Attachment A

**USGS Earthquake Hazards Program Research Priorities for FY2022**

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 described below and the priority research targets listed below for each region and 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. **Proposals applicable to a specific area in which an underserved community resides should be submitted to the relevant regional Research Area.**

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.

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.

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).

Element IV. **Earthquake safety policy and communication.** 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. **See Section 1 for earthquake safety policy and communication priorities common to all Research Areas. Proposals for research on earthquake safety policy and communication applicable to a specific area should be submitted to the relevant regional or topical Research Area.**

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

1. Central and Eastern United States (CEUS): The United States east of the Rocky Mountains, including Puerto Rico and the U.S. Virgin Islands;
2. 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);
3. Earthquake Physics (EP): Basic and applied, geographically broad research on the physics of earthquakes;
4. Induced Seismicity (IS): A sub-topic of Earthquake Physics (EP), basic and applied research on the physics of induced earthquakes;
5. Earthquake Early Warning (EEW): Basic and applied research to improve the accuracy, reliability, and timeliness of earthquake early warning alerts generated by ShakeAlert;
6. Intermountain West (IMW): Seismically active regions of the Intermountain West;
7. National (NAT): Research applicable nationally, especially activities related to the National Seismic Hazard Model;
8. 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;
9. Pacific Northwest and Alaska (PNA): Washington, Oregon, California north of Cape Mendocino (Cascadia), and Alaska;
10. Southern California (SC): From the Carrizo Plain south to the international border with Mexico.

Please also note that the USGS has developed 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. Please direct these proposals to the most appropriate regional or topical category.

The USGS has also recently published *Science for a Risky World: a USGS Plan for Risk Research and Applications* (hereafter "**Risk Plan**"). The 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. The EHP encourages research proposals responsive to the Risk Plan. Please direct these proposals to the most appropriate regional or topical category.

Proposals for research on earthquake occurrence and effects applicable to a specific topic or region should be directed to the relevant topical or regional panel. 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. Proposed research to improve algorithms and processes that provide information about earthquakes that are invariant to geography should be sent to Engineering Seismology and Impacts (ESI) 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 and there should be a clear explanation of how the research will help understand or assess earthquake hazards in the U.S. **If uncertain, please contact one or more of the regional and/or topical coordinators to determine the most appropriate category.**

**Proposals submitted in response to this Program Announcement must indicate the regional or topical area that the proposed research addresses; if the proposal addresses a specific priority noted in this attachment it must also be indicated. 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.**

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](https://www.usgs.gov/natural-hazards/earthquake-hazards/external-grants).

Regional and topical coordinators are available to 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.

Descriptions of USGS internal projects can be found at: [http://earthquake.usgs.gov/research](http://earthquake.usgs.gov/research). It is **strongly recommended** that the applicant contact the appropriate regional or topical 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.

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, below.

Proposals for research making use of data from other federally supported facilities (e.g., National Science Foundation, National Oceanic and Atmospheric Administration, NASA) should address EHP goals and objectives. Proposals for such projects that are not directly related to EHP goals and objectives should be directed to the relevant agency. In particular, EHP does not tend to fund proposals related to ground remediation, engineering mitigation strategies, site- or material-specific geotechnical analyses, or elaborate structural modeling.

**Following are priority tasks for the EHP Program Elements for each regional and topical area. We emphasize that this listing of Priority Topics is not an exclusive listing of all potential research topics and is not intended to discourage submission of proposals to accomplish other important tasks. We encourage discussions with the regional and topical coordinators before proposing work outside of these listed priorities.**

**1. Common Priority Topics for all Research Areas (CEUS, ESI, EP, IS, EEW, IMW, NAT, NC, PNA, SC)**

Contact one of the Regional or Topical Coordinators to learn more about the status of internally supported projects or to discuss potential proposals.

**Element IV. Earthquake safety policy and communication.**

- 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.

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## 2. Priority Topics for Research in the Central and Eastern U.S. (CEUS) Coordinator: Thomas Pratt, 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).

CEUS Element I. **Regional earthquake hazards assessments.**

- Assess the seismic potential of earthquake source zones and active faults in the CEUS using geological, paleoseismological, paleotsunami, seismological, machine learning, and geophysical studies, and analyses of historical accounts. Emphasis should be on seismic zones where studies could have the greatest impact, either due to a lack of knowledge about a source 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 the Puerto Rico trench and Antilles subduction zone, ground motions in the region, and associated hazards 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 determine the frequency of strong shaking. Examples might include studies of fragile geologic structures (stalactites, balanced rocks) or constraints from slope failures such as landslides, turbidites or rockfalls.
- 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.
- Improve estimates of site response and liquefaction potential using field experiments or instrumental recordings, with an emphasis on geologic units that underlie large areas of the CEUS.
- Improve the accuracy of regional attenuation models and ground motion models suitable for use in National Hazard Maps.

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 areas represent aftershocks of larger prehistoric earthquakes.
- Reduce earthquake location errors using improved 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.

CEUS Element IV. **Earthquake safety policy and communication.** See Section 1.

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

The EHP supports basic and applied, geographically broad geotechnical and structural studies into the ***effects*** of earthquakes on the natural environment, including ground deformation (e.g., liquefaction, landslides, lateral spreading), and related ***impacts*** to the built environment, including buildings, bridges, and lifelines. Research and development related to the National Earthquake Information Center (NEIC) and the National Seismic Hazard Modeling Project (NSHMP) science and products is welcome, but integrative efforts with the USGS/NEIC/NSHMP should indicate to what degree such efforts have been coordinated or planned. Contact the ESI Coordinator to learn more about internally supported projects, or to discuss potential proposals.

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

- Improve predictive models of earthquake-triggered ground failures including landslides and liquefaction that can be characterized and employed at regional/global scales rather than site-specific or material behavior studies. The ESI panel prioritizes the development of innovative models, efforts to validate/refine existing models through comparison with case histories, development of new inventories of earthquake-induced ground failure, and the use of new innovations in other fields, including but not limited to remote sensing and/or artificial intelligence technology.
- Important issues for regional-scale models include the characterization and triggering influence of the most pertinent loading parameters for ground failure (e.g., frequency- and duration-dependent intensity measures), or the use of innovative proxies for susceptibility characteristics, such as water table depth, grain size distribution, and rock strength.
- In consultation with USGS earthquake and landslide scientists, develop or contribute to national or international databases and methods to help quantitatively estimate losses from ground failure.

ESI Element II. **Earthquake information, monitoring and notification.**
This element supports improved regional or global seismic monitoring techniques consistent with USGS priorities in the National Earthquake Information Center Strategic Plan 2019-23 (USGS Circular 1457).

- The EHP supports efforts to improve algorithms and processes to provide information about source characteristics of earthquakes in near-real time, and the estimation of rupture extent (for example, the integration of multiple data sets, including seismic and geodetic data, in spatial/temporal finite-fault rupture estimations, and approaches to estimate uncertainties in fault rupture extent and moment tensors).
- The EHP encourages efforts to develop or improve novel techniques for earthquake detection, phase association, and location with associated uncertainties. Techniques leveraging machine leaning, native cloud-based processing, and automation are encouraged.
- In coordination with USGS personnel, develop new products and procedures that will allow the USGS to deliver more rapid and/or more accurate post-earthquake loss and risk information. Focus should be on improving estimates on shaking- induced casualties, building damage, and social and economic impacts for domestic and worldwide events, as well as the impacts from earthquake ground failure (e.g., landslides, lateral spread, and liquefaction). The EHP encourages development of procedures/framework for near-real time earthquake shaking and loss model updating capabilities using a variety of datasets such as pre- and post-earthquake image processing, and ground-truth observations.
- Develop and implement damage matrices in accordance with EMS-98 vulnerability classes and damage levels for domestic (U.S.) buildings that are missing from EMS-98 so that the U.S. can fully employ EMS-98 methodologies. This work will require special attention for higher intensities where vulnerability assessment and damage grading require engineering expertise, and would benefit from coordination with the USGS, FEMA, ATC, EERI, and others.
- Develop tools for post-earthquake macroseismic data collection domestically and/or globally using EMS-98 assignments; that is, create tools for soliciting and utilizing engineering expertise for post-earthquake intensity assignments via remote evaluations especially in areas of high impact where *DYFI* (*Did You Feel It?*) assignments could be limited or poorly constrained.

- Develop tools for near-real-time seismic network state of health monitoring to ensure continuity of operations, efficient maintenance, and operational effectiveness of regional and national seismic networks.

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

- Develop advanced fragility functions (and, potentially, loss functions) for the use in ShakeCast and/or with the National Seismic Hazard Model; or, provide a synthesis and roadmap of best practices for the use of existing fragilities. Fragilities for critical facilities and lifelines are of particular interest to USGS.
- Contribute to the development and implementation of an International Macroseismic Scale with applicability to the U.S.
- Develop tools to use data from instrumented structures to predict earthquake response, assess damage levels, and investigate failure mechanisms. Develop probabilistic methods to describe building performance in response to strong shaking**.** We encourage the use of data from ANSS instrumented structures (http://strongmotioncenter.org).
- Investigate other ground motion properties, including coherence and variability, spatial correlation structure, ground motion duration and other energy-related parameters, and the spatial cross correlation between different ground motion parameters as needed for engineering and loss analyses.
- In coordination with USGS personnel, investigate the effects/impacts of multiple ground-motion occurrences (e.g., from aftershocks) on the natural/built environment, and the implications for the modeling of earthquake occurrences (e.g., declustering and aftershock forecasting), physics (e.g., in simulations), ground motions (e.g., durations), and/or consequent risks (e.g., monetary losses).

ESI Element IV. **Earthquake safety policy and communication.** See Section 1.

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

Research priorities for Earthquake Physics and Induced Seismicity are considered by a combined panel with a sub-panel of supplemental reviewers, as needed and based on the required expertise. Priorities specific to each topic are listed separately below and applicants should direct their proposals to the most applicable topic (**EP or IS**).

Understanding earthquake phenomena and evaluating earthquake hazards requires research on the controlling processes and conditions, including anthropogenic influences. The EHP supports field, geophysical, seismologic, theoretical, numerical, and laboratory studies to address these needs and to contribute to improved hazard assessment and risk mitigation throughout the U.S. Contact the EP/IS Coordinator to learn more about internally supported projects or to discuss potential proposals.

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 within the Collaboratory for the Study of Earthquake Predictability (CSEP). 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 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.

EP Element IV. **Earthquake safety policy and communication.** See Section 1.

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

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.

IS Element IV. **Earthquake safety policy and communication.** See Section 1.

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**5. Priority Topics for Earthquake Early Warning (EEW) Research Coordinator: Jeffrey McGuire, 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.

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. 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 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
- Evaluation and prototyping the use of artificial intelligence, machine learning 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 or 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.

EEW Element IV. **Earthquake safety policy and communication. See Section 1.**
**In addition to Section 1, ShakeAlert focused priorities are:**

- Advance messaging and communication strategies for critical ShakeAlert topics such as use of countdowns on Apps, the late alert zone, and other topics that communicate appropriate expectations from ShakeAlert.
- 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.
- Research channels to provide access to ShakeAlert for people without access to technologies due to disabilities, socioeconomic variances, and/or other factors.
- Explore potential iconography, images, sounds, or other cognitive tools that can improve various communities understanding and use of ShakeAlert and protective actions.
- Advance understanding of how ShakeAlert can catalyze discourse about retrofitting and improving building codes.
- Study integration of ShakeAlert into educational environments (e.g. K-16 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.
- 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.
- 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?).
- 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.

**6. Priority Topics for Intermountain West (IMW) Research Coordinators: Ryan Gold, rgold@usgs.gov, Christopher DuRoss, cduross@usgs.gov**

Priorities for research in the IMW focus on the collection of data that directly contributes to DOI's goal of "Protecting our people and the border." For example, data are used to update the U.S. 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.

IMW Element I. **Regional earthquake hazards assessments.**

- Conduct Quaternary geologic, geomorphic, and paleoseismic investigations to estimate the timing, recurrence, rupture lengths, and magnitudes of large prehistoric earthquakes on significant hazardous Quaternary faults in the IMW.
- 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.nbmg.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 Region:** 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

- Compile and/or update information on Quaternary fault geometry and source parameters (e.g., paleoseismic history and fault slip rate) to support the USGS Quaternary Fault and Fold database and NSHM earthquake geology input data.

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

- The EHP supports efforts to improve algorithms and processes to provide information about earthquakes in near real time, including early warning, estimation of fault rupture extent, and refined seismic moment determinations. The EHP encourages efforts to advance machine learning/artificial intelligence methods for earthquake monitoring. Please note that all other monitoring and notification activities are evaluated and funded under a separate solicitation for seismic and geodetic network operations.

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 posed by IMW faults, including: Prehistoric earthquake correlation and fault rupture length; Fault structural segmentation versus rupture length; Long-term paleoseismic and slip histories; Fault scaling relations (e.g., between fault length and displacement), Empirical regressions on moment magnitude; Fault dip (e.g., planar versus listric subsurface geometry) and the intersection of antithetic fault pairs; and Fault creep and afterslip.
- Collect geological, geophysical, and geotechnical data that develop and refine community velocity models in urban areas of the IMW region. Specific areas of interest include but are not limited to parts of the Wasatch Front, Utah outside of Salt Lake Valley; the Reno-Carson City urban corridor; and the Las Vegas urban area of Nevada. 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 models in the IMW region.

- The possible relationship between injection of fluids in the subsurface and swarms of earthquakes is a topic of considerable recent scientific interest. PIs interested in proposing work on this subject should consult the Earthquake Physics (EP) priority list; proposals should be directed to the EP panel.

IMW Element IV. **Earthquake safety policy and communication. See Section 1.**

**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, such as community velocity models, defining priority faults for further study, fault setback planning, or similar.

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**7. Priority Topics for National Research (NAT) Coordinator: Morgan Moschetti, mmoschetti@usgs.gov**
Research topics should relate to the production and future directions of the National Seismic Hazard Model (NSHM). PIs are encouraged to contact the NAT Coordinator to coordinate their proposed research with current and on-going efforts of USGS personnel. Note that proposals focused on improved earthquake monitoring techniques should be directed to the Engineering Seismology and Impacts (ESI) panel.

NAT Element I. **Regional earthquake hazards assessments. Research activities supporting the USGS National Seismic Hazard Model**.
**High-priority topics:**
- Develop methodologies and frameworks for implementing nonergodic GMMs into the NSHM
- Develop seismic source and ground motion models for Puerto Rico
- Improve upon current site characterization and develop ground motion and site response models for Hawaii for the Vs30 requirements of the NSHM
- Develop multi-period amplification factors and uncertainties for the central and eastern U.S. (CEUS), including for regional variations within the CEUS, that permit conversion between hard-rock conditions and alternative Vs30 values

**Priority topics:**
- Develop earthquake rate forecasts from new data (e.g., earthquake catalogs, geological information, geodetic data) and methods (e.g., earthquake simulators and geodetic inversions)
- Develop seismic source and ground motion models for Alaska
- Develop new magnitude-area and slip-area relations
- Develop new or improve existing GMMs or other strategies for ground motion and macroseismic intensity estimation that can be used to improve the NSHM and to reduce uncertainty in ShakeMaps
- Define sedimentary basin geometry, depths, and shear-wave velocities, with high priority on U.S. urban sedimentary basins and coordinate with USGS personnel on implementation into NSHM
- Develop methods and products that can be used to improve long-period (T>1 s) GMMs in areas with deep sediments and sedimentary basins (e.g., 3D simulations, amplification factors, basin models). Of particular interest are proposals addressing improved GMMs for urban areas of the western U.S. and on deep sediments in the CEUS
- 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 methods for propagating these uncertainties
- Develop and/or apply procedures for testing the accuracy of hazard models and their component (e.g., GMM and earthquake rate forecast) models
- Develop alternative methodologies for representing epistemic uncertainties in ground motion for NSHM
- Develop new or improved seismic directivity models or facilitate implementation of directivity models into seismic hazard analyses. Models should consider varying styles of faulting, be capable of handling complex (and multi-segment) ruptures, and be applicable to relevant magnitudes and periods
- Develop and/or implement conditional ground motion models for other parameters besides spectral acceleration, e.g., Arias intensity, significant duration, or inelastic spectral acceleration
- Develop local or regional relationships, with uncertainty, between magnitudes reported in routine earthquake catalogs (e.g. $M_L$, $M_d$, $m_{bLg}$) and $M_w$, and improve documentation and standards for magnitude characterization, with emphasis on small-magnitude earthquakes (M 2.5-4.5).

NAT Element IV. **Earthquake safety policy and communication.** See Section 1.

**8. 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 to understand the plate boundary system, to characterize the earthquakes it may produce, and/or to evaluate hazards to critical infrastructure. Feel free to contact the NC Coordinator to learn more about coordination with internally supported projects and/or to discuss potential proposals.

NC Element I. **Regional earthquake hazards assessment.**

Conduct paleoseismic and other geological investigations of the behavior and location of active faults in Northern California. Studies should be conducted and published so that results can be readily incorporated in rupture forecast modeling, regional probabilistic hazard assessments, and the 3D geologic and velocity model.

Priorities include:

- Develop information on earthquake recurrence, segmentation, and history of active faults in Northern California, and add these data to existing fault databases;
- Utilize increasingly available lidar and other remote sensing datasets to improve understanding of active fault processes and to refine estimates of slip in historical and prehistoric earthquakes;
- Evaluate the connectivity of faults to place constraints on the long multi-segment and multi-fault ruptures that contribute significantly to current probabilistic hazard and risk assessments (possible faults of interest might include the Greenville, Contra Costa Shear Zone, Northern Calaveras, and Concord);
- Create or refine maps of active faults and evaluate the completeness of previous active fault mapping efforts. Because the presence or absence of a nearby fault plays an important role in hazard assessments, review and documentation of lower slip rate faults that are (or are not) currently part of the Quaternary fault and fold database is needed.

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.

Priorities:

- Provide bounds for slip rates on all reaches of the main faults of the plate boundary, like the San Andreas, Calaveras, Hayward-Rodgers Creek, Concord-Green Valley-Bartlett Springs fault systems, thrust faults in the region, other zones of deformation that may provide fault connectivity, as well as faults that contribute significantly to the hazard to the Sacramento-San Joaquin Delta area;
- Develop methods to forecast co-seismic and post-earthquake slip on faults that produce surface-rupturing earthquakes in Northern California;
- Develop and apply methods that elucidate distribution of fault creep and other deformation in a synoptic manner.
- Perform studies that synthesize the state of knowledge of fault behavior over the mid to late Holocene in northern California with formal uncertainty assessment. These studies should aim to assess how knowledge gaps and uncertainties propagate into seismic hazard models, and to assess if current practices are the best methods for improving rupture forecasts and seismic hazard models.

Improve earthquake ground motion models for Northern California.

Priorities:

- Validate, improve, and incorporate seismic tomography models into, the 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 at seismic stations throughout Northern California, particularly stations that have recorded strong ground motion. Use these data to build and add a shallow surficial or "geotechnical" layer to the 3D model. And, develop general methodology for incorporating shallow information (which may be spatially sparse) into broader velocity models.
- Validate models for historical earthquakes using existing and augmented seismic intensity data.

- Update existing seismic tomography models using ambient noise methods, shear wave arrival times from 3-component stations, and data from new network stations added for earthquake early warning, and collaborate to ensure these models are used in modifying the 3D geology and velocity models.
- Improve modeling of ground motion, hazard and risk specific to Northern California and the Sacramento-San Joaquin Delta.

NC Element II. **Earthquake information, monitoring, and notification.**
Integrate and improve seismic monitoring efforts in Northern California, in particular to enable recognition of anomalous or precursory behavior.
Priorities:
- Develop methods to assess and refine catalogs of current and historical seismicity.
- Advance machine learning/artificial intelligence methods for earthquake and deformation monitoring.
- Measure crustal strain at a variety of scales from site to regional scale using borehole strain meters, GPS, InSAR, etc....
- Assess creep rates and locations to identify fault coupling, frictional properties, and transient aseismic events, and also identify locations/faults that do not creep.
- Identify and catalog 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 the Uniform California Earthquake Rupture Forecast (UCERF).
Priorities:
- Evaluate differences between geologic and geodetic strain rates used in assigning slip rates to faults and off-fault deformation models.
- Evaluate inputs and improve methods and input data needed to characterize regional landslide, liquefaction, and lateral spread potential and probabilities, and apply these new methods to hazard mapping in Northern California. Use these approaches to evaluate risks to infrastructure.
- Develop metrics to evaluate risk from different branches of the UCERF model and identify priority targets for future research to improve the model.

NC Element IV. **Earthquake safety policy and communication.** See Section 1.
**In addition to Section 1, NC focused priorities are:**
Modeling, understanding, or communicating earthquake hazard mitigation and risk reduction in underserved communities in Northern California, and in populations whose vulnerability may be directly related to socioeconomic factors.

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## 9. 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. Where appropriate, 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) EarthScope Plate Boundary Observatory 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; 6) the Ocean Networks Canada and Oceans Observatory Initiative off-shore cabled networks; and 7) data from offshore earthquake-related temporary and permanent deployments. Proposals should address needs described in USGS Circular 1428, *Reducing Risk Where Tectonic Plates Collide – A Plan to Advance* ***Subduction Zone Science***. 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 goals of the NSF-supported collaborative amphibious controlled source seismic experiment to image Cascadia's megathrust and the subducting and overriding plates (cruise planned for summer 2021). Topics noted below should focus on the Cascadia subduction zone, although research elsewhere with clear relevance may also be proposed. Product development activities should demonstrate user involvement in product conception, implementation, and evaluation. Activities that are proposed by, engage, or address issues related to underserved communities are particularly encouraged.

PNA-Pacific Northwest Element I. **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 applicable to hazard maps at urban scales, building codes, and long-term planning. In particular, ground motion models that include complex wave propagation effects for M8- 9 Cascadia plate-interface earthquakes and upper-plate fault earthquakes are needed.
- 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 including 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. 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.
- Use geodetic data to improve maps of crustal deformation and better constrain slip rates of crustal faults.
- Characterize the response of earthquake ground motions in sedimentary basins, including research into the geologic structures and processes that amplify ground shaking in such basins.
- Develop new or advance existing geochronology methods to improve paleo-earthquake age and interseismic deformation rate estimates.

PNA-Pacific Northwest Element II. **Earthquake information, monitoring, and notification.**
- 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.
- Improve existing 3D seismic velocity models of crustal structure onshore and offshore, particularly for sedimentary basins beneath or near urban areas, with application to earthquake source and ground motion characterization.
- 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).

PNA-Pacific Northwest Element IV. **Earthquake safety policy and communication.** See Section 1.

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**9.2 Priority Topics for Research in Alaska (PNA-Alaska) Alaska Coordinator: Peter Haeussler, pheuslr@usgs.gov**

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.

PNA-Alaska Element I. **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 lake 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.
- Utilize geodetic and/or seismicity data to define 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 Sem. 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.

PNA-Alaska Element IV. **Earthquake safety policy and communication**. See Section 1.

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**10. 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 continue 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.

SC Element I. **Regional earthquake hazards assessment.**

- Determine the activity of faults using paleoseismology, geomorphology, and geologic mapping; integrate field observations with new and complimentary data (e.g., LiDAR, imagery) to constrain timing and deformation from past earthquakes.
- Refine models of relative or absolute activity of offshore faults system using geophysical data and chronostratigraphic constraints from sediment cores.
- Investigate 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 and earthquake geology.
- Refine estimates of interseismic deformation field through studies of GPS and space-based geodetic data through examination of vertical deformation, anthropogenic effects, creep, and mechanisms of lower crustal response.
- Improve data on basin structure and refine understanding of the fault network through data collection.
- 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 the 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 for incorporating shallow ergodic (e.g. VS30) and nonergodic (e.g., VS, dominant site frequency, Z1.0, 2.5, etc.) parameters into these 3D models.
- Develop, refine, and test probabilistic models for earthquake rupture using the tools and methods 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 and crustal structure and the state of stress in the crust, including further development and testing of 2- and 3-D structural models.
- Develop methodology to improve the characterization of past notable earthquakes and earthquake interactions.
- Advance machine learning/artificial intelligence methods for earthquake and deformation monitoring.
- Collaborate with the USGS and university-based seismic and geodetic networks to enhance tools needed for accurate and rapid portrayal of the severity and geographical distribution of strong ground shaking, surface rupture, and ground deformation.

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

- Explore and characterize the prospect for earthquake ruptures that involve multiple fault segments, step-overs, or multiple distinct faults, clarify the roles of seismic and aseismic processes.
- 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.
- Use crustal deformation measurements to constrain regional deformation rates, fault slip rates, the role of fault creep, fault mechanics, origins of strain transients, and anomalous strain rates and models of stress evolution.

SC Element IV. **Earthquake safety policy and communication.** See Section 1.

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