2004 PROGRAM ANNOUNCEMENT
FOR THE SOUTHERN CALIFORNIA EARTHQUAKE CENTER

I. INTRODUCTION

On February 1, 2002, the Southern California Earthquake Center (SCEC) changed from an entity within the NSF/STC program to a free-standing center, funded by NSF/EAR and the U. S. Geological Survey. This document solicits proposals from individuals and groups to participate in the third year of the program.

II. GUIDELINES FOR PROPOSAL SUBMISSION

A. Due Date: November 17, 2003, 5:00 pm PST. Late proposals will not be accepted.

B. Delivery Instructions. Proposals and annual reports should be submitted as separate PDF documents via the SCEC Proposal web site at http://www.scec.org/proposals. Submission procedures will be found at this web site.

C. Formatting Instructions.

- ***Cover Page:*** Should begin with the words "2004 SCEC Proposal," the project title, Principal Investigator, institution, proposal category (from types listed in Section IV), and the disciplinary committee(s) and focus group(s) that should consider your proposal. Indicate if the proposal should also be identified with one or more of the SCEC special projects (SCIGN, Borderland, and IT) or advanced Implementation Interface projects (see Section VII.B for examples). 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, 2004.

- ***Technical Description:*** Describe in **five pages or fewer (including figures)** the technical details of the project and how it relates to the short-term objectives outlined in the SCEC Science Plan (Section VI.B).

- ***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.

- ***2003 Annual Report:*** Scientists funded by SCEC in 2003 must submit a report of their progress to the 2004 proposals. 2004 proposals lacking 2003 reports (which may cover 2002 to mid-year 2003 results) will neither be reviewed nor will they be considered for 2004 funding. Reports should be up to five pages of text and figures.

D. Investigator Responsibilities. Investigators 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 (e.g., Fault Activity Database—FAD), 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/research/scecnumber/index.html. 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

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. 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 new information about earthquakes in Southern California;
- Integrate this information into a comprehensive and predictive understanding of earthquake phenomena; and
- Communicate this understanding to end-users and the general public in order to increase earthquake awareness, reduce economic losses, and save lives.

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 Section VI.A.

B. Disciplinary Activities. The Center sustains disciplinary science through standing committees in *seismology*, *geodesy*, *geology*, and *fault and rock mechanics*. 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 VI.A.

C. Interdisciplinary Focus Areas. Interdisciplinary research is organized into five science focus areas: 1) *unified structural representation*, 2) *fault systems*, 3) *earthquake source physics*, 4) *ground motion*, *and* 5) *seismic hazard analysis*. In addition, interdisciplinary research in risk assessment and mitigation will be the subject for collaborative activities between SCEC scientists and partners from other communities including earthquake engineering, risk analysis, and emergency management. High-priority activities are listed for each of these interdisciplinary focus areas in Section VI.B.

D. Special Projects. SCEC encourages and supports several special projects including the Southern California Integrated GPS network (SCIGN), the Southern California Continental Borderland initiative, and the development of an advanced IT infrastructure for system-level earthquake science in Southern California. High-priority activities are listed for each of these interdisciplinary focus areas in Section VI.C.

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; 4) promote earthquake preparedness, mitigation, and planning for response and recovery. Opportunities for participating in the CEO program are described in Section VII. 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 VI, and may include a brief description (<200 words) as to how the proposed research and/or its results might be used in an educational or outreach mode (see section VII).

C. Workshops. SCEC participants who wish to host a workshop between February 2004, and February 2005, should submit a proposal for the workshop in response to this RFP. Workshops in the following topics are particularly relevant:

- Organizing collaborative research efforts for the five-year SCEC program (2002-2007). 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 VII. Investigators who are interested in participating in this program should contact Mark Benthien (213-740-0323; benthien@usc.edu) before submitting a proposal.

V. EVALUATION PROCESS AND CRITERIA

- 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 A).
    - 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.

- 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 VII.B, Advanced Implementation Interface)
    - 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
            - Presentations to schools near research locations
            - Participation in data collection

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

- 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.

- 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.

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

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

- The review process should be completed and applicants notified by mid-February, 2004.

VI. Coordination of Research between SCEC and USGS-ERHP

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.

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

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 government, 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.

The EHRP web page, http://erp-web.er.usgs.gov/, 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 early 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.

USGS internal earthquake research is summarized by topic at http://earthquake.usgs.gov/scitech/research/ and by project at http://earthquake.usgs.gov/research/program/. Projects of particular relevance to SCEC are described under the following titles:

- Southern California Earthquake Project
- FOCUS on Quaternary Stratigraphy in the Los Angeles Region
- National Seismic Hazard Maps
- Earthquake Probabilities And Occurrence
- The Physics of Earthquakes
- Earthquake Effects
- Deformation
- U.S. National Strong Motion Program
- Earthquake Information
- Seismograph Networks

VII. Research Objectives

The research objectives outlined below are priorities for immediate research. 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.

A. Disciplinary Activities

The Center will sustain disciplinary science through standing committees in *seismology*, *geodesy*, *geology*, and *fault and rock mechanics*. 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

Data Gathering: Maintain and improve the ability of SCEC scientists to collect seismograms to further the goals of SCEC. Efforts may include: 1) Maintaining and adding to the network of borehole seismometers in order to improve resolution of earthquake source physics and the influence of the near-surface on ground motions, and 2) maintaining and upgrading a pool of portable instruments in support of targeted deployments or aftershock response.

Other activities might include seed money for design of future experiments such as dense array measurements of basin structure and large earthquake properties, OBS deployments, and deep basement borehole studies. Workshops to explore SCEC's interface with EarthScope are encouraged.

Data Products: Improve the ability of users to retrieve seismograms and other seismic data and enhance the usefulness of data products, such as catalogs of earthquake parameters, arrival time and polarity information, and signal-to-noise measures. An important SCEC resource is the Southern California Earthquake Data Center (SCEDC), which continues to be an integral part of the Center. The continued operation of the SCEDC is essential to deciphering Southern California seismicity and fault structure.

Enhancements to the SCEDC are encouraged that will extend its capabilities beyond routine network operations and waveform archiving, and assist researchers in using more of the data. Desirable improvements include support hardware and software enhancements, better integration with data centers in other regions, and expansion of catalogs, including the offshore region. Specific goals include: 1) developing the ability to preview seismograms and construct record sections before downloading, 2) implementing software that permits accessing both northern and southern California data with a single data request, 3) improving feedback mechanisms for users to report problems and assist in network quality control, 4) incorporating additional catalogues of locations and moment tensors as they become available, and 5) keeping the database up to date with current data.

2. Tectonic Geodesy

Data gathering: Provide support to assist in the operation of, and data distribution from, the Southern California Integrated GPS Network (SCIGN); support to be provided in response to a

single proposal (addressing all aspects of SCIGN), prepared by the SCIGN Executive Committee and approved by the SCIGN Coordinating Board.
Provide support to assist in the operation of, and data distribution from, the WInSAR Archive.

Support the collection of geodetic data (other than continuous GPS) that will improve knowledge of crustal motion in areas of special interest; the proposal should explain how this improvement is likely to occur. Examples of such areas are the San Gabriel Mountains, the Ventura and Los Angeles Basins, northern Baja California, the Garlock fault, and the eastern California Shear Zone north of the Landers/Hector-Mine area. Provide support to assist in the collection of other data relevant to time-varying deformation. Support acquisition and distribution of high-resolution topographic data in areas where it will be useful to other SCEC activities.

Data products: Prepare and release Version 4.0 of the Crustal Motion Map, which should incorporate additional GPS data and other data (possibly along a larger portion of the transform boundary) and provide estimates of vertical motions, along with better descriptions of the postseismic and coseismic motions from previous earthquakes. Support small-scale projects which use InSAR data, combined with other measurements, to improve our knowledge of tectonic deformation (which may include delineating areas of nontectonic motion). Investigate the usefulness of combining GPS data with data from inertial seismometers for improving measurements of ground motion.

3. Earthquake Geology

Data gathering: Plan, coordinate, and provide infrastructure for onshore and offshore geologic fieldwork, including chronologic support and shared equipment; formulate field tests of paleoseismic methodology; collect new information on fault slip rates, including rates over 10^4-10^6 year timescales to compare to short term and GPS rates, paleoseismic chronologies that span multiple recurrence cycles, slip in past earthquakes, and other geologic measurements of active tectonics; develop, build and contribute new and existing data sets to the Fault Information System (FIS), including probability density functions of earthquake event ages; complete initial population of the vertical motion database and incorporate as a layer into the FIS; assess models used to segment fault zones and the role of structural features that limit fault rupture. Foster subsurface analysis of fault systems, including blind thrusts and the role of off-fault deformation; begin incorporation of horizon structure maps, including well-dated Quaternary stratigraphy and magnetic reversal stratigraphy, all in a geo-referenced format, for incorporation into the FIS; develop techniques to test and validate kinematic and structural models of fold and fault growth.

Develop methodology to test and improve resolution of event chronologies, including methods for resolving event correlations; develop statistical tests for models of earthquake recurrence, clustering and other behavior based on geologic data; compile existing information and conduct detailed studies of fault zone materials and structures in and adjacent to active and exhumed faults in order to understand deformation processes and conditions, and their implications for the nucleation and propagation of earthquake ruptures.

Organize workshops and other activities to develop proposals for alternative major sources of external funding of collection of earthquake geology data.

Data products: Integrate field and laboratory efforts to date geologic samples and events, including standardized procedures for field documentation, sample treatment, dating methodologies, and data archiving and distribution (FAD); produce long-term rupture histories for selected fault systems in Southern California, with specific interest in the Los Angeles, Mojave, and southern San Andreas systems; construct a community vertical motions map (10^5 yr timescale).

4. Fault and Rock Mechanics

Data gathering: Areas of FARM research include fault modeling, laboratory studies, and field studies of exhumed faults. While all areas of FARM research in support of the interdisciplinary working groups will be considered, greatest emphasis will be given to research that can increase our understanding of fault behavior during dynamic earthquake slip and thereby provide useful input for models of dynamic rupture propagation. In particular, emphasis will be given to: 1) pilot studies to determine the feasibility of using a variety of new experimental techniques to measure sliding resistance at seismic slip rates, with the aim of ascertaining whether these techniques, or perhaps a new facility using these or other techniques, might allow the collection of these important data, 2) exploring the capabilities of a variety of existing and analytical techniques, and laboratories, to detect and characterize small amounts of rheologically important materials on slip surfaces in experimental and natural fault zones, and 3) modeling activities to predict fault behavior during dynamic slip with extreme weakening. Also of importance, but of lower priority, is to conduct coordinated field, laboratory and theoretical studies to determine the time evolution of physical parameters during the inter-seismic period that might control the onset and characteristics of earthquake faulting. Such parameters might include those controlling fault/fluid interactions and frictional properties.

Data products: Assess information and products from rock-mechanics experiments and fieldwork that will be most useful in SCEC studies of earthquake source physics and fault-system dynamics; begin to outline an IT framework for an open database of experimental, model, and field results.

Workshops fostering collaborative interactions for research on fault and earthquake processes are encouraged.

B. Interdisciplinary Focus Areas

Interdisciplinary research will be organized into five science focus areas**: 1) structural representation, 2) fault systems, 3) earthquake source physics, 4) ground motion, and 5) seismic hazard analysis.** In addition, interdisciplinary research in risk assessment and mitigation will be the subject for collaborative activities between SCEC scientists and partners from other communities – earthquake engineering, risk analysis, and emergency management. This partnership will be managed through: **6) an implementation interface**, designed to foster two-way communication and knowledge transfer between the different communities. SCEC will also sponsor a partnership in**: 7) information technology**, with the goal of developing an advanced IT infrastructure for system-level earthquake science in Southern California. High-priority objectives are listed for each of the five interdisciplinary focus areas below. Collaboration within and across focus areas is strongly encouraged.

1. Structural Representation

- ***Community velocity model (CVM):*** Refine and test the CVM by improving the definition of model objects (e.g., incorporating fault representations from the Community Fault Model), evaluating the model with data (e.g., waveforms, gravity), and comparing the model to alternative structural representations. Add attenuation to the model. Quantify the uncertainties in the model. Provide interfaces with focus and disciplinary groups to permit ready use of the model. Develop specifications for new velocity model schemes that will facilitate alternative parameterizations.

- ***Community fault model (CFM):*** Improve and evaluate the CFM, placing emphasis on: a) defining the geometry of major faults that are incompletely, or inaccurately represented in the current model; b) producing and evaluating alternative fault representations, and c) delivering the model and database to users.

- ***Unified structural representation (USR):*** Develop specifications for a unified, object-oriented representation of active faults and 3D earth structure for use in fault-system analysis, earthquake source physics, and ground-motion prediction. Refine the Community Block Model (CBM). Begin integration of CVM, CBM, and CFM into the USR.

2. Fault Systems

- ***Fault-system behavior:*** Investigate the system-level architecture and behavior of fault networks to better understand the cooperative interactions that take place over a wide range of scales, assessing the ways in which the system-level behavior of faults controls seismic activity and regional deformation; produce fault-slip and surface-strain maps from the CMM; compare short-term geodetic rates with long-term geologic rates and explain the differences; quantify the space-time behavior of the Southern California fault system, both on-shore and off-shore, using tectonic geomorphology, paleoseismology, historical records of seismicity, and instrumental catalogs; foster collaborations to obtain outside funding to investigate paleoseismic earthquake history to illuminate disagreements between geodetic and geologic inferences of fault slip rates and discriminate among competing stress evolution and seismicity simulation models; determine how geologic deformation is partitioned between slip on faults and distributed off-fault deformation and how geodetic strain is partitioned between long-term and short-term elastic strain and on-fault slip or permanent distributed strain.

- ***Deformation models:*** Develop, validate, and facilitate use of modular 3D quasi-static codes for simulating crustal motions utilizing realistic, highly resolved geometries (e.g., USR fault geometry and elastic structure) and rheological properties (e.g., Burgers body viscoelasticity, rate-state friction, poroelasticity, damage rheology); develop representations of fault system behavior on scales smaller than can be resolved on computationally feasible meshes; develop a closed volume representation of southern California (Community Block Model—CBM) that unifies the geometric representations of CFM and the CVM and that serves as a basis for efficient meshing and remeshing of models; assess mechanical compatibility of CFM and how slip is transferred between recognized fault segments, beginning with simple geometries and moving to the actual geometry; evaluate mesh generation strategies and generate realistic finite element meshes of Southern California consistent with CFM and CVM/USR structure; develop models of time-dependent stress transfer and deformation of Southern California over multiple earthquake cycles addressing geologic slip rates, geodetic motions (including CMM 4.0), and earthquake histories; use these models to infer fault slip, 3D rheologic structure, and fault interactions through the transfer of stresses; test model predictions of stress evolution by comparisons with observations of state of stress, high-resolution earthquake location and mechanism studies, and constraints from earthquake source physics models; develop tectonic models that explain the rates of fault slip inferred for the southern California fault system; develop systems which can be used to estimate earthquake parameters to rapidly provide information, such as expected postseismic deformation, useful in planning post-earthquake geodetic deployments.

- ***Seismicity evolution models:*** Develop, validate, and facilitate use of codes for ensemble models simulating earthquake catalogs using CFM fault structure, USR and CBM, as well as stochastic representations of faults not included in CFM; incorporate constraints (including data assimilation) from geologic slip rates, geodetic data, realistic boundary conditions, and fault rupture parameterizations, including rate-state friction and normal stress variations; assess the processes that control the space-time-magnitude distribution of regional seismicity; quantify sources of complexity, including geometrical structure, stress transfer, fault zone heterogeneity, and slip dynamics; assess the utility of these models in forecasting Southern California earthquakes as part of the RELM effort; search for statistically significant signals in the space-time-magnitude distribution of seismicity and understand their physical origin.

- ***Quantify the temporal evolution of fault zone properties on postseismic, interseismic, and pre-rupture time scales to better understand stress transfer and to constrain conditions at the onset of failure (with Earthquake Source Physics):*** Develop numerical models of the interseismic period and couple them to quasi-static full-cycle fault models to better constrain stress transfer and conditions and processes at the start of dynamic rupture. Include forcing by realistic coseismic displacements and dynamic stresses.

3. Earthquake Source Physics

- ***Numerical simulations of the earthquake source:*** Conduct numerical simulations of dynamic rupture nucleation, propagation, and termination that include known or realistic complexity in fault geometry, material properties, and stress state, with an emphasis on models that can test constitutive relations. Compare results with source and fault zone observations. Use this information to test hypotheses or develop new testable hypotheses about earthquake source physics. Explore what aspects of the source generate high-frequency waves. Use numerical simulations results to guide the use of fault segmentation in seismic hazards analysis (*joint with SHA Focus Group*). Participate in the code validation exercises for 3D spontaneous rupture simulations (Pathway 3 of the SCEC ITR) by performing benchmark tests and comparing results with the rest of the Pathway 3 community. Bridge the interface between Earthquake Source Physics and Fault Systems by conducting multi-earthquake-cycle physics-based dynamic simulations (*joint with Fault Systems Focus Group*).

- ***Reference earthquakes:*** Establish a reference southern California earthquake, such as Landers, for which geodetic, geologic, and seismological data (and metadata) as well as models derived from them, are gathered in a common database in order to facilitate comparison of different models and analysis of multiple datasets. The reference earthquake database will be used for testing/validation of earthquake physics concepts and modeling techniques and as a template for additional reference earthquakes.

- ***In-situ studies of fault-zones (exhumed faults and cores from depth):*** Examine and document features of fault zones in Southern California, including the San Andreas fault system, that reveal the mechanical, chemical, thermal, and kinematic processes that occur during dynamic rupture. Include measurements and inferences of on-fault and near-fault stress, slip-zone thickness, fine-scale fault-zone geometry, adjacent damage, and fluid content at seismogenic depths. *(Joint with Geology Disciplinary Group).*

- ***Earthquake scaling:*** Determine to what extent earthquake behavior depends on earthquake size. Determine if there are breaks in scaling behavior of quantities, such as stress drop or radiated seismic energy. If so, determine how they can constrain models of the earthquake source.

- ***Laboratory studies of the earthquake source:*** Explore lab experiments on faults in rock or analog materials, to determine shear resistance at high slip speeds (on the order of 1 m/s) and stress conditions at seismogenic depths (or appropriately scaled conditions for analog materials). Measure hydrologic properties of likely fault zone materials at high rates of deformation and fluid flow. Conduct theoretical studies of expected behavior for possible high-speed weakening mechanisms. Determine how changes in normal stress might affect shear resistance during dynamic rupture. Compare results with source observations. Use this information to test proposed constitutive relations or develop new testable constitutive relations. (*Joint with FARM)*.

- ***Earthquake interaction as an approach to explain earthquake physics:*** Use observations of earthquake triggering or suppression to test models of earthquake interaction and constrain the physics of earthquake rupture nucleation, propagation, and arrest.

4. Ground Motions

- ***Deterministic wavefield modeling:*** Analyze the computed ground motion from the scenario earthquakes* for deterministic and stochastic effects. Determine how the complexity in the ground motion can be related to the complexity in the source. Determine where geometrical and geological structures manifest their presence in the ground motion. Compare wavefields for moderate-sized events (M 3.5 to 5.0 earthquakes) with synthetics using both the CVM and the Harvard model. Determine at what frequencies such events can be successfully modeled deterministically with particular attention to the SCEC borehole data when possible. Develop and quantify a goodness-of-fit criterion for time series. Use ground motion from scenario earthquakes to quantify differences in ground motion.

- ***CVM improvement:*** Use data from well-recorded earthquakes to assess, as a function of frequency, wavefield simulations based on the CVM. Improve the S-wave velocity structure in the CVM and the Harvard model. Develop models for seismic attenuation (1/Q) based on data recorded by CISN and borehole instruments in Southern California. Attenuation models are to complement the SCEC CVM and be used in comparisons between data and synthetics for well-recorded earthquakes. Develop methods for incorporating nonlinear site response for large amplitude ground motion events in Southern California. Ideas that improve our understanding of linear site response should make a significant improvement over the SCEC Phase 3 work or lead to a new understanding of how site response varies spatially. Develop methods for improving the accuracy and frequency range of deterministic 3D wavefield modeling, including the assimilation of seismographic data into the CVM. Compare 3D results with those from other structural representations including 1D and 2D representations that will allow propagation of higher frequencies.

- ***Stochastic wavefield models:*** *This is a high-priority research item in 2004*. Develop stochastic models of high-frequency ground motion that can be combined with models of low-frequency ground motion from scenario earthquakes* to predict strong ground motion. Validate models by comparisons and testing with observed data. Validate hybrid models—models that combine deterministic low-frequency with stochastic high-frequency ground motion—by comparing different metrics of the radiation versus data. For example, metrics that might be useful can be found in *Geotechnical Earthquake Engineering*, Chapter 3, Section 3, by Steven L. Kramer. Estimate the range of different ground motion parameters that might be expected from simulated broadband scenario earthquakes. Produce broadband ground motions for earthquake scenarios* simulated in 2003. Develop methods that assess broadband ground motion that include nonlinear site response.

*A description of scenario earthquakes will be posted on the SCEC website; data from the scenario earthquakes will be available to SCEC researchers.

5. Seismic Hazard Analysis

- ***OpenSHA*:** Contribute to the developing Community Modeling Environment for Seismic Hazard Analysis (known as OpenSHA; www.OpenSHA.org). This is an open-source, object oriented, and web-enabled framework that will allow various, arbitrarily complex (e.g., physics based) earthquake-rupture forecasts, ground-motion models, and engineering response measures to plug in for SHA. Part of this effort is to use information technology to enable the various models and databases they depend upon to be geographically distributed and run-time accessible. Contributions may include: 1) implementing any of the various components (in Java or other language), 2) testing any of the various components/applications, and 3) extending the existing framework to enable other capabilities, such as vector-valued hazard analysis, to interface with existing risk/loss estimation tools, or to web-enable the testing of the various RELM forecast models.

• ***Regional Earthquake Likelihood Models (RELM):*** Via the RELM working group, develop various, viable earthquake-forecast models for southern California (the more physics-based approaches should be developed in coordination with the Fault Systems focus group). Continue the development of shared data resources needed by the RELM working group, especially in terms of making them on-line and machine readable. These should be coordinated with other focus/disciplinary groups as appropriate (e.g., the needed quantification of alternative, internally-consistent fault-system representations should be coordinated with the CFM effort). Establish quantitative tests of the various forecast models using observed seismicity, precarious-rock constraints, historically observed intensity levels, or other viable approaches.

• ***Improved Intensity-Measure Relationships:*** Work with the Ground Motion focus group and/or the Implementation Interface to develop improved models for predicting intensity measures (empirical attenuation relationships, theoretical models, or hybrid approaches). Proposals to implement new types of Intensity Measures (new functionals of ground motion, or vectors of functionals) that predict engineering damage measures better than traditional peak acceleration or spectral response are encouraged.

• ***Contribute to SCEC's System-Level Earthquake Rupture Forecast Model:*** Although several of the RELM models are appropriately exploring the use of different types of information separately (e.g., a model based only on geology or only on geodesy), there is the need for a system-level model that attempts to reach consilience among all significant processes and constraints. Such a model is currently under development (see http://www.RELM.org/models/scec_erf). The structure of this model is necessarily object oriented, enabling different groups to develop the different modular components separately, as well as enabling alternative components (e.g., with more or less physics) to be swapped in or added later. Proposals will be considered for participation in the following tasks: 1) quantify alternative, viable CFMs for at least the greater LA region; 2) quantify slip rates for the CFM(s) using geology and/or other constraints; 3) quantify the stress-loading rates for faults in the CFM(s) using virtual dislocation, deep slip, community block, finite element, or other types of models; 4) develop fault-rupture models for faults in southern California (e.g., based on a synoptic view of paleoseismic data; with or without fault segmentation); 5) help constrain fault-to-fault rupture probabilities using dynamic-rupture modeling (or by compiling previous results thereof) 6) develop stress-change-dependent probability models; 7) develop stress-change monitors or calculators that provide the average stress change on an arbitrary surface caused by an arbitrary rupture (e.g., using Coulomb or viscoelastic models, or by inversion of observed seismicity using rate and state), 8) develop methods of adding foreshock/aftershock statistics to the model.

C. <u>Special Projects</u>

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

1. **SCIGN (www.scign.org)**

   Southern California now benefits from a state-of-the-art geodetic array for monitoring earthquake-related crustal deformation, and we encourage use of these data in support of the SCEC science goals and mission. The Southern California Integrated GPS Network (SCIGN), an array of 250 continuously operating GPS stations and one long-baseline laser strainmeter, tracks regional strain changes with unprecedented precision. Scientists of organizations participating in SCEC designed and manage SCIGN; SCEC also played a vital coordinating role in making SCIGN possible. The array is now operational and is already providing horizontal station velocities good to within 1 mm/yr for most stations. This new network provides data with which to improve seismic hazard assessments, through the innovation of new methods as part of the SCEC seismic hazard analysis efforts. SCIGN will also enable us to quickly measure the larger displacements that occur during and immediately after earthquakes, and it is important that these static deformation data are integrated with other intensity measures for use by emergency responders and the engineering community, through SCEC's Implementation Interface efforts. SCEC encourages proposals that make innovative use of the openly available data from this unique array to further any of the short or long-term scientific goals of SCEC, and in any of the interface areas that will potentially foster greater use of SCIGN data throughout an even wider range of applications.

2. **Continental Borderland (www.scec.org/borderland)**

   SCEC recognizes the importance of the offshore Southern California Continental Borderland in terms of understanding the tectonic evolution, active fault systems, and seismic hazard of Southern California. SCEC encourages projects that focus on the offshore region's: 1) plate-boundary tectonics, including the currently active Pacific-North American plate motions, and its lithospheric seismic and geologic structure; 2) fault systems, including the distribution and subsurface geometry of active faults, the Quaternary rates of fault slip, and the interactions between intersecting fault systems in three dimensions with time (for example, resolving how high-angle and low-angle faults interact to accommodate long-term oblique finite strain); and 3) offshore earthquakes, including their parameters and the hazard potential of offshore geologic structures in general.

   To address these issues, new methods, new datasets, and in some cases new technology may need to be developed and/or acquired. For example, detailed mapping of the active offshore faults will require complete coverage of the Borderland with high-resolution multibeam bathymetry or other high-resolution seafloor imaging systems. Development of high-resolution techniques for conducting paleoseismology in a submarine environment will require innovative multidisciplinary techniques for imaging, sampling, and dating. Long-term monitoring of earthquake activity and geodetic strain in the Borderland will require the establishment of seafloor observatories. Such efforts may be best developed in collaboration with other disciplines (climate, oceanography, marine habitat studies, etc.), programs (EarthScope) and agencies (NOAA, NSF, ONR, etc.). SCEC wishes to encourage and endorse cooperative and collaborative projects that promote these objectives.

3. **Information Technology (www.scec.org/cme)**

   SCEC needs to implement the tools of information technology (IT) to carry out its research agenda. A major collaboration involving SCEC scientists and IT researchers was recently funded by the NSF Information Technology Research Program to develop an advanced information infrastructure for earthquake science in Southern California (the SCEC Community Modeling Environment). The Center encourages participation by SCEC scientists in its IT activities, either directly or as part of ongoing research projects. These include: 1) defining the data structures needed to exchange information and computational results in SCEC research, including implementing these data structures via XML schema for selected computational pathways in seismic hazard analysis and ground-motion simulation; 2) developing, verifying, benchmarking, documenting, and maintaining SCEC community models; 3) developing tools for visualizing earthquake information that improve the community's capabilities in research and education; and 4) organizing collections for, and contributing IT capabilities to, the *Electronic Encyclopedia of Earthquakes* (E^3).

VIII. SCEC COMMUNICATION, EDUCATION, AND OUTREACH PLAN

SCEC is a community of over 500 scientists, students, and staff from 44 institutions across the United States, in partnership with more than 50 other science, engineering, education, and government organizations worldwide. To facilitate applications of the knowledge and scientific products developed by this community, 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. Many of these objectives are opportunities for members of the SCEC community to become involved in CEO activities. These objectives set the programmatic milestones for the Center's internal assessments, guide the development of research results needed for effective education and outreach, and identify priorities for information technology and other resources.

Management Objectives

M1. Develop CEO five-year strategic plan
M2. Establish additional collaborations with partner organizations and pursue funding opportunities
M3. Represent the SCEC Community in partner organizations, science, engineering and education conferences, etc.

CEO Focus Area Objectives

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

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

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

Implementation Interface (activities with engineers and other scientists, practicing professionals, risk managers, and government officials.

- I1 Engage in collaborations with earthquake engineering researchers and practitioners
- 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

A. Potential CEO-Supported Projects for 2004

Projects listed below are new opportunities for involvement within the CEO program. To support as many of these activities as possible, budgets for proposed projects should be on the order of $5,000 to $10,000. Therefore proposals that include additional sources of support (cost-sharing, funding from other organizations, etc.) are recommended. Those interested in submitting a CEO proposal should first contact Mark Benthien, director for CEO, at 213-740-0323 or benthien@usc.edu.

Application and implementation of SCEC research is especially important during the next year, as SCEC coordinates plans for activities related to the ten-year anniversary of the Northridge earthquake (January 17, 2004). Products and activities, developed around a consistent theme, will be promoted throughout 2004 at earthquake-related annual conferences, seminars, and workshops. A public awareness campaign at multiple levels will include earthquake education, mitigation advocacy, and involvement of policy makers. These activities will be opportunities for communicating outcomes of projects within all SCEC focus groups, disciplinary committees, special projects, and CEO focus areas.

1. Education Focus Area

College Course Development. CEO seeks proposals to participate in the development of resources for undergraduate general-education earthquake courses. Materials will include online PowerPoint files for lectures, portable demonstrations, and interactive online exercises for use in the classroom for by students at home. The online materials will be freely available to instructors at any school. The project may eventually lead to the development of a consensus-based course that could allow interaction between students and faculty at separate institutions.

SCEC Student Network. This network will involve students at SCEC institutions (and elsewhere) in SCEC activities (research, seminars, workshops, annual meeting), provide educational and career resources, and encourage continuation to graduate school. The network will eventually be expanded to include high schools students through mentoring by SCEC undergraduate and graduate students. CEO seeks proposals for creation of this network, including developing a database of potential student members, establishing communication tools (e-mail lists, web pages, etc.), and coordinating participation in SCEC activities.

Education Products and Activities Assessment Planning. In order to understand and improve the effectiveness of SCEC's educational activities, CEO is developing a formal evaluation plan. Partners experienced in evaluation of education products and activities are invited to help CEO staff in this process. This first phase will be to develop evaluation methodologies for SCEC's activities, based on decisions of what should be evaluated and why the evaluation is needed.

Proposals that combine education assessment and public outreach assessment planning will be considered.

2. Public Outreach Focus Area

Spanish-Language Products and Activities Development. To be responsible to a large portion of the southern California population, CEO plans to develop products and activities in Spanish. These will include the update of "*Roots*" (see above) as well as portions of the SCEC web pages, fact sheets, media interactions, etc. Proposals are requested for participation in this effort; contact Mark Benthien to discuss details.

Public Outreach Assessment Planning. In order to understand and improve the effectiveness of SCEC's public outreach activities, CEO is developing a formal evaluation plan. Partners experienced in evaluation of public outreach products and activities are invited to help CEO staff in this process. This first phase will be to develop evaluation methodologies for SCEC's activities, based on decisions of what should be evaluated and why the evaluation is needed. Proposals that combine education assessment and public outreach assessment planning will be considered.

3. Implementation Interface Focus Area

a. General

Implementation Interface Management. CEO provides coordination for developing research partnerships between SCEC scientists and partners that are involved in earthquake engineering or other earthquake-related technical disciplines. Proposals are requested from investigators with multi-disciplinary expertise for management of this coordination.

Southern California HAZUS User Group. CEO is coordinating the development and activities of the Southern California HAZUS Users Group (SoCalHUG) with the Federal Emergency Management Agency (FEMA) and the California Office of Emergency Services (OES). HAZUS is FEMA's earthquake loss estimation software program. SCEC is also encouraging the improvement of USGS ShakeMap (to include scenarios based on SCEC Research) for use in HAZUS scenarios. Proposals are requested for assistance with coordinating user group activities, such as: coordinating meetings, trainings, and presentations; working with local governments getting started with HAZUS; and working with the HAZUS Resource Committee to develop a system for sharing building inventory, demographic, and geological data.

Implementation assessment. In order to understand and improve the effectiveness of SCEC's implementation interface activities, CEO is developing a formal evaluation plan. Partners experienced in evaluation of technical products and activities are invited to help CEO staff in this process. This first phase will be to develop evaluation methodologies for SCEC's activities, based on decisions of what should be evaluated and why the evaluation is needed.

b. Implementation Interface Research Projects

The purpose of the Implementation Interface is to implement knowledge about earthquake hazards developed by SCEC into practice. Essential to this objective is fostering collaboration between SCEC scientists and partners that are involved in research or practice in earthquake engineering, or other earthquake-related technical disciplines. Individual SCEC investigators or groups of SCEC investigators are encouraged to identify collaborative projects with individuals or groups of investigators from other organizations. SCEC investigators should request funding within SCEC Focus Groups, and describe how the project will relate to projects with partners, such as those listed in the tables below. Engineers and other potential partners should seek funding from their own organizations. As a guide to this process, Tables 1 and 2 list current ongoing projects and potential future project topics that could involve collaboration between SCEC and earthquake engineering organizations.

As a guide to this process, Table 1 lists potential future project topics that could involve collaboration between SCEC and earthquake engineering organizations. Table 1 also identifies potential co-sponsors of collaborative implementation-oriented work. The identification of these potential collaborative projects and potential co-sponsors does not imply a commitment on the part of these organizations to co-fund projects. These organizations have their own internal processes for reviewing and approving projects, whose schedules are not necessarily synchronous with the SCEC schedule. Accordingly, Table 1 should be viewed as a preliminary identification of potential mutual interests that could be pursued with additional discussion, and does not preclude other ideas for collaboration with these or other earthquake-related research organizations.

Table 1. Potential Research Partnership Projects

THEME	PROJECT	POTENTIAL PARTNERS
Ground Motion Time Histories	Provide spatial wave-field and distributed input ground motions for bridges	PEER
	Provide ground motion time histories for use in earthquake engineering testing facilities and simulation software	NEES
	Validation of simulated ground motions for performance assessment of buildings and bridges, including site effects	PEER
Information Technology	Exchange information on information technologies	NEES
	Simulation and visualization of earthquake hazards, ground motions, geotechnical/structural response and damage	PEER
Ground Motion Response	Improved regional site response factors from detailed surface geology and from geotechnical borehole data bases (follow through on SCEC Phase III)	CGS, PEER-Lifelines
	Seismic velocity profiles from micro-tremor arrays for deep Vs profiles to complement SASW testing	PEER-Lifelines
	Mapping of basin edge effects using geological data consistent with engineering model from the "Basins" project (see Table 1)	CGS, PEER-Lifelines
Relationship Between Ground Motion Characteristics and Building Response	Identify damaging characteristics of ground motions, and mapping of associated hazard intensity measures	PEER
	How ground motions enter low-rise buildings	PEER
Societal Implications of Earthquake Hazard	Risk and implications of earthquake hazards on distributed lifeline systems and regional economies	PEER, PEER-Lifelines

Ground Motion Prediction Model	Next Generation Attenuation Ground Motion Model	PEER-Lifelines
Loss Estimation	Loss estimation methodology for evaluating societal impacts of SCEC products such as alternative RELM fault models or alternative ground motion models	

APPENDIX A: LONG-TERM RESEARCH GOALS

This section outlines the SCEC science priorities for the five-year period from February 1, 2002, to January 31, 2007. 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/SCEC).

Long-term research goals have been formulated in six problem areas: plate-boundary tectonics, fault systems, fault-zone processes, rupture dynamics, wave propagation, and seismic hazard analysis. These goals delineate the general areas of research where substantial progress is expected during the next five years, and they provide the scientific context for the short-term objectives outlined in Section VI.B.

Plate-Boundary Tectonics

Goal: To determine how the relative motion between the Pacific and North American plates is distributed across Southern California, how this deformation is controlled by lithospheric architecture and rheology, and how it is changing as the plate-boundary system evolves.

Key Questions:

- How does the complex system of faults in Southern California accommodate the overall plate motion? To what extent does distributed deformation (folds, pressure-solution compaction, and motions on joints, fractures and small faults) play a role within the seismogenic layer of the crust?
- What lateral tractions drive the fault system? What are the directions and magnitudes of the basal tractions? How do these stresses compare with the stresses due to topography and variations in rock density? Do they vary through time?
- What rheologies govern deformation in the lower crust and mantle? Is deformation beneath the seismogenic zone localized on discrete surfaces or distributed over broad regions? How are these deformations related to those within the seismogenic zone?
- What is the deep structure of fault zones? Are major strike-slip faults such as the SAF truncated by décollements or do they continue through the crust? Do they offset the Moho? Are active thrust faults best described by thick-skin or thin-skin geometries?
- How is the fault system in Southern California evolving over geologic time, what factors are controlling the evolution, and what influence do these changes have on the patterns of seismicity?

Fault Systems

Goal: To understand the kinematics and dynamics of the plate-boundary fault system on interseismic time scales, and to apply this understanding in constructing probabilities of earthquake occurrence in Southern California, including time-dependent earthquake forecasting.

Key Questions:

- What are the limits of earthquake predictability, and how are they set by fault-system dynamics?
- How does inelastic deformation affect strain accumulation and release through the earthquake cycle? Does inelastic deformation accumulated over repeated earthquake cycles give rise to landforms and geologic structures that can be used to constrain deformation rates and structural geometries on time intervals of thousands to hundreds of thousands of years?

- Are there patterns in the regional seismicity related to the past or future occurrence of large earthquakes? For example, are major ruptures on the SAF preceded by enhanced activity on secondary faults, temporal changes in *b*-values, or local quiescence? Can the seismicity cycles associated with large earthquakes be described in terms of repeated approaches to, and retreats from, a regional "critical point" of the fault system?
- What are the statistics that describe seismic clustering in time and space, and what underlying dynamics control this episodic behavior? Is clustering observed in some fault systems due to repeated ruptures on an individual fault segment, or to rupture overlap from multiple segments? Is clustering on an individual fault related to regional clustering encompassing many faults?
- What systematic differences in fault strength and behavior are attributable to the age and maturity of the fault zone, lithology of the wall rock, sense of slip, heat flow, and variation of physical properties with depth? Is the mature SAF a weak fault? If so, why? How are the details of fault-zone physics such as "critical slip distance" expressed at the system level?
- To what extent do fault-zone complexities, such as bends, changes in strength, and other quenched heterogeneities control the nucleation and termination of large earthquakes and their predictability? How repeatable are large earthquakes from event to event, both in terms of location and slip distribution? How applicable are the "characteristic-earthquake" and "slip-patch" models in describing the frequency of large events? How important are dynamic cascades in determining this frequency? Do these cascades depend on the state of stress, as well as the configuration of fault segments?
- How does the fault system respond to the abrupt stress changes caused by earthquakes? To what extent do the stress changes from a large earthquake advance or retard large earthquakes on adjacent faults? How does stress transfer vary with time? Does a more realistic lower-crustal rheology affect the spatial and temporal evolution of seismicity?
- What controls the amplitude and time constants of the post-seismic response, including aftershock sequences and transient aseismic deformations? In particular, how important are induction of self-driven accelerating creep , fault-healing effects, poroelastic effects, and coupling of the seismogenic layer to viscoelastic flow at depth?

Fault-Zone Processes

Goal: To understand the internal structure of fault zones and the microscale processes that determine their rheologies in order to formulate more realistic macroscopic representations of fault-strength variations and the dynamic response of fault segments and fault networks.

Key Questions:

- Which small-scale processes—pore-water pressurization and flow, thermal effects, geochemical alteration of minerals, solution transport effects, contact creep, microcracking and rock damage, gouge comminution and wear—are important in describing the earthquake cycle of nucleation, dynamic rupture, and post-seismic healing?
- What fault-zone properties and processes determine velocity-weakening vs. velocity-strengthening behavior? How do these properties and processes vary with temperature, pressure, and composition? How do significant changes in normal stress modify constitutive behavior?
- How does fault strength drop as slip increases immediately prior to and just after the initiation of dynamic fault rupture? Are dilatancy and fluid-flow effects important during nucleation?
- What is the explanation of the discrepancy between the small values of the critical slip distance found in the laboratory (< 100 microns) and the large values (> 100 millimeters)

inferred from the fracture energies of large earthquakes? What is the nature of near-fault damage and how can its effect on fault-zone rheology be parameterized?

- How does fault-zone rheology depend on microscale roughness, mesoscale offsets and bends, variations in the thickness and rheology of the gouge zone, and variations in porosity and fluid pressures? Can the effects of these or other physical heterogeneities on fault friction be parameterized in phenomenological laws based on rate and state variables?
- How does fault friction vary as the slip velocities increase to values as large as 1 m/s? How much is frictional weakening enhanced during high-speed slip by thermal softening at asperity contacts and by local melting?
- How do faults heal? Is the dependence of large-scale fault healing on time logarithmic, as observed in the laboratory? What small-scale processes govern the healing rate, and how do they depend on temperature, stress, mineralogy, and pore-fluid chemistry?

Rupture Dynamics

Goal: To understand the physics of rupture nucleation, propagation, and arrest in realistic fault systems, and the generation of strong ground motions by earthquakes.

Key Questions:

- What is the magnitude of the stress needed to initiate fault rupture? Are crustal faults "brittle" in the sense that ruptures require high stress concentrations to nucleate, but, once started, large ruptures reduce the stress to low residual levels?
- How do earthquakes nucleate? What is the role of foreshocks in this process? What features characterize the early post-instability phase?
- How can data on fault friction from laboratory experiments be reconciled with the earthquake energy budget observed from seismic radiation and near-fault heat flow? What is explanation of short apparent slip duration?
- How much inelastic work is done outside a highly localized fault-zone core during rupture? Is the porosity of the fault zone increased by rock damage due to the passage of the rupture-tip stress concentration? What is the role of aqueous fluids in dynamic weakening and slip stabilization?
- Do minor faults bordering a main fault become involved in producing unsteady rupture propagation and, potentially, in arresting the rupture? Is rupture branching an important process in controlling earthquake size and dynamic complexity?
- Are strong, local variations in normal stress generated by rapid sliding on nonplanar surfaces or material contrasts across these surfaces? If so, how do they affect the energy balance during rupture?
- What produces the slip heterogeneity observed in the analysis of near-field strong motion data? Does it arise from variations in mechanical properties (quenched heterogeneity) or stress fluctuations left in the wake of prior events (dynamic heterogeneity)?
- Under what conditions will ruptures jump damaged zones between major fault strands? Why do many ruptures terminate at releasing step-overs? How does the current state of stress along a fault segment affect the likelihood of ruptures cascading from one segment to the next?
- What are physical mechanisms for the near-field and far-field dynamical triggering of seismicity by large earthquakes?

Ground Motion

Goal: To understand seismic ground motion in urbanized Southern California well enough to predict the ground motions from specified sources at frequencies up to at least 1 Hz, and to formulate useful, consistent, stochastic models of ground motions up to at least 10 Hz.

Key Questions:

- How are the major variations in seismic wave speeds in Southern California related to geologic structures? How are these structures best parameterized for the purposes of wavefield modeling?
- What are the contrasts in shear-wave speed across major faults in Southern California? Are the implied variations in shear modulus significant for dynamic rupture modeling? Do these contrasts extend into the lower crust and upper mantle?
- How are variations in the attenuation parameters related to wave-speed heterogeneities? Is there a significant dependence of the attenuation parameters on crustal composition or on frequency? How much of the apparent attenuation is due to scattering?
- What are the differences in near-fault ground motions from reverse, strike-slip, and normal faulting? In thrust faulting, how does energy trapped between the fault plane and free surface of the hanging-wall block amplify strong ground motions?
- How does the structure of sedimentary basins affect the amplitude and duration of ground shaking? How much of the amplification pattern in a basin is dependent on the location of the earthquake source? Can the structure of sedimentary basins be determined in sufficient detail to usefully predict the pattern of ground shaking for future large earthquakes?
- Is the ability to model recorded seismograms limited mainly by heterogeneity in source excitation, focusing by geologic structure, or wavefield scattering?
- What role do small-scale heterogeneities and irregular interfaces play in wave propagation at high frequencies? How do they depend on depth, geological formation, and tectonic structure? How important is multiple scattering in the low-velocity, uppermost layers? Can stochastic parameterizations be used to improve wavefield predictions?

Seismic Hazard Analysis

Goal: To incorporate time dependence into the framework of seismic hazard analysis in two ways: (a) through the use of rupture dynamics and wave propagation in realistic geological structures, to predict ground-motion time histories for anticipated earthquakes, and (b) through the use of fault-system analysis, to forecast the time-dependent perturbations to average earthquake probabilities in Southern California.

Key Questions:

- What factors limit fault-rupture propagation? How valid are the cascade and characteristic-earthquake models? What magnitude distribution is appropriate for Southern California?
- How can geodetic (GPS and InSAR) measurements of deformation be used to constrain short- and long-term seismicity rates for use in seismic hazard assessment? How can geologic and paleoseismic data on faults be used to determine earthquake recurrence rates?
- What temporal models and distributions of recurrence intervals pertain to faults in Southern California? Under what circumstances are large events Poissonian in time? Can PSHA be improved by incorporating non-Poissonian distributions?
- Can physics-based scenario simulations produce more accurate estimates of ground-motion parameters than standard attenuation relationships? Can these simulations be used to reduce the high residual variance in these relationships ?

- What is the nature of near-fault ground motion? How do fault ruptures generate long-period directivity pulses? How do near-fault effects differ between reverse and strike-slip faulting? Can these effects be predicted?
- What are the earthquake source and strong ground motion characteristics of large earthquakes (magnitudes larger then 7.5), for which there are few strong motion recordings? Can the shaking from large earthquakes be inferred from smaller events?
- How does the nonlinear seismic response of soils depend on medium properties, amplitude, and frequency?