2005 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 fourth year of the program.

II. GUIDELINES FOR PROPOSAL SUBMISSION

A. Due Date: November 19, 2004, 5:00 pm PST. Late proposals will not be accepted.

B. Delivery Instructions. Proposals and annual reports must be submitted as separate 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. Please note the separate instructions for submitting science nuggets.

C. Formatting Instructions.

- ***Cover Page:*** Should begin with the words "2005 SCEC Proposal," the project title, Principal Investigator, institution, proposal categories (from types listed in Section IV, including the new SCEC Intern Support category), 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 (see Section VII) or advanced Implementation Interface projects (see Section VIII 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, 2005.
- ***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 VII).
- ***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. Budgeted matching funds for SCEC interns will only be awarded if a PI for the project is paired with a student intern.
- ***Current Support:*** Statements of current support, following NSF guidelines, should be included for each Principal Investigator.
- ***2004 Annual Report:*** Scientists funded by SCEC in 2004 must submit a report of their progress with the 2005 proposals. 2005 proposals lacking 2004 reports (which may cover 2003 to mid-year 2004 results) will neither be reviewed nor will they be considered for 2005 funding. Reports should be up to five pages of text and figures.
- ***Science Nuggets:*** All SCEC2 PI's must submit "science nuggets" that highlight their research findings in SCEC2. Nuggets that highlight interdisciplinary work are especially important. These nuggets will be needed for the preparation of the SCEC3 proposal. Instructions for submitting these nuggets are at the proposal web site.

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
- 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. 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 Appendix 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 VII.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 VII.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 VII.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 VIII. 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 an educational or outreach mode (see Section VII).

C. Workshops. SCEC participants who wish to host a workshop between February 2005, and February 2006, 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 VIII. 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 Intern Support. Each year SCEC coordinates the SCEC Summer Undergraduate Research Experience (SCEC/SURE) program to support undergraduate student research with SCEC scientists. See the SCEC Internship website at <http://www.scec.org/internships> for more information. Proposals in categories A, B, and D are encouraged to specify a project for a student for Summer 2005, and provide at least $2,500 of the $5,000 student stipend. (The remainder of the stipend will be matched by NSF REU Supplement support.) The project description should include a one paragraph statement of the scientific problem, research location, intern responsibilities, necessary skills and educational preparation. Proposals selected for SCEC funding that have specified intern projects will be announced on the SCEC Internship web page (using the one paragraph statement) to allow applicants to rank their preferred projects. If a student is not selected for a project, the funding allocated for the student will be removed before project funds are transferred to the PI.

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 VIII, 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 the end of February, 2005.

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/scitech/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.

• ***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), whose continued operation is essential to deciphering Southern California seismicity, crustal 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 directly load waveforms into programs, 2) Implementing software that permits access to both northern and southern California data with a single data request, and 3) Incorporating first motion and moment tensors as they become available.

2. Tectonic Geodesy

• ***Data Gathering:*** Support the collection of geodetic data that will improve knowledge of crustal motion, particularly in the vertical, in areas of special interest; the proposal should explain how this improvement is likely to occur, and how the proposed measurements relate to others, both existing (the CMM and SCIGN) and planned (PBO). Measurements may include reobservations to lower errors, reobservations at sites observed only once before, or new sites.

Measurements may be done with any relevant geodetic technique. Observations which will help to clarify vertical motions are especially valued.

Provide support to assist in the collection of other data relevant to time-varying deformation.

Provide support to assist in the operation of, and data distribution from, the WInSAR Archive.

• ***Data Products:*** Continue to assimilate newly acquired GPS data into new versions of the Crustal Motion Map, to provide better descriptions of the postseismic and coseismic motions from earthquakes, estimates of vertical motion, and a description of motions along a larger portion of the transform boundary. This should work towards the combination of survey-mode and continuous GPS data into a seamless set of products.

Support small-scale projects which use InSAR data, solely or combined with other measurements, to produce products for general use or for targeted study of special areas.

• ***Workshops:*** There is interest in a workshop to ensure that measurements of postseismic motion from the next large earthquake are as scientifically informative as possible. Such a workshop would bring together modelers, who can describe signals to be expected from different mechanisms, with field observers who will need to organize future observations.

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 and develop approaches for marine paleoseismology; collect new information on fault slip rates, paleoseismic chronologies that span multiple recurrence cycles, slip in past earthquakes, and other geologic measurements of active tectonics that help resolve the current discrepancies between long-term geologic rates and GPS measurements and further our understanding of earthquake recurrence processes; coordinate fault geology studies with upcoming LiDAR data collection; develop, build and contribute new and existing data to the southern California fault activity database (FAD; www.scec.org/FAD); develop methodology to test and improve resolution of event chronologies and correlations; foster subsurface analysis of fault systems, including the 3D configuration of emergent and blind thrusts and the role of off-fault deformation; compile and generate data on vertical motions to compare to geodetic (including InSAR) results. Compile existing information and conduct detailed studies of fault zone materials and structures in and adjacent to exhumed faults in order to understand deformation processes and conditions and their implications for the nucleation and propagation of earthquake ruptures, including fault zone signatures of rupture direction. Proposals should focus on studies that can be completed in the timeframe of SCEC 2, and that will yield tangible data products that contribute to our understanding of the fault system.

• ***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; address the GPS/geology discrepancy for some faults; construction of a community vertical motions map (10^5 year timescale).

4. Fault and Rock Mechanics

• ***Data Gathering:*** Areas of FARM research include fault modeling, laboratory studies, field studies of exhumed faults, and studies of faults from drill cores. 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 designed to develop and test new techniques, or to develop a new facility, to measure sliding resistance of faults at seismic slip rates, 2) detailed characterizations of natural slip surfaces and the products of high-speed deformation experiments to identify the structures diagnostic of dynamic slip and to test hypotheses of dynamic weakening, 3) modeling activities to predict fault behavior during dynamic slip with extreme weakening, 4) field studies geared towards developing a model of the 3D structure of a fault zone, particularly to define and quantify geometric and material property variations that influence rupture propagation, 5) developing a database for large strike-slip faults world-wide that could serve as analogs to the seismogenic depth range of the modern San Andreas fault in Southern California and that includes information about tectonic setting and history, depth of exhumation, locations, quality and extent of exposures, and an annotated bibliography for each fault including any relevant fault and rock mechanics research, 6) modeling fault behavior on the San Andreas near the EarthScope SAFOD site and collaborative studies of the structure and properties of material recovered during SAFOD drilling, and 7) cataloging of and studies of existing industry core material crossing significant faults in Southern California in order to address fault zone process questions. 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; develop an IT framework for an open database of experimental, model, and field results and expand upon existing databases.

A field-trip/workshop focused on well-exposed and studied exhumed fault zones is encouraged in order to foster discussions about what has been learned at the sites, what more ought to be studied there, and what other types of sites are needed.

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):*** Develop and implement improvements to the current SCEC velocity models, with emphasis on more accurate representations of Vs and density structure, and attenuation. Improve the definition of basin shapes and velocity structures, including the Salton Sea/Imperial Valley, Ventura basin, and southern Central Valley regions. Make the models compatible with fault positions and displacements as represented in the CFM. Evaluate the models with data (e.g., waveforms, gravity), and quantify model uncertainties.

• ***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 alternative fault representations; and c) providing more detailed representations of fault terminations and linkages. Emphasis will be placed on evaluating CFM 2.0 and its alternative fault representations.

• ***Unified Structural Representation (USR):*** Develop a flexible delivery system for the USR and its model components. Generate volumetric meshes of the Community Block Model (CBM), a database of CBM components, and faulted horizons (as strain markers and property boundaries) that are compatible with the CBM and CFM.

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; infer rates of change in stress from geodetic and seismic observations; compare and interpret quantitatively short-term geodetic rates of deformation, long-term geologic rates, and rates predicted by seismicity simulators; quantify the space-time behavior of the Southern California fault system in ways that are targeted to test models of earthquake occurrence and stress evolution; foster collaborations to obtain outside funding to support large, coordinated data-gathering efforts; determine how geologic deformation is partitioned between slip on faults and distributed off fault deformation and how geodetic strain is partitioned between long-term permanent 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 and rheological properties (e.g., Burgers body viscoelasticity, rate-state friction, poroelasticity, damage rheology); develop continuum representations of fault system behavior on scales smaller than can be resolved as faulting 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; generate finite element meshes of the CBM; assess mechanical compatibility of CFM and how slip is transferred between recognized fault segments; develop a reference model of the time-dependent stress transfer and deformation associated with the 1992 Landers earthquake; extend models of time-dependent stress transfer and deformation of Southern California to cover 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; couple numerical models of the interseismic period to quasi-static full-cycle fault models to better constrain stress transfer and conditions and processes at the start of dynamic rupture, including forcing by realistic coseismic displacements and dynamic stresses (with Source Physics); develop tectonic models that explain the inferred rates of fault slip; develop a plan for post-earthquake geodetic deployments.

• ***Seismicity Evolution Models:*** Determine the effects of fault system scale and resolution in models of geometrically complex fault systems; develop and validate rapid simulation methods for modeling earthquakes in fault systems over a wide range of magnitudes (with Source Physics); develop, validate, and facilitate use of codes for ensemble models simulating earthquake catalogs using CFM, USR and CBM, as well as effects 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; search for statistically significant signals in the space-time- magnitude distribution of seismicity and understand their physical origin.

3. Earthquake Source Physics

• ***Numerical Simulations of the Earthquake Source and Earthquake Cycle:***

- Conduct numerical simulations of dynamic rupture nucleation, propagation, and termination that include known or realistic complexity in fault geometry, material properties, stress state, and 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.
- Explore what aspects of the source and fault zone determine propagation direction (directivity).
- Use numerical simulations results to guide seismic hazards analysis (Joint with SHA Focus Group), such as quantifying fault-to-fault rupture probabilities for earthquake forecasting.
- Participate in the code validation exercises for 3D spontaneous rupture simulations (also Pathway 3 of the SCEC ITR) by performing benchmark tests and comparing results with the rest of the ESP and Pathway 3 community. As part of this exercise, use the M6.0 2004 Parkfield earthquake as a validation test. (Joint with GM Focus Group).
- Bridge the interface between Earthquake Source Physics and Fault Systems by conducting physics-based fully dynamic multi-earthquake-cycle simulations, and by determining if simpler, quasi-dynamic or quasi-static simulations may suffice as a proxy for full dynamic simulations in long-term fault-systems simulations. (Joint with FS Focus Group).

- Participate in NGA-H. Investigate particular problems of interest to NGA-H, including the observation that ground-rupturing earthquakes produce smaller ground motion than buried earthquakes. See Section VIII, Part A4 – Implementation Interface Focus Area – for more information on the NGA-H Program.

• ***Reference Earthquakes***
Building on efforts started in 2004, continue construction of a database that includes geodetic, geologic, and seismological data (and metadata), as well as models derived from them. The goal is 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 will serve as a template for additional reference earthquakes.

• ***In-Situ Studies of Fault-Zones (Exhumed Faults & Deep Cores)***
Examine and document features of fault zones in Southern California, including the San Andreas fault system, Parkfield, and the SAFOD site, 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 and FARM Discipline Groups)

• ***Earthquake Scaling***
- Determine to what extent earthquake behavior depends on earthquake size.
- Determine if there are breaks or trends 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.

• ***Lab Studies of the Earthquake Source* (*Joint with FARM*)**
- Carry out 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 dynamic rupture source observations.
- Use this information to test proposed constitutive relations or develop improved constitutive relations.
- Use this information to test numerical spontaneous rupture simulations of the earthquake source

• ***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

• ***Broadband Ground Motion Modeling Project*:** Multiple groups/investigators will calculate synthetic seismograms up to 10Hz by combining deterministic and high frequency (stochastic or other) synthetics and comparing with observations. Successful approaches will be used to extend existing 3D scenarios* to broadband by end of SCEC2, and may be used in the NGA-H Program, described in more detail in Section VIII, Part A4 –Implementation Interface Focus Area.

• ***Inversion and CVM Testing:*** Use data from well-recorded earthquakes to assess wavefield simulations based on the CVM. Identify regions where CVM fails to predict ground motion. Develop methods to invert ground motion data for source and path effects, their resolution and uncertainties. Improve the S-wave velocity structure in the CVM and the Harvard model by inversion of waveform data.

• ***SCEC Scattering and Attenuation Model:*** Attenuation/scattering models are to complement the SCEC CVM and be used in calculating high frequency synthetics. Develop methods/experiments to identify and model sources of scattering/attenuation in seismic body waves and coda by analyzing data from CISN and borehole instruments.

• ***Non-Linear Site Response*:** 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 lead to a new understanding of how site response varies spatially. Investigate soil- (building) structure interaction and its effect on ground response including nonlinear effects.

• ***High Frequency Wavefield:*** Develop strategies/experiments to separate source and path effects in high frequency wavefields. This could include empirical Green's functions, results from the scattering model, inversion. Develop hybrid models (e.g., 3D+asymptotic methods, 3D+2D, 3D+1D) to include higher frequencies. Evaluate basin-edge effects.

• ***Building Response:*** Develop collaborations with engineers (with IIG) to add building response to synthetic seismograms and compare with COSMOS and NGA data bases for seismograms from different floors. Evaluate the relative effects on damage of near-field acceleration and resonance excitation by long term coda. Collaborations that leverage outside funding sources for engineering analyses are desirable (e.g., PEER, MCEER, etc...).

• ***Towards the SCEC Synthetic Catalog:*** Collaborate with CME to set up an internal website to compare observed seismograms from medium sized earthquakes with synthetics. This will require site effects (f, Z dependent), a scattering operator, at stations of CISN.

*A description of scenario earthquakes is posted on the SCEC website http://webwork.sdsc.edu:10081/sceclib/portal.

5. Seismic Hazard Analysis

• ***OpenSHA*:** Contribute to the 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, 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, and 4) conducting outreach activities (e.g., workshop) with potential user groups.

• ***Regional Earthquake Likelihood Models (RELM):*** Via the RELM working group, develop, submit (for testing and SHA), and publish viable earthquake-forecast models for southern California or the entire state (the more physics based approaches should be developed in coordination with the Fault Systems focus group). Of particular interest are simulations methods to extend "next-event" forecasts to forecasts of all possible sequences of events. 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 and implement quantitative tests of the various forecast models using observed seismicity, precarious-rock constraints, historically observed intensity levels, or other viable approaches. Conduct workshops to facilitate the various RELM activities (e.g., to establish standards for testing the models).

• ***Contribute to SCEC's System-Level Earthquake Rupture Forecast Model:*** We encourage development of a system-level earthquake forecast employing relevant information from geology, seismology, and geodesy, comparable in scope to those reported by the Working Group on California Earthquake Probabilities. See http://www.RELM.org/models/scec_erf for details. 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, complete, viable fault models (CFMs); 2) compile paleoseismic data for these faults; 3) develop regional deformation models (slip and loading rates on and off faults) by combining geologic and geodetic constraints with the fault models; 4) develop models of the rate and/or probability of earthquake rupture on the fault(s) (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.

• ***Improved Ground-Motion Models and Intensity-Measure Relationships:*** Work with the Ground Motion focus group and/or the Implementation Interface to develop improved models for predicting ground motion and/or intensity measures (empirical attenuation relationships, waveform modeling, or hybrid approaches). Of particular interest are models that can take an arbitrary earthquake rupture and site, and give back a suite of synthetic seismograms (the suite representing the propagation of all influential uncertainties). Proposals to implement new types of Intensity Measures (new functionals of ground motion, or vectors thereof) that predict engineering damage measures better than traditional intensity measures (e.g., PGA, SA) are also encouraged.

C. Special Projects

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. SCIGN maintenance is now funded by PBO/UNAVCO (which will maintain 125 sites), the USGS (which will maintain 90+ sites) and southern California counties (which will maintain the remaining sites). The SCIGN 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. This includes the re-examination and analyses of newly released grids of industry seismic data to better quantify the location, subsurface geometry and late-Quaternary history of active offshore structures. More comprehensive detailed mapping of active offshore faults will likely 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, NURP, 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 50 institutions across the United States, in partnership with many 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 present opportunities for members of the SCEC community to become involved in CEO activities, which are for the most part coordinated by CEO staff. To support the involvement of as many others as possible, budgets for proposed projects should be on the order of $3,000 to $7,000 (Implementation Interface research proposals excluded). Hence proposals that include additional sources of support (cost-sharing, funding from other organizations, etc.) are highly recommended. Those interested in submitting a CEO proposal should first contact Mark Benthien, Director for CEO, at 213-740-0323 or benthien@usc.edu.

A. 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. ***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

B. Implementation Interface Program

1. Earthquake Engineering Research and Professional Practice Organizations: The purpose of the Advanced Implementation Interface is to implement knowledge about earthquake hazards developed by SCEC into research and practice. This is done by 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, especially Earthquake Source Physics and Ground Motions, and describe how the project will relate to projects with partners, such as those listed in the table below. Engineers and other potential partners should seek funding from their own organizations.

This year, SCEC received a separate three-year grant from NSF, with contributions from both EAR and CMS, to work on three topics at the interface between earthquake science and earthquake engineering, summarized in Table 1. The proposal for this project can be found on the SCEC website, and excerpts are attached in the file NSF-ProposalExcerpts.doc.

The work described in Table 1 (below) will be done by the individuals and groups identified in the table, and funded separately from the SCEC 2005 program. However, at least one of the three topics, the one related to the NGA Program, will require involvement of SCEC scientists beyond the scope contained in the proposal, and it is anticipated that SCEC will have funds to cover that additional involvement. Accordingly, SCEC scientists are encouraged to submit proposals that augment the work on all three topics described in the proposal. In particular, the development and testing of additional procedures for broadband ground motion simulation in the NGA Project, beyond the two that have been used to date (Graves and Pitarka, and Zeng), is solicited. These procedures need to be tested against the strong motion recordings of the following earthquakes: 1979 Imperial Valley, 1989 Loma Prieta, 1992 Landers, 1994 Northridge, 1995 Kobe, and 1999 Kocaeli. Additional information about the validation of these broadband simulation procedures can be found on the PEER-Lifelines website (http://peer.berkeley.edu/lifelines/).

Table 2 lists current potential future project topics that could involve collaboration between SCEC and earthquake engineering organizations. Among these topics, those shown in boldface are components of the new three-year NSF grant described above. Table 2 lists other topics for potential future collaboration between SCEC and earthquake engineering organizations, which are identified in the table as potential co-sponsors of collaborative implementation-oriented work. The identification of these other 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, the topics not in boldface in Table 2 should be viewed as a preliminary identification of potential mutual interests that could be pursued with additional discussion. Table 2 does not preclude other ideas for collaboration with these or other earthquake engineering organizations.

Table 1. Summary of NSF Project on Implementation Interface

TASK	PARTICIPANTS	SCEC ACTIVITIES & ACCOMPLISHMENTS	PRODUCTS	POTENTIAL USERS[1]
1. Ground-Motion Time Histories for Performance-Based Earthquake Engineering	Archuleta, Liu, Beroza, Bielak, Graves, Pitarka, Somerville, Zeng	Validation of 3D ground motion simulation methods in sedimentary basins Validation of broadband 1D simulation methods.	Ground-motion time histories, especially for large earthquakes at close distances	PEER, MAE, MCEER, NEES Consortium, CSMIP
2. Next-Generation Attenuation (NGA) Project	Anderson, Zeng, Beroza, Day, Olsen, Graves, Pitarka, Somerville	SCEC Phase III Report: Site Effects, Basin Effects, and Attenuation Relations for Southern California Pseudo-dynamic earthquake rupture models	NGA Hybrid ground-motion attenuation model based on simulations as well as data	Caltrans, CEC, PG&E, ATC, BART, BSSC, CSSC, DOE, NRC, DSOD, DWR, EBMUD, FERC, LADWP, OES, SCE
3. Ground-Motion and Structural Simulations for Scenario Earthquakes in Los Angeles	Archuleta, Liu, Lavallee, Bielak, Graves, Pitarka, Somerville, Hall, Heaton ,Olsen, Shaw, Tromp	Development of Puente Hills fault model Development of SCEC 3D velocity model Validation of 3D ground motion simulation methods in sedimentary basins	Scenario ShakeMaps for emergency planning and loss estimation Time histories and response spectra Structural simulations for large LA buildings	EERI & SEAOSC members, Caltrans, LADWP, DWP, SCE, SCG, PEER, SoCalHUG, practicing engineers

Table 2. SCEC Advanced Implementation Interface, 2005 RFP - Potential Project Topics

THEME	PROJECT	POTENTIAL CO-SPONSORS	PRIORITY
Ground Motion Prediction Model	**Broadband Ground Motion Simulations for Next Generation Attenuation Ground Motion Model**	PEER-Lifelines	1
	Physical constraints on upper bound ground motions	DOE	2
Ground Motion Time Histories	**Provide ground motion time histories for use in earthquake engineering testing facilities and simulation software**	NEES, MAE, MCEER, PEER	1
	Provide ground motion inputs into the FEMA/ATC 58 Performance Based Seismic Design Project	ATC	1
	Validation of simulated ground motions for performance assessment of buildings and bridges, including site effects	MAE, MCEER, PEER	2
	Provide spatial wave-field and distributed input ground motions for bridges	NEES, Caltrans, FHWA	2
Relationship Between Ground Motion Characteristics and Building Response	**End-to-end simulation of earthquake rupture process, wave propagation, and structural response of distributed systems**	NEES, MAE, MCEER, PEER, CUREe	1
	How ground motions enter low-rise buildings	PEER, CUREe	2
	Identify damaging characteristics of ground motions, and mapping of associated hazard intensity measures	MAE, MCEER, PEER	2
Information Technology	Exchange experience with information technologies	NEES	2
	Simulation and visualization of earthquake hazards, ground motions, geotechnical/structural response and damage	NEES, MAE, MCEER, PEER	2
Loss Estimation	Loss Estimation Methodology for evaluating societal impacts of SCEC products such as alternative RELM fault models or alternative ground motion models	MAE, MCEER, PEER, CUREe	2
Societal Implications of Earthquake Hazard	Risk and implications of earthquake hazards on distributed lifeline systems and regional economies	MAE, MCEER, PEER-Lifelines	2

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 VII.

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?