2016 Science Collaboration Plan

Southern California Earthquake Center

Issued October 2015

Proposals Due: November 6, 2015

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1. What's New This Year

The most substantial changes in this year's Science Collaboration Plan include:

1. 2016 is the final year of the SCEC4 research program. Proposals should not include plans that will involve multi-year efforts beyond January 2017, except for proposed CCSP-related research projects.
2. Develop methods for combining GPS and InSAR data in the CGM by characterizing seasonal/hydrologic/anthropogenic signals, accounting for earthquake effects as needed, and quantifying covariances in order to produce a reliable consensus model.
3. An explicit call for a synthesis of results at the Ventura and San Gorgonio Pass special fault study areas.
4. A call to develop improved representations of, and user interfaces to, the USR.
5. The need for develop and implement simulation methods for the modeling of bending faults and multi-segment ruptures.
6. A further request to compare and assess engineering metrics in ground motion validation.
7. A call to catalog the quality and supporting evidence for unique offsets, and to develop techniques to estimate slip distributions from field, LiDAR, and SfM datasets.
8. A call to test potential rupture histories using geometrically realistic fault configurations in dynamic rupture models.

For more specific guidance on each of these changes please see the relevant section of the Collaboration Plan.

2. Preamble

The Southern California Earthquake Center (SCEC) coordinates basic research in earthquake science using Southern California as its natural laboratory. SCEC emphasizes the connections between information gathering by networks of instruments, fieldwork, and laboratory experiments; knowledge formulation through physics-based, system-level modeling; improved understanding of seismic hazard; and actions to reduce earthquake risk and promote resilience. The Center is a consortium of institutions that coordinates earthquake system science within Southern California. SCEC's long-term goal is to understand how seismic hazards change across all time scales of scientific and societal interest, from millennia to seconds. The fourth phase of SCEC (SCEC4) moves earthquake science forward through highly integrated collaborations that are coordinated across scientific disciplines and research institutions and enabled by high-performance computing and advanced information technology. It focuses on six fundamental problems of earthquake physics:

1. Stress transfer from plate motion to crustal faults: long-term fault slip rates.
2. Stress-mediated fault interactions and earthquake clustering: evaluation of mechanisms.
3. Evolution of fault resistance during seismic slip: scale-appropriate laws for rupture modeling.
4. Structure and evolution of fault zones and systems: relation to earthquake physics.
5. Causes and effects of transient deformations: slow slip events and tectonic tremor.
6. Seismic wave generation and scattering: prediction of strong ground motions.

The six fundamental problems constitute the basic-research focus of SCEC. They are interrelated and require an interdisciplinary, multi-institutional approach. Interdisciplinary research initiatives focus on special fault study areas, the development of a community geodetic model for Southern California, and a community stress model. The latter is a new platform where the various constraints on earthquake-producing stresses are integrated. Improvements are also being made to SCEC's unified structural representation and its statewide extensions.

Collaboration Plan. On February 1, 2012, the Southern California Earthquake Center (SCEC) transitioned from SCEC3 to SCEC4 under joint funding from NSF/EAR and the U.S. Geological Survey. SCEC4 is funded for the period February 2012 through January 2017. This document, referred to as the Collaboration Plan, solicits proposals from individuals and groups to participate in the SCEC4 research program.

3. Guidelines for Proposal Submission

A. ***Eligibility.*** Investigators or co-investigators with an overdue project report from prior SCEC-funded awards are not eligible to submit a new SCEC proposal.

   Proposals can be submitted by eligible Principal Investigators from **U.S. academic institutions** and **U.S. private corporations**. For international institutions, funding will mainly be available for travel only to SCEC-sponsored meetings in the U.S. Due to limited funding, requests for travel to the SCEC Annual Meeting must be cost shared by the investigator's institutions. Cost sharing must be described in the proposal.

B. ***Due Date.*** Friday, November 6, 2015, 5:00 pm PST. Late proposals will not be accepted.

C. ***Delivery Instructions.*** Proposals do not need to be formally signed by institutional representatives and should be for one year in duration, with a start date of February 1, 2016 and end date of January 31, 2017.

Proposals must be submitted online through the SCEC Proposal System (http://www.scec.org/scienceplan). A proposal submission will be considered complete **only if all the following** are received through the online system by the due date:

1. ***Investigator Profiles.*** Every investigator listed on the proposal must be registered in the SCEC Community Information System and his/her user profile updated with the current contact information. To update your profile log in at www.scec.org and click "My Account". New investigators can register for a SCEC profile at www.scec.org/user/register.

2. ***Proposal Information.*** The Proposal Information information required for the Cover Page must be entered through the online submission system (see 5a below).

3. ***Budget Information.*** The Budget Information for each organization requesting funding must be entered through the online submission system and the budget tables with justifications must be included in the full proposal PDF (see below).

4. ***Current and Pending Support.*** The Current and Pending Support for each investigator requesting funding must be entered through the online submission system and be included in the full proposal PDF (see below).

5. ***Full Proposal PDF.*** The proposal file should include (a) Cover Page, (b) Project Plan, (c) Budget Information, and (d) Current and Pending Support. Proposal PDF file names should follow the SCEC proposal naming convention: PI last name followed by 2016 (e.g. Sleep2016.pdf). If more than one proposal is submitted per PI, then label as follows: Sleep2016_1.pdf, Sleep2016_2.pdf, etc.

   (a) Cover Page. On the cover page include the words "2016 SCEC Proposal", Project Title, Principal Investigator(s), Institutional Affiliation(s), Amount of Request per Investigator, Total Amount of Request, and Proposal Category (see Section 5). Also list, in order of priority, three SCEC science objectives that your proposal addresses (e.g. 1a, 3c and 4b; see Section 8). If the proposal includes undergraduate student intern funding, please note this on the cover page.

   (b) Project Plan. In 5 pages maximum (including figures), describe the technical details of the proposed project and how it relates to the short-term objectives outlined in the SCEC Research Priorities and Requirements (Section 8). If the proposed project is related to a previously funded SCEC project, the technical description must also include a 1-page summary of previous research results. The research summary is part of the 5-page limit. References are excluded from the 5-page limit. See note below on submission of collaborative proposals.

   (c) Budget Information. Every proposal must include a budget table and budget justification for each institution requesting funding. The budgets should be constructed using NSF categories (http://www.nsf.gov/pubs/policydocs/pappguide/nsf15001/gpg_2.jsp#IIC2h). Under guidelines of the SCEC Cooperative Agreements and A-81 regulations, secretarial support and office supplies are not allowable as direct expenses.

   (d) Current and Pending Support. Statements of current and pending support should be included for each Principal Investigator requesting funding on the proposal, following NSF guidelines (http://www.nsf.gov/pubs/policydocs/pappguide/nsf11001/gpg_2.jsp). Proposals without a current and pending support statement will not be reviewed.

D. ***Principal Investigator Responsibilities.*** By submitting a proposal, investigators agree to the following conditions:

1. ***Community Participation*****.** Principal investigators will interact with other SCEC scientists on a regular basis (e.g., by attending the annual meeting and presenting results of SCEC-funded research in the poster sessions, workshops and working group meetings) and to contribute data, analysis results, and/or models to the appropriate SCEC resource (e.g., Southern California Earthquake Data Center, database, community model).

2. ***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.

3. ***Project Report.*** Principal investigators will submit a project report by the due date listed below.

   (a) Workshop Awards. A report on results and recommendations of the workshop funded by SCEC is due no later than 30 days following the completion of the workshop. The report will be posted on the SCEC website as soon as possible after review by SCEC leadership.

   (b) Annual Meeting Participation Awards. A report on results and recommendations from travel funded by SCEC is due no later than 30 days following the completion of the travel.

   (c) Research Awards. Investigators funded by SCEC must submit a project report no later than March 15 (5:00 pm PST) in the year after the funding was received. Reports should be a maximum of 5 pages (including text and figures). Reports must include references to all SCEC publication during the past year (including papers submitted and in review) with their SCEC contribution number (see 2 above).

E. ***Collaborative Proposals.*** Collaborative proposals with investigators from the USGS are encouraged. USGS employees should submit their requests for support through USGS channels.

Collaborative proposals involving multiple investigators and/or institutions are strongly encouraged. The lead investigator should submit only one proposal for the collaborative project. Information on all investigators requesting SCEC funding (including budgets and current support statements) must be included in the proposal submission. The project plan may include one extra page per investigator to report results of previously-funded, related research. Funding for Collaborative Proposals may be delayed or denied if any of the investigators has overdue project report(s) for prior SCEC funding.

F. ***Budget Guidance.*** Typical SCEC grants funded under this Science Collaboration Plan fall in the range of $10,000 to $35,000. This is not intended to limit SCEC to a fixed award amount, nor to a specified number of awards, rather it is intended to calibrate expectations for proposals written by SCEC investigators. **Field research investigations outside southern California will not be supported.**

G. ***Award Procedures.*** The Southern California Earthquake Center is funded by the National Science Foundation and the U.S. Geological Survey through a cooperative agreement with the University of Southern California. Additional funding for the SCEC core research program is provided by the Pacific Gas and Electric Company, geodesy royalty funds, the NSF SAVI supplement, and potentially other sources. All research awards will be funded as subawards or fixed priced contract from the University of Southern California. Workshop and travel award expenditures will be managed through the master SCEC account at USC.

SCEC4 will end on January 31, 2017. All funds awarded as a result of favorable review on a 2016 SCEC proposal must be spent by January 31, 2017. Extensions will not be possible on new or existing SCEC awards beyond that date.

4. SCEC Organization

A. ***Mission and Science Goal.*** SCEC is an interdisciplinary, regionally focused organization with a mission to:

- Gather data on earthquakes in Southern California and other places where such data has direct relevance to Southern California

- Integrate information into a comprehensive, physics-based understanding of earthquake phenomena

- Communicate understanding to the world at large as useful knowledge for reducing earthquake risk
- SCEC's primary science goal is to develop a comprehensive, physics-based understanding of earthquake phenomena in Southern California through integrative, multidisciplinary studies of plate-boundary tectonics, active fault systems, fault-zone processes, dynamics of fault ruptures, ground motions, and seismic hazard analysis.

B. ***Disciplinary Activities.*** The Center sustains disciplinary science through standing committees in Seismology, Geodesy, Geology, and Computational Science. These committees are responsible for planning and coordinating disciplinary activities relevant to the SCEC Science Collaboration Plan, and they make recommendations to the SCEC Planning Committee regarding support of disciplinary research and infrastructure. High-priority disciplinary activities are summarized in Section 9.

C. ***Interdisciplinary Focus Areas.*** Interdisciplinary research is organized into science focus areas: Unified Structural Representation (USR), Fault and Rupture Mechanics (FARM), Stress and Deformation Over Time (SDOT), Earthquake Forecasting and Predictability (EFP), Ground Motion Prediction (GMP), Southern San Andreas Fault Evaluation (SOSAFE), and Earthquake Engineering Implementation Interface (EEII). High-priority activities are listed for each of these interdisciplinary focus areas in Section 10.

D. ***Special Projects and Initiatives.*** Special Projects and Initiatives are organized around large-scale projects funded through special grants outside of the NSF-USGS cooperative agreements that support the SCEC base program, but have synergistic goals and are aligned with the overall SCEC research program priorities. The current Special Projects teams include Working Group on California Earthquake Probabilities (WGCEP), the Collaboratory for the Study of Earthquake Predictability (CSEP), the Community Modeling Environment (CME), the Virtual Institute for the Study of Earthquake Systems (VISES), and the Central California Seismic Project (CCSP). See Section 11 for a summary of the high priority activities for the Special Projects.

E. ***Technical Activity Groups.*** Various groups of SCEC experts have formed Technical Activity Groups (TAGs) to verify the complex computer calculations needed for wave propagation and dynamic earthquake rupture simulations, to assess the accuracy and resolving power of source inversions, and to develop geodetic transient detectors and earthquake simulators. TAGs can be thought of as "mini-collaboratories" that pose well-defined “standard problems”, encourage solution of these problems by different researchers using different algorithms or codes, develop a common cyberspace for comparing solutions, and facilitate meetings to discuss discrepancies and potential improvements.

F. ***Communication, Education, and Outreach.*** The theme of the Communication, Education, and Outreach (CEO) program during SCEC4 is *Creating an Earthquake and Tsunami Resilient California*. CEO will continue to manage and expand a suite of successful activities along with new initiatives, within four CEO interconnected thrust areas:

   1. The *Implementation Interface* connects SCEC scientists with partners in earthquake engineering research, and communicates with and trains practicing engineers and other professionals.
   2. The *Public Education and Preparedness* thrust area educates people of all ages about earthquakes, and motivates them to become prepared.
   3. The *K-14 Earthquake Education Initiative* seeks to improve earth science education and school earthquake safety.
   4. Finally, the *Experiential Learning and Career Advancement* program provides research opportunities, networking, and more to encourage and sustain careers in science and engineering.

   Opportunities for participating in the CEO program are described in Section 12.

5. Proposal Categories

A. ***Data Gathering and Products.*** SCEC coordinates an interdisciplinary and multi-institutional study of earthquakes in Southern California, which requires data and derived products pertinent to the region. Proposals in this category should address the collection, archiving and distribution of data, including the production of SCEC community models that are online, maintained, and documented resources for making data and data products available to the scientific community.

B. ***Integration and Theory.*** SCEC supports and coordinates interpretive and theoretical investigations on earthquake problems related to the Center's mission. Proposals in this category should be for the integration of data or data products from Category A, or for general or theoretical studies. Proposals in Categories A and B should address one or more of the goals in Section 8, and may include a brief description (<200 words) as to how the proposed research and/or its results might be used in a special initiative (see Section 11) or in education and/or outreach (see Section 12).

C. ***Special Fault Study Areas.*** Special Fault Study Areas (SFSA) are integrated, multidisciplinary projects focused on areas of complex fault behavior within southern California that would contribute to an improved understanding of earthquake processes through focused observation and modeling. There are two primary goals of SFSA, as articulated in the SCEC4 proposal: (1) To understand how fault complexities affect the propagation of earthquake ruptures and the heterogeneity of stress in the crust, and (2) To investigate how tremor and microseismicity (including induced seismicity) affect the nucleation of large earthquakes. Tackling these problems will require the assembly of teams of researchers with diverse expertise. For example, research areas of fault complexity may seek to merge geological, seismological, and potential-field data to elucidate fault structure and paleoseismic history, integrate this information with geodetic data to derive fault loading and stressing rates, and apply dynamic rupture simulations to explore how earth structure and rupture history affect the potential sizes of future earthquakes. One of the anticipated advantages of SFSA is to leverage the impact of new and/or densified instrumentation. It is expected that collaborations built around SFSA will be open to the community, and generate open community data sets.

Two SFSAs were established in SCEC4: the **San Gorgonio Pass** and **Ventura Area** SFSAs. The SFSA website (http://www.scec.org/research/sfsa.html) contains a Science Plan and contact information for each area. The Science Plans identify key problems in earthquake science, and research targets, timelines for achieving goals, and a discussion of integrative activities and broader impacts specific to each area. An updated science plan for the San Gorgonio Pass project, following from the 2014 Workshop, is available on the SFSA website. The SFSA Science Plans should be considered for proposal development. Special emphasis this funding cycle will be placed on completing projects associated with the goals of both SFSA's.

<u>SCEC Proposals associated with a SFSA</u>: Each principal investigator should submit a separate, standard 5-page SCEC proposal that clearly ties the investigator's work to the Science Collaboration Plan, provides additional background and details on the data collection and/or analyses to be completed by that investigator, and a budget for that investigator. Each investigator's proposal will be evaluated separately through the standard SCEC proposal process (see Evaluation Process and Criteria). Workshop proposals for activities around the SFSA should be developed according to the standard workshop proposal process as outlined in the Science Collaboration Plan.

D. ***Workshops.*** SCEC participants who wish to convene a workshop between February 1, 2016 and January 31, 2017 should submit a proposal for the workshop in response to this Collaboration Plan. The proposed lead convener of the workshop must contact Tran Huynh (scecmeet@usc.edu) for guidance in planning the scope, budget and scheduling of the proposed workshop before completing the proposal submission. Note that workshops scheduled in conjunction with the SCEC Leadership Retreat (June) or SCEC Annual Meeting (September) are limited in number and may have further constraints due to space and time availability.

Workshops in the following topics are particularly relevant:

- Summarize collaborative research findings wrapping up research efforts for the current five-year SCEC program (2012-2017). In particular, interactive workshops that engage more than one focus and/or disciplinary group are strongly encouraged.
- Engaging earthquake engineers and other partner and user groups in SCEC-sponsored research.
- Participating in national initiatives such as EarthScope and the Advanced National Seismic System (ANSS).

E. ***Communication, Education, and Outreach.*** SCEC has developed a long-range CEO plan and opportunities for participation are listed in Section 12. Investigators who are interested in participating in this program should contact Mark Benthien (213-740-0323; benthien@usc.edu) before submitting a proposal.

F. ***SCEC/SURE Intern Project.*** Each year SCEC coordinates the Summer Undergraduate Research Experience (SCEC/SURE) Program, which supports undergraduate students working one-on-one with SCEC scientists on diverse research projects. Recruitment for SURE intern mentors begins in the fall. Potential research projects are published on the SCEC Internships website (http://www.scec.org/internships), where undergraduate students may apply and identify their preferred projects. Interested SCEC scientists are encouraged to include support for an undergraduate SURE intern in their SCEC proposals. SURE mentors are required to provide at least $2500 of the $5000 intern stipend. Mentor contributions can come from any source, including SCEC-funded research projects. Questions about the SCEC/SURE Program should be referred to Robert de Groot (degroot@usc.edu).

G. ***SCEC Annual Meeting Participation.*** This category includes proposals by investigators requesting travel funding to participate in the SCEC Annual Meeting only. Investigators who are (a) new to SCEC who would benefit from exposure to the SCEC Annual Meeting in order to fine-tune future proposals and/or (b) already funded on study projects outside of SCEC that would be of interest to the SCEC community are encouraged to apply. Due to limited funding, requests for travel to the SCEC Annual Meeting must be cost shared by the investigator's institutions. **Proposals will not be accepted under the "new to SCEC" element in 2015 for the last year for SCEC4.**

6. Evaluation Process and Criteria

Proposals should be responsive to the Collaboration Plan. A primary consideration in evaluating proposals will be how directly the proposal addresses the main objectives of SCEC. Important criteria include (not necessarily in order of priority):

1. Scientific merit of the proposed research,
2. Competence and performance of the investigators, especially in regard to past SCEC-sponsored research,
3. Priority of the proposed project for short-term SCEC objectives as stated in the Collaboration Plan,
4. Promise of the proposed project for contributing to long-term SCEC goals,
5. Commitment of the principal investigator and institution to the SCEC mission,
6. Value of the proposed research relative to its cost,
7. Ability to leverage the cost of the proposed research through other funding sources,
8. Involvement of students and junior investigators,
9. Involvement of women and underrepresented groups, and
10. Innovative or "risky" ideas that have a reasonable chance of leading to new insights or advances in earthquake physics and/or seismic hazard analysis.

Proposals may be strengthened by describing:

1. Collaboration within or between disciplinary and/or focus groups; with modeling and/or data gathering activities; and with engineers, government agencies, and other organizations.
2. Leveraging additional resources from other agencies, your institution, and by expanding collaborations.
3. Development and delivery of products, such as community research tools, software, models, databases, and communication and educational materials.
4. Educational opportunities (e.g. graduate student research assistantships, undergraduate summer and year-round internships (funded by the project), K-14 educator and student activities, and participation in data collection).

All research proposals will be evaluated by the appropriate disciplinary committees and focus groups, the Science Planning Committee, and the Center Director. CEO proposals will be evaluated by the CEO Associate Director and the Center Director.

The Science Planning Committee is chaired by the SCEC Co-Director and Planning Committee Vice-Chair, and includes the chairs of the disciplinary committees, focus groups, and special projects. It is responsible for recommending a balanced science budget to the Center Director.

Recommendations of the Science Planning Committee will be combined into an annual spending plan and forwarded to the SCEC Board of Directors for approval.

Final selection of research projects will be made by the Center Director, in consultation with the Board of Directors.

The review process should be completed and applicants notified circa March 2016.

7. Coordination of Research between SCEC and USGS-EHRP

Earthquake research in Southern California is supported both by SCEC and by the USGS Earthquake Hazards Program (EHP). EHP's mission is to provide the scientific information and knowledge necessary to reduce deaths, injuries, and economic losses from earthquakes. Products of this program include timely notifications of earthquake locations, size, and potential damage, regional and national assessments of earthquakes hazards, and increased understanding of the cause of earthquakes and their effects. EHP funds research via its External Research Program, as well as work by USGS staff in its Pasadena (California), Menlo Park (California), Vancouver (Washington), Seattle (Washington), and Golden (Colorado) offices. The EHP also directly supports SCEC.

SCEC and EHP coordinate research activities through formal means, including USGS membership on the SCEC Board of Directors and a Joint Planning Committee, and through a variety of less formal means. Interested researchers are invited to contact Dr. Rob Graves, EHP coordinator for Southern California, or other SCEC and EHP staff to discuss opportunities for coordinated research.

The USGS EHP supports a competitive, peer-reviewed, external program of research grants that enlists the talents and expertise of the academic community, state and local governments, and the private sector. The investigations and activities supported through the external program are coordinated with and complement the internal USGS program efforts. This program is divided into six geographical/topical 'regions', including one specifically aimed at Southern California earthquake research and others aimed at earthquake physics and effects and at probabilistic seismic hazard assessment (PSHA). The Program invites proposals that assist in achieving EHP goals.

The EHP web page, http://earthquake.usgs.gov/research/external, describes program priorities, projects currently funded, results from past work, and instructions for submitting proposals. The annual EHP external funding cycle has different timing than SCEC's, with the USGS RFP due out in February and proposals due in May. Interested PIs are encouraged to contact the USGS regional or topical coordinators for Southern California, Earthquake Physics and Effects, and/or National (PSHA) research, as listed under the "Contact Us" tab.

The USGS internal earthquake research program is summarized at http://earthquake.usgs.gov/research/topics.php.

8. SCEC4 Fundamental Problems of Earthquake Physics: Research Priorities and Requirements

The six fundamental problems constitute the basic-research focus of SCEC4. They are listed in the preamble and expanded in detail below. They are interrelated and require an interdisciplinary, multi-institutional approach. Interdisciplinary research initiatives focus on special fault study areas, the development of a community geodetic model for Southern California, and a community stress model. The latter is a new platform where the various constraints on earthquake-producing stresses can begin to be integrated. In addition, improvements are to be made to SCEC's unified structural representation and its statewide extensions.

1. Stress transfer from plate motion to crustal faults: long-term fault slip rates

Priorities and Requirements

1a. Mapping and studying faults in Southern California to determine slip rates for faults at multiple time scales and characterize fault zone properties for which brittle/ductile transitions have been exposed by detachment faulting or erosion.

1b. Focused laboratory, numerical, and geophysical studies of the character of the lower crust, its rheology, stress state, and expression in surface deformation. We will use surface-wave dispersion to improve depth resolution relative to teleseismic studies.

1c. Regional searches for seismic tremor at depth in Southern California to observe if (some) deformation occurs by slip on discrete structures at depth.

1d. Development of a Community Geodetic Model (CGM) for California, in collaboration with the UNAVCO community, to constrain long-term deformation and fault-slip models.

1e. Combined modeling/inversion studies to interpret GPS and InSAR geodetic results on postseismic transient deformation without traditional simplifying assumptions.

2. ***Stress-mediated fault interactions and earthquake clustering: evaluation of mechanisms***

Priorities and Requirements

2a. Improvement of earthquake catalogs, including non-point-source source descriptions, over a range of scales. Traditional aftershock catalogs can be improved through better detection of early aftershocks. Long-term (2000-yr) earthquake chronologies, including slip-per-event data, for the San Andreas Fault system and other major faults are necessary to constrain long-term recurrence behavior.

2b. Improved descriptions of triggered earthquakes. While temporal earthquake clustering behavior (Omori's Law) is well known, the spatial and coupled temporal-spatial behavior of triggered earthquakes, potentially key diagnostics, are not well constrained.

2c. Lowered thresholds for detecting aseismic and infraseismic transients, and improved methods for separating triggering by aseismic transients from triggering by other earthquakes.

2d. Development of a Community Stress Model (CSM) for Southern California, based on merging information from borehole measurements, focal mechanisms, paleo-slip indicators, observations of damage, topographic loading, geodynamic and earthquake-cycle modeling, and induced seismicity. Use of seismicity to constrain CSM and investigate how stress may control earthquake clustering and triggering. Collaboration with other organizations in fault-drilling projects for in situ hypothesis testing of stress levels.

2e. Development of physics-based earthquake-cycle simulators that can unify short-term clustering statistics with long-term renewal statistics, including the quasi-static simulators that incorporate laboratory- based nucleation models.

2f. Development of a better understanding of induced seismicity, specifically induced by geothermal power production in the Salton Sea area, which warrant study as potential hazards.

3. ***Evolution of fault resistance during seismic slip: scale-appropriate laws for rupture modeling***

Priorities and Requirements

3a. Analysis of laboratory experiments on fault materials under appropriate confining stresses, temperatures, and fluid contents/pressures through targeted experiments in collaboration with rock mechanics laboratories.

3b. Observations of geological, geochemical, paleo-temperature, microstructural, and hydrological indicators of specific resistance mechanisms that can be measured in the field. In particular, evidence of thermal decomposition in exhumed fault zones. Collaboration with other organizations involved in fault-drilling projects to measure observables for constraining coseismic resistance mechanisms, such as the temperature on faults before and after earthquakes.

3c. Formulation of theoretical and numerical models of specific fault resistance mechanisms for seismic radiation and rupture propagation, including interaction with fault roughness and damage-zone properties.

3d. Development of parameterized fault rheologies suitable for coarse-grained numerical modeling of rupture dynamics and for simulations of earthquake cycles on interacting fault systems. (Currently, the constitutive laws for co-seismic slip are often represented as complex coupled systems of partial differential equations, contain slip scales of the order of microns to millimeters, and hence allow detailed simulations of only small fault stretches.)

3e. Construction of computational simulations of dynamic earthquake ruptures to help constrain stress levels along major faults, to help explain the heat-flow paradox, and to help us understand extreme slip localization, the dynamics of self-healing ruptures, and the potential for repeated slip on faults during earthquakes.

3f. Development of computational earthquake-cycle simulators that can incorporate realistic models of fault-resistance evolution during earthquake cycles and the wave-propagation that occurs during seismic events.

4. Structure and evolution of fault zones and systems: relation to earthquake physics

Priorities and Requirements

4a. Detailed geologic, seismic, geodetic, and hydrologic investigations of fault complexities at Special Fault Study Areas and other important regions.

4b. Investigations of along-strike variations in fault roughness and complexity (including slip rate and geometry) as well as the degree of localization and damage perpendicular to the fault.

4c. Improvements to the CFM using better mapping, including LiDAR, and precise earthquake relocations. We will also extend the CFM to include spatial uncertainties and stochastic descriptions of fault heterogeneity.

4d. Use of special fault study areas to model stress heterogeneities both deterministically and stochastically. We will integrate the results of these special studies into the CSM.

4e. Use of earthquake and earthquake-cycle simulators and other modeling tools, together with the CFM and CSM, to quantify how large-scale fault system complexities govern the probabilities of large earthquakes and rupture sequences.

5. Causes and effects of transient deformations: slow slip events and tectonic tremor

Priorities and Requirements

5a. Improvement of detection and mapping of the distribution of tremor across southern California by applying better instrumentation and signal-processing techniques to data collected in the special study areas, such as those outlined in the proposal.

5b. Application of geodetic detectors to the search for aseismic transients across southern California. We will use the CGM as the time-dependent geodetic reference frame for detecting geodetic anomalies.

5c. Collaboration with rock mechanics laboratories on laboratory experiments to understand the mechanisms of slow slip and tremor.

5d. Development of physics-based models of slow slip and tectonic tremor. We will constrain these models using features of tremor occurrence and its relationship to seismicity, geodetic deformation, and tectonic environment, as well as laboratory data.

5e. Use of physics-based models to understand how slow slip events and tremor activity affect earthquake probabilities in Southern California.

6. Seismic wave generation and scattering: prediction of strong ground motions

Priorities and Requirements

6a. Development of a statewide anelastic Community Velocity Model (CVM) that can be iteratively refined through 3D waveform tomography. Integration of new data (especially the Salton Sea Imaging Project) into the existing CVMs with validation of improvements in the CVMs. We will extend current methods of full-3D tomography to include ambient-noise data and to estimate seismic attenuation, and we will develop methods for estimating and representing CVM uncertainties.

6b. Modeling of earthquake ruptures that includes realistic dynamic weakening mechanisms, off-fault non-elastic deformation, and is constrained by source inversions. The priority is to produce physically consistent rupture models for broadband ground motion simulations of hazard-scale ruptures, such as ruptures envisioned in UCERF3. An important issue is how to treat multiscale processes; for example, might off-fault plasticity regularize the Lorentzian scale collapse associated with strong dynamic weakening? If not, how might adaptive meshing strategies be most effectively used to make full-physics simulations feasible?

6c. Development of stochastic representations of small-scale velocity and attenuation structure in the CVM for use in modeling high-frequency (> 1 Hz) ground motions. We will test the stochastic models with seismic and borehole logging data and evaluate their transportability to regions of comparable geology.

6d. Measurement of earthquakes with unprecedented station density using emerging sensor technologies (e.g., MEMS). The SCEC Portable Broadband Instrument Center will work with IRIS to make large portable arrays available for aftershock and flexible array studies.

6e. Collaboration with the engineering community in validation of ground motion simulations. We will establish confidence in the simulation-based predictions by continuing to work with engineers in validating the simulations against empirical attenuation models and exploring coherency and other standard engineering measures of ground motion properties.

9. Disciplinary Activities

The Center will sustain disciplinary science through standing committees in Seismology, Tectonic Geodesy, Earthquake Geology, and Computational Science. These committees will be responsible for planning and coordinating disciplinary activities relevant to the SCEC Science Collaboration Plan, and they will make recommendations to the SCEC Planning Committee regarding the support of disciplinary infrastructure. High-priority disciplinary objectives are detailed below.

A. Seismology

Objectives

The objectives of the Seismology group are to gather data on the range of seismic phenomena observed in southern California and to integrate these data into models of fault slip. Of particular interest are proposals that foster innovations in network deployments, data collection, real-time research tools, and data processing. Proposals that provide community products that support one or more of the SCEC4 goals or those that include collaboration with network operators in Southern California are especially encouraged. Proposers should consider the SCEC resources available including the Southern California Earthquake Data Center (SCEDC) that provides extensive data on Southern California earthquakes as well as crustal and fault structure, the network of SCEC funded borehole instruments that record high quality reference ground motions, and the pool of portable instruments that is operated in support of targeted deployments or aftershock response.

Example Research Strategies

- Enhancement and continued operation of the SCEDC and other existing SCEC facilities particularly the near-real-time availability of earthquake data from SCEDC and automated access.
- Real-time processing of network data such as improving the estimation of source parameters in relation to faults, especially evaluation of the short-term evolution of earthquake sequences and real-time stress perturbations on major fault segments.
- Enhance or add new capabilities to existing earthquake early warning (EEW) systems or develop new EEW algorithms. Develop real-time finite source models constrained by seismic and GPS data to estimate evolution of rupture and potentially damaging ground shaking; develop strategies for robust uncertainty quantification in finite-fault rupture models.
- Advance innovative and practical strategies for densification of seismic instrumentation, including borehole instrumentation, in Southern California and develop innovative algorithms to utilize data from these networks. Develop metadata, archival and distribution models for these semi-mobile networks.
- Develop innovative methods to search for unusual signals using combined seismic, GPS, and borehole strainmeter data; collaborations with EarthScope or other network operators are encouraged.
- Investigate near-fault crustal properties, evaluate fault structural complexity, and develop constraints on crustal structure and state of stress.

- Collaborations, for instance with ANSS that would augment existing and planned network stations with downhole and surface instrumentation to assess site response, nonlinear effects, and the ground coupling of built structures.
- Preliminary design and data collection to seed future passive and active experiments such as dense array measurements of basin structure and large earthquake properties, OBS deployments, and deep basement borehole studies.
- Improve locations of important historical earthquakes.

Priorities for Seismology

1. ***Tremor.*** Tremor has been observed on several faults in California, yet it does not appear to be ubiquitous. We seek proposals that explore the distribution and source characteristics of tremor in California and those that explore the conditions necessary for the generation of seismically observable tremor.
2. ***Low-cost seismic network data utilization and archiving.*** Several groups are developing seismic networks that use low-cost MEMS accelerometers. We seek proposals that would address development of seismological algorithms to utilize data from these networks in innovative ways. We also seek proposals that would develop metadata and archiving models for these new semi-mobile networks, as well as archive and serve these data to the SCEC user community.
3. ***Short-Term Earthquake Predictability.*** We seek proposals that develop new methods in earthquake statistics or analyze seismicity catalogs to develop methods for determining short-term (hours to days) earthquake probability gain.
4. ***Seismicity studies* in the two SFSA; Ventura and San Gorgonio.** We seek proposals that use earthquake data to map the structure and seismotectonics of these regions as part of the SFSA community effort.

B. Tectonic Geodesy

Tectonic Geodesy activities in SCEC4 will focus on data collection and analysis that contribute to improved earthquake response and to a better understanding of fault loading and stress transfer, the causes and effects of transient deformation, and the structure and evolution of fault zones and systems. The following are research strategies aimed at meeting these broad objectives:

1. **Contribute to the development of a Community Geodetic Model (CGM).** The goal of this effort is to develop a crustal motion model consisting of velocities and time series for southern California that leverages the complementary nature of GPS and InSAR observations. This requires development of optimal methods for combining GPS and InSAR data, characterizing seasonal/hydrologic/anthropogenic signals, accounting for earthquake effects as needed, and quantifying covariances in order to produce a suite of reliable models. Proposals should demonstrate coordination with the current activities and established timeline of the CGM project. 2016 work should focus on completion and evaluation of the CGM merged GPS time series solution; estimation and comparison of velocities, seasonal, and earthquake-related motion from these time series; and development of InSAR velocity maps for the southern California region. Technique development to prepare for full utilization of legacy and newly available SAR data for time series analysis and identification of optimal approaches for mitigating temporally and spatially correlated noise in GPS or InSAR time series are also particularly encouraged.
2. **Analysis of geodetic data to address specific SCEC4 research targets.** Studies addressing geodetic/geologic slip rate discrepancies, assessing the role of lower crust/upper mantle processes in driving fault loading, developing more physically realistic deformation models, providing input to the development of Community Stress Models, and constraining physics-based models of slow slip and tremor are encouraged, as are studies that pursue integrated use of geodetic, geologic, seismic, and other observations targeting special fault study areas. Proposals that include collection of new data should explicitly motivate the need for such efforts. In compliance with SCEC's data policy, data collected with SCEC funding must be made publicly available upon collection by archiving at UNAVCO (contact Jessica Murray (jrmurray@usgs.gov) for further information on archiving). Annual reports should include a description of archive activities.

3. **Improve our understanding of the processes underlying detected transient deformation signals and/or their seismic hazard implications through data collection and development of new analysis tools.** Work that advances methods for near-real-time transient detection and applies these algorithms within the SCEC transient detection testing framework to search for transient deformation in southern California is encouraged. Approaches that can be automated or semi-automated are the highest priority, as is their inclusion in the testing framework now in place at SCEC (contact Rowena Lohman (rbl62@cornell.edu) for details on how to address this in the proposal). Extension of methods to include InSAR and strainmeter data and, when available, the CGM is also a priority. Work that develops means for incorporating the output of transient detection algorithms into time-dependent earthquake forecasting is encouraged.
4. **Develop and apply algorithms that use real-time high-rate GPS data in concert with seismic data for improved earthquake response.** We encourage proposals that explore new approaches for assimilating real-time high-rate GPS, seismic data, and other potential observations into efforts to rapidly characterize earthquake sources. Also of interest is the development and application of rigorous retrospective and prospective tests to evaluate algorithm performance.

C. Earthquake Geology

Objectives

The Earthquake Geology Disciplinary Committee promotes studies of the geologic record of the Southern California natural laboratory that advance SCEC science. Its primary focus is on the Late Quaternary record of faulting and ground motion, including data gathering in response to major earthquakes. Geologic observations provide important contributions, either directly or indirectly, to all six of the fundamental problems in earthquake physics identified in the SCEC4 proposal. Earthquake Geology also fosters research activities motivated by outstanding seismic hazard issues, understanding of the structural framework and earthquake history of special fault study areas (see Section 8, Problem 4), or will contribute significant information to the statewide Unified Structural Representation. Collaborative proposals that cut across disciplinary boundaries are encouraged.

Example Research Strategies

- Gathering well-constrained slip-rates on the southern California fault system, with emphasis on major structures (Problem 1).
- Mapping and analysis of fault-zone properties where the seismogenic zone or brittle-ductile transition has been exhumed (Problems 1a, 3b).
- Paleoseismic documentation of earthquake ages and displacements, with emphasis on long paleoseismic histories, slip-per-event, and slip-rate histories, including a coordinated effort to develop slip rates and slip-per-event history of southern San Andreas fault system (Problem 2a, in collaboration with the SoSAFE focus group).
- Improve understanding of the architecture and tectonic activity of the Ventura and San Gorgonio Pass special fault study areas (Problem 4a), such as using B4 and other lidar data sets to better define fault traces, fault activity, and geologic structure.
- Improve the statewide community fault model in areas of inadequate fault representations or where new data is available, such as using high-resolution topographic data sets to better define fault traces, spatial uncertainty, and stochastic heterogeneity of fault geometry (Problem 4c).
- Quantifying along-strike variations in fault roughness, complexity, strain localization, and damage in relation to the rupture propagation processes, including evaluation of the likelihood of multi-fault ruptures (Problem 4b).
- Validation of ground motion prediction through analysis and dating of precariously balanced rocks and other fragile geomorphic features (Problem 6).

Geochronology Infrastructure

The shared geochronology infrastructure supports C-14, optically stimulated luminescence (OSL), and cosmogenic dating for SCEC-sponsored research. The purpose of shared geochronology infrastructure is to allow flexibility in the number and type of dates applied to each SCEC-funded project as investigations proceed. Investigators requesting geochronology support should clearly state in their proposal an estimate of the number and type of dates required. For C-14 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. Sample preparation costs must be included in the proposal budget unless preparation has been pre-arranged with one of the laboratories listed. Investigators are encouraged to contact the investigators at the collaborating laboratories prior to proposal submission. Currently, SCEC geochronology has established relationships with the following laboratories:

- C-14: University of California at Irvine (John Southon, jsouthon@uci.edu) and Lawrence Livermore National Laboratory (Tom Guilderson, tguilderson@llnl.gov),
- OSL: University of Cincinnati (Lewis Owen, lewis.owen@uc.edu) and Utah State University (Tammy Rittenour, tammy.rittenour@usu.edu), and
- Cosmogenic: Lawrence Livermore National Laboratory (Susan Zimmerman, zimmerman17@llnl.gov).

Investigators may alternatively request support for geochronology outside of the infrastructure proposal for methods not listed here or if justified on a cost-basis. These outside requests must be included in the individual proposal budget. Please direct questions regarding geochronology infrastructure to the Earthquake Geology group leader, Mike Oskin (meoskin@ucdavis.edu).

Data Reporting Requirements

PIs are required to provide full reporting of their geochronology samples, including raw data, interpreted age, and geographic/stratigraphic/geomorphic context (what was dated?). This reporting requirement will be coordinated with the geochronology infrastructure program.

Priorities for Earthquake Geology

- Support integrative research and synthesis of results at the Ventura and San Gorgonio Pass special fault study areas.
- Requests for geochronology support should include a plan for timely completion of sample collection, processing, and analysis by the end of SCEC4.

D. Computational Science

Objectives

The Computational Science group promotes the use of advanced numerical modeling techniques and high performance computing (HPC) to address the emerging needs of SCEC users and application community on HPC platforms. The group works with SCEC scientists across a wide range of topics to take advantage of rapidly changing computer architectures and algorithms. It also engages and coordinates with national HPC labs/centers and vendors in crosscutting efforts enabling large-scale computing milestones. The group encourages research using national supercomputing resources, and supports students from both geoscience and computer science backgrounds to develop their skills in the area. Projects listing Computational Science as their primary area should involve significant software-based processing or high performance computing in some way; research utilizing standard desktop computing should list the most relevant non-Computational Science disciplinary or focus group as the primary area.

Computational Requirements

If your proposed research will require substantial SCEC computing resources or allocations, the Planning Committee requests that your SCEC proposal include a brief summary of computational requirements that includes the following information:

1. The scientific goal of your computational research,
2. The scientific software you plan to use or develop,
3. A list of computations you plan to run,
4. The estimated computing time you believe will be required, and
5. The computer resources you plan to use to perform your simulations.

Note that XSEDE startup allocations can be requested from NSF (https://www.xsede.org/allocations).

Example Research Strategies

1. Reengineering and optimizations of HPC codes, required to reach SCEC research goals, for parallel systems with multi-core processors, GPU accelerators and/or Xeon Phi coprocessors, with emphasis on issues such as performance, portability, interoperability, power efficiency and reliability.
2. Novel algorithms for earthquake simulation, particularly those that either improve efficiency and accuracy, or expand the class of problems that can be solved (e.g., adaptive mesh refinement).
3. Optimization of earthquake-cycle simulators that can resolve the faulting processes across the range of scales required to investigate stress-mediated fault interaction, including those caused by dynamic wave propagation, generate synthetic seismicity catalogs, and assess the viability of earthquake rupture forecasts.
4. Tools and algorithms for uncertainty quantification in large-scale inversion and forward-modeling studies, for managing I/O, data repositories, workflow, advanced seismic data format, visualization and end-to-end approaches.
5. Data-intensive computing tools, including but not limited to InSAR and geodesy, 3D tomography, cross-correlation algorithms used in ambient noise seismology, and other signal processing techniques used, for example, to search for tectonic tremor.

Key Problems in Computational Science

1. Seismic wave propagation
    - Validate SCEC community velocity models.
    - Develop high-frequency simulation methods and investigate the appropriate upper frequency limit of deterministic ground motions.
    - Extend existing simulation methodologies to a set of stochastic wavefield simulation codes that can extend the deterministic calculations to frequencies as high as 20 Hz, providing the capability to synthesize “broadband” seismograms.
    - Develop wave propagation incorporating more advanced media response, including inelastic material response and scattering by small-scale heterogeneities and topography.
2. Tomography
    - Assimilate regional waveform data into the SCEC community velocity models.
3. Rupture dynamics
    - Evaluate proposed fault weakening mechanisms in large-scale earthquake simulations, determine if small-scale physics is essential or irrelevant, and determine if friction law parameters can be artificially enhanced without compromising ground motion predictions.
    - Evaluate different representations of earthquake source complexity, including stress heterogeneity, variability in frictional properties, fault geometrical complexity, and dynamic rupture propagation in heterogeneous media.
4. Scenario earthquake modeling
    - Model a suite of scenario ruptures, incorporating material properties and fault geometries from the unified structural representation projects.
    - Isolate causes of amplified ground motions using adjoint-based sensitivity methods.
5. Data-intensive computing
    - Develop computational tools for advanced signal processing algorithms, such as those used in ambient noise seismology and tomography, as well as InSAR and other forms of geodesy.
    - Integrate Big Data analytics techniques involving software stacks such as Hadoop, fault recovery, data format, generation, partitioning, abstraction and mining.

6. Engineering applications

   - Investigate the implications of ground motion simulations results by integrating observed and simulated ground motions with engineering-based building response models. Validate the results by comparison to observed building responses.
   - Facilitate the “rupture-to-rafters” modeling capability to transform earthquake risk management into a Cyber Science and Engineering discipline.

10. Interdisciplinary Focus Areas

Interdisciplinary research will be organized into seven science focus areas: Unified Structural Representation (USR), Fault and Rupture Mechanics (FARM), Stress and Deformation Over Time (SDOT), Earthquake Forecasting and Predictability (EFP), Ground Motion Prediction (GMP) Southern San Andreas Fault Evaluation (SOSAFE) and Earthquake Engineering Implementation Interface (EEII). Collaboration within and across focus areas is strongly encouraged.

A. Unified Structural Representation (USR)

The Unified Structural Representation group develops three-dimensional models of active faults and earth structure (velocity, density, attenuation, etc.) for use in fault-system analysis, ground-motion prediction, and hazard assessment. This year’s efforts will focus on (1) making improvements to existing community models (CVM, CFM) that will facilitate their uses in SCEC science, education, and post-earthquake response planning; (2) developing methods to represent smaller scale features, such as stochastic variations of seismic velocities and attenuation structure; and (3) improving IT tools that are used to deliver the USR components to the user community.

- ***Community Velocity Model (CVM).*** Improve the current SCEC CVMs, with emphasis on more accurate representations of Vp, Vs, density, attenuation, and basin structure. Incorporate new data (NOTE: May choose to highlight specific items following discussions at the Annual Meeting.) into the CVMs with validation of improvements for ground-motion prediction. Perform waveform and geophysical inversions for evaluating and improving the CVMs. Develop and apply procedures (i.e., goodness-of-fit measures) for evaluating updated models against observations (e.g., waveforms, gravity, etc) to discriminate among alternatives and quantify model uncertainties.
- ***Community Fault Model (CFM).*** Improve and evaluate the CFM and statewide CFM (SCFM), placing emphasis on defining the geometry of major faults that are incompletely, or inaccurately, represented in the current model, and on faults of particular concern, such as those that are located close to critical facilities. Refine representations of the linkages among major fault systems. Extend the CFM to include spatial uncertainties and stochastic descriptions of fault geometry. Evaluate the new CFM version (5.0) with data (e.g., seismicity, seismic reflection profiles, geologic slip rates, and geodetic displacement fields) to discriminate among alternative models. Update the CFM-R (rectilinear fault model) to reflect improvements in the CFM. Improve the statewide CFM in regions outside the SCEC CFM in coordination with the appropriate agencies (e.g., USGS for central and northern CA).
- ***Unified Structural Representation (USR).*** Develop better IT mechanisms for delivering the USR, particularly the CVM parameters and information about the model's structural components, to the user community for use in generating and/or parameterizing numerical models. Develop improved representations of and user interfaces to the CVMs in support of additional features, including characterization of uncertainties and small-scale features, and scalable computing (laptops to large scale clusters). Develop new tools and formats for making the CFM geometries and properties available to the user community. Generate maps of geologic surfaces compatible with the CFM that may serve as strain markers in crustal deformation modeling and/or property boundaries in future iterations of the USR. These efforts should be coordinated with SCEC CME efforts.

B. Fault and Rupture Mechanics (FARM)

The primary mission of the Fault and Rupture Mechanics focus group is to develop physics-based models of the nucleation, propagation, and arrest of dynamic earthquake rupture. We specifically solicit proposals that will contribute to the six fundamental problems in earthquake physics defined in the SCEC4 proposal and enhance understanding of fault system behavior through interdisciplinary investigation of the special fault study areas. We encourage researchers to address this mission through field, laboratory, and modeling efforts directed at characterizing and understanding the influence of material properties, geometric irregularities and heterogeneities in stress and strength over multiple length and time scales, and that will contribute to our understanding of earthquakes in the Southern California fault system.

Priorities for FARM

- Investigate the importance of different dynamic weakening and fault healing mechanisms, and the slip and time scales over which these mechanisms operate (3a, 3b, 3c, 3e).
- Determine the properties of fault cores and damage zones (1a, 1b, 3a, 3b, 4a, 4b) and characterize their variability with depth and along strike (1a, 1b, 4a, 4b) to constrain theoretical and laboratory studies, including width and particle composition of actively shearing zones, signatures of temperature variations, extent, origin and significance of on- and off-fault damage, healing, and poromechanical behavior.
- Determine the relative contribution of on- and off-fault damage to the total earthquake energy budget (3c, 4a, 4b), and the absolute levels of local and average stress (3e). Collaboration with the Community Stress Model (CSM) TAG is encouraged.
- Develop, test, and apply innovative source-inversion strategies to image the space-time rupture evolution of earthquakes reliably, propose source-inversion methods with minimal assumptions, and provide robust uncertainty quantification of inferred source parameters; propose and develop new source-inversion benchmarks, and generate synthetic data of various types (seismic, static, far-field, near-field) in cooperation with other SCEC groups; collaboration with the Source Inversion Validation (SIV) TAG is encouraged.
- Develop realistic descriptions of heterogeneity in fault geometry, rock properties, stresses and strains, and tractable ways to incorporate heterogeneity in numerical models of single dynamic rupture events and multiple earthquake cycles (3e, 3f, 4b, 4d, 6b). Test dynamic rupture modeling that incorporates these heterogeneities first by verifying the computational algorithms with benchmark exercises of the Dynamic Rupture Code Verification TAG, then by comparing the results with geological and geophysical observations.
- Understand the significance of fault zone characteristics and processes for fault dynamics (3a, 3b, 3c) and formulate constitutive laws for use in dynamic rupture models (3d).
- Evaluate the relative importance of fault structure and branching, material properties, interseismic healing, fluid processes and prior seismic and aseismic slip to earthquake dynamics, in particular, to rupture initiation, propagation, and arrest, and the resulting ground motions (3c, 3d, 3f).
- Characterize earthquake rupture, fault loading, degree of localization, role of fluids and constitutive behavior at the base of and below the seismogenic zone (1a, 1b, 1e, 4a).
- Preparatory efforts, including creep law compilations and a database and modeling framework design workshop, to finalize the design criteria for the future Community Rheology Model (CRM), integrating these FARM priorities with the community modelling efforts.
- Develop observations of slow slip events and non-volcanic tremors in southern California and understand their implications for constitutive properties of faults and overall seismic behavior (3a, 5a-5e).
- Assess the predictability of rupture direction and directivity of seismic radiation by collecting and analyzing field and laboratory data (4a, 4b), and conducting theoretical investigations to understand implications for strong ground motion.
- Develop physics-based models that can describe spatio-temporal patterns of seismicity and earthquake triggering (2e, 4e).
- Explore similarities between earthquakes and offshore landslide sources with the goal of better understanding their mechanics and the tsunami hazard from sources in southern California.

C. Stress and Deformation Over Time (SDOT)

The focus of the interdisciplinary focus group Stress and Deformation Over Time (SDOT) is to improve our understanding of how faults are loaded in the context of the wider lithospheric system evolution. SDOT studies these processes on timescales from 10s of Myr to 10s of yrs, using the structure, geological history, and physical state of the southern California lithosphere as a natural laboratory. The objective is to tie the present-day state of stress and deformation on crustal-scale faults and the lithosphere as a whole to the long-term, evolving lithospheric architecture and mantle convection, through 4-D geodynamic modeling, constrained by the widest possible range of observables from disciplines including geodesy, geology, and geophysics.

One long-term goal is to contribute to the development of a physics-based, probabilistic seismic hazard analysis for southern California by developing and applying system-wide deformation models of lithospheric processes at time-scales down to the earthquake cycle. These deformation models require a better understanding of a range of fundamental questions such as the forces loading the lithosphere, the relevant rock rheology, fault constitutive laws, and the spatial distribution of absolute deviatoric stress. Tied in with this is a quest for better structural constraints, such as on density, rock type, Moho depths, thickness of the seismogenic layer, the geometry of lithosphere-asthenosphere boundary, as well as basin depths, rock type, temperature, water content, and seismic velocity and anisotropy.

Priorities for SDOT

- Seismological imaging of crust, lithosphere and upper mantle using interface and transmission methods with the goal of characterizing the 3-D distribution of isotropic and anisotropic wave speed variations. Assembly of 3D lithological models of crust, lithosphere, and mantle based on active- and passive-source seismic data, potential field data, and surface geology.
- Contributions to our understanding of geologic inheritance and evolution, on faults and off, and its relation to the three-dimensional structure and physical properties of present-day crust and lithosphere. Contributions to efforts of building a 4-D model of lithospheric evolution over 10s of Myr for southern California.
- Research into averaging, simplification, and coarse-graining approaches across spatio-temporal scales, addressing questions such as the appropriate scale for capturing fault interactions, the adequate representation of frictional behavior and dynamic processes in long-term interaction models, fault roughness, structure, complexity and uncertainty. Modeling approaches may include analytical or semi-analytical methods, spectral approaches, boundary, finite, or distinct element methods, and a mix of these, and there are strong links with all other SCEC working groups, including FARM, Earthquake Simulators, and USR.
- Development of models of interseismic, earthquake cycle and long-term deformation, including efforts to estimate slip rates on southern CA faults, fault geometries at depth, and spatial distribution of slip or moment deficits on faults. Incorporation of rheological and geometric complexities and such models and exploration of mechanical averaging properties. Assessments of potential discrepancies of models based on geodetic, geologic, and seismic data. Development of deformation models (fault slip rates and locking depths, off-fault deformation rates) in support of earthquake rupture forecasting.
- General geodynamic models of southern California dynamics to allow hypothesis testing on issues pertaining to post-seismic deformation, fault friction, rheology of the lithosphere, seismic efficiency, the heat flow paradox, stress and strain transients, fault system evolution, as tied in with stress and deformation measurements across scales.
- Contributions to the development of a Community Stress Model (CSM), a set of spatio-temporal (4-D) representations of the stress tensor in the southern California lithosphere. In particular, we seek compilations of diverse stress constraints (e.g. from borehole or anisotropy measurements) for validation, geodynamic models that explore the coupling of side, gravity, and basal loading to observed geodetic strain-rates and co-seismically imaged stress, and studies that explore regional, well-constrained settings as test cases for larger scale models.
- Preparatory efforts, including creep law compilations and a database and modeling framework design workshop, to finalize the design criteria for the future Community Rheology Model (CRM), which ideally informs many of the core SDOT priorities.

D. Earthquake Forecasting and Predictability (EFP)

The Earthquake Forecasting and Predictability (EFP) focus group coordinates five broad types of research projects: (1) the development of earthquake forecast methods, (2) the development of testing methodologies for evaluating the performance of earthquake forecasts, (3) expanding fundamental physical or statistical knowledge of earthquake behavior that may be relevant for forecasting earthquakes, (4) the development and use of earthquake simulators to understand predictability in complex fault networks, and (5) fundamental understanding of the limits of earthquake predictability.

We seek proposals that will increase our understanding of how earthquakes might be forecast, to what extent and precision earthquakes are predictable, and what is a physical basis for earthquake predictability. Proposals of any type that can assist in this goal will be considered. In order to increase the amount of analyzed data, and so decrease the time required to learn about predictability, proposals are welcome that deal with global data sets and/or include international collaborations.

For research strategies that plan to utilize the Collaboratory for the Study of Earthquake Predictability (CSEP), see Section 11 to learn of its capabilities. Successful investigators proposing to utilize CSEP would be funded via core SCEC funds to adapt their prediction methodologies to the CSEP framework, to transfer codes to the externally accessible CSEP computers, and to be sure they function there as intended. Subsequently, the codes would be moved to the identical externally inaccessible CSEP computers by CSEP staff who will conduct tests against a variety of data as outlined in the CSEP description.

Priorities for EFP

- Support the development of statistical or physics-based real-time earthquake forecasts.
- Utilize and/or evaluate the significance of earthquake-cycle simulator results. See sections on WGCEP and CSEP for more details.
- Study how to properly characterize and estimate various earthquake-related statistical relationships (including the magnitude distribution, Omori law, aftershock productivity, etc.).
- Focus on understanding patterns of seismicity in time and space, as long as they are aimed toward understanding the physical basis of earthquake predictability.
- Develop useful measurement/testing methodology that could be incorporated in the CSEP evaluations, including those that address how to deal with observational errors in data sets.
- Develop approaches to test the validity of the characteristic earthquake vs. Gutenberg-Richter earthquake models as they are used in seismic hazard analysis.

E. Ground-Motion Prediction (GMP)

The primary goal of the Ground-Motion Prediction focus group is to develop and implement physics-based simulation methodologies that can predict earthquake strong-motion waveforms over the frequency range 0-10 Hz. Source characterization plays a vital role in ground-motion prediction. At frequencies less than 1 Hz, the methodologies should deterministically predict the amplitude, phase and waveform of earthquake ground motions using fully three-dimensional representations of Earth structure, as well as dynamic or dynamically compatible kinematic representations of fault rupture. At higher frequencies (1-10 Hz), the methodologies should predict the main character of the amplitude, phase and waveform of the motions using a combination of deterministic and stochastic representations of fault rupture and wave propagation. *Note: the GMP focus group also shares interests with the GMSV TAG (Earthquake Engineering Implementation Interface, EEII) and CME (Special Project) - consult these sections for additional GMP-related research priorities.*

Priorities for GMP

- Developing and/or refining physics-based simulation methodologies, with particular emphasis on high frequency (1-10 Hz and higher) approaches. This work could include implementation of simulation methodologies onto the Broadband Simulation Platform, or implementation of more efficient approaches in wave and rupture propagation schemes (in collaboration with CME), allowing accurate simulation of higher frequency ground motion in models with lower seismic wave speeds (e.g. in sedimentary basins). Determine spectral and spatial limits for simulating deterministic high-frequency wave propagation.
- Waveform modeling of past earthquakes to validate and/or refine the structure of the Community Velocity Models (CVMs) (in collaboration with USR). This includes exploration and validation of the effects of statistical models of structural and velocity heterogeneities on the ground motion, the significance of the lowest (S-wave) velocities as frequencies increase, the significance of including geotechnical layers (GTLs) in the CVMs, and development and validation of improved (possibly frequency-dependent) attenuation (intrinsic or scattering) models in physics-based simulations (in

collaboration with USR). Quantify uncertainty in the CVM structure and its impact on simulated ground motions. Note that the Central California Seismic Project (CCSP, see below) targets this goal specifically for Central California.

- Develop and implement simulation methods for the modeling of bending faults and multi-segment ruptures. The highest priority need is for kinematic rupture generators for implementation on the Broadband Platform (BBP). Proposals are requested for 1) including the software modeling capability itself and 2) scientific research (e.g., analysis of dynamic rupture modeling on multi-segmented faults) to inform input parameters such as the timing of the i^{th} segment rupture, moment distribution on segments and so on (see CME section on this RFP for related efforts).
- Investigate the importance of including 3D basin effects on ensemble averaged long-period ground motions on the BroadBand Platform, e.g., by comparing ensemble averages of long-period (<~1Hz) ground motions computed in 1D and 3D crustal models for events included in the GMSV. Develop and implement methods for computing and storing 3D Green's functions (GFs) for use in the Broadband Platform. Proposals for both source- and site-based GFs are solicited (see CME section on this RFP for related efforts).
- Develop and implement new models or implement existing models for frequency-dependent site effects into the SCEC BroadBand Platform (site effects module). Because site-specific profiles are rarely available for large scale simulations, the priority will be given to models that can work with generic site profiles or that use simplified site factors (e.g. empirical Vs30-based factors for example). Models that require a site profile as input will also be considered. The site effects models are to be applied so as to produce time series that include site effects.
- Incorporate off-fault plasticity into physics-based ground motion simulation methodologies, quantify uncertainties, and validate the effects using observations from large earthquakes.
- Development of more realistic implementations of dynamic or kinematic representations of fault rupture, including simulation of higher frequencies (up to 10+ Hz). Possible topics include simulation of dynamic rupture on nonplanar faults and studying the effects of fault roughness on the resulting synthetic ground motion, and development of kinematic representations based on statistical models constrained by observed and/or dynamic ruptures. This research could also include the examination of current source-inversion strategies and development of robust methods that allow imaging of kinematic and/or dynamic rupture parameters reliably and stably, along with a rigorous uncertainty assessment. Close collaboration with the Technical Activity Group (TAG) on Source Inversion Validation (SIV) is encouraged. Construct Equivalent Kinematic Source (EKS) models that approximate the effects of near-fault nonlinearities in a linear scheme and test the EKS model in CyberShake. Projects that involve dynamic earthquake rupture simulations should involve preliminary code testing using benchmarks developed by the Dynamic Rupture Code Verification Technical Activity Group (TAG).
- Verification (comparison against theoretical predictions) and validation (comparison against observations) of the simulation methodologies with the objective to develop robust and transparent simulation capabilities that incorporate consistent and accurate representations of the earthquake source and three-dimensional velocity structure. Compare and assess engineering metrics in ground motion validation. Comparison of synthetic ground motions from deterministic and stochastic approaches to data for overlapping bandwidths. Close collaboration with the Technical Activity Group (TAG) on Ground Motion Simulation Validation (GMSV) is encouraged.

It is expected that the products of the Ground Motion Prediction group will have direct application to seismic hazard analysis, both in terms of characterizing expected ground motion levels in future earthquakes, and in terms of directly interfacing with earthquake engineers in the analysis of built structures. Activities within the Ground Motion Prediction group will be closely tied to several focus areas, including the GMSV TAG, with particular emphasis on addressing ground motion issues related to seismic hazard and risk (see EEII below).

F. Southern San Andreas Fault Evaluation (SoSAFE)

The SCEC Southern San Andreas Fault Evaluation (SoSAFE) Project aims to increase knowledge of slip rates, paleoearthquake ages, and slip distributions of past earthquakes, for the past two thousand years on the southern San Andreas fault system. From Parkfield to Bombay Beach, and including the San Jacinto fault, the objective is to obtain new data to clarify and refine relative hazard assessments for each potential source of a future 'Big One'.

Priorities for SoSAFE

- Lengthen existing paleoearthquake chronologies that will improve understanding of the last 2000 years of this fault system. This includes radiocarbon dating and analysis of stratigraphic evidence of paleoearthquakes.
- Determine slip rates at many time scales, so that possible system-level interaction can be documented.
- Obtain the best possible measurements of geomorphic slip distributions from past earthquakes by developing field, LiDAR, or SfM datasets and validate the different measures or test uncertainties determined by each method. Catalogue the quality and supporting evidence for unique offsets, develop techniques to estimate slip distributions from these datasets.
- Explore chronometric, geomorphic, or statistical approaches to linking geomorphic offsets to dated paleoearthquakes.
- Use novel methods for estimating slip rates from geodetic data.
- Investigate methodologies for integrating paleoseismic (including geomorphic measures of slip) and geologic data into rupture histories. For example, studies may improve or inform interactions between SoSAFE results and scenario rupture modeling or rupture forecasts, test rupture histories using geometrically realistic fault configurations in dynamic rupture models.

Requests for geochronology support (e.g., to date 12 radiocarbon samples) are encouraged and shall be coordinated with Earthquake Geology; a portion of SoSAFE funds will be contributed towards joint support for dating. We also welcome proposals that seek to add other data (such as climate variations) to earthquake chronologies, which may be used to improve age control, understanding of the formation of offset features, or site-to-site correlation of events.

Research by single or multi-investigator teams will be supported to meet priority scientific objectives related to the mission of the SoSAFE Interdisciplinary Focus Group. SoSAFE objectives also foster common longer-term research interests and facilitate future collaborations in the broader context of a decade-long series of interdisciplinary, integrated and complementary studies on the southern San Andreas Fault system such as those targeted by teams investigating Special Fault Study Areas.

G. Earthquake Engineering Implementation Interface (EEII)

The purpose of the Earthquake Engineering Implementation Interface is to create and maintain collaborations with research and practicing engineers, much as the Seismic Hazard and Risk Analysis focus group did during SCEC3. These activities may include ground motion simulation validation, rupture-to-rafters simulations of building response as well as the end-to-end analysis of large-scale, distributed risk (e.g., ShakeOut-type scenarios). Our goal of impacting engineering practice and large-scale risk assessments requires even broader partnerships with the engineering and risk-modeling communities, which motivates the activities described next.

Technical Activity Group (TAG) on Ground Motion Simulation Validation (GMSV)

A TAG focused on validation of ground motion simulations for use in engineering applications is developing and implementing testing/rating methodologies, via collaboration between ground motion modelers and engineering users. The workshops and research of this TAG to date have identified the efforts below as potential priority activities in this area. See the Ground-Motion Prediction (GMP) and the Community Modeling Environment (CME) sections of the Collaboration Plan for related research priorities. Proposals on these topics will be reviewed with all other SCEC proposals in January of 2016. Interested researchers are invited to visit the GMSV TAG wiki (http://collaborate.scec.org/gmsv/) and contact Dr. Nicolas Luco (nluco@usgs.gov) and Dr. Sanaz Rezaeian (srezaeian@usgs.gov) to discuss opportunities for coordinated research. Note that any PIs funded to work on GMSV-related projects will become members of the TAG and will be required to coordinate with each other, in part via participation in monthly conference calls and annual workshops/meetings.

- Develop validation methodologies that use relatively simple metrics (e.g., significant duration), and demonstrate them with existing simulated ground motions and their recorded counterparts. Such research must be coordinated with the Broadband Platform Validation Project.
- Develop validated and efficient methods for either i) adjusting ground motion time series simulated by the SCEC Broadband Platform to account for the local site conditions at historical earthquake stations;

or ii) de-convolving recorded ground motion time series to a reference site condition corresponding to that for simulated ground motions.

- Develop and demonstrate validation methodologies that use common models of structures of interest (e.g. multi-degree-of-freedom nonlinear models of building or geotechnical systems) for particular engineering applications. Such research must be coordinated with the validation efforts of the Software Environment for Integrated Seismic Modeling (SEISM) project.
- Develop and demonstrate validation methodologies for the use of CyberShake ground motion simulations in developing probabilistic and deterministic hazard maps for building codes and other engineering applications. In particular, investigations of observed versus simulated region-specific path effects for small-magnitude earthquakes in Southern California are encouraged. Such research must be coordinated with the Committee for Utilization of Ground Motion Simulations (UGMS).
- Research important ground motion or structural (e.g. building or geotechnical system) response parameters and statistics that should be used in validation of simulations. Demonstrate similarities and differences between otherwise parallel validation tests/ratings using these ground motion or structural response parameters.
- Demonstrate validation methodologies with ground motions simulated with deterministic and stochastic methods above 1 Hz.
- Improve ground motion simulations by closely collaborating with modelers on iterative applications of validation methodologies.

Improved Hazard Representation

- Develop improved hazard models that consider simulation-based earthquake source and wave propagation effects that are not already well reflected in observed data. These could include improved methods for incorporating rupture directivity effects, basin effects, and site effects in the USGS ground motion maps, for example. The improved models should be incorporated into OpenSHA.
- Use broadband strong motion simulations, possibly in conjunction with recorded ground motions, to develop ground motion prediction models (or attenuation relations). Broadband simulation methods must be verified (by comparison with simple test case results) and validated (against recorded strong ground motions) before use in model development. The verification, validation, and application of simulation methods must be done on the SCEC Broadband Simulation Platform. Such developments will contribute to the future NGA-H Project.
- Investigate bounds on the median and variability of ground motions for a given earthquake scenario.

Ground Motion Time History Simulation

- Develop acceptance criteria for simulated ground motion time histories to be used in structural response analyses for building code applications or risk analysis. This relates closely to the GMSV section above.
- Assess the advantages and disadvantages of using simulated time histories in place of recorded time histories as they relate to the selection, scaling and/or modification of ground motions for building code applications or risk analysis.
- Develop and validate modules for simulation of short period ground motions (< 1 sec) for incorporation in the SCEC Broadband Platform.
- Develop and validate modules for the broadband simulation of ground motion time histories close to large earthquakes, and for earthquakes in the central and eastern United States, for incorporation in the SCEC Broadband Platform.
- Develop and validate modules for nonlinear site response, including criteria for determining circumstances under which nonlinear modeling is required. Incorporate the modules into the SCEC Broadband Platform.
- Compare simulated versus recorded ground motions for different models of the regional geologic structure.

Collaboration in Structural Response Analysis

- Infrastructure Systems. Assess the performance of distributed infrastructure systems (e.g., water, electrical and transportation) using simulated ground motions. Evaluate the potential impact of basin effects, rupture directivity, spatial distribution of ground motion, or other phenomena on risk to infrastructure systems.

- Tall Buildings and Other Long-Period Structures. Enhance the reliability of simulations of long period ground motions in the Los Angeles region using refinements in source characterization and seismic velocity models, and evaluate the impacts of these ground motions on tall buildings and other long-period structures (e.g., bridges, waterfront structures).

- End-to-End Simulation. Interactively identify the sensitivity of structural response to ground motion parameters and structural parameters through end-to-end simulation. Buildings of particular interest include non-ductile concrete frame buildings.

- Reference Buildings and Bridges. Participate with PEER investigators in the analysis of reference buildings and bridges using simulated broadband ground motion time histories. The ground motions of large, rare earthquakes, which are poorly represented in the NGA strong motion database, are of special interest. Coordination with PEER can be done through Yousef Bozorgnia (yousef@berkeley.edu).

- Earthquake Scenarios. Perform detailed assessments of the results of scenarios such as the ShakeOut exercise, and the scenarios for which ground motions were generated for the Tall Buildings Initiative (including events on the Puente Hills, Southern San Andreas, Northern San Andreas and Hayward faults) as they relate to the relationship between ground motion characteristics and structural response and damage.

Ground Deformation

- Investigate the relationship between input ground motion characteristics and local soil nonlinear response, liquefaction, lateral spreading, local soil failure, and landslides -- i.e., geotechnical hazards. Investigate hazards due to surface faulting and to surface deformation caused by subsurface faulting and folding.

Risk Analysis

- Develop improved site/facility-specific and portfolio/regional risk analysis (or loss estimation) techniques and tools, and incorporate them into the OpenRisk software.
- Use risk analysis software to identify earthquake source and ground motion characteristics that control damage estimates.

Other Topics

- Proposals for other innovative projects that would further implement SCEC information and techniques in seismic hazard, earthquake engineering, risk analysis, and ultimately loss mitigation, are encouraged.

11. Special Projects and Initiatives

The following are special projects for which SCEC has obtained funding beyond the core program. This Collaboration Plan is not for those funds, which are committed; rather it is for SCEC core funding for research projects that are consonant with these special projects. This is consistent with SCEC policy that requires that special projects be aligned with core SCEC goals.

A. Working Group on California Earthquake Probabilities (WGCEP)

The WGCEP is a collaboration between SCEC, the USGS, and CGS aimed at developing official earthquake-rupture-forecast models for California. The project is closely coordinated with the USGS National Seismic Hazard Mapping Program, and has received financial support from the California Earthquake Authority (CEA). The WGCEP has now completed the time-independent UCERF3 model (UCERF3-TI, which relaxes segmentation and includes multi-fault ruptures) and the long-term, time-dependent model (UCERF3-TD, which includes elastic-rebound effects). We are now working on adding spatiotemporal clustering (UCERF3-ETAS) to account for the fact that triggered events can be large and damaging. As the latter will require robust interoperability with real-time seismicity information, UCERF3-ETAS will bring us into the realm of operational earthquake forecasting (OEF). We are also starting to plan for UCERF4, which we anticipate will utilize physics-based simulators to a greater degree (see last bullet below).

The following are examples of SCEC activities that could make direct contributions to WGCEP goals:

- Evaluate fault models in terms of the overall fault connectivity at depth (important for understanding the likelihood of multi-fault ruptures) and the extent to which faults represent a well-define surface versus a proxy for a braided deformation zone.
- Evaluate existing deformation models, or develop new ones, in terms of applicability of GPS constraints, categorical slip-rate assignments (based on “similar” faults), applicability of back-slip methods, and other assumptions. Of particular interest is the extent to which slip rates taper at the ends of faults and at fault connections.
- Evaluate the UCERF3 implication that 30% to 60% of off-fault deformation is aseismic.
- Help determine the average along-strike slip distribution of large earthquakes, especially where multiple faults are involved (e.g., is there reduced slip at fault connections?).
- Help determine the average down-dip slip distribution of large earthquakes (the ultimate source of existing discrepancies in magnitude-area relationships). Are surface slip measurements biased with respect to slips at depth?
- Develop a better understanding of the distribution of creeping processes and their influence on both rupture dimension and seismogenic slip rate.
- Contribute to the compilation and interpretation of mean recurrence-interval constraints from paleoseismic data and/or develop site-specific models for the probably of events going undetected at a paleosiesmic site.
- Develop ways to constrain the spatial distribution of maximum magnitude for background seismicity (for earthquakes occurring off of the explicitly modeled faults).
- Address the question of whether small volumes of space exhibit a Gutenberg Richter distribution of nucleations (even on faults).
- Develop improved estimates (including uncertainties) of the total long-term rates of observed earthquakes for different sized volumes of space.
- Refine our magnitude completeness estimates (as a function of time, space, and magnitude). Develop such models for real-time applications (as will be needed in operational earthquake forecasting).
- Develop methods for quantifying elastic-rebound based probabilities in un-segmented fault models.
- Help quantify the amount of slip in the last event, and/or average slip over multiple events, on any major faults in California (including variations along strike).
- Develop models for fault-to-fault rupture probabilities, especially given uncertainties in fault endpoints.
- Determine the extent to which seismicity rates vary over the course of historical and instrumental observations (the so-called Empirical Model of previous WGCEPs), and the extent to which this is explained by aftershock statistics.
- Determine the applicability of higher-resolution smoothed-seismicity maps for predicting the location of larger, more damaging events.
- Explore the UCERF3 “Grand Inversion” with respect to: possible plausibility filters, relaxing the UCERF2 constraints, not over-fitting data, alternative equation-set weights, applying a characteristic-slip model, and applicability of the Gutenberg Richter hypothesis on faults (see report at www.WGCEP.org).
- Develop applicable methods for adding spatiotemporal clustering to forecast model s(e.g., based on empirical models such as ETAS). Are sequence-specific parameters warranted?
- Determine if there is a physical difference between a multi-fault rupture and a separate event that was triggered quickly.

- Develop more objective ways of setting logic-tree branch weights, especially where there are either known or unknown correlations between branches.
- Develop easily computable hazard or loss metrics that can be used to evaluate and perhaps trim logic-tree branches.
- Develop techniques for down-sampling event sets to enable more efficient hazard and loss calculations.
- Develop novel ways of testing UCERF3, especially ones that can be integrated with CSEP.
- Study and test the behavior of computational earthquake-cycle simulators, envisioning that they could become essential ingredients in future UCERF projects and a cornerstone of SCEC5. The goal is to develop the capability of simulators to be able to contribute meaningfully to hazard estimates. Examples of important tasks:
    a. Study and test, using code verification exercises and more than one code, the sensitivity of simulator results to input details including fault-system geometry, stress-drop values, tapering of slip, methods of encouraging rupture jumps from fault to fault, cell size, etc.
    b. Develop physically realistic ways of simulating off-fault seismicity.
    c. Add additional physics into simulators, for example, the inclusion of high-speed frictional weakening and of off-fault viscoelastic and heterogeneous elastic properties.
    d. Develop alternate methods of driving fault slip besides “back-slip”.
    e. Make access to existing simulators easy for new users, including adequate documentation and version numbers, examples of input and output files for initial testing, and access to analysis tools. Publicize availability.
    f. Develop new approaches to designing simulators and/or of making them more computationally efficient, including the use of better algorithms, point source Greens functions, and GPUs.
    g. Develop validation tools for simulators, utilize existing UCERF data comparison tools with them, and develop capabilities for simulators to interact with UCERF infrastructure.
    h. Develop the capability of simulators to deal with UCERF and SCEC CFM fault geometries, both for rectangular and triangular cell representations.
    i. Create statewide synthetic earthquake catalogs spanning 100 My using as many different simulators as possible, in order to generate statistically significant behavior on even slow-slipping faults. Use small time-steps to permit evaluation of short-term clustering.
    j. Use these catalogs as synthetic laboratories for CSEP testing as described under CSEP.
    k. Data-mine these catalogs for statistically significant patterns of behavior. Evaluate whether much-shorter observed catalogs are statistically distinguishable from simulated catalogs. Consider and explore what revisions in simulators would make simulated catalogs indistinguishable from observed catalogs.
    l. Develop and test a variety of statistical methods for determining the predictability of the of earthquakes in these simulated catalogs.
    m. Compute other data types such as gravity changes, surface deformation, InSAR images, in order to allow additional comparisons between simulated results and observations.

Further suggestions and details can be found at http://www.WGCEP.org, or by contacting the project leader (Ned Field: field@usgs.gov; (626) 644-6435).

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

CSEP is developing a virtual, distributed laboratory—a collaboratory—that supports a wide range of scientific prediction experiments in multiple regional or global natural laboratories. This earthquake system science approach seeks to provide answers to the questions: (1) How should scientific prediction experiments be conducted and evaluated? and (2) What is the intrinsic predictability of the earthquake rupture process?

Priorities for CSEP

- Retrospective Canterbury experiment: finalizing the retrospective evaluation of physics-based and statistical forecasting models during the 2010-12 Canterbury, New Zealand, earthquake sequence by (i) comparing retrospective forecasts against extent prospective models, (ii) transitioning models to prospective evaluation, including in other regions;
- Global CSEP experiments: developing and testing global models, including, but not limited to, those developed for the Global Earthquake Model (GEM);
- Strengthening testing and evaluation methods: developing computationally efficient performance metrics of forecasts and predictions that (i) account for aleatory variability and epistemic uncertainties, and (ii) facilitate comparisons between a variety of probability-based and alarm-based models (including reference models);
- Supporting Operational Earthquake Forecasting (OEF): (i) developing forecasting methods that explicitly address real-time data deficiencies, (ii) updating forecasts on an event basis and evaluating forecasts with overlapping time-windows or on an event basis, (iii) improving short-term forecasting models, (iv) developing prospective and retrospective experiments to evaluate OEF candidate models;
- Earthquake rupture simulators: developing experiments to evaluate the predictive skills of earthquake rupture simulators, against both synthetic (simulated) and observed data (see also the WGCEP section), with specific focus on how to automate the identification of a large earthquake with a modeled fault;
- External Forecasts and Predictions (EFP): developing and refining experiments to evaluate EFPs (generated outside of CSEP), including operational forecasts by official agencies and prediction algorithms based on seismic and electromagnetic data;
- Induced seismicity: developing models and experiments to evaluate hypotheses of induced seismicity, e.g. in the Salton Trough or in Oklahoma, including providing data access to injection/depletion rates and other potentially pertinent data;
- Hybrid/ensemble models: developing methods for forming optimal hybrid and ensemble models from a variety of existing probability-based or alarm-based forecasting models;
- Hazard models: developing experiments to evaluate seismic hazard models and their components (e.g., ground motion models);
- Coulomb stress: developing forecasting models based on the Coulomb stress hypothesis that can be tested retrospectively and prospectively within CSEP;
- Developing methodology to forecast focal mechanisms and evaluating the skill of such forecasts;
- Testing paleo-based forecasts: developing experiments to prospectively test the fault rupture and earthquake probabilities implied by paleoseismic investigations of California faults (e.g., testing probabilities of future ruptures at paleoseismic sites where numerous ruptures have been documented, the relative effectiveness of proposed fault segment boundaries at stopping ruptures, and the relative frequency of on-fault and off-fault ruptures in California) (see also the WGCEP and SoSafe sections).

General Contributions

- Establishing rigorous procedures in controlled environments (testing centers) for registering prediction procedures, which include the delivery and maintenance of versioned, documented code for making and evaluating predictions including intercomparisons to evaluate prediction skills;
- Constructing community-endorsed standards for testing and evaluating probability-based, alarm-based, fault-based, and event-based predictions;
- Developing hardware facilities and software support to allow individual researchers and groups to participate in prediction experiments;
- Designing and developing programmatic interfaces that provide access to earthquake forecasts and forecast evaluations.
- Providing prediction experiments with access to data sets and monitoring products, authorized by the agencies that produce them, for use in calibrating and testing algorithms;

- Characterizing limitations and uncertainties of such data sets (e.g., completeness magnitudes, source parameter and other data uncertainties) with respect to their influence on experiments;
- Expanding the range of physics-based models to test hypotheses that some aspects of earthquake triggering are dominated by dynamic rather than quasi-static stress changes and that slow slip event activity can be used to forecast large earthquakes;
- Evaluating hypotheses critical to forecasting large earthquakes, including the characteristic earthquake hypothesis, the seismic gap hypothesis, and the maximum-magnitude hypothesis;
- Conducting workshops to facilitate international collaboratories;

A major focus of CSEP is to develop international collaborations between the regional testing centers and to accommodate a wide-ranging set of prediction experiments involving geographically distributed fault systems in different tectonic environments.

C. Community Modeling Environment (CME)

The Community Modeling Environment is a SCEC special project that develops improved ground motion forecasts by integrating physics-based earthquake simulation software, observational data, and earth structural models using advanced computational techniques including high performance computing. CME projects often use results, and integrate work, from SCEC groups including Interdisciplinary Focus Groups Technical Activity Groups. The SCEC research community can contribute research activities to CME by providing scientific or computational capability that can improve ground motion forecasts.

Examples of CME research includes development of earth structural models, curation of data sets to support forecast validation, and development of scientific software that simulates physical processes in the earth including dynamic ruptures (such as those that are verified in the Dynamic Rupture Code Verification Technical Activity Group (TAG)), and wave propagation simulations. Proposals are encouraged that work towards improving the accuracy of the statewide community velocity model (SCVM).

CME computationally based research projects include three types of forecast evaluation and testing systems; transient detection and forecast evaluation, earthquake early warning earthquake parameter and ground motion forecast evaluation, and short-term earthquake forecast evaluation.

CME is developing ground motion simulations that produce broadband seismograms. These simulation tools include rupture generators, low frequency wave propagation models, high frequency stochastic models, non-linear site response modules, and validation capabilities including assembled observational strong motion data sets and waveform-matching goodness of fit algorithms and information displays. Proposals that enhance our ability to extend ground motion simulations to higher frequencies through high frequency source generation models, and stochastic models of source, propagation, and site effects are encouraged.

Ground motion simulation validation computational and organizational tools are needed to establish repeatable validation of ground motion simulations to engineering standards. Research in this area would contribute to the efforts under the ground motion simulation validation TAG.

CME is working to improve probabilistic seismic hazard calculations. CME physics-based PSHA research requires a high resolution 3D velocity model for California, a pseudo-dynamic rupture generator capable of generating an extended earthquake rupture forecast from UCERF3.0, highly efficient reciprocity-based seismogram calculations, and probabilistic hazard model information system providing access to calculation results. Proposals that develop improved pseudo-dynamic models, including parameterizations that include the possibility of super-shear rupture, are encouraged. Proposals that seek to use existing CyberShake simulations as a research database are encouraged.

D. Virtual Institute for the Study of Earthquake Systems (VISES)

Note: SCEC has not yet received the final year of funding for VISES. Funding under this program is contingent on SCEC receiving funds for the final year of VISES from NSF. Travel support for successful proposals will be managed from SCEC headquarters. Do not include overhead in the proposed budget.

NSF has funded a new effort within SCEC to broaden and deepen our collaborations with Japanese earthquake scientists. A particular emphasis will be to broaden the participation of early career scientists. Collaborative research funded through VISES should have relevance for research questions of concern to the SCEC core program.

Examples of relevant research activities include testing earthquake forecast models, numerical simulation of earthquake ground motion to high frequencies, ground motion simulation using dense networks of high-dynamic range sensors, and geodynamical studies of fault interaction and deformation. Travel support to Japan for early career scientists developing collaborations with colleagues in Japan is a priority for funding under the VISES program.

E. Central California Seismic Project (CCSP)

Note: Terms of the master agreement funding CCSP limits indirect costs to 15%. Please use this rate only for CCSP proposal budgets.

The largest uncertainties in the estimation of the catastrophic risks to California utilities come from the seismic hazard uncertainties at low exceedance probabilities. Recent analyses indicate that these are dominated by the uncertainties in path effects; i.e., in the prediction of strong ground motions at a fixed surface site from specified seismic sources. SCEC has joined the Pacific Gas & Electric Company (PG&E) in developing a long-term research program aimed at reducing the uncertainties in seismic hazard estimation with a particular emphasis of reducing the uncertainty in path effects.

A pilot project focused on the central coast of California was initiated in 2015. The goal of this Central California Seismic Project (CCSP) is to assess the effectiveness of physics-based seismic wavefield modeling in reducing path-effect uncertainties. Currently planned objectives of the program are fourfold:

- Analyze the existing seismic, geophysical, and geologic data for constraints on the 3D crustal structure of Central California. The seismic constraints include earthquake waveforms and ambient-field correlagrams; the geologic constraints include surface and subsurface data on basin, fault, and basement structure.
- Invert the seismic and geologic constraints to improve models of Central California crustal structure. Priority will be given to full-3D tomographic methods that can account for 3D wave propagation and the nonlinearity of the structural inverse problem.
- Deploy an array of temporary seismic stations in Central California to collect new earthquake and ambient-field data. Assess the efficacy of these data in reducing path-effect uncertainties and validating model-based uncertainty reductions.
- Compute large ensembles of earthquake simulations for central California sites that are suitable for probabilistic seismic hazard analysis (PSHA). Compare the simulation results with those from ground motion prediction equations (GMPEs). Use this modeling to understand the aleatory variability encoded by the GMPEs and to assess the epistemic uncertainties in the simulation-based PSHA.

The Planning Committee seeks additional effort in order to:

- Incorporate data from ocean bottom seismometer observations into improved community velocity models near- and off-shore Central California.
- Improve understanding of the fault system, both onshore and offshore, in Central California using precise earthquake locations, high-resolution geophysical imaging surveys, and other methods.
- Use observations of ground motion from local earthquakes, and dense recordings of ground motion (where available) to characterize the ability to predict the intensity of strong ground motion and its variability.
- Improve characterization of historical earthquakes in the region, including their location, mechanism, and finite-source characteristics (if relevant).

In evaluating CCSP-targeted proposals, the Planning Committee will consider the relevance of the proposed work to the overall project plan and the ability of investigators to deliver timely results during the pilot study. The PC will also consider novel approaches to the uncertainty-reduction problem in addition to those explicitly listed in the project plan.

F. Collaboratory for Interseismic Simulation and Modeling (CISM)

The Collaboratory for Interseismic Simulation and Modeling (CISM) is an effort to forge physics-based models into comprehensive earthquake forecasts using California as its primary test bed. Short-term forecasts of seismic sequences, in combination with consistent long-term forecasts, are critical for reducing risks and enhancing preparedness. CISM seeks to improve predictability by combining rupture simulators that account for the physics of rupture nucleation and stress transfer with ground-motion simulators that account for wave excitation and propagation. CISM forecasting models will be tested against observed earthquake behaviors within the existing Collaboratory for the Study of Earthquake Predictability.

G. National Partnerships through EarthScope

The NSF EarthScope program (http://www.earthscope.org) provides unique opportunities to learn about the structure and dynamics of North America. SCEC and the NSF EarthScope program encourage proposals that integrate the goals of the SCEC Science Plan with the many overlapping goals of the EarthScope Science Plan (http://www.earthscope.org/information/publications/science-plan/). Topics of interest include applying EarthScope observational resources to SCEC science and hazard problems; characterizing the crust and lithosphere of the natural laboratory of Southern California; exploring stress and deformation over time using EarthScope resources (including high resolution topography); testing hypothesis and enhancing models of earthquakes, faulting, and the rheology of the lithosphere; developing innovative contributions to identifying earthquake hazard and community response; and promoting Earth Science literacy in education and outreach in SCEC and EarthScope topic areas. These partnerships should seek to strengthen the connections across the organizations and leverage SCEC and EarthScope resources.

12. Communication, Education, and Outreach

The theme of the CEO program during SCEC4 is *Creating an Earthquake and Tsunami Resilient California*. CEO will continue to manage and expand a suite of successful activities along with new initiatives, within four CEO interconnected thrust areas:

1. The *Implementation Interface* connects SCEC scientists with partners in earthquake engineering research, and communicates with and trains practicing engineers and other professionals.

2. The *Public Education and Preparedness* thrust area educates people of all ages about earthquakes, and motivates them to become prepared.

3. The *K-14 Earthquake Education Initiative* seeks to improve earth science education and school earthquake safety.

4. Finally, the *Experiential Learning and Career Advancement* program provides research opportunities, networking, and more to encourage and sustain careers in science and engineering.

These thrust areas present opportunities for members of the SCEC community to partner with CEO staff. Limited funding (typically no more than $2000-$5000) may be available as direct payments from SCEC (not subcontracts) for materials or activities and typically does not require a formal proposal. For larger activities, joint proposals with SCEC CEO to potential sources are the best approach. Those interested in partnering with SCEC CEO on activities, submitting a joint proposal, or in submitting a CEO proposal responding to this Collaboration Plan should first contact the Associate SCEC Director for CEO (Mark Benthien: benthien@usc.edu, 213-740-0323).