Statewide California Earthquake Center

2024 Science Plan

Proposals Due: December 8, 2023

1. SCEC Mission

The Statewide California Earthquake Center (SCEC) is a collaborative research center that brings together experts from different fields to study earthquakes and their cascading effects to reduce earthquake risk. SCEC scientists gather information from field observations and laboratory experiments, conduct theoretical and computational studies, develop system-level physics-based models, and communicate the understanding of seismic hazards to build community resilience.

SCEC emphasizes investigator-driven, interdisciplinary research, and fosters connections among scientific, engineering, government, and community-based organizations to help society prepare for earthquakes. SCEC's major activities include Earthquake System Science, Research Computing, Community Engagement, Workforce Development, and Collaboration Planning and Program Evaluation.

SCEC's vision is to support a diverse community of scientists and students to develop better, data-validated models of earthquake processes and improve our understanding and ability to predict earthquake behavior. The SCEC collaboration welcomes new investigators with fresh perspectives and from diverse backgrounds to join our community and take advantage of our resources and opportunities.

2. SCEC Science Plan

The Statewide California Earthquake Center aims to sustain a research collaboration for basic and applied earthquake science, with the agility to pursue unanticipated research directions, the ability to remain open to new investigators, and the convening authority to provide a global platform for multidisciplinary research, workforce development, and community engagement across earthquake science. These goals encourage a professional culture that values equity, diversity, and inclusion, which allows the Center to maximize contributions from the next generation of earthquake scientists.

This Science Plan emphasizes new opportunities – particularly those enabled by a geographic scope that includes the entire transform plate boundary between the Pacific and North American Plates from western Nevada to the Borderlands offshore, and from Baja California to Cape Mendocino. It provides a roadmap on how to distribute efforts in southern, central, and northern California to develop statewide Community Earth Models and other goals of the Center.

We welcome all proposals that can contribute to SCEC's science goals in general, along with related community engagement and workforce development activities, but are recruiting specific efforts as described below.

3. Earthquake System Science

Understanding the dynamics of earthquakes and faulting and associated geohazards requires: (i) understanding the *distribution of forces* that load the fault network, (ii) developing *constitutive relations* that govern the response of crustal materials, (iii) understanding the *coupling mechanisms* that quantify how failure processes modify geometrical and material properties of fault zones, and how these changes influence subsequent failures, and (iv) *a system-level approach to estimate* the evolving seismicity and *earthquake ground motion* in predictive multi-scale crustal models, and their potential for direct and cascading hazards.

To achieve these science goals, we envision investigations along the following research thrusts. (A) Improve observations with a focus on closing critical data gaps and work on synthesizing results in Community Earth Models (previously known as CXMs) that are representations of key aspects of the earthquake system that are used to facilitate quantitative analyses and simulations. (B) Develop rheologies appropriate for capturing the behavior of fault-zone and crustal materials needed to simulate earthquake and fault phenomena with increased fidelity. (C) Develop methods and computational frameworks to extend knowledge beyond the available data using simulations, and verify and validate their predictions about earthquake phenomena. (D) Develop improved techniques for forecasting seismicity, simulating strong ground motion, and estimating surface

deformation, and for testing results in the context of natural and induced seismicity across and along the plate boundary system in California.

A detailed set of milestones for realizing the science goals of the Statewide California Earthquake Center over a three-year project period is outlined in §8 below.

3.A. Improving observations and closing critical data gaps

Detailed *in-situ* observations are essential for testing and developing models of earthquakes and faults. The San Andreas Fault System (SAFS), from Cape Mendocino to Baja California, provides outstanding opportunities to improve knowledge by closing critical data gaps in the immediate vicinity of faults and the shallow crust, and by merging local results within regional- and plate-boundary-scale Community Earth Models (CEM). Exceptional aspects of the San Andreas Fault System include direct access to large faults spanning a range of tectonic environments, extensive networks of instruments, developed paleoseismic records, and subregions with distinct deformation styles that increase the diversity and richness of the natural laboratory. In addition to research supporting this effort in general, we are recruiting initiatives in the following specific activities:

- Assess the availability and quality of geological and geophysical data, as well as existing Community Earth Models, including community velocity models developed by U.S. Geological Survey and California Geological Survey, for different regions of the SAFS, particularly outside southern California.

- Improve and extend Community Earth Models over the geographic scope of the entire transform plate boundary, including collecting new data and assessing and incorporating existing data to meet that goal.

- Create labeled training data sets with associated metadata, for machine learning analyses of seismic, geodetic, and geologic observations, with a focus on unifying heterogeneous data sets and their varied resolution across the entire plate boundary system.

- Train machine learning models to extract information from existing data sets across disciplines.

- Synthesize existing paleoseismic and slip-rate datasets and identify fault zones for which new data would significantly reduce uncertainty in seismic hazard determinations for both ground motion and surface rupture, including for time-dependent models.

- Use high-resolution topography and imagery, geologic, and geomorphic tools to identify sites along these faults that are accessible and conducive to earthquake geology studies.

- Improve constraints on elastic and anelastic crustal structure and its spatial variation across California to support the development of non-ergodic ground-motion models.

- Identify areas and sites where pre-event geodetic and geomorphic observations would significantly improve the scientific return in the event of a future earthquake.

3.B. Developing rheologies that bridge scales and conditions for the San Andreas Fault System

Constitutive laws govern the dynamics of earthquakes, faults, and the crust. They should incorporate information from lab experiments and multi-scale field observations. Rheologies for brittle and ductile failure modes should account for shear and dilatational deformation in a heterogeneous environment under variable pressure, temperature and fluid content. We seek to construct effective constitutive laws to advance the Community Rheology Model (CRM) and facilitate simulations of crustal deformation and earthquake processes. Bringing the entire plate boundary within the scope of SCEC will require considering a broad range of temperature and pore pressure regimes, different degrees of localization and damage, as well as different deformation mechanisms and loading rates. In addition to research supporting this effort in general, we are recruiting initiatives in the following specific activities:

- Extend the geologic framework model underpinning the CRM to increase the diversity of rock types and material behaviors that are needed to span the geographic scope of the Center.

- Develop prototype rate-dependent constitutive models for gouge materials in crustal fault zones and deeper shear zones at the boundary between major tectonic blocks.

- Identify important minerals or mineral aggregates for which ductile flow laws are insufficiently characterized and develop a plan to remedy this situation.

3.C. Developing advanced modeling frameworks

We aim to develop computational frameworks to conduct numerical experiments for conditions not accessible for laboratory and field investigations (e.g., the span of spatial and temporal domains), and to simulate crustal deformation phenomena, seismic and aseismic failure events, and ground motion. The natural laboratory comprising the entire San Andreas Fault System matches the natural system boundaries, enables exploration of fault network evolution, and includes a broad range of faulting types. Simulation results can suggest observational strategies for closing critical data gaps, and contribute to improving the predictability of seismicity patterns, surface deformation, and strong ground motion. These activities will utilize the advances made under §3.A and §3.B and create unique opportunities for interdisciplinary system-level collaboration. In addition to research supporting this effort in general, we are recruiting initiatives in the following specific activities:

- Develop, extend and maintain code training, benchmarks, verification (inter-code comparison) and validation (comparison with observations) standards and exercises in seismic cycle, dynamic rupture and ground motion modeling, as well as earthquake forecasting and testing.

- Develop and utilize existing and emerging cyberinfrastructure to allow for 3D visualization and data access.

- Work towards the fusion of different community models into an integrated web-based Community Earth Model Framework that provides consistent definitions of geological, geodetic, and geophysical parameters over the entire San Andreas Fault System.

- Create workflows for unifying and curating simulation results following FAIR (Findability, Accessibility, Interoperability, and Reusability) best practices to be used in machine learning analysis and observational validation, and to better link existing modeling capabilities and bridge time and space scales.

3.D. Improving predictive analyses of seismicity and ground motion

Improved forecasting of earthquakes has been a longstanding goal of earthquake science. We seek to make progress in this area by combining physics-based, statistical, and machine learning forecasting of seismicity, hierarchical searches of informative spatio-temporal patterns in seismic and geodetic data, and rigorous testing of signals and predictive models. We aim to advance the forecasting of aftershocks and earthquake sequences, and to improve the understanding and predictability of induced seismicity. This includes modeling efforts and collaborations with computer scientists, applied mathematicians and statisticians. We will seek to test forecasts quantitatively against data and compare them with alternative frameworks using the Collaboratory for the Study of Earthquake Predictability (CSEP). In addition to research supporting this effort in general, we are recruiting initiatives in the following specific activities:

- Assess space- and time-dependent geophysical variables that influence seismicity rates and occurrence patterns across the SAFS, such as heat flow, slow slip and fault network characteristics.

- Improve long-term and time-dependent earthquake forecasting capabilities over the entire SAFS exploiting new data and modeling approaches, such as machine learning and advanced physics-based models; this may include potential interactions across the geographic boundaries of the study area.

- Develop flexible methods for evaluating earthquake forecasts that arise, for example, from the application of artificial intelligence to seismicity catalogs.

- Extend ground motion validation efforts for physics-based simulations, which previously have focused on southern California, to northern and central California; for velocity models with enhanced shallow crustal resolution, perform validation efforts using appropriately resolved 3D physics-based wave propagation simulators.

- Synthesize ground motion simulations and observations with machine learning algorithms in space, time and frequency domains, to bridge data gaps and constraint uncertainty of simulated ground motions.

4. Research Computing and Software Development

The Center relies on software development, workflows, and computational frameworks created by SCEC collaborators and staff to support research that advances its scientific goals. SCEC's research computing activities emphasize simulation software to reproduce earthquake phenomena (dynamic rupture, seismicity, ground motion, deformation, fault system evolution, etc.), earthquake forecasting models and evaluation methods, and software or data used to access and distribute Community Earth Models. Activities in these directions can benefit from the new Quakeworx (quakeworx.org) science gate which aims to facilitate simulations and reduce barriers to users, and interactions with other SCEC partners such as Earthscope (www.earthscope.org), Computational Infrastructure for Geodynamics (geodynamics.org), and DesignSafe (www.designsafe-ci.org). Proposals to perform or develop computing capabilities in support of the four research thrusts (§3.A-D) are welcome, with the following efforts particularly encouraged:

- Develop or improve physics-based ground motion methods including performing, evaluating, or applying ground motion modeling with broad applications.

- Initiate or accelerate the development, application, and use of machine learning methods to enhance SCEC research.

- Prepare SCEC research software for use on next generation computing systems, facilitating simulation of rupture and ground motion for large-scale earthquake scenarios in southern and northern California

Some SCEC research computing staff time can be directed towards projects selected for funding through the annual planning process. In addition to requesting a total funding amount, proposals may also include a request for technical support from SCEC research computing staff (in units of weeks). Consult with Philip Maechling (maechlin@usc.edu) to develop estimates for SCEC software developer time.

5. Community Workshops and Trainings

Sustained interactions within the SCEC community and with other communities that interface with SCEC are essential for advancing earthquake science and engineering. SCEC fosters these interactions through a variety of activities, including technical activity groups, workshops, field activities, annual meetings, and skills training. These activities enable a diverse group of researchers to collaborate over sustained periods, building deep scientific collaborations and interpersonal networks. SCEC also interacts with federal and state agencies to support seismic risk reduction and promote community resilience. The Center aims to maximize the contributions from the next generation of earthquake scientists by providing them with opportunities to learn from and collaborate with experienced researchers, develop new skills, and build their networks.

We welcome proposals for the following activities:

- Focused workshops in areas highlighted in the Science Plan, which may include field trips to key localities in the Center's research domain.

- Workshops or training sessions to accelerate progress on focused topics, engage students and early career researchers, and increase participation from underrepresented minorities (URMs).

- Training sessions for students and early career researchers in multidisciplinary research and to develop the skills needed to engage in the science collaboration.

- Engagement with communities that interface with the Center, such as technical stakeholders and downstream users, to apply geoscientific knowledge to hazard quantification, validate ground motion simulations and earthquake rupture forecasts, and integrate and use SCEC science products.

- Public engagement and preparedness activities that promote community resilience, including communicating the understanding of seismic hazards to broad audiences.

6. Workforce Development Opportunities

SCEC develops the future workforce by offering transformative research experiences, building communities, developing technical skills, and supporting students and early career researchers through key career transitions. SCEC nurtures the development of the next generation of researchers through mentorship training designed to improve research mentorship relationships. Strong mentorship is linked to enhanced science identity, sense of belonging, self-efficacy, persistence, research productivity, higher career satisfaction, and recruitment of URMs. Through the SOURCES and SURE Internships, we provide undergraduates with authentic research experiences that incorporate professional skills development with key competencies such as systems thinking and problem-solving.

Supplemental support for student participation in research projects, community workshops, field work, and national meetings is available through these programs. SCEC Investigators play an important role in these efforts, and are encouraged to integrate student participation in their proposal work plans where appropriate. SCEC encourages our diverse network of collaborators to participate in the following activities:

- Engage in undergraduate research mentorship and support your research by becoming a research mentor to a SCEC intern during the summer or throughout the academic year. Learn more at: www.scec.org/internships. SCEC accepts applications for undergraduate internships in the January-March timeframe, and matches students and mentors in April-May each year.

- Participate in mentorship training to learn strategies for effective research mentoring. Contact gnoriega@usc.edu to learn more.

- Promote research skills with Research and Travel Awards, aiding students and postdocs in expanding their professional profiles, networks, and research interests. Learn more at: www.scec.org/elca/awards.

Investigators proposing a project that includes aspects of workforce development may contact Gabriela Noriega (gnoriega@usc.edu) for planning guidance.

7. Proposal Submission Guidelines

Potential investigators should read the SCEC Science Plan in its entirety, and understand the expectations for participation in the SCEC collaboration (see §7.D for Investigator Responsibilities). Individual investigators should ensure they have a current SCEC.org account and have updated their profile information, and submitted any past due reports. Successful proposals are contracted with the University of Southern California (USC). Funded institutions should be eligible to receive Federal funds and have a Negotiated Indirect Cost Rate Agreement (NICRA) and be located in the United States. Any possible exceptions should contact proposals@scec.org for additional guidance.

Researchers employed by state or federal government entities are encouraged to seek internal funding from their institutions to work with SCEC-funded private researchers on collaborative proposals. SCEC has achieved great success with this model for research advancements, which also provides unique opportunities for cross-pollinating workforce development.

7.A. Preparing Your Proposal for Submission

All proposals must be submitted through SCEC's online proposal system, accessible at www.scec.org/scienceplan. The following steps walk through the proposal submission process:

Step 1. Proposal Information / Cover Page. Complete the online form with the same information as the proposal cover page, using the template in Step 4.

Step 2. Institutional Budget and Justification. Proposals must include a detailed budget and justification. SCEC does not require that initial proposals go through your institution's authorized representative at this point, but your institution may require a pre-proposal process internally. It is highly encouraged that investigators utilize their institution's expertise to build an accurate proposal budget. If the project is awarded, the subaward request must then be submitted formally by the subrecipient institution, and the pre-proposal process can smooth the way. For detailed budget guidance, see Step 4 below. Enter the detailed budget for each institution on the SCEC website and include it in the uploaded proposal PDF.

Step 3. Current and Pending Support. All investigators requesting funding must submit an up-to-date statement of their current and pending (C&P) support, and describe any potential overlap with the proposed SCEC project. Enter the C&P support for each investigator on the SCEC website and include it in the uploaded proposal PDF. For Workshop or Training Proposals: Investigators who are requesting funds only to support participant costs and meeting expenses do not need to submit C&P support information.

Step 4. Proposal Content / Upload Single File. To be complete, your proposal must include all required information listed below (a-d) and be submitted by the due date. Incomplete proposals will be rejected. Upload your complete proposal as a single PDF file on the SCEC website.

a. <u>Cover Page</u>: Please prepare your proposal cover page using the template provided at www.scec.org/scienceplan. The template is designed to ensure proposals submitted include all of the required information in a consistent format.

b. <u>Project Description</u>: The Project Description should clearly articulate the research to be undertaken, including the specific objectives, anticipated significance, and experimental methods. Where appropriate, the work plan should include information about data management and sharing, contributions of named collaborators, and results of prior SCEC support. It should also justify the project both scientifically and in terms of its broader impacts, and explain how it achieves SCEC goals and priorities.

   ○ <u>Format</u>: The Project Description should be no more than 5 pages maximum (including figures), and follow NSF formatting requirements (https://new.nsf.gov/policies/pappg/23-1/ch-2-proposal-preparation#2C2) for font, spacing and margin. Reference information is required, and is excluded from the 5-page limit.

c. <u>Budget and Justification</u>: Each institution must include a budget table and justification in their proposal PDF and enter the information online. Incomplete budgets will be rejected. Proposals should use NSF budget categories (https://new.nsf.gov/policies/pappg/23-1/ch-2-proposal-preparation#2D2f).

   ○ <u>Budget Guidance</u>: Typical SCEC awards range from $10,000 to support workshops up to $35,000 for collaborative research projects with multiple investigators. These amounts are not fixed, but rather to calibrate expectations for proposal budgets. Eligible expenses include salary funds for the investigator, postdocs, and students (including tuition), materials and supplies, travel to the SCEC annual meeting to present project results, and indirect costs per the subrecipient institution's federally negotiated rate. Investigators can receive no more than 1 month of summer salary support per year from combined SCEC grants. Researchers whose annual salary is solely funded by external grants are exempt from this restriction. In general, SCEC does not fund equipment, foreign travel outside the U.S., or contractor services. Field investigations outside California may be considered if they are directly relevant to SCEC goals, and cannot otherwise be achieved in the California natural laboratory. Expenses related to workshops and trainings, SCEC geochronology infrastructure, SCEC developer time requests, and supplemental funding for undergraduate student support are managed through the master SCEC funding at USC.

   ○ <u>Workshops and Trainings</u>: SCEC hosts 6-8 workshops and training sessions per year, recommended by the Collaboration Planning Committee to achieve SCEC goals. These events may be in-person or virtual. Engaging students, early-career researchers, and broadening participation is a top priority. Events scheduled in conjunction with the SCEC Annual Meeting are limited in number and may have further constraints. Proposals that include travel support for international participants must clearly explain how they

are critical to the project. Before submitting a workshop or training proposal, contact Tran Huynh (scecmeet@usc.edu) for guidance in planning the scope, budget, and scheduling.

- ○ Geochronology: SCEC geochronology infrastructure supports ^{14}C and cosmogenic dating. Other methods should be budgeted for directly in the proposal. Investigators should state in the Project Description the number and type of dates required. For ^{14}C, specify if sample preparation will take place at a location other than the designated laboratory. For cosmogenic dating, investigators are required to arrange for sample preparation and include these costs in the proposal budget. Investigators are encouraged to contact the collaborating laboratories prior to proposal submission. Student participation in lab analysis is strongly encouraged by SCEC and the participating geochronology laboratories. For more information, contact Mike Oskin (meoskin@ucdavis.edu).

- ○ Software Developer Support: Some SCEC research computing staff time can be directed towards projects selected for funding through the annual science planning process. Proposals may include a request for technical support from SCEC research computing staff (in units of weeks). Consult with Philip Maechling (maechlin@usc.edu) to develop estimates for the request of SCEC software developer time, which should be entered in the online budget form.

- ○ Supplemental Undergraduate Student Funding: Investigators proposing a project that includes undergraduate student support may also be able to get funding for the students through SCEC's SOURCES and SURE Internship Programs: www.scec.org/internships. For more information, contact Gabriela Noriega (gnoriega@usc.edu).

d. Current and Pending Support: All investigators requesting funding must submit an up-to-date statement of their current and pending (C&P) support, and describe any potential overlap with the proposed SCEC project. Submit C&P support for each investigator through the SCEC website and include it in the uploaded proposal PDF.

- ○ Workshops and Trainings: Investigators who are requesting funds only to support participant costs and meeting expenses do not need to submit C&P support information.

Step 5. Summary / Acknowledgement. Once all of the steps above are completed, you will be able to review your proposal package before submitting it. Please be sure to acknowledge all information is complete and accurate before clicking on "Submit". Please note that if the proposal is awarded, the Principal Investigator may be asked to demonstrate their individual and/or institutional commitments to the responsible conduct of research by providing (on request) documentation such as individual or departmental diversity statement, fieldwork safety plans, postdoc mentoring plan, and/or data management plan.

7.B. Proposal Review Process

To construct the Annual Collaboration Plan, proposals are evaluated based on (a) scientific merit of the proposed research; (b) competence, diversity, career level, performance of the investigators; (c) alignment of the proposed project with SCEC priorities; (d) promise of the proposed project for contributing to long-term SCEC goals; (e) commitment of the investigators and institutions to the SCEC mission, including commitment to enhanced diversity, equity and inclusion in geosciences; (f) value of the proposed research relative to its cost; and (g) the need to achieve a balanced budget while maintaining reasonable scientific continuity with limited funding. Note that proposals that receive a low rating or no funding are not necessarily scientifically inferior. Instead, they may not meet the criteria above.

The Annual Collaboration Plan aims to achieve a coherent science program that aligns with SCEC's mission, institutional composition, and budget that meets its short-term and long-term goals.

Science Planning. In late spring, the SCEC Leadership is convened to review the Center's programs and activities, and discusses research priorities. The Collaboration Planning Committee then drafts an annual Science Plan based on these priorities. In September, the draft Science Plan is presented at the Annual Meeting. SCEC uses the results of prior research and community feedback to finalize the Science Plan. A solicitation is typically released in October, and investigators submit proposals due one month later.

Note that SCEC maintains close alignment with the USGS Earthquake Hazards Program (EHP) through: (1) project reporting to the USGS as a sponsor, (2) USGS liaison membership on the SCEC Board of Directors, and (3) participation by the USGS Joint Planning Committee in the annual SCEC planning process. The USGS EHP website describes the program's priorities, funded projects, and proposal submission process. The EHP funding cycle differs from SCEC's, with proposals due in May. Interested investigators should contact the USGS regional or topical coordinators for more information.

Review of Proposals. Proposals are independently reviewed by the SCEC Director, Co-Director, Vice-Chair of the Collaboration Planning Committee (CPC), and leaders of at least three relevant review groups. A subset of the CPC meets as a panel in January to construct and recommend the Annual Collaboration Plan, which is a portfolio of projects to fund to achieve the Center's goals. The plan and budgets are approved by the Board of Directors and sponsoring agencies before investigators are notified as early as possible, typically in March.

Project Period. The project performance period is typically February 1 to January 31, but most SCEC-funded work should happen such that investigators have preliminary results for the September Annual Meeting. See Award Procedure section below for more detailed information on the award process.

Project Reporting. Following preliminary results presented at the SCEC Annual Meeting in September, investigators will submit a final technical report in March (after the project period ends). These reports inform Center reports to funding agencies and build the annual Science Plan for the following year.

7.C. Award Procedure

The University of Southern California (USC) is the lead institution for SCEC, and receives annual funding from the NSF, USGS, and other federal and non-federal sources. Sponsors have different priorities and contract terms, so SCEC matches funded proposals to the most appropriate prime award. Investigators will receive additional information about the prime award with their notification of award.

Within 30 days of receiving award notification, investigators must submit a formal request for a subaward through their sponsored research office. SCEC/USC reviews the submitted statement of work, budget, and budget justification for each project to ensure they reflect the approved scope. Before the final subaward can be established, USC/SCEC submits the complete subaward request to the prime sponsoring agency for final approval.

SCEC research awards are funded as subcontracts between USC and the investigator's institution. Multiple awards at the same institution from the same funding source will be set up as a single contract (with a designated "lead" Principal Investigator), while awards from different funding sources will be set up as separate contracts. Every effort is made to minimize the administrative burden on all sides, while diligently avoiding commingling of funds from separate sponsors. The budget period for each project/task is set for one year. If an investigator is funded in consecutive years, the institution's subcontract is usually amended to add on the new year of funding. Alternatively, investigators may not be funded in consecutive years, in which case the subcontract may be extended without additional tasks/funding that year. Carry-over of funds is not allowed, since each budget period represents that year's project task(s) only.

This process means that the roster of participating investigators changes each year, as new people and institutions join the SCEC collaboration. This annual review of the Center's program allows SCEC to drive and change the direction of research as needed to meet the Center's goals, milestones, and metrics. This is a unique characteristic of SCEC, and very different from how other research centers typically operate. Funding received from all sources is considered for the purposes of building the overall Annual Collaboration Plan, supporting projects that engage an interdisciplinary community of over 1,000 active participants.

7.D. Investigator Responsibilities

By accepting funding through SCEC, investigators agree to meet the following terms. Investigators who fail to meet these conditions may become ineligible to submit a future proposal to SCEC.

Community Participation. Principal Investigators will interact with other SCEC scientists on a regular basis and contribute data, results, and models to the appropriate SCEC resource.

1. SCEC Annual Meeting. The PI or delegated collaborator will attend the annual meeting and present SCEC-funded project results in the poster sessions, workshops, and/or working group meetings.

2. Data Sharing. Funded investigators are required to contribute data and results to the appropriate SCEC resource and/or shared facilities.

3. Code of Conduct. The Statewide California Earthquake Center is committed to providing a safe, productive, and welcoming environment for all participants. We take pride in fostering a diverse and inclusive SCEC community, and therefore expect all participants to abide by the SCEC Activities Code of Conduct (www.scec.org/meetings/code-of-conduct).

Project Reporting. Principal investigators must submit a project report within 45 days of the project end date, or 30 days of the event date for funded workshops and trainings. Reports inform the annual review of the SCEC program and allow SCEC to adapt the Science Plan to meet its goals. Reports must be submitted through the investigator's dashboard at SCEC.org, where additional instructions are posted.

Registration of Publications. Principal investigators will register publications resulting entirely or partially from SCEC funding in the SCEC Publications System (www.scec.org/publications) to receive a SCEC contribution number. Publications resulting from SCEC funding should acknowledge SCEC and include the SCEC contribution number.

Professional Standards. Principal investigators will be prepared to demonstrate their individual and/or institutional commitments to the responsible conduct of research by providing (on request) documentation such as individual or departmental diversity statement, fieldwork safety plans, postdoc mentoring plan, and/or data management plan.

8. SCEC Science Milestones

Research milestones for the Statewide California Earthquake Center (SCEC) are organized by the four main research thrusts and listed by year. These milestones are used by SCEC and its sponsors as an indicator of research progress along conceptual pathways towards the goals of the Center. Some milestones are standalone efforts, others require year-by-year evolution, and others are better thought of as annual improvements. While the milestones are meant to be comprehensive in the sense that they span the activities of the Center, they are not intended to be exhaustive nor overly prescriptive on exactly how those goals should be achieved.

When submitting a proposal, you will be asked to indicate which SCEC Science Milestones the project will address. Use the designations listed below to select the appropriate milestones.

8.A. Improving observations and closing critical data gaps

<u>Year 1</u>

A1-1   Assess availability and quality of Community Earth Models (CEMs) for different regions of the SAFS.

A1-2   Create prototype labeled training data sets with metadata, for machine learning (ML) analyses of seismic, geodetic, and geologic observations.

A1-3   Identify fault zones across the entire San Andreas Fault System for which new paleoseismic or geologic slip rate data would significantly reduce uncertainty in seismic hazard determinations for both ground motion and surface rupture, including for time-dependent models. Use high resolution topography (lidar and photogrammetry) and imagery, geologic, and geomorphic tools to identify sites along these faults that are accessible and conducive to earthquake geology studies.

<u>Year 2</u>

A2-1   Develop spatially variable Sedimentary Velocity Models for major sedimentary basins. Merge multi-scale seismic velocity models across southern, central, and northern California. Test incremental resolution results via wave propagation simulations.

A2-2   Constrain updated versions of the Geological Framework (GF) and Community Thermal Model (CTM) using data and modeling. Work toward quantifying distributed upper-crust deformation including folding.

A2-3   Develop a high-resolution ML-based earthquake catalog with precise locations for the entire SAFS.

Year 3

A3-1   Establish a SAFS-wide Community Fault Model (CFM) that includes more realistic 3D geometry and reconciles inconsistencies between the existing CFM and the lower-resolution National Seismic Hazard Model (NSHM) faults.

A3-2   Extend the high-resolution earthquake catalog to include focal mechanisms.

A3-3   Integrate new data and simulation constraints into the Community Stress Model (CSM).

A3-4   Determine geologic slip rates and paleoseismic histories (particularly the date of the most recent earthquake) for faults currently lacking this information. Prioritize faults passing through populated areas and/or those for which geodetic slip rates are difficult to obtain.

A3-5   Develop new and/or improved geodetic-based fault slip rates with a focus on Northern California and poorly characterized fault systems. Compare with geologic slip-rate observations where available and use them to constrain the geographic extent of off-fault deformation.

A3-6   Establish preliminary SAFS-wide Community Velocity Model (CVM) and Community Geodetic Model (CGM). Curate a Unified Structural Representation combining the CVM and CFM for the entire SAFS. Establish a Community Rheology Model (CRM) that spans all principal fault systems of the plate boundary.

8.B. Developing rheologies that bridge scales and conditions for the San Andreas Fault System

Year 1

B1-1   Prototype rate-dependent constitutive models for gouge materials in crustal fault zones. Identify important minerals for which ductile flow laws are insufficiently characterized and develop a plan to remedy this situation.

Year 2

B2-1   Develop the first Community Fault Zone Model to curate data on multi-scale fault zone architecture. Extend the scope of the geological framework to cover the entire SAFS. Include elastic properties of compliant fault zones in the CRM.

B2-2   Incorporate fluid effects in models for inelastic response of rocks and gouge materials to illuminate the interplay between inelastic deformation and fluid flow, including the dependence of hydraulic parameters on mechanical deformation, localization and delocalization of strain, as well as generating a spectrum of slip phenomena.

Year 3

B3-1   Establish a SAF-wide Community Thermal Model and Geologic Framework Model.

B3-2   Update the flow laws used to model bulk deformation and ductile shear zones for a broad range of relevant minerals. Incorporate grain size in CRM definitions.

B3-3   Create prototype bulk damage rheology for long- and short-term deformation in the upper crust including the sediment velocity model. Validate long-term stress field simulations conducted with the CRM against CSM observations.

8.C. Developing advanced modeling frameworks

<u>Years 1-3</u>

C1,2,3-1   Develop, extend and maintain code training, benchmarks, verification (inter-code comparison) and validation (comparison with observations) standards and exercises in seismic cycle, dynamic rupture and ground motion modeling, as well as earthquake forecasting and testing.

<u>Year 1</u>

C1-1   Develop and utilize existing and emerging cyberinfrastructure to allow for 3D visualization and data (and model data) access. Work towards integration of different Community Earth Models into an integrated web-based Community Earth Model Framework.

C1-2   Create workflows for unifying and curating simulation results following FAIR best practices to be used in ML analysis, observational validation and to better link existing modeling capabilities and bridge time and space scales

<u>Year 2</u>

C2-1   Apply new capabilities to model spontaneous generation of localized and distributed damage features along with tectonic deformation.

C2-2   Develop, verify and validate open-source algorithms and prototype solvers promoting reproducible research through support of open data access and public software infrastructure for simulations of earthquakes, large scale fault slip, rock damage and deformation and their coupled evolution. Work on improved solid flow and temperature solvers for tectonic deformation.

<u>Year 3</u>

C3-1   Develop prototype 2D and 3D simulations of coupled evolution of earthquakes, faults, and tectonic deformation within an integrated Model/Software Ecosystem.

8.D. Improving predictive analyses of seismicity and ground motion

<u>Year 1</u>

D1-1   Assess space- and time-dependent geophysical variables that influence seismicity rates and occurrence patterns across the SAFS, such as heat flow, slow slip and fault network characteristics.

Year 2

D2-1   Improve clustered seismicity forecasting models for California for evaluation within CSEP. Identify and promote benchmarks to compare the performance of various machine learning and other new algorithms to standard models such as ETAS.

D2-2   Determine signals (e.g., localization, accelerated activity, quiescence) preceding $M>7$ earthquakes in California and large events in lab experiments.

Year 3

D3-1   Create frameworks for seismicity forecasting as alternatives to ETAS (the Epidemic Type Aftershock Sequence model) for CSEP evaluation. Develop methodology for detecting localization and other transient signals of shear deformation in geophysical observations.

D3-2   Combine high resolution Sediment Velocity Models with high resolution spatio-temporal physics based simulations in 3D (AWP-OCD) and perform systematic validation studies against observations and ergodic ground motion models. Quantify the implications of improved crustal models for ground motion characterization.

D3-3   Develop a library of California-wide ground motion simulation scenarios to provide input for median scaling of non-ergodic ground motion models. Illuminate path effects through the basins of the statewide Sediment Velocity Model.

SCEC Proposal Cover Page Template

SCEC Identifier	24123 (*provided by the online proposal system*)
Project Title	*Enter proposal title*
Project Period	February 1, 2024 - January 31, 2025
Proposal Category	*Select one from below:* Individual Research Project (Single Investigator / Institution) Collaborative Research Project (Multiple Investigators / Institutions) Community Workshop Community Technical Skills Training
SCEC Science Milestones Addressed	*See Section 8 of 2024 Science Plan for the SCEC Milestones. List all the milestones this proposal might address. For example:* A1-1, A1-2, B1-2

Institutional Affiliation	Investigators	Budget Request
Institution Name Address, City, ST	First Lastname 1 First Lastname 2	$15,000
Institution Name Address, City, ST	First Lastname 3	$10,500
Institution Name Address, City, ST	First Lastname 4	$12,000
	Total Project Budget	**$37,500**

About Participants	
How many people will be involved in the project (including PIs, and those directly funded or otherwise)?	##
Will the project funds support Early Career faculty or postdoctoral researchers?	yes / no
Will the project funds support Graduate Students?	yes / no
Will the project funds support Undergraduate Students?	yes / no
Are any of the collaborating institutions a Regional Public University (RPU), Minority Serving Institution (MSI) or Primarily Undergraduate Institution (PUI)?	yes / no

Suggested Review Groups	*Select the three most relevant review groups based on the descriptions provided below. For example:* Seismology, Plate Boundary System, Community Earth Models

SCEC Review Groups

The **Seismology** disciplinary group collects data on seismic phenomena in the plate boundary system of California, develops new techniques to extract detailed and reliable information from the data, and integrates the results into models of velocity structures, source properties, and seismic hazard. The group fosters innovation in network deployments, data collection, and data processing, especially those that fill important observational gaps and provide real-time research tools.

The **Tectonic Geodesy** disciplinary group uses geodetic measurements to study crustal deformation over the earthquake cycle along the San Andreas Fault System. They aim to determine how faults are loaded and the role of off-fault deformation. The group monitors and responds to earthquakes, tracking surface deformation changes, measuring coseismic displacements, and contributing to the Community Geodetic Model.

The **Earthquake Geology** disciplinary group focuses on the Late Quaternary record of faulting and ground motion, including data gathering in response to major earthquakes. The group fosters research on outstanding seismic hazard issues, the geological framework and earthquake history of faults in California, and contributes significant information to the Community Earth Models. The group manages the SCEC geochronology infrastructure, which provides ^{14}C and cosmogenic dating for SCEC-funded research.

The **Research Computing (RC)** disciplinary group develops research software and uses advanced modeling, data-intensive computing, and high-performance computing to address emerging needs of SCEC users. They work with SCEC scientists to leverage rapidly changing computer architectures, algorithms, and software technology, and engage with academic and national high performance computing (HPC) resource providers to facilitate large-scale and data-intensive research computing. The group also supports students in the geosciences and computer science to develop valuable research computing skills.

The **Plate Boundary System (PBS)** group studies earthquake history to clarify and refine hazard assessments throughout the entire transform plate boundary between the Pacific and North American Plates from western Nevada to the Borderlands offshore, and from Baja California to Cape Mendocino. They develop projects to collect and analyze data on the timing and size of large earthquakes along the San Andreas Fault System and to investigate fault features that may halt or permit continued rupture.

The **Fault and Rupture Mechanics (FARM)** group uses field, lab, and theoretical studies to (1) constrain the properties, conditions, and physical processes that control faulting in the lithosphere throughout the earthquake cycle; and (2) develop physics-based fault models at various scales, such as for earthquake nucleation, propagation, and arrest, or long-term earthquake sequences. They aim to understand earthquakes in the San Andreas Fault System and contribute to seismic hazard estimates and physics-based ground motion predictions.

The **Stress and Deformation Over Time (SDOT)** group studies lithospheric processes in the San Andreas Fault System to understand how faults are loaded and evolve over time on

timescales from tens of millions of years to tens of years. They use geodynamic modeling to characterize present-day stress and deformation, and to tie this to long-term lithospheric evolution. SDOT also develops system-wide deformation models to contribute to physics-based probabilistic seismic hazard analysis.

The **Community Earth Models (CEM)** group develops, refines and integrates community models describing a wide range of features of the California lithosphere and asthenosphere. These features include: elastic and attenuation properties (Community Velocity Model, CVM), temperature (Community Thermal Model, CTM), rheology (Community Rheology Model, CRM), stress and stressing rate (Community Stress Model, CSM), deformation rate (Community Geodetic Model, CGM), and fault geometry (Community Fault Model, CFM). Their ultimate goal is to provide an internally consistent suite of models that can be used together to simulate seismic phenomena in California.

The **Earthquake Forecasting and Predictability (EFP)** group coordinates research on: developing earthquake forecast methods; evaluating earthquake forecasts; expanding knowledge of earthquake processes relevant for forecasting; developing and using earthquake simulators; and understanding the limits of earthquake predictability. Through the Collaboratory for the Study of Earthquake Predictability (CSEP), the EFP group supports a wide range of scientific prediction experiments worldwide, including those involving geographically distributed fault systems in different tectonic environments, through international collaboration.

The **Ground Motions (GM)** group studies ground motion data and models wave propagation mechanisms, including nonlinearity and scattering effects. They develop and validate physics-based simulation methodologies to predict strong-motion broadband waveforms and permanent ground deformation. The group also studies how regional nonlinear effects can be modeled to produce simulated ground motions that are valid across a range of magnitudes, distances, and frequencies, especially for large magnitudes at close distances.

The **Applied Science Implementation (ASI)** group connects SCEC scientists and research results with practicing engineers, government officials, business risk managers, and other professionals, as well as computer scientists, to improve the application of earthquake science and take advantage of emerging technologies to perform research. The ASI group engages with communities that interface with the Center, such as technical stakeholders and downstream users, to apply geoscientific knowledge to hazard quantification, validate ground motion simulations and earthquake rupture forecasts, and integrate and use SCEC science products.

The **Community Capability Building (CCB)** group focuses on activities that train researchers at all career levels in multidisciplinary research and the skills needed to engage in the SCEC collaboration, including new technical skills that emerge and/or are needed for research. They support efforts that maximize the contributions from the next generation of earthquake scientists by providing opportunities to learn from and collaborate with experienced researchers, develop new skills, and build networks. This enables a diverse group of researchers to collaborate over time, building deep scientific collaborations and interpersonal networks to advance earthquake science.