models, compile observational data to test models, or develop and test new predictive models for earthquake occurrence, failure, time to failure, frequency-magnitude distributions, and clustering. Goals could be developing and rigorously testing methods for operational earthquake and aftershock forecasting or developing testable probabilistic or deterministic models for the earthquake cycle and recurrence. Validate and test such models Collaboratory for the Study of Earthquake Predictability (CSEP) software or procedures. Develop new methods for the testing and validation of these models and understanding the effects of changing catalogs and data uncertainties in the forecasts.
- Develop strategies for estimating time-dependent earthquake probabilities and the likelihood of strong shaking, accounting for time since the last event and to reflect complexity such as non-uniform earthquake slip, earthquake clustering, fault interactions, transient deformation, cascading ruptures, and varying fault segment boundaries. Develop testable physical models and theory of multi-fault or multi-segment interactions, in particular addressing what factors control the location, occurrence time, and extent of large earthquake ruptures.
- Quantify processes controlling fault stress and strain accumulation, transfer, and release over the range of tectonic settings and faulting geometries. Reconcile deformation rates inferred from geodetic, geologic, and seismic observations, and differences between depth of seismic rupture versus the "locking" depth based on geodetic or heat flow analysis, in particular whether large earthquakes rupture into areas that are apparently slipping steadily during the interseismic period. Better determine the origin, mechanisms, and duration of post-earthquake deformation, including the relation of aftershocks and other triggered seismicity to deformation and pore fluid pressure in and below the seismogenic zone.
- Determine, refine, and test fault constitutive laws for the earthquake cycle, through laboratory, field, and seismic observations, heat flow studies, and numerical modeling. Use samples, core cutting analyses, downhole measurements and monitoring results from fault-zone drilling projects, where relevant. Determine relations among fault properties, the dynamics of the earthquake source, earthquake nucleation, and ground motion.
- Through observation, modeling, and experimentation, improve understanding of the interactions among rheology, material properties, fault geometry and the free surface boundary condition in determining coseismic motion on the shallow extent of faults. Better determine controls of the near surface extent of faulting on ground motion and tsunami-genesis.
- Develop theory, models, and make field and laboratory measurements of fault zone properties, including damage, permeability, dilatancy, localization, alteration, mineralogy, roughness, shear zone width, and evolution with accumulated offset and shear strain. Determine differences in the physical properties among plate boundary faults, smaller scale fault zones, faulting environments, and further establish the implications of fault zone age and total strain for seismicity, and fault and earthquake mechanics. Observe and evaluate post-mainshock changes in properties, using monitoring data, laboratory measurements on recovered core samples, active source studies, fault zone guided waves, borehole seismic networks, and other geophysical techniques.
- Using seismology, geology, geodesy, available geophysical methods, or a combination of these approaches, determine why earthquake stress drops are on average small, largely independent of scale, depth, temperature, faulting environment, and the amount of shear generated heat. Research

may include improved methods for determining stress drop and fundamental constraints on the earthquake energy budget.

- Conduct field and laboratory studies on mechanisms responsible for episodic tremor and slip (ETS). Determine the mechanical relation between ETS and other transient deformations and the occurrence of earthquakes or provide information that constrains time-dependent earthquake probabilities. Research may include consideration of the brittle- ductile transition, frictional properties, and mineral reactions.
- Develop, improve, and implement long-term, fault system-scale earthquake models to understand predictability in complex fault networks over the range of observed earthquake magnitudes. Priority improvements in the physics of simulators include incorporating off-fault seismicity, dynamic weakening, off-fault viscoelasticity, elastic heterogeneity, ductile deformation in the lower crust and upper mantle and alternative loading schemes. Produce synthetic earthquake catalogs; analyze synthetic catalogs for statistically significant patterns, predictability, clustering, and triggering, and determine the statistical similarities (differences) between simulated and real catalogs. Develop algorithms that can be applied in seismic hazard assessments and compare results with traditional forecasting approaches.

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Priority Topics for Research on Induced Seismicity (IS) Coordinator:  
Nick Beeler, nbeeler@usgs.gov

In addition to the common priorities listed in section 3.3, the following priority tasks are identified:

**IS Element III. Research on earthquake occurrence, physics, effects, impacts, and risks.**

- Using field, theoretical, laboratory studies, or a combination of these approaches, develop and test methods for evaluating the degree to which human activities induce earthquakes. Of particular interest are analyses of new data or analyses methods (including the use of machine learning) of existing case histories that yield novel insights regarding the relationships between the fluid injection or production activity and the resulting induced earthquakes, and methods to distinguish whether earthquakes are natural or induced.
- Conduct seismological, geodetic, numerical modeling, and integrated studies of the ongoing seismicity in the Delaware Basin in Texas and New Mexico. Studies rapidly characterizing the seismicity are particularly desirable.
- Develop methods of anticipating the magnitude distribution of induced earthquakes and their contribution to seismic hazard, on the basis of anthropogenic activities (e.g., injection or production rate, pressure, total volume), presence of nearby seismogenic faults, stress state, and formation properties (e.g., rheology, pore pressure). Determine whether maximum magnitude for induced seismicity differs from that of natural seismicity.
- Improve seismic hazard analyses for induced earthquakes. Examples may include earthquake rupture forecasts that employ earthquake statistics (e.g., foreshock/aftershock, clustering) and ground motion models from analysis of induced strong motion.
- Use numerical models, scalable experiments, or theory to test whether earthquake occurrence and energy release induced by industrial activities can be controlled so as to limit the seismic hazards posed by that operation.
- Determine the role of pore fluid pressure in initiating and during fault slip, including how moment release may be partitioned between aseismic versus seismic slip.
- Develop methods to test short-term forecasts of induced seismicity and its hazard, where possible considering future integration with Operational Earthquake/Aftershock Forecasting and/or in conjunction with CSEP.
- Apply results from studies of earthquakes induced by anthropogenic activities to improve our understanding of natural earthquakes.
- Conduct observational, theoretical, or laboratory studies to constrain the involvement of poroelasticity in induced seismicity, including but not limited to contributions from anisotropy, the influence of the ambient stress state, and long-range stress interactions.
- Develop, utilize, and test theory, numerical tools, and experimental techniques, such as coupled geomechanical and dynamic rupture models, to determine the physics of induced seismicity.
- Conduct research into the spatiotemporal evolution of induced earthquake sequences to determine whether induced earthquake sequences evolve differently than natural sequences.

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Priority Topics for Research on Engineering Seismology and Impacts (ESI) Coordinator:  
Eric Thompson, [emthompson@usgs.gov](mailto:emthompson@usgs.gov)

The EHP supports basic and applied, geographically broad research into the effects of earthquakes, including ground motions characteristics, ground failure (landslide, liquefaction, and lateral spreading) triggering/severity/extent, and the impacts of earthquakes on the built environment. The USGS priorities on these topics are described below and we encourage applicants to consult with USGS staff to coordinate the proposed work with USGS activities when possible.

In addition to the common priorities listed in section 3.3, the following priority tasks are identified under each element:

**ESI Element I. National and regional earthquake hazards assessments.**

- Fundamental investigations into the physical processes that control the character (e.g., frequency content) of ground motions, especially the high frequency (>1 Hz) energy.
- Advancements in the characterization of ground motion uncertainty, including methods for fully capturing epistemic and aleatory sources of uncertainty.
- Development of models for a broad range of ground motion characteristics, including Fourier spectra, inelastic response spectra, coherence and variability, spatial correlation structure, ground motion duration, energy-related parameters, and the spatial cross correlation between different ground motion parameters as needed for engineering and loss analyses.
- Development of rapid, accurate, and reliable methods to automatically estimate the seismic signal from recorded waveforms.
- Estimation of the occurrence of ground failure (liquefaction, landslides, and lateral spreading) as well as resulting displacements. Methods that are applicable at regional scales are the highest priority. Both empirical and mechanistic approaches are encouraged.
- Development of methodologies for combining site-specific and geospatial data to improve on uncertainties in regional-scale ground failure hazard assessments
- Advancements in the characterization of ground failure uncertainty, including methods for fully capturing epistemic and aleatory sources of uncertainty.
- Development of methodologies for rapidly identifying the occurrence of ground failure after an earthquake.
- Development of new curated digital inventories of ground failure including consistent and thorough metadata. Both historic and modern events are priorities.

**ESI Element II. Earthquake information, monitoring and notification.**

- Develop algorithms to provide information about source characteristics of earthquakes in near-real time, including the estimation of characteristics such as location, depth, magnitude, directivity, and rupture extent.
- Develop or improve novel techniques for earthquake detection, phase association, and location with associated uncertainties. Techniques leveraging machine learning, native cloud-based processing, and automation are encouraged.
- Development of finite-fault modeling algorithms with a focus on topics such as the inclusion of multiple geophysical observations, rapid processing, and uncertainty estimation.



ESI Element III. **Research on earthquake occurrence, physics, effects, impacts, and risks.**

- Develop or contribute to national or international databases and methods to help quantitatively estimate losses from ground failure.
- Development of open-source inventories, engineering exposure models, and fragility/vulnerability functions for use in ShakeCast and/or with the National Seismic Hazard Model; fragilities for critical facilities and geo-spatially distributed lifelines are of particular interest to USGS.
- Development of new products and procedures that will allow the USGS to deliver more rapid and/or more accurate post-earthquake loss and risk information.
- Development of tools for use in near-real-time to predict and/or monitor structural health, assess damage levels, and investigate failure mechanisms. We encourage the use of data from ANSS instrumented structures (<http://strongmotioncenter.org>).
- Develop probabilistic methods and open-source models or tools to describe building performance in response to strong shaking. We encourage the use of data from ANSS instrumented structures (<http://strongmotioncenter.org>).
- Development of efficient and rigorous methodologies for propagating uncertainties in ground motion estimation into risk uncertainties, including the effects of the various forms of ground motion correlations.
- Development of open-source methods and tools to demonstrate impacts of hazard uncertainties on loss/risk estimates with the goal of identifying the most influential components of hazard modeling.
- Development of techniques for generating hazard-consistent stochastic event sets for the purpose of estimating seismic risk. These event sets could also be used to inform the development of both hazard- and consequence-driven scenarios for emergency management planning.
- Development of methodologies for rapidly identifying the structural damage after an earthquake.
- Development of probabilistic framework that uses USGS earthquake science and products to assess system-level risk for geo-spatially distributed lifeline infrastructure.

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Priority Topics for National Research (NAT). Coordinator: Morgan Moschetti,  
mmoschetti@usgs.gov

Research topics related to the production and future directions of the National Seismic Hazard Model (NSHM). PIs are encouraged to coordinate their proposed research with existing and ongoing efforts of USGS personnel.

In addition to the common priorities listed in section 3.3, the following priority tasks are identified:

#### NAT Element I. **National and regional earthquake hazards assessments.**

##### **Research activities supporting the USGS National Seismic Hazard Model.**

###### ***High-priority topics***

- Produce new data products (e.g., earthquake catalogs, fault slip rates, magnitude-area or slip-area relations, ground motion models, site effect models), methods (e.g., earthquake simulators, geodetic inversions), and earthquake rate forecasts for Puerto Rico and the U.S. Virgin Islands, Guam and the Northern Mariana Islands, and American Samoa.
- Develop data, methods, and models useful for the NSHM Research Model, which include time-dependent models, consideration of aftershocks, and nonergodic ground-motion models that include adjustments to GMM medians, aleatory variabilities, and epistemic uncertainties appropriate for NSHM.

###### ***Priority topics***

- Produce new data products, methods, and earthquake rate forecasts for regions relevant to NSHM.
- Develop crustal deformation models using geodetic and/or geologic input data to define slip rates along fault sections.
- Develop improved site response models or maps of site parameters that may be used in future versions of NSHM.
- Define sedimentary basin geometry, depths, and shear-wave velocities, with high priority on urban sedimentary basins and coordinate with USGS personnel on implementation into NSHM. Develop methods to improve prediction of long-period ground motions in such regions.
- Develop new/improved or utilize existing seismic directivity models for implementation into PSHA (e.g., adjusting median and variability of ground motions). Models must be applicable to NSHM, which requires consideration of complex fault geometries and a generalized coordinate system.
- Improve on methods used to calculate ground motions near the CEUS-WUS attenuation boundary.
- Develop models of epistemic uncertainty that can be applied to new or existing ground-motion models for implementation in the NSHM.
- Develop and/or implement conditional ground motion models for other parameters besides spectral acceleration (e.g., Arias intensity, significant duration, or inelastic spectral acceleration).
- Define uncertainties in hazard inputs (e.g., slip rates, magnitudes, recurrence), models (e.g., declustering) and equations (e.g., magnitude-area relationships, GMMs), and improve propagation of uncertainties.
- Develop and/or apply procedures for testing the accuracy of hazard models and their component models.

#### NAT Element II. **Earthquake information, monitoring, and notification.**

- Develop local or regional relationships, with uncertainty, between magnitudes reported in routine earthquake catalogs (e.g.,  $M_L$ ,  $M_d$ ,  $m_{bLg}$ ) and  $M_w$ , with emphasis on small magnitudes ( $M_w \sim 2.5-4.0$ ).