Southern California Earthquake Center

Annual Report: Year 1

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Summary

This report outlines the 2012 accomplishments of the SCEC4 program in terms of the SCEC4 milestones. The SCEC Planning Committee articulated policies for the development of Special Fault Study Areas, and interdisciplinary research activities were organized for SFSAs centered on the San Gorgonio Pass and the Ventura Avenue Anticline (Milestone 6). A workshop was held to define the conceptual and geographic scope of the Community Geodetic Model (CGM); initial efforts are bringing together GPS and InSAR time series to exploit their complementary nature (Milestone 4). A strategy was formulated for development of a Community Stress Model (CSM) to constrain the physics of earthquakes in Southern California; preliminary comparisons were made among candidate stress models, and the first steps were taken to integrate various data and model types (Milestone 5). The SCEC Community Fault Model (CFM) was upgraded with improvements in 3D fault representations, a detailed fault surface trace layer, and a new fault naming and numbering scheme that allows for closer links to the USGS/CGS Quaternary Fault database; tomographic refinements and stochastic extensions were added to the Community Velocity Models, CFM-H and CVM-S (Milestone 3). Validation procedures for the application of ground motion simulations in seismic hazard analysis and earthquake engineering were set up by the Ground Motion Simulation Validation technical activity group (GSMV TAG), and a major project to validate ground motion simulations against observed strong motion data was initiated (Milestone 7). The Aseismic Transient Detection TAG has developed the capability of searching systematically through geodetic data for aseismic deformation transients; two detection algorithms with differing treatments of the seasonal, coseismic and postseismic signals within the time series are currently being run in an operational mode within the Collaboratory for the Study of Earthquake Predictability (CSEP) (Milestone 2). The Dynamic Rupture Code Validation TAG developed validation exercises for modeling strongly heterogeneous ruptures and rupture stepovers on vertical strike-slip faults; the Source Inversion Validation TAG held a workshop to incorporate geodetic data into its validation exercises (Milestone 8). The latest version of Uniform California Earthquake Forecast (UCERF3) was developed by the USGS-SCEC-CGS Working Group on California Earthquake Probabilities (Milestone 9). The Earthquake Simulators TAG performed a series of comparison exercises that elucidated how catalogs from different types of earthquake simulators reflect important effects of fault geometry, stress transfer, and rupture nucleation and dynamics, and the results were published in a special issue of *Seismological Research Letters* (Milestone 9). As part of the SoSAFE activity in 2012, a fieldshop was held to explore the reproducibility of field measurements of geomorphic offsets by multiple investigators (Milestone 1). Improved earthquake-relocation and focal-mechanism catalogs were released through the Southern California Earthquake Datacenter (Milestone 1).

Through its engagement with many external partners, SCEC Communication, Education and Outreach (CEO) Program delivered research and educational products to the Center's many audiences, including the general public, government, business, academia, students, practicing engineers, and the media. CEO continued to expand the ShakeOut earthquake preparedness exercises in California and elsewhere. A growing network of official ShakeOut regions are now held in 25 U.S. states and territories as well as several other countries, including Japan, New Zealand, and Italy. In 2012, 19.4 million people registered to participate in 16 ShakeOut drills worldwide. A number of new exhibits have opened within institutions participating in the 60-organization EPIcenters program, managed by CEO through the Earthquake Country Alliance. The Summer Undergraduate Research Experience (SURE) enrolled 16 interns from 12 undergraduate institutions, and the Undergraduate Studies in Earthquake Information Technology (UseIT) Program enrolled 24 interns from 8 colleges and universities.

I. Introduction

The Southern California Earthquake Center (SCEC) was created as a Science & Technology Center (STC) on February 1, 1991, with joint funding by the National Science Foundation (NSF) and the U. S. Geological Survey (USGS). SCEC graduated from the STC Program in 2002, and was funded as a stand-alone center under cooperative agreements with both agencies in three consecutive phases, SCEC2 (1 Feb 2002 to 31 Jan 2007), SCEC3 (1 Feb 2007 to 31 Jan 2012), and SCEC4 (1 Feb 2012 to 31 Jan 2017). This report outlines the accomplishments of the first year of the SCEC4 program.

Box 1.1. SCEC Mission Statement

- **Gather data on earthquakes in Southern California and elsewhere**
- **Integrate information into a comprehensive, physics-based understanding of earthquake phenomena**
- **Communicate understanding to the world at large as useful knowledge for reducing earthquake risk and improving community resilience**

SCEC coordinates basic research in earthquake science using Southern California as its principal natural laboratory. The Center's theme of *earthquake system science* is reflected in its mission statement (**Box 1.1**), which emphasizes the connections between information gathering by sensor networks, fieldwork, and laboratory experiments; knowledge formulation through physics-based, system-level modeling; improved understanding of seismic hazard; and actions to reduce earthquake risk and promote community resilience.

A. Southern California as a Natural Laboratory

Southern California is SCEC's natural laboratory for the study of earthquake physics and geology. This tectonically diverse stretch of the Pacific-North America plate boundary contains a network of several hundred active faults organized around the right-lateral San Andreas master fault (**Fig. 1.1**). Its geographic dimensions are well-suited to system-level earthquake studies: big enough to contain the largest (M8) San Andreas events, which set the system's outer scale, but small enough for detailed surveys of seismicity and fault interactions. The entire fault network is seismically active, making the region one of the most data-rich, and hazardous, in the nation. Research on fundamental problems in this well-instrumented natural laboratory has been progressing rapidly (see §II). SCEC coordinates a broad collaboration that builds across disciplines and enables a deeper understanding of system behavior than would be accessible by individual researchers or institutions working alone.

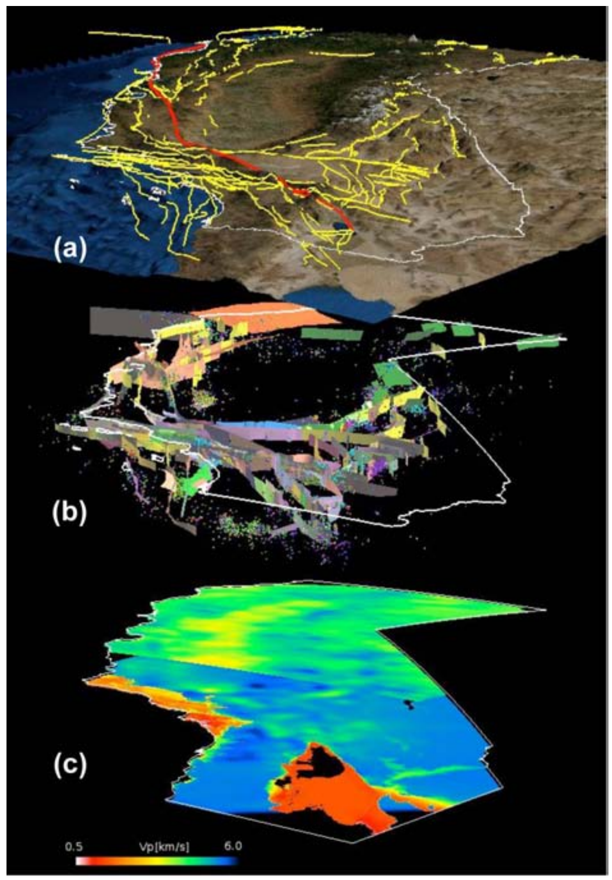

Figure 1.1. Perspective of California, looking northwest and showing elements of the Unified Structural Representation (USR): **(a)** traces of active faults (yellow lines) and the San Andreas master fault (red lines), **(b)** the statewide Community Fault Model (CFM), and **(c)** statewide Community Velocity Model (CVM).

Southern California is home to an urbanized population exceeding 20 million, and it comprises the lion's share of the national earthquake risk [FEMA, 2000]. According to the Uniform California Earthquake Rupture Forecast (UCERF2), the chances of an M > 7 earthquake in Southern California over the next 30 years are 82% ± 14% [Field et al., 2009]. Moreover, SCEC research under the Southern San Andreas Fault Evaluation (SoSAFE) project has demonstrated that the seismic hazard from the southern San Andreas Fault is higher than even the recent UCERF2 estimates [Hudnut et al., 2010]. In particular, the recurrence interval for the Carrizo section of the fault has been revised from a previous estimate of over 200 years to 140 years or

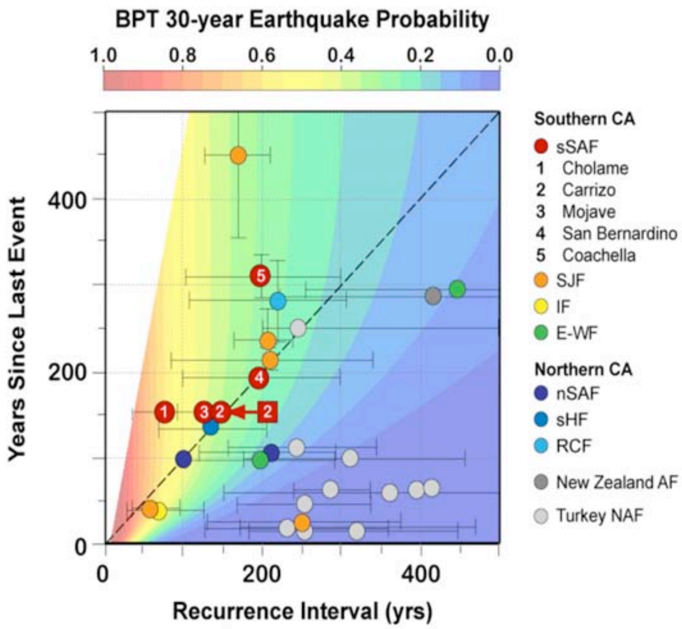

Figure 1.2. A plot of time since the last event vs. mean recurrence interval for sections of the southern San Andreas fault (red points) and other strike-slip faults in California and elsewhere. The arrow indicates the reduction in the mean recurrence interval for the Carrizo section implied by the new SoSAFE data. The color contours show the 30-year earthquake probabilities computed from a Brownian Passage Time (BPT) renewal model. The points for the five major southern San Andreas fault sections lie in the upper triangle; i.e., the entire fault is now "locked and loaded".

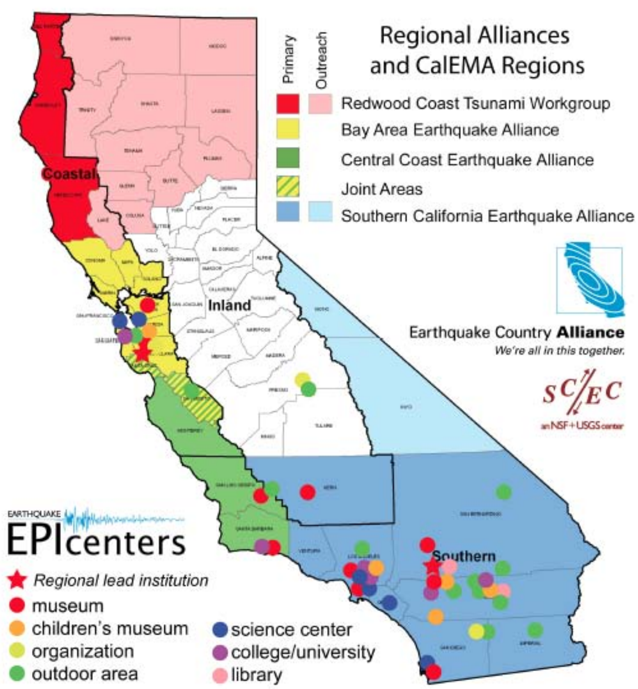

Figure 1.3. Four chapters of the Earthquake Country Alliance (colored areas) and locations of the EPIcenters (colored symbols), two key partnerships developed by the SCEC CEO program.

less [Akciz et al., 2009; Akciz et al., 2010; Zielke et al., 2010; Grant et al., 2010], which compares to the 153-year interval since its last rupture (1857). The urgency of SCEC research has come from a recognition that the entire southern San Andreas may be "locked and loaded" (**Fig. 1.2**).

SCEC research has led to important advances, including a Unified Structural Representation (Fig. 1.1), the statewide UCERF2, and the CyberShake physics-based hazard model. The Center has pioneered novel modes of collaboration, including self-organized Technical Activity Groups (TAGs), the global Collaboratory for the Study of Earthquake Predictability (CSEP), and the statewide Earthquake Country Alliance (**Fig.1.3**). The EPIcenters program, coordinated through the Earthquake Country Alliance (ECA), now involves more than 50 museums, science centers, and other informal education venues (Fig.1.3). The research initiatives and organizational innovations developed by SCEC in Southern California are being emulated in other regions of high seismic risk and promoted by SCEC's growing network of national and international partnerships.

B. SCEC as a Virtual Organization

SCEC is a truly distributed organization, a realization of NSF's original vision of "centers-without-walls", and a prototype for the organizational structures needed to coordinate the interdisciplinary, multi-institutional science of complex natural systems ("system science"). SCEC's cyberinfrastructure has been highlighted by the NSF Cyberinfrastructure Council [NSFCC, 2007] and in other NSF reports on virtual organizations (VOs) [Cummings et al., 2008]. Here we describe five important dimensions of SCEC's organizational capabilities.

1. SCEC is a ***large consortium of institutions*** with a national, and increasingly worldwide, distribution that coordinates earthquake science within Southern California and with research elsewhere. In SCEC4, the number of "core institutions" that commit sustained support to SCEC has grown to 17, and the number of "participating institutions" that are self-nominated through participation of their scientists and students in SCEC research is currently 48 (**Table 1.1**).

The SCEC community now comprises one of the largest formal research collaborations in geoscience. Among the most useful measures of SCEC3 size are the number of people on the Center's email list (1493 on October 31, 2012) and the registrants at the SCEC Annual Meeting (516 in 2012). Annual Meeting registrations for SCEC's entire 21-year history and other demographic information are shown in **Fig. 1.4**.

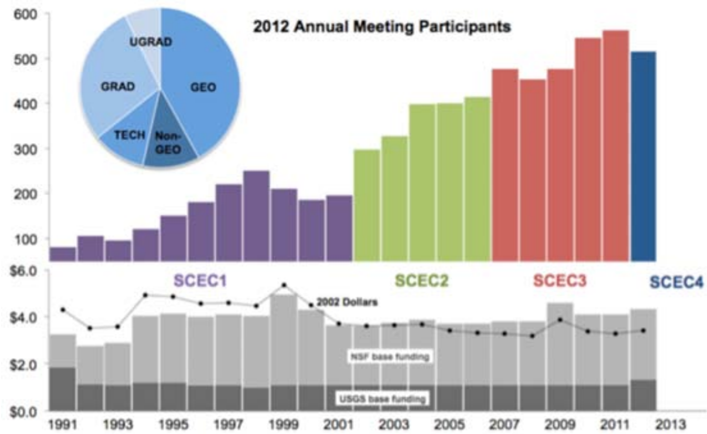

Figure 1.4. Colored bars show total registrants at SCEC Annual Meetings, one measure of how the collaboration has grown during its 22-year history, 1991-2012. Pie chart shows the demographic profile for pre-registrants (516 total) at the 2012 SCEC Annual Meeting. The lower bar chart is the history of SCEC base funding in as-spent dollars; the connected dots are the base-funding totals in 2002 dollars.

2. SCEC is a ***collaboratory for earthquake system science*** that uses advanced IT to synthesize and validate system-level models of earthquake processes. Components include the Community Modeling Environment (CME) and the Collaboratory for the Study of Earthquake Predictability (CSEP). SCEC strives to be a world-leading VO through the innovative use of "vertically integrated" platforms—cyberinfrastructure that combines hardware (equipment), software (knowledge tools), and wetware (professional expertise) to solve system-level problems. SCEC has developed a number of new computational platforms that apply high-performance computing and communication (HPCC) to large-scale earthquake modeling.

3. SCEC is an ***open community of trust*** that nurtures early-career scientists and shares information and ideas about earthquake system science. The Center's working groups, workshops, field activities, and annual meeting enable scientists to collaborate over sustained periods, building strong interpersonal networks that promote intellectual exchange and mutual support. In particular, SCEC encourages colleagues with creative physics-based ideas about earthquakes to formulate them as hypotheses that can be tested collectively. An advantage is that researchers with new hypotheses are quickly brought together with others who have observational insights, modeling skills, and knowledge of statistical testing methods. Participation in SCEC is open, and the participants are constantly changing.

Table 1.1. SCEC4 Member Institutions (August 1, 2012)

Core Institutions (17)	Participating Institutions (48)
California Institute of Technology California Geological Survey Columbia University Harvard University Massachusetts Institute of Technology San Diego State University Stanford University U.S. Geological Survey, Golden U.S. Geological Survey, Menlo Park U.S. Geological Survey, Pasadena University of California, Los Angeles University of California, Riverside University of California, San Diego University of California, Santa Barbara University of California, Santa Cruz University of Nevada, Reno University of Southern California (lead)	Appalachian State University; Arizona State University; Brown University; Cal-Poly, Pomona; Cal-State, Fullerton; Cal-State, Long Beach; Cal-State, Northridge; Cal-State, San Bernardino; Carnegie Mellon University; CICESE (Mexico); Colorado School of Mines; Cornell University; Disaster Prevention Research Institute, Kyoto University (Japan); ETH Zurich (Switzerland); Georgia Tech; Institute of Earth Sciences of Academia Sinica (Taiwan); Earthquake Research Institute, University of Tokyo (Japan); Indiana University; Institute of Geological and Nuclear Sciences (New Zealand); Jet Propulsion Laboratory; National Taiwan University (Taiwan); National Central University (Taiwan); National Chung Cheng University (Taiwan); Oregon State University; Pennsylvania State University; Purdue University; Smith College; SUNY at Stony Brook; Texas A&M University; University of Alaska, Fairbanks; UC, Berkeley; UC, Davis; UC, Irvine; University of Cincinnati; University of Illinois; University of Kentucky; University of Massachusetts; University of Michigan; University of New Hampshire; University of Oregon; University of Texas-El Paso; University of Texas-Austin; University of Western Ontario (Canada); University of Wisconsin; URS Corporation; Utah State University; Utah Valley University; Woods Hole Oceanographic Institution

4. SCEC is a ***reliable and trusted partner*** that collaborates with other organizations in reducing risk and promoting societal resilience to earthquake disasters. SCEC has partnered with the USGS and CGS to create UCERF and coordinate SoSAFE, with UNAVCO to transfer 125 stations of the SCIGN array to the PBO in Southern California, and with the Computational Infrastructure for Geodynamics (CIG), the Geosciences Network (GEON), and the Incorporated Research Institutions for Seismology (IRIS) to develop user-friendly software packages, IT tools, and educational products. The SCEC Communication Education and Outreach (CEO) program has steadily grown a diverse network of partnerships. The statewide ECA now comprises of hundreds of partner organizations, and has greatly increased public participation in earthquake awareness and readiness exercises. The ECA, managed through SCEC's Communication, Education and Outreach (CEO) program, now sponsors yearly preparedness exercises—the Great California ShakeOut—that involve millions of California citizens and expanding partnerships with government agencies, nongovernmental organizations, and commercial enterprises. The CEO program has used SCEC research in developing effective new mechanisms to promote community preparedness and resilience, including the many publications that have branched from the original SCEC publication, Putting Down Roots in Earthquake Country.

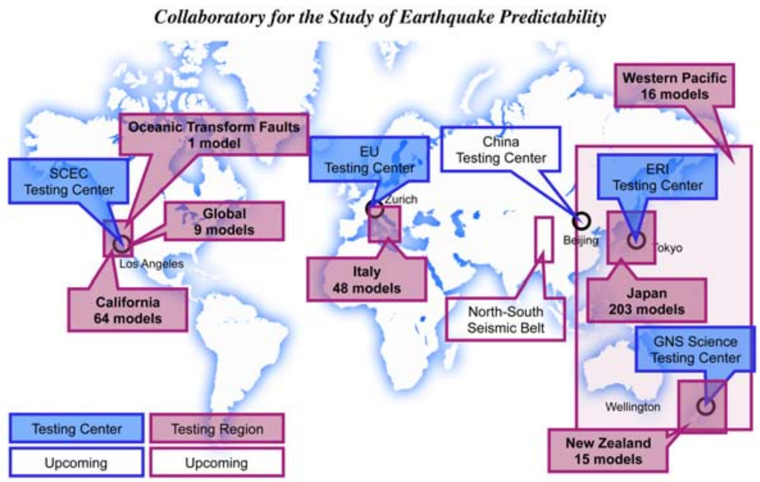

Figure 1.5. Map showing the worldwide distribution of activities developed under the Collaboratory for the Study of Earthquake Predictability (CSEP).

5. SCEC is an ***international leader*** that inspires interdisciplinary collaborations, and it involves many scientists from other countries. Currently, 10 leading foreign universities and research organizations are enrolled as participating institutions (**Table 1.1**), and others are involved through CSEP (**Fig. 1.5**), bilateral memoranda of understanding, and multinational collaborations, such as the Global Earthquake Model (GEM) program. The SCEC program is heavily leveraged by contributions by the foreign participants who are supported through their own institutions.

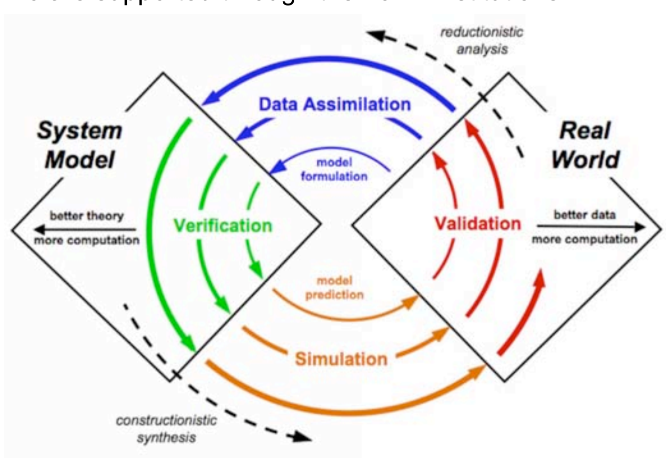

Figure 1.6. The inference spiral for system science, illustrating the improvement of system-level models through an iterated cycle of model formulation (blue), model verification (green), simulation-based prediction (orange), validation against observations (red), and data assimilation (blue). Verification occurs within the system-modeling domain: *does the model do what it's supposed to do at a specified level of precision?* Validation is done in the observational domain: *is the model a credible representation of the real system, adequate for predicting observed behaviors?* Simulation quantifies model predictions for comparisons with observations; data assimilation pulls empirical information into the modeling domain. Moving outward on the spiral involves more computations to incorporate better theories and better observations. Reductionistic analysis complements constructionistic synthesis throughout the process.

C. Earthquake System Science

The SCEC3 research program attacked the three main problems of earthquake system science: (1) *Dynamics of fault systems*—how forces evolve within fractal fault networks on time scales of hours to millennia to generate sequences of earthquakes. (2) *Dynamics of fault rupture*—how forces produce slip on time scales of seconds to minutes when a fault breaks chaotically during an earthquake. (3) *Dynamics of ground motions*—how seismic waves propagate from the rupture volume and cause shaking at sites distributed over a strongly heterogeneous crust. These problems are coupled through the complex and nonlinear processes of brittle and ductile deformation.

Progress in solving these problems has depended on a physics-based, interdisciplinary, multi-institutional approach. The proper use of system models to make valid scientific inferences about the real world requires an iterative process of model formulation and verification, physics-based predictions, validation against observations, and, where the model is wanting, data assimilation to improve the model—reinitiating the inference cycle at a higher level (**Fig. 1.6**). As we move outward on this "inference spiral", the data become more accurate and provide higher resolution of actual processes, and the models become more complex and encompass more information, requiring ever increasing computational resources and an improved arsenal of data and model analysis tools. SCEC provides these resources and tools to the earthquake science community through its core science program and its collaboratories.

II. Organization and Management

SCEC is an institution-based center, governed by a Board of Directors, who represent its members. Current membership stands at 17 core institutions and, as of August 2012, 48 institutions have applied for and received participating status (**Table 1.1**). SCEC currently involves more than 800 scientists and other experts in active SCEC projects. Registrants at our Annual Meetings, a key measure of the size of the SCEC community, is shown for the entire history of the Center in **Fig. 1.4**.

A. Board of Directors

Under the SCEC4 by-laws, each core institution appoints one member to the Board of Directors, and two at-large members were elected by the Board from the participating institutions. The Board is the primary decision-making body of SCEC; it meets three times per year (in February, June, and September) to approve the annual science plan, management plan, and budget, and deal with major business items. The liaison members of the U.S. Geological Survey are non-voting members. The Board is chaired by the Center Director, Tom Jordan, who also serves as the USC representative. The SCEC4 Board has elected Nadia Lapusta of Caltech as its Vice-Chair.

In an invitation sent to all SCEC3 domestic participating institutions, nominations were requested for the two at-large board positions. A number of outstanding nominations were received. As outlined in the by-laws, a secret ballot of the permanent core board members elected Judi Chester of Texas A&M and Roland Bürgmann of UC-Berkeley to the two at-large board positions.

B. Administration

The Director, Tom Jordan of USC, acts as PI on all proposals submitted by the Center, retaining final authority to make and implement decisions on Center grants and contracts, and ensuring that funds are properly allocated for various Center activities. He serves as the chief spokesman for the Center to the non-SCEC earthquake science community and funding agencies, appoints committees to carry out Center business, and oversees all Center activities.

The Deputy Director (DD), Greg Beroza of Stanford, is chair of the Planning Committee, liaison to SCEC science partners, and chair of the annual meeting. The DD oversees the development of the annual RFP, and recommends an annual collaboration plan to the Board based on the review process.

The Associate Director for Administration, John McRaney of USC, assists the Center Director in the daily operations of the Center and is responsible for managing the budget as approved by the Board, filing reports as required by the Board and funding agencies, and keeping the Board, funding agencies, and Center participants current on all Center activities.

C. External Advisory Council

An external Advisory Council (AC) elected by the Board is charged with developing an overview of SCEC operations and advising the Director and the Board. Since the inception of SCEC in 1991, the AC has played a major role in maintaining the vitality of the organization and helping its leadership chart new directions. The AC comprises a diverse membership representing all aspects of Center activities, including basic and applied earthquake research and related technical disciplines (e.g., earthquake engineering, risk management, and information technology), formal and informal education, and public outreach.

Members of the AC are drawn from academia, government, and the private sector. The Council meets annually to review Center programs and plans and prepare a report for the Center. AC reports are submitted verbatim to the SCEC funding agencies and its membership (**Appendix C**).

The SCEC4 external Advisory Council is chaired by Dr. Jeffrey Freymueller of the University of Alaska. John Filson (USGS, emeritus), has rotated off the AC and Susan Cutter (University of South Carolina) has joined AC effective this year.

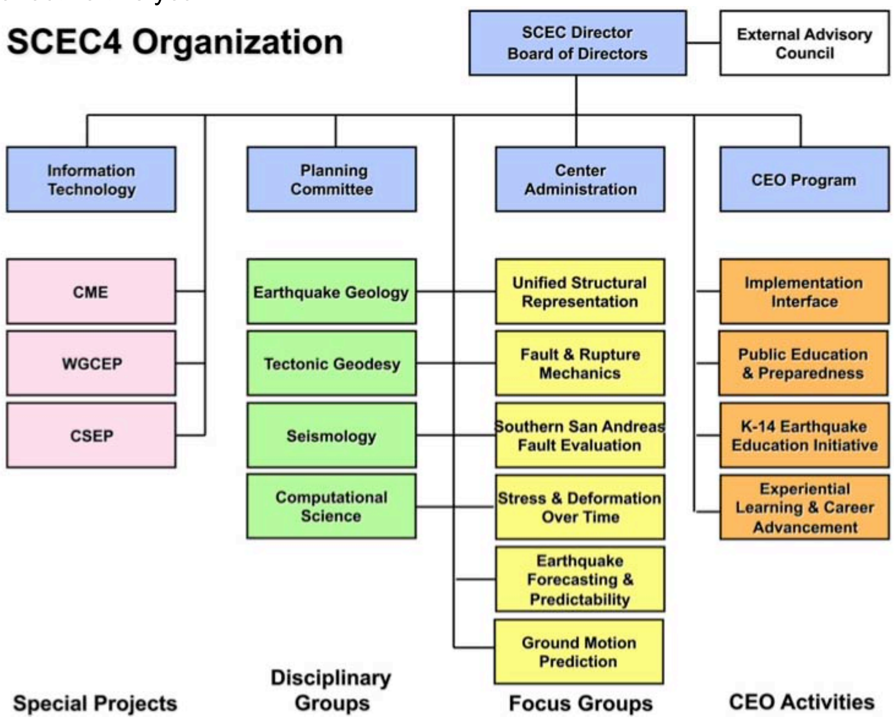

Figure 2.1. The SCEC4 organization chart, showing the disciplinary committees (green), focus groups (yellow), special projects (pink), CEO activities (orange), management offices (blue), and the external advisory council (white).

D. Working Groups

The SCEC organization comprises a number of disciplinary committees, focus groups, special project teams, and technical activity groups (**Fig. 2.1**). The Center supports disciplinary science through standing committees in Seismology, Tectonic Geodesy, and Earthquake Geology (green boxes of **Fig. 2.1**). A new disciplinary committee in Computational Science has been added for SCEC4. They are responsible for disciplinary activities relevant to the SCEC Science Plan, and they make recommendations to the Planning Committee regarding the support of disciplinary research and infrastructure.

SCEC coordinates earthquake system science through interdisciplinary focus groups (yellow boxes). Four of these groups existed in SCEC3: Unified Structural Representation (USR), Fault & Rupture Mechanics (FARM), Earthquake Forecasting & Predictability (EFP), and Ground Motion Prediction (GMP). The Southern San Andreas Fault Evaluation (SoSAFE) project, funded by the USGS Multi-Hazards Demonstration Project for the last four years, has been transformed into a standing interdisciplinary focus group to coordinate research on the San Andreas and the San Jacinto master faults. A new focus group called Stress and Deformation Through Time (SDOT) has merged the activities of two SCEC3 focus groups, Crustal Deformation Modeling and Lithospheric Architecture and Dynamics. Research in seismic hazard and risk analysis is being bolstered through a reconstituted Implementation Interface (an orange box in **Fig. 2.1**) that includes educational as well as research partnerships with practicing engineers, geotechnical consultants, building officials, emergency managers, financial institutions, and insurers.

SCEC sponsors Technical Activity Groups (TAGs), which self-organize to develop and test critical methodologies for solving specific problems. TAGs have formed to verify the complex computer calculations needed for wave propagation and dynamic rupture problems, to assess the accuracy and resolving power of source inversions, and to develop geodetic transient detectors and earthquake simulators. TAGs share a *modus operandi:* the posing of well-defined "standard problems", solution of these problems by different researchers using alternative algorithms or codes, a common cyberspace for comparing solutions, and meetings to discuss discrepancies and potential improvements. There are currently five active TAGs: Ground Motion Simulation Validation (GMSV), Aseismic Transient Detection, Source Inversion Validation (SIV), Dynamic Rupture Code Validation, and Earthquake Simulators.

E. Planning Committee

The SCEC Planning Committee (PC) is chaired by the SCEC Deputy Director and comprises the leaders of the SCEC science working groups—disciplinary committees, focus groups, and special project groups—who together with their co-leaders guide SCEC's research program. The PC has the responsibility for formulating the Center's science plan, conducting proposal reviews, and recommending projects to the Board for SCEC support. Its members play key roles in formulating the SCEC proposals.

F. Communication, Education and Outreach

The Communication, Education, and Outreach (CEO) program is managed by the Associate Director for CEO, Mark Benthien of USC, who supervises a staff of specialists. The Experiential Learning and Career Advancement program and other education programs is managed by Robert deGroot of USC. The Implementation Interface between SCEC and its research engineering partners is managed by Jack Baker of Stanford University, who serves on the Planning Committee.

Through its engagement with many external partners, SCEC CEO fosters new research opportunities and ensures the delivery of research and educational products to the Center's customers, which includes the general public, government offices, businesses, academic institutions, students, research and practicing engineers, and the media. It addresses the third element of SCEC's mission: *Communicate understanding of earthquake phenomena to the world at large as useful knowledge for reducing earthquake risk and improving community resilience*.

The theme of the SCEC4 CEO program is *Creating an Earthquake and Tsunami Resilient California*. CEO will continue to manage and expand a suite of successful activities along with new initiatives, within four CEO interconnected thrust areas. The *Implementation Interface* connected SCEC scientists with partners in earthquake engineering research, and communicates with and trains practicing engineers and other professionals. The *Public Education and Preparedness* thrust area promoted the education people of all ages about earthquakes, and motivated them to become prepared. The *K-14 Earthquake Education Initiative* sought to improve earth science education and school earthquake safety. Finally, the *Experiential Learning and Career Advancement* program provided research opportunities, networking, and more to encourage and sustain careers in science and engineering.

G. SCEC Participants and Diversity Plan

The SCEC leadership is committed to the growth of a diverse scientific community and recognizes that the Center must actively pursue this goal. A diversity working group of the Board of Directors formulates policies to increase diversity, and our progress is closely monitored by the SCEC Advisory Council and feedback to the Board through its annual reports. This diversity planning and review process has provided SCEC with effective guidance. We propose to continue to advance diversity in SCEC4 through several mechanisms:

- Currently, 17 of the 19 Board members are appointed by the core institutions, which are encouraged to consider diversity in their appointments of Board members. SCEC will continue this dialog and will continue to consider diversity in electing the Board's members-at-large.
- Diversity will continue to be a major criterion in appointments to the Planning Committee. The Planning Committee has significant responsibilities in managing SCEC activities and serves as a crucible for developing leadership.
- Many women and minority students are involved in intern and other undergraduate programs; however, successively smaller numbers participate at the graduate student, post doctoral, junior faculty and senior faculty levels. SCEC has little control in hiring scientists and staff at core and participating institutions or in admitting students—institutional diversity goals can be encouraged but not mandat-

ed. However, diversity will be included in the criteria used to evaluate proposals and construct the Annual Collaboration Plan.

- We recognize that the current situation is not unique to SCEC and reflects historical trends in the geoscience and physical science communities. We believe SCEC can be most effective in changing these trends by promoting diversity among its students and early-career scientists; i.e., by focusing on the "pipeline problem". The SCEC internship programs have been an effective mechanism for this purpose (e.g., **Fig. 2.2)**, and we will redouble our efforts to encourage a diverse population of students to pursue careers in earthquake science.

Tangible progress has been made in populating SCEC leadership positions with outstanding women scientists. Four women now serve on the Board of Directors (out of 17), including one as Vice-Chair of the Board. Five women currently serve as working group leaders or co-leaders, and they are participating visibly in the SCEC Planning Committee process. Women also have key roles in SCEC administration and CEO. CEO has contracted with women-owned small businesses in its ECA and ShakeOut activities. Some progress has also been made in terms of participation of minorities in SCEC leadership positions; two Board members and one Planning Committee members are Latino. Early-career scientists occupy SCEC leadership positions, and they have been active in pushing for increased diversity.

Recognizing that diversity is a long-term issue requiring continuing assessments and constant attention by the Center, the leadership has taken a number of concrete steps to improve its understanding of the composition and evolution of the SCEC community. Annual Meeting participants must register with SCEC, which includes providing demographic information. This allows us to continually assess the demographics of the community and track the career trajectories of students and early-career scientists. **Table 2.1** shows a snapshot of the diversity of the SCEC Community as a whole. Diversity levels generally reflect historical trends in the geosciences, with much greater diversity among students than senior faculty. In terms of gender, women account for 51% of SCEC undergraduates, 41% of graduate students, 29% of technical staff, and 22% of researchers. Participation of under-represented minorities is very low, again reflecting the Earth Sciences at large.

Table 2.1. Center database of SCEC participants in 2009-2011.

	Administration or Technical	**Faculty Researcher**	**Non-Faculty Researcher**	**Graduate Student**	**Undergraduate Student**
RACE					
Asian	7	15	22	9	15
Black	1	0	2	0	4
Hispanic or Latin	0	0	1	0	0
White	29	101	122	26	53
Native American	1	2	0	1	2
No info / Withheld	50	81	133	168	32
ETHNICITY					
Latino	6	7	5	8	25
Not Latino	38	122	141	61	55
No info / Withheld	44	70	134	135	23
GENDER					
Female	27	38	67	83	55
Male	61	161	213	121	53
No info / Withheld	0	0	0	0	0
CITIZENSHIP					
US Citizen	44	115	122	54	87
US Resident	3	17	13	4	4
Other	5	19	79	23	4
No info / Withheld	36	53	31	124	14
DISABILITY STATUS					
None	24	98	126	29	66

Hearing	0	1	1	0	0
Visual	1	0	2	0	0
Mobility	0	0	1	0	0
Other	0	1	0	0	0
No info / Withheld	63	99	151	175	42

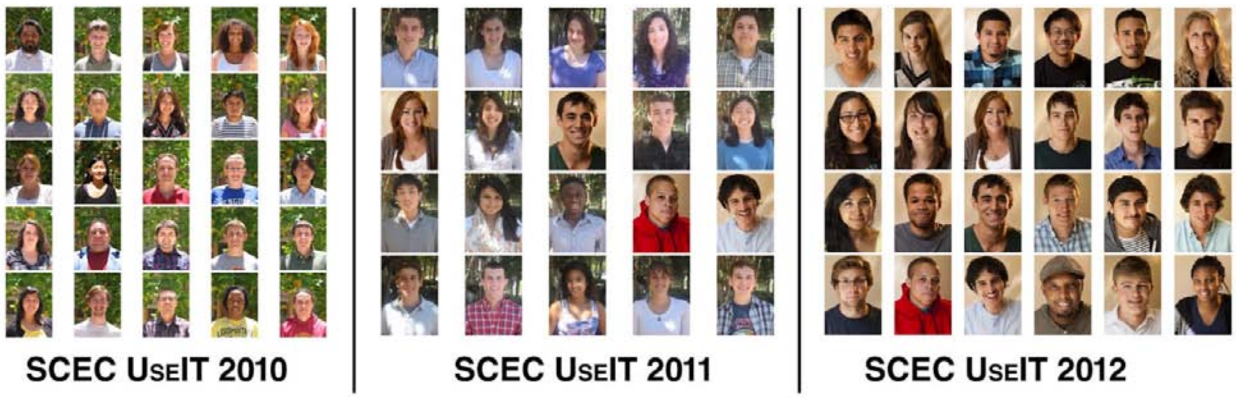

Figure 2.2. Students from around the country who participated in the Undergraduate Studies in Earthquake Information Technology summer internship program at USC in 2010-2012.

A bright spot in our diversity efforts are the SCEC intern programs. During SCEC3, 47% of interns have been women, and 28% were under-represented minorities (**Fig. 2.3**). We believe that the key to increasing the diversity of SCEC participants in the future is to involve, interest, and retain students of diverse backgrounds, encouraging them to continue into research careers. Our recruitment activities now include active participation in regional minority science meetings around the country, and the distribution of recruitment information to historically black colleges and other minority-serving undergraduate institutions nationwide. We are also establishing partnerships with Southern California community colleges, which co-fund students to participate in the SURE and UseIT programs. These recruitment activities have been very successful and will continue in SCEC4.

The expanded Experiential Learning and Career Advancement program (§II.C.4) will add attention to diversity into graduate school and beyond, where the numbers of women and under-represented minorities traditionally decline substantially. Through this program, SCEC mentors students at all levels and encourage trajectories towards STEM careers.

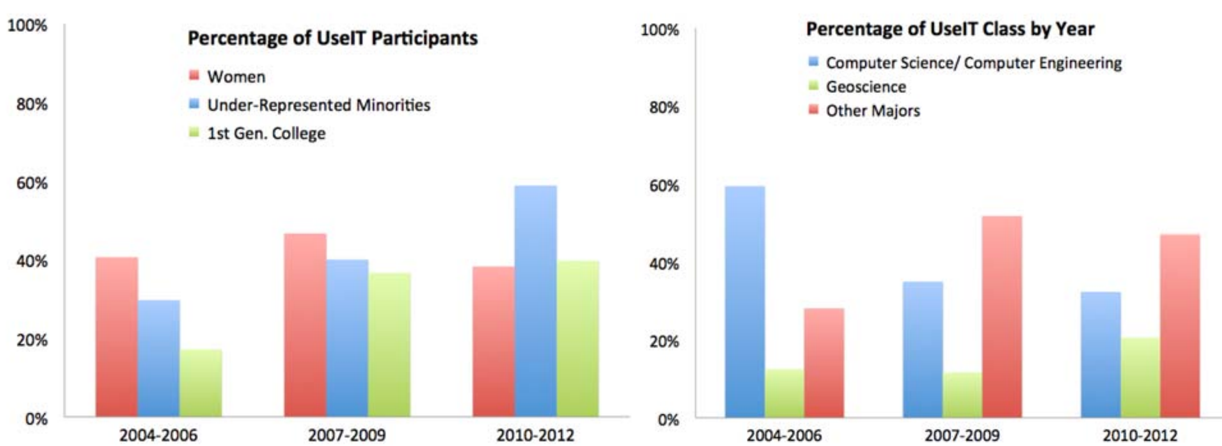

Figure 2.3. (left panel) Percentages of undergraduate students enrolled in the UseIT summer program who are women (red line), under-represented minorities (green line), and first-generation college attendees (blue line). Raising these percentages has been a major objective of the UseIT recruitment effort. **(right panel)** Percentages of undergraduate students enrolled in the UseIT summer program who are computer science/

computer engineering majors (blue line), geoscience majors (green line), and other types of majors (red line). Attracting students from diverse majors to consider careers in geosystem science has been a major objective.

H. International Collaborations

- SCEC Advisory Council. We have one international member, Gail Atkinson of the University of Western Ontario.
- CEO/ShakeOut. SCEC collaborates with Canada, New Zealand, Japan, Italy, and Tajikistan on holding ShakeOut drills. SCEC hosts the websites for all ShakeOut drills worldwide. Mark Benthien and John Marquis traveled to New Zealand to train local officials in the procedure to conduct drills. Benthien also visited Japan during their ShakeOut exercise test.
- ERI/Tokyo and DPRI/Kyoto. SCEC has long term MOU's with the Earthquake Research Institute in Tokyo and the Disaster Prevention Research Institute in Kyoto. A new partnership between SCEC and these two institutions was funded in 2012 by NSF under its Science Across Virtual Institutes (SAVI) initiative. This program will establish a Virtual Institute for the Study of Earthquake Systems (VISES), which will coordinate SCEC/ERI/DPRI collaborations in earthquake system science. Directors Jordan and Beroza visited Japan in May to negotiate the VISES program with the ERI and DPRI leadership, and a three-day workshop involving these organizations was held in Japan in October 2012 to begin collaborative activities.
- CSEP (Collaboratory for the Study of Earthquake Predictability). SCEC founded CSEP in 2006. CSEP testing centers are now located at USC, ERI/Tokyo, GNS/New Zealand, ETH/Zurich, and CEA/China. Masha Liukis, lead software engineer for CSEP, visited Wellington, New Zealand and Potsdam, Germany in 2012 to work with SCEC partners in the development of new CSEP capabilities.
- ACES (APEC Cooperative for Earthquake Simulation). SCEC and JPL are the U.S. organizations participating in ACES. Information on ACES can be found *http://www.quakes.uq.edu.au/ACES/*. Andrea Donnellan of SCEC/JPL is the U.S. delegate the ACES International Science Board and John McRaney of SCEC is the secretary general. The ACES group held a workshop in Maui in October 2012 with SCEC as the host institution. Scientists from Canada, Colombia, New Zealand, Australia, China, Taiwan, and Japan participated in the workshop.
- ETH Zurich/Switzerland. Stefan Wiemar and Jeremy Zechar are participants in the SCEC/CSEP projects. Daniel Roten participates in the source inversion validation project. Luis Dalguer and Seok Goo Song participate in the rupture validation project. Georgia Cua participates on earthquake early warning algorithm testing.
- KAUST/Saudi Arabia. Martin Mai is the leader in the Source Inversion Validation TAG.
- IGNS/New Zealand. Mark Stirling, David Rhoades, and Matt Gerstenberger of the Institute for Geological Nuclear Sciences of New Zealand are involved in the CSEP program. Charles Williams and Susan Ellis participate in the ground motion modeling program.
- Canterbury University/New Zealand. Brendon Bradley participates in the SCEC ground motion simulation program.
- GFZ Potsdam/Germany. Danijel Schorlemmer (also at USC) is the co-leader of the CSEP special project. Olaf Zielke participates in the simulators project.
- UNAM/Mexico. Victor Cruz-Atienza works in the rupture validation project.
- INGV Rome/Italy. Emanuele Casarotti is collaborating with Carl Tape on modeling for the CVM. Warner Marzocchi is a member of the Scientific Review Panel (SRP) for the UCERF3 project.
- University of Naples/Italy. Iunio Iervolino participates in the Ground Motion Simulation Validation TAG under support from the European REAKT Project.
- GSJ/Japan. Yuko Kase works in the rupture validation program.

- CICESE/Mexico. John Fletcher and Jose Gonzalez-Garcia are collaborating with SCEC scientists in post earthquake studies of the El Mayor-Cucupah earthquake and its aftershocks and on modeling for the CGM.
- Scottish Universities Environmental Research Centre Edinburgh/Scotland. Dylan Rood works in the CSEP project.
- SCEC Annual Meeting. The SCEC annual meeting continues to attract international participants each year. There were participants in the 2012 annual meeting from Australia, China, Japan, India, Mexico, Canada, France, Switzerland, Germany, Russia, Italy, Taiwan, Turkey, and New Zealand.
- International Participating Institutions. ETH/Zurich, CICESE/Mexico, University of Western Ontario, and Institute for Geological and Nuclear Sciences/New Zealand; and 4 institutions from Taiwan (Academia Sinica; National Central University; National Chung Cheng University; National Taiwan University) are participating institutions in SCEC.
- International Travel by PI and SCEC Scientists. The PI and other SCEC scientists participated in many international meetings and workshops during the report year. They include: 1) the ACES workshop in Maui in October 2012, 2) the IUGG Conference on Mathematical Geophysics in Edinburgh in June 2012, 3) the 15th World Congress on Earthquake Engineering in Portugal in September 2012 4) the GEM meeting in Pavia, Italy in December 2012, 5) the REAKT annual meeting in Potsdam, Germany in October 2012, 6) the XSEDE/PRACE Computer Science Workshop in Dublin, Ireland in June 2012, and High Performance Computing in China Workshop in Beijing, China in October 2012, and the SCEC-ERI Workshop in Sendai, Japan in October, 2012

III. SCEC Accomplishments

A. Research Accomplishments

The fundamental research goal of SCEC4 is understanding how seismic hazards change across all time scales of scientific and societal interest, from millennia to seconds. The SCEC4 science plan was developed by the Center's Board of Directors and Planning Committee with broad input from the SCEC community in support of this goal. Through that process we identified six fundamental problems in earthquake physics:

Table 3.1 Fundamental Problems of Earthquake Physics

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

These six fundamental problems define the focus of the SCEC4 research program. They are interrelated and require an interdisciplinary, multi-institutional approach. During the transition to SCEC4, we developed four interdisciplinary research initiatives and reformulated our working group structure in accordance with the overall research plan. We have also formalized Technical Activity Groups (TAGs) in which groups of investigators develop and test critical methods for solving specific forward and inverse problems. There are currently five active TAGs. We organized this report to emphasize progress on implementing these activities - particularly those that are new to SCEC4.

1. Special Fault Study Areas: Milestone 6

The SCEC4 proposal made the case for focused interdisciplinary research in special fault study areas (SFSA). Complexities associated with high slip-rate faults provide excellent targets because they are where seismic, geodetic, and geologic signals tend to be strong, and difficult to interpret without a fully interdisciplinary approach. The San Gorgonio structural knot, where slip on the San Andreas Fault is partitioned onto multiple thrust- and oblique-slip strands through a compressive, 10-km double-bend, is the prototypical SFSA. Slip-rates diminish on the San Andreas approaching this bend, suggesting it may act as a persistent rupture barrier. Understanding whether large ruptures might propagate through the San Gorgonio Pass is particularly important for predicting earthquake size and ground motions from future earthquakes on the southern San Andreas. The other SFSA in development in 2012 is the Ventura Avenue Anticline region. We report on four developments related to SFSA in the first year of SCEC4: (a) Policy for SFSA implementation, (b) A workshop on the San Gorgonio Pass, (c) Funded proposals focused on the Ventura Avenue Anticline Area, and (d) A forum on SFSA at the SCEC Annual Meeting. By developing a policy for initiating SFSA, and by nucleating two such areas, we have met science milestone 6 for year 1 of SCEC4.

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

Science Plan. Beginning in 2012, current and future SFSA are required to formulate a Science Plan that describes the general structure and scientific questions to be addressed by the group. Groups interested in formalizing SFSA are encouraged to self-organize and develop a Science Plan or propose a workshop (through the standard *SCEC proposal process*) to explore a new SFSA.

The Science Plan for a SFSA should be developed and written by a group of SCEC investigators, and submitted in conjunction with SCEC proposals due in early November. The plan should include (in ~2 pages plus references):

- Identification of key questions and research targets that address fundamental problems in earthquake science with an interdisciplinary plan for achieving these goals within SCEC4
- Discussion of integrative activities and broader impacts
- Assessment of resources needed to achieve these goals and identification of outside resources that may be required
- Timeline identifying short and long term goals and completion date

2013 SCEC Proposals Associated with SFSA. Each principal investigator should submit a separate, standard 5 page SCEC proposal for 2013 that clearly ties the investigator's work to the Science Plan, provides additional background and details on the data collection and/or analyses to be completed by that investigator, and includes a budget for that investigator. Each investigator's proposal will be evaluated separately through the standard *SCEC proposal process* (see 2013 SCEC Science Collaboration Plan). Workshop proposals for activities around the SFSA should be developed according to the standard workshop proposal process as outlined in the 2013 Collaboration Plan.

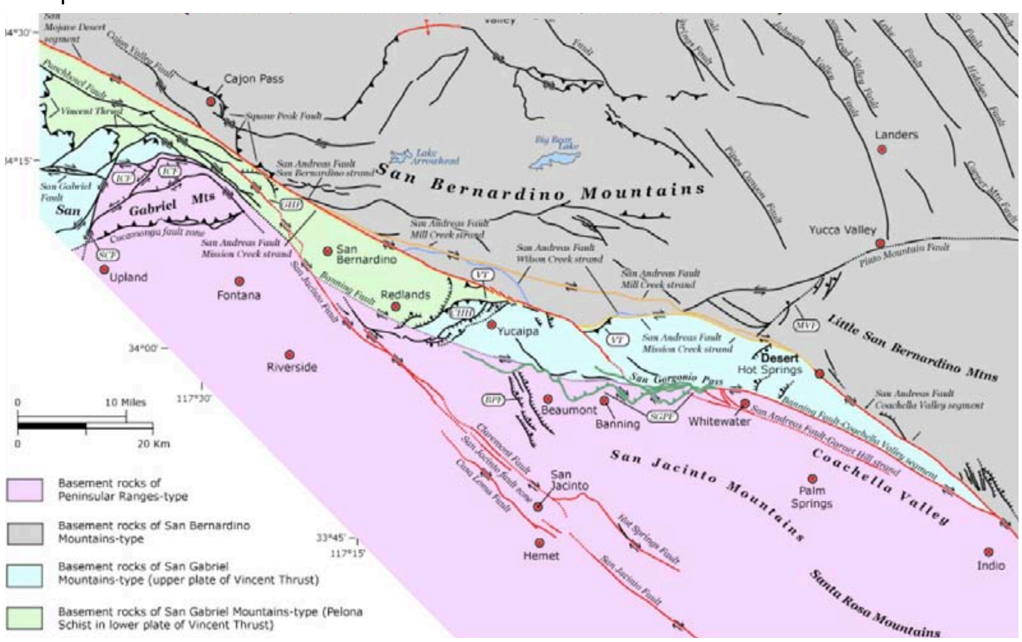

Figure 3.1. Geologic map of the San Bernadino Mountains segment of the San Andreas Fault Zone centered on San Gorgonio Pass (after *Matti et al*., 2004). Understanding the complex interaction of the multiple faults across this structural knot is key to understanding the earthquake potential of the Southern San Andreas Fault.

b. San Gorgonio Pass Workshop (June 1-2, 2012): This workshop explored the San Gorgonio Pass "knot" region as a candidate for a SCEC Special Fault Study Area and outlined a plan to fill existing knowledge gaps. Specific topics included the geometry of active subsurface faulting, the potential for earthquakes on the complex fault system in this region, and the likelihood of a 'super-earthquake' that would propagate along the San Andreas system through the pass, leading to a very large-magnitude and damaging event. The workshop brought together geoscientists from a wide spectrum of interests including tectonic geomorphology, structural geology, mechanical modeling, rupture modeling, gravity and magnetic modeling, seismology, geochronology, geodesy, and fault and rock mechanics. The first day was a blend of short science talks on case studies with discussions of specific topics. On the second day, we took a field trip to view key sites in San Gorgonio Pass. (For results, see: *http://scec.org/workshops/2012/sgp/index.html*).

c. Ventura Avenue Anticline Area: The goal of this SFSA is to focus multi-disciplinary efforts on the common problem of understanding the structure, state of activity, slip rates, and seismic hazards of the Ventura region faults, and more generally on assessing the degree to which these faults provide potential structural linkages for through-going, large-magnitude multi-segment ruptures. Much of this research is already under way with SCEC funding, including 3D structural modeling using industry well and seismic reflection data and newly collected high-resolution reflection data, both onshore and offshore paleoseismologic work aimed at determining the slip rates of these faults and the ages and displacements of ancient earthquakes that they have generated, studies of tsunami records preserved in estuarine sediments, mechanical modeling of regional fault interactions, and dynamic rupture simulations. There are plans for a SCEC workshop on this SFSA to be held in 2013.

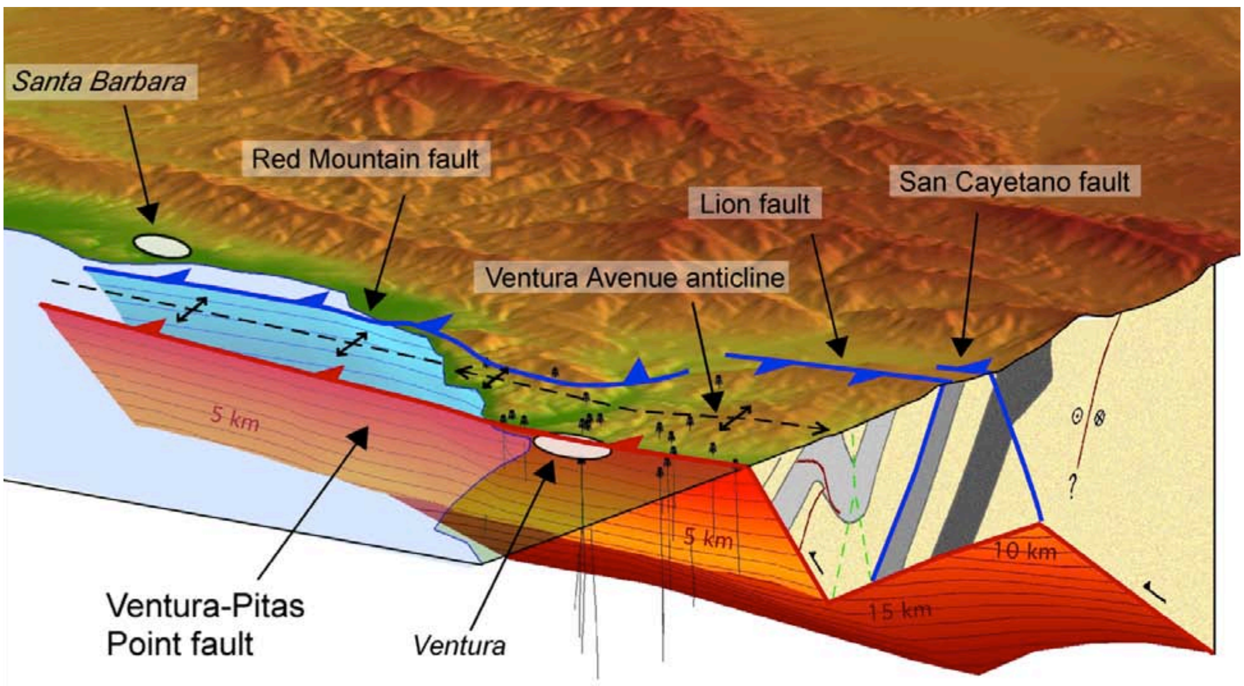

Figure 3.2. from *Hubbard et al.* (submitted) 3D cross section showing possible linkages between the fault underlying the Ventura Avenue Anticline, and other major faults in the western Transverse Ranges. Several lines of evidence, including archeological observations at Pitas Point, indicate extremely large earthquakes on this structure in the past, which in turns suggests these structures can rupture in a single event.

d. SCEC Annual Meeting Session: We convened a session at the SCEC Annual Meeting in September (*http://www.scec.org/meetings/2012am/agenda.html*) entitled, "Super-Natural Laboratories - Special Fault Study Areas in SCEC4." The session was chaired by Kate Scharer (USGS) and Mike Oskin (UC Davis) and featured talks by James Dolan (USC) entitled, "The Ventura Region Special Fault Study Area: Towards and Understanding of the Potential for Large, Multi-Segment Thrust Ruptures in the Transverse Ranges" and Doug Yule (CSUN) entitle, "SCEC Workshop on San Gorgonio Pass: Structure, Stress, Slip, and Likelihood of Through-Going Rupture."

2. Community Geodetic Model: Milestone 4

Densification of GPS arrays as part of Earthscope, the rapidly growing volumes of InSAR data from various satellites, and the development of time series analysis for InSAR data all motivated the development of a Community Geodetic Model (CGM), and we report here on progress in meeting science milestone 4. The CGM should improve geodetic studies of non-secular strain phenomena observed in Southern California, including post-seismic deformation. It will be distinct from the past SCEC Crustal Motion Map (CMM) because it will be time dependent and will incorporate InSAR data to constrain both the vertical deformation field and small-scale details of the regional deformation. This will lead to refined and improved tectonic geodesy data products for use in modeling. The CGM would be used in combination with other SCEC community models to infer the evolution of sub-surface processes. It will also provide a time-dependent reference frame for transient detection algorithms, as well as models of interseismic loading to evaluate stress changes and update rupture forecast models as tectonic conditions evolve in California. The challenge of the CGM is to exploit the spatially sparse, temporally dense 3D GPS time series and spatially dense, temporally sparse InSAR line-of-site time series consistent with GPS time series in an appropriate projection. The CGM and activities stemming from it, was the topic of a workshop led by Jessica Murray (USGS) and Rowena Lohman (Cornell) at the 2012 SCEC Annual Meeting.

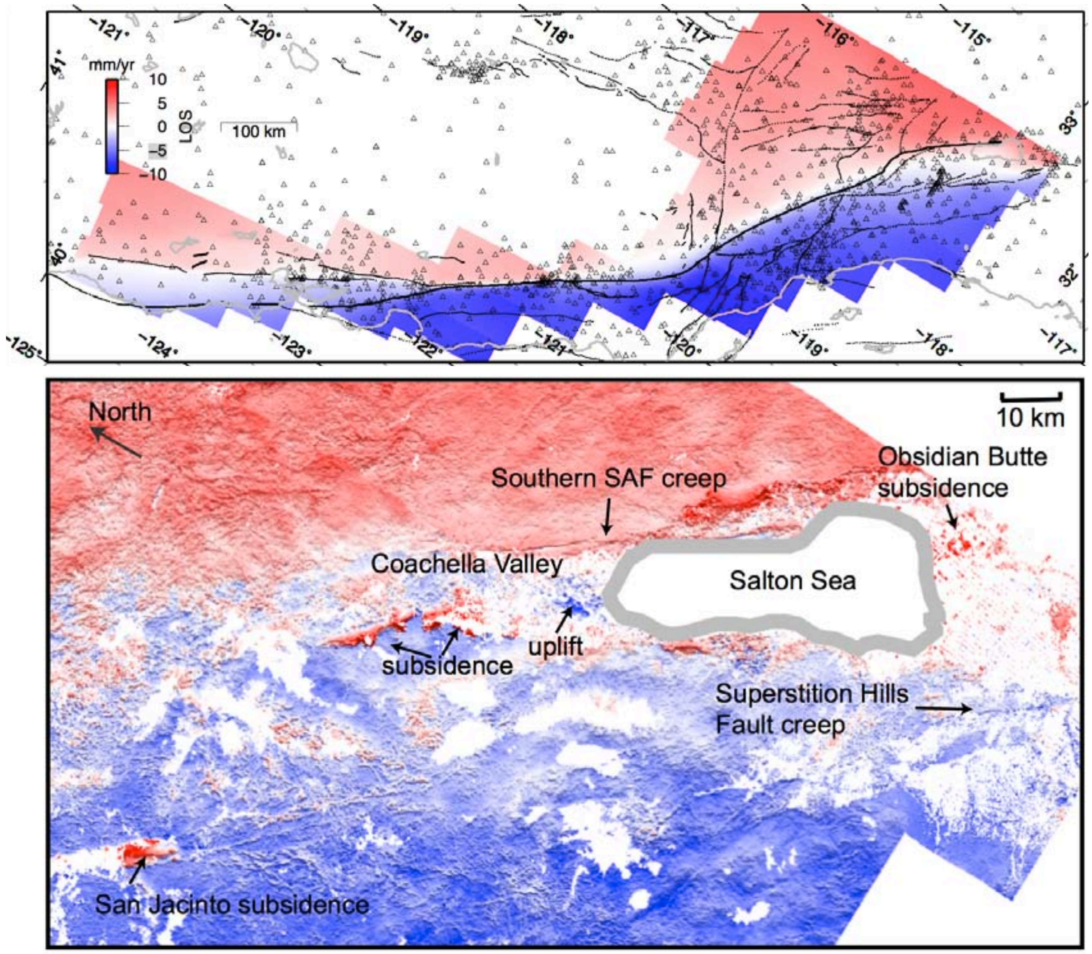

Figure 3.3. After Tong et al. (in press), upper panel shows crustal velocity model in line-of-sight (LOS) velocity based on regional GPS velocity field (Smith-Konter and Sandwell, 2009). Colors represent the LOS velocity field along 13 ALOS ascending tracks. Positive velocities (red) show the ground moving relatively away from the satellite. Small triangles are the GPS stations used to constrain the velocity model. Black lines indicate fault traces. Lower panel shows integration of GPS and ALOS InSAR data (2006.5-2010). Areas with low coherence and large standard deviation (> 6 mm/yr) are masked. Southern part of the SAFS shows the broad transition in velocity across the San Andreas and San Jacinto Faults as well as many local features related to fault creep or land subsidence.

a. Modeling Advances in the SCEC Geodesy Community Workshop (September 9, 2012): This workshop (full report available at: *http://www.scec.org/workshops/2012/geodesy/index.html*) addressed three major SCEC4 Tectonic Geodesy modeling activities: the Community Geodetic Model (CGM), Geodetic Transient Detection, and a new Geodetic Source Inversion exercise.

The first portion of the workshop focused on the Community Geodetic Model (CGM). The CGM will be a time-dependent geodetic data product that provides a reference frame for a variety of SCEC research including development and testing of the Community Stress Model, transient detection algorithms, and studies of time-varying deformation. The initial focus of this effort is on bringing together GPS and InSAR time series to exploit the complementary spatial and temporal features of these two data types (**Fig. 3.3**). Ultimately other data types (such as strain data) may be incorporated as appropriate and if feasible. A variety of approaches exist, and all are to some degree model-dependent. One challenge for the development of the CGM will be to identify the most promising approaches for southern California and provide appropriate uncertainty information for the resulting product accounting for the error sources inherent in both data types.

The primary goal of this portion of the workshop was to introduce the CGM to the SCEC community and initiate discussion. A follow-on workshop involving scientists who are likely to be directly involved in developing and applying the CGM is envisioned for 2013. A goal for that workshop will be establishing timelines and a work plan for generating the CGM.

3. SDOT and the Community Stress Model: Milestone 5

Stress and Deformation Over Time (SDOT) is a new interdisciplinary focus group in SCEC4. It is concerned with developing an understanding of how stress is transmitted from the very largest (plate boundary) scales, down to the scale of fault zones. Central to this is determining what is known about the stress distribution in space and time. For this reason, we have undertaken the challenging task of developing Community Stress Models (CSMs) to constrain the physics of earthquakes. In this first year of SCEC4, we have achieved science milestone 5, which describes laying the foundation for the CSMs. Building CSMs will provide a platform where different constraints on stress can begin to be integrated and agreements and conflicts between models examined in a quantitative and comprehensive way. CSMs will bear many similarities to other SCEC community models. At long wavelengths, we can use observations from seismology and geodesy to constrain the tectonic components of CSMs deterministically. A variety of observations are relevant: focal mechanisms, fault orientations, shear wave splitting, heat flow, stress orientations in boreholes, and topography. Numerous modeling approaches are available: block and viscoelastic loading models to constrain stressing rates, and joint inversions that combine geodetic and focal-mechanism data with gravimetric and tectonic modeling to constrain absolute stress. At short wavelengths, the stress field is thought to become highly heterogeneous, and it will be necessary to employ stochastic descriptions. Constraints are available through the observable effects of stress heterogeneity on larger scale behaviors, such as on aftershock decay rates, aftershock locations, and focal mechanism diversity.

CSMs should properly reflect “uncertainties” in an extensive and systematic fashion, both in terms of measurement and inversion robustness issues, and in terms of alternative physical descriptions (e.g. statistical vs. deterministic, fractal vs. euclidean). The representation of such alternative hypotheses and uncertainties should ideally be in terms of (spatiotemporally variable) probability density functions for all relevant tensorial components, as a function of model assumptions and priors. Approximations and judicious parameterizations will have to be made, but the challenges will be synergistic with other SCEC4 objectives, such as to better characterize the uncertainties in our other community models.

We recognize that CSMs represent a considerable challenge, and have held several workshops and dedicated considerable time at the 2011 and 2012 Annual meetings to engage the SCEC community in this effort.

a. Workshop on Strategies for Implementing a Community Stress Model (September 14, 2011): This workshop helped kick off the discussions of the construction of a community stress model (CSM). The workshop was held after the 2011 Annual SCEC meeting in Palm Springs (i.e., near the end of SCEC3). The program consisted of six invited presentations, 15 minutes each, four contributed five-minute discussion presentations, and extensive group discussions (total of ~two hours), as detailed in the appendix. Workshop presentations were chosen to represent the observational, theoretical, and modeling aspects involved in the construction of a CSM.

Lively discussions ensued, including on the degree of homogeneity or heterogeneity of crustal stress, how to best model it, and how to take action to get started on the assembly of a stress indicator database. It was decided that the logical first step for the CSM group and SCEC CSM efforts is to compile all of the existing relevant data and stress models for California, and put them into common formats. This compilation should eventually become a resource for the SCEC community to be able to easily find and use these data and models. Such a compilation will also facilitate comparisons between the currently existing stress models in order to better understand where various models differ. The database will also facilitate evaluating the relative coverage of various data/models, etc, and will help get the ball rolling on putting together a numerical implementation of stress models overall.

It was also decided to strive to hold a follow-up CSM workshop in 2012 focused on comparing the currently existing stress models (including the full range from geodynamic models to observational "models" such as borehole measurement compilations or focal mechanisms inversions). As one goal of the 2012 workshop, the group identified the process of coming with specific next steps by targeting areas of differences between the existing models. Attendance of the 2012 workshop is to be limited to contributors of data/models and representatives of user communities of the CSM, as we will be getting into the nitty-gritty of data/model formats and comparisons. The larger community will of course be updated on our progress, and a mailing list was established to continue the discussions related to the CSM and the CSM 2012 workshop.

b. SCEC Community Stress Model Workshop (October 15-16, 2012): This workshop of the SCEC CSM project focused on compiling and integrating existing stress models and data contributed by the SCEC community. The workshop format was primarily group discussions, rather than formal presentations. We started off with an overview of each of the submitted models followed by exploration of the similarities and differences between them. A focus of this workshop was to identify: first steps for integrating the various data and models to build the CSM, major incompatibilities that may represent branches in the CSM, and possible research avenues to address outstanding issues. **Fig. 3.4** shows a preliminary averaging and comparison of the compatibility of different stress models that came out of that workshop.

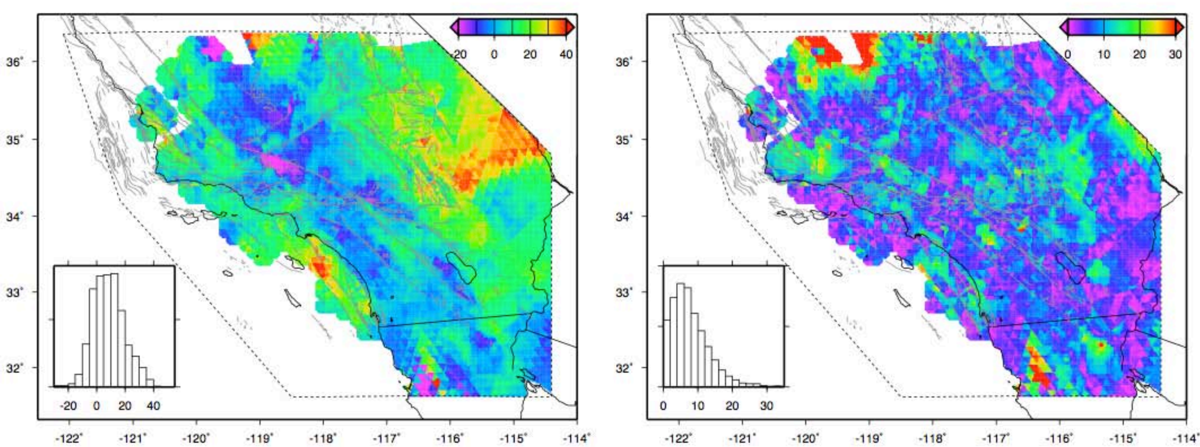

Figure 3.4. SHmax (left) for an average stress model generated by averaging the normalized stress tensors of the models of Bird; Luttrell, Smith-Konter and Sandwell; and Yang and Hauksson. Right panel shows RMS difference of SHmax orientation of the three models relative to the mean.

The leaders of the CSM effort, identified six specific high-priority needs for the coming year, each with an identified point-of-contact person as follows:

- Acquisition and Compilation of Borehole Data (POC: John Shaw)
- Acquisition and Compilation of Geologic Data (POC: Joann Stock)
- Stressing Rate Models from UCERF3 Deformation Models (POC: Liz Hearn)
- Crustal Anisotropy Compilation (POC: Jeanne Hardebeck)

- Compilation of Stress Estimates from Ductile Rocks (POC: Greg Hirth)
- Physics-based Long-Term Deformation Models of the Southern California Lithosphere (POC: Thorsten Becker)

4. Unified Structural Representation: Milestone 3

The initiative to combine the Community Fault and Velocity Models into a self-consistent Unified Structural Representation (USR) began in SCEC2 and continues in SCEC4 as the need to improve and extend the USR is driven by research needs. Versions of the CVM now directly incorporate results from full-3D waveform tomography. These methods offer clear paths for improving the CVM's, which are critical in ground motion simulations and, remain a key focus for SCEC4 because other research depends on them. Through these actions, and by improving access and output options for the USR, have made a major contribution to meeting science milestone 3.

Extension of ground motion simulations to higher frequencies requires increased accuracy in velocity representations within the CVM's. We have implemented a Geotechnical Layer in recent versions of CVM-H for this reason. Several research teams are exploring the development and use of stochastic approaches to characterize the variability of wavespeeds as described below. Small-scale structure is particularly important in shallow sediments for predicting strong ground motion to high frequencies. The performance of these alternative parameterizations will ultimately be measured through direct comparisons of observed and synthetic waveforms at higher frequencies, and validated as part of the newly established Ground Motion Simulation Validation Technical Activity Group.

LiDAR, as well as relocated seismicity and focal-mechanism catalogs provide important opportunities to improve fault geometries in the Community Fault Model (CFM). Tomographic refinements will offer new constraints on fault geometries at depth. The CFM will need to incorporate revised, alternative representations of fault geometries that properly reflect these new constraints in hazard calculations and fault system models. A new emphasis will be on representing smaller scale features, such as the detailed representations expected from the special fault study areas.

a. Upgrades and Improvements to the SCEC Community Fault Model: Increasing 3D fault complexity and compliance with surface and subsurface data. Important upgrades to the SCEC Community Fault Model (CFM) was released as CFM v.4.0 in Fall, 2012. The release incorporates improvements in 3D fault representations, a detailed fault surface trace layer, and a new fault naming and numbering scheme that allows for closer links to the USGS/CGS Quaternary Fault database (Qfaults). Fault representations in CFM are now available referenced to the modern WGS84 datum and the new surface layer in CFM allows upgraded 3D fault models to be registered to the more detailed Qfaults and other digital fault maps. Registration of older CFM faults to the Qfault surface traces is still ongoing. We use alignments of hypocenters and nodal planes from relocated earthquake catalogs (e.g., *Hauksson et al*., 2012; **Fig. 3.5**) to define better the subsurface geometry of active faults. These new revised CFM fault models and interpretations allow for more non-planar, multi-stranded 3D fault geometry, and characterize a more complex pattern of fault interactions at depth. This increasing 3D fault complexity for CFM representations is particularly evident along the multi-stranded San Andreas fault and adjacent secondary structures in the Coachella Valley and through San Gorgonio Pass, as well as for the complex surface and subsurface ruptures associated with the Laguna Salada and related faults involved in the El Mayor-Cucapah sequence. The CFM fault database hierarchical naming and numbering scheme was substantially revised and sent out for review, in order to identify areas of CFM for further improvements and upgrades.

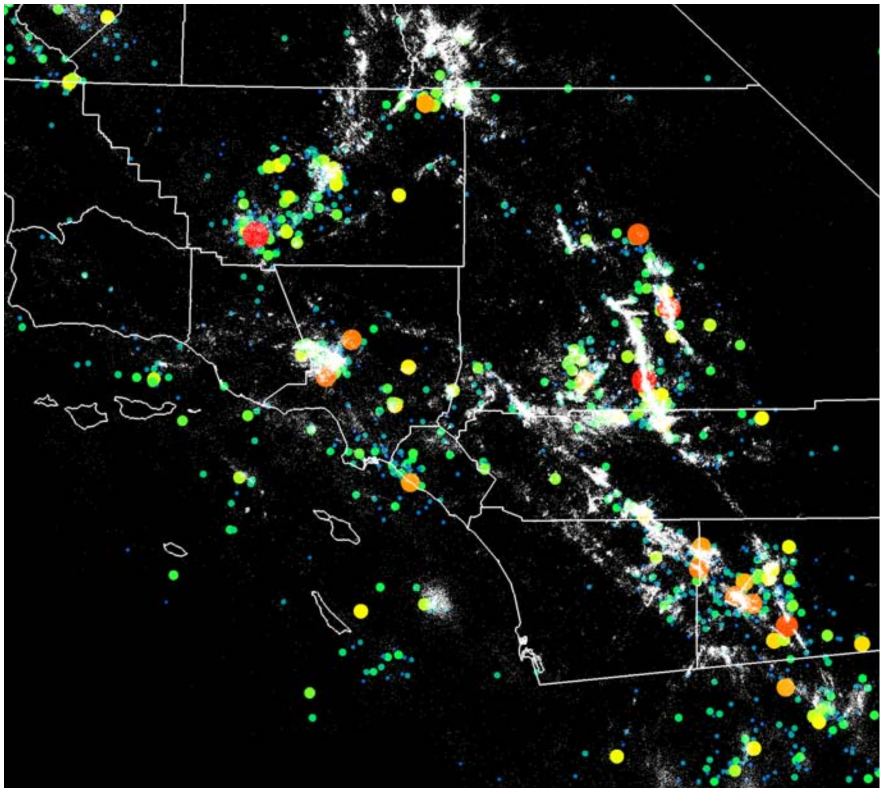

Figure 3.5. Relocated earthquakes (*Hauksson et al.,* 2012) used to refine CFM 4.0.

b. Stochastic Descriptions of Basin Velocity Structure from Analyses of Sonic Logs and the SCEC Community Velocity Model (CVM-H): The trend of numerical wave propagation studies to shorter periods creates a demand for higher resolution velocity models. An important initiative within the USR is to characterize small scale-length (<100m) structure stochastically. Sonic logs in the Los Angeles basin together with the existing CVM-H can be used to represent compressional and shear wave slowness in the upper 3 km (**Fig. 3.6**). As a first step, smoothed well log data were used to define the scale of variability present in the data, but not represented in current models. This analysis reveals a variation of 157 ms/m around a mean of 1.3 ms/m for P-wave slowness. Vertical analyses were conducted in individual wells, whereas groups of closely spaced wells were used to analyze horizontal variability. The smallest lag where variance starts to level out to a background level can be considered the largest correlation distance. Preliminary results show a vertical correlation distance of about 80m at which variance levels reach about 430 ms^2/m^2. In the horizontal analysis, variograms were constructed with lags varying from 100 m to 8 km. This analysis showed a maximum correlation distance of about 900m where variance reaches a high level of about 750 ms^2/m^2. Thus, the model analysis suggests a ratio of horizontal to vertical correlation lengths of about 11:1. Other analysis suggests that wavespeed variations conform to a fractal distribution with fractal dimensions of 1.5-1.8 and related Hurst exponents of 0.2-0.5.

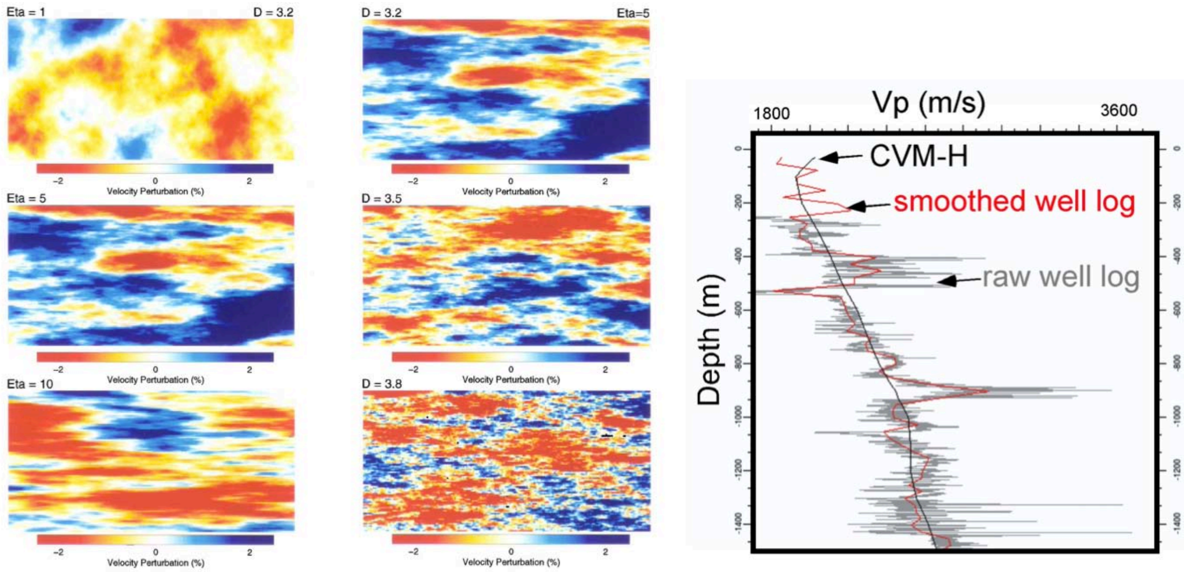

Figure 3.6. Left panels depict vertical sections through realizations of the 3D Goff-Jordan stochastic model. Far left panels show the isotropic case (η = 1) and two levels of anisotropy (η = 5, 10) for σ =2%andv=0.8. Middle-left panels show three values of the self-affine scaling (v = 0.8, 0.5, 0.2). corresponding to fractal dimensions of 3.2, 3.5, and 3.8. Right panel shows sonic logs - both smoothed (red) and raw (gray) - from which information on small-scale wavespeed variations can be estimated.

An intermediate-term goal of these efforts is for future releases of the CVM-H to provide, as an option, stochastic representations of the finer scale velocity structure that can be used to simulate ground motions at higher frequencies. The effects of the near-surface heterogeneities on ground motion and scattering will be tested using simulations of selected historical earthquakes with a high density of strong motion recordings available. These simulations will be calculated for variable values of Qs and Qp, in order to examine the interdependency between intrinsic and scattering attenuation on the ground motion.

c. Full-3D Waveform Tomography for Southern California: SCEC investigators are using full 3D tomography (F3DT) that uses 3D SCEC Community Velocity Model Version 4.0 (CVM4) in Southern California as initial model, a staggered-grid finite-difference code to simulate seismic wave propagation and sensitivity (Fréchet) kernels calculated based on the scattering integral and adjoint methods to iteratively improve the model. Both earthquake recordings and ambient noise Green's function data are used in our F3DT inversions. To reduce errors of earthquake sources, the epicenters and source parameters of earthquakes used in our F3DT are inverted based on full-wave method. The resulting model shows many features related to the geological structures at shallow depth and contrasting velocity values across faults. The perturbations with respect to the initial model in some regions approach 40% in places where the current model is refined (such as southern Great Valley). The waveform fittings of earthquake waveforms and ambient noise Green's function data are both improved after iterations. The earthquake waveform misfit and summation of square of ambient noise Green's function group velocity delay time between observed waveforms and updated synthetic waveforms are both reduced more than 50%.

5. Ground Motion Simulation Validation (GMSV) TAG: Milestone 7

Technical Activity Groups (TAGs) are organized within SCEC to develop and test critical methods for solving specific forward and inverse problems. TAGs typically involve:

1. posing well-defined “standard problems”
2. solving them by different researchers with different approaches
3. virtual/in person meetings to compare solutions, discuss discrepancies, and work on improvements

Ground Motion Simulation Validation (GSMV) is a TAG that was initiated in SCEC4, to validate ground motion simulations against observed strong motion data. SCEC has recruited the involvement of earthquake engineers and engineering seismologists, because they are the critically important potential users of ground motion simulations. Thus, they are ideally situated to judge whether or not ground motion simulations are reasonable. For this reason we have recruited substantial involvement in this TAG by earthquake engineers, and it is led by Nico Luco, an earthquake engineering seismologist at the USGS. This TAG is in the early stages, but has been very active (*collaborate.scec.org/gmsv*) in the first year of SCEC4. Activities to date include:

- April 2012 Coordination Workshop - Click *SCEC Award 12171* for workshop summary and report.
- Special Session at 2012 SSA Annual Meeting
- September 2012 Workshop - Click *SCEC Award 12171* for workshop summary and report.
- SCEC Annual Meeting Session *“The Importance of Faking It - Ground Motion Simulation for Earthquake Engineering”*, featuring C.B. Crouse talk on “The Role SCEC Can Play in Improving Seismic Provisions in US Codes through Ground-Motion Simulations”, which led to follow-up activities including
- Formation of the *“Committee for use of Ground-Motion Simulations in Seismic Provisions”* (chaired by Crouse), and tasked to develop long-period response spectral acceleration maps for Los Angeles region for inclusion in NEHRP and ASCE 7 Seismic Provisions and in Los Angeles City Building Code. The maps would be based on 3-D numerical ground-motion simulations, and ground motions computed using latest empirical ground-motion prediction equations from the on-going PEER NGA project. The project would be coordinated with other SCEC projects, such as CyberShake and UCERF, and with the USGS national seismic hazard mapping project.

By developing a set of standards, and a set of earthquake ground motions to validate ground motion simulations against, we have met science milestone 7.

6. Aseismic Transient Detection TAG: Milestone 2

The Aseismic Transient Detection TAG has developed the capability of searching systematically through geodetic data for aseismic deformation transients. This TAG was formed during SCEC3 when SCEC leadership expressed concern that there was little effort apparent being dedicated to detecting anomalies in geodetic observations in Southern California. Most of the activity during SCEC3 was focused on blind tests of synthetic data, which was created by Duncan Agnew. The activity was led by Jessica Murray USGS) and Rowena Lohman (Cornell) and the response was tremendous - to the point that a milestone for the first year of SCEC4 is to initiate a testing center with operational transient detectors running on real data (**Fig. 3.7**). The transient detection group has developed the framework for hosting detection algorithms that includes an authoritative GPS data stream as well as a catalog of GCMT earthquake solutions through CSEP. Two detection algorithms are currently hosted at CSEP, with differing treatments of the seasonal, coseismic and postseismic signals within the time series. The newest algorithm also outputs the magnitude and functional form of seasonal signals - a product that may aid in development of the Community Geodetic Model. Thus, science milestone 2, which concerns transitioning the transient detection endeavor to operational status, has been achieved.

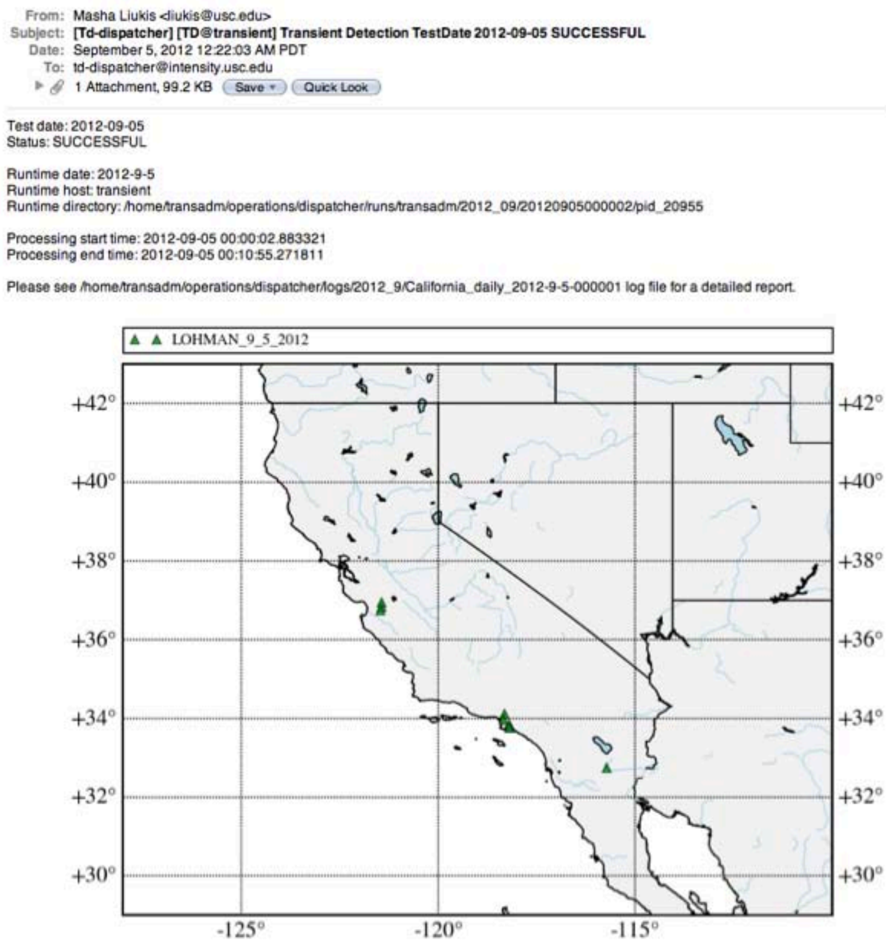

Figure 3.7. Screenshot of an automated email from an algorithm that is part of the test Green triangles show locations where transient behavior has been flagged.

7. Source Inversion Validation TAG: Milestone 8

The Source Inversion Validation (SIV) TAG is focused on determining what aspects of finite-source models are robustly determined. This is a challenging problem because there are strong trade-offs, for example between slip velocity and rupture time, and because the inverse problem is underdetermined and thus has a null space that is filled according to assumptions made by different investigators as part of the inversion process. The SIV TAG held a workshop at the SCEC annual meeting, and there is a call among geodetic modelers to have an element of the exercise that is focused on source estimation using geodetic data. This is an interesting adjunct to the seismic data because it is sensitive to the final slip distribution and source geometry, but not to the time evolution of rupture. This effort is an important part of meeting science milestone 8.

8. Dynamic Rupture Code Validation TAG: Milestone 8

The Dynamic Rupture Code Validation TAG is focused on developing benchmarks for dynamic rupture simulation. This is a long-running (since 2003) and very successful TAG. Although the notion of a finite lifetime is purposely built into our philosophy of TAGs, this TAG has been so successful, and the need for testing increasingly capable dynamic rupture modeling algorithms that can model more complex geometry and physics, means that this TAG is not likely to sunset soon. Tasks for this years exercise include modeling strongly heterogeneous rupture and modeling rupture of a stepover on a vertical strike-slip fault.

9. Earthquake Simulators TAG: Milestones 3, 9

The Earthquake Simulators TAG is focused on developing simplified representations of earthquake rupture that account for the important effects of fault geometry, stress transfer, and rupture nucleation and dynamics, in order to develop long-term synthetic seismicity catalogs. Different simulators take different approaches to capturing what is judged to be the essential elements of fault systems and the physics that govern it. The latest comparison of output between competing simulators uses a simplified version of the statewide community fault model (**Fig. 3.8**), such that the geometry is common to all the simulators, to test simulator outputs.

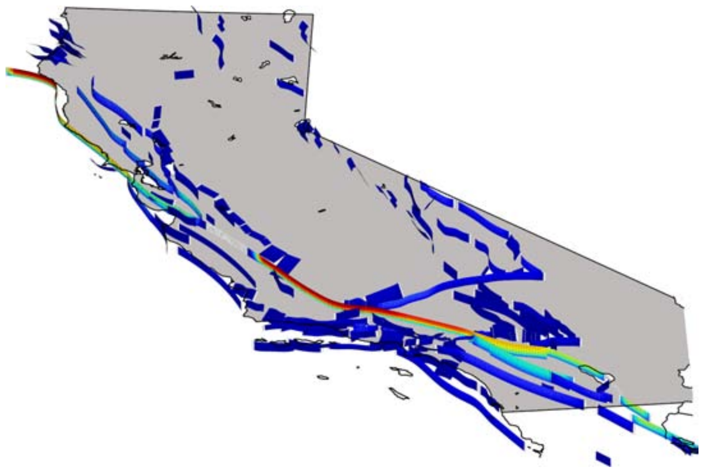

Figure 3.8. Perspective view of simplified version of CFM with 3x3 km fault elements, that was used in the 2012 earthquake simulator comparison. Faults are color-coded by slip rate (warmer colors = higher slip rate).

Despite the common geometry, different assumptions about, for example, visco-elasticity, the nature of friction on faults, or the propagation of a rupture once initiated, lead to different simulator outputs. One of the important long-term goals of this activity is to provide an approach to earthquake rupture forecasting that, for example, could be used directly as input into earthquake rupture forecasts (**Fig. 3.9**), and would move beyond statistically based methods currently being considered (such as ETAS models).

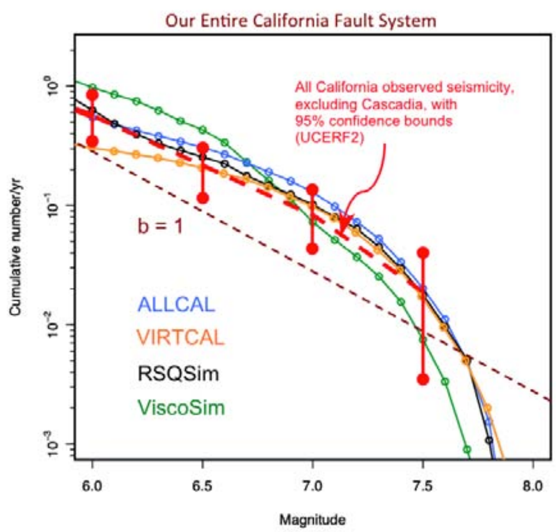

Figure 3.9. A comparison of cumulative MFD distribution for four earthquake simulators with observed seismicity. Although the goal of earthquake simulators is to move beyond such simple magnitude-frequency distribution characterizations of seismicity, MFDs provide a useful check.

The simulators also have the potential to play a key role in moving from time-independent earthquake rupture forecasts, to time-dependent earthquake forecasts, because simulator output can inform the probabilities of large earthquakes triggering other large earthquakes. Time-dependent earthquake rupture forecasts form an important part of the SCEC4 research objectives.

10. Earthquake Forecasting and Predictability and UCERF3: Milestones 3, 9

The Earthquake Forecasting and Predictability interdisciplinary focus group is concerned with forecasting earthquake behavior at short, intermediate, and long time scales. Like other such groups, it has linkages across a wide range of SCEC activities. Both the earthquake simulator effort and UCERF are closely aligned with EFP goals and efforts. UCERF3 is a critically important activity for SCEC, both in terms of societal impact, and because it requires us to capture what we know, or think we know, about earthquake behavior into a forecast of likely future earthquakes. 2012 has been an exceptionally busy year for UCERF3 activity as we strive to meet the deadline for its completion. UCERF3 has seen important innovations relative to UCERF2 in the use of new magnitude-area relations, as well as new information on fault slip rates and past earthquake history. Assumptions on fault segmentation have been relaxed, and for the first time, geodetically derived crustal deformation models are being used directly as input into the earthquake rupture forecast. Finally, all of the information we have, and assumptions we feel justified in making, on earthquake rates and ruptures are being assimilated into what has come to be known as "the grand inversion" (**Fig. 3.10**). The grand inversion (*Andrews and Schwerer*, 2000; *Field and Page*, 2011) combines slip-rates from geodetic/geologic data, paleoseismic event rates, rupture plausibility constraints, magnitude-frequency distributions, as well as other possible *a priori* constraints, to solve for the magnitude and long-term rate of each rupture.

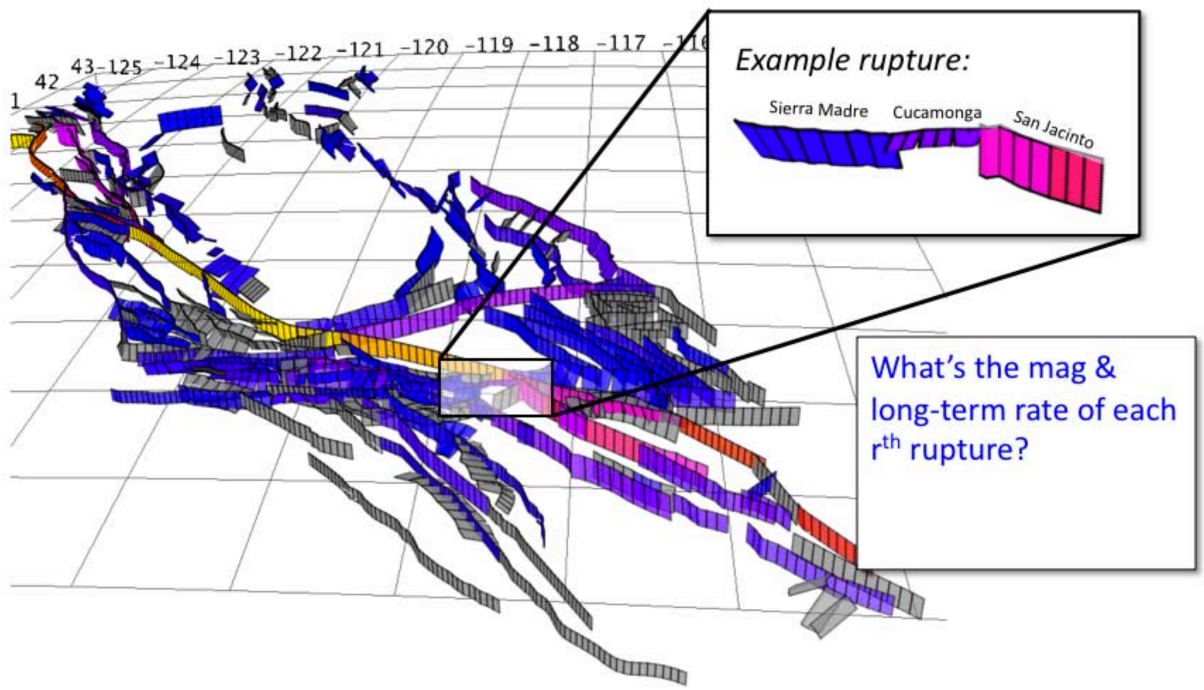

Figure 3.10. Example of a potential rupture linking the Sierra Madre-Cucamonga-San Jacinto Faults in a single earthquake. The grand inversion uses all available information to try to estimate the likely magnitude and long-term rate of that earthquake (as well as over 200,000 others).

The first year of SCEC4 has seen widespread and intense effort on bringing UCERF3 to a successful and on-time conclusion, and to the degree that proves successful, SCEC will have reachedf science milestone 9.

11. SoSAFE: Milestones 6, 9

In the transition to SCEC4, the Southern San Andreas Fault Evaluation (SoSAFE) special project has become part of the SCEC core program, and the SCEC collaboration was reorganized accordingly by creating a SoSAFE focus group led by Kate Scharer (USGS) and Ramon Arrowsmith (ASU). The focus of SoSAFE remains on multidisciplinary studies of the San Andreas and San Jacinto Fault systems, with special attention to slip rates, slip per event, and past earthquake history. As part of the SoSAFE activity in 2012, a "Fieldshop" was held at the SCEC Annual Meeting in Palm Springs. The SoSAFE Fieldshop (**Fig. 3.11**) combined field activity and a workshop, and focused on field interpretation and measurement of small (< 50 m) offsets of geomorphic features along faults. Interest in this issue stems largely from the proliferation of undated, small geomorphic offsets now used in efforts such as the Uniform California Earthquake Rupture Forecast (UCERF3) to calculate paleo-earthquake magnitude and paleo-earthquake rupture extent and estimate future timing or slip along the faults given standard recurrence models. The Fieldshop explored the reproducibility of field measurements of geomorphic offsets by multiple investigators and generated a rich discussion on the uncertainties and qualification of these data, and participants came up with a set of six findings and recommendations for future work.

Figure 3.11. The 27 participants in the Fieldshop travelled to the Mojave section of the San Andreas Fault and worked on two areas southeast of Palmdale, CA. They mapped on two DEMs, one derived from the B4 LiDAR dataset and the other derived from a TLS scan near Littlerock CA The participants had a mix of experience but most were familiar with the goals and typical procedures for measuring offsets. These included graduate students (8) measuring offsets for their own research, early career scientists (6), and mid-career scientists (8).

In addition to the new initiatives and TAGs, there is a great deal of science being carried out under the SCEC core program. In the following pages we highlight a few of the notable accomplishments of the first year of SCEC4. For convenience only, we organize them by disciplinary/interdisciplinary focus groups.

12. Earthquake Geology: Milestones 6, 8, 9

New technologies and new capabilities, including LiDAR and new dating techniques, are creating exciting new opportunities in earthquake geology to answer long-standing questions that bear directly on seismic hazard evaluation. *Roder et al* (2012) and *Lawson et al.* (2012) have reported encouraging results for K-feldspar TL dating of sediments in the Mojave. *Compton and Cowgill* (2012) have used LiDAR measurements to document further evidence for time-dependent slip rates on the Mojave segment of the San Andreas Fault. *Akciz et al.* (2012) are developing new slip-rate estimates from the classic Wallace Creek site, for which the original rate, which is based on just a few ^{14}C dates. They are now in the process of dating ~50 newly collected samples. *Fletcher et al.* (2012) have found an order of magnitude longer recurrence interval on the Borreggo Fault, which ruptured in the 2010 El Mayor-Cucapah earthquake, than on the nearby Laguna Salada Fault, which ruptured in the 1892 earthquake. *Blisniuk et al.* (2012) have found fairly high slip rates on the Mission Creek strand of the San Andreas Fault in Coachella Valley (**Fig. 3.12**). We anticipate that in SCEC4, substantial attention will be paid to tsunami hazard, and that earthquake geology has a key role to play in that effort; however, current efforts are limited to analysis of potential tsunami deposits in Carpinteria Slough resulting (most likely) from large events on structures related to the nearby Ventura Avenue Anticline.

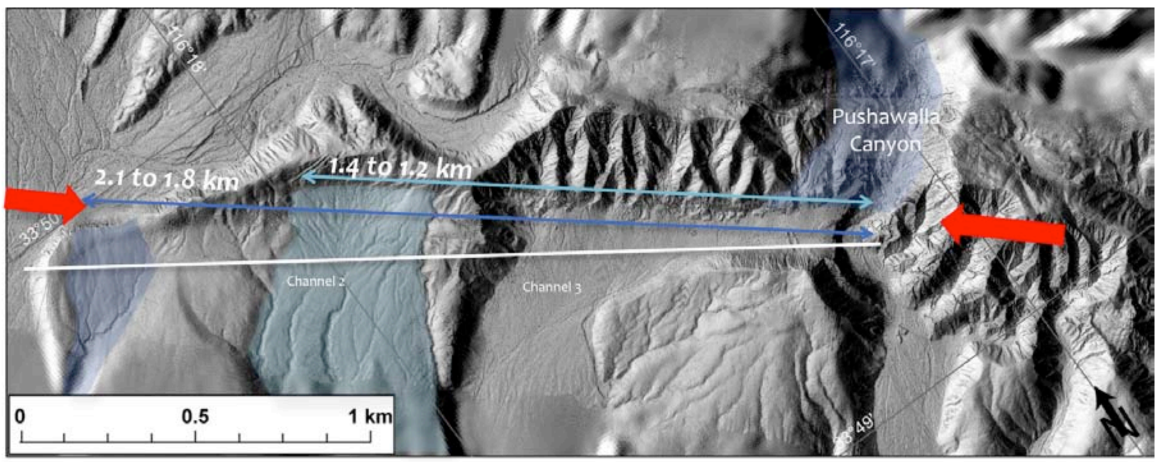

Figure 3.12. Blisniuk and others have carried out Uranium dating of channels deposits on the Mission Creek strand of the San Andreas in Coachella Valley and found high geologic slip rate of ~17-24 mm/yr (17-20 mm/yr preferred) since ~50 to 70 ka.

13. Seismology: Milestone 1

The Southern California Earthquake Data Center continues to archive and serve seismic data and data products to the research community. Improvements to earthquake locations and focal mechanisms are ongoing. The first year of SCEC4 saw the publication of two important catalogs. The first is the latest version of the southern California relocated seismicity catalog (*Hauksson et al.,* 2012) containing high-precision locations of over 500,000 events from 1981 to June 2011. The second is a catalog of opver 137,000 refined focal mechanisms (*Yang et al.,* 2012). These catalogs are available at the SCEDC. This essential activity satisfies an important part of milestone 1 (**Appendix A**). *Kroll et al.* (2012) report that aftershock activity in the Yuha Desert region of California following the El Mayor-Cucapah mainshock was strongly affected by the 14 June 2010 M5.7 Ocotillo, California, in a possible demonstration of a static stress change "shadow."

Shearer (2012) studied earthquake clustering in southern California and found that while some of the clustering can be attributed to earthquake-to-earthquake triggering, as in an ETAS model, there is a significant component of clustering that arises from underlying physical driving mechanisms, such as are often invoked to explain swarms. *Chen et al.* (2012) examined compact 'bursts' of seismicity in southern California and found that 37 out of 69 exhibited statistically significant spatial migration of seismicity. About half of the migrating swarms are best fit with linear migration velocities. The other half are best fit with the diffusion equation, with diffusion coefficients comparable to those found in previous studies. These two results suggest fluid flow as a primary driver of Southern California earthquake swarms. *Chen et al.* (2012) also studied foreshock and aftershock sequences for the Landers, Hector Mine, and El Mayor-Cucapah earthquake and report the somewhat surprising result that foreshock stress drops are systematically lower than those of aftershocks in each case (**Fig. 3.13**).

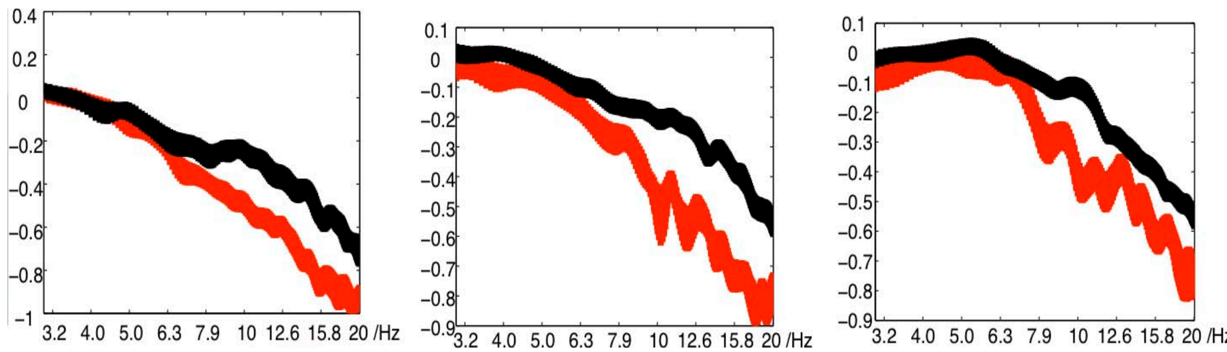

Figure 3.13. Foreshocks are observed to have lower-than-average stress drops (red spectra) when compared to aftershocks from the same region (black spectra). Individual stress drop estimates have large scatter, but the median stress drop is clearly lower for the foreshocks of the 1992 Landers, 1999 Hector Mine and 2010 El Major earthquakes as expressed in their stacked spectra (from left to right). The foreshocks radiate relatively weaker high frequencies than the aftershocks. This difference is unlikely to be caused by attenuation changes induced by the mainshock, because attenuation has been observed to increase following large earthquakes, which would produce the opposite effect.

14. Computational Science: Milestones 7, 8

The Computational Science disciplinary group, led by Yifeng Cui (USC) and Eric Dunham (Stanford) was formed due to the recognition that in order to realize fully the potential benefits of high-performance computing, SCEC needed to devote greater attention to it than had been done in SCEC3, where it was primarily limited to specific goals under special projects. We devoted two talks and dedicated discussion at the SCEC annual meeting to ways to broaden the penetration of HPC into SCEC activities. Here we report on several projects that have recently taken advantage of HPC. *Zhou et al.* (2012) have adapted the AWP code to take advantage of GPU processors for finite-difference simulation of wave propagation in 3D media. *Kozdon and Dunham* (2012) have used adaptive mesh refinement (AMR) for 2D dynamic rupture simulations (**Fig. 3.14**). By varying the mesh in space and time, they were able to achieve the resolution required to explore the effects of rate-and-state friction and off-fault plasticity on dynamic rupture.

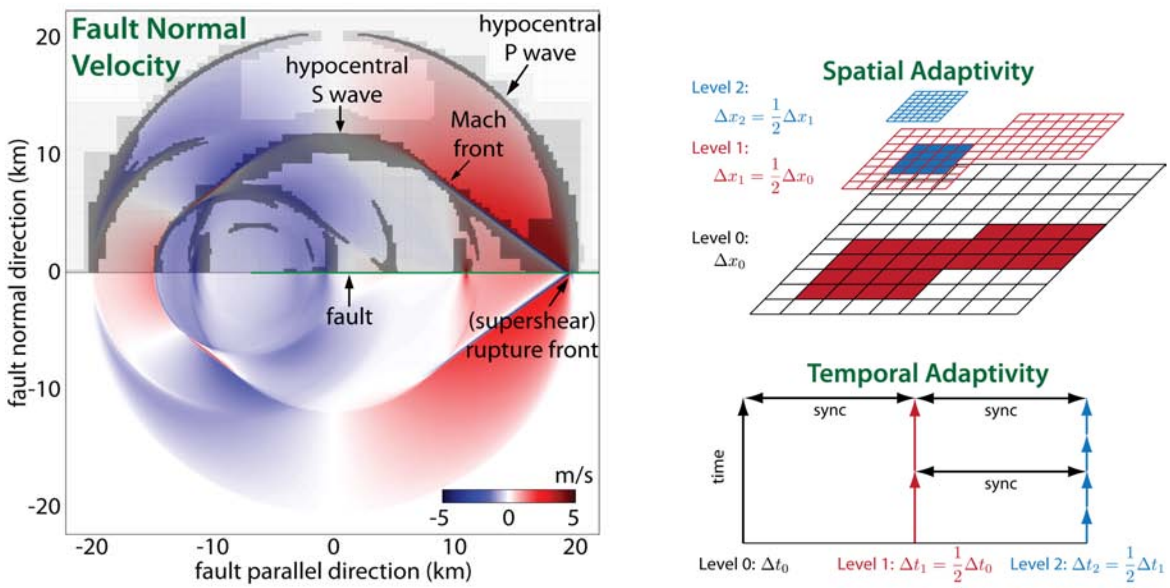

Figure 3.14. AMR in both space and time, applied to dynamic rupture modeling (*Kozdon and Dunham*, 2012). Gray areas on the left panel show areas where the mesh is densified to resolve important details.

15. Ground Motion Prediction: Milestone 7

The Ground Motion Prediction (GMP) interdisciplinary group focuses on issues related to modeling earthquake strong ground motion. Research from many different fields contributes to this effort, and strong ground motion modeling has been the topic of many special projects. *Denolle et al.* (submitted) have developed a pathway for correcting ambient-field Green's functions for depth of excitation and focal mechanism and validated the corrections against four moderate earthquakes in southern California. An emerging theme in SCEC4, called the “High-F project,” is to push ground motion simulations to higher frequencies (**Fig. 3.15**). *Taborda and Bielak* (2012) have carried out simulations of the Chino Hills earthquake to 4 Hz, but concluded that realistic earthquake simulations at frequencies higher than 1 Hz will require improvements in velocity and attenuation models to make synthetic results compatible with strong motion records. *Shi and Day* (2012) have performed ground motion simulations for M > 7 earthquakes up to 10 Hz using 3D rupture simulations along rough faults. *Olsen et al.* (2012) have explored the effect of small-scale inhomogeneities, such as those that are now being developed for CVM-H, on the seismic wavefield at high frequencies.

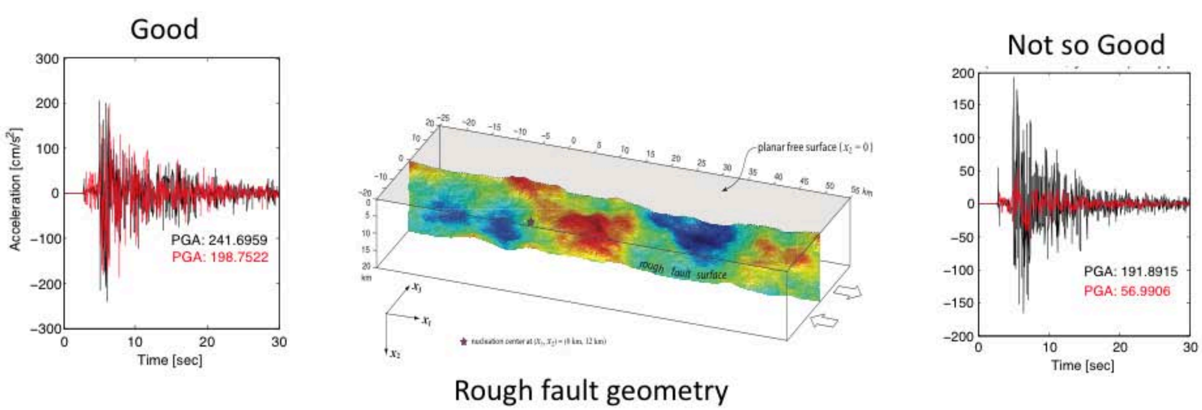

Figure 3.15. Example of high-frequency ground motion simulations from *Shi and Day* (2012). *Withers et al.* (2012) performed kinematic simulations using this geometry and compared resulting time series to stochastic high-frequency simulations. High frequency deterministic simulations produced realistic time-series. Study of these new high frequency deterministic simulation techniques is an opportunity for future validation work with hybrid stochastic methods.

16. Fault and Rupture Mechanics: Milestone 8

The Fault and Rupture Mechanics (FARM) interdisciplinary group focuses on understanding earthquake rupture mechanics through laboratory experiments, theoretical modeling, and field observations. Progress in this area is diverse and projects are numerous; however, there are several themes emerging from these activities in SCEC4. Computational capabilities are approaching the point where it is now possible to properly model dynamic rupture propagation on geometrically realistic fault structures. This presents challenging issues in how fault response is characterized, and increases the importance of the other emerging theme, which is understanding plastic, off-fault deformation. Here too there are challenges to be met, such as the dependence on absolute stress levels, in modeling plastic deformation. Another trend that is likely to continue is the development of comprehensive, integrative models of fault behavior. *Barbot et al.* (2012) developed a model of the San Andreas Fault at Parkfield that combined dynamic rupture modeling, seismic and geodetic observations (co-seismic, post-seismic, and inter-seismic) into a consistent synoptic model for fault behavior (**Fig. 3.16**).

Weakening mechanisms continue to be of great interest due to their importance for understanding both earthquake physics and earthquake strong ground motion. *Bernardo et al.* (2012) explored auto-acoustic weakening, which is distinct from acoustic fluidization. They found that the effect was most important at intermediate slip velocities. *Platt et al.* (2012) studied strain-rate localization driven by thermal pressurization and thermal decomposition, e.g., in phyllosilicates and carbonate components of fault gouge. They found that thermal decomposition leads to extreme localization down to zones ~30 microns wide. Reactant depletion leads to migration of the localized straining zone, leading to complex final strain profiles. The final deformed zone could be an order of magnitude wider than the width of the zone deforming at a given time. Fault mineralogy controls the migration velocity, allowing a qualitative link with field studies. *Goldsby et al.* (2012) used laboratory experiments to show that the effects of flash heating saturate at slip rates of 1 m/s. *Hirth et al.* (2012) investigated the effects of pore fluids near the base of the seismogenic zone. They found that high-temperature creep renders the effective pressure law less efficient near the brittle-plastic transition, if it works at all. Clearly, there is no shortage of potential weakening mechanisms. The challenge is to identify which ones are relevant to rupture in the Earth, and how to characterize them in earthquake rupture modeling - both to improve understanding of earthquake physics, and to predict strong ground motion more accurately. This is an important, ongoing effort, and constitutes an important part of science milestone 8. We have worked towards this milestone in the first year of SCEC4, but a more systematic approach in year 2 should be considered.

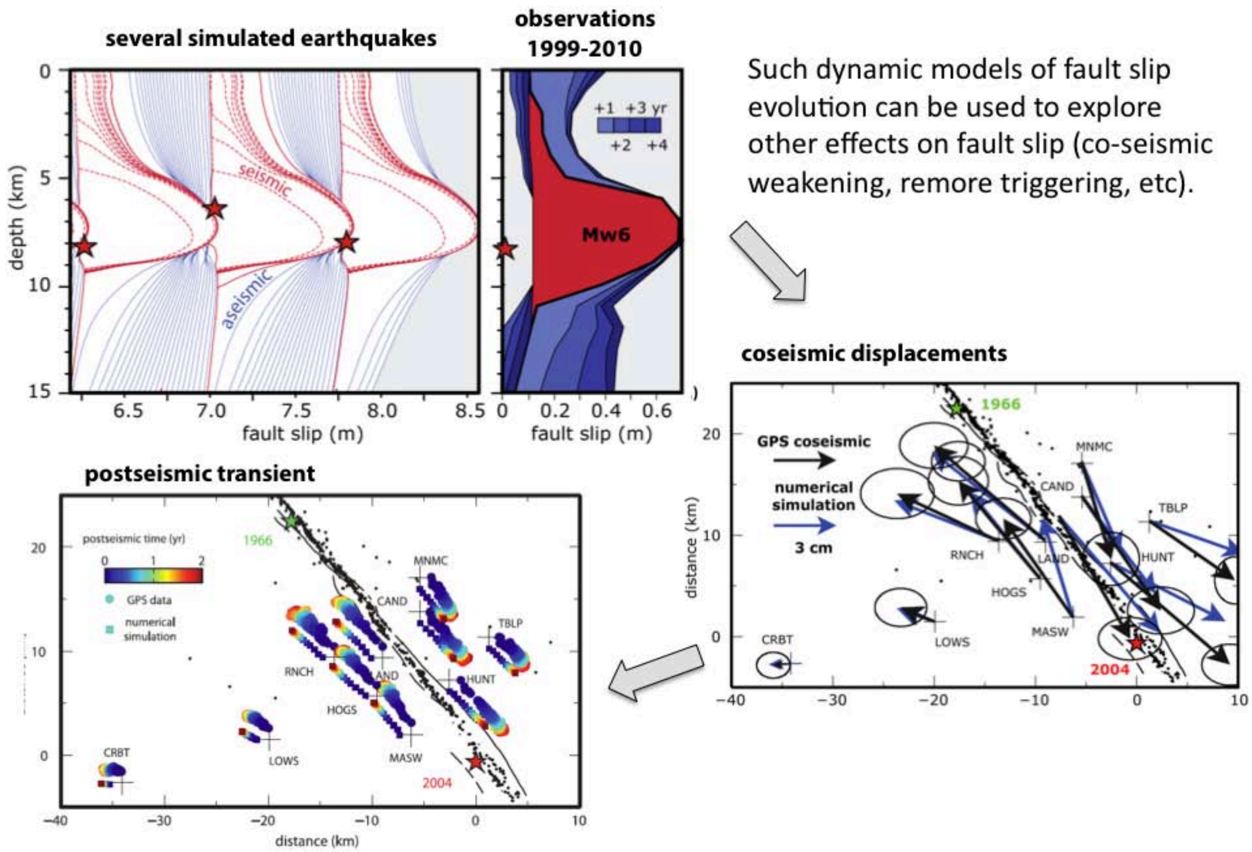

Figure 3.16. From *Barbot et al.* (2012) showing model that predicts fault slip compatible with recent (1999-2010) geodetic observations. The model reproduces several aspects of the earthquake cycle at Parkfield on various temporal scales and can be used to study other aspects of fault slip such as additional co-seismic weakening, the effect of fluids or remote triggering.

Appendix A lists science milestones for SCEC's interdisciplinary activities in earthquake system science. Owing to the unpredictable nature of basic research, the milestones for the first years are more explicit than those for the out-years of the SCEC4 program. As detailed in the preceding text, we have successfully achieved all of the year-1 science milestones for SCEC4.

B. Communication, Education and Outreach Accomplishments

Through its engagement with many external partners, SCEC CEO delivers research and educational products to the Center's many audiences, including the general public, government, business, academia, students, practicing engineers, and the media. The theme of the CEO program during SCEC4 is *Creating an Earthquake and Tsunami Resilient California.* This includes: increased levels of preparedness and mitigation; routine training and drills; financial preparedness; and other ways to speed recovery. In particular, we are preparing Californians for making decisions in response to changing seismic hazards, in anticipation of operational earthquake forecasts and earthquake early warning. Although tsunami research is not a focus of SCEC, tsunami education and preparedness is an activity of SCEC CEO and ECA.

This theme will be addressed within four interconnected thrust areas. The *Implementation Interface* connects SCEC with engineering partners in research and practice, as well as other technical audiences. The *Public Education and Preparedness* thrust area educates people of all ages about earthquakes, and motivates them to become prepared. The *K-14 Earthquake Education Initiative* seeks to improve earth science education and school earthquake safety. Finally, the *Experiential Learning and Career Advancement* program fosters and sustains careers in science and engineering.

A SCEC CEO Strategic Plan with metrics and milestones for activities within each thrust area was submitted to NSF in late 2011 (see **Appendix B**). At the February 2012 SCEC Board Meeting it was proposed that this plan would be reviewed by a new CEO subcommittee of the Advisory Council when convened at the SCEC Annual Meeting. Unfortunately several members of this subcommittee were unable to attend the meeting, and the review is now planned for early 2013. The group will help simplify and prioritize the proposed metrics to align with budget and staffing realities. A structure for tracking CEO milestones and metrics is currently under development and pending review from the CEO subcommittee when it convenes. With the exception of a few obvious metrics (e.g., ShakeOut participation, intern program participants), actual values of proposed milestones have not been retroactively assessed. The target numbers given in Appendix B are tentative and also pending review and advice from the CEO subcommittee.

1. Implementation Interface

The implementation of SCEC research for practical purposes depends on interactions with engineering researchers and organizations, and with practicing engineers, building officials, insurers, emergency managers, and other technical users of our information.

a. Research Engineering Partnerships

These activities are coordinated as a SCEC research focus group, managed by representatives on the planning committee. SCEC has produced a large body of knowledge about the seismic hazard in California that enhances the seismic hazard maps currently used in building codes and engineering risk assessments. For example, Cybershake results are being used by the USGS's National Seismic Hazard Mapping Program in its 2013 revisions. In the long term, we will to test enhanced CyberShake models as an alternative to empirical ground motion prediction equations and also as a database of simulated time histories for the design of critical facilities and other structures. Further details of recent activities are described in §III.A.5 above.

b. Activities with Technical Audiences

The Implementation Interface also involves interactions with technical audiences that make decisions based on understanding of earthquake hazards and risk, including practicing engineers, geotechnical consultants, building officials, emergency managers, and financial institutions. SCEC, ECA, and our partners are planning training sessions for practicing engineers and building officials to introduce new technologies (including time-dependent earthquake forecasts), discuss interpretation of simulation records, and provide a forum for SCEC scientists to learn the needs of practicing professionals.

The key activity of this area in 2012 was the second annual *Buildings at Risk* Summit held on October 11th (as a "precursor" to the Great California ShakeOut one week later). This is a significant partnership of the Structural Engineers Association of Southern California, SCEC, ECA, CalEMA, and other partners that brought together over 200 research and practicing engineers, scientists, government leaders, building code officials, and others to learn and discuss earthquake risk reduction strategies. To support the activity, SCEC hosted regular in-person meetings of the planning committee.

2. Public Education and Preparedness

This thrust area spans a suite of partnerships, activities, and products for educating the public about earthquakes, and motivating them to become prepared for earthquakes and tsunamis. To work towards these goals, we will increase the application of social science research, with sociologists and other experts.

a. Earthquake Country Alliance (ECA)

The ECA public-private partnership is the primary organizational structure within the Public Education and Preparedness thrust area. Due to the success of the ShakeOut, the ECA is now statewide and includes three established regional alliances (**Fig 1.3**) with several hundred participants statewide. In September, 2011 the relationship between SCEC and the ECA (managed by SCEC since its inception in Southern California in 2003) was formalized via a memorandum of understanding specifying SCEC as the administrative headquarters of the now statewide alliance and SCEC'S Associate Director for CEO as ECA's Executive Director. SCEC remains very involved within the southern California regional effort, including the development of a speakers bureau in 2012.

In 2012 SCEC received $220K of funding from FEMA through CalEMA to administer ECA activities, including monthly calls of 8-10 committees, funding for activities of each regional alliance, and a leadership retreat (held at SCEC) of the Steering Committee and key partners. In late 2012 a new cooperative agreement was established directly with FEMA ($300K) for supporting the ECA as well as ShakeOut activities nationwide.

Because of the growth of the ShakeOut and its other activities, ECA has received national recognition. In fall, 2011 ECA was recognized by FEMA with the "Awareness to Action" award, which resulted in SCEC's Associate Director for CEO Mark Benthien being named a "Champion of Change" by the White House in early 2012. In April 2012, ECA also received the "Overall National Award in Excellence" at the quadrennial National Earthquake Conference in Memphis.

b. ShakeOut Earthquake Drills

A major focus of the CEO program since 2008 has been organizing the *Great California ShakeOut* drills and coordinating closely with ShakeOut drills in other states and countries. The purpose of the Shakeout is to motivate people to practice how to protect ourselves during earthquakes and to get prepared at work, school, and home. ShakeOut is based on 30 years of social science research about why people choose to get prepared.

The ShakeOut began in southern California in 2008, to involve the general public in a large-scale exercise based on an earthquake on the San Andreas Fault (the "ShakeOut Scenario"). SCEC developed advanced simulations of this earthquake used for loss estimation and to visualize shaking throughout the region. In addition, SCEC hosted the ShakeOut website (*www.ShakeOut.org)* and created a registration system so that participants could be counted. In 2008 more than 5.4 million southern Californians participated. Statewide since 2009, in 2012 more than 9.4 million participated.

In addition to its continued lead role in organizing the California ShakeOut, SCEC now manages a growing network of Official ShakeOut Regions spanning 25

Box 3.1. Growth of ShakeOut Drills

2008: 5.4 million
Southern California
2009: 6.9 million
California, New Zealand West Coast
2010: 7.9 million
California, Nevada, Guam
2011: 12.5+ million
CA, NV, GU, OR, ID, BC
130,000 in 5 Central Asia countries
Central US (AL, AR, GA, IN, IL, KY, MI, MO, OK, SC, TN)
2012: 19.4 million
All above plus:
AK, AZ, Southeast (GA, SC, NC, VA, DC, MD) UT, WA, Puerto Rico, Japan New Zealand, Southern Italy (US Military bases), and a new "Global" site for all other areas
2013 and beyond:
Northeast states, Rocky Mtn States, HI, American Samoa, Mexico (at least Baja), possibly other countries

US states and territories and several other countries (**Box 3.1**). In 2012 19.4 million people participated in 16 ShakeOut drills worldwide. Many millions more see or hear about the ShakeOut via the news media. SCEC manages the websites of every ShakeOut except those in Japan.

New materials and activities for additional communities and in multiple languages are developed each year. In 2012 new guides for people with Access and Functional Needs and for healthcare organizations were developed, and a Global ShakeOut website (for people in any state or country to register) was launched in both English and Spanish. ShakeOut sites also now exist in French (Canada) and Italian (Southern Italy ShakeOut). The website is now optimized to easily add additional languages.

Extensive surveys have been done after each ShakeOut and the results of these surveys are providing insights into what participants are learning and improving in terms of their level of preparedness. The ECA Evaluation Committee is also encouraging additional social science research specific to the ShakeOut.

c. Putting Down Roots in Earthquake Country

This 32-page handbook, has provided earthquake science, mitigation, and preparedness information to the public since 1995. *Roots* was first updated in 2004, when the *Seven Steps to Earthquake Safety* was created to organize the handbook's preparedness content. Since then five additional revisions and printings have produced 3.5 million copies. The first Spanish version of *Roots* was produced in 2006. The 2011 version included new tsunami science and preparedness content, based on content created for the 2009 version of *Living on Shaky Ground*. This is a similar publication of the Redwood Coast Tsunami Workgroup that now also includes the SCEC/ECA *Seven Steps to Earthquake Safety.* The steps were revised subtly in summer 2012 with new wording but essentially the same structure, to be featured within the new ECA website (to be launched in early 2013) and also by the California Earthquake Authority and American Red Cross in a new marketing effort focused around the "Traveling Red Table" which promoted ShakeOut and other preparedness messaging at public venues statewide.

The booklet has spawned the development of region specific versions for the San Francisco Bay Area, Nevada, Utah, Idaho, and the Central U.S. (totaling an additional 4 million copies). SCEC and its partners also have developed a supplement to *Putting Down Roots* titled *The Seven Steps to an Earthquake Resilient Business,* a 16-page guide for businesses to develop comprehensive earthquake plans. All booklets are available on the ECA website (*www.earthquakecountry.org/roots*).

d. ECA Education and Public Information centers (EPIcenters)

SCEC CEO has developed exhibits and partnered with information education venues for many years. The expansion of these partnerships, especially with the San Bernardino County Museum (SBCM) led SCEC to create the ECA Earthquake Education and Public Information Centers (ECA EPIcenters) network which includes museums, science centers, libraries, universities, parks, and other places visited by a variety of audiences including families, seniors, and school groups. Over sixty organizations now participate and have implemented a variety of activities including displays and talks related to the ShakeOut. The statewide Network is coordinated by SCEC Education Program Manager Robert de Groot with SBCM and the San Jose Tech Museum coordinating activities in Southern and Northern California. The following are highlights of 2012 activities:

- SBCM Hall of Geological Wonders Learning Treks Program (GeoTreks): Developed for the 6th grade curriculum in California, this exhibit features the exhibition of two peels from Pallett Creek and Wrightwood in a recreated paleoseismic site, and also a field trip component to the actual "refreshed" sites.
- Hall of Geological Wonders ShakeOut Cabin entrance video: Featuring SCEC scientists and students, this video highlights careers in the earth sciences and will be located outside an earthquake simulation "cabin" in the new Hall.
- Active Earth Monitor – San Andreas Fault Content Set (with IRIS and EarthScope): This online resource is one in a series of products from EarthScope workshops for park and museum interpreters. The product will be online in Spring 2013.
- Citizen Science with the Quake-Catcher Network: This project facilitated the installation and marketing of QCN sensors in museums and other venues. QCN research sensors were installed at three in-

stitutions and an installation protocol and QCN kit were developed. Collaborators include USGS, SBCM, Stanford, and NEES. SCEC also supported a new "Quake Catcher" game for the Kinect video game system by a team led by Debi Kilb at SIO.

- Earthquake Preparedness *Science Spectacular!*™ Program: This collaboration with the California Science Center created a 15-minute presentation that explores the science of earthquakes, and earthquake preparedness and safety practices.
- California Academy of Sciences: Earthquakes: Life on a Dynamic Planet. SCEC staff and scientists participated in the development of the exhibit, education programs, and the accompanying planetarium show *Earthquake: Evidence of a Restless Planet*.
- Natural History Museum of Los Angeles County: SCEC adapted the *Earthquake Country Los Angeles* video for use in the updated Earth Science Hall.

e. Media Relations

SCEC has developed extensive relationships with the news media and is increasingly called upon for interviews by local, national, and international reporters and documentary producers. As a result the demand on SCEC scientists after a large California earthquake or elsewhere will be even greater than in previous earthquakes. An important component to this effort will be media and risk communication training for the SCEC Community. The first such offering was held at the 2012 SCEC Annual Meeting. Social media capabilities are being expanded in SCEC4, including the use of Facebook and Twitter (revamped in Fall 2012).

3. K-14 Earthquake Education Initiative

The primary goal of this new Initiative is to educate and prepare California students for living in earthquake country. This includes improved earth science education as well as broadened preparedness training. The science of earthquakes provides the context for understanding why certain preparedness actions are recommended and for making appropriate decisions; however earthquake science and preparedness instructions are usually taught in a manner that lacks this context. For example, earthquake science is mostly taught in the context of plate tectonics and not in terms of local hazards. Large distant earthquakes are something that happened "over there" and local connections are not often made. SCEC's approach is to facilitate learning experiences and materials for use after large earthquakes worldwide and also the ShakeOut drill, and to develop learning materials that complement traditional standards-based instruction with regional earthquake information. The following are activities in this area in 2012:

- CalState San Bernardino/EarthScope RET program: Since 2009 SCEC has worked with Prof. Sally McGill to lead this summer program in which high school teachers and their students conduct campaign GPS research along the San Andreas and San Jacinto faults. SCEC facilitates the education portion of the project through a professional development model called Lesson Study. This allows for interaction with the teachers for the year following their research. Participants then attend the SCEC Annual Meeting where they present posters of their research and attend sessions. Since 2009, 30 high school teachers and 53 high students have participated (6 high school teachers and 8 high school students in 2012).
- Plate Tectonics Kit*:* This teaching tool was created to make plate tectonics activities more accessible for science educators and their students. SCEC developed a user-friendly version of the *This Dynamic Earth* map, which is used by many educators in a jigsaw-puzzle activity to learn about plate tectonics, hot spots, and other topics. The kit is distributed nationwide.
- California Science Teachers Association*:* SCEC participates each year in national and statewide science educator conferences to promote innovative earthquake education and communicate earthquake science and preparedness to teachers in all states. For the past several years SCEC and the California Geological Survey have shared a booth in the exhibit hall.
- ShakeOut Curricula*:* This suite of classroom materials is designed for use in the week or so before ShakeOut and includes earthquake science concepts and preparedness activities to complement the drill. An important result of the ShakeOut is that it has enhanced and expanded SCEC's reach into schools at all levels from county administrators to individual classroom educators.

4. Experiential Learning and Career Advancement (ELCA)

The SCEC ELCA program seeks to enhance the competency and diversity of the STEM workforce by facilitating career advancement pathways that (1) engage students in research experiences at each stage of their academic careers, and (2) provide exposure and leadership opportunities to students and early career scientists that engage them in the SCEC Community and support them across key transitions (undergraduate to graduate school, etc.).

The ELCA program in SCEC4 is built on the foundation of our long-established UseIT and SURE internship programs that challenge undergraduates with difficult, real-world problems that require collaborative, interdisciplinary solutions:

1) The ***Summer Undergraduate Research Experience (SURE)*** internship places undergraduate students in research projects with SCEC scientists. Internships are supported from base SCEC funding and funding from internship mentors. 247 internships have been supported since 1994. In 2012, SURE had 16 Interns from 12 institutions (including 2 community colleges). They were assigned to 7 SCEC Institutions. Projects involved collaborations with NEES, EarthScope, USGS, IRIS, and USC Earth Sciences, CA Science Center, and San Bernardino County Museum. A total of 23 mentors directly and indirectly participated in advising SCEC interns.
2) The ***Undergraduate Studies in Earthquake Information Technology (UseIT)*** internship brings together undergraduates from many majors and from across the country in an NSF Research Experience for Undergraduates Site at USC. The eight-week program develops and enhances computer science skills while teaching the critical importance of collaboration for successful learning, scientific research and product development. UseIT interns tackle a scientific “Grand Challenge” that varies each year but always entails developing software and resources for use by earthquake scientists or outreach professionals, including SCEC-VDO (visualization software developed and refined each summer by UseIT interns). 220 students have participated since 2002. The 2012 UseIT Program had 24 Interns from 8 colleges and universities (including 2 community colleges). Fifteen SCEC mentors assisted in facilitating the 2012 UseIT Grand Challenge which was to *develop visualization capabilities based on SCEC-VDO and GIS that can display earthquake rupture forecasts, and publish visualization products that can be used to educate the general public about the Uniform California Earthquake Rupture Forecasts, including the new forecasting model, UCERF3*.

In addition to continuing these undergraduate programs, we plan to develop a high school to graduate school career pathway for recruiting the best students, providing them with high-quality research, education, and outreach experiences, and offering career mentoring and networking opportunities.

High school awareness and research opportunities will be closely linked with SCEC’s K-14 Earthquake Initiative and in particular the summer GPS program with Sally McGill. This and other activities may identify students that could participate in UseIT or a SURE project at a local SCEC institution.

In addition to our undergraduate internships, we are exploring additional funding for master’s level internships that provide unique opportunities. Students may participate in the UseIT program as mentors, conduct research projects with scientists at SCEC institutions (different than their own), and participate in CEO activities such as media relations, curricula development, and program evaluation (in 2012 CEO involved 4 masters students and 1 PhD student in its activities).

The final element of the ELCA program is career advancement opportunities for early-career researchers, including post-docs, young faculty, and research staff. In addition to employment opportunities that are shared via SCEC’s email list, SCEC also appoints early career researchers to SCEC leadership positions, especially the planning committee, which provides significant opportunities for career advancement.

C. Honors and Awards

SCEC Director Tom Jordan won the 2012 Outstanding Contribution to the Public Understanding of the Geosciences Award, given by the American Geosciences Institute, for "advancing the public understanding of earthquakes, their hazards, and ways to reduce risk in the United States and the rest of the world." He was also elected as a Fellow of the American Association for the Advancement of Science for his leadership in earthquake system science, and he presented the 2012 AGU Gutenberg Lecture on "Earthquake Forecasting as a System-Science Problem." SCEC Deputy Director Greg Beroza was selected as the 2012 IRIS/SSA Distinguished Lecturer, and he was elected president of AGU's Seismology section.

Because of the creation and growth of the ShakeOut, and other activities and products, the SCEC-managed Earthquake Country Alliance has received national recognition. In late 2011, ECA was recognized by FEMA with the "Awareness to Action" award, which resulted in SCEC's Associate Director for CEO Mark Benthien being named a "Champion of Change" by the White House in early 2012. In April 2012 ECA also received the "Overall National Award in Excellence" at the quadrennial National Earthquake Conference held in Memphis.

Many other SCEC participants received awards during 2012. For example, the 2012 American Geophysical Union honors included the following recipients: Jim Rice (Harvard) was awarded the Bucher Medal; David Shelly (USGS/Menlo Park) was awarded the Macelwane Medal; Hitoshi Kawakatsu (ERI/Tokyo), Thomas Parsons (USGS), and Toshiro Tanimoto (UCSB) were elected AGU Fellows; and Victor Tsai (Caltech) received the Aki Award.

IV. SCEC Goals and Objectives

A. 2013 Science Collaboration Plan

1. Disciplinary Activities

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

a. Seismology

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

Example Research Strategies

- Enhancement and continued operation of the SCEDC and other existing SCEC facilities particularly the near-real-time availability of earthquake data from SCEDC and automated access.
- Real-time processing of network data such as improving the estimation of source parameters in relation to faults, especially evaluation of the short-term evolution of earthquake sequences and real-time stress perturbations on major fault segments.
- Enhance or add new capabilities to existing earthquake early warning (EEW) systems or develop new EEW algorithms. Develop real-time finite source models constrained by seismic and GPS data to estimate evolution of rupture and potentially damaging ground shaking; develop strategies for robust uncertainty quantification in finite-fault rupture models.
- Advance innovative and practical strategies for densification of seismic instrumentation, including borehole instrumentation, in Southern California and develop innovative algorithms to utilize data from these networks. Develop metadata, archival and distribution models for these semi-mobile networks.
- Develop innovative methods to search for unusual signals using combined seismic, GPS, and borehole strainmeter data; collaborations with EarthScope or other network operators are encouraged.
- Investigate near-fault crustal properties, evaluate fault structural complexity, and develop constraints on crustal structure and state of stress.
- Collaborations, for instance with the ANSS and NEES projects, that would augment existing and planned network stations with downhole and surface instrumentation to assess site response, nonlinear effects, and the ground coupling of built structures.
- Preliminary design and data collection to seed future passive and active experiments such as dense array measurements of basin structure and large earthquake properties, OBS deployments, and deep basement borehole studies.
- Improve locations of important historical earthquakes.

Priorities for Seismology in 2013

- ***Tremor.*** Tremor has been observed on several faults in California, yet it does not appear to be ubiquitous. We seek proposals that explore the distribution and source characteristics of tremor in California and those that explore the conditions necessary for the generation of seismically observable tremor.

- ***Low-cost seismic network data utilization and archiving.*** Several groups are developing seismic networks that use low-cost MEMS accelerometers. We seek proposals that would address development of seismological algorithms to utilize data from these networks in innovative ways. We also seek proposals that would develop metadata and archiving models for these new semi-mobile networks, as well as archive and serve these data to the SCEC user community.
- ***Short-Term Earthquake Predictability.*** We seek proposals that develop new methods in earthquake statistics or analyze seismicity catalogs to develop methods for determining short-term (hours to days) earthquake probability gain.

b. Tectonic Geodesy

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

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

  Data collection and analysis designed to address specific questions regarding geodetic/geologic slip rate discrepancies, to assess the role of lower crust/upper mantle processes in driving fault loading, to constrain more physically realistic deformation models, and to provide input to the development of Community Stress Models are also encouraged, as are studies that pursue integrated use of geodetic, geologic, seismic, and other observations targeting special fault study areas. Proposals for the development of new data products or collection of new data should explicitly motivate the need for such efforts and state how the resulting data or products will be used. Resulting data should be provided for inclusion in the CGM. In compliance with SCEC's data policy, data collected with SCEC funding must be made publically available upon collection by archiving at an appropriate data center (e.g., UNAVCO or SCEC). Annual reports should include a description of archive activities.
- **Improve our understanding of the processes underlying detected transient deformation signals and/or their seismic hazard implications through data collection and development of new analysis tools.** Work that advances methods for near-real-time transient detection and applies these algorithms within the SCEC transient detection testing framework to search for transient deformation in southern California is encouraged. Approaches that can be automated or semi-automated are the highest priority, as is their inclusion in the testing framework now in place at SCEC. Extension of methods to include InSAR and strainmeter data and, when available, the CGM is also a priority.

  Targeted collection and analysis of all types of geodetic data to constrain physics-based models of slow slip and tremor, as well as work that develops means for incorporating the output of transient detection algorithms into time-dependent earthquake forecasting, are also encouraged.
- ***Develop and apply algorithms that use real-time high-rate GPS data in concert with seismic data for improved earthquake response.***

c. Earthquake Geology

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

Example Research Strategies

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

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

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

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

Data Reporting Requirements. Studies under Earthquake Geology gather diverse data that are at times challenging to consistently archive per NSF data reporting requirements. Under SCEC4, PIs will be required to provide full reporting of their geochronology samples, including raw data, interpreted age, and geographic/stratigraphic/geomorphic context (what was dated?). This reporting requirement will be coordinated with the geochronology infrastructure program. A priority at the outset of SCEC4 is to do define additional, achievable goals for geology data reporting to be followed by Earthquake Geology community.

Priorities for Earthquake Geology

- Establish research strategies for special fault study areas and begin data collection.

- Prioritize and coordinate research objectives with respect to SoSAFE focus group goals, targets for slip-rate studies, and mechanisms to achieve progress on exhumed fault-zone problems.
- Define consistent and achievable data reporting requirements for Earthquake Geology in SCEC4. Archive data from SCEC3.
- Improve understanding of the seismogenic faults along the coast and offshore. Search for possible tsunami deposits from offshore sources, including both faults and landslides.

d. Computational Science

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

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

- The scientific goal of your computational research.
- The scientific software you plan to use or develop.
- A list of computations you plan to run.
- The estimated computing time you believe will be required.
- The computer resources you plan to use to perform your simulations.

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

Example Research Strategies

- Porting and optimization of high performance codes on new architectures, and utilize advanced high performance computing programming techniques such as hybrid MPI/OpenMP, MPI/CUDA, PGAS, and auto-tuning.
- Novel algorithms for earthquake simulation, particularly those that either improve efficiency and accuracy or expand the class of problems that can be solved (e.g., adaptive mesh refinement).
- Optimization of earthquake simulators that can resolve the faulting processes across the range of scales required to investigate stress-mediated fault interaction, including those caused by dynamic wave propagation, generate synthetic seismicity catalogs, and assess the viability of earthquake rupture forecasts.
- Tools and algorithms for uncertainty quantification in large-scale inversion and forward-modeling studies, for managing I/O, data repositories, workflow and data analysis.
- Data-intensive computing tools, including but not limited to InSAR and geodesy, 3D tomography, cross-correlation algorithms used in ambient noise seismology, and other signal processing techniques used, for example, to search for tectonic tremor.

Key Problems in Computational Science

- Seismic wave propagation
- Validate SCEC community velocity models.
- Develop high-frequency simulation methods and investigate the upper frequency limit of deterministic ground motions.

- Extend existing simulation methodologies to a set of stochastic wavefield simulation codes that can extend the deterministic calculations to frequencies as high as 20 Hz, providing the capability to synthesize “broadband” seismograms.
- Tomography
- Assimilate regional waveform data into the SCEC community velocity models.
- Rupture dynamics
- Evaluate proposed fault weakening mechanisms in large-scale earthquake simulations, determine if small-scale physics is essential or irrelevant, and determine if friction law parameters can be artificially enhanced without compromising ground motion predictions.
- Evaluate different representations of source complexity, including stress heterogeneity, variability in frictional properties, fault geometrical complexity, and dynamic rupture propagation in heterogeneous media.
- Scenario earthquake modeling
- Model a suite of scenario ruptures, incorporating material properties and fault geometries from the unified structural representation projects.
- Isolate causes of enhanced ground motion using adjoint-based sensitivity methods.
- Data-intensive computing
- Develop computational tools for advanced signal processing algorithms, such as those used in ambient noise seismology and tomography, as well as InSAR and other forms of geodesy.
- Engineering applications
- Facilitate the “rupture-to-rafters” modeling capability to transform earthquake risk management into a Cyber Science and Engineering discipline.

2. Interdisciplinary Focus Areas

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

a. Unified Structural Representation (USR)

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

- ***Community Velocity Model (CVM).*** Improve the current SCEC CVMs, with emphasis on more accurate representations of Vp, Vs, density, attenuation, and basin structure. Generate improved mantle Vp and Vs models, as well as more accurate descriptions of near-surface properties that can be incorporated into the models' geotechnical layers. Perform 3D waveform tomographic inversions and ambient noise analysis for evaluating and improving the CVMs. Develop and apply procedures (i.e., goodness-of-fit measures) for evaluating the existing and future models with data (e.g., waveforms, gravity) to distinguish alternative representations and quantify model uncertainties; apply these methods for well-recorded earthquakes in southern California to delineate areas where CVM updates are needed. Develop databases, models, and model building tools that will help facilitate expansion of the CVMs to statewide and plate-boundary scale velocity representations. These efforts should be coordinated with the SCEC CME special project.
- ***Community Fault Model (CFM).*** Improve and evaluate the CFM and statewide CFM (SCFM), placing emphasis on defining the geometry of major faults that are incompletely, or inaccurately, repre-

sented in the current model, and on faults of particular concern, such as those that are located close to critical facilities. Refine representations of the linkages among major fault systems. Extend the CFM to include spatial uncertainties and stochastic descriptions of fault heterogeneity. Evaluate the CFM with data (e.g., seismicity, seismic reflection profiles, geologic slip rates, and geodetic displacement fields) to distinguish alternative fault models. Update the CFM-R (rectilinear fault model) to reflect improvements in the CFM.

- ***Unified Structural Representation (USR).*** Develop better IT mechanisms for delivering the USR, particularly the CVM parameters and information about the model's structural components, to the user community for use in generating and/or parameterizing numerical models. Generate maps of geologic surfaces compatible with the CFM that may serve as strain markers in crustal deformation modeling and/or property boundaries in future iterations of the USR.

b. Fault and Rupture Mechanics (FARM)

The primary mission of the Fault and Rupture Mechanics focus group in SCEC4 is to develop physics-based models of the nucleation, propagation, and arrest of dynamic earthquake rupture. We specifically solicit proposals that will contribute to the six fundamental problems in earthquake physics defined in the SCEC 4 proposal and enhance understanding of fault system behavior through interdisciplinary investigation of the special fault study areas. We encourage researchers to address this mission through field, laboratory, and modeling efforts directed at characterizing and understanding the influence of material properties, geometric irregularities and heterogeneities in stress and strength over multiple length and time scales, and that will contribute to our understanding of earthquakes in the Southern California fault system.

Priorities for FARM in 2013

- Investigate the relative importance of different dynamic weakening and fault healing mechanisms, and the slip and time scales over which these mechanisms operate (3a, 3b, 3c, 3e).
- Determine the properties of fault cores and damage zones (1a, 1b, 3a, 3b, 4a, 4b) and characterize their variability with depth and along strike (1a, 1b, 4a, 4b) to constrain theoretical and laboratory studies, including width and particle composition of actively shearing zones, signatures of temperature variations, extent, origin and significance of on- and off-fault damage, healing, and poromechanical behavior.
- Determine the relative contribution of on- and off-fault damage to the total earthquake energy budget (3c, 4a, 4b), and the absolute levels of local and average stress (3e).
- Develop, test, and apply innovative source-inversion strategies to image the space-time rupture evolution of earthquakes reliably, propose source-inversion methods with minimal assumptions, and provide robust uncertainty quantification of inferred source parameters; collaboration with the Technical Activity Group (TAG) on Source Inversion Validation (SIV) is encouraged.
- Develop realistic descriptions of heterogeneity in fault geometry, rock properties, stresses and strains, and tractable ways to incorporate heterogeneity in numerical models of single dynamic rupture events and multiple earthquake cycles (3e, 3f, 4b, 4d, 6b). Test dynamic rupture modeling that incorporates these heterogeneities first by verifying the computational algorithms with benchmark exercises of the Dynamic Rupture Code Verification Technical Activity Group (TAG), then by comparing the results with geological and geophysical observations.
- Understand the significance of fault zone characteristics and processes on fault dynamics (3a, 3b, 3c) and formulate constitutive laws for use in dynamic rupture models (3d).
- Evaluate the relative importance of fault structure and branching, material properties, interseismic healing, and prior seismic and aseismic slip to earthquake dynamics, in particular, to rupture initiation, propagation, and arrest, and the resulting ground motions (3c, 3d, 3f).
- Characterize earthquake rupture, fault loading, degree of localization, and constitutive behavior at the base of and below the seismogenic zone (1a, 1b, 1e, 4a).
- Develop observations of slow slip events and non-volcanic tremors in southern California and understand their implications for constitutive properties of faults and overall seismic behavior (3a, 5a-5e).

- Assess the predictability of rupture direction and directivity of seismic radiation by collecting and analyzing field and laboratory data (4a, 4b), and conducting theoretical investigations to understand implications for strong ground motion.
- Develop physics-based models that can describe spatio-temporal patterns of seismicity (2e, 4e).
- Explore similarities between earthquakes and offshore landslide sources with the goal of better understanding their mechanics and the tsunami hazard from sources in southern California.

c. Stress and Deformation Over Time (SDOT)

The focus of the interdisciplinary focus group Stress and Deformation Over Time (SDOT) is to improve our understanding of how faults are loaded in the context of the wider lithospheric system evolution. SDOT studies these processes on timescales from 10s of Myr to 10s of yrs, using the structure, geological history, and physical state of the southern California lithosphere as a natural laboratory. The objective is to tie the present-day state of stress and deformation on crustal-scale faults and the lithosphere as a whole to the long-term, evolving lithospheric architecture, through 4D geodynamic modeling, constrained by the widest possible range of observables from disciplines including geodesy, geology, and geophysics. One long-term goal is to contribute to the development of a physics-based, probabilistic seismic hazard analysis for southern California by developing and applying system-wide deformation models of lithospheric processes at time-scales down to the earthquake cycle. These deformation models require a better understanding of a range of fundamental questions such as the forces loading the lithosphere, the relevant rock rheology, fault constitutive laws, and the spatial distribution of absolute deviatoric stress. Tied in with this is a quest for better structural constraints, such as on density, Moho depths, thickness of the seismogenic layer, the geometry of lithosphere-asthenosphere boundary, as well as basin depths, rock type, temperature, water content, and seismic velocity and anisotropy.

Projects Solicited for SDOT

- Contributions to our understanding of geologic inheritance and evolution, and its relation to the three-dimensional structure and physical properties of present-day crust and lithosphere. Contributions to efforts of building a 4D model of lithospheric evolution over 10s of Myr for southern California.
- Seismological imaging of crust, lithosphere and upper mantle using interface and transmission methods with the goal of characterizing the 3D distribution of isotropic and anisotropic wave speed variations.
- Contributions to the development of a Community Stress Model (CSM), a set of spatio-temporal (4D) representations of the stress tensor in the southern California lithosphere.
- Geodynamic models of southern California dynamics to allow hypothesis testing on issues pertaining to post-seismic deformation, fault friction, rheology of the lithosphere, seismic efficiency, the heat flow paradox, stress and strain transients, fault system evolution, as tied in with stress and deformation measurements across scales.
- Development of models of interseismic and earthquake cycle deformation, including efforts to estimate slip rates on southern CA faults, fault geometries at depth, and spatial distribution of slip or moment deficits on faults. Assessments of potential discrepancies of models based on geodetic, geologic, and seismic data. Development of deformation models (fault slip rates and locking depths, off-fault deformation rates) for UCERF (Unified California Earthquake Rupture Forecast).
- Research into averaging, simplification, and coarse-graining approaches across spatio-temporal scales, addressing questions such as the appropriate scale for capturing fault interactions, the adequate representation of frictional behavior and dynamic processes in long-term interaction models, fault roughness, structure, complexity and uncertainty. Modeling approaches may include analytical or semi-analytical methods, spectral approaches, boundary, finite, or distinct element methods, and a mix of these, and there are strong links with all other SCEC working groups, including FARM, Earthquake Simulators, and USR.

d. Earthquake Forecasting and Predictability (EFP)

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

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

For research strategies that plan to utilize the Collaboratory for the Study of Predictability (CSEP), see §IV.A.3.b to learn of its capabilities. Successful investigators proposing to utilize CSEP would be funded via core SCEC funds to adapt their prediction methodologies to the CSEP framework, to transfer codes to the externally accessible CSEP computers, and to be sure they function there as intended. Subsequently, the codes would be moved to the identical externally inaccessible CSEP computers by CSEP staff who will conduct tests against a variety of data as outlined in the CSEP description.

Priorities for EFP in 2013

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

e. Ground-Motion Prediction (GMP)

The primary goal of the Ground-Motion Prediction focus group is to develop and implement physics-based simulation methodologies that can predict earthquake strong-motion waveforms over the frequency range 0-10 Hz. Source characterization plays a vital role in ground-motion prediction. At frequencies less than 1 Hz, the methodologies should deterministically predict the amplitude, phase and waveform of earthquake ground motions using fully three-dimensional representations of Earth structure, as well as dynamic or dynamically compatible kinematic representations of fault rupture. At higher frequencies (1-10 Hz), the methodologies should predict the main character of the amplitude, phase and waveform of the motions using a combination of deterministic and stochastic representations of fault rupture and wave propagation.

Research Topics in GMP

- Developing and/or refining physics-based simulation methodologies, with particular emphasis on high frequency (1-10 Hz) approaches. This work could include implementation of simulation methodologies onto the Broadband Simulation Platform, or implementation of more efficient approaches in wave and rupture propagation schemes (in collaboration with CME), allowing accurate simulation of higher frequency ground motion.
- Waveform modeling of past earthquakes to validate and/or refine the structure of the Community Velocity Model (CVM) (in collaboration with USR). This includes exploration of the effects of statistical models of structural and velocity heterogeneities on the ground motion, the significance of the lowest (S-wave) velocities as frequencies increase, and development and validation of improved (possibly frequency-dependent) attenuation (intrinsic or scattering) models in physics-based simulations (in collaboration with USR).
- Incorporation of non-linear models of soil response, off-fault plasticity into physics-based simulation methodologies used to simulation ground motions at higher frequencies (>1Hz).

- Development of more realistic implementations of dynamic or kinematic representations of fault rupture, including simulation of higher frequencies (up to 10+ Hz). Possible topics include simulation of dynamic rupture on nonplanar faults and studying the effects of fault roughness on the resulting synthetic ground motion, and development of kinematic representations based on statistical models constrained by observed and/or dynamic ruptures. This research could also include the examination of current source-inversion strategies and development of robust methods that allow imaging of kinematic and/or dynamic rupture parameters reliably and stably, along with a rigorous uncertainty assessment. Close collaboration with the Technical Activity Group (TAG) on Source Inversion Validation (SIV) is encouraged.
- Verification (comparison against theoretical predictions) and validation (comparison against observations) of the simulation methodologies with the objective to develop robust and transparent simulation capabilities that incorporate consistent and accurate representations of the earthquake source and three-dimensional velocity structure. Comparison of synthetic ground motions from deterministic and stochastic approaches to data for overlapping bandwidths. Close collaboration with the Technical Activity Group (TAG) on Ground Motion Simulation Validation (GMSV).
- It is expected that the products of the Ground-Motion Prediction group will have direct application to seismic hazard analysis, both in terms of characterizing expected ground-motion levels in future earthquakes, and in terms of directly interfacing with earthquake engineers in the analysis of built structures. Activities within the Ground-Motion Prediction group will be closely tied to several focus areas, including the GMSV TAG, with particular emphasis on addressing ground motion issues related to seismic hazard and risk (see EEII below).

f. Southern San Andreas Fault Evaluation (SoSAFE)

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

Priorities for SoSAFE in 2013

- Lengthen existing paleoearthquake chronologies or start new sites in key locations along the fault system that will improve understanding of the last 2000 years of this fault system.
- Determine slip rates at many time scales, so that possible system-level interaction can be documented.
- Obtain the best possible measurements of geomorphic slip distributions from past earthquakes using field and LiDAR approaches and to validate the different measures.
- Explore chronometric, geomorphic, or statistical approaches to linking geomorphic offsets to dated paleoearthquakes.
- Use novel methods for estimating slip rates from geodetic data.
- Investigate methodologies for integrating paleoseismic (including geomorphic measures of slip) and geologic data into rupture histories. For example, studies may improve or inform interactions between SoSAFE results and scenario rupture modeling or rupture forecasts.

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

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

g. Earthquake Engineering Implementation Interface (EEII)

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

Technical Activity Group (TAG) on Ground Motion Simulation Validation (GMSV). A TAG focusing on validation of ground motion simulations has been established to develop and implement testing/rating methodologies via collaboration between ground motion modelers and engineering users. A 2011 workshop on this topic (*http://www.scec.org/workshops/2011/gmsv/index.html*) and the GSMV Plenary Session at the Annual Meeting identified the following initial efforts as potential priority activities in this area. Proposals on these topics will be reviewed with all other SCEC proposals in January of 2013. Interested researchers are invited to contact Dr. Nicolas Luco (nluco@usgs.gov) to discuss opportunities for coordinated research. Note that any PIs funded to work on GMSV-related projects will become members of the TAG and will be required to coordinate with each other, in part via participation in approximately two coordination workshops.

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

Improved Hazard Representation

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

- Investigate bounds on the median and variability of ground motions for a given earthquake scenario, in coordination with the Extreme Ground Motion Project.

Ground Motion Time History Simulation

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

Collaboration in Structural Response Analysis

- Tall Buildings and Other Long-Period Structures. Enhance the reliability of simulations of long period ground motions in the Los Angeles region using refinements in source characterization and seismic velocity models, and evaluate the impacts of these ground motions on tall buildings and other long-period structures (e.g., bridges, waterfront structures). Such projects could potentially build on work done in the PEER TBI Project.
- End-to-End Simulation. Interactively identify the sensitivity of structural response to ground motion parameters and structural parameters through end-to-end simulation. Buildings of particular interest include non-ductile concrete frame buildings.
- Reference Buildings and Bridges. Participate with PEER investigators in the analysis of reference buildings and bridges using simulated broadband ground motion time histories. The ground motions of large, rare earthquakes, which are poorly represented in the NGA strong motion database, are of special interest. Coordination with PEER can be done through Yousef Bozorgnia (yousef@berkeley.edu).
- Earthquake Scenarios. Perform detailed assessments of the results of scenarios such as the ShakeOut exercise, and the scenarios for which ground motions were generated for the Tall Buildings Initiative (including events on the Puente Hills, Southern San Andreas, Northern San Andreas and Hayward faults) as they relate to the relationship between ground motion characteristics and structural response and damage.

Ground Deformation

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

Risk Analysis

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

Other Topics

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

3. Special Projects and Initiatives

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

a. Working Group on California Earthquake Probabilities (WGCEP)

Following the 2008 release of the Uniform California Earthquake Rupture Forecast version 2 (UCERF2), the WGCEP is now working on finishing UCERF3 (the time-independent model being due by Jan 2013), and planning for future models. Our primary goals are to relax segmentation, add multi-fault ruptures, and include spatial-temporal clustering (earthquake triggering). As the latter will require robust interoperability with real-time seismicity information, UCERF3 will bring us into the realm of operational earthquake forecasting (OEF). These models are being developed jointly by SCEC, the USGS, and CGS, in close coordination with the USGS National Seismic Hazard Mapping Program, and with support from the California Earthquake Authority (CEA).

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

- Reevaluate fault models in terms of the overall fault connectivity (important for understanding the likelihood of multi-fault ruptures) and the extent to which faults represent a well-define surface versus a proxy for a braided deformation zone.
- Develop improved or a wider range of viable deformation models (defined as giving rakes and slip rates for each fault in a fault model, plus an "off fault" strain-rate map). Of particular interest is the extend to which slip rates taper toward the ends of faults that terminate (do not connect with other faults).
- Help determine the average along-strike slip distribution of large earthquakes, especially where multiple faults are involved (e.g., is there reduced slip at fault connections?).
- Help determine the average down-dip slip distribution of large earthquakes (the ultimate source of existing discrepancies in magnitude-area relationships).
- Develop a better understanding of the distribution of creeping processes and their influence on both rupture dimension and seismogenic slip rate.
- Contribute to the compilation and interpretation of mean recurrence-interval constraints from paleoseismic data and/or develop models for the probably of events going undetected at a paleosiesmic site.
- Develop earthquake rate models that relax segmentation and include multi-fault ruptures (e.g., using physics-based simulators).
- Develop ways to constrain the spatial distribution of maximum magnitude for background seismicity (for earthquakes occurring off of the explicitly modeled faults).
- Address the question of whether every small volume of space exhibits a Gutenberg Richter distribution of nucleations (even those on faults)?
- Develop improved estimates (including uncertainties) of the long-term rates of observed earthquakes for different sized volumes of space.
- Develop methods for quantifying elastic-rebound based probabilities in un-segmented fault models.
- Help quantify the amount of slip in the last event, and/or average slip over multiple events, on any major faults in California (including variations along strike).
- Develop models for fault-to-fault rupture probabilities, especially given uncertainties in fault endpoints.
- Determine the proper explanation for the apparent post-1906 seismicity-rate reduction (the so-called Empirical Model of previous WGCEPs). How temporally variable are seismicity rates (e.g., more so than implied by aftershock statistics)?
- Develop applicable methods for adding spatiotemporal clustering to forecast model s(e.g., based on empirical models such as ETAS, or derived from physics-based simulators). Are sequence-specific parameters warranted?

- Is there a physical difference between a multi-fault rupture and a separate event that was triggered quickly?
- Contribute the robust acquisition of real-time earthquake information needed for operational earthquake forecasting (e.g., a real-time model giving the probability of undetected events as a function of time, space, and magnitude).
- Develop more objective ways of setting logic-tree branch weights, especially where there are either known or unknown correlations between branches.
- Develop easily computable hazard or loss metrics that can be used to evaluate and perhaps trim logic-tree branches.
- Develop techniques for down-sampling event sets to enable more efficient hazard and loss calculations.
- Develop novel ways of testing UCERF3, especially ones that can be integrated with CSEP.

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

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

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

- Establishing rigorous procedures in controlled environments (testing centers) for registering prediction procedures, which include the delivery and maintenance of versioned, documented code for making and evaluating predictions including intercomparisons to evaluate prediction skills;
- Constructing community-endorsed standards for testing and evaluating probability-based, alarm-based, and event-based predictions;
- Developing hardware facilities and software support to allow individual researchers and groups to participate in prediction experiments;
- Providing prediction experiments with access to data sets and monitoring products, authorized by the agencies that produce them, for use in calibrating and testing algorithms;
- Reducing testing latency by reducing the updating interval of the short-term forecasting models (e.g., STEP and ETAS) in order to explore the potential information gain in aftershock sequences. Most desirable is testing on an event by event basis to adapt the testing frequency to the seismic activity;
- Establishing seismicity-based reference models as norms against which the skill of candidate models can be evaluated;
- Developing testing procedures that explicitly recognize that real-time catalogs are incomplete and have larger errors in source parameters;
- Working to develop testable fault-based forecast models;
- Intensifying the collaboration with Japan and New Zealand with a special emphasis on the effect of the Darfield and Tohoku-oki earthquakes, and using data collected from these sequences to retrospectively calibrate and prospectively test improved forecasting models;
- Initiating joint efforts with China;
- Initiating new experiments in existing or new testing regions;
- Re-assessing the geophysical, neotectonic, and paleoseismic data on the long-term recurrence of high-magnitude events and re-examining time-dependent hazard models;
- Developing experiments to test basic physical principles of earthquake generation (e.g., models for estimating the largest possible earthquake on a given fault are important to earthquake scenarios like ShakeOut and to earthquake hazard models. We seek proposals to develop quantitative tests of such models);

- Evaluating hypotheses critical to forecasting large earthquakes, including the characteristic earthquake hypothesis, the seismic gap hypothesis, and the maximum-magnitude hypothesis;
- Expanding the range of physics-based models to test hypotheses that some aspects of earthquake triggering are dominated by dynamic rather than quasi-static stress changes and that slow slip event activity can be used to forecast large earthquakes; and
- Conducting workshops to facilitate international collaboratories.

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

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

c. Community Modeling Environment (CME)

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

The SCEC research community can contribute research activities to CME by providing scientific or computational capability that can improve ground motion forecasts. The following paragraphs briefly describe several current CME computational goals so researchers can propose to develop a needed element that can be integrated into a larger CME calculation.

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

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

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

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

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

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

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

NSF has funded a new effort within SCEC to broaden and deepen our collaborations with Japanese earthquake scientists. A particular emphasis will be to broaden the participation of early career scientists. Collaborative research funded through VISES should have relevance for research questions of concern to the SCEC core program. Examples of relevant research activities include testing earthquake forecast models, numerical simulation of earthquake ground motion to high frequencies, ground motion simulation using dense networks of high-dynamic range sensors, and geodynamical studies of fault interaction and deformation. Travel support to Japan for early career scientists developing collaborations with colleagues in Japan is a priority for funding under the VISES program.

Note: Funding for successful proposals for travel to Japan will be handled from the SCEC office. Your proposed budget should not include overhead.

e. National Partnerships through EarthScope

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

4. Communication, Education, and Outreach

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

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

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

B. 2013 Communication, Education and Outreach Goals and Objectives

SCEC's CEO program addresses the third element of SCEC's mission: Communicate understanding of earthquake phenomena to the world at large as useful knowledge for reducing earthquake risk and improving community resilience. The programs and resources being implemented in SCEC4 provide an expanded capacity for accomplishing this overall goal. See §III.B for descriptions of each thrust area of the CEO program and current activities of each.

A SCEC CEO Strategic Plan with metrics and milestones was submitted to NSF in late 2011 (see **Appendix B**) however this plan has yet to be reviewed by a new CEO subcommittee of the Advisory Council. This review is now planned for early 2013. Currently we are working on a structure for monitoring and tabulating our progress towards the range of milestones that were proposed, though these may be revised by the subcommittee. For now this report summarizes planned activities in 2013 in terms of the proposed metrics.

1. The Implementation Interface

a. Research Engineering Partnerships

As these activities are coordinated as a SCEC research focus group and managed by representatives on the planning committee, see §IV.A.2.g for activities in 2013. Activities to be coordinated, with metrics to be assessed in 2013 include:

- # of research engineers attending SCEC Annual Meeting and other SCEC research workshops;
- # of documented uses (citations, reports) of SCEC simulation models and other SCEC products in engineering research and risk assessments;
- # of SCEC projects and collaborations involving research engineers;
- # of partnerships with engineering and risk modeling organizations (with MOUs or other written partnership);
- # of jointly-funded research projects with partner organizations.

b. Activities with Technical Audiences

To understand SCEC's effectiveness in this area, we are developing structures to document the use of our technical resources and information, and their impact on practice and codes, guidelines, and standards. Those who utilize SCEC products and information may be asked to notify us, especially partners who understand the value to both SCEC and themselves. These are the range of activities and metrics for 2013:

- # of practicing engineers, geotechnical consultants, building officials, emergency managers, financial institutions, and insurers attending SCEC Annual Meeting and other SCEC research workshops;
- # of practicing engineers, geotechnical consultants, building officials, emergency managers, financial institution representatives, and insurers in the ECA (statewide);
- # of training sessions and seminars for practicing engineers, building officials, etc. (organized by SCEC or co-sponsored). The key example of this will be the third annual *Buildings At Risk* Summit in partnership with the Structural Engineers Association of Southern California and other organizations;
- # of online activities such as webinars, trainings, and filmed presentations (each year). These will likely be done with FEMA, EERI, NEES, and other partners;
- # of SCEC researchers (including students) participating in engineering/building code/etc. workshops and other activities (hosted by SCEC or other organizations) (again, such as the *Buildings At Risk* Summit);
- # of documented technical (not research) uses of our models and informational resources (downloads, citations, etc.);
- # of documented uses of SCEC tools/information in developing or conforming to building codes, guidelines, and standards.

2. Public Education and Preparedness

a. Earthquake Country Alliance

In 2013 ECA will continue the progress made in 2012 to establish its leadership structures, including sector-based committees that may be coordinated with partner organizations. For example, the Business Committee may be transitioned to a partnership with the Business and Industry Council on Emergency Planning and Preparedness (BICEPP) or similar organizations that already have extensive connections and activities. FEMA now provides direct funding via a cooperative agreement for supporting these committees (conference calls, development of materials, etc.), for activities of each regional alliance, for leadership meetings, media relations, and for USC students who support California ShakeOut recruitment, data management, and content development.

Overall five-year ECA goals will determine priorities in 2013:

- *Create a Network:*Further develop the awareness of, engagement in, and support for the ECA among internal audiences
- *Working Together:* Cultivate collaboration among stakeholder Alliance members
- *Continued Engagement of the Already Prepared:* Build and maintain a community of earthquake / tsunami-ready Californians who, by demonstrating their readiness activities within their social circles, can help foster earthquake readiness as a social movement as well as all-hazard preparedness
- *Get the Rest of California Prepared:* Expand the community of earthquake / tsunami-ready Californians by reaching out to those who are not yet engaged in earthquake/tsunami readiness activities

Metrics for ECA activities in 2013:

- # of registered ECA Associates;
- # of participants of functional and sector committees;
- # of Strategic Organizational Partners with MOUs;
- # of partner organizations that link to ShakeOut & ECA website;
- # of resources (documents, online tools, etc.) to be used during disaster events to assist with information sharing between experts;
- # of new resources/programs for communities that have not yet been engaged;
- # of ECA curricular resources for use by schools, colleges, and free-choice learning institutions to teach about earthquakes and preparedness;
- # Amount of new funding (grants, donations) for ECA and its activities;
- # of unique visitors to ECA websites).

b. 2.b. ShakeOut Earthquake Drills

Now that the ShakeOut concept has matured (2013 will be the 6th annual drill in California), with additional Official ShakeOut Regions across the country and around the world and more to come, SCEC will develop resources for these regions and others to come to maintain the sustainability of its management of websites for all drills, such that each ShakeOut can manage its own recruitment, media engagement etc.

In the future, operational earthquake forecasts should create additional interest for the ShakeOut drills and increase participation and preparedness in general (as well as interest in earthquake science). The ShakeOut drills are also an excellent structure to prepare Californians to respond to earthquake early warnings. For the warnings to be effective, individuals, organizations, and governments must be trained in how to respond appropriately given their situation. Planning for these aspects will begin in 2013. Also, the Shakeout drills will continue to be an annual exercise of SCEC's post-earthquake response plan.

Extensive surveys have been done after each ShakeOut and will be reported on in 2013; the results of these surveys will provide additional indicators and metrics to monitor in order to assess the effectiveness of the ShakeOut in terms of what was learned, plans improved, and mitigation conducted. The following metrics and milestones are basic aspects of ShakeOut participation and will be monitored in 2013:

- # California ShakeOut Participants;
- # California ShakeOut individual /family registrants;

- # Participants in other U.S. ShakeOuts;
- # Participants in international ShakeOuts (BC, New Zealand, Japan, Central Asia, etc.): While SCEC will be coordinating with ShakeOut Organizers in other countries, and in some cases hosting the websites for the drills, international participation is beyond SCEC's direct influence so this will not have set milestones;
- # of ShakeOut drill franchises: SCEC will report the number of franchises but while we support many we do not actively promote new ShakeOuts as a goal (more is not necessarily better), so specific milestones are not appropriate. For example, at some point multiple ShakeOuts might be combined, reducing the overall total distinct drills.

c. *Putting Down Roots in Earthquake Country* Publication Series

Over the past 8 years this handbook has had several science content updates, new versions, and translations that have expanded its reach. In 2013 experts that specialize in communicating in multiple languages and via culturally appropriate channels, including development of materials for low-literate or visually impaired audiences, will be engaged to develop a simpler set of publications in the *Roots* series that are also for smaller regions of California to allow customization of the hazard information as well.

While the publication remains popular, ongoing evaluation will be conducted which will include information from those who have replicated Roots in other areas. Having multiple versions with different graphical designs and content allows for testing of what works best (in terms of content, terminology, overall design) by sociologists, risk communication experts, marketing specialists, and others.
Activities and metrics for 2013:

- Update and improve So Cal booklet with new science and preparedness information;
- Inclusion of updated earthquake forecasting information (UCERF3, etc.);
- # of area-specific supplements (inserts or online, potentially tied to ShakeOut Areas);
- # of CA versions in different languages or for other audiences;
- # of booklets (Roots, supplements, multi-language versions) distributed;
- Evaluation activities (status will be reported, results may be in following year).

d. 2.d. Earthquake Education and Public Information centers (EPIcenters)

As the EPIcenter network grows in 2013 and beyond, clear agreements for use of materials and participation will be developed. A set of collateral (materials) and memoranda of understanding for their use will be created to outline the costs and benefits of being a partner, along with responsibilities. A rigorous evaluation process will be developed, including surveys that members can conduct of their visitors.

A key activity in 2013 will result from SCEC's collaboration with the USGS, Stanford, and several members of the EPIcenter network to develop a QCN professional development program for science educators which could be administered by free-choice learning institutions across the Network. Once the teachers are trained to use QCN as research and classroom learning tool we would like to build community among those teachers and using their local museum, science center, etc. as a hub for this engagement.

Additionally, in partnership with EarthScope and Open Topography, an updated version of the Wallace Creek Interpretive Trail website (originally developed 1999-2001) will debut in 2013. The new site offers an updated web interface, LiDAR images and movies, links to recent research in the region, and many new education activities developed by SCEC Interns and faculty at Arizona State University.

Metrics for EPIcenter activities:

- # of museums and other free-choice learning venues in California and elsewhere;
- # of national organizations (e.g. research organizations, museum associations, etc.) involved;
- # of SCEC-developed exhibits, interpretive trails, or programs in use;
- # of field trip guides or SCEC Seismic Sites updated or created;
- # of EPIcenter field trips or other professional development field experiences;

- # of EPIcenters using network materials (including materials from national organizations and the ShakeOut).

e. 2.e. Media Relations

In 2013 SCEC will establish new coordination among media relations personnel from SCEC institutions. New content management software for SCEC's web pages will allow members of the community to create online summaries of their research, along with video recordings of presentations, as part of a new experts directory. SCEC will partner with USGS, Caltech, and other partners to offer annual programs that educate the media on how to report earthquake science, including available resources, appropriate experts, etc. SCEC (and the ECA) will also increase the availability of multi-lingual resources (materials, news releases, experts, etc.) to more effectively engage all media, including foreign media. Summer and school-year journalism or communications interns will be offered to assist CEO staff in developing these technologies and resources.

Proposed media relations metrics:

- # of traditional news advisories and releases;
- # of traditional news stories (online, print, radio, TV);
- # of podcasts (audio and/or video);
- # of virtual news conferences / webinars;
- # of people in SCEC Experts directory (with summaries/videos/etc.);
- # of experts identified, trained (if necessary) and available for interviews in languages other than English;
- # of social media posts/followers/etc.;
- # of non-English news advisories/releases (by language);
- # of media and risk communication training seminars for SCEC community (and # of participants);
- # of programs to educate the media on how to report earthquake science (and number of participants).

3. 3. K-14 Earthquake Education Initiative

This new thrust area organizes SCEC's activities in curricula development and teacher professional development, and connects to other CEO activities such as internships for community college students. Highlights include:

- The GPS summer RET program (described in the 2012 CEO plan) will evolve in 2013 with new NASA funding ($350K over sever years) as part of the InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport) mission that will place a single geophysical lander on Mars to study its deep interior. SCEC will adapt standards-aligned materials (provided by InSight) to help teachers work with comparative planetology concepts within the current educational environment. In addition SCEC will promote InSight in the EPIcenter Network.
- SCEC CEO will be participating in the planning of the 2013 California Science Education Conference that will be held in Palm Springs. Additionally, SCEC will participate in finding speakers and planning a field trip along the San Andreas Fault (in partnership with the San Bernardino County Museum).
- Web resources for SCEC's Plate Tectonics Puzzle Map will be developed to facilitate online ordering and access to resources such as activities, plate replacement templates, links to online resources, etc.

Proposed metrics for K-14 activities:

- # of event-based or "place-based" local/regional education opportunities;
- # of educational materials improved or created to provide information about local earthquake hazards and relevance for learning about earthquakes;
- # of follow-up activities over the long-term to help implement the content;
- # of teacher workshops offered to introduce these resources to educators;

- # of participating educational and research organizations in the initiative;
- # of new learning experiences and materials for use after large earthquakes.

4. 4. Experiential Learning and Career Advancement (ELCA)

In 2013 we will leverage SCEC's intern programs to provide additional learning and career opportunities in a continuum beginning in high school, throughout college, and into careers in science and education. These activities will connect with other activities of SCEC CEO and develop partnerships with other organizations, including SCEC institutions.

SCEC involved more than 50 interns each year during SCEC3, through extensive leveraging of stipend support from mentors and institutions. However funding for travel and other program expenses has not increased. We are developing ways to provide experiences to as many students as possible, but increasing expenses beyond stipends likely means a more selective program that may grow more slowly. Also, the REU proposal for continued funding for the UseIT program was submitted in September and results will not be known until early 2013. While we remain optimistic for the continuation of this successful program the following metrics for the intern programs will be significantly impacted if the proposal is not funded:

- # of participants (each summer) in SCEC undergraduate internship programs, based on current funding levels and potential leveraging;
- # of students involved in academic-year research or outreach projects (SCEC/ShakeOut/etc.);
- % of undergraduate interns who are women / % under-represented minorities;
- # of intern alumni in graduate school or having graduate degrees;
- # of intern alumni in STEM professions or internships.

The ELCA program for graduate students and post-docs will be focused on collaboration, networking, and employment opportunities, as most are supported by their institution, or with SCEC research funding. Social networking will allow interaction across institutions and research projects. Students will be encouraged to interact within the SCEC collaboratory regardless if they or their advisor has received SCEC research funding.

In addition to research opportunities, mentoring will be offered to help ELCA participants consider career possibilities, and longitudinal tracking of alumni will provide data on how students are progressing. Alumni will also be able to interact via social networking and SCEC meetings.

Additional proposed ELCA metrics:

- # of high school students provided research, education or outreach experiences;
- # of master's level opportunities;
- # of early career researcher presentations supported;
- # of employment or internship opportunities that are shared via SCEC email or website;
- # of early career researchers active in SCEC (criteria TBD);
- # of early career researchers in SCEC leadership positions (planning committee, etc.);
- % of women/ underrepresented minorities in SCEC leadership positions.

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VI. Appendices

A. Science Milestones

Table 7.1. SCEC4 Fundamental Problems of Earthquake Physics

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

NSF has requested that we submit an annualized list of milestones as part of a revised SCEC4 plan for 2012-2017. According to NSF instructions, these milestones are based on the six fundamental problems in earthquake physics described in the SCEC4 proposal (see Table 1 of this supplement). Our response to the NSF request adopts the premise that milestones are to be used by SCEC and its sponsoring agencies as indicators of research progress along unknown conceptual pathways rather than, say, lists of working-group tasks, timelines for IT developments, or absolute measures of research volume from individual research groups.

We have therefore concentrated on targets for SCEC's interdisciplinary activities in earthquake system science, such as those related to the SCEC Community Models, which will include a new Community Geodetic Model (CGM) and a Community Stress Model (CSM); those related to a proposed new set of Special Fault Study Areas (SFSAs); and those coordinated through the Technical Activity Groups (TAGs), such as the newly established Ground Motion Simulation Validation TAG, which brings earthquake engineers together with ground motion modelers. Because SCEC interdisciplinary activities in some cases depend on ancillary support from special projects (e.g., IT developments, HPC resources), reaching some of the milestones will be contingent on receiving this ancillary support.

The milestones are organized by a numbered research topic or collaboration. The problems addressed by each numbered item are listed parenthetically at the end of each paragraph; e.g., **[I-VI]** indicates that the milestones for that topic or collaboration are relevant to all six problems. Owing to the unpredictable nature of basic research, the milestones for the first two years are more explicit than those for the out-years of the SCEC4 program.

<u>Year 1 (2012-2013)</u>

1. Improved Observations. Archive and make available at the SCEDC waveforms, refined catalogs of earthquake locations and focal mechanisms for the period 1981-2011. Begin cataloging validation earthquakes and associated source descriptions and strong ground motion observations for California for use in ground motion simulation validation. Implement automated access to EarthScope GPS data for transient detections. Initiate planning with IRIS and UNAVCO to improve the scientific response capabilities to California earthquakes. **[I-VI]**

2. Transient Geodetic Signals. Develop data-processing algorithms that can automatically detect geodetic transients localized within Southern California using continuously recorded GPS data. Provide access to authoritative GPS data streams through CSEP. Implement at least two detection algorithms as continuously operating procedures within CSEP. **[V]**

3. Community Modeling Environment. Implement, refine, and release software tools for accessing the SCEC CVMs. Define reference calculations and evaluation criteria for 3D velocity models. Conduct comparative evaluations among different CFMs and CVMs. Deliver statewide versions of CFMs for use by WGCEP in UCERF3. Develop dynamic rupture verification exercises that incorporate effects of large-scale branching fault geometry on dynamic rupture and ground motions. **[II, III, IV, VI]**

4. Community Geodetic Model. Obtain input from the SCEC community via a workshop in order to define the conceptual and geographic scope of the CGM, including the time-independent and time-dependent model components, the data to be assimilated into the model, and the type and spatial distribution of model output. **[I, V]**

5. Community Stress Model. Develop a strategy for archiving and curating observational and model-based constraints on the tectonic stress field in Southern California. Based on this strategy, begin developing components of the database that will underlie the CSM. Organize a SCEC collaboration to contribute existing observational and model-based constraints to this database. **[I, II]**

6. Special Fault Study Areas. Identify requirements for SFSA Science Plans. Solicit SFSA Science Plan(s) from SCEC community to be ratified by PC and then included into 2013 RFP. Coordinate interdisciplinary activities, including workshops, to prototype at least one SFSA. **[I-VI]**

7. Ground Motion Simulation Validation. Develop a set of validation procedures suitable for the application of ground motion simulations in seismic hazard analysis and earthquake engineering. Identify a set of ground motions recorded in large California earthquakes to use for validation. Use codes available in the CME to simulate the ground motions. Compare these simulations with the observed recordings and other empirical models where they are well-constrained. **[VI]**

8. Source Modeling. Assess field evidence for the importance of specific resistance mechanisms during fault rupture, and plan fieldwork to collect new diagnostic data. Develop laboratory experiments that explore novel weakening mechanisms. Standardize observations from key earthquakes for the testing of different methods of finite-fault source inversion, and set up standardized inverse problems as cross-validation exercises. **[III, VI]**

9. Time-Dependent Earthquake Forecasting. Support WGCEP in the development and release of UCERF3. Reduce the updating interval of the short-term forecasting models being tested in CSEP. Improve methods for detecting, classifying, and analyzing various types of seismic clustering. **[II, V]**

Year 2 (2013-2014)

1. Improved Observations. Begin cataloging SCEC-supported geochronology analyses available for Southern California. Complete cataloging validation earthquakes and associated source descriptions and strong ground motion observations for California for use in ground motion simulation validation. Start comparing InSAR and GPS data to flag any suspect data as a first step to integrated use of GPS and InSAR in the CGM. Start developing plans for enhanced seismic instrument deployments in the SFSAs and elsewhere in Southern California. Update coordination of earthquake response capabilities of the SCEC community with partner organizations, including USGS, IRIS, and UNAVCO. **[I-VI]**

2. Transient Geodetic Signals. Increase the number of geodetic transient detection algorithms automated within CSEP that continuously operate on authoritative GPS data streams. Assess and refine detection thresholds through the use of synthetic data for a range of earthquake sizes for all operating detectors. **[V]**

3. Community Modeling Environment. Improve CVMs by applying full-3D waveform tomography to data from hundreds of earthquakes. Perform reference calculations and apply goodness-of-fit measures to evaluate CVMs against earthquake waveform data. Improve stochastic kinematic rupture models that incorporate source complexity observed in dynamic rupture simulations, including supershear rupture. Provide access to the UCERF3 statewide hazard model via the OpenSHA software platform. Develop methodology for calculating an extended ERFs based on UCERF3. **[II, III, IV, VI]**

4. Community Geodetic Model. Start generating a unified GPS time series dataset for secular and transient deformation and compiling LOS velocity maps from available SAR catalogs. Establish strategy for estimating secular rate as well as temporally variable signals (e.g., seasonal, postseismic). Assess the feasibility and the potential benefits of incorporating additional datasets (e.g., strainmeter, LiDAR) into CGM. Specify the CGM output needed for input to the CSM and transient detection and begin providing preliminary datasets as available. **[I, V]**

5. Community Stress Model. Populate the CSM data system with existing observational and model-based constraints. Begin coordination efforts with developers of the CGM and earthquake models. Investigate the variations in directions and magnitudes of stresses and stressing rates predicted by different existing models. **[I, II, IV]**

6. Special Fault Study Areas. Solicit SFSA Science Plan(s) from SCEC Community to be ratified by PC and then included into 2014 RFP. Re-examine requirements for SFSA Science Plans. Evaluate whether SCEC should increase the number of SFSA-oriented studies in the SCEC base program. **[I-VI]**

7. Ground Motion Simulation Validation. Develop a list of metrics identified by earthquake scientists and engineers as needed to validate ground motion predictions for application to seismic hazard analysis and earthquake engineering. Use the observed ground motions of well-recorded California earthquakes to evaluate existing ground motion simulation methods and recommend improvements. Establish the Broadband Simulation Platform as a high-performance cyberfacility for ground motion simulation by outside research communities, including earthquake engineers. **[III, VI]**
8. Source Modeling. Develop numerical methods that simultaneously resolve fault zone processes and large-scale rupture, including fault interaction, complex geometries, heterogeneities and multiple fault physics. Assess data available to distinguish source from path/site effects at high frequencies. Develop a methodology for uncertainty quantification in finite-fault source inversion and back-projection source imaging, tested on standardized data sets. **[III, VI]**
9. Time-Dependent Earthquake Forecasting. Assess the capabilities of UCERF3 for time-dependent forecasting through comparisons with earthquake catalogs or synthetic catalogs from earthquake models. Through CSEP and in collaboration with the USGS and CGS, test the suitability of deploying UCERF3 as an operational earthquake forecast. Couple UCERF3 to the Cybershake simulation suite for the Los Angeles region to prototype a time-dependent urban seismic hazard model. **[II, VI]**
10. Progress Report on SCEC4 Problems. Report to the SCEC4 community and Advisory Council on the progress made so far in formulating and testing hypotheses that address the six fundamental problem areas of earthquake physics.

Year 3 (2014-2015)

1. Improved Observations. Archive and make available at the SCEDC waveforms, refined catalogs of earthquake locations and focal mechanisms for the period 1981-2013. Continue cataloging SCEC-supported geochronology analyses available for Southern California. Submit a proposal to NSF/Earthscope that focuses on high-resolution imaging of SFSA and elsewhere in Southern California. Begin developing catalogs of prehistoric surface rupturing events along major faults in the system. **[I-VI]**
2. Transient Geodetic Signals. Using the first two years of results from Southern California, assess the capability and consistency of the geodetic transient detection procedures. Develop ensemble-based detection procedures that combine the output of multiple detection algorithms. **[II, V]**
3. Community Modeling Environment. Incorporate results from the Salton Seismic Imaging Project into the CVMs. Incorporate stochastic descriptions of small-scale heterogeneities into the upper layers of the CVMs, and evaluate the importance of these heterogeneities in ground motion models. Integrate and evaluate a statewide unified CVM suitable for 3D ground motion modeling. Incorporate new information on fault complexity from SFSA projects into the CFM. **[II, III, IV, VI]**
4. Community Geodetic Model. Integrate InSAR and GPS in order to formulate a uniform resolution model for secular surface velocities and associated uncertainties and covariances. Revise or refine the technical specifications of the CGM based on results obtained in years 1 and 2 and input from the CSM and the Geodetic Transient Detection TAG. Define the framework and infrastructure for maintaining CGM. Identify and test algorithms for time-dependent InSAR analysis. **[I, V]**
5. Community Stress Model. Quantitatively assess discrepancies between various stress models. Begin the process of identifying classes of alternative stress models or branches for the CSM. **[I, II, IV]**
6. Special Fault Study Areas. Continue to execute coordinated plans for disciplinary fieldwork and interdisciplinary synthesis in SFSAs. Finalize the set of SFSAs to be investigated in SCEC4. **[I-VI]**
7. Ground Motion Simulation Validation. Develop scientific and engineering criteria for appropriate use of deterministic and stochastic frequencies in ground motion simulations. Based on the Year-2 evaluation, assess how future SCEC simulation efforts can best assist seismic hazard analysis, risk analysis, and earthquake engineering. Use SCEC4 research on dynamic weakening and the effect of geometrical heterogeneity on faulting to improve estimates of high-frequency wave excitation by seismic sources. **[III, VI]**
8. Source Modeling. Verify numerical methods and assess physical formulations of fault geometries. Develop and calibrate parameterization of resistance mechanisms that are suitable for large scale models of dynamic ruptures, including interaction with fault roughness and damage-zone properties. Develop improved source inversion approaches with enhanced information extraction from high frequencies, including by intergration with back-projection imaging. **[III, VI]**

9. Time-Dependent Earthquake Forecasting. Develop approaches for using physics-based earthquake models in forecasting. Employ these models for studying the predictability of large events and constraining seismic cycle parameters (maximum magnitude, inter-event time, etc.). Conduct prospective forecasting experiments in CSEP that test the key hypotheses that underlie time-dependent forecasting methods. **[II]**
10. Progress Report on SCEC4 Problems. Report to the SCEC4 Community and Advisory Council on the progress made so far in formulating and testing hypotheses that address the six fundamental problem areas of earthquake physics and report to SCEC4 community.

Year 4 (2015-2016)

1. Improved Observations. Refine catalogs of prehistoric surface rupturing events along major faults in the system and, if needed, document more events, including paleo-magnitudes, with more robust uncertainty measurements. Initiate the use of GPS data to better constrain 3D motion observed by InSAR, especially in the North/South direction. **[I-VI]**
2. Transient Geodetic Signals. Incorporate the CGM into the transient detection procedures as the reference model for time-dependent geodetic signals. Using the data collected in Southern California and elsewhere on geodetic transients, assess the observational constraints on the spectrum of deformation transients that might be associated with earthquake processes in San Andreas Fault system. **[II, IV, V]**
3. Community Modeling Environment. Develop a prototype CyberShake hazard model for the Los Angeles region based on extensions of UCERF3 and large suites of ground motion simulations up to 1 Hz calculated from improved CVMs. Provide interactive access to this layered seismic hazard model. **[II, III, IV, VI]**
4. Community Geodetic Model. Use SAR data catalogs from previous and current SAR missions to generate LOS displacement time series over Southern California, and conduct comparisons between InSAR and GPS time series results. **[I, V]**
5. Community Stress Model. Integrate the various stress model developed in years 1-3 into a full-scale version of the CSM that includes both time-independent and time-dependent components. Begin applying results to the problem of discriminating between competing models of fault system loading. **[I, II]**
6. Special Fault Study Areas. Through workshops and other collaborative mechanisms, begin to examine how SFSAs results can be integrated into SCEC products and activities and address SCEC science questions. **[I-VI]**
7. Ground Motion Simulation Validation. Extend validation studies to high-frequency ground motion simulations that incorporate improved representations of source physics, source complexity, attenuation, and high-frequency scattering by near-surface heterogeneities. **[VI]**
8. Source Modeling. Incorporate more realistic models of fault-resistance evolution into CFM- and CSM-based simulations of the earthquake cycle. Compare fault interaction patterns from dynamic rupture models to earthquake simulators. Generate a uniform database of kinematic source models of past earthquakes and extract constraints on mechanical fault properties. Develop fundamental insight into source inversion uncertainties and implications for seismic network design. **[III, VI]**
9. Time-Dependent Earthquake Forecasting. Prototype numerical forecasting earthquake models, and evaluate their utility in developing new versions of a Uniform California Earthquake Rupture Forecast. **[II]**
10. Progress Report on SCEC4 Problems. Report on the progress made so far by SCEC4 investigations of the six fundamental problem areas of earthquake physics. Synthesize the current state of interdisciplinary knowledge in each of these problem areas, and evaluate which among the alternate hypotheses described in the SCEC4 proposal are now favored by the observational data and model-based constraints. This report will be used as input to the SCEC5 proposal. **[I-VI]**

Year 5 (2016-2017)

1. Improved Observations. Archive and make available at the SCEDC waveforms, refined catalogs of earthquake locations and focal mechanisms for the period 1981-2015. Document results from significant earthquakes that occurred during SCEC4. Continue refinement of the catalog of prehistoric surface rupturing events along major faults in the system including realistic uncertainty estimates. Initiate new project for archiving and making available InSAR datasets from Sentinel and ALOS2 acquisitions, which pertain to geological problems being studied by SCEC investigators. Complete comparing InSAR and GPS data to flag any suspect anomalies in GPS data as a first step to resolving discrepancies between GPS and InSAR strain rates. **[I-VI]**

2. Transient Geodetic Signals. Using the data collected in Southern California and elsewhere on geodetic transients during SCEC4, assess the validated and potential utility of geodetic data in time-dependent earthquake forecasting. **[II, IV, V]**

3. Community Modeling Environment. Perform reference calculations and apply goodness-of-fit measures to evaluate a SCEC California statewide CVM using earthquake waveform data. Calculate statewide CyberShake hazard model based on extensions of UCERF3, the California statewide CVM, and large suites of ground motion simulations up to 1 Hz. Provide interactive and programmable access to this layered seismic hazard model. **[II, III, IV, VI]**

4. Community Geodetic Model. Develop a full-scale version of the CGM that integrates data types and includes both time-independent and time-dependent components. Provide outputs from the CGM that can be used as input to the CSM, transient detectors, and time-dependent earthquake forecasting. **[I, V]**

5. Community Stress Model. Release the final SCEC4 version of the CSM and assess its implications for earthquake physics. Recommend guidelines for future data collection and modeling studies to improve resolution of the CSM. **[I, II]**

6. Special Fault Study Areas. Publish synthesis studies of the SCEC4 SFSAs. Assess the utility of these syntheses in improving seismic hazard models for California. **[I-VI]**

7. Ground Motion Simulation Validation. Complete an evaluation of the simulated ground motions produced by the current versions of the Broadband Platform and the statewide CyberShake model. **[VI]**

8. Source Modeling. Develop realistic broadband kinematic source models of well-recorded earthquake in California that are consistent with source inversion and dynamic rupture modeling. Work with USGS/Golden to migrate improvements in source inversion into operational methods. **[III, VI]**

9. Time-Dependent Earthquake Forecasting. Use earthquake models, the CFM and CSM, and other modeling tools to quantify how fault-system complexities govern the probabilities of large earthquakes and rupture sequences. **[II]**

10. Progress Report on SCEC4 Problems. Conduct a final assessment of SCEC4 investigations of the six fundamental problem areas of earthquake physics, and evaluate the utility of new knowledge in time-independent and time-dependent seismic hazard analysis. **[I-VI]**

B. Communication, Education, and Outreach Strategic Plan

2012-2017: Creating an Earthquake and Tsunami Resilient California

SCEC's Communication, Education, and Outreach (CEO) program is an important complement to the SCEC4 Science Plan. Through its engagement with many external partners, SCEC CEO fosters new research opportunities and ensures the delivery of research and educational products to the Center's customers, which include the general public, government offices, businesses, academic institutions, students, research and practicing engineers, and the media. SCEC CEO addresses the third element of SCEC's mission: *Communicate understanding of earthquake phenomena to the world at large as useful knowledge for reducing earthquake risk and improving community resilience.* The programs and resources developed during SCEC3, and planned for SCEC4, provide an expanded capacity for accomplishing this mission.

SCEC will continue to expand its CEO activities through partnerships with groups in academia and practice. The Earthquake Country Alliance (ECA), created and managed by SCEC, will continue to grow and serve as a model for multi-organizational partnerships that we plan to establish within education and among practicing and research engineers. Much of this interaction is virtual, in line with SCEC's "smart and green" Virtual Organization objectives.

The theme of the CEO program during SCEC4 is *Creating an Earthquake and Tsunami Resilient California.* This includes: increased levels of preparedness and mitigation; expanded partnerships with research and practicing engineers, building officials, and others; routine training and drills; financial preparedness; and other ways to speed recovery. Each of these areas builds on improved earthquake science understanding. In particular, we will prepare individuals and organizations for making decisions (split-second through long-term) about how to respond appropriately to changing seismic hazards, including new technologies such as operational earthquake forecasts and earthquake early warning.

While tsunami research will not be a focus of SCEC, tsunami education and preparedness is now an element of the CEO program and the ECA. Awareness of tsunami risk along the coast will grow rapidly as new maps of inundation zones produced by the California Geological Survey lead to posted signs along the coast, and local warning systems are put in place. The activities of the Redwood Coast Tsunami Workgroup will be replicated in the other regional ECA alliances. This will also bring potential new funding to SCEC and the ECA for outreach activities from NOAA and other sources.

The following plan addresses recommendations resulting from the 2009 NSF-Supported SCEC CEO evaluation. The plan also address the challenges of the NSF 2009 *GeoVision* Report, particularly (2) reducing vulnerability and sustaining life and (3) growing the geosciences workforce of the future.

In SCEC4, the CEO program will continue to manage and expand a suite of successful activities along with new initiatives, within four CEO interconnected thrust areas. The *Implementation Interface* connects SCEC scientists with partners in earthquake engineering research, and communicates with and trains practicing engineers and other professionals. The *Public Education and Preparedness* thrust area educates people of all ages about earthquakes, and motivates them to become prepared. The *K-14 Earthquake Education Initiative* seeks to improve earth science education and school earthquake safety. Finally, the *Experiential Learning and Career Advancement* program provides research opportunities, networking, and more to encourage and sustain careers in science and engineering.

The metrics and yearly milestones provided below are a framework for assessing progress and effectiveness of SCEC CEO programs and activities as currently planned. New opportunities, partnerships, and funding, or reduction in funding levels, may result in modifications to these measures when reviewed annually. For example, at the beginning of SCEC3 the ShakeOut initiative did not exist and yet has become a major component of the SCEC CEO program extending our scope internationally. While milestones below are expressed (mostly) numerically, additional qualitative assessments for each metric will be written for review each year. Additionally, some metrics will be reported without specific milestones (as explained for each metric), and some will be tracked for internal purposes but not reported annually.

1. The Implementation Interface

The implementation of SCEC research for practical purposes depends on effective interactions with engineering researchers and organizations, and with practicing engineers, building officials, insurers, utilities, emergency managers, and other technical users of earthquake information. These are most effective as partnerships towards common objectives, although trainings, tools, and other resources are also needed.

a. Research Engineering Partnerships

SCEC3 has produced a large body of knowledge about the seismic hazard in California that will enhance the seismic hazard maps currently used in building codes and engineering risk assessments. For example, Cybershake results will be fed into the USGS's National Seismic Hazard Mapping Program for use in its 2013 revisions. In the long term, we will collaborate with research engineers to test enhanced CyberShake models as an alternative to the empirical ground motion prediction equations and also as a database of simulated time histories for the design of critical facilities and other structures (e.g., tall buildings).

The SCEC4 Implementation Interface will provide the organizational structure for creating and maintaining collaborations with research engineers, much as the SHRA focus group has done in SCEC3. These activities will include rupture-to-rafters simulations of building response as well as the end-to-end analysis of large-scale, distributed risk (e.g., ShakeOut-type scenarios). Analysis of the performance of very tall buildings in Los Angeles using end-to-end simulation remains a continuing task that requires collaboration with both research and practicing engineers through PEER and other organizations. Our goal of impacting engineering practice and large-scale risk assessments require even broader partnerships with the engineering and risk-modeling communities, which motivates the activities described next.

Area	Performance Metric	2012	2013	2014	2015	2016
1.a: Implementation Interface – Research Engineering Partnerships	*Metrics and Milestones to be reported annually*					
	1.a.001: # of research engineers attending SCEC Annual Meeting and other SCEC research workshops	10	12	15	18	20
	1.a.002: # of documented uses (citations, reports) of SCEC simulation models and other SCEC products in engineering research and risk assessments	2	5	10	15	20
	Metrics to be reported annually (without specific targets)					
	1.a.003: # of SCEC projects and collaborations involving research engineers	Given uncertainties in funding and participation we cannot commit to milestones				
	1.a.004: # of partnerships with engineering and risk modeling organizations (with MOUs or other written partnership agreements)	As such partnerships depend on interest of the other organizations we cannot forecast milestones but will report progress each year				
	1.a.005: # of jointly-funded projects with partner organizations	Given the uncertainty in funding we cannot commit to specific milestones, however this is a measure of the success of our Interface				

b. Activities with Technical Audiences

The Implementation Interface will also develop effective mechanisms for interacting with technical audiences that make decisions based on understanding of earthquake hazards and risk, including practicing engineers, geotechnical consultants, building officials, emergency managers, financial institutions, and insurers. This will include expansion of the Earthquake Country Alliance to include members focused on mitigation, policy, and other technical issues. SCEC, perhaps with one or more partner organizations, will develop training sessions and seminars for practicing engineers and building officials to introduce new technologies (including time-dependent earthquake forecasts), discuss interpretation and application of simulation records, and provide a forum for SCEC scientists to learn what professionals need to improve their practice. These activities will increasingly be online, with frequent webinars and presentations and discussions videotaped and available for viewing online.

To understand SCEC's effectiveness in this area, we will track and document use of our technical resources and information, and their impact on practice and codes, guidelines, and standards. Those who utilize SCEC products and information may be asked to notify us, especially partners who understand the value to both SCEC and themselves.

Area	Performance Metric	2012	2013	2014	2015	2016
1.b: Implementation Interface – Activities with Technical Audiences	*Metrics and Milestones to be reported annually*					
	1.b.001: # of practicing engineers, geotechnical consultants, building officials, emergency managers, financial institutions, and insurers attending SCEC Annual Meeting and other SCEC research workshops (each year)	8	10	12	15	18
	1.b.002: # of practicing engineers, geotechnical consultants, building officials, emergency managers, financial institution representatives, and insurers in the ECA (statewide, cumulative)	40	60	80	100	120
	1.b.003: # of training sessions and seminars for practicing engineers, building officials, etc. (organized by SCEC or co-sponsored) (each year)	2	3	4	4	4
	1.b.004: # of online activities such as webinars, online trainings, and filmed presentations (each year)	3	5	6	6	6
	Metrics to be reported annually (without specific targets)					
	1.b. 005: # of SCEC researchers (including students) participating in engineering/building code/etc. workshops and other activities (hosted by SCEC or other organizations) (each year)	This is an activity which we will promote however we have limited ability to require, so milestones cannot be specified (until a trend is determined)				
	1.b.006: # of documented technical (not research) uses of our models and informational resources (downloads, citations, etc., cumulative)	As our capacity builds for documenting such use (perhaps quite complicated) we will report results, however milestones cannot be specified initially.				
	1.b.007: # of documented uses of SCEC tools/information in developing or conforming to building codes, guidelines, and standards (cumulative)	This is something we will develop the capacity to track, however because this can be limited by the frequency of code updates and other external issues, we cannot estimate milestones.				

2. Public Education and Preparedness

This thrust area spans a suite of partnerships, activities, and products for educating the public about earthquake science and motivating them to become prepared for earthquakes and tsunamis. To work towards these goals, we will increase the application of social science, with sociologists and other experts.

a. Earthquake Country Alliance

The ECA public-private partnership is the primary organizational structure within the Public Education and Preparedness thrust area. Due to the success of the ShakeOut, the ECA is now statewide and includes three established regional alliances. In September, 2011 the relationship between SCEC and the ECA (managed by SCEC since it's inception in Southern California in 2003) was cemented via a Memorandum of Understanding specifying SCEC as the administration headquarters of the statewide alliance and SCEC'S Associate Director for CEO as ECA's Executive Director. The MOU describes SCEC's roles and responsibilities in managing the ECA under the direction of a Steering Committee comprised of three representatives of the three regional alliances in Southern California, the Bay Area, and the North Coast. The Great California ShakeOut has been the primary collaborative activity so far, but additional activities with measurable outcomes are also managed or planned by the ECA. This planning builds on a California Emergency Management Agency earthquake communications plan developed in 2009 that emphasizes the value of a statewide collaboration.

As the administrative home of the ECA, USC/SCEC will:

- Appoint the SCEC Associate Director for Communication, Education, and Outreach as ECA's Executive Director to implement ECA programs, manage budgets, supervise staff (including SCEC staff working on ECA activities), students, and contractors, at the direction of the ECA Steering Committee;
- Coordinate the *Great California ShakeOut* and other major activities of the ECA, as requested by the ECA Steering committee;
- Create, update, and maintain ECA-branded websites, including www.earthquakecountry.org, www.shakeout.org, www.dropcoverholdon.org, and www.terremotos.org;
- Provide financial and legal administrative services including contract administration, purchasing, payroll, and legal/government reporting aspects as required of non-profit organizations.

As a partnership program managed by SCEC, ECA will:

- Establish an ECA Steering Committee to establish priorities and objectives, and oversee funding and program decisions
- Select an Executive Committee (of the ECA Steering Committee) to advise and coordinate with the ECA Executive Director;
- Appoint a Strategic Organization Advisory Group with representatives of statewide and other strategic organizations; and
- Establish and maintain statewide committees that will provide coordination of sector-based outreach and projects in coordination with Executive Director and ECA Steering Committee.

Each ECA organization, including SCEC, will independently determine the commitment of the their own resources, including human, technical, and financial resources, as they carry out the fundamental actions of this voluntary, non-binding Agreement. As the home of ECA, SCEC will allocate appropriate staff and administrative resources (phones, mailing, etc.) and may seek additional funding for these resources in partnership with the ECA. SCEC will provide mechanisms for managing ECA-specific funding and resources that are not co-mingled with other SCEC funding, and work with ECA leadership to ensure that such resources are allocated appropriately.

<u>ECA 5-year goals</u>:

- *Create a Network:* Further develop the awareness of, engagement in, and support for the ECA among internal audiences
- *Working Together:* Cultivate collaboration among stakeholder Alliance members

- *Continued Engagement of the Already Prepared:* Build and maintain a community of earthquake / tsunami-ready Californians who, by demonstrating their readiness activities within their social circles, can help foster earthquake readiness as a social movement as well as all-hazard preparedness
- *Get the Rest of California Prepared:* Expand the community of earthquake / tsunami-ready Californians by reaching out to those who are not yet engaged in earthquake/tsunami readiness activities

These goals for building the ECA and its resources/activities will result in new products and programs for which metrics and milestones cannot yet be specified. For example, based on the work of the Redwood Coast Tsunami Workgroup, the other Alliances will expand their tsunami messaging and programming, and all ECA members will receive instructions on implementing and communicating preparedness and mitigation strategies for both earthquakes and tsunamis. However three primary initiatives of the ECA are well-established (ShakeOut, *Putting Down Roots in Earthquake Country* publications, and the EPIcenter network) and measures are listed below. As new initiatives are developed similar metrics and milestones will be developed.

Area	Performance Metric	2012	2013	2014	2015	2016
2.a: Public Education and Preparedness – Earthquake Country Alliance	*Metrics and Milestones to be reported annually*					
	2.a.001: # of registered ECA Associates (cumulative)	400	500	600	650	700
	2.a.002: # of participants of functional and sector committees (each	60	100	120	130	140
	2.a.003: # of Strategic Organizational Partners with MOUs (cumula-	10	16	24	32	40
	2.a.004: # of partner organizations (Associate or strategic orgs) that link to ShakeOut & ECA website	60	100	150	180	200
	2.a.005: # of resources (documents, online tools, etc.) to be used during disaster events to assist with information sharing between experts.	4	6	8	9	10
	2.a.006: # of new resources/programs for cultural/sector communities that have not yet been	3	5	5	6	6
	2.a.007: # of ECA curricular resources for use by schools, colleges, and free-choice learning institutions to teach about earthquakes and preparedness (cumulative)	8	12	15	18	20
	Metrics to be reported annually (without specific targets)					
	2.a.008: # Amount of new funding (grants, donations) for ECA and its activities (each year)	Because of funding uncertainties, this will be reported but milestones cannot be specified				
	2.a.009: # of unique visitors to ECA websites) (each year)	This will be reported but milestones will not be specified until trends can be forecasted (the sites are being revised and may have much more traffic than currently)				
	Metrics to be tracked internally (not reported)					
	2.a.010: # of Associates in each Alliance (cumulative) (initial totals need to be confirmed)	TBD	TBD	TBD	TBD	TBD
	2.a.011: # of active users of ECA communication platform (each year)	80	120	160	200	250

	2.a.012: # of active functional and sector-based committees (each	10	12	13	14	15
	2.a.013: # of people/organizations showcased as “ECA heroes” or “ShakeOut Spotlights”, etc.) (each	12	20	20	25	25
	2.a.014: # cases of transfer and sharing of resources and knowledge among Alliances (each	10	15	20	22	25
	2.a.015: # of ECA Associates who have completed CERT or similar training programs (cumulative)	TBD	TBD	TBD	TBD	TBD
	2.a.016: # of new tsunami messages and programs (each year)	2	4	2	2	2

b. ShakeOut Earthquake Drills

In addition to its lead role in organizing the California ShakeOut, SCEC manages a growing network of ShakeOut Franchises across the country and around the world (see *www.shakeout.org/history* and *www.shakeout.org/regions*). In order to develop and maintain the ShakeOut brand and reduce potential confusion between the different drills, SCEC works with officials in these regions and for most hosts the website for their drill, as we first did for a regional ShakeOut drill in New Zealand in 2009. This approach serves to standardize earthquake messaging nationally and internationally, and allow groups to share best practices for recruiting participation, such as the use of social networking sites. Some ShakeOuts rely more heavily on SCEC, while some are managing more of their content, reviewing registrations, and more actively communicating with participants. Manuals and guidelines for organizing ShakeOut drills will be developed in 2011 and will include criteria for 4 levels of ShakeOut management.

The original California ShakeOut itself has expanded greatly, from 5.4 million in 2008 to well over 8.6 million participants in 2011, with 9.5 million total across 6 ShakeOuts all on Oct. 20, 2011. New materials and activities for additional communities and in multiple languages are developed each year. In the future, operational earthquake forecasts should create additional interest for the ShakeOut drills and increase participation and preparedness in general (as well as interest in earthquake science). The ShakeOut drills are also an excellent structure to prepare Californians to respond to earthquake early warnings. For the warnings to be effective, individuals, organizations, and governments must be trained in how to respond appropriately given their situation. Also, the Shakeout drills will continue to be an annual exercise of SCEC's post-earthquake response plan.

SCEC’s partnership with several state agencies (Department of Education, Emergency Management, etc.) has been bolstered as a result of the ShakeOut, and each has expressed their commitments to support the ShakeOut indefinitely. A state-sponsored survey of household earthquake preparedness in 2008 will hopefully be repeated regularly so that the ShakeOut effort can be continually improved. A new ECA Evaluation Committee will encourage additional social science research specific to the ShakeOut.

NOTE: The following metrics and milestones are basic aspects of ShakeOut participation. Extensive surveys have been done after each ShakeOut and will be reported on in 2011; the results of these surveys will provide additional indicators and metrics to monitor in order to assess the effectiveness of the ShakeOut drills in terms of what participants are learning, plans being improved, and mitigation being conducted.

Area	Performance Metric	2012	2013	2014	2015	2016
cation and Preparedness – ShakeOut Earth-	*Metrics and Milestones to be reported annually (see NOTE above)*					
	2.b.001: # California ShakeOut Participants (each year)	9.0 million	9.5 million	10 million	10 million	10 million
	2.b.002. # California ShakeOut individual /family registrants (included in 2.b.001 (each year)	30,000	50,000	100,000	200,000	300,000

	2.b.003: # Participants in other U.S. ShakeOuts (each year)	2 million	3.0 million	3.5 million	4.0 million	4.5 million
	Metrics to be reported annually (without specific targets)					
	2.b.004: # Participants in international ShakeOuts (BC, New Zealand, Japan, Central Asia, etc.) (each year)	While SCEC will be coordinating with ShakeOut Organizers in other countries, and in some cases hosting the websites for the drills, international participation is beyond SCEC's direct influence so this will be reported without specific milestones to achieve.				
	2.b.005: # of ShakeOut drill franchises (cumulative)	SCEC will report the number of franchises but while we support many we do not actively promote new ShakeOuts as a goal (more is not necessarily better), so specific milestones are not appropriate. For example, at some point multiple ShakeOuts might be combined, reducing the overall total distinct drills.				
	Metrics to be tracked internally (not reported)					
	2.b.006: # of ShakeOut drill franchises at each level (1-5)	This new ratings system is in development and will be used to specify what each franchise needs to do to be self-managing				

c. ***Putting Down Roots in Earthquake Country*** publication series

This print and online publication series remains very popular and likely will be replicated in additional regions during SCEC4, similar to new versions produced since 2005. The existing versions will continue to be updated and improved with new science and preparedness information. For example, tsunami content was added in 2011 to the Southern California version of the handbook, based on content created for the 2009 version of *Living on Shaky Ground.* This is a similar document published by the Redwood Coast Tsunami Workgroup that now also includes the SCEC/ECA *Seven Steps to Earthquake Safety.*

Research results related to earthquake forecasting are already included in the handbook, and this information will be updated as operational earthquake forecasts and earthquake early warning become a reality in California.

Beyond updates focusing on content, new versions or translations of the publication will expand the reach of *Roots* with particular emphasis on underserved communities. This will involve partners that specialize in communicating in multiple languages and via culturally appropriate channels. Additionally, versions for low-literate or visually impaired audiences, and perhaps for children and seniors will be pursued. While the publication remains popular, ongoing evaluation will be conducted which will include information from those who have replicated Roots in other areas. Having multiple versions with different graphical designs and content allows for testing of what works best (in terms of content, terminology, overall design) by sociologists, risk communication experts, marketing specialists, and others.

Area	Performance Metric	2012	2013	2014	2015	2016
tion and Prepared-ness – Putting Down Roots in	*Metrics and Milestones to be reported annually*					
	2.c.001: Update and improve So Cal booklet with new science and preparedness information		✔			✔
	2.c.002: Inclusion of updated earthquake forecasting information		✔			if available

	2.c.003: # of area-specific supplements (inserts or online, potentially tied to ShakeOut Areas)	0	4	8	10	11
	2.c.004: # of CA versions in different languages or for other audiences	7	11	12	14	16
	Metrics to be reported annually (without specific targets)					
	2.c.005: # of booklets (*Roots,* supplements, multi-langage versions) distributed (each year)	Due to uncertain funding for printing, quantities to be printed/distributed cannot be listed as milestones				
	2.c.006: Evaluation activities (status will be reported, results may be in following year)	ECA Review for multi-language versions	Reviewed with statewide prep. Survey	Assess business version	Assess multi-language versions	Reviewed with statewide prep. Survey
	Metrics to be tracked internally (not reported)					
	2.c.007: Inclusion of tsunami content in Bay area versions of the handbook (not SCEC managed, but ECA supported)		✔			
	2.c.008: Funding raised (sponsors, agencies) for developing and printing materials	TBD	TBD	TBD	TBD	TBD

d. Earthquake Education and Public Information centers (EPIcenters)

This network of “free-choice” learning institutions within the ECA has grown rapidly, with over 60 participating institutions involved. Many more are expected to join as a result of outreach by SCEC and the participants, including new museums, parks, and other venues in California, but also in other states. National organizations such as the American Association of Museums and the Association of Science and Technology Centers will also be involved.

Members of the EPIcenter network have well-established ties to the communities that they serve and are regarded as providers of reliable information. They share a commitment to demonstrating and encouraging earthquake preparedness, organize ECA activities in their region, and lead presentations and other events in their communities. For example, they could quickly implement programs based on elevated forecasts and will educate visitors about how to respond to earthquake early warnings.

In addition to managing the EPIcenter network, SCEC will continue to maintain its existing exhibits and interpretive trails, and create new venues with EPIcenter partners. For example, SCEC will be consulting with the California Science Center as it updates its earthquake exhibit. We will also update our field trip guides to local faults, and organize them within a *SCEC Seismic Sites* online framework along with video footage of locations. This will be a resource for EPIcenter partners to use for their field trips.

As the EPIcenter network grows, clear agreements for use of materials and participation will be developed. A set of collateral (materials) and memoranda of understanding for their use will be created to outline the costs and benefits of being a partner, along with responsibilities. A rigorous evaluation process will be developed, including surveys that members can conduct of their visitors.

Area	Performance Metric	2012	2013	2014	2015	2016
2.d: Public Education and Preparedness – EPIcenter Network	*Metrics and Milestones to be reported annually*					
	2.d.001: # of museums, parks, and other free-choice learning venues in California and in other states (cumulative)	65	75	80	85	90
	2.d.002: # of national organizations (e.g. research organizations, museum associations, etc.) involved (cumulative)	5	7	9	11	13
	2.d.003: # of SCEC-developed exhibits, interpretive trails, or programs in use (cumulative)	4	6	8	10	12
	2.d.004: # of field trip guides or SCEC Seismic Sites updated or created (cumulative)	1	2	4	6	8
	2.d.005: # of EPIcenter field trips or other professional development field experiences (each year)	1	2	3	4	5
	2.d.006: # of EPIcenters using network materials (including materials from national organizations and the ShakeOut) (each year)	40	50	65	70	85
	Metrics to be reported annually (without specific targets)					
	2.d.007: % partner participation in EPIcenter surveys (each year)	Participation is uncertain to forecast initially				
	2.d.008: Results of surveys	Once surveys are developed additional metrics may be added to this plan. Until then key results will be reported				

e. Media Relations

SCEC has developed extensive relationships with the news media and is increasingly called upon for interviews by local, national, and international reporters and documentary producers. This is especially true after earthquakes, such as the 2010 Haiti and Chile earthquakes. As a result the demand on SCEC scientists after a large California earthquake will be even greater than in previous earthquakes. In addition, the breadth of SCEC's research, including its information technology programs and the development of time-dependent earthquake forecasting, will also increase the need for expanded media relations. New strategies and technologies will be developed to meet these demands.

One such technology now available to SCEC and the ECA for ShakeOut media relations (and other ECA activities) is media-relations software (purchased by the California Earthquake Authority) that provides current contact information for all reporters and assignment editors, tracks news coverage, distributes news releases, and much more. Another service is also being used by SCEC strictly for tracking news coverage and may be an alternative. Because such software can be used to assess how research findings and other messages are being communicated to the public, we will investigate such an investment, as suggested by the SCEC Advisory Council.

Social media capabilities will be expanded in SCEC4, including the use of podcasts, webinars and other virtual news conferences, twitter, and other technologies. SCEC and the ECA will increase the availability of multi-lingual resources (materials, news releases, experts, etc.) to more effectively engage all media, including foreign media. Summer and school-year internships for journalism or communications students will be offered to assist CEO staff in developing these technologies and resources.

An important component to our media relations strategy will be media and risk communication training for the SCEC Community. Training will likely be held each year at the SCEC Annual Meeting, and will be coordinated among media relations personnel from SCEC institutions. New content management software for SCEC's web pages will allow members of the community to create online summaries of their research, along with video recordings of presentations, as part of a new experts directory. SCEC will partner with USGS, Caltech, and other partners to offer annual programs that educate the media on how to report earthquake science, including available resources, appropriate experts, etc.

Area	**Performance Metric** (Each milestone is split between SCEC Research and CEO-ECA topics, each year)	**2012**	**2013**	**2014**	**2015**	**2016**
2.e: Public Education and Preparedness – Media Relations	*Metrics and Milestones to be reported annually*					
	2.e.001: # of traditional news advisories and releases	4 / 8	6 / 9	8 / 10	10 / 10	10 / 10
	2.e.002: # of traditional news stories (online, print, radio, tv)	30 / 400	60 / 500	100 / 600	150 / 700	200 / 800
	2.e.003: # of podcasts (audio and/or video)	3 / 5	4 / 7	5 / 9	6 / 12	10 / 15
	2.e.004: # of virtual news conferences / webinars	1 / 1	2 / 2	3 / 3	3 /3	4 / 4
	2.e.005: # of people in SCEC Experts directory (with summaries/videos/etc.)	10	20	40	50	60
	2.e.006: # of experts identified, trained (if necessary) and available for interviews in languages other than English	2 / 6	4 / 8	6 / 12	8 / 16	10 / 20
	Metrics to be reported annually (without specific targets)					
	2.e.007: # of social media posts/followers/etc.	As this will be determined by factors beyond our influence (earthquakes in particular) and also the growth of social media, we cannot provide targets until trends are tracked				
	2.e.008: # of non-English news advisories/releases (by language)	This will depend on the number of news stories and our capacity for translation (ideally through partner organizations, as fees can be high)				
	2.e.009: # of media and risk communication training seminars for SCEC community (and # of participants)	Having such trainings is a priority however it is not clear yet how many will be needed, how frequently, and how many people need to participate. This may also depend on costs for trainers and how many people can participate in a single training given the format.				
	2.e.010: # of programs to educate the media on how to report earthquake science (and number of participants)	As we develop this project we will be better able to estimate number of programs that we will offer. These may be best as small workshops, or might be offered as online webinars. Our SCEC institutions and ECA partners will likely co-present.				

3. K-14 Earthquake Education Initiative

The primary goal of this new Initiative is to educate and prepare California students for living in earthquake country. This includes improved standards-based earth science education as well as broadened preparedness training. The science of earthquakes provides the context for understanding why certain preparedness actions are recommended and for making appropriate decisions; however earthquake science and preparedness instructions are usually taught in a manner that lacks this context. For example, earthquake science is mostly taught in the context of plate tectonics and not in terms of local hazards. Large distant earthquakes are something that happened “over there” and local connections that are both contextual and “place-based” (such as materials specific to a school’s geographic region) are not often made.

SCEC’s position is that knowledge of science content and how to reduce earthquake risk may be best achieved through an event-based (teachable-moment) approach to the topic. In other words, even if most earthquake content remains in California’s sixth grade and secondary curriculum, earthquake science and preparedness education should be encouraged in all grades when real-world events increase relevance and therefore interest. While we cannot plan when earthquakes will happen, the annual ShakeOut drill provides teachers a new type of teachable moment for teaching earthquake science.

In addition to event-based education opportunities such as the ShakeOut, educational materials must also be improved or supplemented to provide better information about local earthquake hazards and increase relevance for learning about earthquakes (place-based education). SCEC’s role as a content provider is its ability to convey current understanding of earthquake science, explain how this understanding is developed, and provide local examples. The SCEC4 focus on time-dependent earthquake forecasting may take many years to appear in textbooks, yet SCEC can develop useful resources for teachers now.

SCEC’s approach will be as follows. First, we will facilitate learning experiences and materials for use with real earthquakes and the ShakeOut drill. This will include online resources and activities, appropriate for various subjects (science, math, geography, etc.) for teachers to download immediately after large earthquakes and prior to the ShakeOut, to be hosted on SCEC’s website and also shared with IRIS, UNAVCO, USGS and others for their similar teachable moment resource webpages (similarly as our coordination with IRIS and EarthScope on the Active Earth display. Second, SCEC and our education partners will develop learning materials that complement traditional standards-based instruction with regional and current earthquake information. Teacher workshops will be offered to introduce these resources to educators at all levels, and will include follow-up activities over the long-term to help implement the content. Evaluation will be conducted across all activities, perhaps involving education departments at SCEC institutions.

For these activities to be successful, participation and commitment are essential from groups such as the California Department of Education, producers of educational media and materials (e.g. textbook companies), science educators, providers of teacher education, EPIcenters, and science education advocacy groups such as the California Science Teachers Association. We have developed partnerships with these groups and will bring them together as a new component of the Earthquake Country Alliance.

Area	**Performance Metric** (all categories include materials developed in collaboration with SCEC partners)	**2012**	**2013**	**2014**	**2015**	**2016**
	Metrics and Milestones to be reported annually					
3. K-14 Earthquake Education Initiative	3.001: # of event-based or “place-based” local/regional education opportunities (each year)	2	4	6	8	10
	3.002: # of educational materials improved or created to provide information about local earthquake hazards and relevance for learning about earthquakes (per year)	2	4	5	6	8
	3.003: # of follow-up activities over the long-term to help implement the content (each year)	1	2	3	3	4

	3.004: # of teacher workshops offered to introduce these resources to educators (each year)	1	2	3	3	4
	3.005: # of participating educational and research organizations in the initiative (cumulative)	4	6	8	9	10
	Metrics to be reported annually (without specific targets)					
	3.006: # of new learning experiences and materials for use after large earthquakes (each year)	Specific milestones cannot be projected as this depends on the number of large earthquakes each year				

4. Experiential Learning and Career Advancement

The SCEC Experiential Learning and Career Advancement (ELCA) program seeks to enhance the competency and diversity of the STEM workforce by facilitating career advancement pathways that (1) engage students in STEM-based research experiences at each stage of their academic careers, and (2) provide exposure and leadership opportunities to students and early career scientists that engage them in the SCEC Community and support them across key transitions (undergraduate to graduate school, etc.).

The ELCA program in SCEC4 will be built on the foundation of our long-established USEIT and SURE internship programs that challenge undergraduates with real-world problems that require collaborative, interdisciplinary solutions. Each summer they will involve over 30* students (including students at minority-serving colleges and universities and local community colleges). The interns will experience how their skills can be applied to societal issues, and benefit from interactions with professionals in earth science, engineering, computer science, and policy. Some interns may be able to continue their research during the academic year (especially USC students).

(* Note: SCEC has involved more than 50 interns each year during SCEC3, through extensive leveraging of stipend support from mentors and institutions. However funding for travel and other program expenses has not increased. We are developing ways to provide experiences to as many students as possible which likely means a more selective program that may grow more slowly.

These undergraduate internship programs will be the centerpiece of a high school to graduate school career pathway for recruiting the best students, providing them with high-quality research, education, and outreach experiences, and offering career mentoring and networking opportunities.

At the high school level, this effort will be closely linked with SCEC's K-14 Earthquake Initiative and based on programs that expose high school students to earthquake research, inquiry-based curricula, and visits by SCEC scientists. This may identify students that could participate in USEIT or a SURE project at a local SCEC institution, perhaps even in the summer prior to their first year in college.

For graduate students, we will identify funding for master's level (including new Ph.D. students) internships that provide unique opportunities. This will include support for cross-disciplinary computer science research by master's students similar to the ACCESS program (which completed in 2010). Students may participate in the USEIT program as mentors, conduct research with scientists at other SCEC institutions than their own school, and participate in CEO activities such as media relations, curricula development, and program evaluation.

The ELCA program for graduate students and post-docs will be focused on collaboration, networking, and employment opportunities, as most are supported by their institution, or with SCEC research funding. Social networking will allow interaction across institutions and research projects. Students will be encouraged to interact within the SCEC "collaboratory" regardless if they or their advisor has received SCEC research funding.

In addition to research and education/outreach opportunities, mentoring will be offered to help ELCA participants consider career possibilities, and longitudinal tracking of alumni will provide data on how students are progressing.

The final element of the ELCA program is career advancement opportunities for early-career researchers, including post-docs, young faculty, and research staff. We will highlight employment opportunities via SCEC's email list and on the SCEC website, and perhaps also post CVs of early career researchers seeking positions. We may also provide travel support for early career researchers to give presentations at conferences and department lectures nationwide, and provide presentation materials so that they can highlight their role in SCEC. Also, SCEC leadership positions, especially the planning committee, provide opportunities for exposure and career advancement.

Area	Performance Metric	2012	2013	2014	2015	2016
4. Experiential Learning and Career Advancement	*Metrics and Milestones to be reported annually*					
	4.001: # of participants (each summer) in SCEC undergraduate internship programs, based on current funding levels and potential leveraging (see note in text above)	30	32	34	36	38
	4.002: # of students involved in academic-year research or outreach projects (SCEC/ShakeOut/etc.) (each year)	8	10	12	14	16
	4.003: % of undergraduate interns who are women / % under-represented minorities (each year)	50 / 20	50 / 20	55 / 25	55 / 25	60 / 30
	4.004: # of high school students provided research, education or outreach experiences, (each year)	0	2	4	6	8
	4.005: # of master's level opportunities (see text above) (each year)	3	5	6	8	10
	4.006: # of early career researcher presentations supported (each year)	2	4	6	8	10
	Metrics to be reported annually (without specific targets)					
	4.007: # of intern alumni in graduate school or having graduate degrees	Participation in SCEC is only one factor that may contribute to these metrics, so specific milestones are not appropriate				
	4.008: # of intern alumni in STEM professions or internships (cumulative)					
	4.009: # of employment or internship opportunities that are shared via SCEC email or website (each year)	This depends on external partners and other factors beyond SCEC's control, though will demonstrate our career advancement commitments				
	4.010: # of early career researchers active in SCEC (criteria TBD)	Milestones will likely not be specified as hiring at SCEC institutions is beyond SCEC control, however knowing the total number and having communication with them and allow us to monitor and support their progress				
	4.011: # of early career researchers in SCEC leadership positions (planning committee, etc.) (each year)	Because such positions depend on the pool of potential leaders in each discipline, institutional hiring and appointments, etc., this is not something for which SCEC can forecast milestones. However expanding such opportunities is a priority and will be reported				
	4.012: % of women/ underrepresented minorities in SCEC leadership positions					

C. 2012 Report of the SCEC Advisory Council

Pending delivery from SCEC Advisory Council Chair, Jeff Freymueller.