

# 2012 Science Collaboration Plan

Southern California Earthquake Center

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## Proposals Due: November 7, 2011

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## I. 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 sensor networks, 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) will move 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 will focus 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 will focus on special fault study areas, the development of a community geodetic model for Southern California, and a community stress model. The latter will be a new platform where the various constraints on earthquake-producing stresses can begin to be integrated. Improvements will be made to SCEC's unified structural representation and its statewide extensions.

**Collaboration Plan.** On February 1, 2012, the Southern California Earthquake Center (SCEC) transitions 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 first year of the SCEC4 research program.

## II. Guidelines for Proposal Submission

- A. **Due Date.** Monday, November 7, 2011, 5:00 pm PST. Late proposals will not be accepted. Note the different deadline for submitting annual progress reports below.
- B. **Delivery Instructions.** Proposals must be submitted through the SCEC Proposal Submission System, accessible at <http://www.scec.org/proposals>. See "Formatting Instructions" below for requirements and procedure for submitting proposals.
- C. **Formatting Instructions.**

**Cover Page.** The cover page should be headed with the words "2012 SCEC Proposal" and include the Project Title, Principal Investigator(s), Institutional Affiliation(s), Amount of Request per Investigator, Total Amount of Request, and Proposal Category (see Section IV). Collaborative proposals involving multiple investigators and/or institutions should list all Principal Investigators. Proposals do not need to be formally signed by institutional representatives, and should be for one year, with a start date of February 1, 2012. Also on the cover page, list - in order of priority - three SCEC science objectives (Section VII) that your proposal addresses (e.g. 1a, 3c and 4b). If your proposal includes undergraduate student funding, please be sure to note this on the cover page.

**Technical Description.** In five 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 VII). If the proposed project is a continuation of a previously funded SCEC project, the technical description must also include a one-page summary of previous research results. This research summary is part of the five-page limit. References are not included in the five-page limit. See note below on submission of collaborative proposals.

**Budget Page.** Budgets and budget explanations should be constructed using NSF categories ([http://www.nsf.gov/pubs/policydocs/pappguide/nsf11001/gpg\\_2.jsp](http://www.nsf.gov/pubs/policydocs/pappguide/nsf11001/gpg_2.jsp)). Under guidelines of the SCEC Cooperative Agreements and A-21 regulations, secretarial support and office supplies are not allowable as direct expenses.

**Current Support.** Statements of current support should be included for each Principal Investigator, following NSF guidelines ([http://www.nsf.gov/pubs/policydocs/pappguide/nsf11001/gpg\\_2.jsp](http://www.nsf.gov/pubs/policydocs/pappguide/nsf11001/gpg_2.jsp)). Any proposal without a current and pending support statement will not be reviewed.

**Labeling the Submitted PDF Proposal.** Proposals must be submitted as PDF documents and follow the SCEC proposal naming convention. Investigators must label their proposals with their last name followed by 2012 (e.g. Beroza2012.pdf). If there is more than one proposal, then the file should be labeled as follows: Beroza2012\_1.pdf (for the 1st proposal) and Beroza2012\_2.pdf (for the 2nd proposal).

**2011 Annual Progress Report.** Scientists funded by SCEC in 2011 must submit a progress report by February 29, 2012 (5:00 pm PST). Submission of this report is critical to preparing the Final SCEC3 Report to the funding agencies. **To receive 2012 SCEC funding, all prior SCEC-funded project reports must be submitted and up to date.** Reports should be a maximum of five pages (text and figures). Reports should include references to any SCEC publication during the past year (including papers submitted and in review), including their SCEC contribution number. Publications are assigned numbers when they are submitted to the SCEC publication database (via <http://www.scec.org/signin>).

**Special Note on Workshop Reports.** Reports on results and recommendations of workshops funded by SCEC in 2012 are to be submitted no later than 30 days following the completion of the workshop. The reports will be posted on the SCEC website as soon as possible after review by SCEC directors.

- D. **Principal Investigator Responsibilities.** Principal investigators are expected to interact with other SCEC scientists on a regular basis (e.g., by attending the annual meeting, workshops and working group meetings) and to contribute data, analysis results, and/or models to the appropriate SCEC data center (e.g., Southern California Earthquake Data Center—SCEDC), database, or community model (e.g., Community Velocity Model—CVM). Publications resulting entirely or partially from SCEC funding must include a publication number (<http://www.scec.org/core/cis/pubsearch.php>). By submitting a proposal, investigators are agreeing to these conditions.
- E. **Eligibility.** Proposals can be submitted by eligible Principal Investigators from:
- U.S. academic institutions
  - U.S. private corporations
  - International institutions (funding will mainly be for travel to SCEC-sponsored meetings in the U.S.)
- F. **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. A collaborative proposal should be submitted only by the lead investigator. Information on all investigators (including budgets and current support statements) must be included in the proposal submission. Collaborative proposals may include one extra page per investigator to report results of previous research.
- G. **Budget Guidance.** Typical SCEC grants funded under this Science 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 first-time SCEC investigators. **Field research investigations outside southern California will not be supported.**
- H. **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. All awards will be funded by subcontract from the University of Southern California.

### III. 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 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 support of disciplinary research and infrastructure. High-priority disciplinary activities are summarized in Section VIII.

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 IX.

D. **Technical Activity Groups.** Various groups of experts have formed Technical Activity Groups (TAGs) to verify the complex computer calculations needed for wave propagation and dynamic rupture problems, 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.

E. **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:

- a. The *Implementation Interface* connects SCEC scientists with partners in earthquake engineering research, and communicates with and trains practicing engineers and other professionals.
- b. The *Public Education and Preparedness* thrust area educates people of all ages about earthquakes, and motivates them to become prepared.
- c. The *K-14 Earthquake Education Initiative* seeks to improve earth science education and school earthquake safety.
- d. 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 XI.

### IV. 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 VII, 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 X) or in education and/or outreach (see Section XI).

- C. **Special Fault Study Areas.** Special Fault Study Areas (SFSA) are integrated, multidisciplinary projects focused on areas of complex fault behavior within southern California. 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.

SFSA will be evaluated through the standard SCEC proposal process. So that others are aware of the opportunities to join efforts at SFSA, the Planning Committee requests that a point of contact be identified as soon as possible prior to proposal submission (please email this information to Mike Oskin, [meoskin@ucdavis.edu](mailto:meoskin@ucdavis.edu)). A summary of the proposed SFSA and contact information is posted online at <http://www.scec.org/research/sfsa.html>. Proposals seeking to be part of an SFSA should clearly identify this on the cover page of the proposal. The standard length limit (5 pages, not including references) will apply to SFSA proposals. Disciplinary activities may be broken out into linked, separate proposals. If so, then each of these proposals should begin with a preamble (no more than 1/2 page) describing the greater research objective of the SFSA. Each proposal should also clearly state how its objectives fit into the overall research plan. Workshop proposals designed to plan efforts at proposed or future possible SFSA are strongly encouraged.

- D. **Workshops.** SCEC participants who wish to host a workshop between February 1, 2012 and January 31, 2013 should submit a proposal for the workshop in response to this Collaboration Plan.

Please notify Tran Huynh ([scecmeet@usc.edu](mailto:scecmeet@usc.edu)) before submitting the proposal if you want to organize a workshop around the time of the SCEC Leadership Retreat (June) or SCEC Annual Meeting (September). Note that workshops scheduled in conjunction with the SCEC Annual Meeting are restricted to half-day session only.

Workshops in the following topics are particularly relevant:

- Organizing collaborative research efforts for the 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, the Advanced National Seismic System (ANSS), and the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES).

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

If your proposal includes undergraduate student funding, please be sure to note this on the cover page.

- G. **SCEC Annual Meeting participation.** This category includes proposals by investigators requesting travel funding only for participation at the SCEC Annual Meeting. Investigators who are (a) already funded to study projects that would be of interest to the SCEC community, and/or (b) new to SCEC who would benefit from exposure to the SCEC Annual Meeting in order to fine-tune future proposals are encouraged to apply.

## V. Evaluation Process and Criteria

- A. 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.
- B. Proposals may be strengthened by describing:
1. Collaboration
    - Within a disciplinary or focus group
    - Between disciplinary and/or focus groups
    - In modeling and/or data gathering activities
    - With engineers, government agencies, and others.
  2. Leveraging additional resources
    - From other agencies
    - From your institution
    - By expanding collaborations
  3. Development and delivery of products
    - Community research tools, models, and databases
    - Collaborative research reports
    - Papers in research journals
    - End-user tools and products
    - Workshop proceedings and CDs
    - Fact sheets, maps, posters, public awareness brochures, etc.
    - Educational curricula, resources, tools, etc.
  4. Educational opportunities
    - Graduate student research assistantships
    - Undergraduate summer and year-round internships (funded by the project)
    - K-12 educator and student activities
      - Presentations to schools near research locations
      - Participation in data collection

- C. 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.
- D. The Science Planning Committee is chaired by the Deputy Director and comprises the chairs of the disciplinary committees, focus groups, and special projects. It is responsible for recommending a balanced science budget to the Center Director.
- E. Recommendations of the planning committees will be combined into an annual spending plan and forwarded to the SCEC Board of Directors for approval.
- F. Final selection of research projects will be made by the Center Director, in consultation with the Board of Directors.
- G. The review process should be completed and applicants notified by the end of February 2012.

## VI. 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 earthquake 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, Menlo Park, and Golden 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. Ken Hudnut, 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 EHP external funding cycle is several months offset from SCEC's, with the 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 by topic at <http://earthquake.usgs.gov/research/topics.php>.

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

The six fundamental problems constitute the basic-research focus of SCEC4 and are listed in the preamble. They are interrelated and require an interdisciplinary, multi-institutional approach. Interdisciplinary research initiatives will focus on special fault study areas, the development of a community geodetic model for Southern California, and a community stress model. The latter will be a new platform where the various constraints on earthquake-producing stresses can begin to be integrated. Improvements will 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 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.

**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 are necessary to constrain long-term clustering 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. We will use seismicity to constrain CSM and investigate how stress may control earthquake clustering and triggering. We plan to collaborate with other organizations in fault-drilling projects for in situ hypothesis testing of stress levels.

**2e.** Development of physics-based earthquake 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.** 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.** Laboratory experiments on fault materials under appropriate confining stresses, temperatures, and fluid presence through targeted experiments in collaboration with rock mechanics laboratories.

**3b.** Search for geological, geochemical, paleo-temperature, and hydrological indicators of specific resistance mechanisms that can be measured in the field. In particular, we will look for evidence of thermal decomposition in exhumed fault zones.

**3c.** Theoretical and numerical modeling of specific fault resistance mechanisms for seismic radiation and rupture propagation, including interaction with fault roughness and damage-zone properties. At the scale of meters to hundreds of meters, the behavior of the near-fault layer with evolving damage may have to be included in the fault constitutive relations.

**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.** Dynamic rupture modeling to constrain stress levels along major faults, explain the heat-flow paradox, and understand extreme slip localization, the dynamics of self-healing ruptures, and the potential for repeated slip on the fault during the earthquake. We will collaborate with other organizations in fault-drilling projects to measure temperature on faults before and after earthquakes and thus constrain co-seismic resistance.

**3f.** Development of earthquake simulators that can incorporate realistic models of fault-resistance evolution during the earthquake cycle.

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

Priorities and Requirements

**4a.** Establishment of special fault study areas for detailed geologic, seismic, geodetic, and hydrologic investigations of fault complexities

**4b.** Investigations of along-strike variations in fault roughness and complexity 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 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. 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 ruptures that includes realistic dynamic weakening mechanisms, off-fault plastic deformation, and is constrained by source inversions. The priority is to produce physically consistent rupture models for broadband ground motion simulation. An important issue is how to treat multiscale processes; specifically, does off-fault plasticity regularize the Lorentzian scale collapse associated with strong dynamic weakening? If not, how can adaptive meshing strategies be most effectively used to make full-physics simulations feasible?

**6c.** Develop 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.** Measure 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.** Collaborate 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.

## **VIII. Disciplinary Activities**

The Center will sustain disciplinary science through standing committees in Seismology, Geodesy, 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 include the following tasks:

### **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 physics-based 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 the ANSS and NEES projects, 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.

### **Priorities for Seismology in 2012**

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. **The 2010 M7.2 El Mayor-Cucapah Earthquake Sequence.** The El Mayor sequence ruptured for a distance of more than 120 km, and large data sets were recorded by the SCSN, RESNOM, portable temporary networks, and GPS networks. Proposals that seek to analyze these data and other relevant data sets in the context of SCEC research priorities are encouraged.

### **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 time-dependent geodetic data product for southern California that leverages the complementary nature of GPS and InSAR time series data. The resulting product will consist of well-constrained, temporally and spatially dense horizontal and vertical displacement time series that can be used in meeting a variety of SCEC4 objectives. This will require development of optimal methods for combining GPS and InSAR data, characterizing seasonal/hydrologic/anthropogenic signals, incorporating new data, and accounting for earthquake effects as needed.

Data collection and analysis designed to address specific questions regarding geodetic/geologic slip rate discrepancies, to assess the role of lower crust/upper mantle processes in driving fault loading, to constrain more physically realistic deformation models, and to provide input to the development of Community Stress Models are also encouraged, as are studies that pursue integrated use of geodetic, geologic, seismic, and other observations targeting special fault study areas. Proposals for the development of new data products or collection of new data should explicitly motivate the need for such efforts and state how the resulting data or products will be used. Resulting data should be provided for inclusion in the CGM. In compliance with SCEC's data policy, data collected with SCEC funding must be made publically available upon collection by archiving at an appropriate data center (e.g., UNAVCO). Annual reports should include a description of archive activities.

2. **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. Extension of methods to include InSAR and strainmeter data and, when available, the CGM is also a priority.

Targeted collection and analysis of all types of geodetic data to constrain physics-based models of slow slip and tremor are also encouraged.

3. **Develop and apply algorithms that use real-time high-rate GPS data in concert with seismic data for improved earthquake response.**

## 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 VII, 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).
- Studies to improve understanding of special fault study areas (Problem 4a) or to improve the statewide community fault model, especially that take advantage of 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 investigating the processes and 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 strongly 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](mailto:jsouthon@uci.edu)) and Lawrence Livermore National Laboratory (Tom Guilderson, [tguilderson@llnl.gov](mailto:tguilderson@llnl.gov)),
- OSL: University of Cincinnati (Lewis Owen, [lewis.owen@uc.edu](mailto:lewis.owen@uc.edu)) and Utah State University (Tammy Rittenour, [tammy.rittenour@usu.edu](mailto:tammy.rittenour@usu.edu)), and
- Cosmogenic: Lawrence Livermore National Laboratory (Dylan Rood, [rood5@llnl.gov](mailto:rood5@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 co-leader, Mike Oskin ([meoskin@ucdavis.edu](mailto:meoskin@ucdavis.edu)).

### **Data Reporting Requirements**

Studies under Earthquake Geology gather diverse data that are at times challenging to consistently archive per NSF data reporting requirements. Under SCEC4, PIs will be 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. A priority at the outset of SCEC4 is to do define additional, achievable goals for geology data reporting to be followed by Earthquake Geology community.

### **Priorities for Earthquake Geology in 2012**

- Establish special fault study areas and formulate research strategies for these sites.
- Prioritize research objectives, especially with respect to SoSAFE focus group goals, targets for slip-rate studies, and mechanisms to achieve progress on exhumed fault-zone problems.
- Define consistent and achievable data reporting requirements for Earthquake Geology in SCEC4.
- Improve understanding of the seismogenic faults along the coast and offshore. Search for possible tsunami deposits from offshore sources, including both faults and landslides.

## **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 HPC labs/centers as well as the vendor community in crosscutting efforts enabling SCEC petascale 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.

### **Example Research Strategies**

1. Collaborate with modelers to port and optimize codes on new architectures.
2. Evaluate 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. Support optimization of earthquake simulators that can resolve the faulting processes across the range of scales required to investigate stress-mediated fault interaction, generate synthetic seismicity catalogs, and assess the viability of earthquake rupture forecasts.
4. Foster and help coordinate a research and development effort utilizing advanced techniques for addressing accelerating technologies such as hybrid MPI/OpenMP, MPI/CUDA, PGAS, and auto-tuning; and preparing the community for sea changes in architecture towards exascale computing.
5. Support development of a community model framework for managing I/O, data repositories, workflow and management, analysis/visualization tools, reliability and resilience capabilities.
6. Identify and develop the necessary tools for data-intensive computing, including but not limited to 3D tomography, cross-correlation algorithms used in ambient noise seismology, and other signal processing techniques used, for example, to search for tectonic tremor.
7. Provide tools and algorithms for uncertainty quantification in large-scale inversion and forward-modeling studies.
8. Provide coordinated support to the community on large resource allocation proposals.
9. Participate in major Community Modeling Environment (CME) projects.

## **Key Problems in Computational Science**

1. Seismic wave propagation
  - Validate SCEC community velocity models.
  - Develop high-frequency simulation methods and investigate the 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.
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 source complexity, including stress heterogeneity, variability in frictional properties, and fault geometrical complexity.
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 enhanced ground motion using adjoint-based sensitivity methods.
5. Engineering applications
  - Facilitate the “rupture-to-rafters” modeling capability to transform earthquake risk management into a Cyber Science and Engineering discipline.

## **IX. 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 and (2) expanding into a new area of emphasis by developing methods to represent smaller scale features, such as the detailed representations needed for the special fault study areas and stochastic variations of seismic velocities and attenuation structure.

- **Community Velocity Model (CVM).** Improve the current SCEC CVMs, with emphasis on more accurate representations of  $V_p$ ,  $V_s$ , density, attenuation, and basin structure. Generate improved mantle  $V_p$  and  $V_s$  models, as well as more accurate descriptions of near-surface properties that can be incorporated into the models’ geotechnical layers. Perform 3D waveform tomographic inversions and ambient noise analysis for evaluating and improving the CVMs. Develop and apply procedures (i.e., goodness-of-fit measures) for evaluating the existing and future models with data (e.g., waveforms, gravity) to distinguish alternative representations and quantify model uncertainties; apply these methods for well-recorded earthquakes in southern California to delineate areas where CVM updates are

needed. Develop databases, models, and model building tools that will help facilitate expansion of the CVMs to statewide and plate-boundary scale velocity representations. These efforts should be coordinated with the SCEC CME special project.

- **Community Fault Model (CFM).** Improve and evaluate the CFM, placing emphasis on defining the geometry of major faults that are incompletely, or inaccurately, represented in the current model. Extend the CFM to include spatial uncertainties and stochastic descriptions of fault heterogeneity. Evaluate the CFM with data (e.g., seismicity, seismic reflection profiles, geologic slip rates, and geodetic displacement fields) to distinguish alternative fault models. Evaluate the new statewide fault model (SCFM), and update the CFM-R (rectilinear fault model) to reflect improvements in the CFM.
- **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. 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.

## ***B. Fault and Rupture Mechanics (FARM)***

The primary mission of the Fault and Rupture Mechanics focus group in SCEC4 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 SCEC 4 proposal and enhance understanding of fault system behavior through interdisciplinary investigation of 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 in 2012***

- Investigate the relative 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).
- 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; collaboration with the Technical Activity Group (TAG) on Source Inversion Validation (SIV) 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, 4b, 4d, 6b).
- Understand the significance of fault zone characteristics and processes on fault dynamics (3a, 3b, 3c) and formulate constitutive laws for use in dynamic rupture models (3d).
- Evaluate the relative importance of fault structure, material properties, interseismic healing, 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, and constitutive behavior at the base of and below the seismogenic zone (1a, 1b, 1e, 4a).
- 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 (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, through 4D 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, 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.

#### ***Projects Solicited for SDOT***

1. Contributions to our understanding of geologic inheritance and evolution, and its relation to the three-dimensional structure and physical properties of present-day crust and lithosphere. Contributions to efforts of building a 4D model of lithospheric evolution over 10s of Myr for southern California.
2. Seismological imaging of crust, lithosphere and upper mantle using interface and transmission methods with the goal of characterizing the 3D distribution of isotropic and anisotropic wave speed variations.
3. Contributions to the development of a Community Stress Model (CSM), a set of spatio-temporal (4D) representations of the stress tensor in the southern California lithosphere.
4. 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.
5. Development of models of interseismic and earthquake cycle deformation, including efforts to estimate slip rates on southern CA faults, fault geometries at depth, and spatial distribution slip or moment deficits on faults. Assessments of potential discrepancies of models based on geodetic, geologic, and seismic data.
6. 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.

### ***D. Earthquake Forecasting and Predictability (EFP)***

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



We seek proposals that will increase our understanding of how earthquakes might be forecast, whether or not earthquakes are predictable, and whether or not there exists a physical basis for earthquake predictability. Proposals of any type that can assist in this goal will be considered. In order to increase the number of earthquakes in the data sets, 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 Predictability (CSEP), see Section X 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 in 2012***

- Support the development of statistical or physics-based real-time earthquake forecasts.
- Utilize and/or evaluate the significance of earthquake simulator results.
- Study how to properly characterize 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.

#### ***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.

#### ***Research Topics in GMP***

- Developing and/or refining physics-based simulation methodologies, with particular emphasis on high frequency (1-10 Hz) approaches. This work could include implementation of simulation methodologies onto the Broadband Simulation Platform (in collaboration with CME).
- Waveform modeling of past earthquakes to validate and/or refine the structure of the Community Velocity Model (CVM) (in collaboration with USR).
- Incorporation of non-linear models of soil response.
- Development of more realistic implementations of dynamic or kinematic representations of fault rupture. 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.
- 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. 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).

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 has become an Interdisciplinary Focus Area in SCEC4 and will continue to increase our knowledge of slip rates, paleo-event chronology, 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'.

Past SoSAFE workshops have led to a focused research plan that responds to the needs and opportunities identified across existing research projects.

### ***Priorities for SoSAFE in 2012***

- Help to improve correlation of ruptures over the past 2000 years. This includes short-term (3-5 earthquakes) and slip-per-event data from paleoseismic sites, but can include longer-term rates (60,000 years) in some cases.
- Obtain the best possible measurements of geomorphic slip distributions from past earthquakes using field and LiDAR approaches and to validate the different measures.
- Lengthen existing paleoearthquake chronologies or start new sites in key locations along the fault system.
- 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.

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 advance SCEC research towards meeting 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-rafter 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 require 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 focusing on validation of ground motion simulations has been established to develop and implement testing/rating methodologies via collaboration between ground motion modelers and engineering users. A 2011 workshop on this topic (<http://www.scec.org/workshops/2011/gmsv/index.html>) and the GMSV Plenary Session at the Annual Meeting identified the following initial efforts as potential priority activities in this area. Proposals on these topics will be reviewed with all other SCEC proposals in January of 2012. Interested researchers are invited to contact Dr. Nicolas Luco ([nluco@usgs.gov](mailto:nluco@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 approximately two coordination workshops.

- Generate simulated ground motions for the following past earthquakes, preferably (but not necessarily) via the Broadband Simulation Platform: 1971 San Fernando, 1979 Imperial Valley, 1983 Coalinga, 1984 Morgan Hill, 1986 North Palm Springs, 1987 Whittier Narrows, 1989 Loma Prieta, 1992 Landers, 1992 Big Bear, 1994 Northridge, 1999 Hector Mine, 2004 Parkfield, and 2010 El Mayor-Cucapah.
- Develop validation methodologies that use elastic and inelastic response spectra, and demonstrate them with existing simulated ground motions (preferably, but not necessarily, from the Broadband Simulation Platform) and their recorded counterparts.
- 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).
- Comprehensive analysis and documentation of the sensitivity of simulated ground motions to model input parameters and their interactions and uncertainties.
- Research on important ground motion or structural (e.g. building or geotechnical system) response parameters and statistics that should be used in validation of simulations.
- Demonstrate validation methodologies with ground motions simulated with deterministic and stochastic methods above 1 Hz.

#### ***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.
- Develop ground motion parameters (or intensity measures), whether scalars or vectors, that enhance the prediction of structural response and risk.
- Investigate bounds on the median and variability of ground motions for a given earthquake scenario, in coordination with the Extreme Ground Motion Project.

#### ***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 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 Broadband Platform.
- Develop and validate modules for nonlinear site response, including models for under what circumstances nonlinear modeling is required.

#### ***Collaboration in Structural Response Analysis***

- 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). Such projects could potentially build on work done in the PEER TBI Project.

- 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](mailto: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.

## **X. 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)***

Following the 2008 release of the Uniform California Earthquake Rupture Forecast version 2 (UCERF2), the WGCEP is now working on adding some major enhancements for UCERF3 (due June 2012) and subsequent models. Our primary goals are to relax segmentation, add multi-fault ruptures, and include spatial-temporal clustering (earthquake triggering). As the latter will require robust interoperability with real-time seismicity information, UCERF3 will bring us into the realm of operational earthquake forecasting (OEF). This model is being developed jointly by SCEC, the USGS, and CGS, in close coordination with the USGS National Seismic Hazard Mapping Program. The following are examples of SCEC activities that could make direct contributions to WGCEP goals:

- Reevaluate fault models in terms of the overall fault inventory, specify more precisely fault endpoints in relationship to neighboring faults, and examine the likelihood of possible multi-fault ruptures. Help specify the extent to which faults represent a well-define surface versus a proxy for a braided deformation zone.
- Reevaluate fault slip rates, especially using more sophisticated modeling approaches (e.g., that include GPS data, generate kinematically consistent results, and perhaps provide off-fault deformation rates as well). This may include how we map simplified block-model results back onto the more complex fault system.
- 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).
- Contribute to the compilation and interpretation of mean recurrence-interval constraints from paleoseismic data.

- Develop earthquake rate models that relax segmentation and include multi-fault ruptures.
- Develop ways to constrain the spatial distribution of maximum magnitude for background seismicity (for earthquakes occurring off of the explicitly modeled faults).
- Answer the question of whether every small volume of space exhibits a Gutenberg Richter distribution of nucleations?
- Develop methods for quantifying elastic-rebound based probabilities in un-segmented fault models.
- Help quantify the amount of slip in the previous event (including variations along strike) on any major faults in California.
- Develop models for fault-to-fault rupture probabilities, especially given uncertainties in fault endpoints.
- Determine the proper explanation for the apparent post-1906 seismicity-rate reduction (the so-called Empirical Model of previous WGCEPs). How temporally variable are seismicity rates (e.g., more so than implied by aftershock statistics)?
- Develop applicable methods for adding spatiotemporal clustering to the model (e.g., based on empirical models such as ETAS, or derived from physics-based simulators). Are sequence-specific parameters warranted?
- Is there a physical difference between a multi-fault rupture and a separate event that was triggered quickly?
- Develop easily computable hazard or loss metrics that can be used to evaluate and perhaps trim logic-tree branch weights.
- 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.

Further suggestions and details can be found at <http://www.WGCEP.org>, or by contacting the project leader (Ned Field: [field@usgs.gov](mailto: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? Contributions may include:

1. 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;
2. Constructing community-endorsed standards for testing and evaluating probability-based and alarm-based predictions;
3. Developing hardware facilities and software support to allow individual researchers and groups to participate in prediction experiments;
4. 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;
5. Reducing testing latency by reducing the updating interval of the short-term forecasting models (e.g., STEP and ETAS) from 1 day to 1 hour or less, in order to explore the potential information gain in aftershock sequences;
6. Establishing seismicity-based reference models as norms against which the skill of candidate models can be evaluated;
7. Developing testing procedures that explicitly recognize that real-time catalogs are incomplete and have larger errors in source parameters;
8. Working to develop testable fault-based forecast models;
9. Intensifying the collaboration with Japan and New Zealand with a special emphasis on the effect of the Darfield and Tohoku-oki, and using data collected from these sequences to retrospectively calibrate and prospectively test improved forecasting models;

10. Initiating joint efforts with China;
11. Re-assessing the geophysical, neotectonic, and paleoseismic data on the long-term recurrence of high-magnitude events and re-examining time-dependent hazard models;
12. Developing experiments to test basic physical principles of earthquake generation (e.g., models for estimating the largest possible earthquake on a given fault are important to earthquake scenarios like ShakeOut and to earthquake hazard models. We seek proposals to develop quantitative tests of such models);
13. Evaluating hypotheses critical to forecasting large earthquakes, including the characteristic earthquake hypothesis, the seismic gap hypothesis, and the maximum-magnitude hypothesis;
14. 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; and
15. Conducting workshops to facilitate international collaborations.

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.

*SPECIAL NOTE: Global travel grants for CSEP from 2006 to 2010 were funded with a grant from the W. M. Keck Foundation, which ended in early 2011. Future funding for CSEP global travel has not been obtained at the time of the release of this document.*

### **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. The following paragraphs briefly describe several current CME computational goals so researchers can propose to develop a needed element that can be integrated into a larger CME calculation.

Examples of CME research requirements include earth structural models, curated data sets to support forecast validation, and scientific software that simulates physical processes in the earth including dynamic ruptures 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.

Proposals that seek to use existing CyberShake simulations as a research database are encouraged.

CME is working to improve probabilistic seismic hazard calculations. CME 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.

#### ***D. National Partnerships through EarthScope***

The NSF EarthScope project (<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/ESSP>). 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.

### **XI. 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](mailto:benthien@usc.edu), 213-740-0323).