# 2010 Program Announcement

For the Southern California Earthquake Center

*Table of Contents*

# 2010 Program Announcement

For the Southern California Earthquake Center

*Released October 2009*

## I. Introduction

On February 1, 2002, the Southern California Earthquake Center (SCEC) changed from an entity within the NSF/STC program to a freestanding center, funded by NSF/EAR and the U.S. Geological Survey. SCEC2 was funded for a five-year period, February 2002 to January 2007. SCEC was renewed for the period February 2007 through January 2012, referred to now as SCEC3. This document solicits proposals from individuals and groups to participate in the fourth year of the SCEC3 research program.

## II. Guidelines for Proposal Submission

A. ***Due Date.*** Friday, November 6, 2009, 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 as PDF documents via the SCEC Proposal web site at *http://www.scec.org/proposals*. Submission procedures, including requirements for how to name your PDF files, will be found at this web site.

C. ***Formatting Instructions.***

- ***Cover Page.*** The cover page should be headed with the words "2010 SCEC Proposal" and include the project title, Principal Investigator(s), institutional affiliation, amount of request, and proposal categories (from types listed in Section IV). List in order of priority three science objectives (Section VII) that your proposal addresses, for example A3, A5 and A11. Indicate if the proposal should also be identified with one or more of the SCEC special projects (see Section VIII). 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, 2010.
- ***Technical Description.*** Describe in up to five pages (including figures) the technical details of the project and how it relates to the short-term objectives outlined in the SCEC Science Objectives (Section VII). References are not included in the five-page limit.
- ***Budget Page.*** Budgets and budget explanations should be constructed using NSF categories. 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, following NSF guidelines, should be included for each Principal Investigator.
- ***2009 Annual Report.*** Scientists funded by SCEC in 2009 must submit a report of their progress by 5:00 pm PST February 28, 2010. 2010 proposals approved by the PC will not be funded until all progress reports are submitted. Reports should be up to five pages of text and figures. Reports should include bibliographic 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 at *http://www.scec.org/signin*.
- ***Special Note on Workshop Reports.*** Reports on results and recommendations of workshops funded by SCEC in 2010 are to be submitted no later than 30 days following the completion of the workshop. The reports will be posted on the SCEC web site as soon as possible after review by the directors.

- ***Labeling the Submitted PDF Proposal.*** PI's must follow the proposal naming convention. Investigators must label their proposals with their last name followed by 2010, e.g., Archuleta2010.pdf. If there is more than one proposal, then the file would be labeled as: Archuleta2010_1.pdf (for the 1st proposal) and Archuleta2010_2.pdf (for the 2nd proposal).

D. ***Principal Investigator Responsibilities.*** PI's are expected to interact with other SCEC scientists on a regular basis (e.g., by attending workshops and working group meetings), and 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 available at *http://www.scec.org/signin*. 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)

F. ***Collaboration.*** 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; these can be submitted with the same text, but with different institutional budgets if more than one institution is involved.

G. ***Budget Guidance.*** Typical SCEC grants funded under this Science Plan in the past have fallen 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.

H. ***Award Procedures.*** All awards will be funded by subcontract from the University of Southern California. The Southern California Earthquake Center is funded by the National Science Foundation and the U.S. Geological Survey.

## 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 elsewhere
- 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. The long-term science goals are summarized in Appendix A.

B. ***Disciplinary Activities.*** The Center sustains disciplinary science through standing committees in seismology, geodesy, and geology. These committees will be responsible for planning and coordinating disciplinary activities relevant to the SCEC science 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 VII.A.

C. ***Interdisciplinary Focus Areas.*** Interdisciplinary research is organized within five science focus areas: 1) Unified Structural Representation (URS), 2) Fault and Rupture Mechanics (FARM), 3) Crustal Deformation Modeling (CDM), 4) Lithospheric Architecture and Dynamics (LAD), 5) Earthquake Forecasting and Predictability (EFP), 6) Ground Motion Prediction (GMP) and 7) Seismic Hazard and Risk Analysis (SHRA). High-priority activities are listed for each of these interdisciplinary focus areas in Section VII.B.

D. ***Special Projects.*** SCEC supports eight special projects that will advance designated research frontiers. Several of these initiatives encourage further development of an advanced IT infrastructure for system-level earthquake science in Southern California. High-priority initiatives are listed and described in Section VIII.

E. ***Communication, Education, and Outreach.*** SCEC maintains a strong Communication, Education, and Outreach (CEO) program with four principal goals: 1) coordinate productive interactions among SCEC scientists, and with partners in science, engineering, risk management, government, business, and education; 2) increase earthquake knowledge and science literacy at all educational levels; 3) improve earthquake hazard and risk assessments; and 4) promote earthquake preparedness, mitigation, and planning for response and recovery. Opportunities for participating in the CEO program are described in Section IX. Current activities are described online at *http://www.scec.org/ceo*.

## 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 on-line, 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 VIII) or in an educational or outreach mode (see Section IX).

C. ***Workshops.*** SCEC participants who wish to host a workshop between February 2010 and January 2011 should submit a proposal for the workshop in response to this RFP. This includes workshops that might be organized around the SCEC annual meeting in September. Workshops in the following topics are particularly relevant:

- Organizing collaborative research efforts for the five-year SCEC program (2007-2012). 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).

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

E. ***SCEC/SURE Intern Project.*** If your proposal includes undergraduate funding, please note this on the cover page. Each year SCEC coordinates the SCEC Summer Undergraduate Research Experience (SCEC/SURE) program to support one-on-one student research with a SCEC scientist. See *http://www.scec.org/*internships for more information. SCEC will be recruiting mentors in November 2009, and will request descriptions of potential projects via email. In December, these descriptions will be published on the SCEC Internship web page to allow applicants to identify their preferred projects.

Mentors will be required to provide at least $2500 of the $5000 intern stipend, and SCEC will pay the balance. Mentor contributions can come from any source, including SCEC-funded research projects. Therefore, interested SCEC scientists are encouraged to include at least $2500 for an undergraduate intern in their 2009 SCEC proposals, and then respond to the recruitment emails.

Questions about the SCEC/SURE Intern Project should be referred to Robert de Groot, *degroot@usc.edu*.

F. ***SCEC Annual Meeting participation.*** Investigators who wish to only request funding to cover travel to the annual meeting can participate in a streamlined review process with an abbreviated proposal. Investigators who are already funded to study projects that would be of interest to the SCEC community, and investigators new to SCEC who would benefit from exposure to the 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 RFP. 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):

- Scientific merit of the proposed research
- Competence and performance of the investigators, especially in regard to past SCEC-sponsored research
- Priority of the proposed project for short-term SCEC objectives as stated in the RFP
- Promise of the proposed project for contributing to long-term SCEC goals as reflected in the SCEC science plan (see Appendix).
- Commitment of the P.I. and institution to the SCEC mission
- Value of the proposed research relative to its cost
- Ability to leverage the cost of the proposed research through other funding sources
- Involvement of students and junior investigators
- Involvement of women and underrepresented groups
- 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:

- 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. (See Section IX)
- Leveraging additional resources
  - From other agencies
  - From your institution
  - By expanding collaborations
- 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.

• Educational opportunities
  - Graduate student research assistantships
  - Undergraduate summer and year-round internships (funded by the project)
  - K-12 educator and student activities
    - o Presentations to schools near research locations
    - o 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 Planning Committee 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. The CEO Planning Committee is chaired by the Associate Director for CEO and comprises experts involved in SCEC and USGS implementation, education, and outreach. It is responsible for recommending a balanced CEO budget to the Center Director.

F. Recommendations of the planning committees will be combined into an annual spending plan and forwarded to the SCEC Board of Directors for approval.

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

H. The review process should be completed and applicants notified by the end of February 2010.

## VI. Coordination of Research Between SCEC and USGS-EHRP

A. Earthquake research in Southern California is supported both by SCEC and by the USGS Earthquake Hazards Reduction Program (EHRP). EHRP'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. EHRP funds research via its External Research Program, as well as work by USGS staff in its Pasadena, Menlo Park, and Golden offices. The EHRP also supports SCEC directly with $1.1M per year.

B. SCEC and EHRP 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, EHRP coordinator for Southern California, or other SCEC and EHRP staff to discuss opportunities for coordinated research.

C. The USGS EHRP 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 EHRP goals.

D. The EHRP web page, http://earthquake.usgs.gov/research/external/, describes program priorities, projects currently funded, results from past work, and instructions for submitting proposals. The EHRP external funding cycle is several months offset from SCEC's, with the RFP due out in February and proposals due in May. Interested PI's 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.

E. USGS internal earthquake research is summarized by topic at *http://earthquake.usgs.gov/research/topics.php*

## VII. SCEC3 Science Priority Objectives

The research objectives outlined below are priorities for SCEC3. They carry the expectation of substantial and measurable success during the coming year. In this context, success includes progress in building or maintaining a sustained effort to reach a long-term goal. How proposed projects address these priorities will be a major consideration in proposal evaluation, and they will set the programmatic milestones for the Center's internal assessments. In addition to the priorities outlined below, the Center will also entertain innovative and/or "risky" ideas that may lead to new insights or major advancements in earthquake physics and/or seismic hazard analysis.

There are four major research areas with the headings **A, B, C** and **D** with subheadings given by numbers. The front page of the proposal should specifically identify subheadings that will be addressed by the proposed research.

A. **Develop an extended earthquake rupture forecast to drive physics-based SHA**

A1. Define slip rates and earthquake history of southern San Andreas fault system for the last 2000 years

A2. Investigate implications of geodetic/geologic rate discrepancies

A3. Develop a system-level deformation and stress-evolution model

A4. Statistical analysis and mapping of seismicity and source parameters with an emphasis on their relation to known faults

A5. Develop a geodetic network processing system that will detect anomalous strain transients

A6. Test scientific prediction hypotheses against reference models to understand the physical basis of earthquake predictability

A7. Determine the origin, evolution and implications of on- and off-fault damage

A8. Test hypotheses for dynamic fault weakening

A9. Assess predictability of rupture extent and direction on major faults

A10. Develop statistical descriptions of heterogeneities (e.g., in stress, strain, geometry and material properties), and understand their origin and implications for seismic hazard by observing and modeling single earthquake ruptures and multiple earthquake cycles.

A11. Constrain absolute stress and understand the nature of interaction between the faulted upper crust, the ductile crust and mantle, and how geologic history helps to resolve the current physical properties of the system.

B. **Predict broadband ground motions for a comprehensive set of large scenario earthquakes**

B1. Develop kinematic and dynamic rupture representations consistent with seismic, geodetic, and geologic observations.

B2. Investigate bounds on the upper limit of ground motion

B3. Develop high-frequency simulation methods and investigate the upper frequency limit of deterministic ground-motion predictions

B4. Validate ground-motion simulations and verify simulation methodologies

B5. Improve our understanding of site effects and develop methodologies to include these effects in broadband ground-motion simulations.

B6. Collaborate with earthquake engineers to develop rupture-to-rafters simulation capability for physics-based risk analysis

C. **Improve and develop community products (data or descriptions) that can be used in system-level models for the forecasting of seismic hazard. Proposals for such activities should show how they would significantly contribute to one or more of the numbered goals in A or B.**

D. **Prepare post-earthquake response strategies**

Some of the most important earthquake data are gathered during and immediately after a major earthquake. Exposures of fault rupture are erased quickly by human activity, aftershocks decay rapidly within days and weeks, and post-seismic slip decays exponentially. SCEC solicits proposals for a workshop to plan post-earthquake science response. The goals of the workshop would be to: 1) develop a post-earthquake science plan that would be a living document such as a wiki; 2) identify permanent SCEC and other science facilities that are needed to ensure success of the science plan; 3) identify other resources available in the community and innovative ways of using technology for coordination and rapid data processing that will allow for rapid determination of source parameters, maps, and other characteristics of the source and ground motion patterns; 4) develop plans for use of simulations in post-earthquake response for evaluation of short-term earthquake behavior and seismic hazards; and 5) develop mechanisms for regular updates of the SCEC post-earthquake response plan

## VII-A. Disciplinary Activities

The Center will sustain disciplinary science through standing committees in seismology, geodesy, and geology. These committees will be responsible for planning and coordinating disciplinary activities relevant to the SCEC science 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:

### 1. Seismology

A. ***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 numbered goals in **A, B, C** or **D** 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.

B. ***Research Strategies.*** Examples of research strategies that support the objectives above include:

- 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 known and unknown faults (A3, A4, A10), especially evaluation of the short term evolution of earthquake sequences and real-time stress perturbations on nearby major fault segments (D).
- Enhance or add new capabilities to existing earthquake early warning (EEW) systems or provide new EEW algorithms. Develop real-time finite source models constrained by incoming seismic and GPS data to estimate evolution of the slip function and potentially damaging ground shaking (D).
- 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 new methods to search for unusual signals using combined seismic, GPS, and borehole strainmeter data (A5, A6); 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, and (A7, A10, C).
- 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 (B4, B6).
- 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.

C. ***Priorities for Seismology in 2010:***

- ***Earthquake early warning research.*** In the next few years, earthquake early warning (EEW) systems will be installed in California. The seismology group seeks proposals that will provide new algorithms, enhance or add new capabilities to existing EEW algorithms. The development of Bayesian probabilities that would take advantage of the extensive knowledge developed by SCEC about fault structures and spatial and temporal seismicity patterns are needed to make EEW algorithms more robust. Similarly, high-sample rate GPS 1 second solutions are being made available real-time for EEW development. Using these new data to develop new EEW algorithms for finite sources is a new area of research for SCEC scientists. For instance, we seek proposals that will provide algorithms for real-time finite source models constrained by incoming real-time seismic and GPS data to predict spatial and temporal development of the slip function, as well as the resulting potentially damaging ground shaking.
- ***Low-cost dense sensor networks.*** Several low cost seismic sensors networks are being developed in California. 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.
- ***Near Real-time earthquake sequence source processes.*** Two recent earthquake sequences (in Italy and near Bombay Beach in the Salton Sea area of southern California) highlight the need for rapid evaluation of earthquake probabilities and to identify the onset of significant events within evolving earthquake sequences. We seek proposals that would address the earthquake statistics aspects of earthquake sequences, and quantifying source processes that may have value for predicting short-term evolution of earthquake sequences. In addition, small sequences may perturb the state of stress on nearby major fault segments. We seek proposals that would provide quantitative evaluation of such

processes, and possibly provide near real-time estimates of changes in earthquake probabilities for these major fault segments.

## 2. Tectonic Geodesy

A. ***Objectives.*** The broad objective of SCEC's Tectonic Geodesy disciplinary activities is to foster the availability of the variety of geodetic data collected in Southern California and the innovative and integrated use of these observations, in conjunction with other relevant data (e.g., seismic or geologic information), to address the spectrum of deformation processes affecting this region. Topics of interest include, but are not limited to, rapid earthquake response, transient deformation, anthropogenic or nontectonic effects, and the quantification and interpretation of strain accumulation and release, with one goal being the increased use of insights from geodesy in seismic hazard assessment. Proposed work may overlap with one or more focus areas, such as Crustal Deformation Modeling (CDM).

B. ***Research Strategies.*** The following are research strategies aimed at meeting the broad objective:

- Develop reliable means for detecting, assessing, and interpreting transient deformation signals and for using this information in monitoring and response activities. (A5).
  - Develop detection algorithms. Work that extends the demonstrated capability of such algorithms to real data, that utilizes other data types in addition to or instead of GPS, or that explores means for incorporating such algorithms into monitoring systems is encouraged, as is participation in the ongoing Transient Detection Blind Test Exercise.
  - Generate sets of real or synthetic GPS or other types of data for the Transient Detection Blind Test Exercise.
  - Investigate processes underlying detected signals and/or their seismic hazard implications.
- Extend methods for estimating crustal motion and refine such estimates for southern California (A1, A2, A3, B1, C, D). In all cases, work should include assessment of the sources of uncertainty in the analysis and quantification of uncertainties in results (especially those relating to model uncertainty). Proposals for the development of new data products or collection of new data must explicitly motivate the need for such efforts and state how the resulting data or products will be used. Data collected with SCEC funding must be made publically available in an online archive within two years of its collection, although PIs may choose to share data on a case-by-case basis earlier than the two-year deadline.
  - Collaborate on the generation and maintenance of an up-to-date consensus velocity field for southern California.
  - Improve vertical velocity estimates, for example by refining or extending data processing and analysis strategies or approaches for the combined use of multiple data types.
  - Identify possible trade-offs in regional slip rate models, conduct quantitative comparison of such models, and/or develop new models.
  - Develop methods for combining data types (e.g., GPS, InSAR, strainmeter, and/or other data) that have differing spatial and temporal apertures, sampling frequencies, and sensitivities, and assess the utility of such combinations for interpreting tectonic or nontectonic signals.
  - Develop tools for using high-rate and real-time GPS positions and demonstrate application of these data to address topics such as rapid earthquake response, postseismic analysis, or the combined use of GPS and seismic data.

## 3. Earthquake Geology

A. ***Objectives.*** The Earthquake Geology group promotes studies of the geologic record of the Southern California natural laboratory that advance SCEC science. Geologic observations can provide important contributions to nearly all SCEC objectives in seismic hazard analysis (A1-A3, A6-A11) and ground motion prediction (B2-B5). Studies are encouraged to test outcomes of earthquake simulations and crustal deformation modeling. Earthquake Geology also fosters data-gathering activities that will contribute demonstrably significant geologic information to (C) community data sets such as the Unified Structural Representation. The primary focus of the Earthquake Geology is on the Late Quaternary record of faulting and ground motion in southern California. Collaborative proposals that cut across disciplinary boundaries are especially competitive.

B. ***Research Strategies.*** Examples of research strategies that support the objectives above include:

- Paleoseismic documentation of earthquake ages and displacements, including a coordinated effort to develop slip rates and earthquake history of southern San Andreas fault system (A1).
- Evaluating the potential for 'wall-to-wall' rupture or a brief cluster of major earthquakes on the San Andreas fault system (A1, A9).
- Investigating the likelihood of multi-segment and multi-fault ruptures on major southern California faults (A1, A9).
- Testing models for geologic signatures of preferred rupture direction (A9).
- Development of slip rate and slip-per-event data sets, taking advantage of newly collected GeoEarthScope LiDAR data, and with a particular emphasis on documenting patterns of seismic strain release in time and space (A1-A3, A5, A6, A9).
- Development of methods to evaluate multi-site paleoseismic data sets and standardize error analysis (A1, A9).
- Characterization of fault-zone geology, material properties, and their relationship to earthquake rupture processes, including studies that relate earthquake clustering to fault loading in the lower crust (A7, A8, A10).
- Quantitative analysis of the role of distributed deformation in accommodating block motions, dissipating elastic strain, and modifying rheology (A2, A3, A7, A10, A11).
- Development of constraints on the magnitude and recurrence of strong ground motions from precarious rocks and slip-per-event data (B2-B5).

C. ***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 must estimate the number and type of dates needed in their proposal. 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. These 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*) 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*)
- Cosmogenic: Lawrence Livermore National Laboratory (Tom Guilderson, *tguilderson@llnl.gov*).

Investigators at collaborating laboratories are requested to submit a proposal that states the cost per sample analysis and estimates of the minimum and maximum numbers of analyses feasible for the upcoming year. These investigators are also strongly encouraged to request for funds to support travel to the SCEC annual meeting. New proposals from laboratories not listed above will be considered, though preference will be given to strengthening existing collaborations.

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*).

## VII-B. Interdisciplinary Focus Areas

Interdisciplinary research will be organized into seven science focus areas: 1) Unified Structural Representation (USR), 2) Fault and Rupture Mechanics (FARM), 3) Crustal Deformation Modeling (CDM), 4) Lithospheric Architecture and Dynamics (LAD), 5) Earthquake Forecasting and Predictability (EFP), 6) Ground Motion Prediction (GMP) and 7) Seismic Hazard and Risk Analysis (SHRA). High-priority objectives are listed below for each of the seven interdisciplinary focus areas. Collaboration within and across focus areas is strongly encouraged.

### 1. Unified Structural Representation (USR)

The Structural Representation group develops unified, three-dimensional representations of active faults and earth structure (velocity, density, etc.) for use in fault-system analysis, ground motion prediction, and hazard assessment. This year's efforts will focus on making improvements to existing community models (CVM-H, CFM) that will facilitate their uses in SCEC science, education, and post-earthquake response planning.

A. ***Community Velocity Model (CVM).*** Improve the current SCEC CVM-H model, with emphasis on more accurate representations of Vp, Vs, density structure, and basin shapes, and derive models for attenuation. Generate improved mantle Vp and Vs models, as well as more accurate descriptions of near-surface property structure that can be incorporated into a revised geotechnical layer. Evaluate the existing models with data (e.g., waveforms, gravity) to distinguish alternative representations and quantify model uncertainties. Establish an evaluation procedure and benchmarks for testing how future improvements in the models impact ground motion studies. Special emphasis will be placed on developing and implementing 3D waveform tomographic methods for evaluating and improving the CVM-H.

B. ***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. Evaluate the CFM with data (e.g., seismicity, seismic reflection profiles, geodetic displacement fields) to distinguish alternative fault models. Integrate northern and Southern California models into a statewide fault framework, and update the CFM-R (rectilinear fault model) to reflect improvements in the CFM.

C. ***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 computational grids and meshes. An example of such IT mechanism is a web-based system that allows plot and download of profiles and cross sections of the CVMs and related data (i.e., Vs30) at desired locations. 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.

### 2. Fault and Rupture Mechanics (FARM)

The primary mission of the Fault and Rupture Mechanics focus group in SCEC3 is to develop physics-based models of the nucleation, propagation, and arrest of dynamic earthquake rupture. We specifically solicit proposals that 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 strain over multiple length and time scales (A7-A10, B1, B4), and that will contribute to our understanding of earthquakes in the Southern California fault system.

We invite proposals to:

A. Investigate the relative importance of different dynamic weakening and fault healing mechanisms, and the slip and time scales over which these mechanisms operate (A7-A10).

B. Determine the properties of fault cores and damage zones and characterize their variability with depth and along strike 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 (A7-A11).

C. Determine the relative contribution of on- and off-fault damage to the total earthquake energy budget, and the absolute levels of local and average stress (A7-A11).

D. Develop realistic descriptions of heterogeneity in fault geometry, properties, stresses, and strains, and tractable ways to incorporate heterogeneity in numerical models of single dynamic rupture events and multiple earthquake cycles (A10-11, B1, B4).

E. Understand the significance of fault zone characteristics and processes on fault dynamics and formulate constitutive laws for use in dynamic rupture models (A7-11, B1, B4).

F. Assess the predictability of rupture direction and directivity of seismic radiation by collecting and analyzing field and laboratory data, and conducting theoretical investigations to understand implications for strong ground motion (A7-A10, B1).

G. 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 (A7-A10, B1).

H. Characterize earthquake rupture, fault loading, degree of localization, and constitutive behavior at the base of and below the seismogenic zone. Understand implications of slow events and non-volcanic tremors for constitutive properties of faults and overall seismic behavior. Use these data to evaluate seismic moment-rupture area relationships (A3, A11).

## 3. Crustal Deformation Modeling (CDM)

We seek proposals aimed at resolving the kinematics and dynamics of southern California faults over time scales ranging from hours to thousands of years. Our long-term goal is to contribute to the SCEC objective of developing a physics-based probabilistic seismic hazard analysis for southern California by developing and applying system-wide deformation models of processes at time-scales of the earthquake cycle. Our immediate goals include assessing the level of detail necessary in deformation models to achieve the broader SCEC objectives. Collaborations with geologists and researchers in other SCEC groups are strongly encouraged.

**System-Wide Deformation Models:**

A. Develop kinematic models of interseismic deformation or the earthquake cycle to estimate slip rates on primary southern CA faults, fault geometries at depth, and spatial distribution slip or moment deficits on faults. Compare with or refine SCEC CFM and assess discrepancies of the kinematic models with geodetic, geologic, and seismic data (A1, A3).

B. Develop a system-wide model of southern California faults, incorporating the SCEC CFM, properties derived from the SCEC CVM, and realistic inferred rheologies, to model interseismic deformation, including transfer of stress across the fault system (A3).

C. Develop simpler models to compare with the system-wide deformation model above for benchmarking purposes and to assess the degree of detail needed to adequately represent interseismic deformation and stress transfer. Various modeling approaches are requested and might include boundary element methods, 2D simplifications, and analytical or semi-analytical methodology (A10, A3).

D. Assess whether stress transfer implicitly assumed in earthquake simulator models is similar to stress transfer estimated from either category of deformation model mentioned above (A11).

**More Focused Deformation Models:**

A. Determine the extent to which rheological heterogeneity (including damage) influences deformation and stress transfer at various spatial and temporal scales. What level of detail will be required for the system-wide model (A7, A10, A11, A3)?

B. Evaluate spin-up effects for viscoelastic models and methods to accelerate this process. How much does deep viscoelastic relaxation influence interseismic deformation and stress transfer? Can it be neglected or "worked around" in a southern-California-wide stress transfer model (A11, A3)?

C. Evaluate whether nonlinear rheologies be represented with heterogeneous distributions of linearly viscoelastic material (A11, A3).

D. Investigate causes of discrepancies between geologic and geodetic slip rate estimates (A2).

E. Investigate possible causes and effects of transient slip and earthquake clustering (A1, A11).

## 4. Lithospheric Architecture and Dynamics (LAD)

The lithospheric architecture and dynamics group (LAD) seeks proposals that will contribute to our understanding of the structure, geologic provenance and physical state of the major southern California lithospheric units, and how these relate to absolute stress in the crust and the evolution of the lithospheric system (A3, A11).

The principal objective of this group is to understand the physics of the southern California system, the boundary conditions and internal physical properties. Special attention is given to constraining the average absolute stress on southern California faults. Our general approach is to use 3D geodynamic models to relate the various forces loading the lithosphere to observable fields such as geodetic and geologic strain, seismic anisotropy and gravity. Of particular importance are: how flow in the sub-seismogenic zone and the asthenosphere accommodates plate motion, constraints on density structure and rheology of the southern California lithosphere, and how the system loads faults.

Physics models will be developed that use the paleo-history of the 3D geology to infer how present physical conditions were created, such as depths of Moho, the seismogenic layer, base of the lithosphere, topography and basin depths, rock type, temperature, water content, rheology and how these relate to mantle flow, velocity, anisotropy and density.

The LAD work will interface with the geology group to better understand crustal structure and North America mantle lithosphere. Of particular interest are the distribution of the underplated schist and the fate of Farallon microplate fragments and their relation to inferred mantle drips. We will interact with FARM to obtain constraints on rheology and stress (absolute and dynamic), with the USR and seismology groups on 3D structure, and CDM on current stress and strain rates.

In this context, proposals are sought that contribute to our understanding of geologic inheritance and its relation to the three-dimensional structure and physical properties of the crust and lithosphere. Proposals should indicate how the work relates to stress evolution (A2, A3, A11) as well as the current geological structure (C). A primary goal is to generate systems-level models that describe southern California dynamics against which hypotheses can be tested regarding the earthquake mechanism, fault friction, seismic efficiency, the heat flow paradox and the expected evolution of stress and strain transients (A5).

The LAD group will be involved in the USGS-NSF Margins/EarthScope Salton Trough Seismic Project and will interface to the southern California offshore seismic (OBS) experiment, and will consider proposals that piggyback these experiments and integrate the results into LAD goals.

### 5. Earthquake Forecasting and Predictability (EFP)

In general we seek proposals that will increase our understanding of how earthquakes might be forecast and whether or not earthquakes are predictable (A6). Proposals of any type that can assist in this goal will be considered. We are especially interested in proposals that will utilize the Collaboratory for the Study of Earthquake Predictability (CSEP). 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 CSEP, see the description of CSEP under Special Projects 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 (A6). 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. In general, methodologies will be considered successful only if they do better than null hypotheses that include both time-independent and time-dependent probabilities. Proposals aimed toward developing useful measurement/testing methodology that could be incorporated in the CSEP evaluations are welcomed, including those that address how to deal with observational errors in data sets.

Proposals are also welcome that assist in attaining the goals of these two Special Projects: WGCEP (the Working Group on California Earthquake Probabilities) and SoSAFE (the Southern San Andreas Evaluation), especially if the proposals focus on understanding some physical basis for connections between earthquakes. Proposals to utilize and/or evaluate the significance of earthquake simulator results are encouraged. Investigation of what is an appropriate magnitude-area relationship, including the maximum depth of slip during large earthquakes, is encouraged. Studies of how to properly characterize the relationship between earthquake frequency and magnitude for use in testing prediction algorithms are also encouraged.

Proposals that can lead to understanding whether or not there exists a physical basis for earthquake predictability (A6) are welcome, even if they are not aimed toward, or are not ready for, tests in CSEP, or are not aimed toward assisting WGCEP or SoSAFE. For example, proposals could include ones that connect to objectives A1, A2, A3, A5, A9, A10 and A11, as well as ones focused on understanding patterns of seismicity in time and space, as long as they are aimed toward understanding the physical basis of some aspect of extended earthquake predictability (A6). Development of methods for testing prediction algorithms that are not yet in use by CSEP is encouraged.

Proposals for workshops are welcome. Specific workshops of interest include one on earthquake simulators and one on setting standards that could be used by CSEP for testing and evaluation, data, and products.

### 6. 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 the ground 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 within the Ground Motion Prediction program include:

A. Developing and/or refining physics-based simulation methodologies, with particular emphasis on high frequency (1-10 Hz) approaches (B3)

B. Incorporation of non-linear models of soil response (B2, B4, B5);

C. Development of more realistic implementations of dynamic or kinematic representations of fault rupture. In collaboration with FARM, 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. (B1, B2).

D. Verification (comparison against theoretical predictions) and validation (comparison against observations) of the simulation methodologies with the objective of being to develop robust and transparent simulation capabilities that incorporate consistent and accurate representations of the earthquake source and three-dimensional velocity structure (B4, C).

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 (B6). Activities within the Ground Motion Prediction group will be closely tied to several special projects, with particular emphasis on addressing ground motion issues related to seismic hazard and risk. These special projects include the Extreme Ground Motion Project and the Tall Buildings Initiative (see SHRA below).

### 7. Seismic Hazard and Risk Analysis (SHRA)

The purpose of the SHRA Focus Group is to apply SCEC knowledge to the development of information and techniques for quantifying earthquake hazard and risk, and in the process to provide feedback on SCEC research. Projects in this focus group will in some cases be linked to the Ground Motion Prediction Focus Group, to SCEC special projects such as the Extreme Ground Motion Project, and to Pacific Earthquake Engineering Research Center (PEER) special projects such as the Tall Buildings Initiative (TBI) and Reference Buildings and Bridges Project. Projects that involve interactions between SCEC scientists and members of the community involved in earthquake engineering research and practice are especially encouraged. Examples of work relevant to the SHRA Focus Group follow:

**Improved Hazard Representation**

A. 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.

B. 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.

C. Develop ground motion parameters (or intensity measures), whether scalars or vectors, that enhance the prediction of structural response and risk.

D. Investigate bounds on the variability of ground motions for a given earthquake scenario.

**Ground Motion Time History Simulation**

A. Develop acceptance criteria for simulated ground motion time histories to be used in structural response analyses for building code applications or risk analysis.

B. 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.

C. 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.

**Collaboration in Building Response Analysis**

A. Tall Buildings. 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. Such projects could potentially build on work done in the TBI Project.

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

C. 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.

D. 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 building response and damage.

**Ground Deformation**

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

**Risk Analysis**

A. Develop improved site/facility-specific and portfolio/regional risk analysis (or loss estimation) techniques and tools, and incorporate them into the OpenRisk software.

B. Use risk analysis software to identify earthquake source and ground motion characteristics that control damage estimates.

**Other Topics**

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

## VIII. Special Projects and Initiatives

The following are SCEC special projects with which proposals in above categories can be identified:

### 1. Southern San Andreas Fault Evaluation (SoSAFE)

The SCEC Southern San Andreas Fault Evaluation (SoSAFE) Project 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. We strongly welcome proposals that will help to improve correlation of ruptures over the past 2000 years. This includes short-term (3-5 earthquake) and slip-per-event data from paleoseismic sites, but can include longer-term rates (60,000 years) in some cases. Use of novel methods for estimating slip rates from geodetic data would also potentially be supported within the upcoming year. Lengthening existing paleoearthquake chronologies or starting new sites in key locations along the fault system is encouraged. It is expected that much support will go towards improved dating (e.g., radiocarbon and OSL) of earthquakes within the past 2000 yrs., so that event correlations and coefficient of variation in recurrence intervals may be further refined. We welcome requests for infrastructure resources, for example geochronology support. That is, an investigator may ask for dating support (e.g., to date 12 radiocarbon samples). Requests for dating shall be coordinated with Earthquake Geology and a portion of SoSAFE funds will be contributed towards joint support for dating. However, we also welcome proposals, which seek to add other data (such as climate variations) to earthquake chronologies, which may be used to improve age control or site-to-site correlation of events.

We also welcome proposals that investigate methodologies for integrating paleoseismic and geologic data into rupture histories. For example, ongoing interaction between SoSAFE and the scenario rupture modeling activities of SCEC will continue beyond the ShakeOut, as we continue to develop constraints such as dating or slip data that can be used to eliminate the scenario of a "wall-to-wall" rupture (from Parkfield to Bombay Beach). SoSAFE will also work to constrain scenario models by providing the best possible measurements of actual slip distributions from past earthquakes on these same fault segments as input, thereby enabling a more realistic level of scenario modeling. Research will address significant portions of the fault system, and all investigators will agree to collaboratively review one another's progress. Research by single or multi-investigator teams will be supported to rapidly advance SCEC research towards meeting priority scientific objectives related to the mission of the SoSAFE special project. SoSAFE objectives also foster common longer-term research interests and engage in facilitating future collaborations in the broader context of a decade-long series of interdisciplinary, integrated and complementary studies on the southern San Andreas fault system.

The fourth year of SoSAFE may again be funded at $240K by USGS, depending on 1) the report on progress in the first three years, 2) effective leveraging of USGS funds with funds from other sources, 3) level of available funding from USGS for the year, and 4) competing demands for the USGS Multi-Hazards Demonstration Project funding.

### 2. 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 in a forthcoming UCERF3. 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. This model is being developed jointly by SCEC, the USGS, and CGS, with tight coordinated with the USGS National Seismic

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

A. Reevaluate fault models in terms of the overall inventory, and specify more precisely fault endpoints in relationship to neighboring faults (important for multi-fault rupture possibilities)

B. 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).

C. 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?)

D. Help determine the average down-dip slip distribution of large earthquakes (the ultimate source of existing discrepancies in magnitude-area relationships).

E. Contribute to the compilation and interpretation of mean recurrence-interval constraints from paleoseismic data.

F. Develop earthquake rate models that relax segmentation and include multi-fault ruptures.

G. Develop ways to constrain the spatial distribution of maximum magnitude for background seismicity (for earthquakes occurring off of the explicitly modeled faults).

H. Answer the question of whether every small volume of space exhibits a Gutenberg Richter distribution of nucleations?

I. Develop methods for quantifying elastic-rebound based probabilities in un-segmented fault models.

J. Help quantify the amount of slip in the previous event (including variations along strike) on any major faults in California.

K. Develop models for fault-to-fault rupture probabilities, especially give uncertainties in fault endpoints.

L. Determine the proper explanation for the apparent post-1906 seismicity-rate reduction (which appears to be a statewide phenomenon)?

M. Develop applicable methods for adding spatial and temporal clustering to the model.

N. Develop easily computable hazard or loss metrics that can be used to evaluate and perhaps trim logic-tree branch weights.

O. Develop techniques for down-sampling event sets to enable more efficient hazard and loss calculations.

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

### 3. Next Generation Attenuation Project, Hybrid Phase (NGA-H)

The NGA-H Project is currently on hold, but it is hoped that it will go forward at some point in the future in conjunction with PEER. It will involve the use of broadband strong motion simulation to generate ground motion time histories for use, in conjunction with recorded ground motions, in the development of ground motion attenuation relations for hard rock that are based on improved sampling of magnitude and distance, especially large magnitudes and close distances, and improved understanding of the relationship between earthquake source and strong ground motion characteristics. Broadband simulation methods are verified (by comparison of simple test case results with other methods) and validated (against recorded strong ground motions) before being used to generate broadband ground motions for use in model development. These simulation activities for verification, validation, and application are done on the SCEC Broadband Simulation Platform. The main SCEC focus groups that are related to this project are Ground Motion Prediction and Seismic Hazard and Risk Analysis.

### 4. End-to-End Simulation

The purpose of this project is to foster interaction between earthquake scientists and earthquake engineers through the collaborative modeling of the whole process involved in earthquake fault rupture, seismic wave propagation, site response, soil-structure interaction, and building response. Recent sponsors of this project have been NSF (tall buildings) and CEA (wood frame buildings), and new sponsors are being sought. The main SCEC discipline and focus groups working on this project are Geology, especially fault models; Unified Structural Representation; Faulting and the Mechanics of Earthquakes; Ground Motion Prediction; Seismic Hazard and Risk Analysis; and PetaSHA – TeraShake and CyberShake.

### 5. 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:

A. 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;

B. Constructing community-endorsed standards for testing and evaluating probability-based and alarm-based predictions;

C. Developing hardware facilities and software support to allow individual researchers and groups to participate in prediction experiments;

D. 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;

E. Intensifying the collaboration between the US and Japan through international projects, and initiating joint efforts with China;

F. 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); and

G. 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.

### 6. National Partnerships through EarthScope

The NSF EarthScope project provides unique opportunities to learn about the structure and dynamics of North America. SCEC encourages proposals to the NSF EarthScope program that will address the goals of the SCEC Science Plan.

### 7. Extreme Ground Motion Project (ExGM)

Extreme ground motions are the very large amplitudes of earthquake ground motions that can arise at very low probabilities of exceedance, as was the case for the 1998 PSHA for Yucca Mountain when extended to 10**-8/yr. This project investigates the credibility of such ground motions through studies of physical limits to earthquake ground motions, unexceeded ground motions, and frequency of occurrence of very large ground motions or of earthquake source parameters (such as stress drop and faulting displacement) that cause them. Of particular interest to ExGM (and more generally to ground-motion prediction and SHRA) is why crustal earthquake stress drops are so independent of earthquake size (amidst considerable scatter) and so much less than the frictional strength of rocks at mid-crustal depths.

Since the summer of 2005, the DOE-funded Extreme Ground Motion (ExGM) program has supported research at SCEC, both institutionally and individually. ExGM funding has been dramatically cut in the current year, and prospects for the future are uncertain. Available funds will be directed to ground-motion simulations in accord with the original ExGM prospectus and schedule. While the status of ExGM as a separately funded, Special Project is thus uncertain, the research imperatives of ExGM remain significant to several of the SCEC focus and disciplinary groups, including, Geology – especially fault zone geology; Faulting and Mechanics of Earthquakes, Ground-Motion Prediction, and Seismic Hazard and Risk Analysis. This project is also discussed above within SHRA.

### 8. Petascale Cyberfacility for Physics-Based Seismic Hazard Analysis (PetaSHA)

SCEC's special project titled "A Petascale Cyberfacility for Physics-based Seismic Hazard Analysis" (PetaSHA) aims to develop and apply physics-based predictive models to improve the practice of seismic hazard analysis. This project will utilize numerical modeling techniques and high performance computing to implement a computation-based approach to SHA. Three scientific initiative areas have been identified for this project to help to guide the scientific research. The PetaSHA initiative areas are: (1) development of techniques to support higher frequencies waveform simulations including deterministic and stochastic approaches; (2) development of dynamic rupture simulations that include additional complexity including nonplanar faults, a variety of friction-based behaviors, and higher inner /outer scale ratios (e.g. (fault plane mesh dimension) / (simulation volume dimension)); and (3) physics-based probabilistic seismic hazard analysis including probabilistic seismic hazard curves using 3D waveform modeling. All of these modeling efforts must be accompanied by verification and validation efforts. Development of new techniques that support the verification and validation of SCEC PetaSHA modeling efforts are encouraged.

The SCEC PetaSHA modeling efforts address several of the SCEC3 objectives. Development of new verification and validation techniques (B4) are common to each of the PetaSHA initiative areas. Research activities related to the improved understanding and modeling of rupture complexity (A8, B1) support the PetaSHA initiatives. In addition, research into the upper frequency bounds on deterministic ground motion predictions (B2, B3) are SCEC3 science objectives that are important work areas in the PetaSHA Project.

## IX. SCEC Communication, Education, and Outreach

SCEC maintains a Communication, Education, and Outreach (CEO) program with four long-term goals:

- Coordinate productive interactions among a diverse community of SCEC scientists and with partners in science, engineering, risk management, government, business, and education.
- Increase earthquake knowledge and science literacy at all educational levels, including students and the general public.
- Improve earthquake hazard and risk assessments
- Promote earthquake preparedness, mitigation, and planning for response and recovery.

Short-term objectives are outlined below. These objectives present opportunities for members of the SCEC community to become involved in CEO activities, which are for the most part coordinated by CEO staff. As project support is very limited, budgets for proposed projects should be on the order of $2,000 to $5,000.

Hence proposals that include additional sources of support (cost-sharing, funding from other organizations, etc.) are highly recommended. Smaller activities can be supported directly from the CEO budget and do NOT need a full proposal. Those interested in submitting a CEO proposal should first contact Mark Benthien, associate SCEC director for CEO, at 213-740-0323 or *benthien@usc.edu*. There may be other sources of funding that can be identified together.

***CEO Focus Area Objectives***

1. ***SCEC Community Development and Resources*** (activities and resources for SCEC scientists and students)

    SC1 Increase diversity of SCEC leadership, scientists, and students

    SC2 Facilitate communication within the SCEC Community

    SC3 Increase utilization of products from individual research projects

2. ***Education*** (programs and resources for students, educators, and learners of all ages)

    E1 Develop innovative earth-science education resources

    E2 Interest, involve and retain students in earthquake science

    E3 Offer effective professional development for K-12 educators

3. ***Public Outreach*** (activities and products for media reporters and writers, civic groups and the general public)

    P1 Provide useful general earthquake information

    P2 Develop information for the Spanish-speaking community

    P3 Facilitate effective media relations

    P4 Promote SCEC activities

4. ***Knowledge transfer*** (activities to engage other scientists and engineers, practicing engineers and geotechnical professionals, risk managers, government officials, utilities, and other users of technical information)

    I1 Communicate SCEC results to the broader scientific community

    I2 Develop useful products and activities for practicing professionals

    I3 Support improved hazard and risk assessment by local government and industry

    I4 Promote effective mitigation techniques and seismic policies

## Appendix: SCEC3 Long-Term Research Goals

This section outlines the SCEC science priorities for the five-year period from February 1, 2007, to January 31, 2012. Additional material on the science and management plans for the Center can be found in the SCEC proposal to the NSF and USGS (*http://www.scec.org/aboutscec/documents/*).

### Basic Research Problems

SCEC is, first and foremost, a basic research center. We therefore articulate our work plan in terms of four basic science problems: (1) earthquake source physics, (2) fault system dynamics, (3) earthquake forecasting and predictability, and (4) ground motion prediction. These topics organize the most pressing issues of basic research and, taken together, provide an effective structure for stating the SCEC3 goals and objectives. In each area, we outline the problem, the principle five-year goal, and some specific objectives. We then assess the research activities and the new capabilities needed to attain our objectives.

### 1. Earthquake Source Physics

***Problem Statement.*** Earthquakes obey the laws of physics, but we don't yet know how. In particular, we understand only poorly the highly nonlinear physics of earthquake nucleation, propagation, and arrest, because we lack knowledge about how energy and matter interact in the extreme conditions of fault failure. A complete description would require the evolution of stress, displacement, and material properties throughout the seismic cycle across all relevant scales, from microns and milliseconds to hundreds of kilometers and many years. A more focused aspect of this problem is the physical basis for connecting the behavior of large ruptures at spatial resolutions of hundreds of meters and fracture energies of megajoules per square meter with laboratory observations of friction at centimeter scales and fracture energies of kilojoules per square meter. Two further aspects are the problem of stress heterogeneity—the factors that create and maintain it over many earthquake cycles—and the related problem of defining the concept of strength in the context of stress and rheological heterogeneity.

***Goal and Objectives.*** The goal for SCEC3 will be to discover the physics of fault failure and dynamic rupture that will improve predictions of strong ground motions and the understanding of earthquake predictability. This goal is directly aligned with our mission to develop physics-based seismic hazard analysis. Specific objectives include:

A. Conduct laboratory experiments on frictional resistance relevant to high-speed coseismic slip on geometrically complex faults, including the effects of fluids and changes in normal stress, and incorporate the data into theoretical formulations of fault-zone rheology.

B. Develop a full 3D model of fault-zone structure that includes the depth dependence of shear localization and damage zones, hydrologic and poroelastic properties, and the geometric complexities at fault branches, step-overs, and other along-strike and down-dip variations.

C. Combine the laboratory, field-based, and theoretical results into fault constitutive models for the numerical simulation of earthquake rupture, test them against seismological data, and extend the simulation methods to include fault complexities such as bends, step-overs, fault branches, and small-scale roughness.

D. Develop statistical descriptions of stress and strength that account for slip heterogeneity during rupture, and investigate dynamic models that can maintain heterogeneity throughout many earthquake cycles.

### 2. Fault System Dynamics

***Problem Statement.*** In principle, the Southern California fault system can be modeled as a dynamic system with a state vector $\mathbf{S}$ and an evolution law $d\mathbf{S}/dt = \mathbf{F}(\mathbf{S})$. The state vector represents the stress, displacement, and rheology/property fields of the seismogenic layer as well as its boundary conditions. Its evolution equation describes the forward problem of fault dynamics. Many of the most difficult (and interesting) research issues concern two inference or *inverse problems*: (1) model building—from our knowledge of fault physics, what are the best representations of **S** and **F**?—and (2) data assimilation—how are the parameters of these representations constrained by the data $D$ on the system's present state $S_0$ as well as its history?

The SCEC approach is not to proceed by trying to write down general forms of **S** and its rate-of-change **F**. Rather, we use judicious approximations to separate the system evolution into a series of numerical simulations representing the interseismic, preseismic, coseismic, and postseismic behaviors. In particular, the natural time-scale separation between inertial and non-inertial dynamics usually allows us to decouple the long-term evolution of the state vector from its short-term, coseismic behavior. Therefore, in describing many interseismic and postseismic processes, we can treat the fault system quasi-statically, with discontinuous jumps in **S** at the times of earthquakes. On the other hand, the dynamics of earthquake rupture is clearly important to the basic physics of fault system evolution. In the modeling of stress heterogeneity, for example, the coupling of inertial and non-inertial dynamics must be addressed by integrating across this scale gap.

***Goal and Objectives.*** The principal SCEC3 goal for fault system dynamics is *to develop representations of the postseismic and interseismic evolution of stress, strain, and rheology that can predict fault system behaviors within the Southern California Natural Laboratory*. The SCEC3 objectives are six fold:

A. Use the community modeling tools and components developed in SCEC2 to build a 3D dynamic model that is faithful to the existing data on the Southern California fault system, and test the model by collecting new data and by predicting its future behavior.

B. Develop and apply models of coseismic fault slip and seismicity in fault systems to simulate the evolution of stress, deformation, fault slip, and earthquake interactions in Southern California.

C. Gather and synthesize geologic data on the temporal and spatial character and evolution of the Southern California fault system in terms of both seismogenic fault structure and behavior at geologic time scales.

D. Constrain the evolving architecture of the seismogenic zone and its boundary conditions by understanding the architecture and dynamics of the lithosphere involved in the plate boundary deformation.

E. Broaden the understanding of fault systems in general by comparing SCEC results with integrative studies of other fault systems around the world.

F. Apply the fault system models to the problems of earthquake forecasting and predictability.

## 3. Earthquake Forecasting and Predictability

***Problem Statement.*** The problems considered by SCEC3 in this important area of research will primarily concern the physical basis for earthquake predictability. Forecasting earthquakes in the long term at low probability rates and densities—the most difficult scientific problem in seismic hazard analysis—is closely related to the more controversial problem of high-likelihood predictions on short (hours to weeks) and intermediate (months to years) time scales. Both require a probabilistic characterization in terms of space, time, and magnitude; both depend on the state of the fault system (conditional on its history) at the time of the forecast/prediction; and, to put them on a proper science footing, both need to be based in earthquake physics.

***Goal and Objectives.*** The SCEC3 goal is *to improve earthquake forecasts by understanding the physical basis for earthquake predictability*. Specific objectives are to:

A. Conduct paleoseismic research on the southern San Andreas and other major faults with emphasis on reconstructing the slip distributions of prehistoric earthquakes, and explore the implications of these data for behavior of the earthquake cycle and time-dependent earthquake forecasting.

B. Investigate stress-mediated fault interactions and earthquake triggering and incorporate the findings into time-dependent forecasts for Southern California.

C. Establish a controlled environment for the rigorous registration and evaluation of earthquake predictability experiments that includes intercomparisons to evaluate prediction skill.

D. Conduct prediction experiments to gain a physical understanding of earthquake predictability on time scales relevant to seismic hazards.

## 4. Ground Motion Prediction

***Problem Statement.*** Given the gross parameters of an earthquake source, such as its magnitude, location, mechanism, rupture direction, and finite extent along a fault, we seek to predict the ground motions at all regional sites and for all frequencies of interest. The use of 3D velocity models in low-frequency (< 0.5 Hz) ground motion prediction was pioneered in SCEC1 (§II.A), and this type of simulation, based on direct numerical solution of the wave equation, has been taken to new levels in SCEC2 (§II.B.6). The unsolved basic research problems fall into four classes: (a) the ground motion inverse problem at frequencies up to 1 Hz; (b) the stochastic extension of ground motion simulation to high frequencies (1-10 Hz); (c) simulation of ground motions using realistic sources; and (d) nonlinear wave effects, including nonlinear site response. In addition, there remain scientific and computational challenges in the practical prediction of ground motions near the source and within complex structures such as sedimentary basins, as well as in the characterization of the prediction uncertainties.

***Goal and Objectives.*** The principal SCEC3 goal is *to predict the ground motions using realistic earthquake simulations at frequencies up to 10 Hz for all sites in Southern California*. The SCEC3 objectives are:

A. Combine high-frequency stochastic methods and low-frequency deterministic methods with realistic rupture models to attain a broadband (0-10 Hz) simulation capability, and verify this capability by testing it against ground motions recorded at a variety of sites for a variety of earthquake types.

B. Use observed ground motions to enhance the Unified Structural Representation (USR) by refining its 3D wavespeed structure and the parameters that account for the attenuation and scattering of broadband seismic energy.

C. Apply the ground-motion simulations to improve SHA attenuation models, to create realistic scenarios for potentially damaging earthquakes in Southern California, and to explain the geologic indicators of maximum shaking intensity and orientation.

D. Investigate the geotechnical aspects of how built structures respond to strong ground motions, including nonlinear coupling effects, and achieve an end-to-end simulation capability for seismic risk analysis.