Southern California Earthquake Center

2005 Annual Report

NSF Cooperative Agreement EAR-0106924 and USGS Cooperative Agreement 02HQAG0008

I. Introduction

The Southern California Earthquake Center (SCEC) is a regionally focused organization with a tripartite mission to

- gather new information about earthquakes in Southern California,
- integrate this information into a comprehensive and predictive understanding of earthquake phenomena, and
- communicate this understanding to end-users and the general public in order to increase earthquake awareness and reduce earthquake risk.

SCEC was founded in 1991 as a Science and Technology Center (STC) of the National Science Foundation (NSF), receiving primary funding from NSF's Earth Science Division and the United States Geological Survey (USGS). SCEC graduated from the STC Program after a full 11-year run (SCEC1). It was reauthorized as a free-standing center on February 1, 2002 (SCEC2) with base funding from NSF and USGS. In addition, the Center was awarded major grants from NSF's Information Technology Research (ITR) Program and its National Science, Technology, Engineering, and Mathematics Digital Library (NSDL) program.

This report summarizes the Center's activities during the fourth year of SCEC2. The report is organized into the following sections:

II. Planning, Organization, and Management of the Center

The transition from SCEC1 to SCEC2 involved considerable planning and restructuring. A five-year planning document, *The SCEC Strategic Plan 2002-2007*, was submitted to the sponsoring agencies in October, 2001. This plan articulates the Center's long-term research goals, which are reproduced here in Appendix A. The current organization chart of the Center is shown on the next page.

SCEC is an institution-based center, governed by a Board of Directors who represent its members. During the past year, the Board approved one new core institution, the University of California at Santa Cruz, one new U.S. participating institution (University of Utah) and one new foreign institution (Institute for Geological and Nuclear Sciences, New Zealand). The SCEC membership now comprises 16 core institutions and 39 participating institutions. One measure of the size of the SCEC community is the attendance at the Annual Meeting (September 11-14, 2005), which again was >400 scientists, teachers, and students.

Board of Directors

Under the SCEC2 by-laws, each core institution appoints one board member, and two at-large members are elected by the Board from the participating institutions. Emily Brodsky, now a Profesor at UC-Santa Cruz, continues on the board representing UCSC. Peter Bird will replace Brodsky as the board member from UCLA. The 18 members of the Board are listed in Table II.1.

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Table II.1. SCEC Board of Directors

Institutional and At-Large Representatives

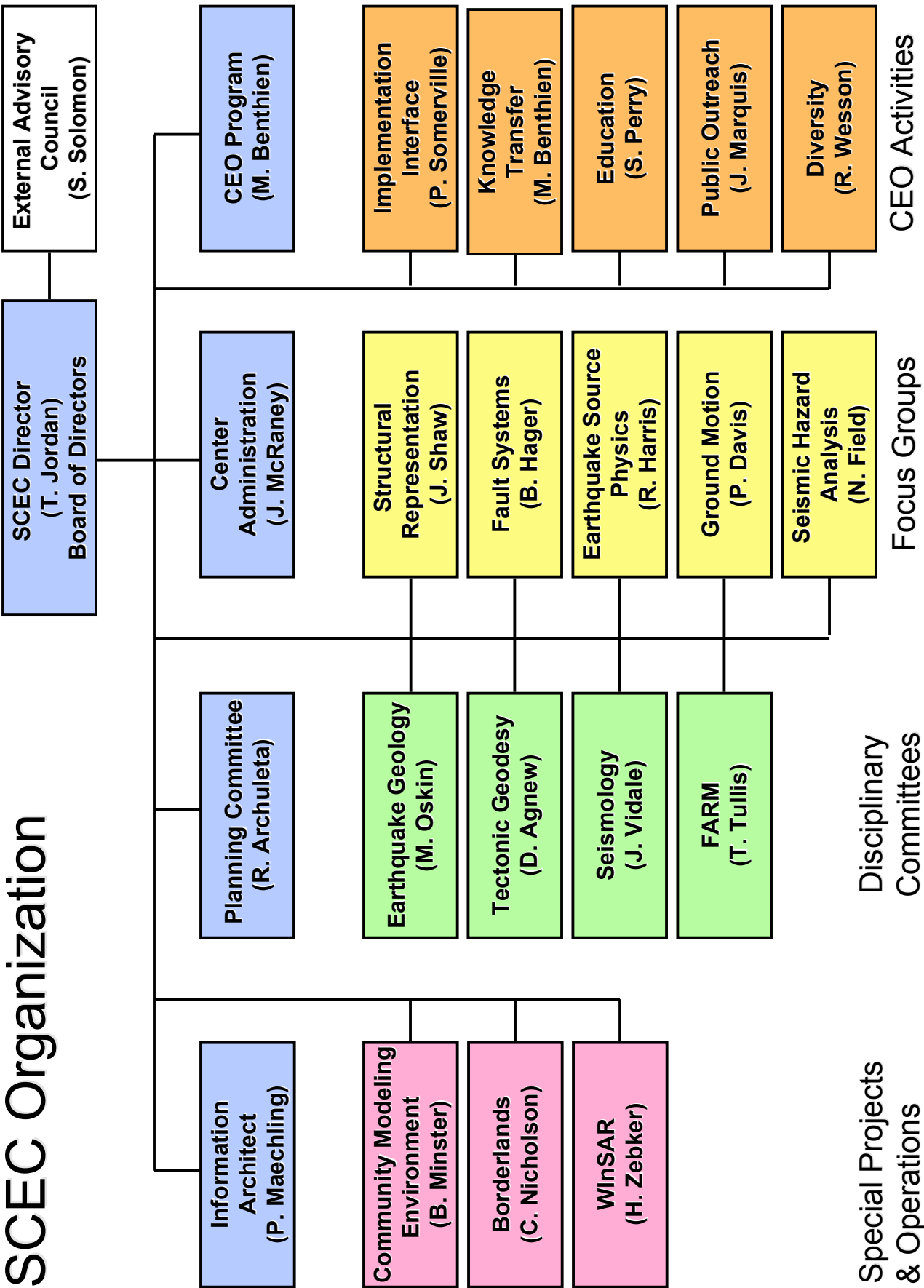|	
Thomas H Jordan* (Chair)	University of Southern California
Gregory C. Beroza* (Vice-Chair)	Stanford University
Peter Bird	University of California, Los Angeles
Emily Brodsky	University of California Santa Cruz
James N. Brune	University of Nevada Reno
Douglas Burbank*	University of California Santa Barbara
Steven M. Day	San Diego State University
James Dieterich	University of California, Riverside
Bill Ellsworth	USGS-Menlo Park
Lisa Grant (At-Large)	University of California Irvine
Thomas Heaton	California Institute of Technology
Thomas A. Herring	Massachusetts Institute of Technology
Lucile Jones*	USGS-Pasadena
J. Bernard Minster*	University of California San Diego
James Rice	Harvard University
Bruce Shaw	Columbia University
Terry Tullis (At-Large)	Brown University
Robert Wesson	USGS-Golden

Ex-Officio Members

Ralph Archuleta (Deputy Director), John McRaney* (Executive Secretary), Mark Benthien (Associate Director, CEO), Phil Maechling (IT Architect)

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* Executive Committee members

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SCEC Organization

External Advisory Council (S. Solomon)

SCEC Director (T. Jordan) **Board of Directors**

CEO Program (M. Benthien)

- **Implementation Interface** (P. Somerville)
- **Knowledge Transfer** (M. Benthien)
- **Education** (S. Perry)
- **Public Outreach** (J. Marquis)
- **Diversity** (R. Wesson)

CEO Activities

Center Administration (J. McRaney)

- **Structural Representation** (J. Shaw)
- **Fault Systems** (B. Hager)
- **Earthquake Source Physics** (R. Harris)
- **Ground Motion** (P. Davis)
- **Seismic Hazard Analysis** (N. Field)

Focus Groups

Planning Committee (R. Archuleta)

- **Earthquake Geology** (M. Oskin)
- **Tectonic Geodesy** (D. Agnew)
- **Seismology** (J. Vidale)
- **FARM** (T. Tullis)

Disciplinary Committees

Information Architect (P. Maechling)

- **Community Modeling Environment** (B. Minster)
- **Borderlands** (C. Nicholson)
- **WInSAR** (H. Zebker)

Special Projects & Operations

Ex officio members include the SCEC Deputy Director, Ralph Archuleta; the Associate Director for Administration, John McRaney, who also serves as Executive Secretary to the Board; the Associate Director for Communication, Education and Outreach, Mark Benthien, and the SCEC IT Architect, Phil Maechling.

External Advisory Council

SCEC's Advisory Council (AC) is an external group charged with developing an overview of SCEC operations and giving advice to the Director and the Board. Sean Solomon of the Carnegie Institution of Washington continues as Chair of the AC in 2005. During 2005, the terms of several AC members expired and they rotated off the AC. They are Raul Madariaga (Ecole Normale Superieure, Paris), Farzad Naeim (John A. Martin & Associates), Robert Smith (U. of Utah), Haresh Shah (RMS, Inc.), and Susan Tubbesing (EERI). Continuing AC members are: Sean Solomon (Chair/Carnegie Institution of Washington), Jeff Freymueller (U. Alaska), Jack Moehle (PEER), Garry Rogers (Geological Survey Of Canada), Chris Rojahn (Applied Technology Council), and Ellis Stanley (LA Emergency Preparedness Department). New members of the AC are: Gail Atkinson (Carleton University, Ottawa), Lloyd Cluff (PG&E), Patti Guatteri (Swiss Re), Kate Miller (UTEP), and John Rudnicki (Northwestern). The Advisory Council's second report is reproduced verbatim in Section VI.

Organization of Research

A central organization within SCEC is the Science Planning Committee (PC), which is chaired by the Deputy Director and has the responsibility for formulating the Center's science plan, conducting proposal reviews, and recommending projects to the Board for SCEC funding

The PC membership includes the chairs of the major SCEC working groups. There are three types of working groups—disciplinary committees, focus groups, and special project groups. The Center is fortunate that some of its most energetic and accomplished colleagues participate as group leaders (Table II.2). During the past

Table II.2. Leadership of the SCEC Working Groups

Disciplinary Committees

Seismology:	John Vidale (chair)*
	Peter Shearer (co-chair)
Geodesy:	Duncan Agnew (chair)*
	Mark Simons (co-chair)
Geology:	Mike Oskin (chair)*
	Tom Rockwell (co-chair)
Fault & Rock Mechanics:	Terry Tullis (chair)*
	Judi Chester (co-chair)

Focus Groups

Structural Representation:	John Shaw (leader)*
	Jeroen Tromp (co-leader)
Fault Systems:	Brad Hager (leader)*
	Jim Dieterich (co-leader)
	Sally McGill (co-leader)
Earthquake Source Physics:	Ruth Harris (leader)*
	David Oglesby (co-leader)
Ground Motions:	Paul Davis (leader)*
	Robert Graves (co-leader)
Seismic Hazard Analysis:	Ned Field (leader)*
	David Jackson (co-leader)

Special Project Groups

Implementation Interface:	Paul Somerville (leader)*
	Rob Wesson (co-leader)
SCEC/ITR Project:	Bernard Minster (liaison)*
Borderland Working Group:	Craig Nicholson (chair)*

* Science Planning Committee members

year, Mike Oskin and Tom Rockwell swapped positions for the Geology group with Oskin assuming the chair and Rockwell moving to co-chair.

The Center sustains disciplinary science through standing committees in *seismology*, *geodesy*, *geology*, and *fault and rock mechanics*. These committees are responsible for planning and coordinating disciplinary activities relevant to the SCEC science plan, and they make recommendations to the Science Planning Committee regarding the support of disciplinary infrastructure. Interdisciplinary research is organized into five science focus areas: *structural representation*, *fault systems*, *earthquake source physics*, *ground motion*, and *seismic hazard analysis*. The focus groups are the crucibles for the interdisciplinary synthesis that lies at the core of SCEC's mission.

In addition to the disciplinary committees and focus groups, SCEC manages several special research projects, including the Southern California Integrated GPS Network (SCIGN), the Western InSAR Consortium (WInSAR), the Borderland Working Group, and the SCEC Information Technology Research (SCEC/ITR) Project. Each of these groups is represented on the Science Planning Committee by its chair, with the exception of the SCEC/ITR Project, which is represented by Bernard Minster, a Co-P.I. of the project (the P.I. is the Center Director, Tom Jordan).

In June, 2005, the SCEC board voted to disband the SCIGN group as a standing committee of SCEC. SCIGN had completed its mission and the future maintenance of continuous GPS site in southern California will be handled by UNAVCO, the USGS, and the county surveyors. This action was approved by NSF and the USGS.

SCEC is in the process of transferring its activities in support of WInSAR to another group. This process should be completed in 2006.

The Borderland Working Group represents SCEC researchers interested in coordinating studies of the offshore tectonic activity and seismic hazards in California Borderland.

The goal of the SCEC/ITR Project is to develop an advanced information infrastructure for system-level earthquake science in Southern California. Partners in this SCEC-led collaboration include the San Diego Supercomputer Center (SDSC), the Information Sciences Institute (ISI), the Incorporated Research Institutions for Seismology (IRIS), and the USGS. In many respects, the SCEC/ITR Project presents a microcosm of the IT infrastructures now being contemplated in the context of EarthScope and other large-scale science initiatives, so the opportunities and pitfalls in this area need to be carefully assessed. The SCEC/ITR annual report has been submitted as a separate document to NSF.

The long-term goals and short-term objectives laid out in the SCEC Strategic Plan provided the basis for the SCEC Program Announcements, which are issued annually in October. This proposal process is the primary mechanism through which SCEC recruits scientists to participate in its research collaborations. The process of structuring the SCEC program for 2005 began with the working-group discussions at the annual meeting in September, 2004. An RFP was issued in October, 2004, and 155 proposals (120 projects, considering collaborations) requesting a total of $6,000K were submitted in November, 2004. The 2005 RFP is reproduced in Appendix C.

All proposals were independently reviewed by the Director and Deputy Director. Each proposal was also independently reviewed by the chairs and/or co-chairs of three relevant focus groups or disciplinary committees. (Reviewers were required to recuse themselves when they had a conflict of interest.) The Planning Committee will met on January 18-19, 2005, and spent two long days discussing every proposal. The objective was to formulate a coherent, budget-balanced science program consistent with SCEC's basic mission, short-term objectives, long-

term goals, and institutional composition. Proposals were evaluated according to the following criteria:

a. Scientific merit of the proposed research.
b. Competence and performance of the investigators, especially in regard to past SCEC-sponsored research.
c. Priority of the proposed project for short-term SCEC objectives.
d. Promise of the proposed project for contributing to long-term SCEC goals.
e. Commitment of the P.I. and institution to the SCEC mission.
f. Value of the proposed research relative to its cost.
g. The need to achieve a balanced budget while maintaining a reasonable level of scientific continuity given very limited overall center funding.

The recommendations of the PC were reviewed by the SCEC Board of Directors at a meeting on February 7-8, 2005. The Board voted unanimously to accept the PC's recommendations, pending a final review of the program by the Center Director, which was completed on February 18. A list of funded projects has been submitted separately to NSF and the USGS. Section III outlines the progress achieved in the 2005 research program.

SCEC is coordinating its research program with the USGS through a Joint Planning Committee (JPC). The USGS members of the JPC attend the proposal review meeting of the SCEC Planning Committee as non-voting participants and contribute to the discussion of proposals

A proposal to fund SCEC3 for the period from 2007-2012 was submitted to NSF and USGS in March, 2005.

In June, a site visit was conducted by and NSF site team and USGS agency officials. We were notified in September, 2005 that SCEC3 would be funded.

Communication, Education, and Outreach

SCEC is committed to applying the basic research in earthquake science to the practical problems of reducing earthquake losses. To accomplish this aspect of its mission, SCEC maintains a vigorous Communication, Education, and Outreach (CEO) Program that receives 10% of its base funding plus other funds from special projects, such as the Electronic Encyclopedia of Earthquakes. CEO activities are managed by the Associate Director for CEO, Mark Benthien. The programmatic elements include structured activities in education and public outreach and two new structures: an *Implementation Interface*, designed to foster two-way communication and knowledge transfer between between SCEC scientists and partners from other communities—in particular, earthquake engineering, risk analysis, and emergency management, and *a Diversity Task Force*, responsible for furthering the goal of gender and ethnic diversity in earthquake science. A report on the third-year CEO activities is given in Section IV.

III. Research Accomplishments

This section summaries the main research accomplishments and research-related activities organized by the disciplinary committees, focus groups, and special project working groups during 2005.

Disciplinary Activities

The following reports summarize the infrastructure activities and the discipline-oriented research.

Seismology

Four projects were funded in the Seismology Infrastructure focus group in 2004-2005. These were the Southern California Earthquake Data Center, the Borehole Seismometer Network, the Portable Broadband Instrument Center, and a Caltech/UCSD collaboration assembling earthquake catalogs and measuring earthquake properties and structure.

Southern California Earthquake Data Center (SCEDC)

The Archive (as of Sept. 9, 2005) has assembled 5.151 TB of waveform data, with the SCEDC database containing 237,263,860 rows and including data for 623,872 earthquakes (1932 to present). The totals represent roughly 10–20% increases over the past year. On average 1 waveform per second was distributed to eager researchers.

Several improvements were made to existing software and databases:

(1) The SCEDC is distributing scanned images of pre-digital analog recordings of major earthquakes recorded in Southern California between 1962 and 1992. Scanned images of paper records for M>3.5 southern California earthquakes and several significant teleseismic events are available. The web interface allows users to search the available files, select multiple files for download and then retrieve a zipped file containing the results.

(2) Catalogs now available at the SCEDC include the 1932-present SCSN Searchable Catalog Page, pre-compiled ASCII catalog files, and alternate location catalogs. For example, SCEDC added two catalogs (see below) that use results from a SCEC-sponsored project that applies waveform cross-correlation to make precise differential times between nearby events.

(3) Updated search tools available at the SCEDC include: 4-Point polygon catalog search, radius catalog search, search by event ID, and multiple-magnitude catalog search.

(4) The SCEDC is now archiving and delivering searchable Moment Magnitudes and Moment Tensor Solutions (MTS) produced by the SCSN in real-time and post-processing solutions for events spanning back to 1999. The automatic MTS runs on all local events with $M \geq 3.0$, and all regional events with $M \geq 3.5$ identified by the SCSN real-time system.

(5) The workhorse program Seismic Transfer Program (STP) had several improvements: XML output format is now available via STP, A new STP Client – Version 1.4.1 for Macintosh is

available, coda decay measurements now available via STP. This type of measurement has been used to look for spatial and temporal variation in scattering Q. The seismic network uses the coda decay to determine coda-magnitude (Mc) estimates for local events. Measurements are available for most local events from 1980 to June 2001.

(6) The Station Information System (SIS) will provide users with an interface into complete and accurate station metadata for all current and historic data at the SCEDC. The goal of this project is to develop a system that can interact with a single database source to enter, update and retrieve station metadata easily and efficiently.

The overall goals of the system are to develop and implement a simplified metadata information system with the following capabilities: (1) Provide accurate station/channel information for active stations to the SCSN real-time processing system. (2) Provide accurate station/channel information for active and historic stations that have parametric data at the SCEDC, i.e., for users retrieving data via STP from the SCEDC. (3) Provide all necessary information to generate dataless SEED volumes for active and historic stations that have data at the SCEDC. (4) Provide all necessary information to generate COSMOS V0 metadata. (5) Be updatable through a graphical interface that is designed to minimize editing mistakes. (6) Allow stations to be added to the system with a minimum, but incomplete set of information using predefined defaults that can be easily updated as more information becomes available. (7) Facilitate statewide metadata exchange for both real-time processing and provide a common approach to CISN historic station metadata.

Consequently, station information has been improved at the SCEDC. Dataless SEED Volumes are available at http://www.data.scec.org/stations/seed/dl_seed.php for all currently-active SCSN broadband stations. This effort is being expanded to provide complete station history in the SEED volumes distributed by the SCEDC. Also, a clickable Station Map is available.

2005 SCEC Borehole Program Activity

This program is mainly maintaining existing sites and continuing to take advantage of cost sharing with other agencies to support operations and collaborate with NEES. We have established collaboration with EarthScope. SCEC/CISN Borehole stations have also been integrated into UCSB NEES database and real-time processing software.

PI Jamie Steidl has developed combined Wavelet/Spectral inversion techniques solving for attenuation and velocity structure:

Assimaki, D. P-C. Liu, and J. H. Steidl (2005). Attenuation and velocity structure for site response analyses via downhole seismogram inversion, *PAGEOPH*, in press.

Assimaki, D., K. Tsuda, and J. H. Steidl (2005). Inverse analysis of weak and strong motion borehole array data from the $M_w7.0$ Sanriku-Minami earthquake, *Soil Dynamics and Earthquake Engineering*, submitted.

In winter 2005/2006, PBO, with SCEC, NEES, UCSD will install 7 sites equipped with strainmeters, seismometers, and accelerometers, all in hard rock.

2005 SCEC Portable Broadband Instrument Center Activities

The PBIC is in a maintenance mode for 2005. Every DAS has been opened up to replace the power supply board, NiCd backup battery, and CPU board. Each system has been lab-bench tested.

Three experiments used PBIC equipment, one of which is ongoing – investigating Peninsular Range receiver functions. Two new experiments used PBIC equipment in 2004/2005: the USGS/CGS Parkfield aftershock deployment and structural monitoring of the Caltech Broad Center.

Four undergraduate students participated in 2005 PBIC activities.

IRIS Passcal is shipping a pallet of RefTek 72A-08 DAS's and associated hardware and cables to the PBIC for "long-term" RAMP loan. These additional instruments should bring the PBIC capacity back to about 20 working stations and put us in a better position to respond to a major event in California. We are still pursuing a joint IRIS/ANSS/SCEC RAMP equipment upgrade.

Caltech/UCSD Waveform Analysis Projects

Egill Hauksson (Caltech) and Peter Shearer (UCSD) have assembled an on-line database of southern California waveforms (1984 to present) for use in a variety of projects. Waveform cross-correlation of over 300,000 events, each with 100 neighboring events, is now completed for 1984 to 2002 data. The resulting differential times have been used to generate two new catalogs of southern California seismicity, which may be obtained through the SCEDC. One catalog uses the double-difference method (Hauksson and Shearer, 2005), the other uses source-specific station terms and a cluster analysis approach (Shearer et al., 2005). Both reveal more fine scale fault structure than previous catalogs. The processing methods and the catalogs are described in two 2005 BSSA papers:

Hauksson, E. and P. Shearer, Southern California hypocenter relocation with waveform cross-correlation, Part 1: Results using the double-difference method, *Bull. Seismol. Soc. Am.*, 95, 896-903, doi:10.1785/0120040167, 2005.

Shearer, P., E. Hauksson and G. Lin, Southern California hypocenter relocation with waveform cross-correlation, Part 2: Results using source-specific station terms and cluster analysis, *Bull. Seismol. Soc. Am.*, 95, 904-915, doi:10.1785/0120040168, 2005.

These efforts will continue with the goal of beginning to integrate cross-correlation methods into standard network processing. In addition, some funding has gone to Felix Waldhauser to begin comparisons with the techniques used for his northern California waveform cross-correlation project.

Hauksson and Shearer have computed P and S spectra for the online waveforms using a multi-taper method and begun analysis to recover t^* measurements and source spectra. The t^* values are being used for attenuation tomography to produce 3-D crustal Q models. Stacking methods are used to isolate source spectra and estimate stress drops and radiated energy. These measurements will enable progress on a range of earthquake scaling issues. These results are summarized as follows:

Attenuation study

Hauksson and Shearer have analyzed high-fidelity waveform spectra to determine t^* values for both *P*- and *S*-waves from earthquakes in southern California and inverted the t^* values for three-dimensional (3D) frequency-independent *Qp* and *Qs* regional models of the crust. The models have 15 km horizontal grid spacing and an average vertical grid spacing of 4 km, down to 30 km depth, and extend from the US-Mexico border in the south to the Coast Ranges and Sierra Nevada in the north. Figure 1 shows maps of the QP structure at four different depths. In general, *Qp* and *Qs* increase rapidly with depth, consistent with crustal densities and velocities. The 3D *Qp* and *Qs* models image prominently the major tectonic structures and to a much lesser extent the thermal structure of the southern California crust. The near-surface low *Qp* and *Qs* zones coincide with major sedimentary basins such as the San Bernardino, Chino, San Gabriel Valley, Los Angeles, Ventura, Santa Maria basins, and the Salton Trough. In contrast, at shallow depths beneath the Peninsular Ranges, southern Mojave Desert and southern Sierras, we image high *Qp* and *Qs* zones, which correspond to the dense and high velocity rocks of the mountain ranges. Several clear transition zones of rapidly varying *Qp* and *Qs* coincide with major late Quaternary faults and connect regions of high and low *Qp* and *Qs*. At mid-crustal depths the *Qp* and *Qs* form imbricate stacks of slightly higher and lower *Qp* or *Qs* zones, which is consistent with reported crustal reflectivity. In general, for the southern California crust, *Qs/Qp* is greater than 1.0, suggesting dry crust. A few limited regions of *Qs/Qp* less than 1.0 correspond to areas around some of the major strike-slip faults and the Salton Trough and suggest a larger reduction in the shear modulus compared to the bulk modulus or fluid saturation.
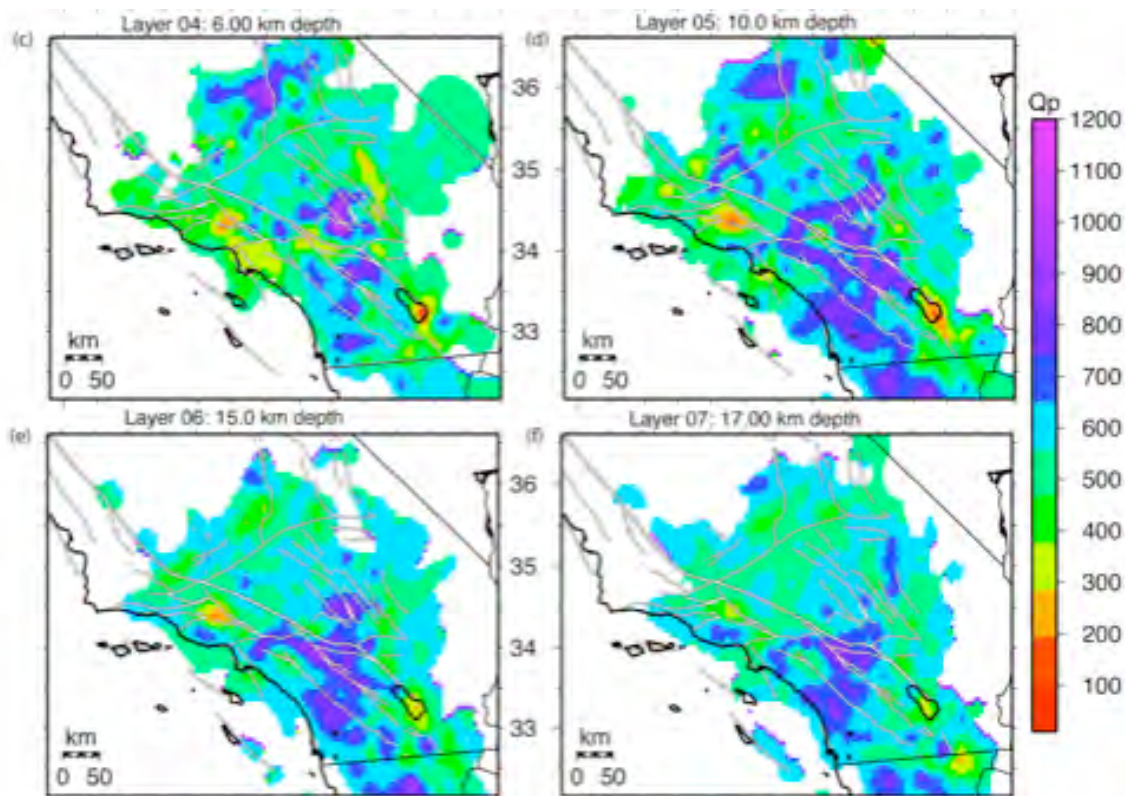

Figure 1. *Qp* 3D model shown in map view in four depth sections, at 6, 10, 15, and 17km. The color bar shows the variations in *Qp*. The model is not shown in areas with sparse ray coverage.

Brune stress drop study

Shearer and Hauksson have computed and analyze *P*-wave spectra from earthquakes in southern California between 1989 and 2001 using a method that isolates source, receiver and path dependent terms. They correct observed source spectra for attenuation using both fixed and spatially varying empirical Green's function methods. Estimated Brune-type stress drops for over 60,000 *ML* = 1.5 to 3.1 earthquakes range from 0.2 to 20 MPa with no dependence on moment or b-value. Median stress drop increases with depth in the upper crust, from about 0.6 MPa at the surface to about 2.2 MPa at 8 km, where it levels off and remains nearly constant in the mid-crust down to about 20 km. Normal fault earthquakes have a higher median stress drop than strike-slip or reverse fault events. Spatially coherent variations in median stress drop are observed, with generally low values for the Imperial Valley and Northridge aftershocks and higher values for the eastern Transverse ranges and the north end of the San Jacinto fault (see Figure 2). There is no correlation between observed stress drop and distance from the San Andreas and other major faults. Significant along-strike variations in stress drop exist for aftershocks of the 1992 Landers earthquake, which may correlate with differences in mainshock slip.
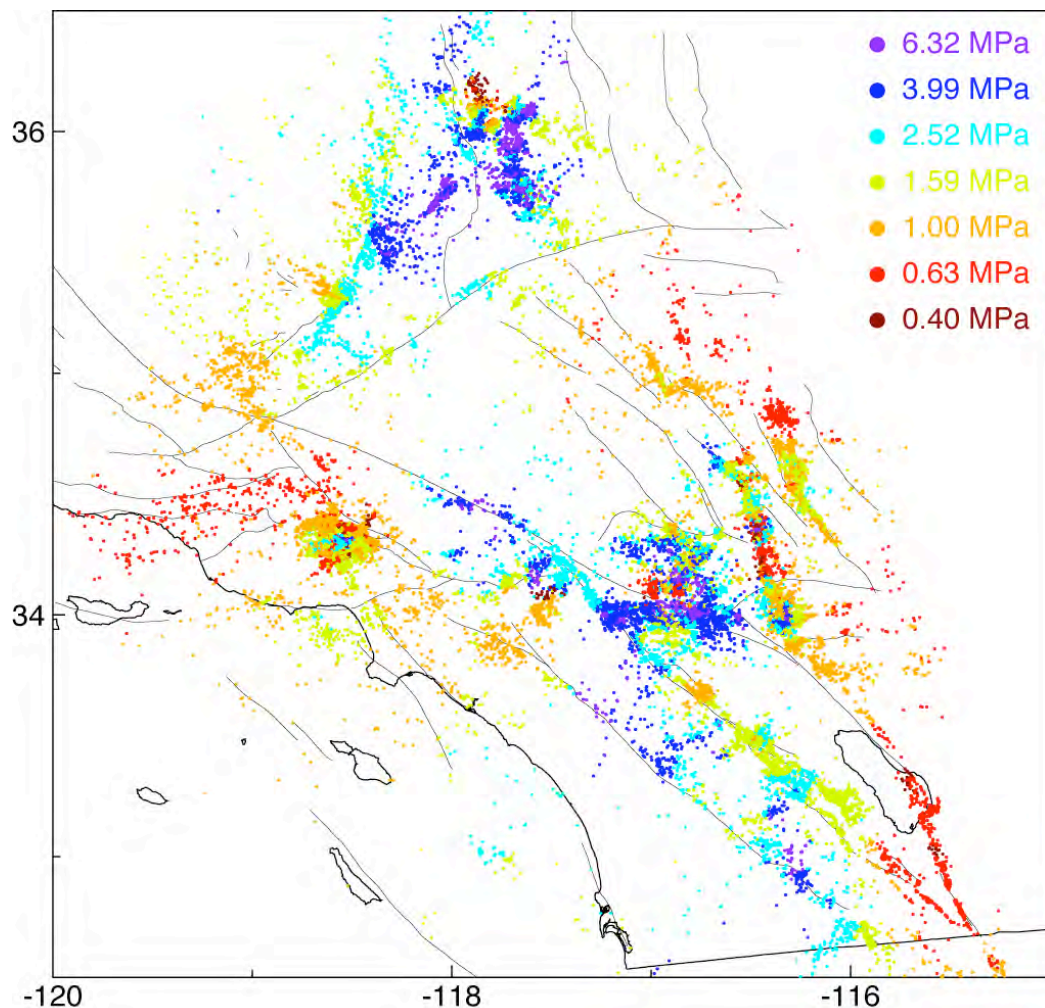
Figure 2. Computed Brune stress drops for 64,801 earthquakes from stacked spectra. Results are shown for the best-fitting constant stress drop model for each earthquake and its 500 nearest neighbors. Results are colored in equal increments of log Δσ.

Geodesy

In 2005 geodesy-related activities in SCEC continued to combine data collection and interpretation. As before, a major effort continued to be devoted to the SCEC Crustal Motion Map Project. This included the usual combination of recovery of older data, new and old data made relevant by new earthquakes (the San Simeon and Parkfield shocks), and new data from various sources, mostly ones that would usually be inaccessible to the academic community (Caltrans surveys). In the past year, we have incorporated these data, and continuous stations that now have adequately long runs of data. The results are visible in Figure 3, in which black points are in CMM Version 3 and red are new points. (There are in addition points for which more data has shrunk the error bars.) Overall, these data provide velocities at about 240 sites for which CMM3 does not have them, a substantial increase over the 640 GPS sites in that release.

Two other efforts in geodetic data-gathering are the laser strainmeters at Pinon Flat Observatory (PFO), and the Southern California Integrated GPS Network (SCIGN). For PFO, the primary activity was to continue to collect high-quality continuous deformation data. These systems observed strong evidence for deep aseismic slip following a very recent earthquake nearby (12 June 2005,15:41:46.27, or 2005:163.654). This magnitude 5.2 shock was in the San Jacinto fault zone; though it occurred within the Anza slip gap, it was in a region of abundant small and moderate earthquakes that bound a 15-km section of fault that is relatively aseismic (a seismicity gap). The top panel of Figure 4 shows the time series from all three long-base strainmeters at PFO; note that the coseismic offset was not recorded because strong ground shaking deflected the strainmeter laser beams. Two strain records (from the NS and EW instruments) show a clear strain change over the seven days after the earthquake. The NW-SE strainmeter shows no response until about a week after the earthquake. The response seen-- roughly equal and opposite on the NS and EW, and near zero on the NW--is consistent with slip at about 5 km (horizontal coordinate of the cross-section), which is in the region of the triggered earthquakes; the later positive strain on the NWSE would be produced by slip further to the NW. The moment release inferred depends on the depth, which is not well constrained, but if the slip is colocated with the aftershock seismicity, the aseismic moment release is equivalent to a magnitude 5.0 event, close to the mainshock moment.

Operation of the SCIGN array was, during this year, split between the USGS, UNAVCO, and Scripps. The array has continued to produce data of consistently high quality. Rate changes in a number of GPS time series were first noticed by USGS personnel in June 2005, and led to some concern that there might be a deformation transient in progress. Further investigation suggested that the signal was more localized, and that hydrological effects were a plausible cause. Figure 5 shows the anomalous displacements of early 2005: the displacement between 2005 and 2005.4, after removing the displacements predicted from fitting a linear trend plus annual and semiannual variations to the GPS time series between 2000.0 and 2005.0. The time series used were the SOPAC cleaned and filtered displacements; similar processing of the JPL-produced time series showed little difference. The breakpoint at 2005.0 was chosen because visual examination of the displacement series indicates rate changes at this time, a result confirmed by a more detailed statistical analysis (Dr. N. King, pers. comm.). What is immediately apparent is the very large horizontal displacements at stations around the San Gabriel Valley, away from the center; while the one station in the center moves up at a rapid rate

(100 mm/yr). The time history of this strongly suggests a response to the very heavy rainfalls of January and February 2005, which led to substantial groundwater rise in many areas. Modeling of this, to understand why the stations shown were so affected, is in progress.

The WInSAR data were used by Prof. Yuri Fialko to to investigate the interseismic deformation on the southern San Andreas fault (SAF) system around the Coachella Valley and Salton Sea. Due to a lack of significant (moment magnitude greater than 7) historic earthquakes on the southern SAF, and portions of the adjacent San Jacinto fault (e.g., the Anza gap), these faults are currently believed to pose the largest seismic risk in California. Stacked InSAR data from 35 radar interferograms spanning a time period between 1992 and 2000 clearly document a relative motion between the North American and Pacific plates, with the total relative velocity of about 45 mm/yr. Most of that motion is localized on the southern SAF and San Jacinto faults. Figure 6 shows the ground velocity derived from the stacked InSAR data (gray dots) and GPS/EDM data (color symbols) projected onto the satellite line of sight from a profile that runs perpendicular to the mapped fault traces. Vertical bars denote the 2-sigma errors of the point measurements. Vertical lines show the position of major crustal faults. Red line is a theoretical (finite element) model of interseismic strain accumulation due to a deep slip on the San Andreas and San Jacinto faults in the presence of large lateral variations in the rock rigidity across the fault zones. These results imply significant (about a factor of 3) variations in the host rock rigidity across the San Andreas, and, possibly, Coyote Creek faults.
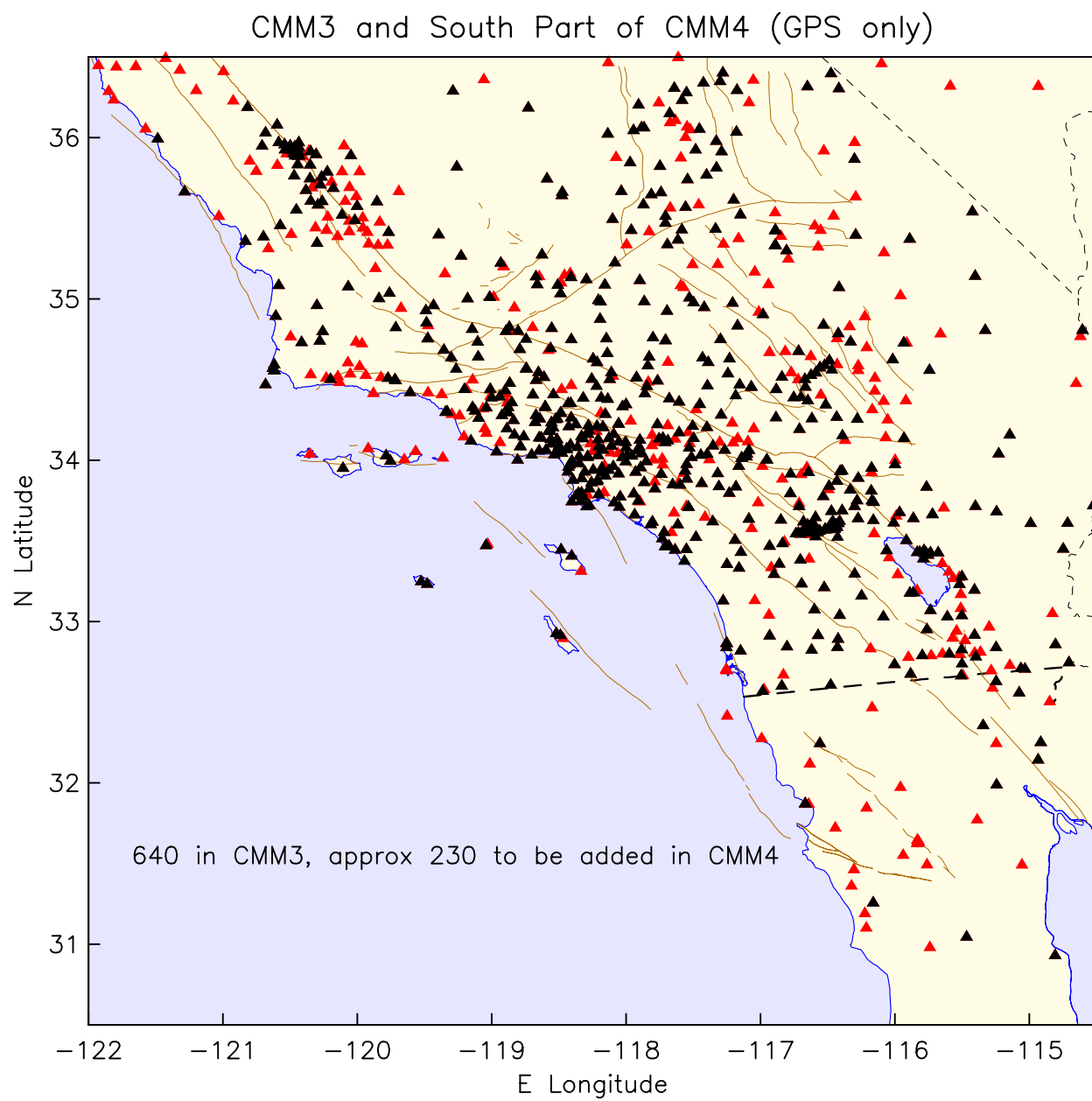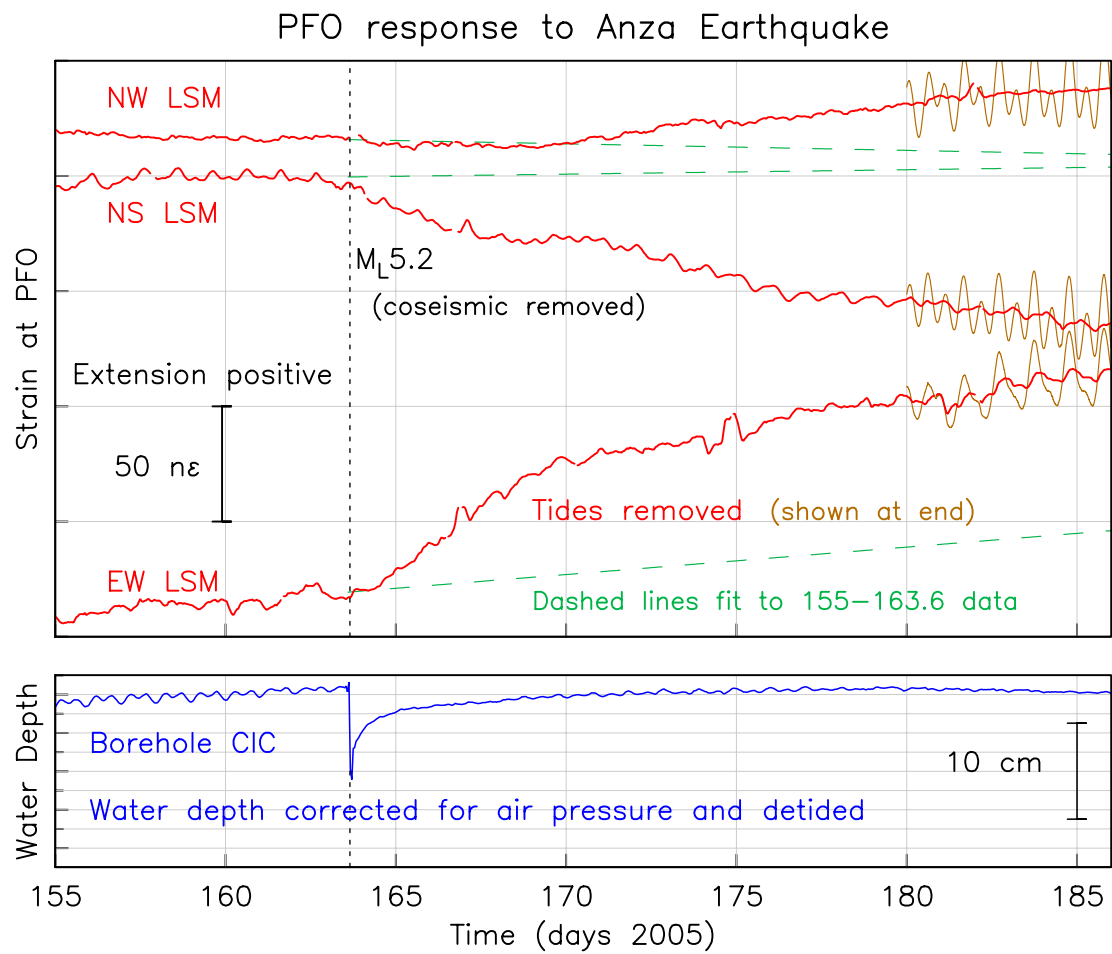
CMM3 and South Part of CMM4 (GPS only)

640 in CMM3, approx 230 to be added in CMM4

Figure 3

PFO response to Anza Earthquake

Strain at PFO

NW LSM

NS LSM

$M_L5.2$
(coseismic removed)

Extension positive

50 nε

EW LSM

Tides removed (shown at end)

Dashed lines fit to 155−163.6 data

Water Depth

Borehole CIC

Water depth corrected for air pressure and detided

10 cm

Time (days 2005)

Figure 4

Anomalous Dispalcements, 2005.0−2005.4
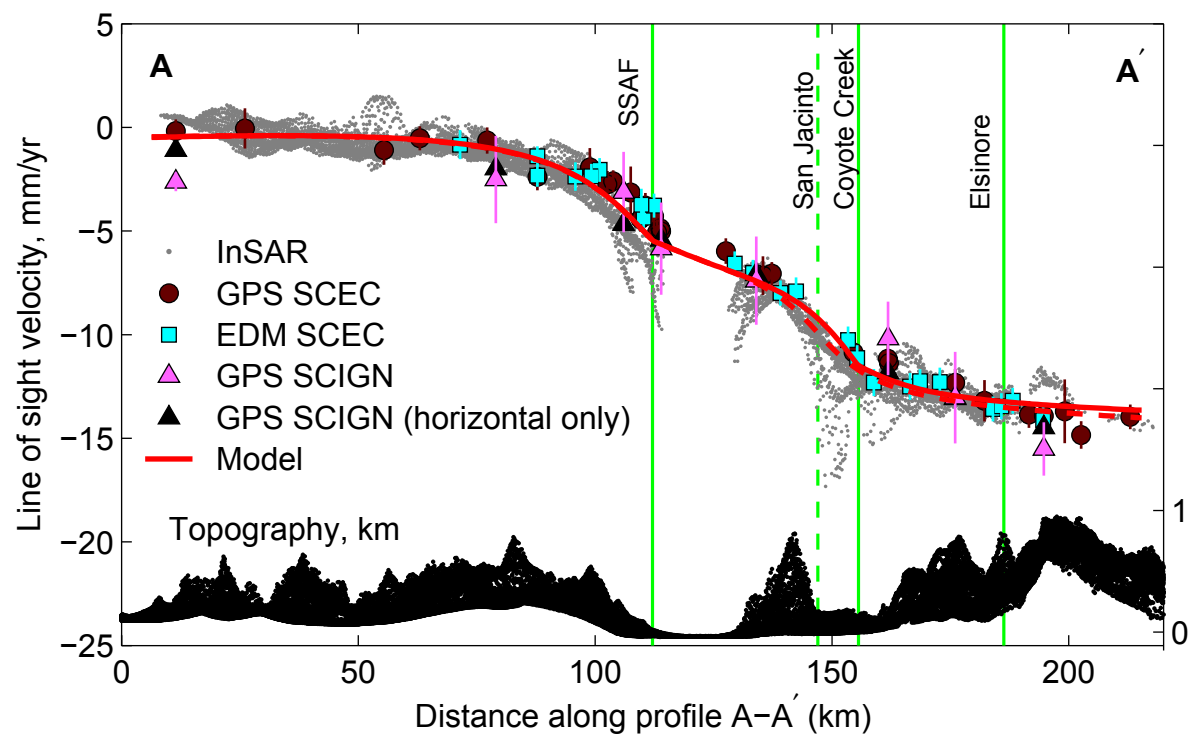
Horizontal Displacement

Vertical Displacement
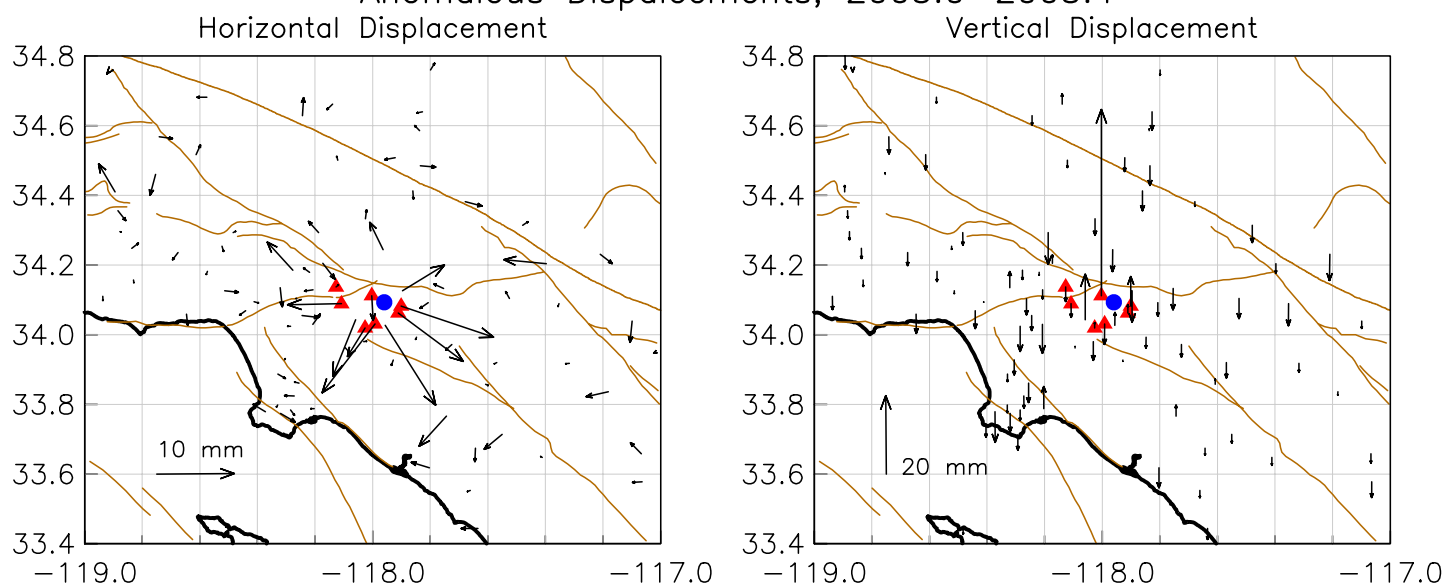
Figure 5

Figure 6

Geology

SCEC sponsored investigations in geology in 2005 gathered and analyzed data in four principal research areas: (1) Pursuit of deep paleoseismic archives and development of quantitative paleoseismic methodology from investigations of the major plate boundary faults of southern California, e.g., the southern San Andreas fault and San Jacinto fault; (2) Seismic hazard investigations of major compressive structures proximal to urban Los Angeles with emphasis on defining their activity and geometry at depth; (3) Investigations of the development of fault segmentation, near-fault deformation, and the relationship of these properties to fault slip rates, past earthquake ruptures, and preferred rupture direction; (4) Tests of potentially discrepant geologic versus geodetic strain rates from fault slip-rate studies, compilation of geologic vertical motion data. Much of the SCEC geology effort is collaborative with other SCEC focus groups, especially Fault and Rock Mechanics, the Unified Structural Representation, and Seismic Hazard Analysis. This summary focuses on the geologic data gathering and hypothesis testing efforts not covered elsewhere.

New Paleoseismic Results

Paleoseismic studies funded through SCEC this year address the outstanding problem of the prolonged dormancy of the southern San Andreas fault. This segment of the fault has not ruptured in over 300 years – a time period that is two to three times the average recurrence interval of great earthquakes on other segments of the fault. Geodetic modeling results suggest that the present strain accumulation rate on the southern San Andreas fault may be as low as 5 mm/yr, and compilation of geologic data may support alternation of slip between the San Andreas fault, San Jacinto fault, and the Eastern California shear zone. Thus, variable activity of the southern San Andreas fault could provide a key to understanding slip rate variability and discrepant geodetic and geologic data over a significant portion of the southern California fault system. Paleoseismic investigations are now underway on two sites that will yield longer records of earthquake activity of the southern San Andreas fault and test whether this long dormancy is a normal component of its Late Holocene behavior. One site is at Salt Creek, where Williams and Sietz have opened a new exposure of the fault. Several SCEC scientists took the opportunity to view the new exposure prior to the 2005 annual meeting in nearby Palm Springs. Investigations at a second site on the southern San Andreas fault, at Thousand Palms oasis, will be underway this fall and winter. Ongoing investigation and SCEC-supported geochronology at the Hog Lake site on the San Jacinto fault has begun to reveal this fault may move in counterpoint to the San Andreas fault.

SCEC researchers are also pushing the frontiers of methodology for paleoseismology. Biasi et al. continue to develop a Bayesian framework for rupture scenarios from variable-length paleoseismic records. Their effort identifies multiple potential rupture scenarios for the San Andreas fault, from as few as 14, well-correlated earthquakes to over twice as many, smaller events with commensurably less correlation from site to site. Scoring mechanisms, in development, will refine this unbiased method for testing paleoseismic data and ingesting the results into seismic hazard assessments. Ragona et al. are developing a Field Imaging Spectroscopy technique to acquire, interpret and store stratigraphic and structural information from paleoseismic exposures and cores. Their approach employs portable hyperspectral cameras to acquire field-based visible-near infrared (VNIR) and short wave infrared (SWIR) images at

sub-mm resolution. This new data collection and interpretation methodology makes available, for the first time, a tool to quantitatively analyze paleoseismic and stratigraphic information. In addition, hyperspectral datasets in the visible short-wave infrared spectral range provide a better alternative for data storage. The reflectance spectra at each pixel of the images provide unbiased compositional information that can be processed in a variety of ways to assist with the interpretation of stratigraphy and structure at a site (Fig. 7).

Figure 7

Digital photograph (top), False composite of SWIR (middle), and decorrelation stretch of SWIR (bottom) of 60 x 60 cm portion of a trench exposure of the San Jacinto fault at Hog Lake. Processed hyperspectral imagery significantly refines definition of the stratigraphy and the correlation of layers across the fault zone.
Letters a to e correspond to stratigraphic units correlated across the fault from the hyperspectral analysis.

Investigations of Seismic Hazard from Blind Thrust Faults

Two SCEC-sponsored geology studies this year address the problems of extent and activity of blind thrust faults, which remain one of the greater unknowns in computing seismic hazard for the Los Angeles region. Shaw et al. have commenced a shallow crustal imaging study of Quaternary strata deformed by the Compton – Los Alamitos ramp. The activity of this structure is a major concern because the ramp is the updip portion of a very large thrust system proposed to underlie the entire Los Angeles basin. In the nearby offshore region, Sorlien continued SCEC-supported studies of the onshore-offshore Palos Verdes anticlinorium and the faults responsible for it. Results indicate that this structure constitutes a single, actively growing

fold for at least 50 km northwest of the Palos Verdes peninsula. The expanded definition of this structure significantly impacts seismic hazard of the adjacent urban area. Also, the interaction of this structure with the other faults underlying the Santa Monica bay (Fig. 8) may provide insight into the complex kinematic evolution of faults elsewhere in the urban region.
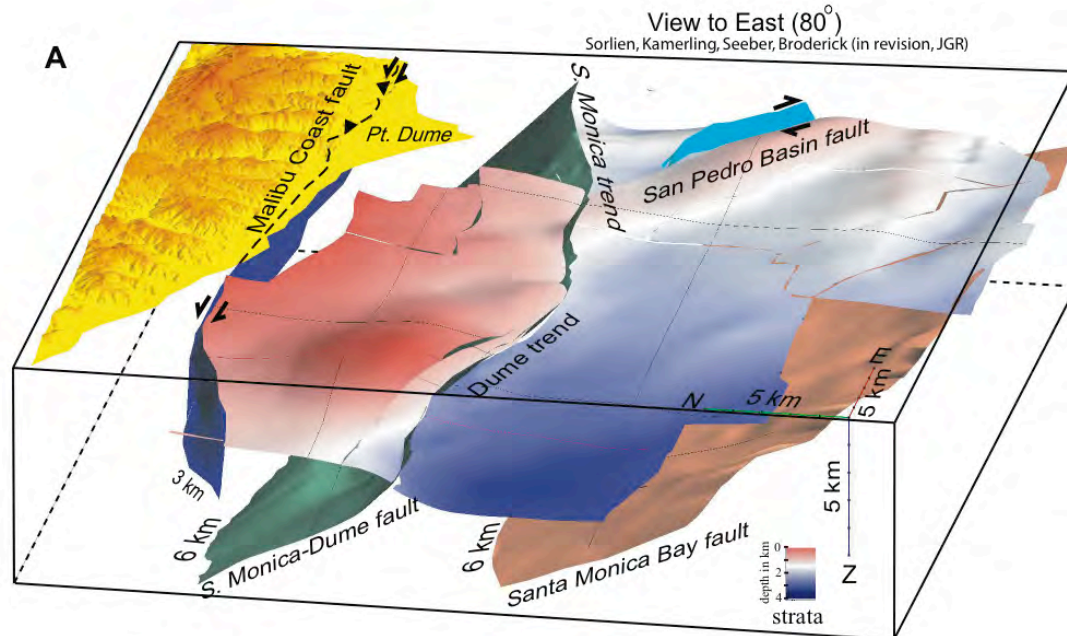

Figure 8: 3D structural representation of faults and deformed 4 Ma horizon beneath the Santa Monica bay, offshore of Los Angeles.

New Fault Segmentation and Near-Fault Deformation Studies

The nature of how and where earthquakes start, propagate, and stop may depend, in part, on the properties of fault zones and the damaged rocks immediately surrounding faults. SCEC sponsored direct geological studies of fault-zone materials that are described further in the FARM section. In addition to these, 2005 SCEC also sponsored studies of deformation adjacent to faults to understand how faults and near-fault deformation distribute strain and evolve with progressive slip.

Two studies focused on the Lenwood fault, in the eastern California shear zone. The Lenwood fault has very low total slip (<2 km) but a slip rate that may exceed 3 mm/yr. Thus the fault may preserve relationships between its slip rate, the extent of earthquakes, and near-fault deformation. Oskin and Perg are testing if the slip rate of the highly segmented Lenwood fault has increased as these boundaries are breached (Fig. 9). A companion study by Lindvall will examine if individual fault ruptures vary as a result of segment boundaries. Both of these studies take advantage of high resolution LiDAR topography for precise measurement of displaced features.

Another group of SCEC scientists, Ben-Zion et al., are investigating whether mechanically pulverized rocks adjacent to faults preserve a record of preferred rupture propagation direction. They find structural similarities between the active San Andreas Fault zone and older, exhumed faults of the San Andreas Fault system. Most outcrops of the

pulverized fault zone rocks appear on the northeast side of the principal slip zone of the San Andreas Fault, which is the block with faster seismic velocities at seismogenic depth. The large-scale asymmetric pattern of the pulverized rocks is supported by detailed mapping in selected sites. An apparent pulverization of sandstones and conglomerates, together with field relations between bodies of pulverized rocks and younger sediments, imply that pulverization along this portion of the fault occurred in the top few km of the crust. The width of the pulverized fault zone rocks and inferred depth extent of pulverization are similar to the dimensions of imaged low velocity fault zone layers that act as waveguides for seismic trapped waves. The observed asymmetric pattern of shallow damaged fault zone rocks is compatible with predictions for wrinkle-like ruptures along a material interface, with a preferred northwest propagation direction of large earthquakes on the Mojave section of the San Andreas fault.
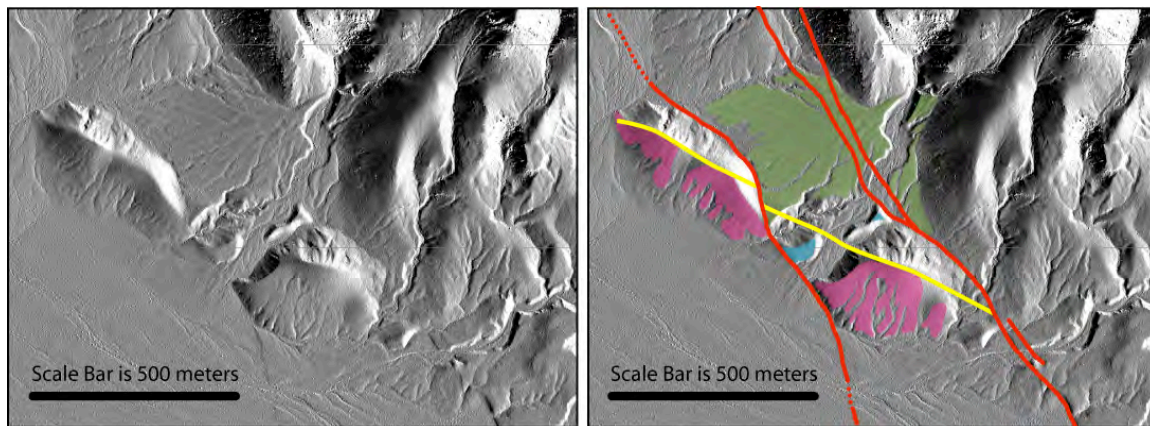

Figure 9: Bare and interpreted shaded-relief image of anticline segment boundary breached by slip on the Lenwood fault. Cosmogenic dating of the deformed surfaces (green blue, and purple) is in progress to test if folding rate decreases after breeching of anticline.

Investigations of Geologic versus Geodetic Discrepancies

Discrepancies between geologic fault activity and geodetic strain accumulation rate can provide information on rheology, test alternative fault geometry, and lend insight into the interaction of faults within a complex fault network. In 2005, SCEC sponsored a new geochronology study of the Death Valley fault to test for a potential geodetic versus geologic discrepancy in the northern part of the Eastern California shear zone. In-situ cosmogenic ^{10}Be measured in quartzite clasts yielded a weighted-mean exposure age of the displaced Red Wall Canyon alluvial fan surface of 72 ± ka years. Restoration of the dextrally-offset alluvial surface using ALSM data shows a total displacement of 305 m (Fig. 10). Combining the offset measurement with the new surface age from cosmogenic nuclide geochronology yields a very precise late-Pleistocene to recent slip rate of 4.2 ± 0.1 mm/yr. This slip effectively pins the long-term strain accumulation rate for this part of the Death Valley fault and will be a critical constraint in modeling geodetic data.
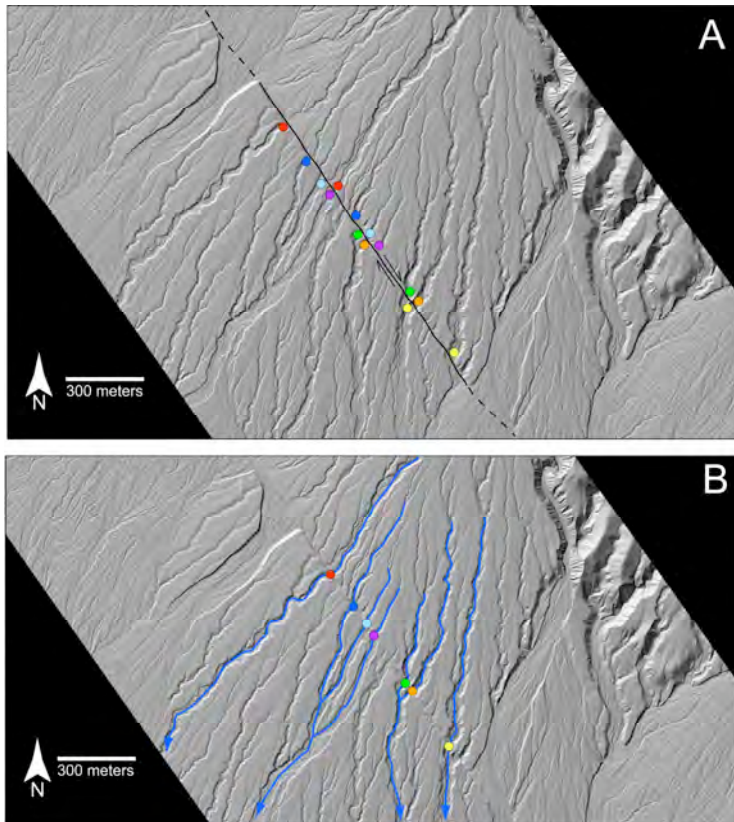
Figure 10. Sub-meter ALSM digital topographic data along the Northern Death Valley fault zone and Red Wall Canyon alluvial fan. A) Original, offset alluvial fan surface. Colored dots indicate channels that correlate when offset is restored. B) Alluvial fan restored to its original, pre-faulting configuration. Total fault offset since the late-Pleistocene is 305 m.

Fault and Rock Mechanics

Research in this area continued this year on several fronts, including laboratory studies of friction at high slip rates, theoretical modeling of earthquakes using such results, and field studies of exhumed fault zones. We will highlight some of these.

The studies of Vikas Prakash of Case Western Reserve University that investigate the potential of novel new experimental laboratory techniques have continued. The method that is being focused on for this year is a new one still under development, that involves combining a spinning rock disk with a split Hopkinson bar. The face of a spinning rock disk is initially placed in close proximity to the end of a tubular rock sample that is then rapidly forced against the face of the rotating disk by a stress pulse traveling down the split Hopkinson bar incident tube driven by a gas gun. The experimental configuration is shown in Figure 11. One advantage of this method over the torsional Kolsky bar apparatus studied in the previous year is that greater control is possible over the slip speeds attained. It is also possible suddenly to alter the normal stress during sliding so the response to changes in normal stress, such as may result during earthquakes, can be studied. The conditions attainable with this new technique include normal stresses
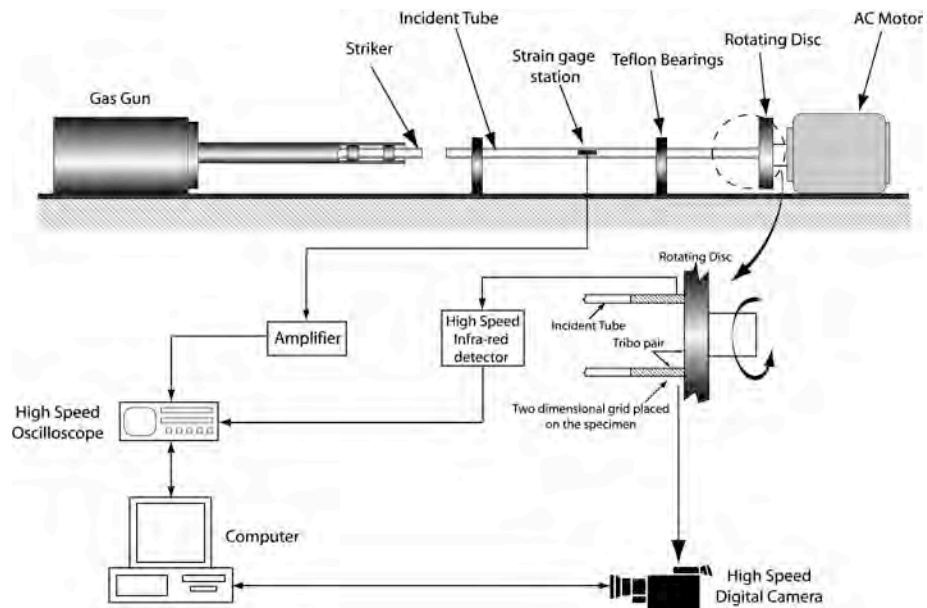

Figure 11: Schematic of the modified split Hopkinson pressure bar configuration to study high-speed friction.
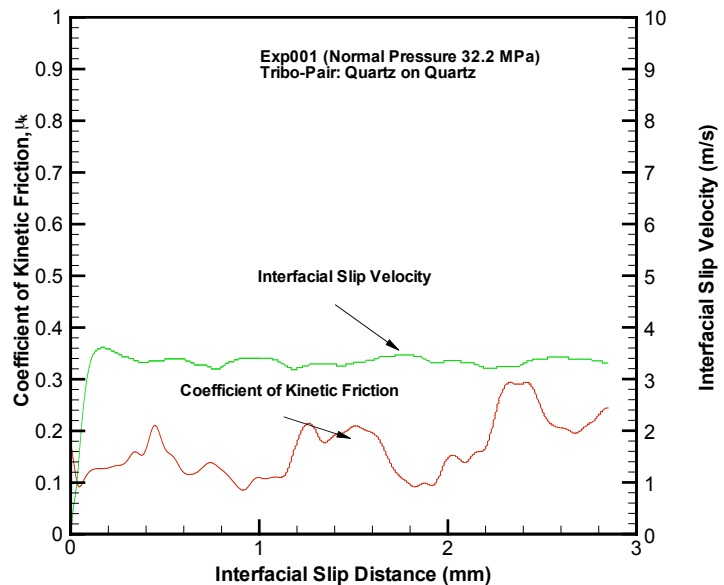

Figure 12: Dynamic friction and slip velocity vs. slip using torsional Kolsky bar apparatus..

from 1 to 100 MPa, slip speeds from 1 to 10 m/s and slip distances up to 10 mm. This combination of the split Hopkinson pressure bar with a rotating disk has never been used before, even in the engineering community, so considerable development was needed, and results from this technique are not yet available. However, the results from the torsional Kolsky bar apparatus show that the friction at coseismic slip speeds on the order of a few m/s is on the order of 0.2 (Figure 12), much lower than the friction at lower slip rates. As the previous theoretical and experimental results of FARM research has shown, this resistance appears to be explained by the mechanism of flash weakening at highly stressed transient contacting asperities on the sliding surface.

New experimental data on weakening at seismic slip rates has resulted from an international collaboration between Hiroko Kitajima, Judi Chester and Fred Chester of Texas A&M University, and Toshihiko Shimamoto of Kyoto University (Chester et al., 2005; Kitajima et al., 2005). The work was motivated by the microstructures of recent high-speed friction experiments on the Nojima fault gouge (Mizoguchi & Shimamoto, 2004; Shimamoto, 2004; Mizoguchi et al., 2004) that revealed remarkable similarities to the optical-scale microstructures documented along the natural slip surface of the Punchbowl fault ultracataclasite (Figure 13). Disaggregated
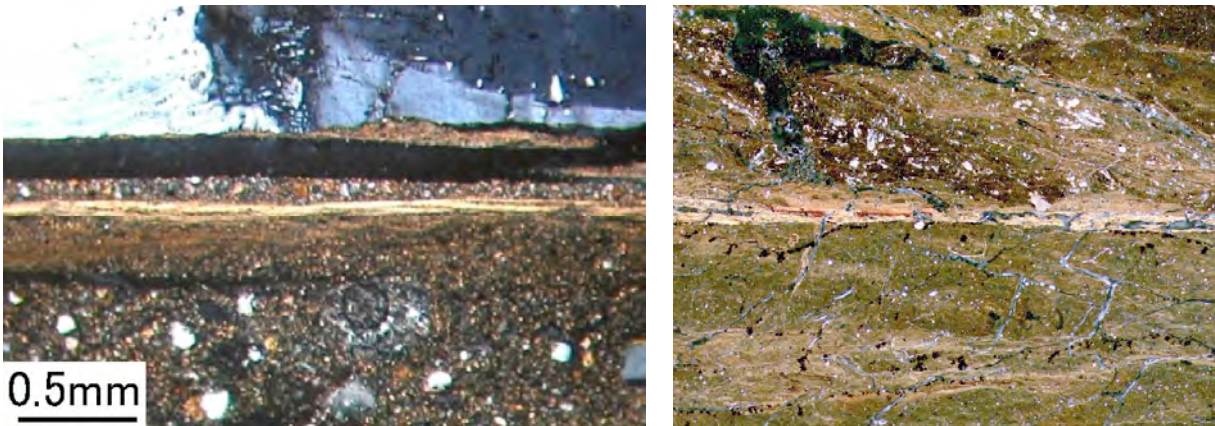

Figure 13. Similarity of optical microstructures of experimentally sheared gouge from the Nojima fault (left) and ultracataclasite from the Punchbowl fault (right).

ultracataclasite from the Punchbowl fault core was sheared in a high-velocity rotary apparatus at Kyoto University at slip speeds of 0.1, 0.7 and 1.3 m/s, normal stress of 0.2, 0.6, and 1.3 MPa, to displacements from 1.5 m to 80 m. As shown in Figure 14, at 1.3 m/s, the friction coefficient rapidly increases to a peak of about 0.8 to 1.0 followed by gradual decrease to 0.05 over a slip-weakening distance (Dc) of about 15m. At the lower speed of 0.1m/s, the coefficient friction is about 0.8 and there is little change in strength with slip. At the higher slip rates, Dc decreases with an increase in normal stress and increase in slip rate. That significant weakening is only observed at higher slip rates, and that the critical slip distance for weakening decreases with increase in normal stress and slip rate, implies weakening results from an increase in temperature of the slipping surface. Moreover, slide-hold-slide tests show rapid strength recovery consistent with transient thermal effects. Current work is directed at correlating the microstructure with frictional behavior, identification of the weakening mechanisms, and comparing the microstructures of the experiments to the natural Punchbowl ultracataclasite microstructures.
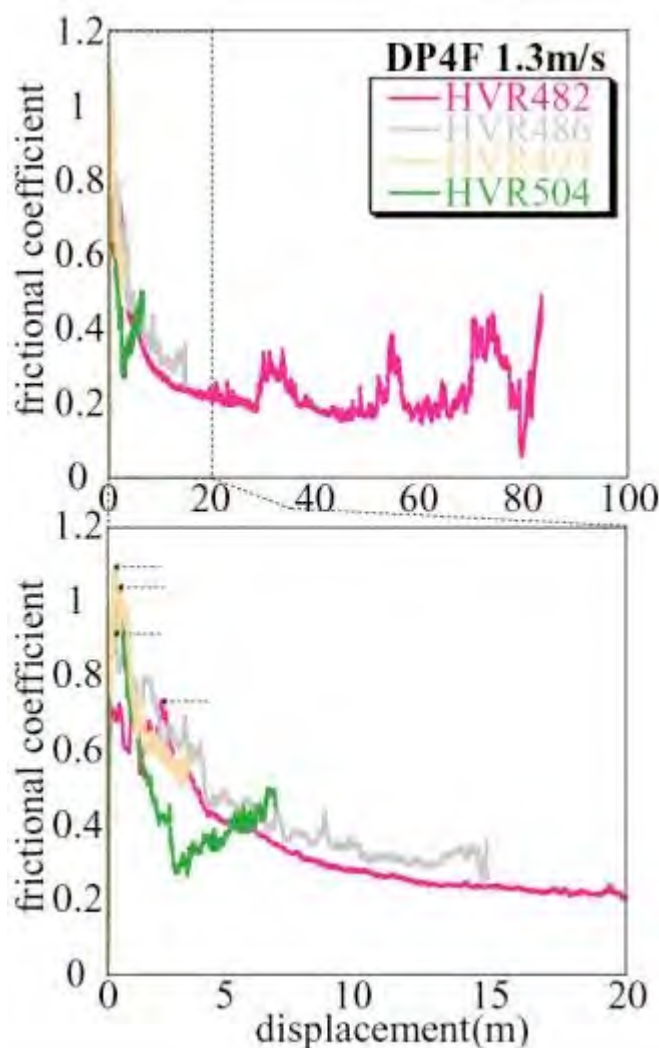
Figure 14. Overview and enlarged view of friction in several experiments to different total displacements on gouge from the Punchbowl fault at 1.3 m/s showing decay of slip resistance with slip.

After the 2005 SCEC meeting, the FARM and ESP groups held a field-trip-based workshop focusing on field visits to some of the classic exhumed fault localities that have been used in a variety of studies to define fault zone structure and processes related to earthquake faulting. The primary goals of the fieldtrip were to provide a wide range of geophysicists and geologists an opportunity to see these sites with the researchers who have studied them, and to foster cross-disciplinary discussions regarding future research efforts. The field trip ran from Sept. 14-16, and focused on exhumed portions of the Punchbowl and San Andreas faults in the San Gabriel Mountains. The field trip had 36 participants who ranged from senior-level faculty to graduate students at SCEC universities and the USGS. Jim Evans organized the trip, and the primary field trip leaders were Judith and Fred Chester and Jim Evans. An additional stop was provided by Tom Fumal [USGS] who provided an overview of the Wrightwood trenches across the San Andreas Fault near Wrightwood. The field trip provided detailed visits to the Punchbowl fault where it cuts Proterozoic gneisses and Tertiary sedimentary rocks exhumed from 3-4 km depth, shallow-level portions of the San Andreas Fault where zones of pulverized rock along the trace of the fault can be seen, and a portion of the Punchbowl fault where it cuts the Pelona Schist. Numerous discussions at the sites focused on the field sites and how they have been interpreted. In addition, the group held discussions in the field and a wrap-up session in which we outlined what these field exposures mean for workers who try to model dynamic slip processes, interpret earthquake data for nucleation and propagation processes, and discussed how we might investigate fault zones using shallow borehole-based work.

This field trip workshop featured a beta version of a new FARM/ESP integrated rock mechanics – seismological summary and field guide to exhumed faults of southern California, the development of which was spearheaded by Jim Evans. The guide is intended to allow users to visit sites in Southern California that have been instrumental in formulating a series of important

contributions since 1980 regarding the composition and structure of fault zones as applied to earthquake source and propagation processes. Concepts such as fault slip localized to very narrow zones (mm – cm), a fault core embedded in a damaged zone, fluid-rock interactions, variations in fault structure as a function of lithology and structural position, and frictional and physical properties of fault related rocks have been studied at these localities. The field guide provides the following information for 12 sites along 5 exhumed faults [San Andreas, San Gabriel, Clamshell, and northern San Bernardino Mountains area]:

- location of site, including clear directions to site
- basic geological and seismological context of site; rock type, exhumation amount,
- fault history (in the context of geologic/seismological history over past 5-10 my).
- current understanding of fault geometry, segmentation, and seismic history
- summary of observations from the site; this includes
  - physical characteristics, such as density of fractures, small faults, location of fault core
  - chemical characterization; mineralogy, whole-rock chemistry, isotopic analyses
  - particle size distribution
  - summary of FARM/ESP related interpretations of the site(s)

The guide consists of a pdf file for each site which is planned to be posted on the SCEC website. Authors of the guide include Judith Chester, Fred Chester. Ory Dor, James Evans, and Joe Jacobs. The guide was edited by Joe Jacobs, Sam Howard, and David Foreand. Jacobs was a graduate student at Utah State Univ., and Foreand and Howard were undergraduate SCEC interns on the project.

The following two pages from the guidebook illustrate examples of the type of information it presents.

Chapter 1: Punchbowl Fault

Site 2—Lone Pine Canyon

Directions

1. From the town of Wrightwood, take Angeles Crest Highway west (State Highway 2) to the split with Big Pines Highway.

2. At the split, turn left and continue on Angeles Crest Highway (State Highway 2).

3. Follow Angeles Crest Highway for about 4 miles until you see a dirt road on your left (there may be sign mentioning Guffy Campground).

4. Turn left and follow the dirt road until you reach a gated jeep road.

5. Park at Guffy Campground (Figure 1).

Directions to Station A

1. Walking from the Guffy campground trailhead, follow the jeep road until a split occurs.

2. Take the right fork and continue for about 2 miles.

3. The fault exposure will be on your right (west) before the road makes a sharp turn (Figure 2).

   UTM (WGS 84): 3799152 N, 0440107 E
   **Elevation:** 7358 feet

Directions to Station B

1. From the Guffy campground trailhead, follow the jeep road until a split occurs.

2. Take the left fork and follow the jeep trail until it comes to a junction with a single track trail, which is marked by a sign.

3. Follow the trail south down the slope. The fault zone is exposed in the saddle (Figure 2).

   UTM (WGS 84): 3798732 N, 0441381 E
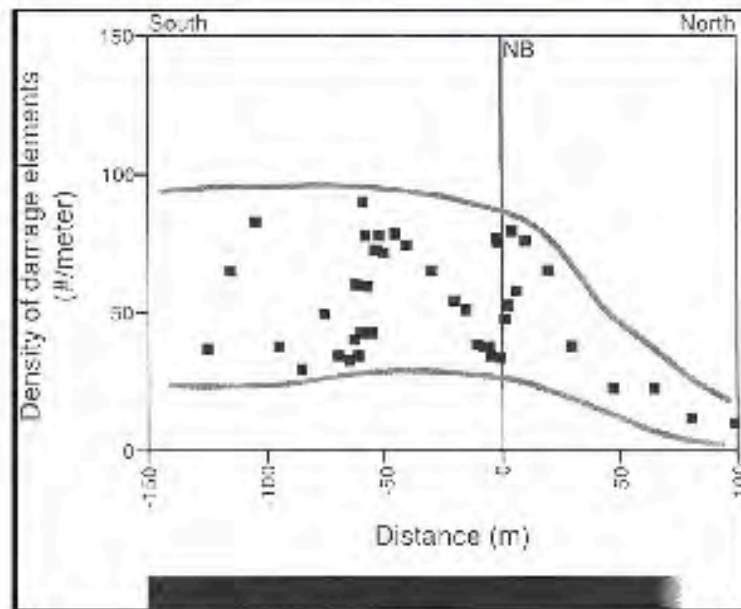   **Elevation:** 8271 feet

Figure 1. Topographic map of the Wrightwood area showing directions to Guffy Campground. The "P" outlined in red is the parking area.
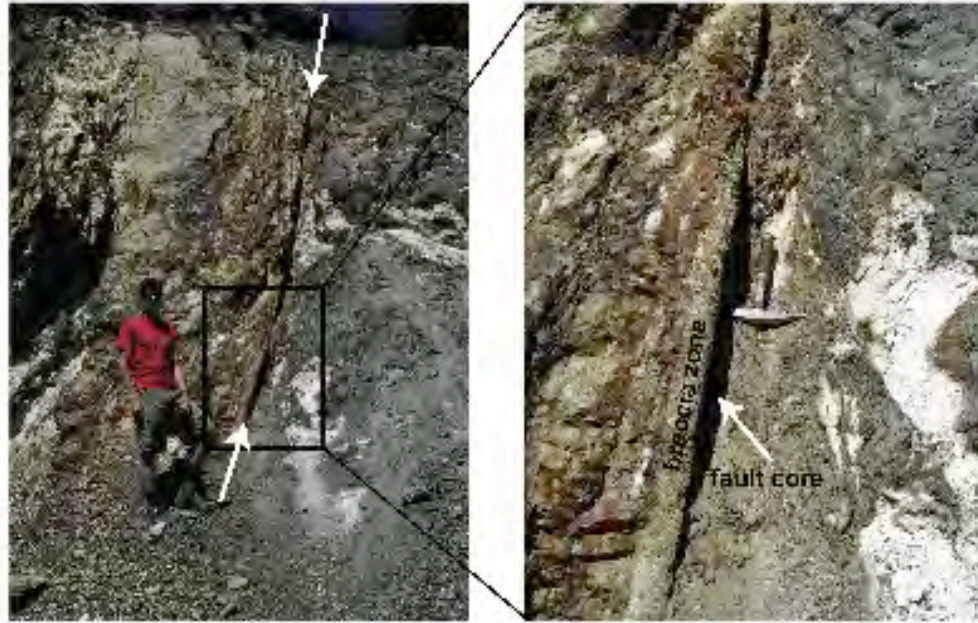
Figure 3. View to the west of the Punchbowl fault at Station A. White arrows indicate the location of the fault core.

Figure 4. Densities of mesoscopic damage elements plotted with respect to the distance from the fault core at Station A. In the Pelona Schist, solid lines indicate the location of fault cores of the major strands of the Punchbowl fault. Grey lines outline the maximum and minimum deformation ranges measured. The bar beneath the graph shows the extent of the damage zone. (Figure 15a from Schulz, 1997.)

"The schist in traverse 1 [Station A] is relatively undeformed up to roughly 30 m from the fault trace, where the rock changes from a thinly foliated, grey, quartz-mica schist to a green-grey, highly fractured altered rock. The schist has a well-defined foliation north of the fault core and its orientation is unaffected by the Punchbowl fault. Beginning at 30 m north of the fault core,

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Focus Group Activities

Within the new SCEC structure, the focus groups are responsible for coordinating interdisciplanary activities in five major areas of research: *structural representation*, *fault systems*, *earthquake source physics*, *ground motion*, and *seismic hazard analysis*. The following reports summarize some of the year's activities in each of these areas.

Unified Structural Representation

Introduction

The Unified Structural Representation (USR) Focus Area supports SCEC's science mission by providing digital models of crust and upper mantle structure in southern California for use in fault systems analysis, dynamic rupture modeling, strong ground motion prediction, and earthquake hazards assessment. These efforts include development of a Community Velocity Model (CVM), a Community Fault Model (CFM), and a Community Block Model (CBM), which comprise the USR.

In 2005, the USR Focus Area group delivered a series of new model releases, while supporting basic science studies to evaluate and improve the models. Highlights of the community modeling efforts include development and delivery of:

1) new versions of the alternative Community Velocity Models (CVM 4.0, CVM-H 2.0);
2) a new version of the Community Fault Model (CFM v.2.0), following a comprehensive peer-review of previous model versions; and
3) a new rectilinear version of the CFM, termed CFM-R.

Furthermore, a new version of the velocity model now incorporates major fault positions and offsets from the CFM, thereby achieving status as a Unified Structural Representation (USR).

Community Models

Community Velocity Models

The SCEC Community Velocity Models are 3D descriptions of crust and upper mantle compressional velocity (v_P) structure with derivative shear-wave velocity and density models. We now supports two alternative velocity models: CVM, which employs a rule-based approach for defining the velocity structure in sedimentary basins (Magistrale et al., 2000; Magistrale, 2005), and CVM-H, a geostatistical parameterization based on petroleum well and seismic reflection data (e.g., Süss & Shaw, 2003; Süss et al., 2005). Both models are embedded in regional tomographic (Hauksson, 2000) and 1D background models.

The newly released CVM 4.0 includes several major updates. The basic compressional velocity (Vp)-to-density relation has been redefined based on well log data, thereby yielding a new derivative shear wave velocity (Vs) model. Furthermore, the model includes improved structural representations of the Salton Trough (Figure 15) and San Gabriel Valley, with new

definitions of basin shapes and internal velocity parameterization. CFM-H 2.0 also includes substantial improvements, including a new top basement surface that is compatible with the positions and offsets of major faults represented in the Community Fault Model (CFM) (Figure 16). CVM-H also includes new definitions of the Salton Trough/Imperial Valley, Ventura and Santa Barbara basins, and the Inner California Borderlands. Finally, CVM-H includes a new independent density model for the Los Angeles basin that is incorporates more than 600 formation density logs. New models are already being tested by use in strong ground motion simulations, and showing marked improvements (see Evaluating and Employing Models section). Both the CVM and CVM-H are distributed through the SCEC Community Modeling Environment (CME).

Community Fault Models

This year, SCEC completed an extensive review of the Community Fault Model (CFM 2.0), which including a virtual workshop facilitating peer-review of the model using LA3D, a multi-platform visualization tool developed by the SCEC intern program. The review led to the addition of more than 50 new fault representations, many of which providing more geometrically and kinematically viable depictions of how major fault systems interact at depth. Reviewers of the CFM were also instructed to rate the quality of fault surface representations. These ratings were used to define a ranking of preferred and alternative fault models. These improvements and rankings are manifest in CFM 2.5 (Figure 17), which was released at the Annual Meeting (Plesch et al., 2005).

Several of SCEC's current research efforts in seismic hazards assessment and fault systems modeling (e.g., Bird et al., 2004; Rundle et al., 2004; Meade and Hager, 2004) require fault representations that are rectilinear (i.e., faults composed of rectangular planes). These are generally much simpler representations than the triangulated fault surfaces found in the CFM. This need for simpler fault representations inspired the development of a new fault model, CFM-R (Figure 18), which provides rectilinear fault representations that are derived from the native triangulated surfaces that comprise the CFM. The first version of the CFM-R (listed as 2.5 to reflect the CFM version on which it was based), was delivered at the Annual Meeting. The CFM-R model is currently being updated to include all of the alternative fault representations present in CFM 2.5, and through collaboration with the U.S. and California Geological Surveys will be used as the basis for various planned seismic hazard assessments. As part of the process of generating CFM and CFM-R 2.5, we have also released a new fault trace map. These models and derivative products are available at http://structure.harvard.edu.

Unified Structural Representation

The Unified Structural Representation (USR) consists of an integrated description of major fault systems and crust and upper mantle property structure in southern California. Thus, it is comprised of versions of the CFM, CVM, and Community Block Model (CBM) that are consistent with one another. Recent improvements to the CVM-H, in particular the inclusion of major fault boundaries from the CFM, provide the first realization of this goal. The main tasks remaining for the USR are to: 1) continue improving the property and block models, such that they include additional faults and geologic horizons; 2) support efforts towards 3D tomographic

inversions that will improve the models; and 3) deliver these products in an integrated IT framework that will serve the fault systems, strong ground motions, and seismic hazard communities.

Evaluating and Employing Models

The SCEC community models are intended to serve a wide array of earthquake science being pursued by the Center's other disciplinary groups and focus areas. Thus, many of the efforts to evaluate and employ these models are illustrated in other sections of this report. Nevertheless, the USR group directly engages in various studies that provide additional constraints on the models, and that evaluate the models with geodetic, seismologic, and geologic data. Here, we briefly summarize several of these efforts.

Ground Motions

The CVM models continue to be used in various studies to simulate strong ground motions, including the TeraShake (Olson et al., 2005) and the NSF Project on Implementation Interface (NGA-H) projects. In addition, various investigators have been evaluating specific improvements to the CVM models. In the case of the CVM-H, improvements in the structural representation of the Salton Trough – Imperial Valley region have clearly been shown to improve the correlation between observed and synthetic waveforms (Figure 19), illustrating that continued updates to the CVM are translating into incremental improvements in our abilities to model and predict earthquake ground motions.

Frechet Kernals/3D Tomographic Inversions

Using a Green's functions database established in summer 2004 for 33 CISN stations, a SCEC collaboration has been using the alternative CVM models to computed Frechet kernels for about 2000 frequency-dependent phase and amplitude anomaly measurements from 12 local earthquakes. Using this dataset and their Frechet kernels, this group carried out a first-ever fully 3D tomography inversion based on 3D reference model without any high-frequency approximations (Zhao et al. 2005). The preliminary model was consistent with earlier observations that the SCEC Community Velocity Model for the Los Angeles Basin, SCEC CVM3.0, is too slow in the basin. Thus, this experimental inversion demonstrated that the algorithms we developed are suitable for iterative improvements of the various community models.

Mechanical Modeling based on the CFM

The SCEC Faults Systems group is pursuing a range of mechanical modeling studies that employ the CFM and CBM to investigate geodetic, geologic, and seismologic constraints on fault system behavior. These studies have addressed the longstanding controversy about the nature of strain accommodation in the northern Los Angeles basin (vertical thickening vs. escape tectonics), highlighting the role of active blind-thrust fault in accommodating shortening (Griffith and Cooke, 2005; Argus, 2005) (Figure 20). In addition, collaborations between modelers and tectonic geomorphologists have evaluated alternative geometries and slip rates on

various fault systems, including the Puente Hills Thrust, Hollywood, and Raymond faults (e.g., Fawcett et al., 2005; Cooke et al., 2005). These efforts highlight that modeling studies can help to address gaps in our geologic and geodetic constraints of fault slip rates, and in turn make direct contributions to the CFM through evaluation of alternative fault representations.

Seismicity

In coordination with the Seismology Disciplinary group, the USR collaboration continues to support efforts to improve earthquake catalogs in southern California. These data are primary constraints on fault representations in the CFM and velocity structure in the CVM. This past year, these efforts have included rigorous tests of alternative relocation methods (Shearer et al., 2005), incorporation of more precise velocity descriptions in examining specific earthquake clusters and fault systems, and comparisons of hypocenter locations with the entire CFM (Hauksson et al., 2005).

Fault studies

The CFM is a product of numerous fault-specific studies carried out by scientists within and beyond SCEC. Thus, efforts to improve the CFM include support of collaborations to investigate the geometries and slip rates on many active faults. In this past year, various USR investigators have collaborated with the Disciplinary groups to: 1) characterize active faults using new data types, such as LIDAR (Oskin, 2004); 2) improve our understanding of fault zone structure and slip rates in the Santa Barbara Channel and Borderlands (Nicholson et al., 2005); and 3) investigate active blind thrust fault in the Los Angeles basin through acquisition of new high-resolution seismic reflection data (Leon et al., 2005).

Hazard assessment

Working in partnership with the Seismic Hazard Analysis Focus area in SCEC, the USR group has developed a series of alternative, comprehensive fault models that reflect significant uncertainties in our knowledge of major earthquake sources. Alternative models have been produced for the Los Angeles basin, the Western Transverse Ranges (including the Santa Barbara Channel), the central segment of the San Andreas Fault, and the Death Valley region. We are currently working with the U. S. and California Geological Surveys to generate rectilinear versions of these alternative fault representations, which will be used as the basis for future hazard assessment projects.

Summary

The USR Focus Area group continues to develop new models of crust and upper mantle fault zone and property (Vp, Vs, density) structure in southern California, with releases of several new model versions (CVM 4.0; CVM-H 2.0; CFM 2.5; CFM-R 2.5) in 2005. These models incorporate results from a wide range of geologic, geodetic, and seismologic studies, and serve major efforts in fault systems modeling, strong ground motions prediction, and seismic hazards assessment within SCEC.

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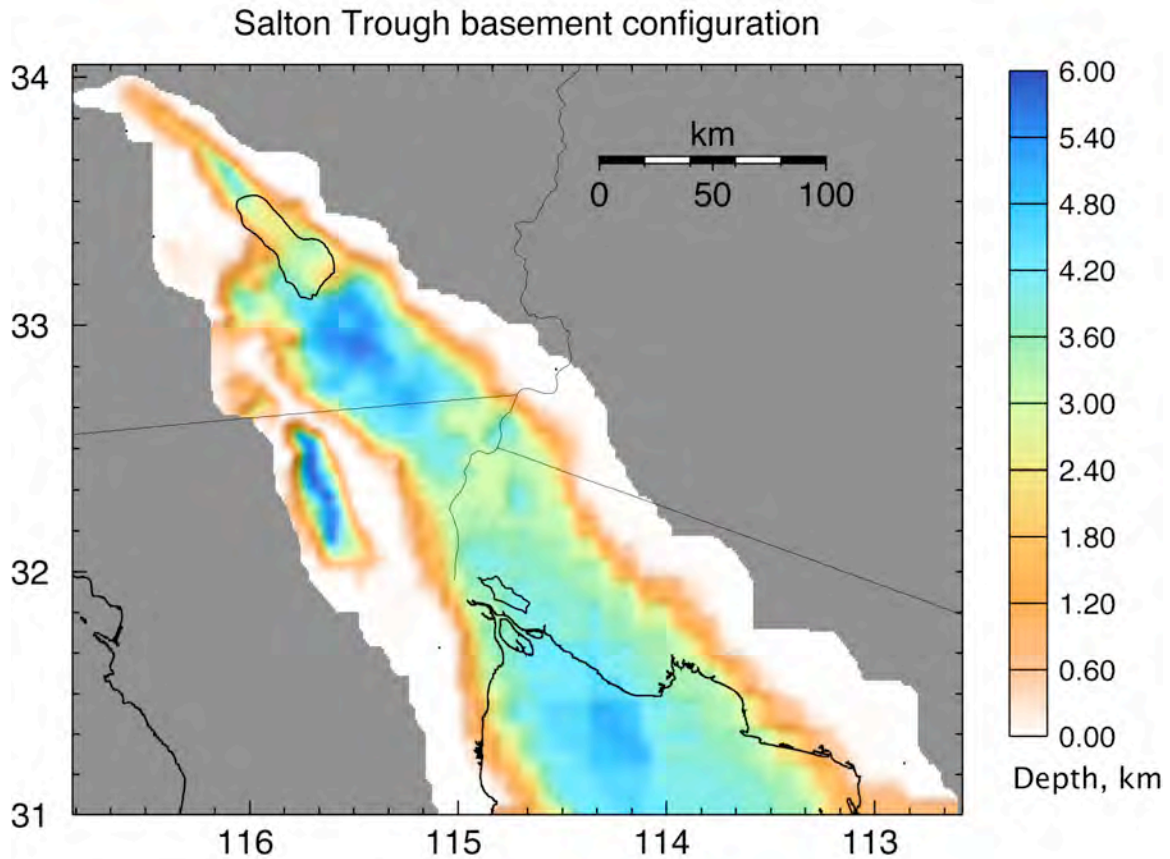
Figure 15: Map of the top of basement in the Salton Trough region used to improve CVM version 4.0. (Magistrale, 2005).
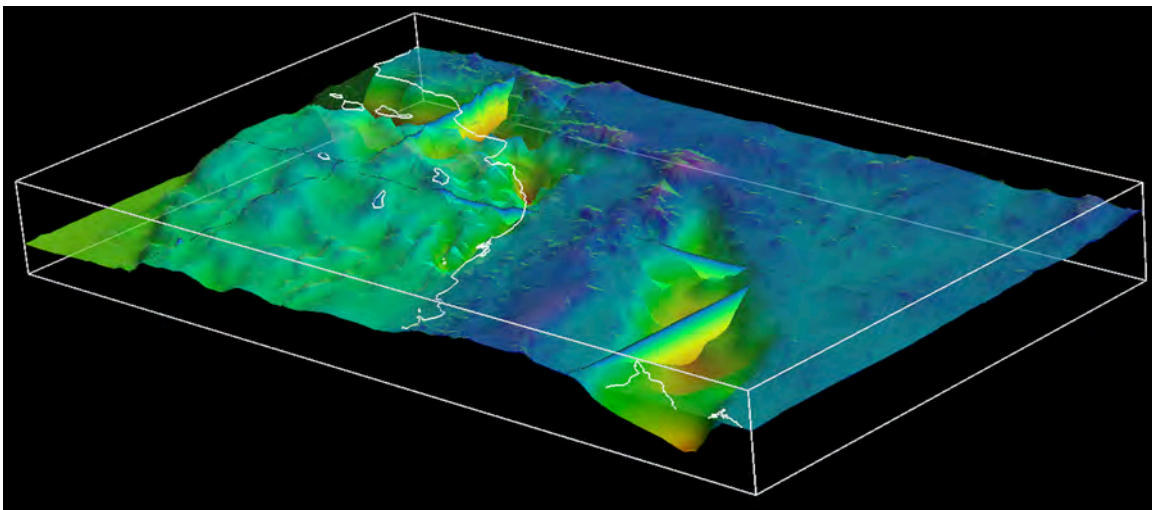
Figure 16: Perspective view of the revised top basement surface in the CFM-H, including new representations of basin structure in the Salton Trough/Imperial Valley, Santa Barbara Channel and Ventura basin, and Inner Borderlands. View is to the northwest. (Süss et al., 2005).
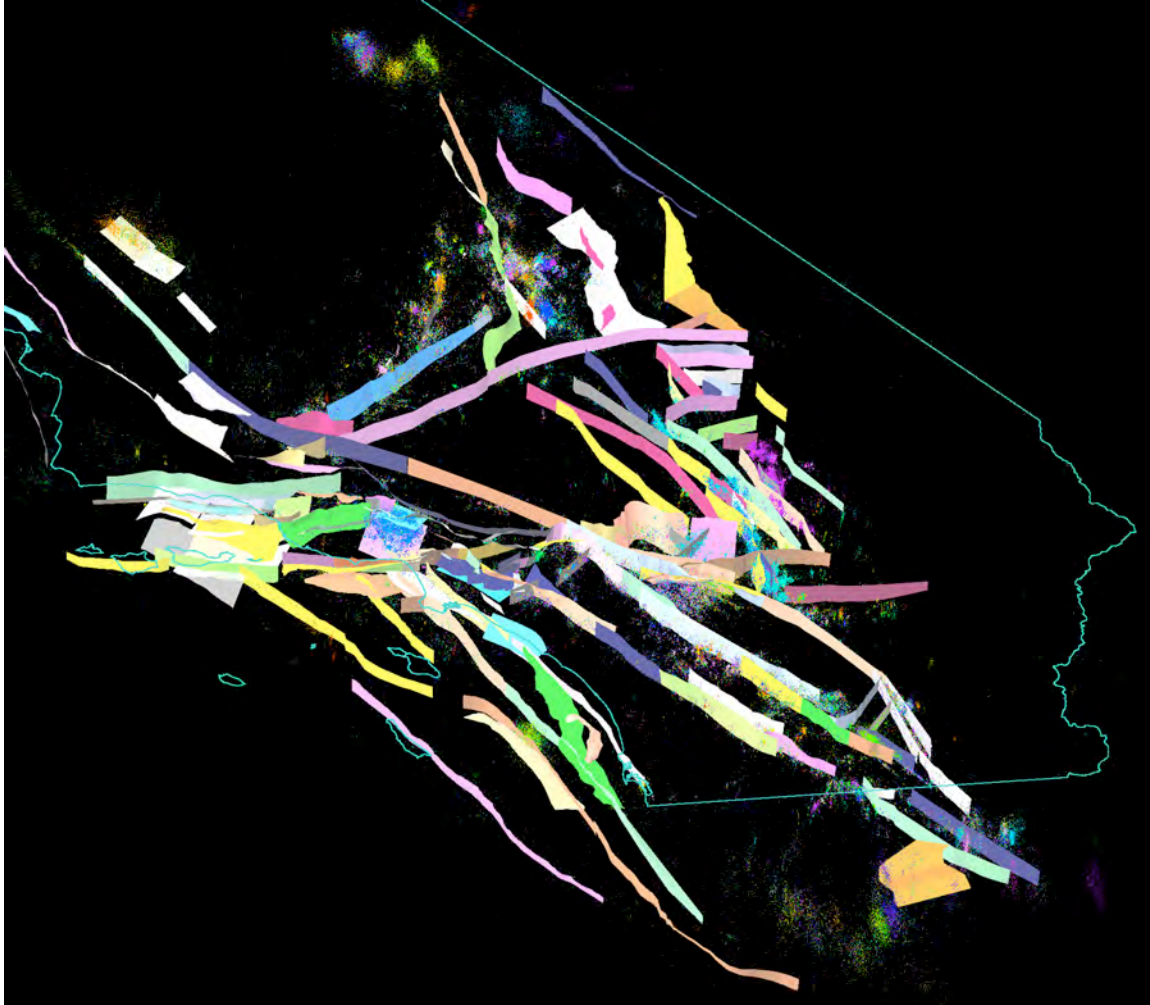
Figure 17: Perspective view of the SCEC Community Fault Model (CFM version 2.5). Seismicity is from Hauksson (2000) and color-coded by year of occurrence. (Plesch et al., 2005).
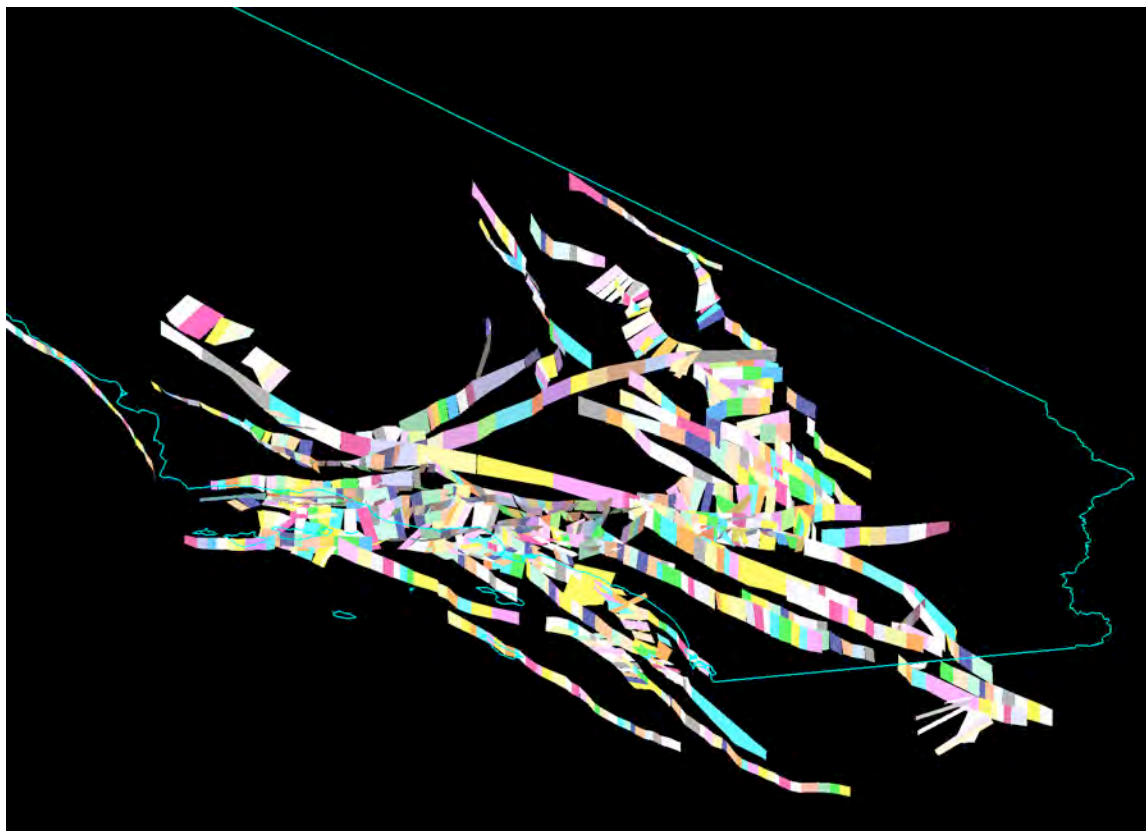
Figure 18: Perspective view of the new rectilinear version of the SCEC Community Fault Model (CFM-R 2.5). Faults are defined by rectangular patches that were derived from the triangulated surface representations in the CFM. (Plesch et al., 2005).

Figure 19: Maps showing seismograms in and around the Salton Trough from the 3 November 2002 M$_w$ 4.2 Yorba Linda earthquake. Black waveforms represent the recorded data and red waveforms represent the synthetic simulations. The left plot shows simulations using the Los Angeles Basin high-resolution velocity model [Süss and Shaw, 2003] embedded in a regional tomography model [Hauksson, 2000] after Komatitsch et al., 2004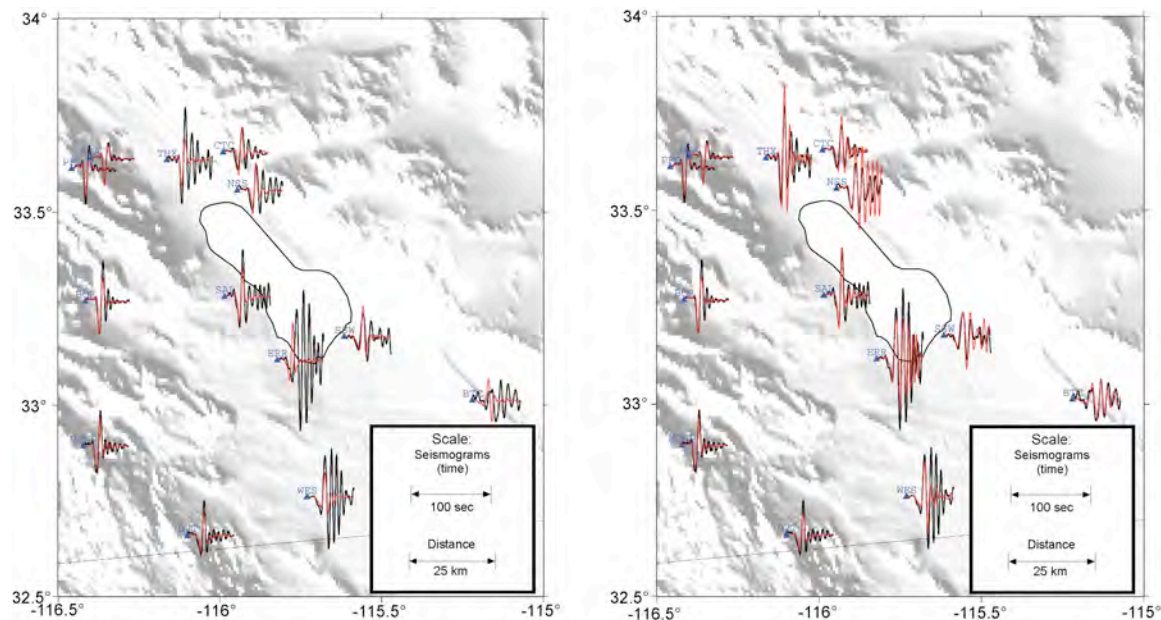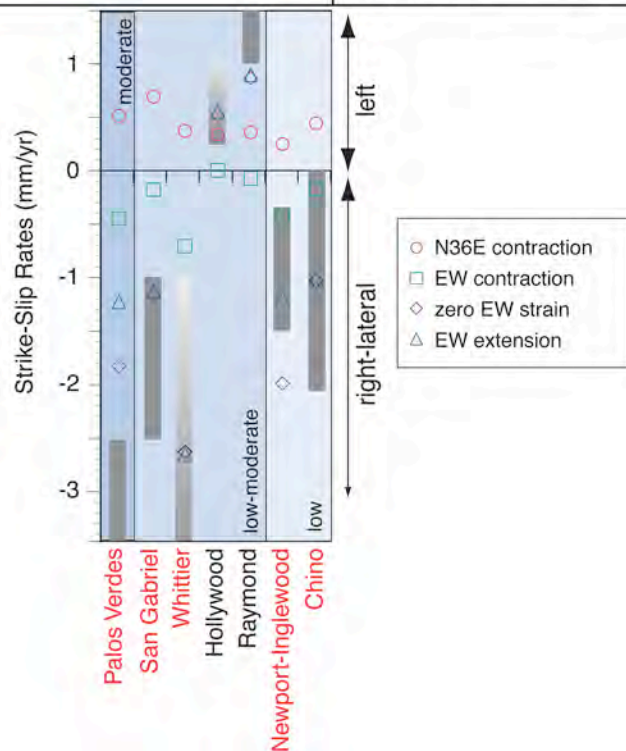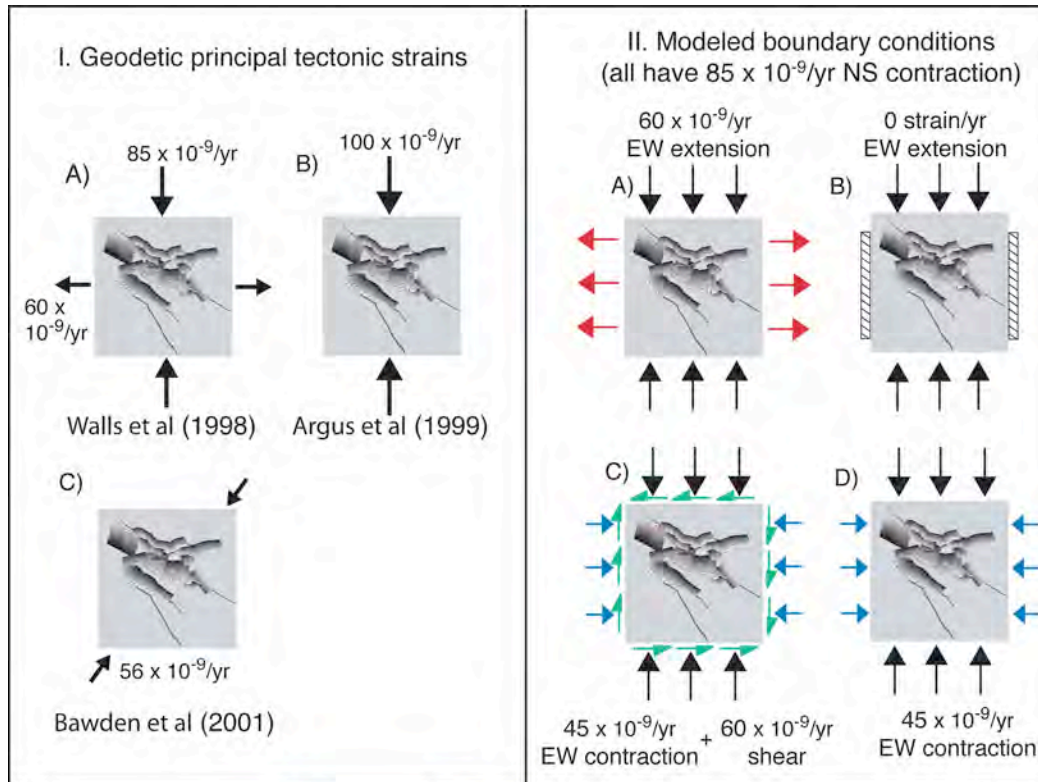]; whereas, the right plot shows simulations incorporating the new Salton Trough velocity model in CFM-H 2.0 (Süss et al., 2005) based on the SEM method. The two figures illustrate the improved accuracy of ground motion simulations produced with the new velocity model. Both the data and the synthetic seismograms were subsequently bandpass filtered between 6 and 35 sec with a four-pole two-pass Butterworth filter. (From Lovely et al., 2005).

Figure 20 (next page): BEM models of the northern Los Angeles basin evaluating slip rates on faults represented in the CFM. Strike slip rates for faults within the Los Angeles basin vary with applied tectonic boundary conditions (*top*). (*bottom*) Grey boxes show the range of paleosiesmic slip rates -- slip rates with gradational ranges are preferred at the darker end. The faults are listed in order of the quality of the paleoseismic slip rates. For contraction at N36E the Palos Verdes, San Gabriel, Whittier, Newport-Inglewood and Chino faults (in red) experience slip opposite to that observed. This result and the large mismatch of paleoseismic and modeled slip rates under east-west extension confirm the results of Argus (2005) that the region is undergoing north-south contraction with negligible or small amounts of east-west contraction. (From Griffith and Cooke, 2005, and Cooke at al., 2005).

I. Geodetic principal tectonic strains

A) 85 x 10^{-9}/yr ... 60 x 10^{-9}/yr ... Walls et al (1998)

B) 100 x 10^{-9}/yr ... Argus et al (1999)

C) 56 x 10^{-9}/yr ... Bawden et al (2001)

II. Modeled boundary conditions (all have 85 x 10^{-9}/yr NS contraction)

A) 60 x 10^{-9}/yr EW extension

B) 0 strain/yr EW extension

C) 45 x 10^{-9}/yr EW contraction + 60 x 10^{-9}/yr shear

D) 45 x 10^{-9}/yr EW contraction

Strike-Slip Rates (mm/yr)

moderate — low-moderate — low

left — right-lateral

○ N36E contraction
□ EW contraction
◇ zero EW strain
△ EW extension

Palos Verdes — San Gabriel — Whittier — Hollywood — Raymond — Newport-Inglewood — Chino

Fault Systems

The goals of the FSWG are to understand the kinematics and dynamics of the southern California fault system on interseismic and geologic time scales and to apply this understanding to constructing probabilities of earthquake occurrence in southern California, including time-dependent earthquake forecasting. Two broad approaches are followed, both rooted in model-based inference: 1) Quantitative comparisons of observations to predictions of models of ongoing crustal deformation and stress evolution, and 2) A systems level approach characterizing and understanding spatial and temporal patterns in regional seismicity, with the ultimate objective of intermediate-term earthquake prediction. FSWG has strong ties to the Unified Structural Representation, Earthquake Source Physics, and RELM Working Groups, and is dependent on observations provided by Earthquake Geology and Tectonic Geodesy.

The scope of the effort is broad, as can be seen by perusing the list of FSWG grant titles and PI's. Scientific projects using the Systems approach include: Earthquake probabilities based on clustering and stress interactions (Y. Kagan); T-RELM, Testing Regional Earthquake Likelihood Models in Southern California (S. Wiemer); Likelihood Tests of RELM earthquake potential models (D. Jackson); Analysis & Integration of the Earthquake Stress Cycle Evolution & Pattern Informatics Techniques (K. Tiampo, C. Bowman); Forecasting and Predicting on Earthquake Fault Systems (J. Rundle, W. Klein); Earthquake Simulation Models of Southern California (S. Ward, L. Grant); Quasi-Dynamic Parallel Numerical Modeling of Earthquake Interactions Over a Wide Magnitude Range Using Rate and State Friction and Fast Multipoles (T. Tullis); Physics-based simulation of earthquake occurrence in fault systems (J. Dieterich, see figure 22); Creating a Framework for Evaluating Earthquake Predictions Using Accelerating Moment Release (D. Bowman); Analysis of spatio-temporal strain patterns associated with southern California earthquakes (T. Becker); Ultimate earthquake triggering: Where and why seismicity migrates along fine-scale lineations in Southern California (H. Houston); Sequences of Cascading Elastodynamic Ruptures on Geometrically Complex Faults: Rupture Initiation, Propagation, Termination, and Variation (B. Shaw); Stress Transfer Triggering and Data Assimilation for RELM (S. Gross); and Data Assimilation for General RELM Forecasts using the Ensemble Kalman-Levy Filter, and Multifractal Stress Activation Model (D. Sornette).

Observations crucial for the Systems approach provided by Earthquake Geology include: Extending the paleoseismic record on the San Andreas fault at Thousand Palms, CA (R. Weldon); Time-Space Probability of San Andreas Fault Earthquake Ruptures (G. Biasi); Development of long-term rupture parameters for the Southernmost San Andreas fault, California (G. Seitz); Determination of Paleoseismic Chronologies and Slip Rates in Southern California Using AMS 14C, 10Be, 26Al and OSL Measurements (M. Kashgarian); Determination of slip rates on the Death Valley-Furnace Creek fault system: Towards an understanding of the spatial and temporal extent of strain transients (J. Dolan); Defining Holocene activity of the Compton blind-thrust fault, Los Angeles basin, California (J. Dolan); Fault Interaction within Major Strike-Slip Fault Restraining Bends Southern California Region (M. Legg); Timing, segmentation, and slip in past earthquake ruptures on the northern Lenwood fault zone, Eastern California Shear Zone (S. Lindvall); A high-resolution geomorphic and chronologic record of the dynamic evolution of a seismogenic strike-slip fault (M. Oskin); and Supplemental Field Support for Paleoseismic Investigations of the Blackwater Fault (C.

Madden).

Development of Community software is a high priority of FSWG: Development of Community Block Model (C. Gable, B. Hager, M. Simons); and Development of a parallelized 3-D finite element code for modeling deformation (C. Williams). Model-related studies include: Crust-Mantle Dynamics, southern California (E. Humphreys); Study of interseismic and transient strain accumulation in Southern California using InSAR and GPS data (Y. Fialko); Kinematic Model of Fault Slip and Anelastic Strain Rates and Long-Term Seismicity (P. Bird); Southern California Tectonic Deformation Modeling (Z-K Shen, D. Jackson); Testing the Community Block Model by Inferring Fault Slip and Crustal Motion from Joint Inversion of Geologic and Geodetic Data (B. Hager); Developing Testable Models of Heterogeneous Crustal Stress (T. Heaton); Inference of crustal rheology from observations following the 2004 Parkfield, California (R. Burgmann); Inference of crustal rheology from observations of postseismic deformation following the 2004 Parkfield, California earthquake (A. Freed); Exploration of Community fault model alternatives via elastic models of deformed geologic markers (M. Cooke), Near-fault deformation measured by geologic methods and InSAR (R. Mellors); and Postseismic Deformation in the Mojave Region: The Effect of Damage Zones and Heterogeneous Elastic Structure (E. Hearn).

The most important FSWG group activity is the annual workshop: "Community Finite Element Models for Fault Systems and Tectonic Studies," hosted by Los Alamos National Laboratory in July. This locale enables SCEC scientists to benefit from interaction with Lab experts. This year we leveraged SCEC funding with support from NSF CIG, NASA, and LANL, allowing us to increase the number of students and senior researchers attending. Part of the group effort is aimed at verifying code accuracy using benchmark problems. Efficient and accurate meshing of complex geologic structures is a very high priority, and hands-on meshing sessions lead by scientists from LANL were extremely useful, with participants installing and learning to use LAGriT.

One of our highest priorities of the is to develop a quasi-static, parallelized finite element code able to represent the deformation and stress fields due to all major faults in southern California, as provided by the Community Block Model, using realistic rheologies and fault behavior. The code should be relatively easy to use and should integrate well with other modeling codes, visualization and meshing packages. Charles Williams (RPI) leveraged SCEC, NSF ITR, and Caltech resources to upgrade Tecton into a SCEC Community code, "Lithomop." A significant fraction of participants succeeded in setting up and running Lithomop on their computers. The NASA-sponsored Quakesim group also participated in the workshop, and most participants also set up and ran GeoFEST. Thus the focus of the workshop was "learning by doing."

In order to develop a realistic continuum mechanics model of Southern California, it is crucial to include the fault system geometry and mechanical structure that is the focus of the USR group. The resulting Community Block Model (CBM) is not only an essential product required by Fault Systems, but also provides the natural way of combining the fault surfaces of the CFM and the volumetric properties of the CVM into a Unified Structural Representation. This year Carl Gable of LANL succeeded in meshing the Mojave region of CBM, providing a

major step forward for realistic models of the southern California fault system (see figure 21).

Community Code Priorities identified for July 2005 - Aug 2006

Benchmarking infrastructure: a lack of infrastructure to manage and manipulate simulation results is hindering benchmarking efforts. A repository is needed to archive the benchmark results, including (1) simulation metadata (name and version of simulation code, benchmark name, who ran the simulation, etc), (2) simulation output data files, and (3) discretization information (basis functions and element shape). A small group of individuals within the working group are spearheading this effort and will submit a proposal to CIG SSC with a request for resources to develop the necessary infrastructure.

Finite-element mesh infrastructure: All of the finite-element codes used by the working group would benefit from tools that aid in efficiently transferring data from mesh generation software to simulation codes. We would like to work with CIG developers and other working groups to identify a common data structure and/or file format to hold mesh topology information (nodes, elements, groups of nodes and elements) and outline the necessary routines to manipulate them. These tools include (1) partitioning the mesh topology information among processors, (2) uniform global mesh refinement, and (3) modules for adjusting the topology to implement faults. The first two are independent of the code used; however, because codes implement faults in different ways, the modules for implementing faults would be specific to different physics codes.

Build procedure: Workshop participants struggled to install software using the Pyre build procedure, although eventually most people were able to install PETSc, Pyre, and Lithomop and run one or more examples. There is a strong desire for a user friendly, robust build procedure capable of handling software dependencies. Users would like something as easy as installation via packages (apt, fink, up2date, yum, etc).

PyLith development: Release of a fully functioning version of PyLith remains a high priority for the working group. The three priorities above are consistent with and essential to the development of PyLith. Users placed high priority on documentation, regression testing, and modularity (e.g., use of the Pyre simulation controller to allow customization of high level functionality).

A more detailed report is available at the CIG web site:

http://www.geodynamics.org/cig/workinggroups/eq/workarea/planning/planspriorities2005/workshop2005
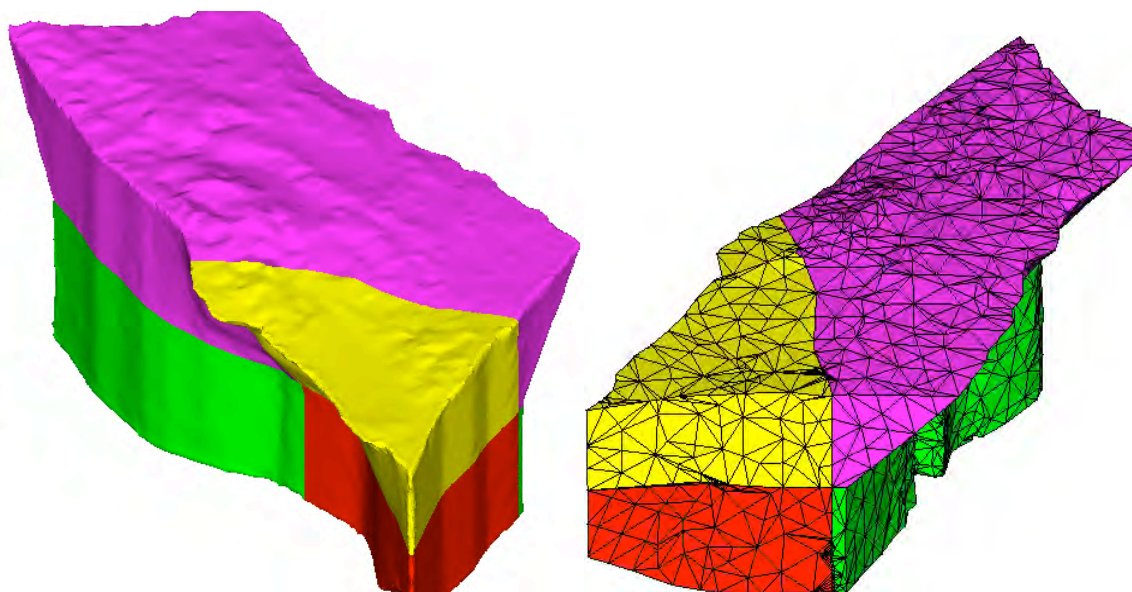
Figure 21. The 4-block Mojave model showing the blocks, with topography (upper left), and a close up of the mesh of tetrahedral elements created from the GOCAD CBM (upper right).
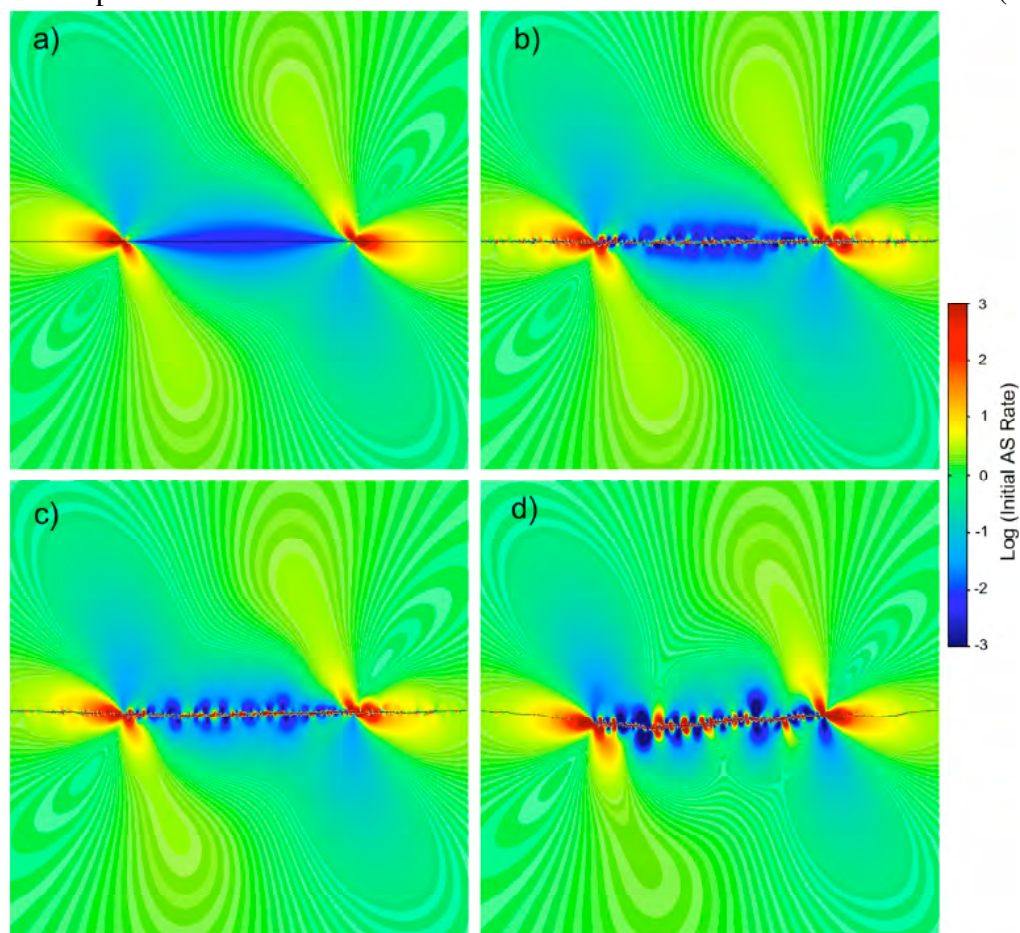
Spatial distributions of aftershock for different amplitudes of fault roughness. Logarithmic scale of initial aftershock rate normalized by the long-term average rate. a) Planar fault. b) Fractal fault with amplitude factor _=0.01. c) Fractal fault with amplitude factor _=0.03. d) Fractal fault with amplitude factor _=0.1.
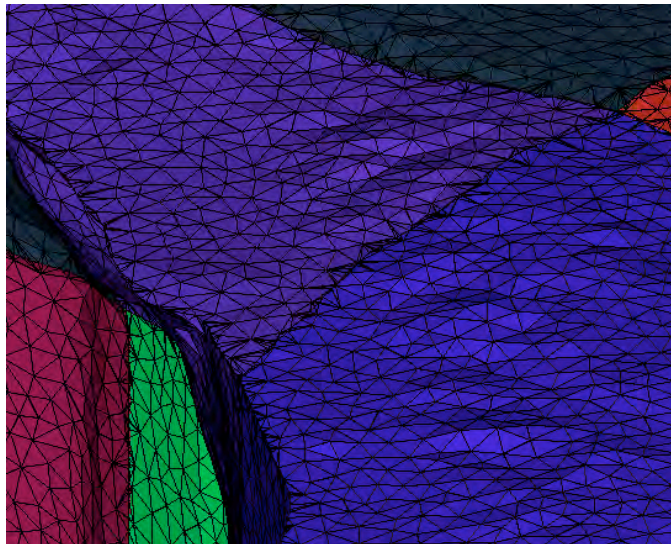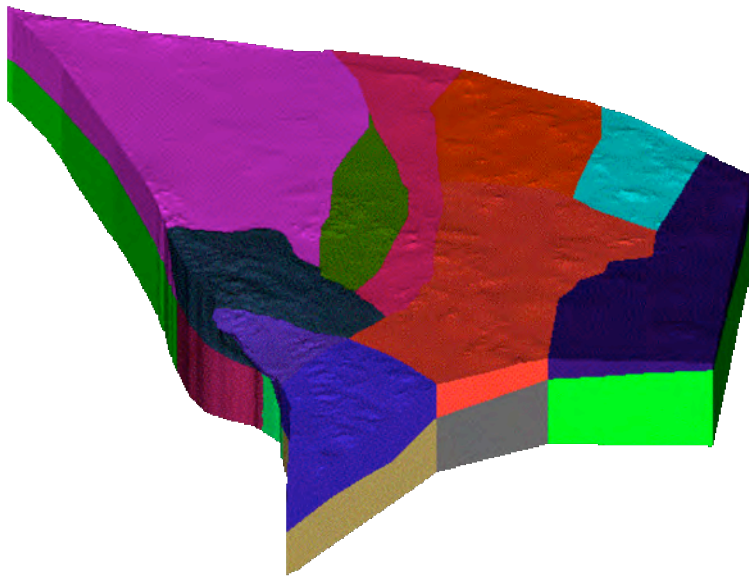
Figure 22
Upper left: USR Community Block Model of the Mojave region, showing two layers of blocks.
Lower right: Zoomed view of mesh generated by Carl Gable using LAGriT.

Earthquake Source Physics (ESP)

The long-term goals for our group are to decipher the physics of earthquakes and the ramifications for ground motions.

In FY2005 Earthquake Source Physics PI's tackled problems in 4 areas:

1. Computationally simulating rupture dynamics to elucidate earthquake physics

Archuleta	(*resolution*)
Ben-Zion	(*materials/damage*)
Day & Harris	(*geometry, materials, friction*)
Harris & Archuleta	(*code-comparison workshop*)
Harris/Aagaard/Ampuero/Andrews/Archuleta/Bielak/	
Day/Dunham/Lapusta/Oglesby/Olsen/Pitarka/Rice	(*code-comparison*)
Lapusta	(*multi-cycle, stress triggering*)
Lavallee	(*source/ground motion statistics*)
Oglesby & Xu	(*multi-cycle, fault geometry*)
Rice & Dmowska	(*geometry, friction, lab*)
Sammis	(*damage/ground motion*)
Shaw	(*multi-cycle*)
Tullis	(*lab*)
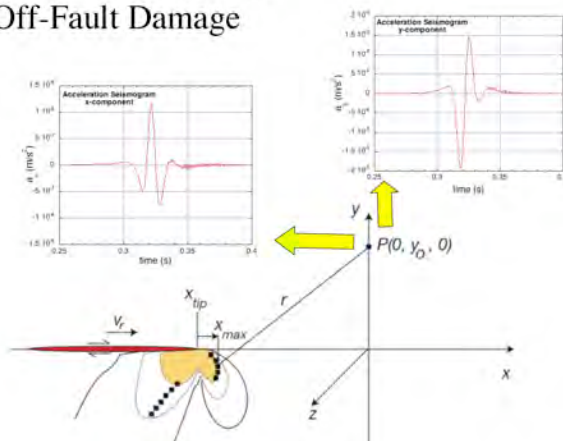
A slip pulse produces off-fault damage This results in high-frequency ground motions.
Figure 23 (courtesy of Sammis et al.)
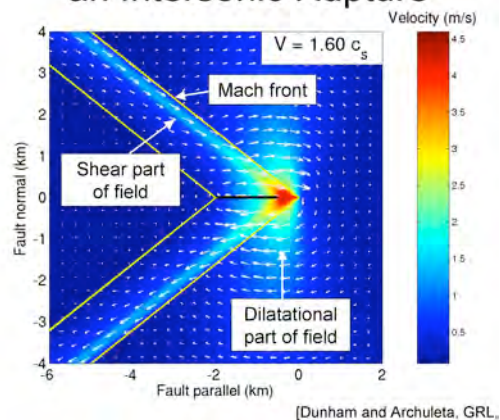
A supershear rupture produces ground motions that decay more slowly with distance than subshear ruptures do.
Figure 24 (courtesy of Dunham & Archuleta.)
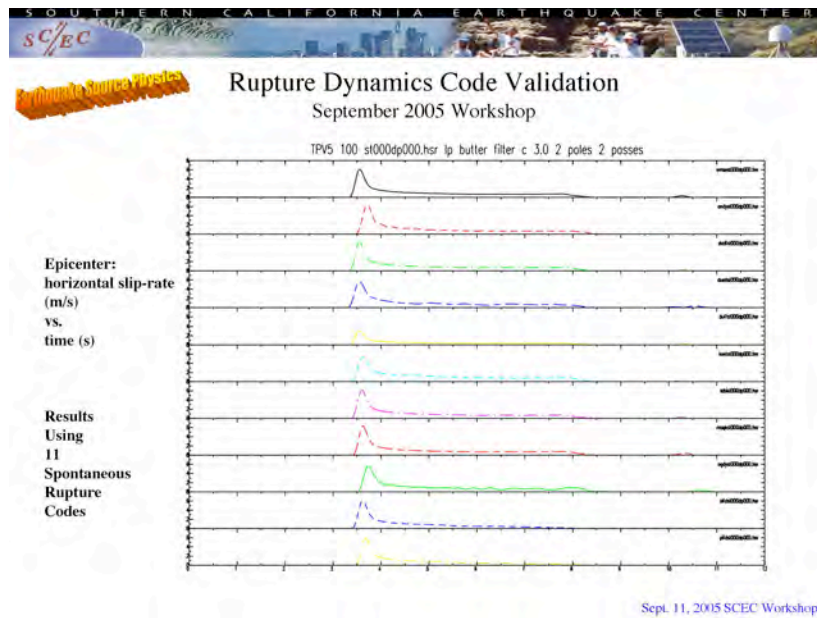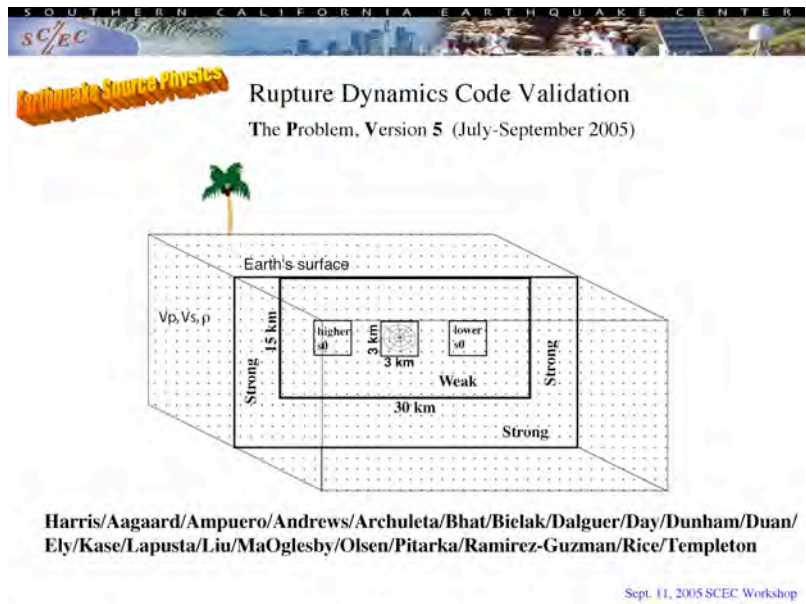
Figure 25. The setting (top) and synthetic seismograms (bottom) for the benchmark problem, The Problem, Version 5, tackled at the 3D Rupture Dynamics Code Validation SCEC workshop held September 2005.

2. Reference Earthquakes Database
Mai   (*many earthquakes*)
Aagaard/Beroza   (*Digital Library*)
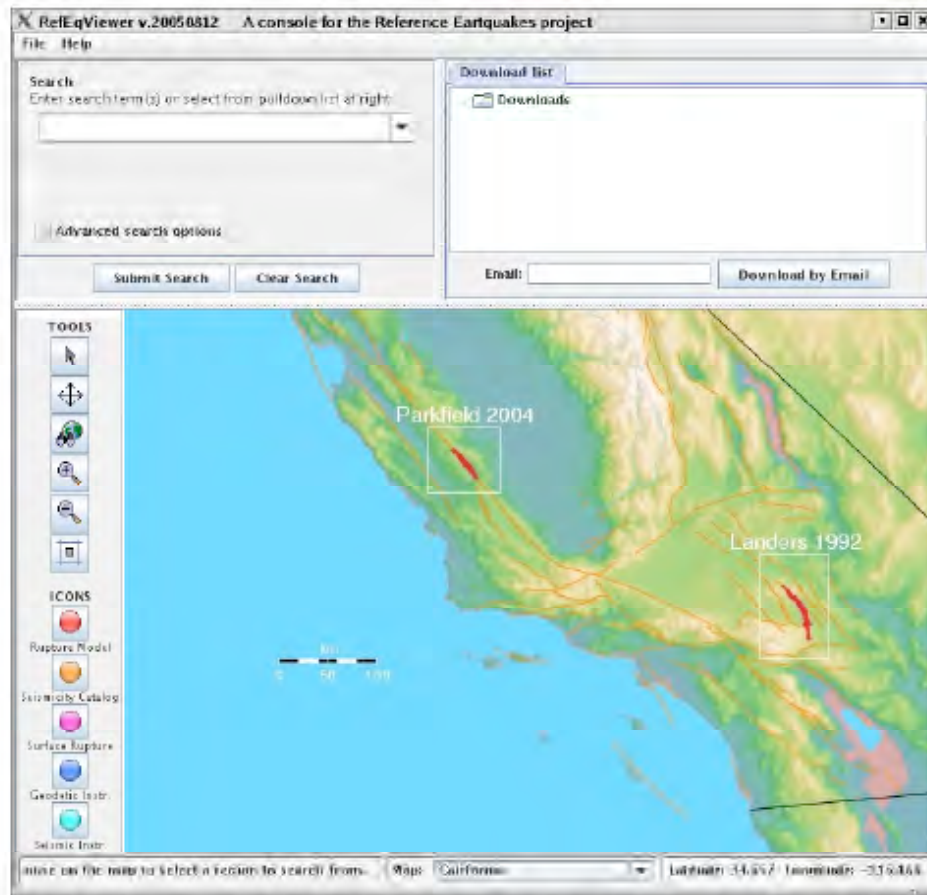
Figure 1.14: RefEqViewer upon startup. The window contains a map (lower portion of window), a search panel (upper left corner), and a results panel (upper right corner).

Figure 26 showing the locations of the first two earthquakes to have data and models collected in the new Reference Earthquake Digital Library. Figure courtesy of Aagaard et al.

3. Investigating large- vs. small-earthquake physics
McGuire (*rupture velocity in small vs. large earthquakes*)

4. Using earthquake triggering observations to decipher earthquake physics
Houston (*aftershocks*)   Vidale (*swarms*)
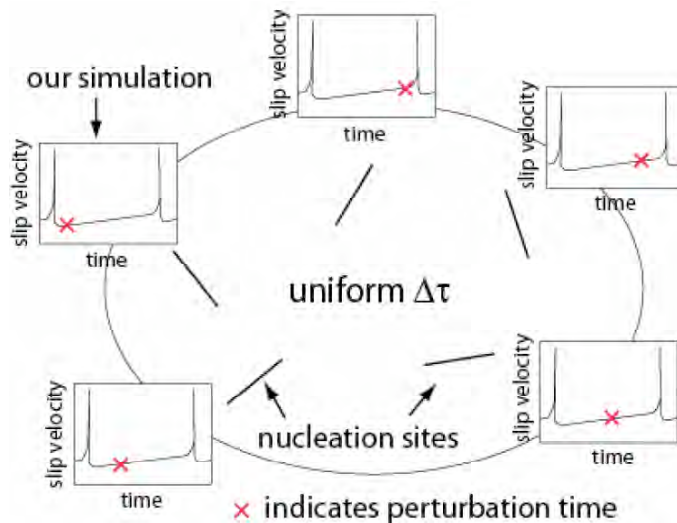
Figure 27 showing the approach for determining earthquake triggering in a sophisticated physics-based model. Figure courtesy of Kaneko & Lapusta.

Some highlights from these research efforts are as follows:

As part of our research into rupture dynamics, we in the Earthquake Source Physics Focus Group have 3 sets of PI's (Lapusta, Oglesby/Xu, Shaw) investigating the multi-cycle fault problem, which involves modeling the long-term dynamics of earthquakes over multiple earthquake cycles [Liu & Lapusta, 2005; Duan & Oglesby, 2005; Shaw, 2005]. This research area overlaps with Fault Systems focus group goals. Each ESP group is examining the problem from a unique perspective, by including complex friction formulations, viscoelasticity, and fault geometry in varying amounts. Additionally, our researchers are continuing their work on the dynamics of single rupture events. Investigators are tackling a range of problems, including the effects of fault geometry, material complexity, and friction formulation.

Fault geometry has been shown by PI's Oglesby/Xu [Oglesby, 2005] and Rice/Dmowska [Fliss et al., 2005] to play critical roles in both rupture extent and rupture nucleation, especially for the case of the fault bend and stepover. PI's Rice/Dmowska have also been testing their theories by comparing their results with lab experiments in the material homalite.

On the materials front, although there a still a few holdouts [Shi & Ben-Zion, 2005], it has been shown by PI's Harris/Day, partly in thanks to observations from 70 years of Parkfield

earthquakes, that material contrast does not assist with the prediction of earthquake propagation direction [Harris & Day, 2005; Andrews & Harris, 2005]. This finding has ramifications for SCEC3 'Earthquake Predictability' work.

On the friction front, we are still learning. Geologic observations (by the FARM and Geology groups) of the widths of principal slip surfaces in exhumed faults are highly relevant to our ESP work, especially as we move to convert these results to understanding energy balance. This work may provide significant constraints on how much energy is released on and off a fault, and the partitioning of this energy into different types of physical and chemical processes. Similarly, direct measurements of fault zone material extracted from depth (e.g. SAFOD, Chelungpu fault, Taiwan; Nojima fault, Japan) and friction experiments on these materials serve to add critical pieces to our puzzle. However we are still in a quandary about which friction formulations might be most appropriate for simulating coseismic behavior. To date most PI's in ESP, even those who are currently researching other friction formulations, often use slip-weakening, or a variation thereof for the coseismic event itself. We anticipate that 2006-2007 may be banner years for distinguishing among coseismic friction mechanisms. The answers will most likely result from the collaborations among field geologists, geophysicists, petrologists, ground motion seismologists, and numerical modelers.

Our most visible ESP current effort is our code validation/comparison exercise, which now involves more than 14 people, including a significant number of students and postdoctoral researchers. We are showing that when we use similar assumptions about fault geometry, materials, friction, stress, many of our codes, if they assume a split-node formulation for the fault plane can produce the same earthquake source physics results [Day et al., 2005]. Our goal is to produce synthetic seismograms that match each other, and are validated by experimental and observational studies. The hope is that our validated methods can then be used with confidence by the engineering community So far we have met in 4 workshops (Nov. 2003, >30 attendees, Sept. 2004, >50 attendees; Nov. 2004, 20 attendees; Sept. 2005, 60 attendees), and our next meeting will be January 2006. We have compared results for five benchmark problems (The Problem, Versions 1,2,3,4,5). Our next goals are to include in our models more of the complexity for spontaneous rupture models such as the TeraShake and Pathway 3 simulations. There is also mention of our efforts as a template for future Extreme Ground Motions and NGA-H simulations. Our collaborative project has received worldwide attention, with scientists from other countries using our findings to benchmark their codes, for example an EU exercise based on our findings will start soon [e.g., Moczo et al., AGU abstract, 2005].

In ESP in 2005 we have seen progress on the research projects that bridge our earthquake source physics work with ground motions ramifications. The Sammis efforts on better understanding potential sources of high frequency wave generation and the Lavallee efforts [Lavallee et al., 2005] on putting together physics-based stochastic source models exemplify this connection. Archuleta [Custodio et al., 2005] has shown in 2005, using the abundant near-field ground motion data from the 2004 M6 Parkfield earthquake, how only the most robust features of a ground motion inversion for seismic fault slip should be counted when these types of studies are performed. They also show that it is quite likely that path and site effects are critical components of the observed ground motion recordings. Therefore, it is important to know what should and

what should not be mapped back into the source, especially when kinematic source models are then used to infer earthquake source physics.

The 2004 Parkfield earthquake [Bakun et al., 2005] is still being studied, with a special issue of Bulletin of the Seismological Society of America anticipated in 2006. This publication, being edited by SCEC researchers Harris and Arrowsmith, will show what has been learned about earthquake source physics, ground motions, and the entire earthquake cycle on an extremely well studied portion of the San Andreas fault. Contributions by SCEC ESP researchers include Li et al. [2005] and Liu et al. [2005], in addition to numerous SCEC researchers from other focus and disciplinary groups, and USGS and academic investigators from around the world.

In 2004 our focus group began its work on a reference earthquake database, whose goal is to provide observations and models derived from the observations in one easy-to-access location. This database will serve as a testbed for hypotheses about earthquake source physics. In 2005 PIs Aagaard and Beroza have put considerable time and thought into this effort, including a SCEC workshop and subsequent online dialogues with all interested SCEC researchers to design templates for data input. They have a pdf report that is accessible on http://www.scec.org.

In the coming year and a half, it is anticipated that part of our ESP group will merge with the FARM group, since we have a large number of overlapping interests and goals. In this new setting we plan even more insightful dialogues and research progress, all with the goal of deciphering earthquake source physics.

SOME 2005 SCEC EARTHQUAKE SOURCE PHYSICS PUBLICATIONS:

The Code-Validation Exercise:

Day, S. M., L. A. Dalguer, N. Lapusta, and Y. Liu, (2005). Comparison of finite difference and boundary integral solutions to three-dimensional spontaneous rupture, *Journal of Geophysical Research*, in press.

Rupture During Multiple Earthquake Cycles:

Duan, B., and D.D. Oglesby, Multicycle dynamics of nonplanar strike-slip faults, J. Geophys. Res., 110, B03304, doi:10.1029/2004JB003298, 2005.

Liu, Y., and N. Lapusta (2005), Three-Dimensional Simulations of Spontaneous Earthquake Sequences, Eos Trans. AGU, 86(52), Fall Meet. Suppl., Abstract S43A-1068.

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The Effect of Material Contrast on Dynamic Rupture Propagation:

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Ground Motions

The challenge facing the ground motion group is validation of codes against available data so that broadband ground motions relevant to building damage can be predicted with confidence from future earthquakes. While considerable progress has been made at frequencies below 1 Hz, large-scale high-frequency modeling is beyond both computational resources and our detailed knowledge of source and path. Various empirical schemes have been used to add high frequencies to computed seismograms, but without a solid physical basis, their reliability still requires further assessment. Even at low frequencies, inadequate knowledge of the path limits how much of the coda can be predicted. Both high frequency strong shaking and long-term coda are important for engineering considerations. The ground motion group has made significant progress in attacking these problems with a series of numerical calculations, validations and experiments coordinated with other groups across SCEC.

Broadband ground simulations involve generating the high frequency parts of the seismogram either as a result of a rough source, rough path, or a combination of both.

MODELS WITH SOURCE HETEROGENEITY

Greg Beroza continued developing the pseudo-dynamic model of the earthquake source. He uses a spatially random displacement field, which is constrained to have rupture time, rise time, stress drop and spectral content (k^{-2}) constrained by rules from dynamic rupture simulations and results of inversion of seismograms. The approach is a compromise between the SCEC goal of fully physics-based prediction of strong ground motion, and approaches that add empirically derived high frequencies to physics-based low-frequency seismograms. Rob Graves and Hong Kie Thio are developing an earthquake rupture computer module which has similar properties to the pseudo-dynamic models, and which will be made available to the community allowing user-defined variation of input parameters. The software module has been implemented into the computational framework of the Community Modeling Environment (CME) and OpenSHA. These two groups whose approach is similar plan to pool their efforts in 2006.

Simulations have been performed for several earthquake scenarios as a first step towards assessing the potential ground shaking hazard posed by the Puente Hills fault system. The simulations were computed by Robert Graves utilizing the resources of CME, including the HPCC Linux cluster at USC. These simulations are unprecedented in scope and scale. For each scenario, broadband (0-10 Hz) ground motion time histories are computed at 66,000 sites, covering most of the Los Angeles metropolitan region. Three rupture scenarios ranging from M_w 6.7 to M_w 7.2 have been simulated thus far. In all scenarios, strong rupture directivity channels large amplitude pulses of motion directly into the Los Angeles basin, which then propagate southward as basin surface waves. Typically, the waveforms near downtown Los Angeles are dominated by a strong, concentrated pulse of motion. At Long Beach (across the LA basin from the rupture) the waveforms are dominated by late arriving longer period surface waves. The great density of sites used in the calculation allows the construction of detailed maps of various ground motion parameters, as well as animations of the propagating broadband wave field (Figure 28).

The Santa Barbara group has a major effort in developing statistical models of fault rupture roughness. They argue that the statistical properties of rupture are related to those of peak ground acceleration measured on the surface in the near-field of earthquakes. Daniel

Lavallée finds that PGA is represented better by a Lévy PDF than other distributions, such as Gaussian or Cauchy, with most of the improvement due to the stronger tail of the Lévy PDF. A higher amplitude tail describes the presence of large scale asperities. Their rupture model for the Parkfield 2004 earthquake includes randomly distributed asperities with a Lévy distribution. It has the advantage of generating PGA statistics compatible with those observed. Pengcheng Liu and Ralph Archuleta present a new model for computing broadband strong ground motions that includes non-linear site effects. Their source employs a truncated Cauchy PDF for slip amplitudes (similar to the Lévy PDF) that are spatially filtered (k^{-2}) with parameters adjusted to match radiated energy. They constrain rupture velocity and slip to be partially correlated. Rise time is determined by a Beta function, whereas slip rate function is a prescribed function of rise time. For low frequencies they use a 3D synthetics code and for high frequencies 1D synthetics. The method has been validated against Northridge spectra. It remains to be seen what are the advantages of this approach relative to the pseudo-dynamic one, in that they have a lot in common.

Martin Mai and colleagues have assembles a web-accessible database of finite-source rupture models. Work in the last year included responding to users who had noted inconsistencies as well as adding older rupture models by scanning published images for events for which digital data is not available.

PATH EFFCTS
In a collaborative effort Martin Mai and Kim Olsen have developed a new approach for calculating broadband synthetic seismograms in which they superpose scattering effects in the medium with seismograms from a deterministic fault model. The high frequencies are then determined by the scattering operator, which is given parameters typical of those observed. Comparison of Northridge earthquake synthetics with observed spectral averages are satisfactory. However this begs the question of how much of the high frequency power is due to path effects and how much source.
In a collaborative program between UCSD and Caltech Peter Shearer and Egill Hauksson are developing methods to separate out source, receiver and path effects in waveforms from the numerous (over 400,000) small earthquakes recorded by the southern California network. Estimated Brune stress drops range from 0.2 to 20 Mpa, and median values appear to increase with depth from about 0.6 MPa at the surface to 2.2 MPa at 8 km, remaining constant to about 20 km. However the scatter is very large suggesting path and source irregularity is not fully understood. Of particular interest to ground motion modelers are the Q structures that have been determined using local tomography methods. As expected basins are found to have low Q and mountains high Q. This contrast with Davis' observation that coda Q is highest in basins suggesting trapping of energy in the coda. At mid-crustal depths layers of low Q are reminiscent of the often-observed mid crust high reflectivity. In general $Q_p/Q_S > 1$. These Q maps need to be incorporated into the CVM.

PRECARIOUS ROCKS

For several years, the Ground Motion group has been investigating the constraint precariously balanced rocks might place on estimates of peak acceleration. Jim Brune and colleagues found a number of such rocks along a 70 km line almost midway between the Elsinore and San Jacinto faults. Tom Rockwell's paleo-seismological studies indicated that these

rocks would experience about 6 M 7 earthquakes every thousand years. The balanced rocks are elongated, parallel to the faults suggesting fault normal accelerations have been weaker than fault parallel. In the last year additional field investigation have been undertaken at three new sites near the San Andreas Fault. At this stage the orientation distributions of the new sites are varied, and do not show the anisotropy seen in the Ensinore - San Jacinto line. In a related effort Hong Kie Thio and Paul Somerville are developing vector-valued probabilistic seismic hazard code that takes into account multiple parameters is assessing hazard, such as direction of shaking, or PGA and PGV and directivity. Matthew Purvance has combined the vector-valued probability approach and mechanical models of toppling rocks to calculate number of years for overturn. They find that prediction equations of Abrahamson (2005) based on data from recent large earthquakes are consistent with the rock data, whereas those of an earlier model of Abrahamson and Silva (1997) predicted higher accelerations that the rocks would not survive.

WORKSHOP ON BROADBAND GROUND MOTION SIMULATION

The Ground Motion Group convened a workshop in January 2005 to discuss simulation methodologies for the synthesis of broadband ground motions. The workshop was organized and led by Robert Graves. The primary recommendations from the workshop are as follows:

1) Rupture model characterization and standardization is a critical issue that needs to be addressed as we proceed with current and planned simulation exercises. This requires specification of standardized file formats and conventions, as well as increased interaction between the Ground Motion Focus Group and the Earthquake Source Physics Group. It is clear that simulation of large magnitude events (Mw > 7.5) will need to be guided, in part, by physics based rupture models (i.e., rupture dynamics).

2) Formation of a formal Broadband Simulation Group. This will facilitate participation in projects such as NGA-H and the NSF Implementation Interface studies. In order for the simulation methodologies to become more accepted, we must demonstrate that the approaches produce reliable and consistent results. And furthermore, the methodologies must be transparent and useable by outside groups. This is particularly true for the NGA-H program.

3) Establishing a set of reference validation earthquakes against which the simulation methodologies can be assessed. The Northridge Simulation Exercise is a prototype of this type of activity. Other California events could include Landers, Hector Mine, Whittier-Narrows, Parkfield, and Loma Prieta.

The workshop included a Northridge simulation exercise to demonstrate the capabilities of the various methods. Each participating modeler submitted ground motion simulations for 30 sites that recorded the Northridge earthquake. The spectral acceleration goodness-of-fit averaged over the 30 sites are shown in Figure 29 for six modeler groups. After the workshop, two groups refined their methodologies and have subsequently recomputed the Northridge exercise. The updated results for these groups are shown in Figure 30.
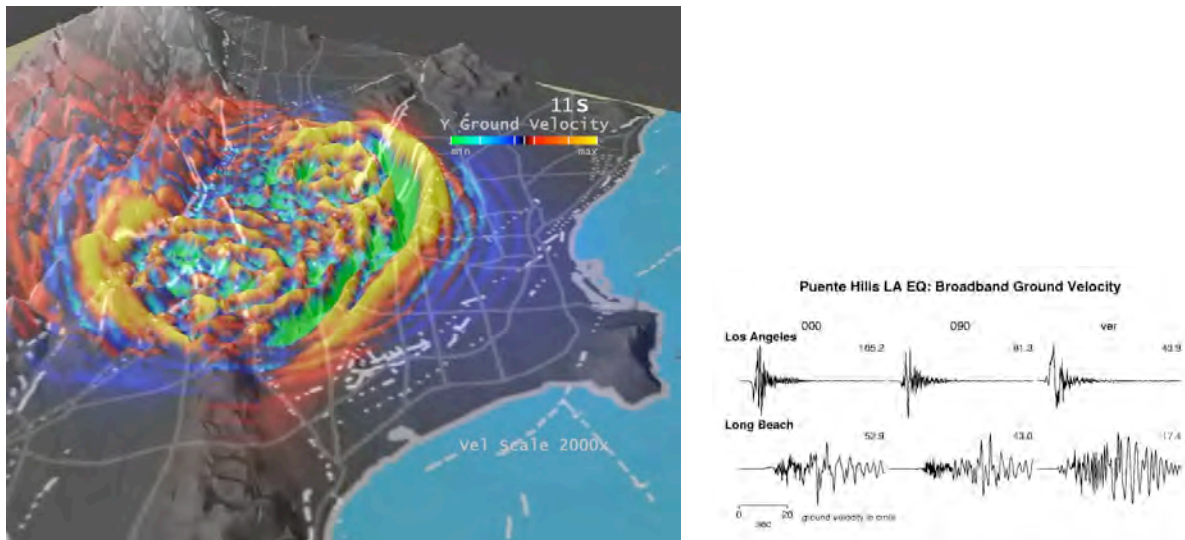
Figure 28: Broadband simulations of scenario ruptures on the Puente Hills Thrust by Robert Graves. Time histories show response at Los Angeles, which is dominated by rupture directivity, and Long Beach, which is dominated by basin surface waves. The great density of sites allows the construction of ground response maps, such as PGA (middle) or SA at 3 sec (bottom).
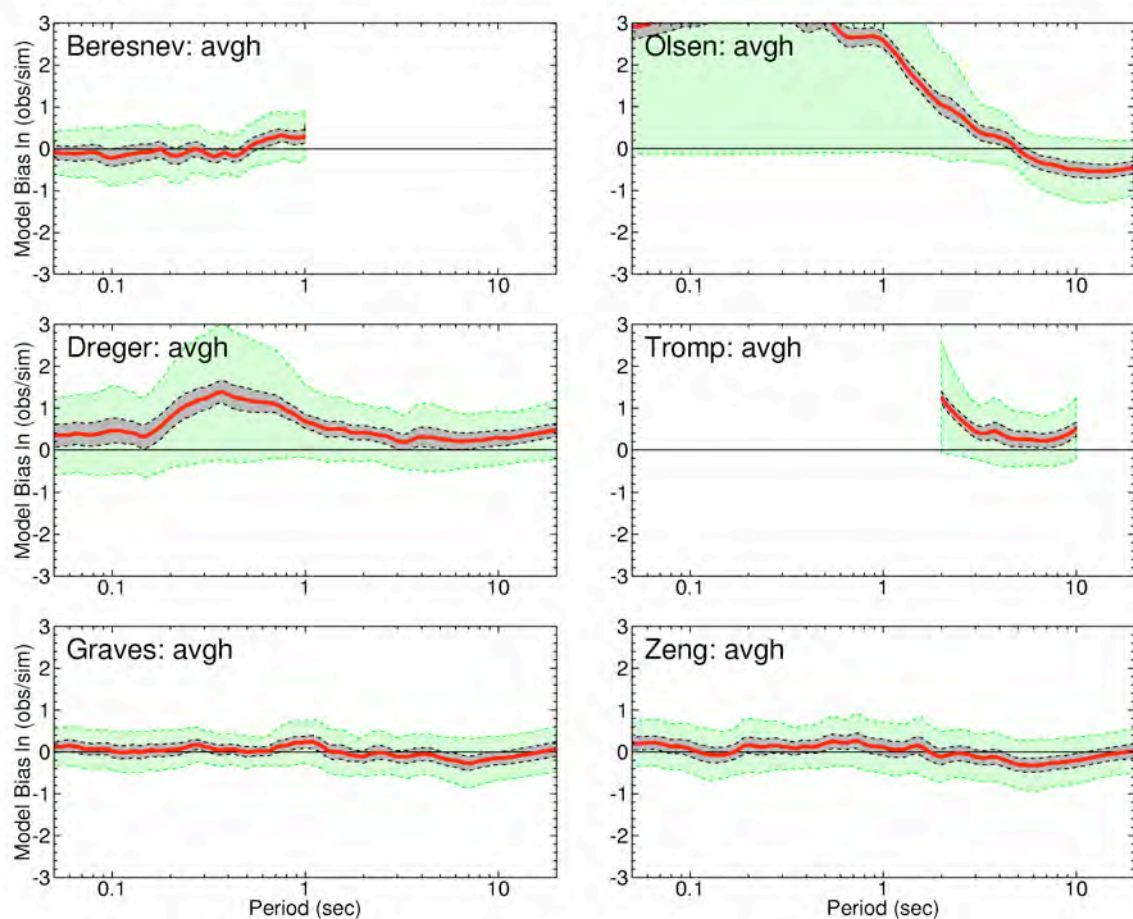
Figure 29: Spectral acceleration goodness-of-fit averaged over 30 sites for the Northridge EQ. Panels are results for different modeler groups.
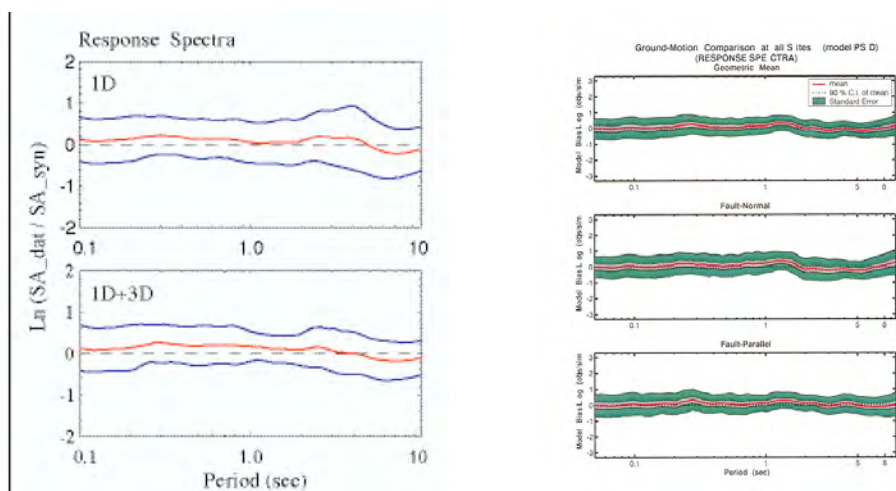
Figure 30: Updated Northridge results from Liu and Archuleta (left) and Mai and Olsen (right).

FUTURE DIRECTIONS

Future directions include comparing and validating broadband ground motion with observations and improving modeling schemes; Testing of the CVM and inversion of observed seismograms to improve the CVM; Adding to the CVM the SCEC scattering and attenuation model by identifying and modeling sources of scattering; Developing methods for incorporating nonlinear site response for large amplitude ground motion events in Southern California including site and structural response; Developing collaborations with engineers (with IIG) to add building response to synthetic seismograms and identify seismogram characteristics important for damage.

The classic problem of how much of the seismogram comes from path and source effects remains unsolved. Basins and near surface layers resonate and isolated scatterers can be identified in seismic data. Sources appear to be rougher than most dynamic models would predict. Kagan and Houston (2006 Preprint Kagan Website) analyze moment-release rate of aftershocks and main shocks for several California events. They find that the moment release rate of the aftershocks increases steadily back in time, with no evidence of a gap. One possible explanation in terms of the triggered branching model is that the main shock arises from dynamic triggering of multiple sub-events which is more effective than static triggering that may be associated with aftershocks. Triggered branching models are 3D distributions of sub-events governed by Omori-type temporal behavior. Eventually full description of ground motion may have to take such volume-dsitributed models into account.

Seismic Hazard Analysis

RELM, OpenSHA, and WGCEP

The goal of seismic-hazard analysis (SHA) is to state the probability that some Intensity Measure Type (any measure of earthquake shaking found to correlate with damage) will exceed a specified level at a site over a particular time span (e.g., the lifetime of a building). The two main model components needed for SHA are an Earthquake Rupture Forecast (ERF), which gives the probability of all possible fault-rupture events over the time span of interest, and an Intensity-Measure Relationship (IMR), which gives the exceedance probability at a site given the occurrence of an arbitrary fault-rupture event.

There is consensus that significant improvements in SHA will require a more physics-based approach to modeling. This applies to forecasting both where and when faults will rupture (an ERF), as well as predicting the consequent ground shaking and exceedance probabilities (an IMR). Unfortunately there is no consensus on how to construct more physics-based models, which explains, in part, why our national seismic hazard maps are based on both a time-independent ERF (where each event is completely independent of all others) and empirically-based IRMs. This lack of consensus means that we will need to accommodate alternative models, and in fact, proper SHA requires that all viable models be included in the analysis (to adequately represent "epistemic" uncertainties). To reach this very challenging goal of accommodating multiple, perhaps physics-based models, we clearly need a computational infrastructure for SHA that enables both users and modelers to "plug in" without creating additional demands on their time or abilities.

The SCEC SHA focus group has three major activities aimed at improving SHA: RELM (to develop alternative, physics-based ERFs), OpenSHA (a community modeling environment for SHA), and the Working Group on California Earthquake Probabilities (WGCEP, to develop a SCEC-, USGS-, and CGS-endorsed statewide, time-dependent ERF). All of these activities are detailed below. There are also related efforts in the Ground Motions focus group and the Implementation Interface. These include the "NGA" project to develop empirically-based IMRs (know as attenuation relationships) and waveform modeling efforts that could someday form the basis of more accurate, physics-based IMRs. Please see the reports from those focus groups for details.

RELM:

RELM stands for the working Group for the development of Regional Earthquake Likelihood Models (http://www.RELM.org). Given a lack of consensus on how to construct an ERF, the goal of RELM has been to develop a variety of alternative, viable models. Those currently under development range in sophistication from simple Poisson models (e.g., based on smoothed historical seismicity), to models that include foreshock/aftershock statistics, to physical earthquake simulators that track stress changes throughout the system. We plan to publish the first-generation set of models in a special, dedicated issue of *Seismological Research Letters*. A list of models that have been submitted for publication is given in Table 1.

Part of the effort is to establish and implement formal test of each model (e.g., compare predicted earthquakes to those that actually occur). To this end, forecast will be formally submitted for evaluation on Jan 1, 2005. This activity has become particularly important in light of recent claims of success with respect to earthquake prediction. We also want to evaluate the hazard implications of each ERF using the OpenSHA tools discussed below, which will not only give us a better idea of the true uncertainty of hazard, but will also suggest studies needed to reduce those uncertainties. This activity will also indicate which models may be exportable to other regions where the options are fewer. More information can be obtained at our web site (http://www.RELM.org).

Table 1. Papers submitted for the RELM special issue of *SRL*.

Cao and Petersen	The 2002 NSHMP Model with Time-Dependent Probabilities
Ward	Different Models Based on Geologic, Seismic, and Geodetic Constraints, as Well as a Simulation-Based Model.
Kagan et al.	An Earthquake Rupture Forecast Based on Smoothed Seismicity
Shen et al.	An Earthquake Rupture Forecast Based on the Geodetic Strain-rate Field
Bird & Liu	A Time-Independent Forecast Based on NeoKinema
Holliday et al.	A Earthquake Forecast Based on Pattern Informatics
Gerstenberger et al.	Short-Term Earthquake Probability (STEP) model
Helmstetter et al.	Epidemic Type Aftershock Sequence (ETAS) model
Console et al.	An Earthquake Clustering Model Constrained by the Rate-and-State Law
Rhoades	Application of the EEPAS model
Ebel et al.	A model based on Non-poissonian earthquake clustering
Ward	Standard Physical Earthquake Simulator for California
Rundle et al.	The Virtual California Earthquake Simulation Model

OpenSHA:

As discussed above, we need a computational infrastructure for SHA that can accommodate a rapid proliferation of new, alternative, and more physics-based models (e.g., new ERFs from RELM or new IMRs from the NGA effort mentioned above). Our answer to this need is OpenSHA (http://www.OpenSHA.org) – a modular, open-source, and web-based "community-modeling environment" or "collaboratory" for SHA. The idea is to enable any arbitrarily sophisticated ERF or IMR to "plug in" for analysis without having to change what is being plugged into (without rewriting existing code).

We currently have web-accessible tools for doing various types of SHA. These include a Hazard Curve Calculator (exemplified in Box 1), a Scenario ShakeMap Calculator (Box 2), and a full Hazard Map Data Calculator and Viewer (Box 3). Again, it's important to emphasize that these applications have not been customized for any particular ERFs or IMRs, so that plugging other models in will not require changing the applications at all. In fact, we eagerly await the availability of RELM ERFs and NGA IMRs. Each of the boxes shown here comes from a paper that was published over the last year (see captions), and tutorials exist at our web site to explain how the OpenSHA applications can be used to reproduce the figures (see http://www.OpenSHA.org/publications).

This community-modeling environment for SHA has benefited greatly by involvement in the SCEC Information Technology Research (ITR) collaboration. Specifically, this collaboration has enabled any of the model components (e.g., the ERFs) to be geographically distributed and runtime accessible over the Internet. This conveniently puts the maintenance onus directly on the host of the component, and makes our applications relatively lightweight and portable (e.g., the same version can be downloaded an run on any computer platform). The ITR collaboration has also enabled us to significantly reduce the computation time for hazard maps. Specifically, using the Condor GRID at USC, which automatically distributes the computation task among any idle UNIX workstations across the university, we have reduced the time needed to make hazard maps by more than an order of magnitude. This is very important in that it will now enable us to compute and compare the hundreds to thousands of hazard maps needed for proper SHA (because all viable models need to be considered). Thus, we are poised to make dramatic

improvement in SHA by accommodating alternative and more physics based model components. For the papers published on the results shown in Box 1 and 3 below, a companion paper on the advance IT capabilities was also published for each in the same issue of the journal (Maechling et al., 2005a, 2005b). More details on OpenSHA accomplishments can be found at our web site (e.g., click "Accomplishments" or "Publications" at http;//www.OpenSHA.org).

Box 1. This is a screenshot from the OpenSHA hazard curve calculator, showing 30-year PGA hazard curves for downtown San Francisco based on the ERF from the 2002 Working Group on California Earthquake Probabilities. This ERF is the most sophisticated forecast model ever developed, both in terms of it being time dependent and in accounting for numerous epistemic uncertainties. The gray lines represent the range of values given these uncertainties, the red curves represent 90% confidence bounds, and the green curve is the mean or "best" estimate. This ERF is deployed as Java-wrapped Fortran code that resides on a server and can be accessed by the application from anywhere over the Internet. The Boore et al. (1997) IMR (attenuation relationship) was used for this calculation, although any of the other supported models could have been chosen as well. This image if from Field et al. (2005b).

Box 2. (top) peak-ground-acceleration (PGA) shaking map for a magnitude 7.5 Puente Hills earthquake beneath Los Angeles (computed using the an OpenSHA application available to anyone). Also shown is the regional building exposure (middle) and earthquake losses (bottom) computed for this event using FEMA's HAZUS loss estimation software. With these tools one can now perform such loss estimates for virtually any earthquake using a variety of ground-motion models and site effect treatments. These plots are from a comprehensive, probabilistic loss analysis that has been published (Field et al., 2005a)

Box 3. Full probabilistic PGA hazard maps, including site effects, computed for the LA region using the ERF applied in our national hazard maps (Frankel et al., 2002). The map on the left was produced using the Abrahamson and Silva (1997) IMR (attenuation relationship), and that on the right was made with the Boore et al. (1997) relationship. Note that one implies the hazard in the San Gabriel mountains is relatively high compared to the adjacent LA basin, whereas the other implies the opposite; this is a manifestation of assumptions related to nonlinear sediment amplification. The application that generates these data utilizes GRID computing, where the computational load is distributed over any idle UNIX computers in USC's Condor pool. This reduces computation time by more than an order of magnitude. These images come from Field et al. (2005c).

Working Group on California Earthquake Probabilities (WGCEP)

A partnership of three organizations—SCEC, the U. S. Geological Survey (USGS), and the California Geological Survey (CGS)—has established a new Working Group on California Earthquake Probabilities (WGCEP). The goal of this initiative is to develop a uniform California earthquake rupture forecast (UCERF) by combining new information with the best available methodologies for time-dependent forecasting. The project will, for the first time, provide California with a uniform rupture forecast for the entire state based on a time-dependent methodology that incorporates seismic, geodetic, and geologic constraints. Funding for this project is being provided by the National Science Foundation, the USGS, the State of California, and the California Earthquake Authority (CEA). The WGCEP is being managed by a project leader and an Executive Committee comprising 6 members who will chair task-oriented subcommittees. The WGCEP reports to a Management Oversight Committee (MOC), comprising the four geoscience organizational leaders, will approve all project plans, budgets, and timetables.

The UCERF plan (see http://www.relm.org/models/WGCEP) identifies five major databasing tasks: (1) a fault-section database; (2) a paleo-sties database; (3) a crustal motion map based on geodetic data; (4) an instrumental earthquake catalog; and (5) a historical earthquake catalog. It also lays out five principal model-construction tasks: (A) a fault model from datasets

1, 4, 5; (B) a deformation model from model A and datasets 2 and 3; (C) an earthquake rate model from model B and datasets 4 and 5; (D) a time-independent UCERF based on model C; and (E) a time-dependent UCERF based on model C and datasets 1, 4, and 5.

An important part of the plan is to build the consensus needed for the acceptance of the UCERF products among experts and stakeholders. In particular, the UCERF development is tightly connected to the National Seismic Hazard Mapping Project (NSHMP), which has well-tested mechanisms for consensus building on a national scale (USGS-Golden is fully involved in the WGCEP). The ambitious schedule for this project will deliver a California earthquake rate model (Model C) in time for inclusion in the 2007 revisions to the national seismic hazard maps. This model will be developed according to NSHMP procedures, and it will be vetted and reviewed by the NSHMP consensus-building process. The two UCERF models (D & E) will be vetted by additional workshops and reviewed by the California Earthquake Prediction Evaluation Council (CEPEC) and a Scientific Review Panel (SRP). A well-articulated management structure will ensure that UCERF products can be developed on schedule and conform to the project goals. The management structure is based on a Management Oversight Committee, chaired by the SCEC director and comprising the other organizational leaders who manage resources, and the WGCEP itself, which will be chaired by N. Field and will comprise experts from the participating organizations. This project will be supported in part by the California Earthquake Authority (CEA), which provides approximately 70% of the earthquake insurance statewide. In February 2005, the CEA Board of Directors approved $1.75 million in funding for this project, which will be managed by SCEC and will support UCERF development through 2007.

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Special Projects

IMPLEMENTATION INTERFACE

Implementation of SCEC Research for Seismic Risk Reduction

Introduction

Implementation work this year has been concentrated in four main areas. First, we have participated in two case studies of end-to-end simulation. Second, we have participated in the development of guidelines for the selection and scaling of ground motion time histories for use in engineering testing and simulation, and in the presentation and discussion of these guidelines at the Annual Meeting of the Network for Earthquake Engineering Simulation (NEES). Third, we have participated in the Next Generation Attenuation (NGA) Project, developing and validating procedures for broadband strong motion simulation. Fourth, we have developed a more realistic representation of seismic hazards using vector-valued seismic hazard analysis, and applied it in a rigorous manner to a structural response problem (toppling of precariously balanced rocks) to place constraints on current ground motion prediction models. The first three of these areas are part of the SCEC Project "Implementation of SCEC Research for Seismic Risk Reduction," sponsored jointly by CMS and EAR (SCEC, 2005).

1. End-to-End Simulations for Scenario Earthquakes in Los Angeles

Current procedures for estimating earthquake damage and losses involve characterizing the ground motion level throughout a region using simple ground motion parameters such as intensity, peak acceleration or response spectral acceleration, and then estimating the losses for individual structures using simple correlations between ground motion level and damage. A much more rigorous procedure is to calculate the full ground motion wave field throughout the region and input it into nonlinear time history analysis of structural response models of the buildings and infrastructure that the region contains. This integrated simulation approach has the advantage of using a complete description of the ground motion in place of the simplified ground motion parameters used in most current practice, thereby enabling realistic analysis of the nonlinear response of structures throughout the region. End-to-end simulation from the earthquake source through to structural response is a means of fully integrating earthquake science and earthquake engineering.

SCEC has been involved in two case studies of end-to-end simulation. The first involves the response of buildings throughout the greater Los Angeles region to a magnitude 7.9 earthquake on the San Andreas fault, shown in Figure 31 (Krishnan et al., 2005). The ground motion wavefield throughout the Los Angeles region was calculated using the spectral element method. The top of Figure 31 shows a map of the peak velocity of the calculated ground motion. The ground motion time histories from this simulation were input into non-linear time domain analyses of models of an 18 story steel moment frame building distributed throughout the Los Angeles region. The bottom left side of Figure 31 shows a map of the drift index, based on the difference in displacement between the top and bottom of the story as a fraction of the story height, derived from the nonlinear response analyses of a model of an existing building. This map portrays the expected level of building deformation for this model building. The bottom right side of Figure 31 shows a map of the drift index of the building after it has been redesigned. By covering the entire region affected by the earthquake scenario, the end-to-end simulation

provides a comprehensive view of the improvement in building performance that is achieved by the redesign of the building. It also shows that there is not a perfect correlation between a single measure of ground shaking intensity, in this case peak velocity, and the damage to the building.

The second example of end-to-end simulation involves scenario earthquakes on the Puente Hills Blind Thrust. Ground motions were simulated using the SCEC Community Velocity Model by several investigators, including Graves (2005), and used to calculate the response of 20 story steel moment frame buildings (Heaton et al., 2005). A map of the peak velocity of the simulated ground motions is shown at the top of Figure 32. Strong rupture directivity channels large amplitude pulses of motion directly into the Los Angeles basin, which then propagate southward as basin surface waves. The waveform at Los Angeles is dominated by rupture directivity, which produces a strong, concentrated pulse of motion. At Long Beach, which is located across the Los Angeles basin from the rupture, it is dominated by late arriving longer period surface waves. These surface waves are generated in the near fault region as the direct waves from the rupture are trapped within the sediments of the basin.

The building response is calculated for typical buildings designed according to current code provisions, as well as for enhanced provisions, to provide a basis for assessing the efficacy of the enhanced provisions. The detailed simulations of nonlinear response use special computer codes developed by Professor John Hall and his students for modeling steel frame buildings (Hall, 1998; Carlson, 1999; Krishnan, 2003). Ground motions caused by a Puente Hills earthquake induce a strongly nonlinear response in buildings. The impact of the ground motions on this kind of building in Los Angeles is shown at the bottom of Figure 32.

2. Ground-Motion Time Histories for Performance-Based Earthquake Engineering

SCEC participated in a special session on ground motions at the NEES 2005 Annual Meeting in Minneapolis on May 14, 2005. Dr Paul Somerville made an introductory presentation on why ground motions are so variable, and Dr Nicolas Luco, Research Structural Engineer at the U.S. Geological Survey in Golden, Colorado and a participant in SCEC, made a presentation on the effect of time histories on inelastic response. Dr Brian S.J. Chiou, California Department of Transportation, made a presentation on resources for selection and characterization of ground motions. He described ground motion data bases, including the data base developed by the PEER-LL Next Generation Attenuation (NGA) project, which has comprehensive metadata. He also described the PEER-LL Design Ground Motion Library (DGML).

Dr Paul Somerville made a presentation on recommendations that was drawn from an extended interchange that took place before the meeting and involved a large number of contributors, notably Cliff Roblee, Allin Cornell, Nicholas Luco, Roberto Leon, and Sharon Wood. These recommendations covered analysis before testing, records to avoid, different kinds of records, special structural behavior, treating variability, guidelines for six situations, and understanding test results using analysis. Different needs were recognized for two different kinds of testing objectives. The first kind is to evaluate the capacity of a specimen to withstand specified level(s) of ground motion. In this case, record reparation follows current best design practice and is critical to outcome. The second kind is to verify or calibrate analytical model. In this case, procedure for record preparation is less structured and less critical to outcome.

Suggestions were made for time history preparation for 3 work scopes: 100 time histories, for simulation; 4-10 time histories, for lab testing; and 1-3 time histories, for lab testing. These suggestions were for two cases. The first case is for a specified site, in which it is possible to be specific about ground motion characteristics, suitable both for capacity testing and verification / calibration. The second case is for an unspecified site, where it is not possible to be specific about ground motion characteristics, and is suitable only for verification / calibration.

2. Next Generation Attenuation (NGA) Project

SCEC held a workshop on January 30, 2005 for the purpose of developing a broader range of procedures for the broadband simulation of strong ground motion. One of the objectives of this workshop was to coordinate the validation of these procedures against recorded strong ground motions of six earthquakes. These simulation procedures will then be used to simulate large suites of time histories for the NGA-H Project.

Groups that are currently enhancing their broadband simulation techniques include Graves and Pitarka (2004), Bielak and students (CMU) in collaboration with Hisada (Kogakuin, Japan), and Olsen (SDSU) in collaboration with Mai (ETH, Switzerland). Bielak and colleagues are enhancing their broadband representation of radiation pattern in their simulations. Olsen and Mai are working on accurate representations of scattering and of the phase at short periods, and on using information from dynamic rupture modeling, including spatial variations in rise time and rupture time. Archuleta and Lavallee have been working on the stochastic representation of earthquake slip models for use in the simulation of strong ground motion. Pitarka has been using rupture dynamic models to shed light on the physics of rupture directivity and shallow/deep faulting effects on strong ground motion, and to explain observations of these effects in strong motion recordings of earthquakes.

Kinematic Simulations

SCEC is a co-sponsor and co-participant with PEER-Lifelines and the USGS in Next Generation Attenuation (NGA) Project. Strong motion simulations by SCEC scientists using validated broadband ground motion simulation techniques were used to constrain features of the NGA-E attenuation models that are poorly constrained by currently available strong motion data, including rupture directivity effects, footwall vs. hanging wall effects for dipping faults, depth of faulting effects (buried vs. surface rupture), static stress drop effects, and depth to basement and basin effects. Comparisons of additional models were made at the SCEC Broadband Strong Motion Simulation Workshop held on January 30, 2005. Goodness of fit between ground motion simulations and recordings of the 1994 Northridge earthquake for the six participants were compared. Mai and Olsen (2005) have enhanced their broadband strong motion simulation procedure to incorporate accurate representations of scattering and of the phase at short periods.

Source Modeling

Studies of the 1999 Chi-Chi, Taiwan earthquake by Lavallee and Archuleta (2005) have shown that the probability density function of the peak acceleration is governed by a Levy law that also governs the probability density function associated with the spatial variation of the slip on the fault. Dynamic rupture analysis of the Chi-Chi earthquake has been conducted by Zang et al. (2005).

Rupture Dynamic Modeling

We have used rupture dynamic modeling (Pitarka and Dalguer, 2003) to shed light on the physics of why surface faulting earthquakes have weaker ground motions than those of buried faulting (Pitarka et al., 2005). The top panel of Figure 33 is a buried rupture, and the panels below it are for increasingly weak shallow zones (represented by decreasing values of stress drop) in the upper 5 km of the crust. With increasing weakness, the shallow zone is increasingly effective at arresting the upward propagation of rupture to the surface, reducing the slip velocity on the fault, and reducing the strength of the ground motion. The ratio of buried to surface spectral acceleration is shown as a function of period in the third column of Figure 33. For increasingly low values of strength of the shallow zone, the ground motion values become increasingly weak. Figure 34 compares buried rupture with the third surface rupture case (shallow stress drop = 1Mpa) from Figure 33, showing much larger slip velocities on the fault for the buried rupture case than for the surface faulting case. This demonstrates that we can find realistic rheological models of the shallow part of the fault that are consistent with the observation of weaker ground motions from surface faulting than from buried faulting earthquakes.

4. Vector Valued Seismic Hazard Analysis

We have developed a more realistic representation of seismic hazards using vector-valued seismic hazard analysis, and applied it in a rigorous manner to a structural response problem (toppling of precariously balanced rocks) to place constraints on current ground motion prediction models (Purvance, 2005).

The objective of vector-valued probabilistic seismic hazard analysis (VPSHA) is to provide the annual frequency of the joint occurrence of more than one ground motion intensity measure (Bazzuro and Cornell, 2002). This approach should prove superior to scalar valued PSHA because the response of most structures depends on more than one ground motion intensity measure. For example, the response of a tall building may have significant contributions from not only its fundamental period but its first higher mode. Similarly, the response of earth structures that are subject to liquefaction effects depends not only on the level of the ground motion but also on its duration.

Analysis of the seismic stability of precariously balanced rocks provides a particularly useful application of vector valued hazard analysis, because it has been shown by Purvance et al. (2005) that rock toppling requires both an acceleration above some threshold value to start a rocking motion, and subsequent longer period ground motion near its rocking period (represented by peak velocity) to topple the rock. We have used this approach to show that the presence of precariously balanced rocks between the San Jacinto and Elsinore faults appears to be inconsistent with current ground motion models. We calculated the vector-valued hazard surface at the location of a rock (lower left of Figure 35) for the joint frequency of exceedance of two ground motion parameters: peak acceleration and peak velocity. The vector valued toppling fragility surface of the rock is shown in the lower right of the figure. Combination of the vector valued hazard and fragility curves yields the vector valued toppling surface (top right of figure). Integration of the toppling surface gives the toppling curve (top left), shown as the probability of toppling as a function of time. This rock is thought to have been in its current precarious state for 10,000 years, in which time the probability that it should have toppled is 99%; several other

rocks also have high calculated probabilities. The fact that this rock has not toppled indicates that the ground motion model overestimates the seismic hazard at the site of the rock. The ground motion model used in this analysis predates the NGA-E models described above. We have shown that the new NGA-E models, with their lower predicted ground motions from large earthquakes, are compatible with the presence of the precariously balanced rocks.

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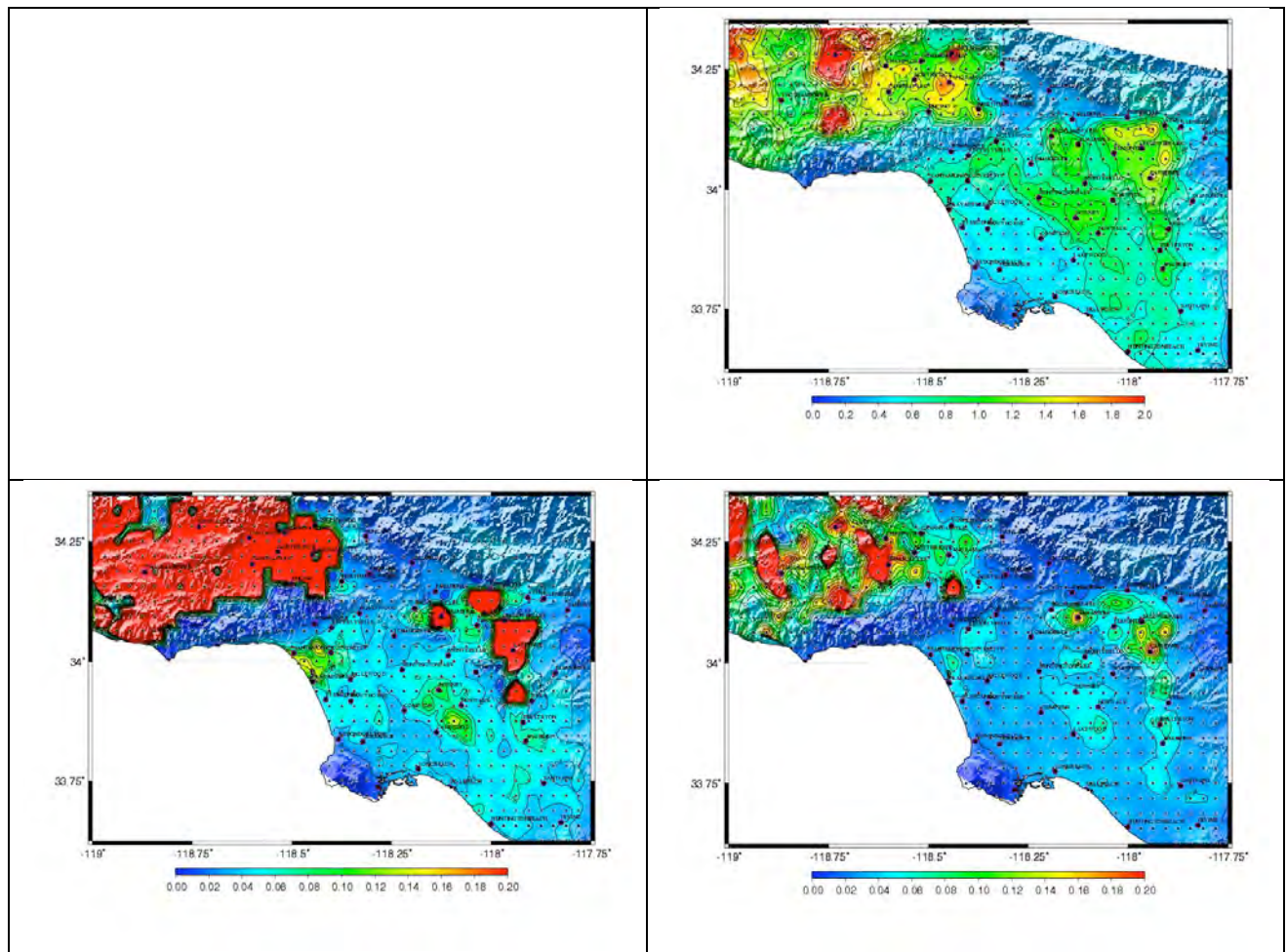
Figure 31. Top: Peak ground velocity from a large San Andreas earthquake, lowpass filtered at 0.5 Hz. Bottom: Drift index for an 18 story steel moment frame building for the existing design (left) and the redesigned building (right). Source: Krishnan et al. (2005).
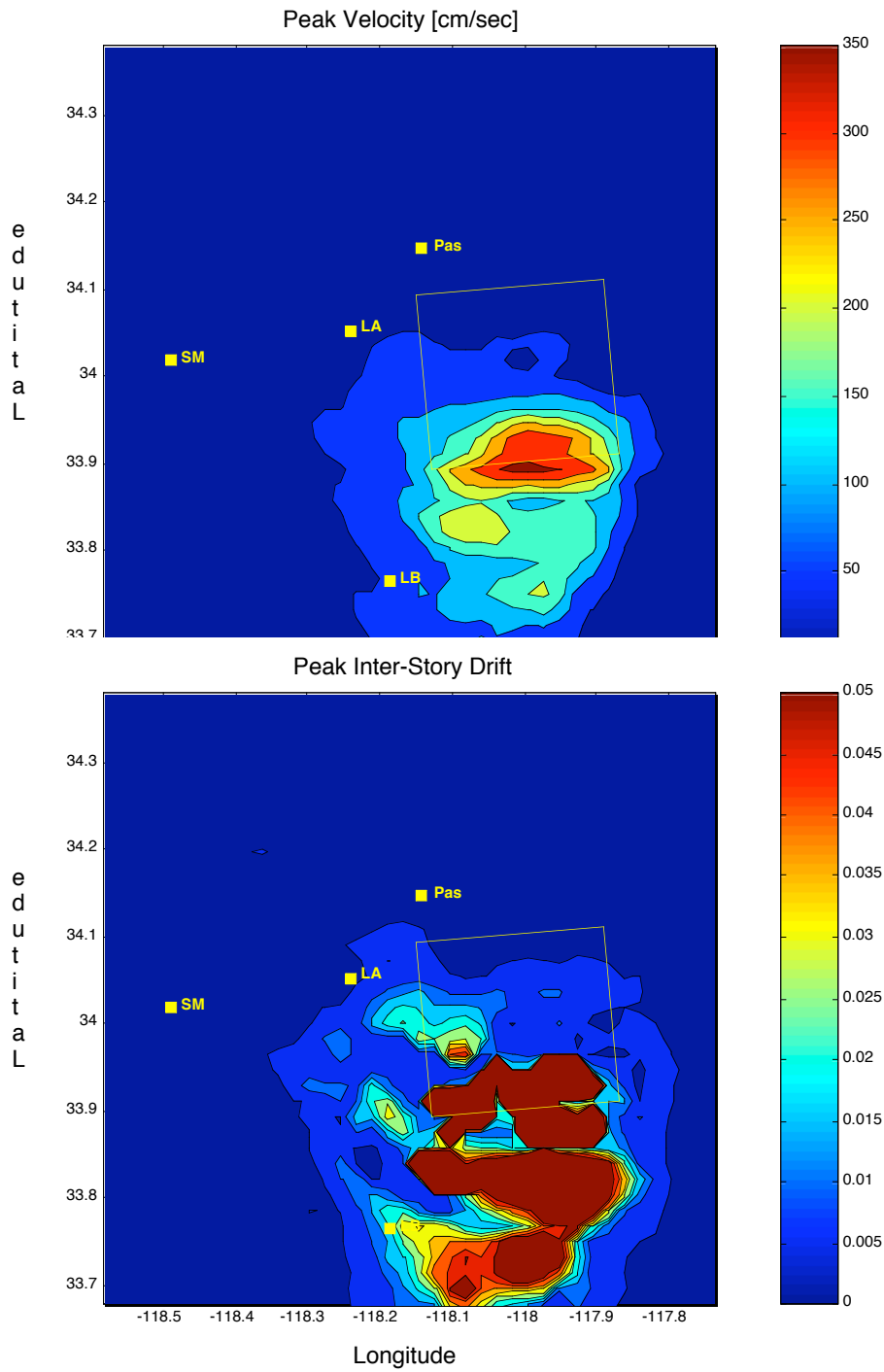
Figure 32. Map of peak velocity (top) and peak inter-story drift (bottom) in 20 story steel moment frame buildings subject to an earthquake on the Puente Hills Blind Thrust. Source: Heaton et al., 2005.
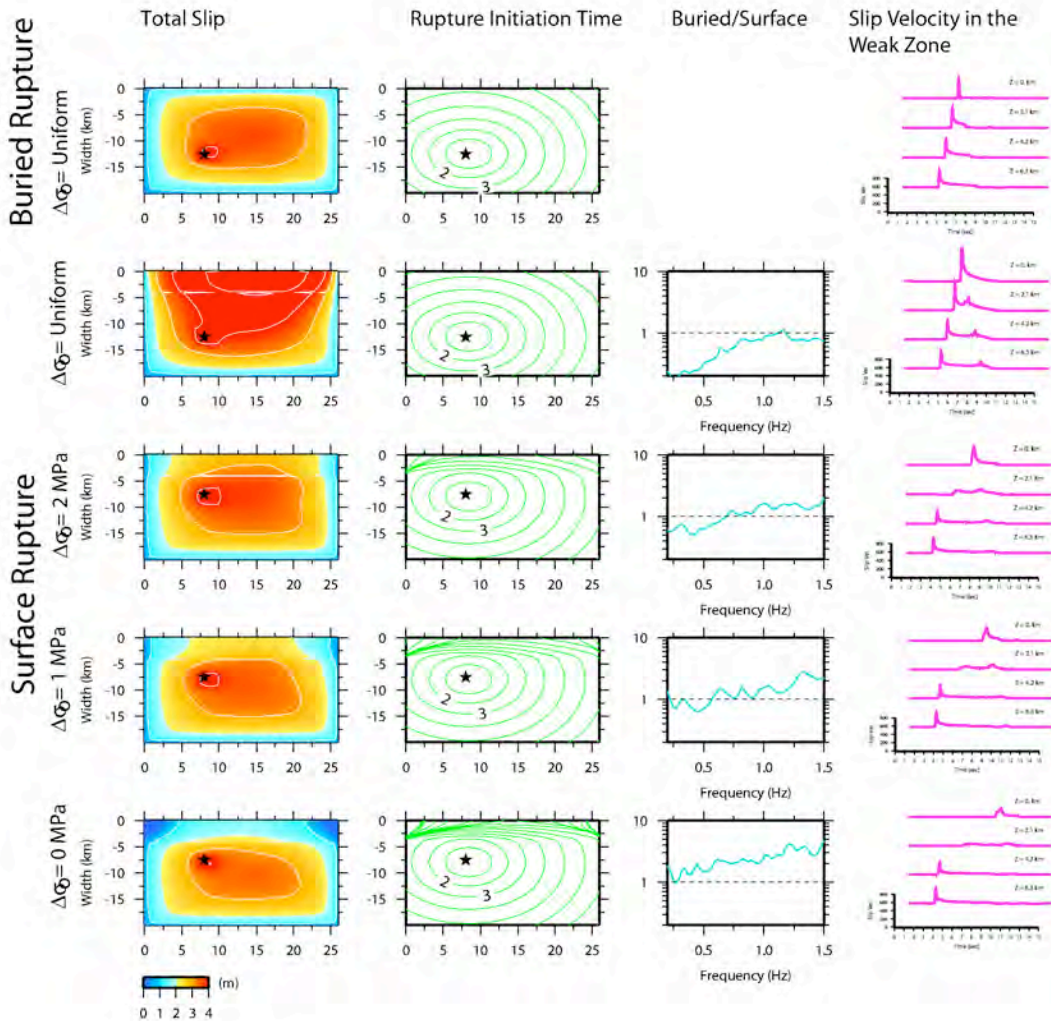
Figure 33. Dynamic simulation of buried and surface rupture earthquakes. The top panel is a buried rupture, and the panels below it are for increasingly weak shallow zones in the upper 5 km of the crust. The shallow zone is increasingly effective at arresting the upward propagation of rupture to the surface, reducing the slip velocity on the fault, and reducing the strength of the ground motion. Source: Somerville and Pitarka, 2005.
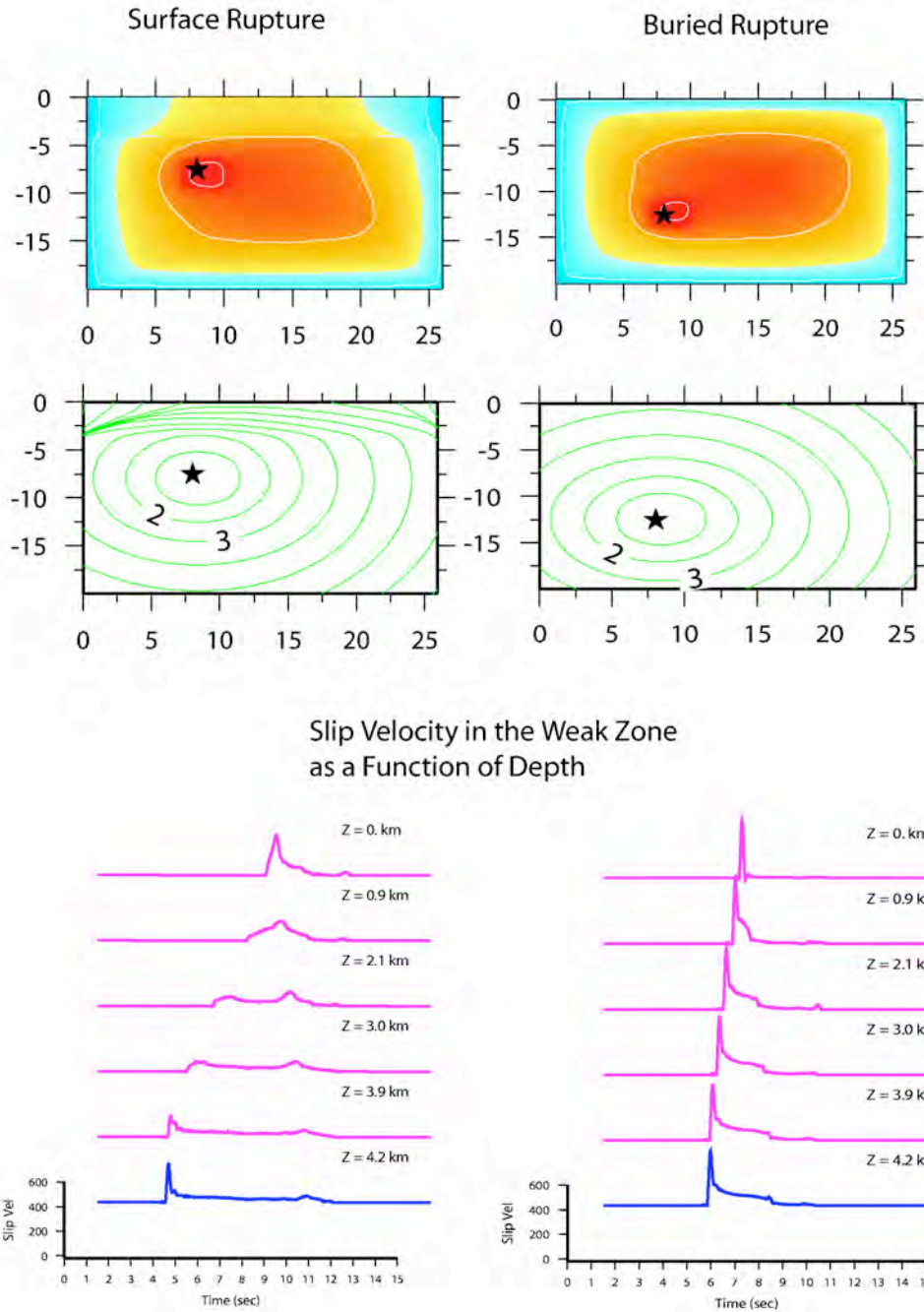
Figure 34. Detail from Figure 3 comparing buried rupture with third surface rupture case (shallow stress drop = 1Mpa), showing much larger slip velocities on the fault for the buried rupture case. Source: Somerville and Pitarka (2005).
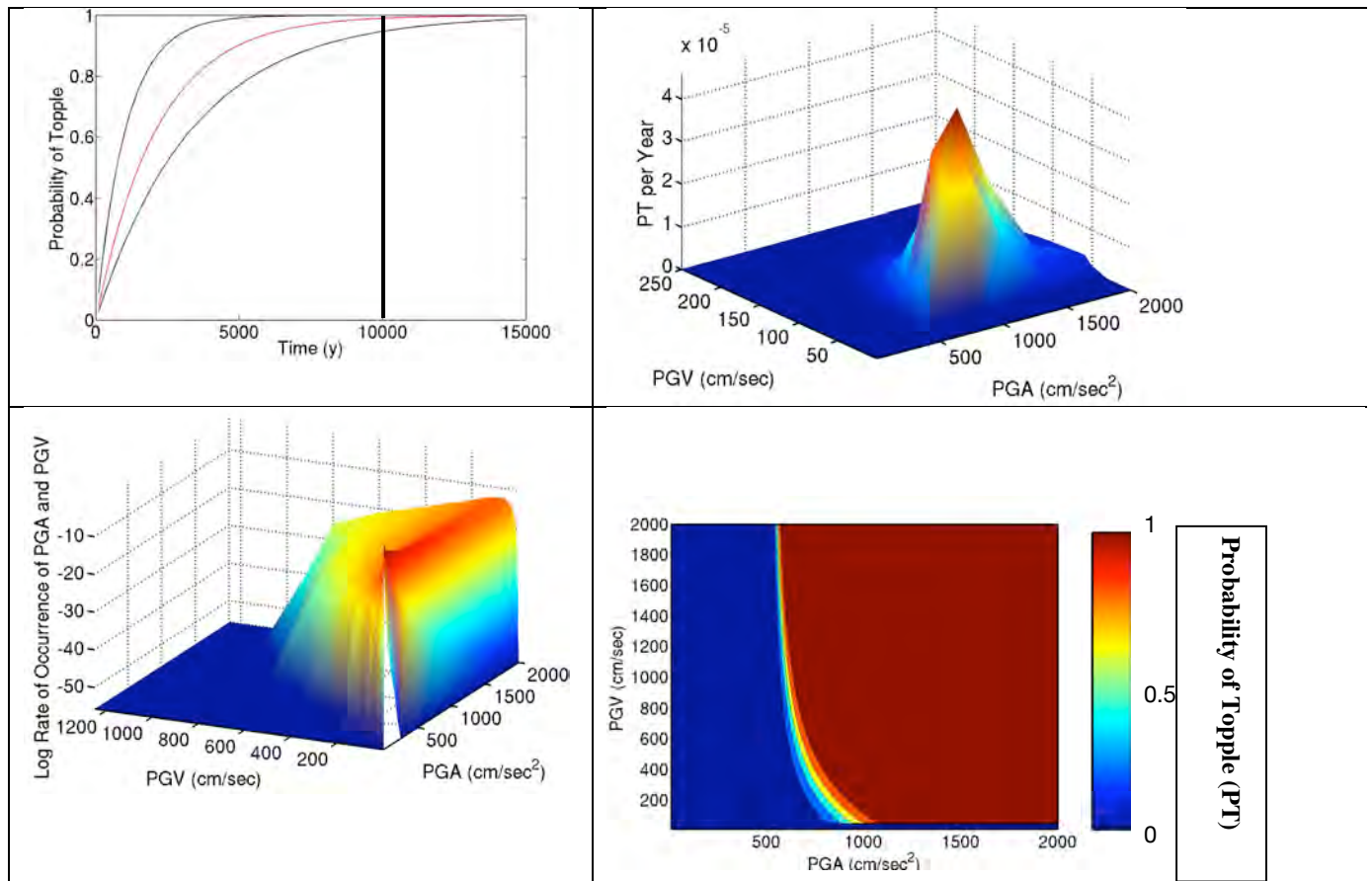
Figure 35. Vector-valued hazard surface at the location of the rock for the joint frequency of exceedance of peak acceleration and peak velocity (lower left). The vector valued toppling fragility surface of the rock is shown in the lower right of the figure. Combination of the vector valued hazard and fragility curves yields the vector valued toppling surface (top right of figure). Integration of the toppling surface gives the toppling curve, shown as the probability of toppling as a function of time on the top left of the figure.

Integration of Products
within the
SCEC Fault Information System

The current phase of development in the SCEC Fault Information System (FIS) has focused on delivery of capabilities and products needed by a new Working Group on California Earthquake Probabilities (WGCEP). Funding on this grant is leveraged with funding by EHRP-External to support the WGCEP project. The WGCEP is being funded by the California Earthquake Authority to create the first statewide, time dependent, earthquake rupture forecasting tool, and will use programmatic inputs from fault databases at the USGS and SCEC. For this project, a new paleosite database (paleoDB) has been fashioned that incorporates data from the SCEC Fault Activity Database (FAD) and the USGS-National Quaternary Fault and Fold Database (Qfaults) and supplies some additional fields, that are needed by WGCEP modelers, including new representations of uncertainties such as probability density functions.

The FIS has been envisioned to streamline interdisciplinary research, with a goal to provide scientists with 'one-stop,' internet access to a suite of fault-related data, models, and visualization tools, and to enables users to discover and locate the myriad of available products, and understand how the datasets interrelate.   A successful FIS requires buy-in by database and dataset curators at multiple organizations, and requires putting a high priority on FIS-related, cooperative activities. Over the last few years, we have gradually forged a strong relationship with fault databasers at CGS and USGS-Golden, but only with the advent of the WGCEP have we had the resources and institutional commitment to restructure separate efforts and work towards a genuine fault information system.

During SCEC year 2005, Perry's principal accomplishments for this project were:

1) convening of a workshop of fault geologists and databasers to discuss the parameters needed for the paleoDB;

2) finalizing of the conceptual data model for the paleoDB, based on the workshop and after an extensive series of subsequent conversations, by phone, email, and in person with WGCEP modelers, geologists, databasers and other project stakeholders;

3) collaborating with WGCEP software developer Vipin Gupta and potential database contributors to develop a user-friendly, graphical user interface (Figure 36) for paleoDB data entry and review;

4) resolving a multitude of niggly details as Gupta created a physical database from the conceptual data model;

5) revising the paleoDB data model and GUI to accommodate evolving needs of the WGCEP project; most significant of these was a shift from using expert-preferred, to as-published, values;

6) working with Gupta, Peter Bird, Chris Wills and Bill Bryant of the CGS, and Kathy Haller, USGS-Golden, to begin migrating available data into the paleoDB from the SCEC FAD, Qfaults, and Bird's personal research compilation;

7) recruiting and managing the 22 summer 2005 UsEIT interns to guide development of their visualization software, to incorporate capabilities and datasets needed by the WGCEP. (Figure 37)

Figure 36 (left). One window from the Graphical User Interface (GUI) that allows a user to add data to the paleoDB, or view data already in the paleoDB. Database use is password protected, and all entries are reviewed by the database manager. The GUI is written in Java and may be run in a browser window or as a downloaded application. It connects to an Oracle database in Pasadena. An identical database is maintained at the USGS-Golden, and will serve as the final long-term site for paleoDB and FIS data. However, USGS firewall restrictions prevent easy day-to-day development or maintenance of a database from outside locations. (Hence the equivalent Pasadena database.)
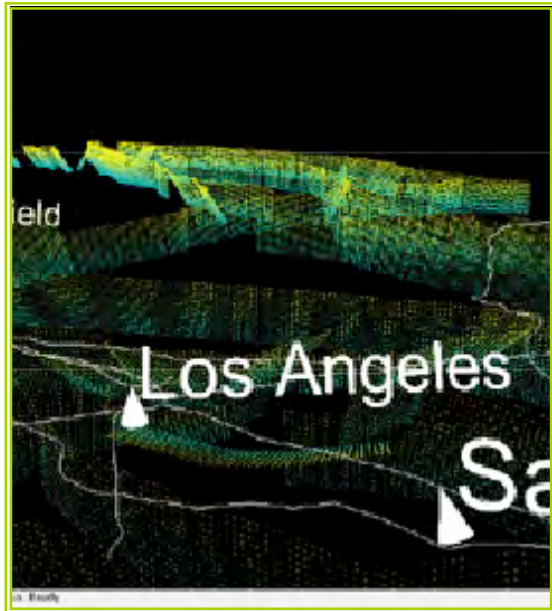
Figure 37a (left). A SCEC-VDO screenshot of a portion of the 2002 fault model used in the National Seismic Hazard Maps (NSHM). This fault representation was obtained using the Gridded Surface Advanced Programming Interface (API) from OpenSHA. Here, the faults are characterized by a series of down-dip nodes perpendicular to local strike ("Stirling method"), with nodes colored based on depth. Faults can also be displayed using the "Frankel method" of calculating dip from strike (not shown.) **Figure 37b** (below). Some 1996 NSHM faults (grey surfaces) juxtaposed with rectilinear representations of CVM v.2 ("confetti" surfaces). Any fault representation can be displayed with any other; so, for example, the 1996 and 2002 NSHM faults could also be juxtaposed.
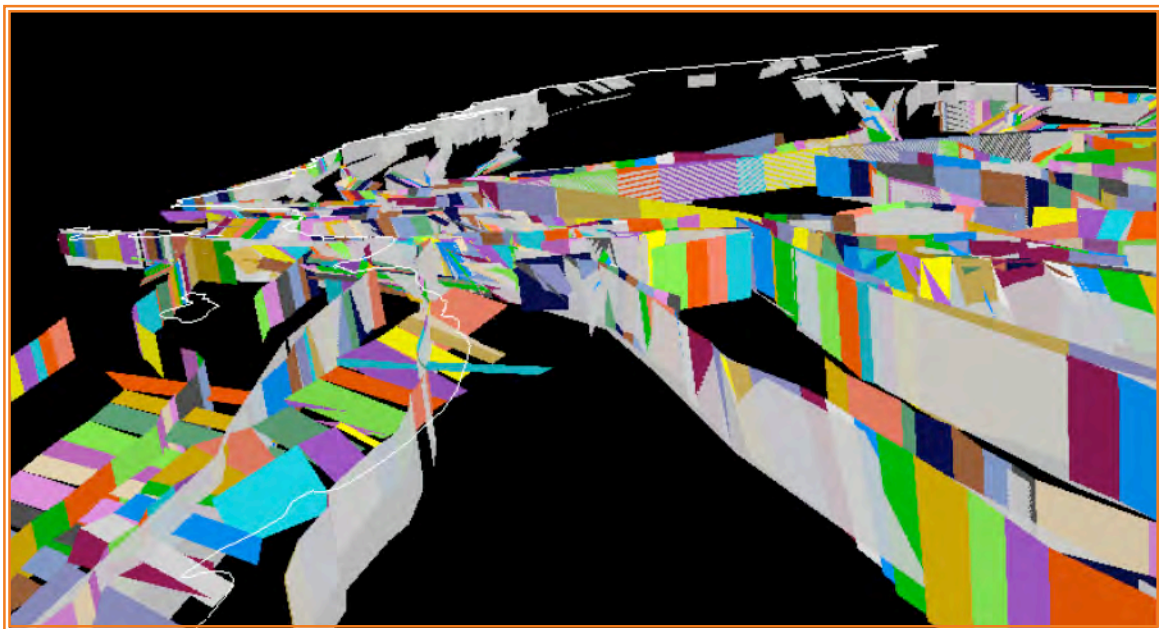
SCEC/CME Project: Introduction

The SCEC Community Modeling Environment (SCEC/CME) Project continues to make excellent progress in the construction of an information infrastructure for Seismic Hazard Analysis (SHA).

Researchers on the SCEC/CME Project perform basic research in both the Geosciences and in Information Science. The Geosciences research is focused on the problem of seismic hazard analysis. The Information Science research on the Project includes the application of knowledge representation and reasoning to the construction of scientific workflows as well as research in grid computing, large scale data management, and high performance computing. Together with this basic research, Project participants are also building and integrating the SCEC/CME system that allows researchers to execute SHA programs using a variety of geophysical models. In addition, SCEC/CME researchers perform special studies utilizing the technologies and computing techniques developed on the project.

The SCEC/CME geophysical research is organized around four computational pathways as shown in Figure 38. The first three pathways represent increasing levels of sophistication in the use of physics-based simulations to forward-model earthquake behaviors, while the fourth represents a collection of important seismological inverse problems. SCEC/CME researchers performed basic geophysical research in all four of these pathways during this Project year.
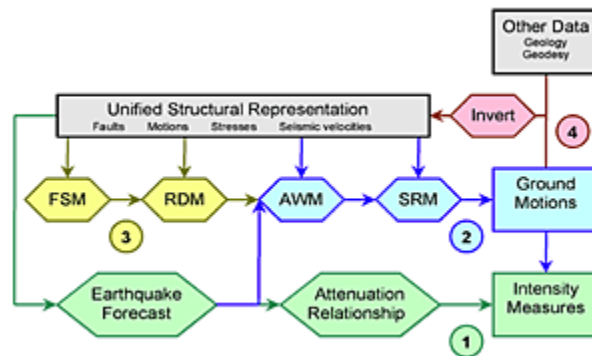
Figure 38: SCEC/CME Computational Pathways are used to organize the geophysical research on the Project. The Pathways are (1) Current methodology in probabilistic seismic hazard analysis. (2) Ground-motion prediction using an anelastic wave model (AWM) and a site-response model (SRM). (3) Earthquake forecasting using a fault-system model (FSM) and a rupture-dynamics model (RDM). (4) Inversion of ground-motion data for parameters in the unified structural representation (USR), which includes 3D information on active faults, tectonic stresses, and seismic wave speeds.

2 Major SCEC/CME Accomplishments during 2005

The SCEC/CME Project is a large and active Project. In this report, we will describe a number of activities and accomplishments that we believe represent transformative results. For more detailed information on these activities and on other SCEC/CME work, please see our SCEC/CME Project Year 4 status report.

These accomplishments highlight our significant progress towards the goal of a Community Modeling Environment for Seismic Hazard Analysis and are representative of the type of work being performed on the Project. We believe that the progress of these selected efforts provide some indication of the overall progress of the Project.

Each of these accomplishments is an interdisciplinary, collaborative, and integration-oriented activity. In each case, the results have been produced by computer scientists working closely with SCEC geoscientists. We believe these results from our interdisciplinary collaboration are a strong validation of the interdisciplinary research goal of the NSF Information Technology Research (ITR) Program.

2.2 Pathway 1 - OpenSHA Applications

The OpenSHA software development is a component-based framework for Seismic Hazard Analysis (SHA). This framework implements software tools that support Probabilistic Seismic Hazard Analysis. The OpenSHA capabilities represent the SCEC/CME Pathway 1 computational approach to SHA.

The OpenSHA conceptual framework has proven to be a flexible and robust characterization of seismic hazard analysis. OpenSHA represents PSHA calculations through a set of fundamental objects. Two primary objects within the OpenSHA framework are an Earthquake Rupture Forecast (ERF), and an Intensity Measure Relationship (IMR). Seismic Hazard codes are written to implement instances of these fundamental objects.

The power of the OpenSHA framework is that any SHA codes that are implemented as instances of the basic OpenSHA objects can be combined to perform PSHA and SHA analysis. OpenSHA has transformed how PSHA calculations are done because it provides interoperability between SHA components. Prior to the development of the OpenSHA, each implementation of a Seismic Hazard code was stand alone. However, basic SHA analysis requires that ERF and IMR capabilities are combined to calculate hazard curves. By implementing SHA codes as OpenSHA components, SHA codes can be combined in ways never before possible, providing scientists with insights not available prior to the development of OpenSHA.

The flexibility of OpenSHA's component model has been demonstrated by its proven ability to support a wide range of PSHA components including the WGCEP-2002 Earthquake Rupture Forecast (ERF) for Northern California which is the most sophisticated ERF ever developed.

In addition to developing the OpenSHA framework, and implementing components within the framework, the OpenSHA group has applied these tools to particular problems in a number of special studies. In one study, the OpenSHA group calculated a series of probabilistic Hazard Maps using the OpenSHA components. These maps were calculated by combining the WGCEP-2002 ERF with a variety of Intensity Measure Relationships that have been implemented as components in the OpenSHA system. The variations in

these PSHA hazard maps indicating the uncertainties in the existing geophysical models and in the IMR's.

Another study performed by the OpenSHA working group involved calculations of ground motions for a specific scenario event, in this case, an earthquake on the Puente Hills Fault underneath downtown Los Angeles. The OpenSHA software was used to calculate a series of ground motion estimates, exploring the uncertainties in the geological models, the intensity measure relationships, and the magnitude of the earthquake. The resulting ground motion estimates were used as inputs to a loss-estimation program called HAZUS-MH. The resulting calculations produced loss estimates for the scenario events. Several maps produced in this study is shown in Figure 39. A loss estimate map indicating building loss estimates are shown in Figure 40.
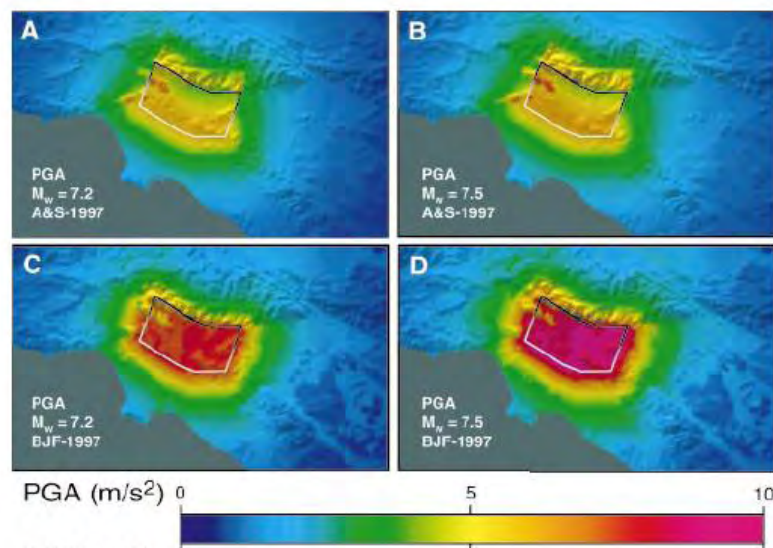
Figure 39: Peak Ground Acceleration (PGA) ground motion maps calculated using OpenSHA software for simulated Puente Hill's earthquakes showing regions of strong ground motion calculated.
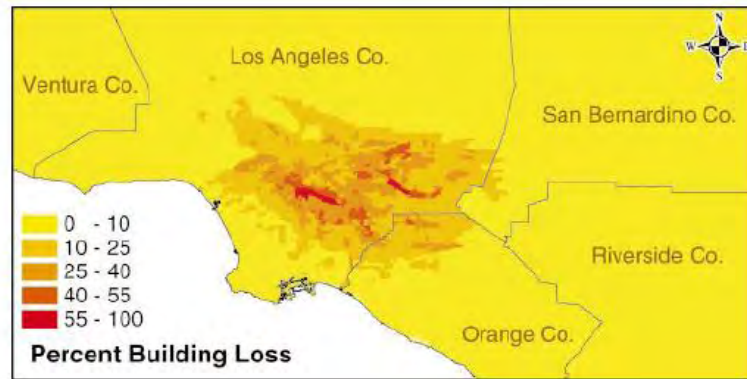
Figure 40: Building Loss Estimates from HAZUS-MH for a scenario Puente Hills earthquake.

The OpenSHA working group has also been actively publishing their results. They have published several seismological articles that outline the OpenSHA tools and capabilities (Field et al, 2005). They have also published a number of computer science-oriented material in geophysical magazines (Maechling et al, 2005) describing aspects of the design and implementation of their software.

2.3 Pathway 2 - TeraShake Wave Propagation Simulations

The SCEC/CME Project conducted a series of large earthquake wave propagation simulations this year. These simulations are termed the "TeraShake" simulations. These large collaborative efforts are transformative in several ways. One, the large scale and high resolution of the simulations have established new standards for regional earthquake simulations. Also, the large interdisciplinary group involved in this work has moved geophysicists toward large, big science, collaborative efforts in support of such simulations. And finally, the software tools developed to run these simulations, optimized to run at large scale at national supercomputer facilities, are now a "simulation platform" upon which further similar studies can be based.

The TeraShake simulations are a series of scenario wave propagation simulations of a large rupture (Mw7.7) on the southern San Andreas Fault. Paleo-seismic studies indicate that this region may be overdue for a significant earthquake and the fault geometry indicates the fault is capable of large earthquakes including events in the Mw7.7 range.

The TeraShake simulations explore the consequences of such a large earthquake on southern California. The simulations were performed using tested, validated, anelastic wave propagation simulation software written by SCEC/CME researcher Kim Olsen. The simulations used the SCEC CVM3.0, a 3D velocity model of the region. The simulations used a kinematic rupture description derived by SCEC/CME researcher Steven Day from the observed 2002 Denali rupture but scaled down to a magnitude appropriate for the southern San Andreas fault segment. A variety of rupture descriptions were simulated, including a south to north breaking rupture, and a north to south breaking rupture.

The TeraShake simulations showed significant differences in the ground motions based on the rupture direction. A side-by-side comparison of cumulative peak ground velocity magnitude produced by the two of the simulations is shown in Figure 41.
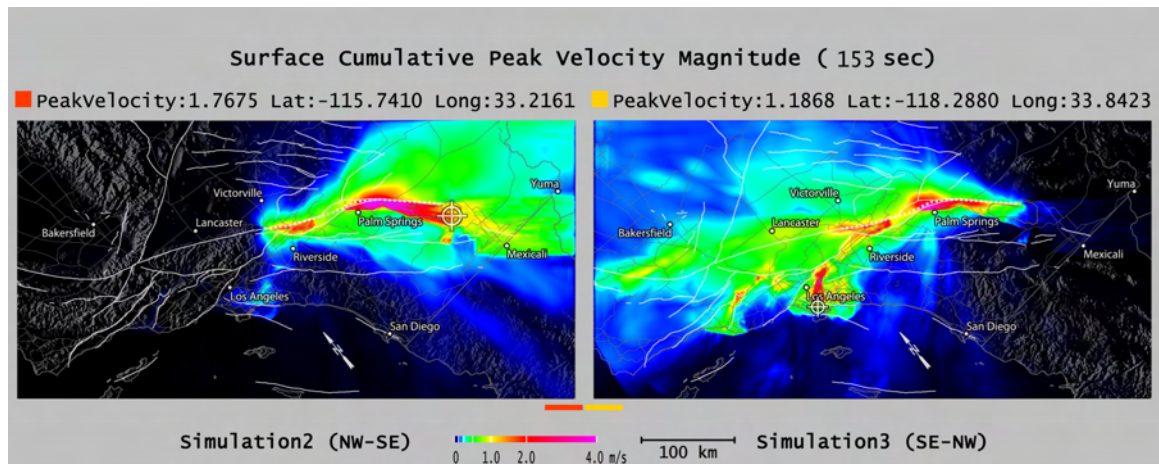
Figure 41: Side-by-Side comparison of Peak Ground Velocity Magnitude (PGV) of two Mw7.7 ruptures on the southern San Andreas. The left image shows a north to south rupture, and the right image shows a south to north rupture.

Figure 42 shows a peak spectral acceleration map for one of the north breaking TeraShake simulations.
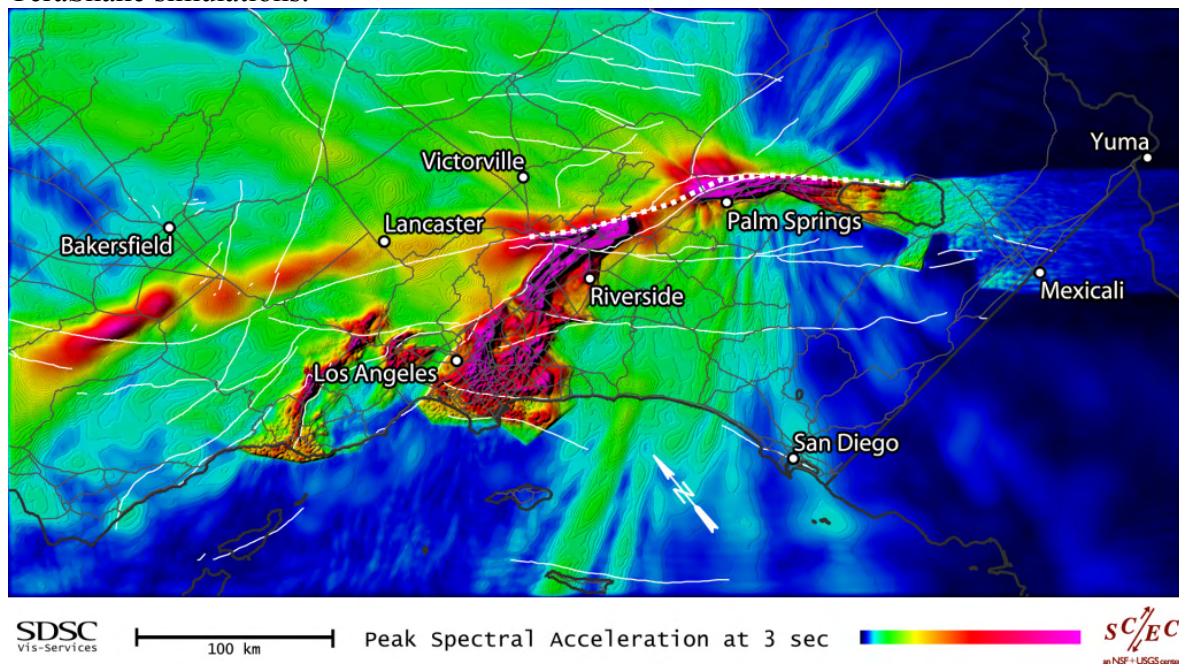
Figure 42: Peak Spectral Acceleration at 5.0 seconds for the TeraShake 1.3 TeraShake simulation shows wide regions of strong, long-period, motions that are well off the fault.

The TeraShake simulations were run at the San Diego Supercomputer Center. We received significant technical support from the TeraGrid scientific computing staff. The AWM-Olsen code was identified as a TeraGrid Strategic Application Collaboration (SAC). Through this program, we received significant help porting and optimizing our software for the TeraGrid machines.

The San Diego Supercomputer Center Visualization Services group also worked very closely with the SCEC/CME Project to produce a series of outstanding animations showing the TeraShake simulation results in great detail. An image from one of these animations is shown in Figure 43.
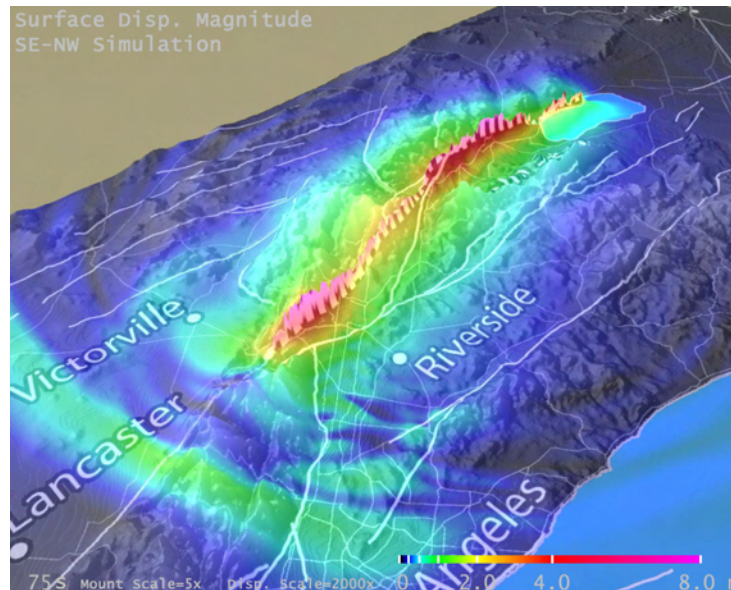
Figure 43: Image from SDSC Visualization Services animation of a TeraShake Rupture showing instantaneous displacement magnitude 75 seconds into a simulation of a south to north breaking Mw7.7 rupture.

The scientific analysis of the TeraShake simulations has produced several interesting results. The large, off-fault, strong ground motions produced by the south to north breaking rupture are quite remarkable. Just what combination of basin effects, edge effects, and wave guiding by the terrain lead to these motions is still being investigated, but this result has significant implications for seismic hazard analysis in the southern California region.

These simulations demonstrate the value of working at the Tera-Scale level. Smaller simulations, using a region close to the fault, would not have observed the large ground motions located well off the fault that are seen in these simulations.

The process of planning, and running these simulations has established the AWM-Olsen software a type of "simulation platform". The software has been carefully evaluated and optimized for use at national Supercomputer facilities. While the initial simulation run took several months to plan and the simulation run-time lasted several days, later simulations were performed in a week's time, with simulation run time of less than two days. This increased efficiency is due largely to the accumulated knowledge, software tools, and lessons learned during the initial TeraShake simulation.

The code has now been entered in the SCEC software repository for use by other modelers interested in running this type of simulation. The software has become part of the SCEC/CME Cyberinfrastructure.

2.4 Component-based Workflow System

A Community Modeling System for the geosciences is a system that enables scientists to run earthquake simulations by combining simulation codes, and geophysical models, easily and in new combinations. Such a system would allow scientists to explore ideas, and to ask "what if", without large investments of time integrating disparate components.

Our work this year on a component-based workflow system of seismological components changes how scientists and students perform wave propagation simulations. Using our system, scientists can now combine geophysical models and geophysical codes together in new combinations. The system allows the user to configure the simulation, select the computational and geophysical components to use, and then run the simulations using a grid-based workflow system, and also manage the metadata required to make use of the results of computations done with the system.

As we expressed earlier, the OpenSHA software tools have enabled this type of capability for Pathway 1 SHA calculations. Our work this year has successfully

Figure 44: Ground Motion Maps produced by the SCEC/CME system for a series of simulated earthquake. The simulations used a variety of geophysical models (velocity models) and AWM codes and displayed results as either Peak Ground Velocity or Peak Ground Acceleration.

implemented a corresponding, component-based, simulation system for the more complex, computationally expensive, and data intensive Pathway 2 simulations. Now,

Pathway 2 geophysical models, such as velocity models, and computational models, such as AWM simulation codes can be used interchangeably in our scientific workflows.

As an example, Figure 44 shows a series of calculations for the same simulated earthquake produced by the SCEC/CME component-based pathway 2 workflow system. This image shows how an operator has run a series of wave propagation simulations using the SCEC/CME System. In each simulation, the operator has varied some aspect of the simulation. In some cases, they have selected different velocity models, including the SCEC CVM3.0, the Harvard Velocity Model, and the Hadley-Kanamori model. The resulting images show how the selection of velocity model affects the ground motions predicted by the simulation. The operator has also selected different wave propagation codes, selecting Olsen-AWM (Finite Difference), Graves-AWM (Finite Difference), or CMU's Hercules (Finite element). The codes, although validated against each other, produce slightly different ground motion predictions as shown in Figure 45.

An important capability of this component-based workflow system is the careful metadata management performed behind the scenes. The computations in our system are metadata driven. At each step, in the multi-step workflow, metadata describing the computational setup and parameters is managed by the system. This metadata is associated with the data products and it provides a detailed description of the data products so that they can be properly interpreted.

Our component-based pathway 2 simulation system has a browser-based user interface. The simulations are run using our grid-based workflow. We have written a User's Guide to the SCEC/CME System that describes how to run simulations using the system. Graduate students at SCEC participating Universities have used the system to run simulations as part of their graduate work.
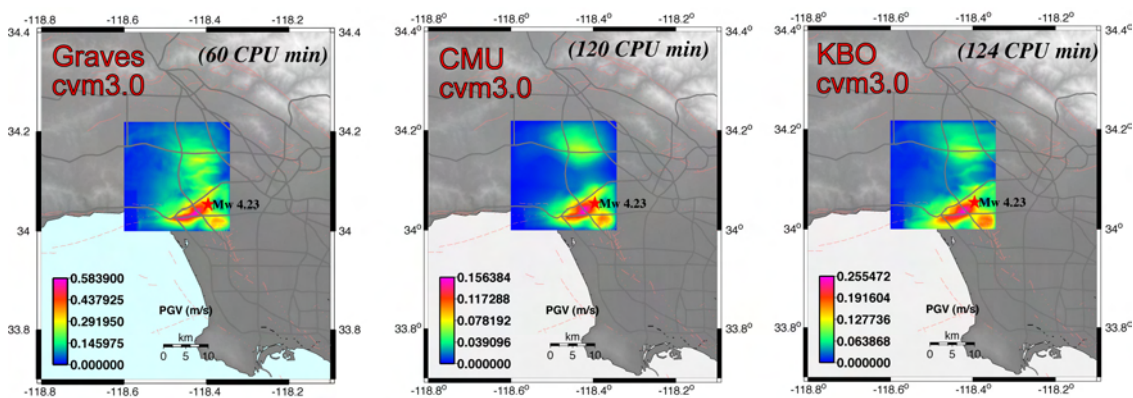
Figure 45: Three AWM codes for the same sub-region and double couple point source. Hollywood earthquake (-118.396^o, 34.053^o, Mw 4.23, 7 km depth, strike 165°, dip 60°, rake 0°. Compute time takes into account multiple nodes.

The capabilities of this system are exactly aligned with the goals of the SCEC/CME proposal. The component-based Pathway 2 simulation capabilities developed this year on the Project are a realization of the geophysical collaboratory concept expressed in the SCEC/CME proposal.

2.5 IT Research - Integrated Scientific Workflow System

An important Information Technology research area in the SCEC/CME Project is in the area of scientific workflows. Our integrated scientific workflow system transforms the construction and execution of scientific workflows by allowing non-expert users to construct and run complex simulations. The enabling technologies behind our workflow system are knowledge-bases, created by domain experts, which help shield users from the complexity of the underlying computational models and execution environment.

A large, interdisciplinary, group of SCEC/CME Project participants including geoscientists, knowledge capture experts, knowledge representation and reasoning experts, data management experts, and grid computing experts created a working group this year to develop and integrate an end-to-end scientific workflow system.

The focus of this effort is to produce a scientific workflow system that is easy or easier, to use. We believe this work can transform scientific workflow system from complex, experts-only tools, to tools accessible to non-sophisticated users. This ease-of-use is enabled through knowledge-based tools that hide the complexity of the computational models, and the computational environment, from the user while providing the user with assistance as they perform their workflow construction and job submission. Scientific workflow support for non-sophisticated users is a key requirement of the SCEC/CME system.

6 Intelligent Interfaces (smart assistants)

5 Integrated system tools (workbench/dashboard)

4 Workflow management

3 Domain Applications (webservices/applications)

2 Resource sharing (compute grid/data grid)

1 Hardware (computing, networking, storage)
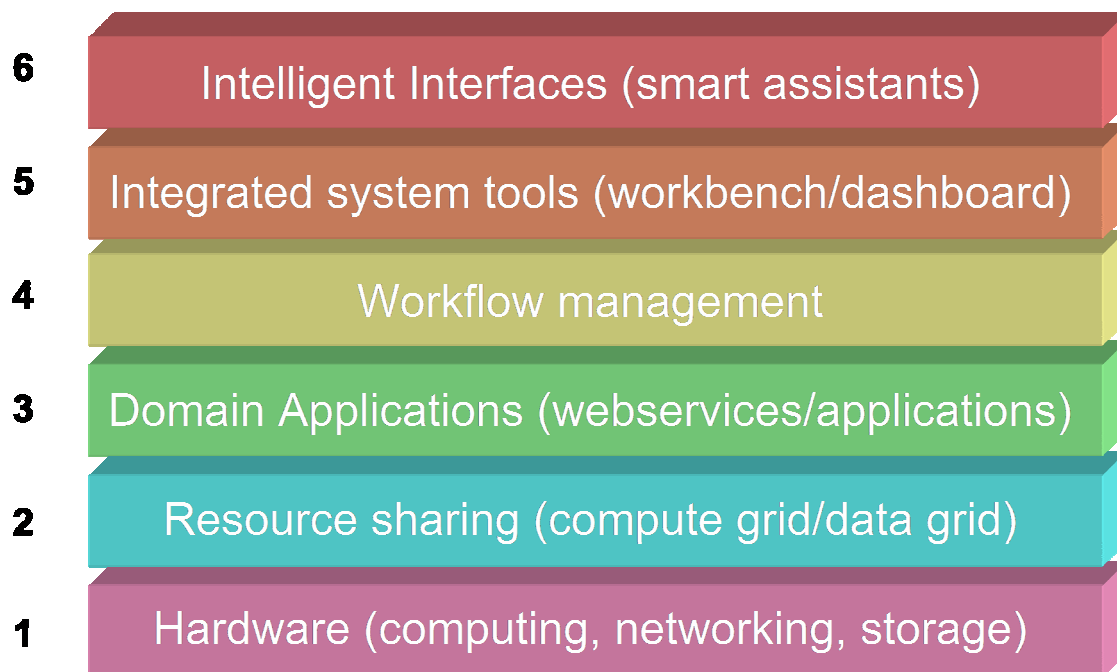
Figure 46: The SCEC/CME layered software architecture is designed to support both expert and non-export as they run geophysical application program and develop scientific workflows.

Our architecture and design group recognizes that ease-of-use must be implemented at each stage in workflow construction and execution. This requires an integrated effort across all layers in the workflow construction and execution. The SCEC/CME software architecture is based on a layered model that extends from computing hardware and storage at the bottom all the way to top layers that provide intelligent assistants to users as they develop workflows. This SCEC/CME layered software architectures is show.n in Figure 46.

The workflow system integration we performed this Project year spanned all the layers in the software stack, from Intelligent Interfaces that guide construction of a workflow, to concept-based metadata management tools, to meta-schedulers that help execute workflows in a grid-based, high-performance and high throughput environment. The overall architecture of our workflow system is shown in Figure 47.

Figure 47: SCEC/CME Integrated Workflow Architecture. Intelligent Assistants help users construct and run complex workflows in a grid-based environment.

Our workflow system begins with an Intelligent Assistant interface called the Composition Analysis Tool (CAT). This browser-based workflow template editor uses an OWL-based description of computational modules and their associated data to types to guide the user in the construction of a valid workflow.

Once a workflow template has been constructed, our system allows users to search for metadata using a concept-based metadata search tool, called DataFinder. This tool helps to map from domain concepts to specific metadata attributes using a domain ontology that characterizes metadata attributes in domain concepts.

Both our CAT and DataFinder intelligent assistant tools use a service-based architecture that allows them to be integrated into distributed applications without requiring distribution of the knowledge-bases themselves.

Our workflow system has integrated SCEC geophysical models and geophysical application programs into this workflow system.

In order to execute workflows, and to manage the data and metadata associated with these simulations, we have integrated the Virtual Data System, a collection of grid-based tools that include Globus, CondorG, Chimera, Pegasus, and data management tools including the Replica Location Service (RLS) and the Metadata Catalog System (MCS). The Pegasus system functions as a meta-scheduler, providing analysis of workflows, job

bundling, data transfers, and metadata management. The user is shielded from the underlying complexities of the grid-based execution environment through these workflow tools.

The architecture, design, development and integration of this system were major Project development efforts during this year. We believe that it is only through a highly interdisciplinary group effort, like ours on the SCEC/CME Project, that such a highly vertically integrated system can be developed. Not only does the Project bring the inter-disciplinary information technologist together to build the system, we have also applied the emerging system to a challenging domain problem, the problem of seismic hazard analysis. This effort, and the successful demonstration of the end to end functionality of this system at the SCEC/CME Summer 2005 All-Hands meeting represents an very good example of SCEC/CME vertical integration across leading-edge Cyberinfrastructure technologies.

A journal article describing the SCEC/CME Workflow system was published in an Association for Computing Machinery (ACM) Special Interest Group on Management of Data (SIGMOD) issue on Scientific Workflows.

2.6 Scientific Visualization

The variety of data sets and audiences for SCEC data products calls for a variety of visualization tools. The SCEC/CME Project has several groups working on scientific visualizations.

2.6.1 Puente Hills Rupture Visualizations

To support a SCEC Press Conference in May 2005 describing an Earthquake Spectra article written by SCEC and USGS researcher Edward Field, a team of project members created animations of a 10HZ Puente Hills simulated rupture.

The Puente Hills simulation was run by Robert Graves. The simulation output data was transferred into the SCEC Digital Library. David Okaya performed initial data handling of the Puente Hills 3D simulation in support of the SDSC visualization products. Then the SDSC Visualization Services group, created a series of animations showing the Puente Hills simulation. An image from these remarkable animations is shown in Figure 48.

Many regional and national news agencies picked up these animations and used them to explain the SCEC research results detailed in the Earthquake Spectra article.
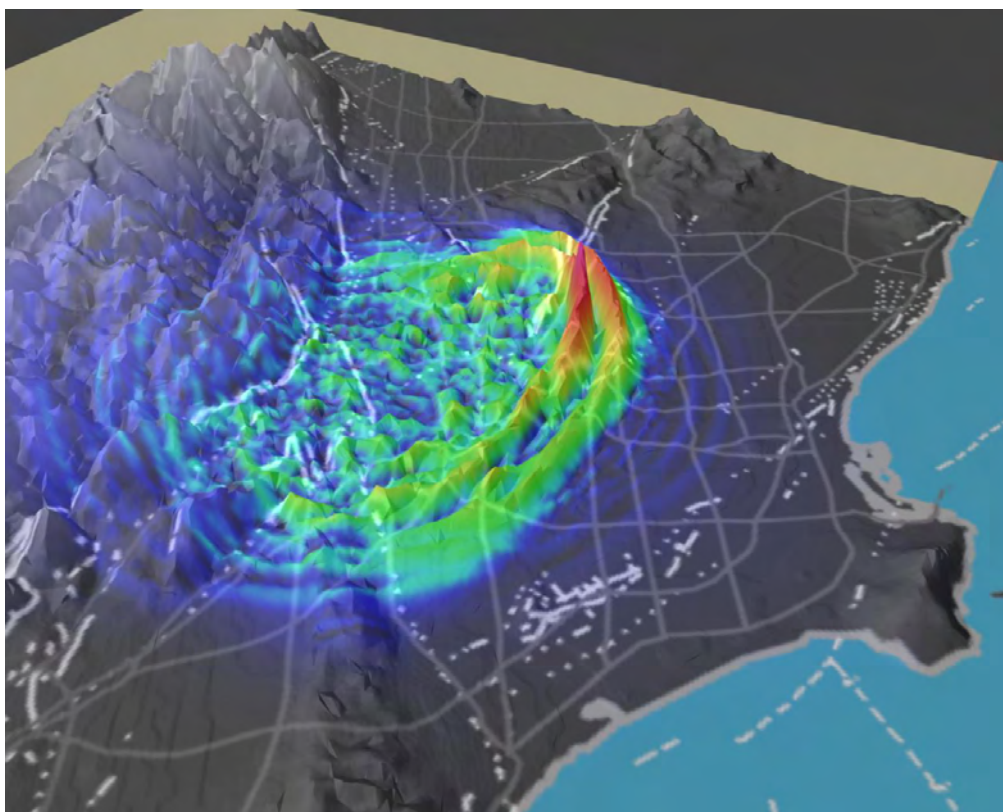
Figure 48: Ground motion velocity in the Los Angeles area from a Puente Hills earthquake. X Component of velocity.

2.6.2 SCEC Visual Data Object (SCEC-VDO) Development

During this year, a group at USC lead by UseIT Program Manager Sue Perry and USC graduate student Peter Powers worked on the development of visualization tools to facilitate study of static stress, fault, and seismicity interactions.

This year, the UserIT Intern software development transitioned from LA3D to SCEC-VDO. LA3D, developed over years 1-3 by the SCEC UseIT interns, served as a "prototype" platform for viewing faults, earthquakes, and other geo-referenced data sets in southern California. SCEC-VDO, on the other hand, can display global datasets and is backed by a metadata structure that permits enhanced interactivity and data exploration. For example, this metadata structure will make it easier for users to pick and choose rupture sources for static-stress change calculations and examine the resultant stress changes and aftershock seismicity associated with the earthquake rupture event.

We believe that the transitioned to SCEC-VDO (from LA3D) as the primary application for future SCEC UseIT intern development will benefit the SCEC Intern group. This new code with its plugin architecture does not have the hard coded georeferencing scheme used by the earlier LA3D software. Examples of the LA3D code and the new SCEC-VDO code are shown below (Figure 49).

As an example of the SCEC-VDO we used this new program to work within a fault-specific reference frame to characterize scaling relations of seismicity with respect to nearby faults (Figure 50).
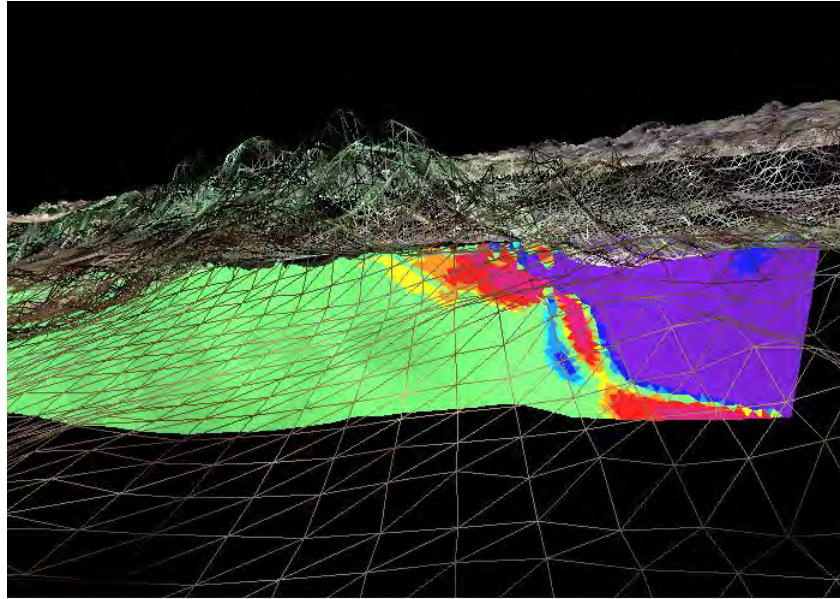
Figure 49: View (using LA3D) through mesh topography of the San Andreas Fault. The same static stresses resulting from the event in figure 1 are displayed but calculated for individual triangles of the 3D San Andreas Fault.
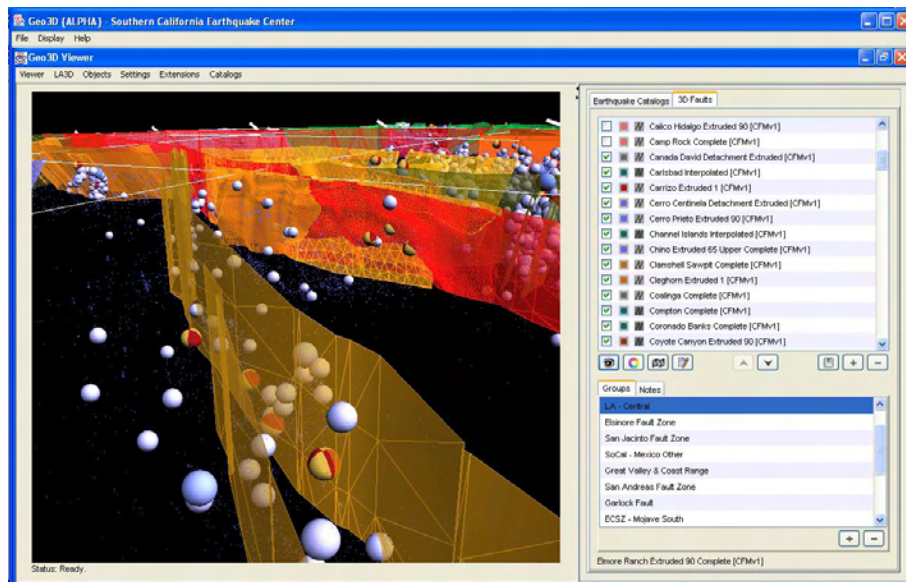
Figure 50: Screenshot of SCEC-VDO development showing interface for managing and displaying earthquake catalog objects with the new plugin API. View of Northridge rupture plane with focal mechanisms of events M>4.5

2.7 Digital Library - Access to Observed and Synthetic Data

The SCEC/CME Project is developing a digital library that is a collection of files and associated metadata that contains significant simulation results. Several developments this year were designed to improve access to these data in the SCEC digital library. In this section, we describe three of these data access tools.

2.7.1 3D Motion in Basins Data Sets

The first collection of data is the SCEC/PEER 3D Motion in Basin Validation effort. This study produced a collection of over 70 simulations of scenario earthquakes in the LA Basin. The resulting seismograms and spectral acceleration data was checked into the SCEC/CME digital library.

This data is distributed to geoscientists and engineers through a specialized scenario interface that allows researches to specify the fault, the slip distribution, and the hypocenter. Then waveforms, metadata, and spectral acceleration values for the specified scenario earthquake are then retrievable from this SRB collection. An example of this scenario interface is shown in Figure 51.
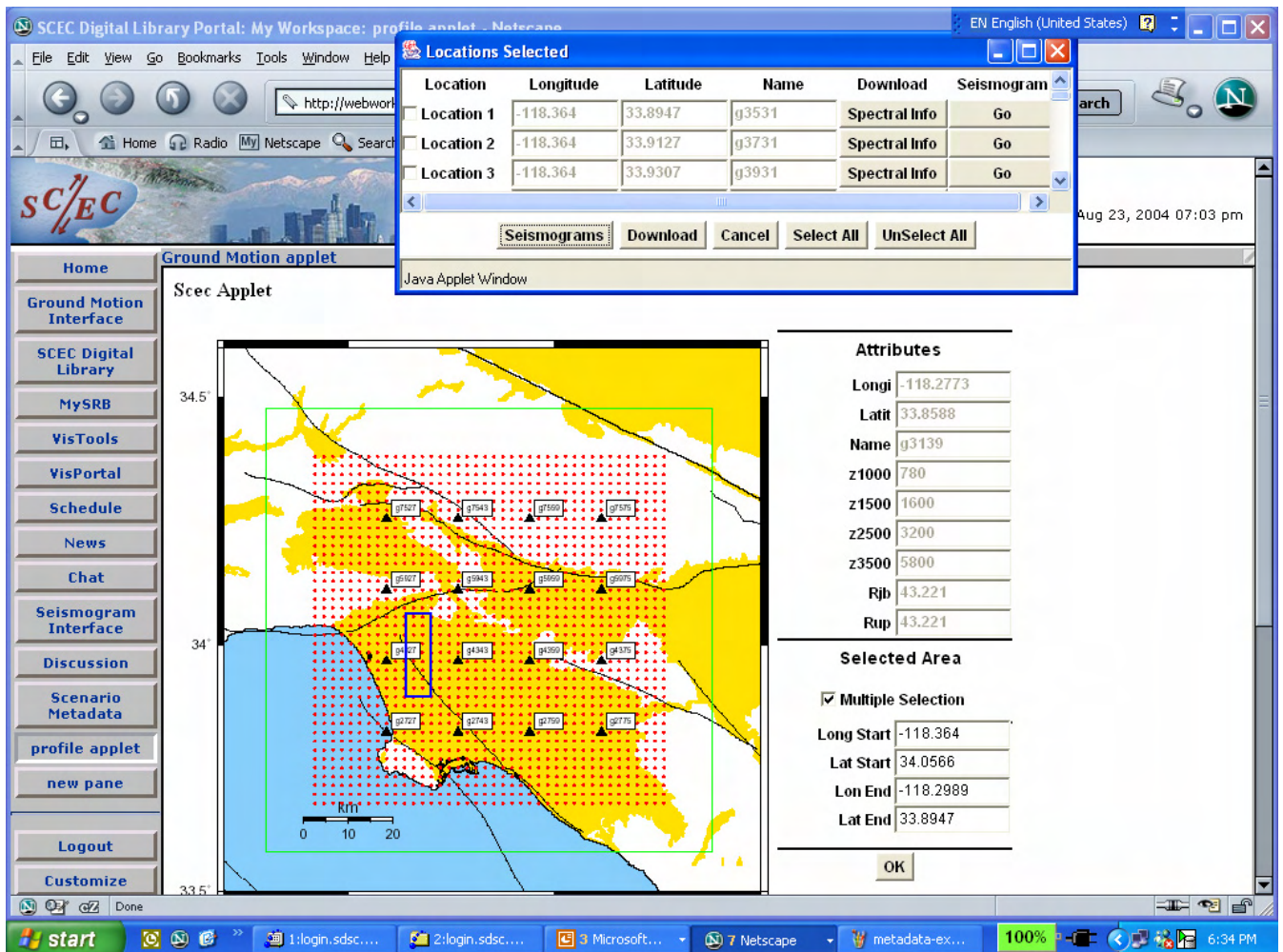
Figure 51: 3D Motion in Basin Validation Scenario Data Access Interface

2.7.2 Scenario TeraShake Data Access Interfaces

A specialized, map-based, interface was developed to provide access to the TeraShake data. Through this interface, researchers can select a point on a map, and retrieve seismograms, and metadata for any of the TeraShake simulations. This map based interface is shown in Figure 52.

A user can select a TeraShake simulation scenario, select a location on the surface, and by pointing and clicking over an interactive cumulative peak velocity map retrieve seismogram plots. The portal accesses the correct file within the SCEC community digital library, and displays all three velocity components for the chosen seismogram. Users can use this web application to interact with the full surface resolution (3000 x 1500) data of a TeraShake scenario, amounting to 1TB per simulation.
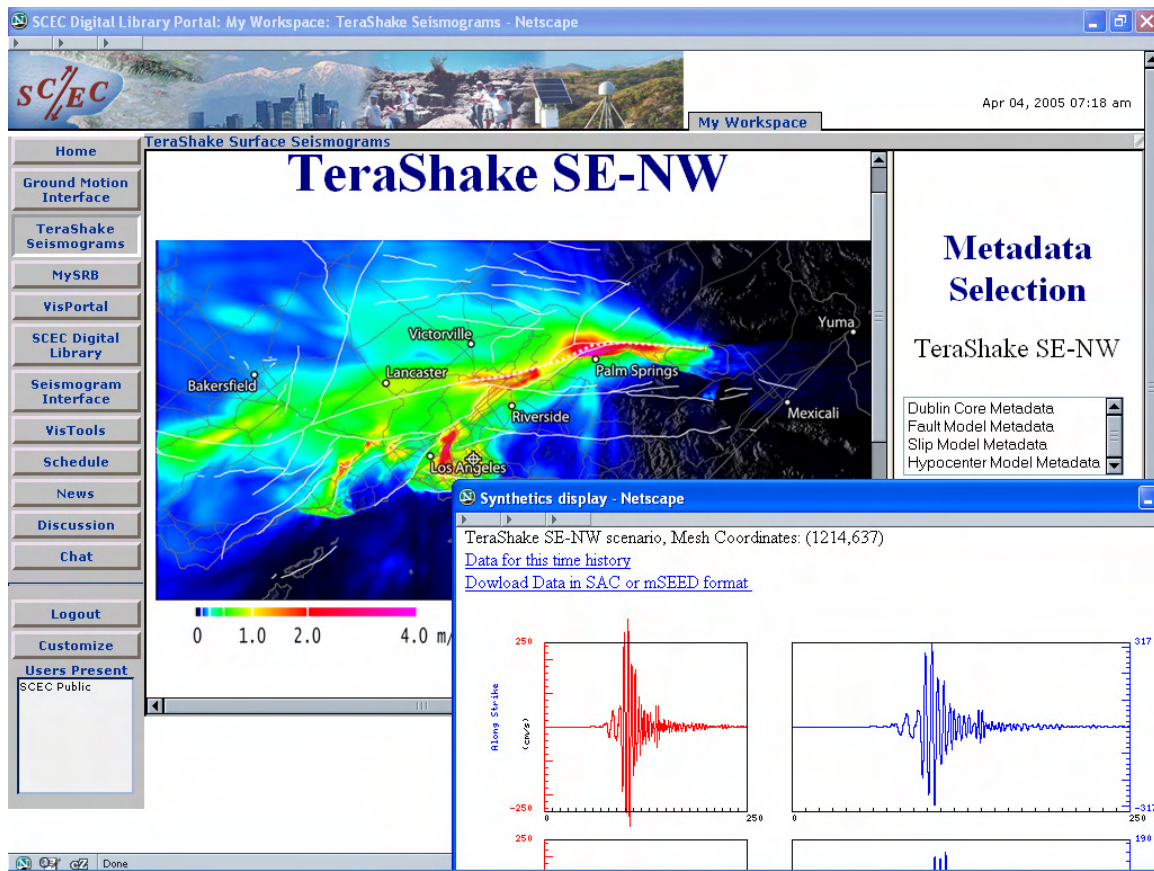
Figure 52: User interaction with the TeraShake Surface Seismograms portlet at the SCECLib Portal. The portal accesses the correct file within the SCEC community digital library, and displays all three velocity components for the chosen seismogram. The seismograms shown in the figure above display velocities exceeding 3 m/s on a location near Los Angeles (lat: 34.0326, lon: -118.078), for a southeast to northwest earthquake rupture scenario.

2.7.3 Synthetic and Observed Seismogram Access (SOSA)

IRIS participates in the SCEC-ITR Project with the primary goal of making IRIS data directly available for use within the Community Modeling Environment and additionally providing IT and programming experience to support other CME efforts. IRIS released the first version of SOSA (Synthetic and Observed Seismogram Analysis) in April, 2005. The SOSA 1.0 application combines the common tasks of retrieving observed and synthetic seismograms and applying analysis routines into a single software application. The tool enables researchers to retrieve observed seismograms accessible through a DHI (Data Handling Interface) and seismograms saved locally or accessible through an SRB (Storage Resource Broker). Seismograms retrieved from any source can be processed together, allowing easy comparison between synthetics and observed seismograms. Built-in processing abilities are re-sampling, tapering, filtering, rotation, convolution with instrument response and correlation between seismograms; web services provide access to other processes. Scientists may save seismograms into SAC or mSEED format. Saved seismograms include associated metadata that details the

source(s) of the seismogram and history of processing, including application version and computational platform. **Figure 53** shows a screenshot from the processing portion of SOSA 1.0.
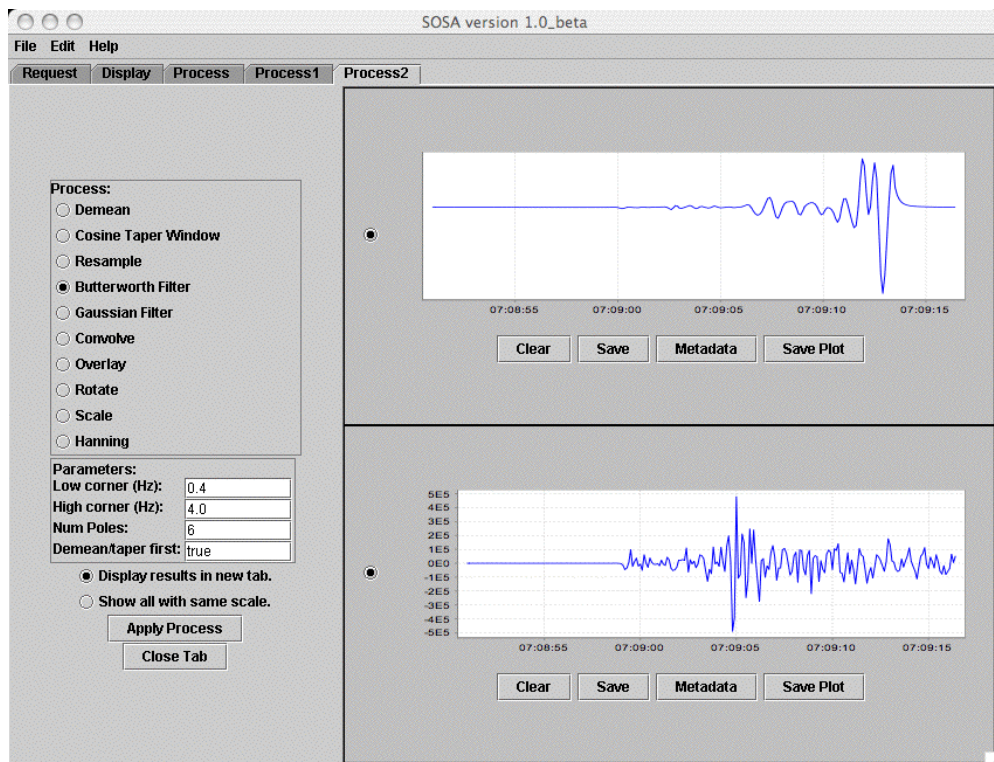
Figure 53: Setting up a comparison between a synthetic seismogram (top waveform) and observed (bottom waveform) in SOSA.

The latest SOSA release includes easy access to synthetic seismograms from over 60 SCEC model runs, using the metadata-based descriptions of the data stored in the SRB. A preliminary version of SOSA 1.1 was released at the end of June, 2005 as part of the IRIS SCEC-ITR work.

3   SCEC/CME Special Studies

Together with SCEC/CME system development, and basic IT and geoscience research, SCEC/CME Project members develop and execute large interdisciplinary collaborative special studies. During this year, two large collaborative special studies have been formulated and are under active development.

The following two special studies, the TeraShake 2 Project and the CyberShake Project both utilize capabilities developed on the SCEC/CME Project. Also, both of these projects applied for, and received, computing and storage allocation on the Extensible TeraScale Facility (ETF), called the TeraGrid, which is an NSF-funded national Supercomputing Facility. Base on the outstanding results of the TeraShake simulations, together with large-scale TeraShake 2 simulations, and grid-based workflow computation of the CyberShake Project, SCEC has developed significant visibility in the national supercomputing community.

3.2 TeraShake 2 – Large Scale Dynamic Ruptures and Wave Propagation Simulations

The original TeraShake simulations produced new insights into earthquake wave propagation in southern California. However, the SCEC/CME roadmap is to continually implement more physically realistic elements into these simulations.

TeraShake researchers would like to change the earthquake source description to make the TeraShake simulations more physically realistic. In the original TeraShake simulations, a kinematic source description, based on the Denali earthquake, was used. The kinematic source description could contain some physically non-realistic characteristics. To make these TeraShake scale simulations more physically realistic, the SCEC scientists want to use a dynamic rupture simulation as the source description. A dynamic rupture will simulate friction-based slip on the fault. The dynamic rupture simulation results will then be coupled into a wave propagation code to produce a Tera-scale, TeraShake simulation.

The dynamic ruptures codes developed by SCEC scientists are still under active research and development. A dynamic rupture validation effort is currently being conducted by SCEC working groups. The TeraShake 2 simulations will combine the Anelastic Wave Propagation software developed and optimized during the TeraShake 1 simulations with dynamic rupture codes that have been developed and validated through the SCEC dynamic rupture validation work. Several dynamic ruptures codes including finite difference code, mimetic code, and finite element codes are being developed and investigated for use in this simulation.

TeraShake 2 simulations are under active development. The TeraShake 2 dynamic ruptures are at a significantly larger scale than the ruptures used in the validation exercise. Also, the TeraShake 2 ruptures have special properties, such as strong velocity contrasts across the faults that are not present in most previous simulations.
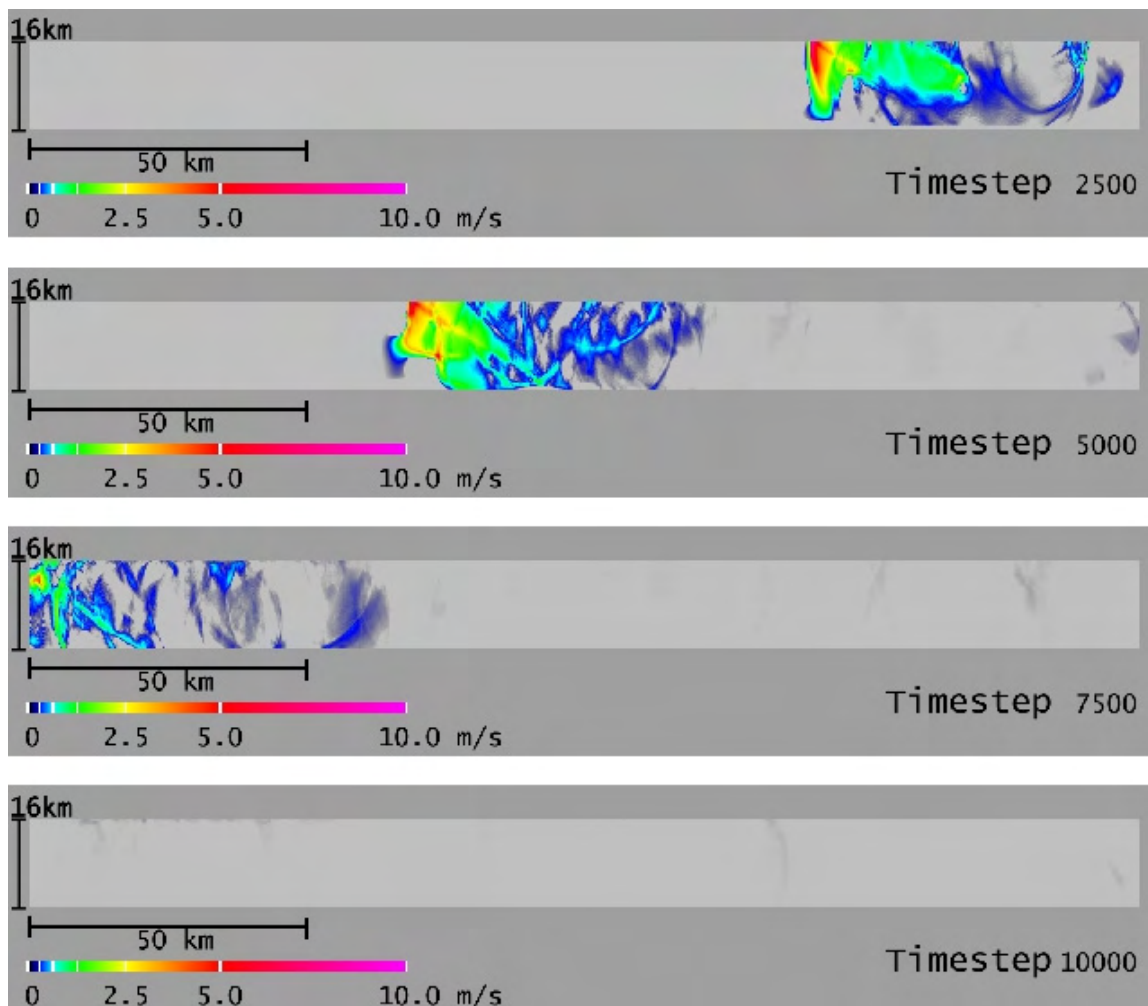
Figure 54: TeraShake 2.1 dynamic rupture slip-time history simulates a Mw 7.7 earthquake on the San Andreas Fault.

Early this year, several initial, full-scale dynamic rupture simulations were run. These dynamic rupture simulation was based on a Lander simulation performed earlier. The Landers initial stresses were used and duplicated along the larger TeraShake fault surface. Slip time history produced by this initial TeraShake 2 dynamic rupture is shown in Figure 54. These results will be analyzed before the wave propagation portion of the first TeraShake 2 simulation is run. Once satisfactory slip-time history data is produced by a dynamic rupture simulation, it will be used as a source description for a earthquake wave propagation simulation. At that point, the TeraShake 2 dynamic rupture results will be compared to the results produced using a kinematic source description in TeraShake 1.

3.3 CyberShake – 3D Waveform-based Probabilistic Seismic Hazard Analysis

The CyberShake Project is an effort to change the way Probabilistic Seismic Hazard Analysis is performed. The SCEC/CME Project is working to develop new

approaches to seismic hazard analysis by developing a more physics based approach. In the CyberShake Project, our goal is to utilize 3D waveform modeling as an intensity measure relationship in a full probabilistic hazard curve calculation.

PSHA typically involves two main components, an Earthquake Rupture Forecast (ERF), which identifies all the probable earthquakes, and an Intensity Measure Relationship (IMR) that determines how ground motions decay with distance from the hypocenter.

State-of-the-art PSHA is currently conducted using IMR's that use empirically-based attenuation relationships. These attenuation relationships represent relatively simple analytical models based on the regression of observed data. However, it is widely believed that significant improvements in SHA will rely on the use of more physics-based, waveform modeling. In fact, a more physics-based approach to PSHA was endorsed in a recent assessment of earthquake science by National Research Council (2003).

In order to introduce the use of 3D seismic waveform modeling into PSHA hazard curve calculations, the SCEC/CME CyberShake group is integrating state-of-the-art PSHA software tools (OpenSHA), SCEC-developed geophysical models (SCEC CVM3.0), validated anelastic wave modeling (AWM) software, and state-of-the-art computational technologies including high performance computing and grid-based scientific workflows in an effort to develop an OpenSHA-compatible 3D waveform-based IMR component. This will allow researchers to combine a new class of waveform-based IMRs with the large number of existing PSHA components, such as Earthquake Rupture Forecasts (ERF's) that are currently implemented in the OpenSHA system.

To calculate a probabilistic hazard curve for a site of interest, we use the OpenSHA implementation of the NSHMP-2002 ERF and identify all ruptures within 200km of the site of interest. For each of these ruptures, we convert the NSHMP-2002 rupture definition into one, or more, Ruptures with Slip Time History (Rupture Variations) using newly developed Rupture Generator software. Strain Green Tensors are calculated for the site using the SCEC CVM3.0 using well-validated AWM software together with the SCEC CVM3.0 3D velocity model. Then, using a reciprocity-based approach, we calculate synthetic seismograms for each Rupture Variation. The resulting suite of synthetics is processed to extract peak intensity measures of interest (such as spectral acceleration). The peak intensity measures are combined with the original rupture probabilities to produce probabilistic seismic hazard curves for the site.

The CyberShake calculations are performed on high performance computing systems including multiple TeraGrid sites (currently SDSC and NCSA), and at USC's High Performance Computing and Communications (HPCC) center. The CyberShake job submission and data management uses a grid-based scientific workflow system based on the Virtual Data System (VDS) to manage the job scheduling and data management requirements of the work.

The CyberShake Project has identified 10 initial sites of interest in southern California for which hazard curves will be calculated as shown in Figure 55. These sites include soft soil, rock, urban, places where there are CISN sensors, and places at which strong ground motions have been historically observed

The processing for a single site includes two large Strain Green Tensor Calculations (one for each horizontal component) and then thousands of seismogram synthesis jobs. The seismogram synthesis jobs are run as scientific workflows.
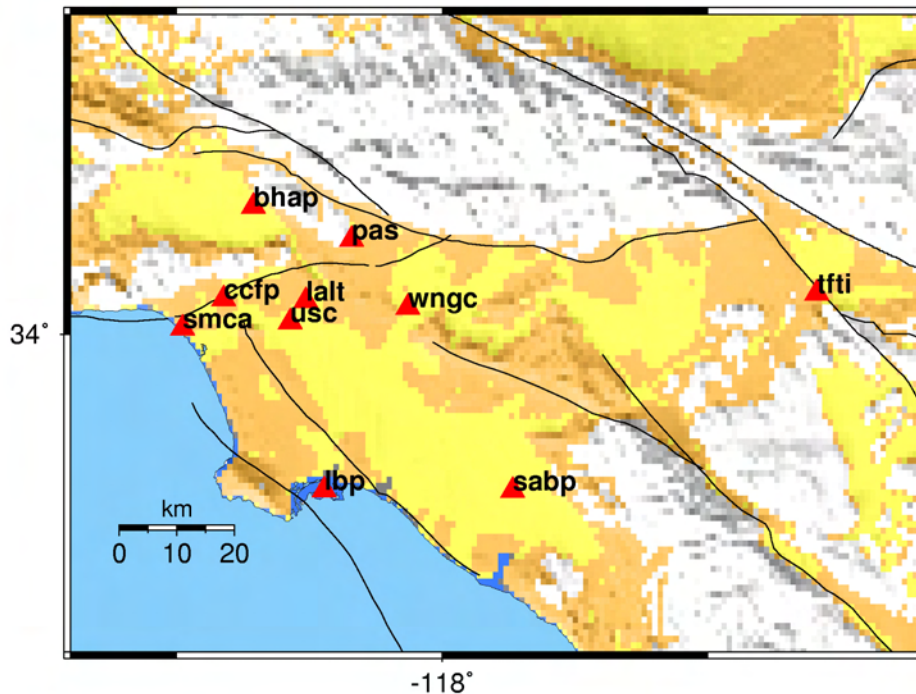
Figure 55: Map of the first 10 CyberShake sites for which hazard curves will be calculated.

The SCEC/CME CyberShake group has performed extensive validation testing to verify the accuracy of the reciprocity-based synthetics calculated in the workflows. They have also performed validations on the spectral acceleration calculations used in this calculation.

The CyberShake group has recently completed their first full site calculation. The hazard curves generated by these simulations are currently being analyzed at several different spectral acceleration periods. The CyberShake hazard curves are being compared to curves produced by a number of attenuation relationships.

4 Summary

The SCEC/CME Project continues as an outstanding example of the NSF Information Technology Research Program. The Program goal of encouraging interdisciplinary research is being met on a daily basis on our Project. Not only are geoscientists and computer scientists working together, but more importantly, innovative, and potentially transformative research is being done in both the geoscience and computer science domains.

The continuing series of strong SCEC/CME Project successes is a result of several factors. The Project personnel represent an outstanding group of Geoscientist and Computer Scientists. The Project proposal provides a clear focus for the research

activities, namely, improving the science and practice of Seismic Hazard Analysis. The Project development goals, defined as four computational pathways in the Project proposal, define a clear series of geophysical and IT research activities that will lead to improvements in the practice of Seismic Hazard Analysis.

In addition, the SCEC/CME Project benefits greatly by being planted and nurtured within a vibrant SCEC scientific community. By placing the SCEC/CME collaboratory within SCEC, an outstanding synergy has begun to occur. The SCEC/CME Project leverages the strong scientific community and expertise that has been developed by SCEC geoscientists over the last 13 years. And in reverse, the Project is anticipating and addressing the IT needs of SCEC scientists. The leading-edge SCEC/CME IT technology has arrived just in time to help the SCEC Geoscientists with their work. By locating the SCEC/CME Project within the context of the SCEC community, the SCEC Community provides a focusing effect and a user community that ensures the SCEC/CME Project is producing capabilities needed by working scientists.

Borderland Working Group

The offshore California Continental Borderland is a critical element in terms of understanding the tectonic evolution, active fault systems, and seismic hazard of Southern California. As a result, SCEC created the Borderland Working Group. Its purpose is to focus and integrate research activities within the offshore Continental Borderland that relate to the scientific mission and objectives of SCEC. This includes the coordination of cooperative and collaborative research projects, helping to assess, archive and analyze existing offshore geologic and geophysical data, and helping to plan new research activities including future experiments within the Continental Borderland.

A major accomplishment of the Borderland Working Group was the successful transfer of extensive grids of high-quality, proprietary multichannel seismic (MCS) reflection data—collected by the industry for hydrocarbon exploration—to the public domain. These data constitute the National Archive of Marine Seismic Surveys (NAMSS) recently established by the USGS [*Childs and Hart*, 2004]. Digital basemaps, navigation files and initial data sets (e.g., BWG-Figure 1) are now available at: http://walrus.wr.usgs.gov/NAMSS, and new additional data sets are coming on-line all the time. These data represent an invaluable community resource tool. When correlated with well data and seismicity, these data can be used to map 3D reference horizons and fault surfaces to seismogenic depths, and provide accurate, quantifiable 3D images of subsurface fault geometry, basin development and finite deformation. With these and other high-resolution data sets in hand, substantial progress can be made in investigating the active deformation and hazard potential of the offshore Continental Borderland.

In 2005, various Borderland projects were conducted or initiated that were either partially or fully funded by SCEC. NSF funded Kennett, Nicholson, and Sorlien (UCSB)—in collaboration with Normark, Sliter and Kooker (USGS)—to test the viability of extending the high-resolution climate record in Santa Barbara Basin. The project used high-resolution seismic stratigraphy and the USGS towed chirp system to map the 3D structure and outcrop stratigraphy along the Mid-Channel Trend [*Nicholson et al.,* 2005]. The older stratigraphic sequences were then sampled by piston core in August 2005. In addition to providing one of the highest-resolution paleo-climate records yet recovered from the world's oceans, this project will also help to quantify patterns and rates of offshore late-Quaternary faulting and folding in the Santa Barbara Channel.

In 2005, SCEC helped support Sorlien (UCSB) to conduct continued analysis of active fault systems in Santa Monica Bay and comparison of these active plate-boundary structures with those in the Marmara Sea associated with the North Anatolian fault system [*Sorlien et al.,* 2005]. This includes investigation of the Palos Verdes, San Pedro Basin and San Pedro Escarpment faults of the inner Borderland that interact with and terminate against the more east-west-striking, north-dipping Malibu Coast and Santa Monica-Dume faults (e.g., BWG-Figure 2). This work led to the identification and mapping of the Palos Verdes anticlinorium that may be the offshore extension of the active Compton blind thrust ramp beneath the Los Angeles basin [*Sorlien et al.,* 2004]. This project, in collaboration with colleagues at USGS and LDEO, mapped stratigraphic reference horizons and 3D fault surfaces to document subsurface fault geometry and the amounts of deformation absorbed by fault slip, folding and rotation. It also contributed several new 3D fault surfaces to the SCEC Community Fault Model.

In 2005, SCEC helped support Legg (LGI) to investigate active faults and restraining bends in the northern Continental Borderland [*Legg and Kamerling*, 2005]. This included compilation

of high-resolution multibeam and NOAA point bathymetry data showing the detailed seafloor morphology associated with the San Clemente and Catalina Ridge faults (BWG-Figure 3), as well as evaluation of high-resolution seismic reflection data (BWG-Figure 4) collected in collaboration with OSU colleagues, Goldfinger and Chaytor [*Legg et al.,* 2005]. The value and usefulness of the high-resolution multibeam and seismic data to map near-seafloor expressions of active offshore faults is clearly evident. This project also provided new and improved representations of offshore faults to the SCEC Community Fault Model.

In 2005, in addition to expanding the NAMSS on-line digital database, USGS personnel continued or completed work on: submarine landslide hazards in the Santa Barbara Channel [*Fisher et al.,* 2005d], analysis of industry MCS data to document the location, geometry, and timing of near-shore faulting off San Diego County [*Ryan et al.,* 2005], re-examination and analysis of LARSE Line-1 to evaluate upper-crustal structure of the Inner Continental Borderland [*Baher et al.,* 2005], and multi-disciplinary studies of the offshore seismic, gravity, and seafloor morphology data to understand the development, geometry and seismic hazard potential of active faults along the southern frontal fault system of the Northern Channel Islands–Western Transverse Ranges Province, in collaboration with colleagues at UCSB [*Fisher et al,* 2005a-c]. The USGS Coastal and Marine Geology program also recently completed their Cabrillo Mapping and Hazards Project of coastal Southern California and are preparing a Geological Society of America Special Paper publication of their results.

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USGS CMG Organizations (WesternGeco) Data & Metadata

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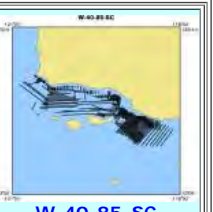
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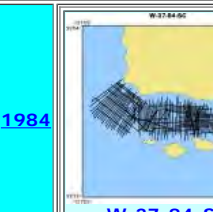
1985   W-39-85-WO   W-40-85-SC   **1984**   W-37-84-SC   **1983**   W-36-83-SC

BWG-Figure 1. Screen capture from USGS National Archive of Marine Seismic Surveys (NAMSS) website (http://walrus.wr.usgs.gov/NAMSS/) showing thumbnail basemaps of some of the industry (WesternGeco) multichannel seismic reflection data (including digital navigation and seismic data files) now available along the Western United States [Childs and Hart, 2004].

BWG-Figure 2. Map showing the Palos Verdes anticlinorium [Sorlien et al., 2004; 2005], a major regional fold structure, and its relation to the active underlying blind faults (red lines represent fault tips) that are driving this deformation. In this model, the Palos Verdes anticlinorium represents the offshore extension of the active Compton thrust ramp beneath the Los Angeles basin. Much of the uplift of the Palos Verdes Peninsula is then just a part of a much broader, more regional uplift associated with the Palos Verdes anticlinorium.
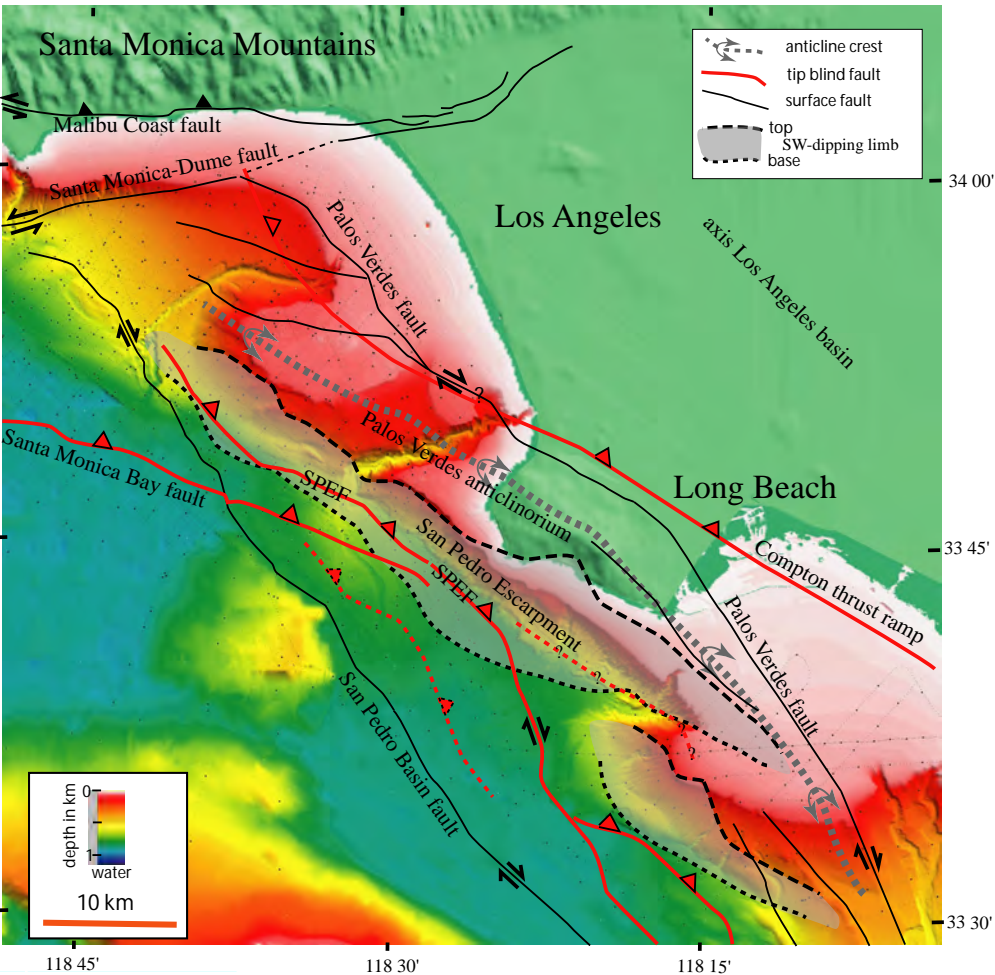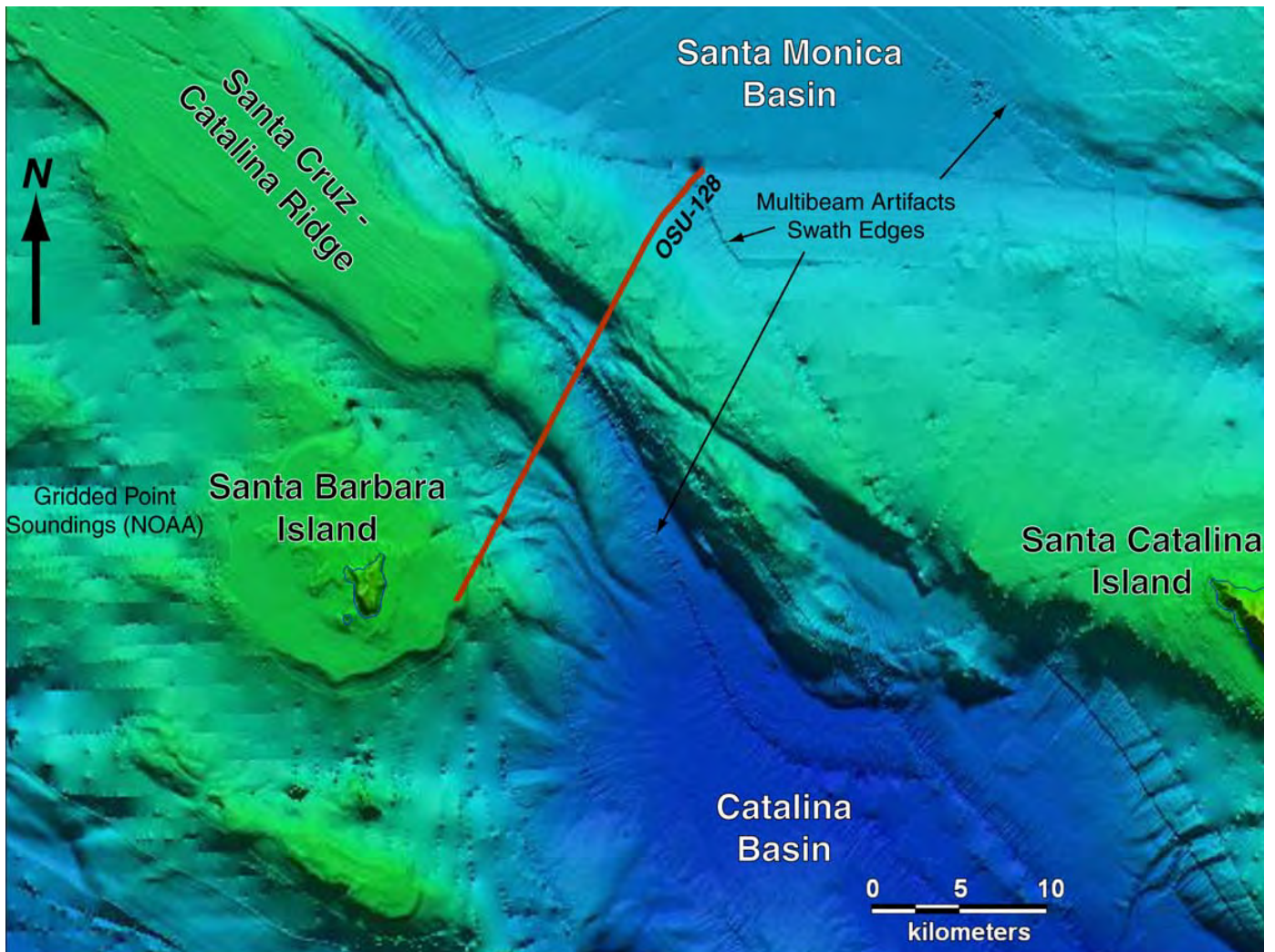
BWG-Figure 3. High-resolution composite of multibeam and NOAA point bathymetry showing the intersection of the San Clemente and Catalina Ridge faults [Legg et al., 2005]. Red line shows location of high-resolution seismic profile (24-channel mini-sparker) collected in collaboration with OSU.
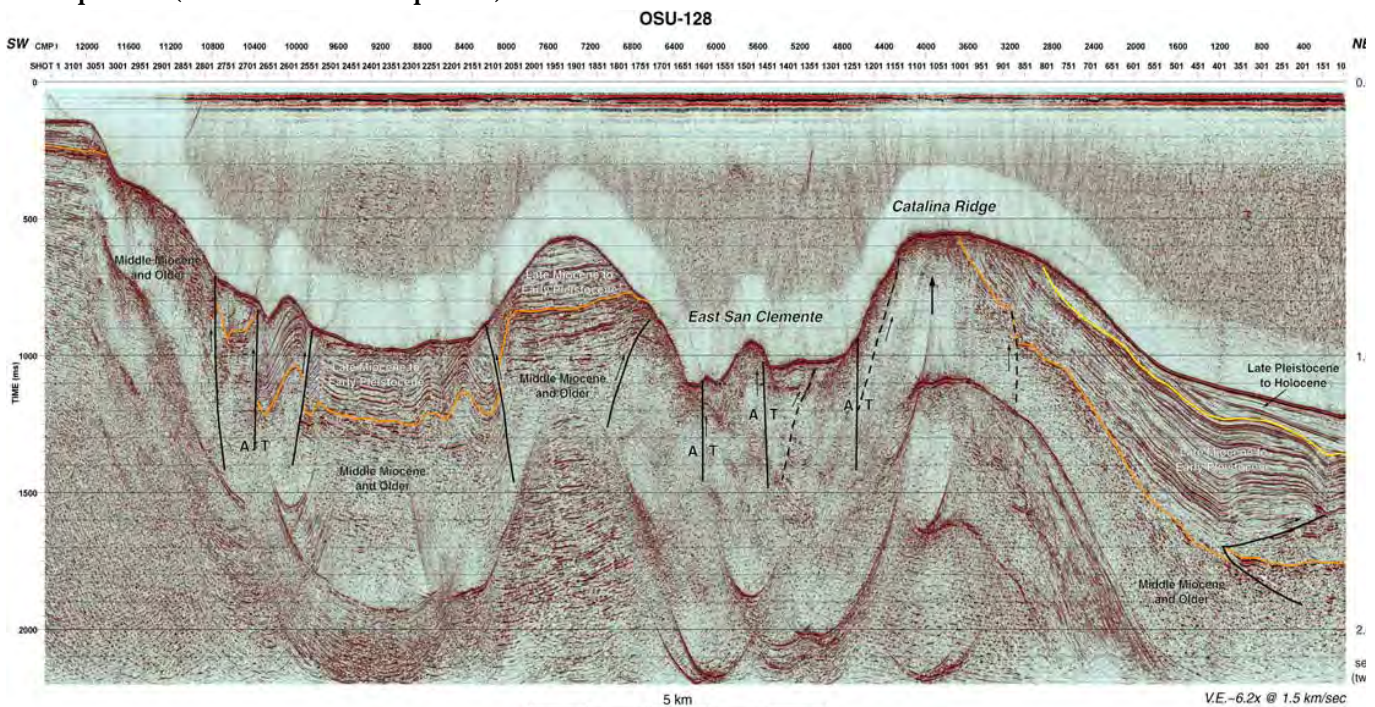
BWG-Figure 4. High-resolution 24-channel seismic line across southeastern Santa Cruz-Catalina Ridge showing major faults and deformed sedimentary sequences [Legg et al., 2005].   Page 107

Workshops and Community Activities

One of the very positive attributes of SCEC has been its service to the broader geophysics community throughout it history, both nationally and internationally. The last director of SCEC1, Tom Henyey, served as chair of the EarthScope Working Group that organized the US Earth Science community's effort to get EarthScope funded by the NSF and US Congress. The current director, Tom Jordan, and the Associate Director, John McRaney, also served on that working group.

SCEC organized and conducted several critically important EarthScope workshops from 1999-2003, including the main EarthScope science workshop in October, 2001. SCEC also organized three workshops to define the Plate Boundary initiative part of EarthScope (PBO I in 1999, PBO II in 2000, and Geo/PBO in 2001); the EarthScope SAR workshop in 2000, the EarthScope IT workshop in 2002, and the EarthScope Complementary Geophysics workshop in 2003.

SCEC (and JPL) serve as the US coordinating organizations for the ACES (APEC Cooperative for Earthquake Simulation) international collaboration and hosted three international ACES workshops in 2000, 2001, and 2002. SCEC will also host the 2006 ACES workshop in April, 2006 in Maui.

SCEC assisted the community in three other activities in 2005. We co-hosted (with FEMA) a HAZUS meeting in March and co-hosted (with the USGS) an extreme ground motion workshop in September.

We hosted several workshops addressing center research activities. SCEC hosted workshops on reference earthquakes in May, a San Andreas/FARM workshop in September, a workshop on folds in the Los Angeles basin in October, and several workshops of the Working Group on California Earthquake Probabilities. All center workshops are open to all interested scientists.

The Southern California Earthquake Center

Communication, Education and Outreach
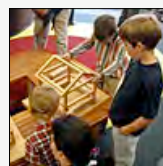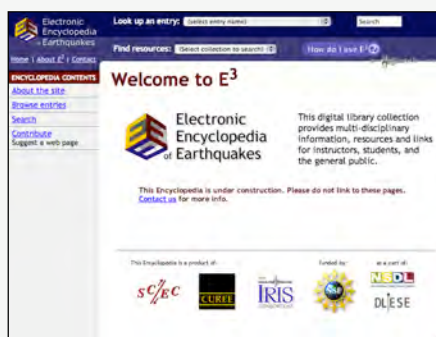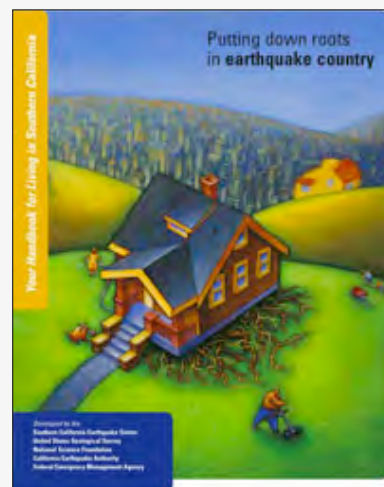
SCEC Communication, Education and Outreach (CEO) program

The SCEC2 *Communication, Education, and Outreach* (CEO) program is built upon the methods, achievements, and experience of SCEC's eleven years as an NSF Science and Technology Center, and a series of community planning workshops prior to SCEC2. These workshops led program with four long-term goals that have been pursued during SCEC2:

- Coordinate productive interactions among a diverse community of SCEC scientists and with partners in science, engineering, risk management, government, business, and education (see Figure 1.A.4).
- Increase earthquake knowledge and science literacy at all educational levels, including students and the general public.
- Improve earthquake hazard and risk assessments
- Promote earthquake preparedness, mitigation, and planning for response and recovery.

CEO is well integrated within the SCEC science planning process. This includes participation of CEO staff in the development of short-term research objectives and evaluation of proposals received each year in order to develop products and services needed by our various audiences (Figure II.C.1). SCEC scientists in turn are involved in developing and fulfilling CEO short-term objectives, which are organized within four CEO focus areas: *education* programs and resources for students, educators, and learners of all ages; *public outreach* activities and products for the general public, civic and preparedness groups, and the news media; *knowledge transfer* activities with practicing professionals, government officials, scientists and engineers (with research partnerships coordinated within the SCEC *implementation interface)*; and *SCEC Community development* activities and resources for SCEC scientists and students.

The list of activities is long and SCEC's organizational relationships are often complex, but we emphasize that the Center's resources, including its staff time, are carefully allocated through a prioritizationprocess that maintains good alignment between the CEO and science objectives. For example, the yearly revisions to the CEO plan are articulated within the revised SCEC Science Plan, published each October, which solicits annual proposals from the SCEC Community; the proposals that respond to the CEO solicitation are evaluated along side the science proposals in the collaboration-building process managed by the Planning Committee. This mechanism involves scientists in setting and achieving the CEO objectives.

SCEC Activity Development and Assessment process relative to the SCEC Mission. Both initial data gathering activities and integrated research results create or support a broad range of products and services. Assessments of these products and services
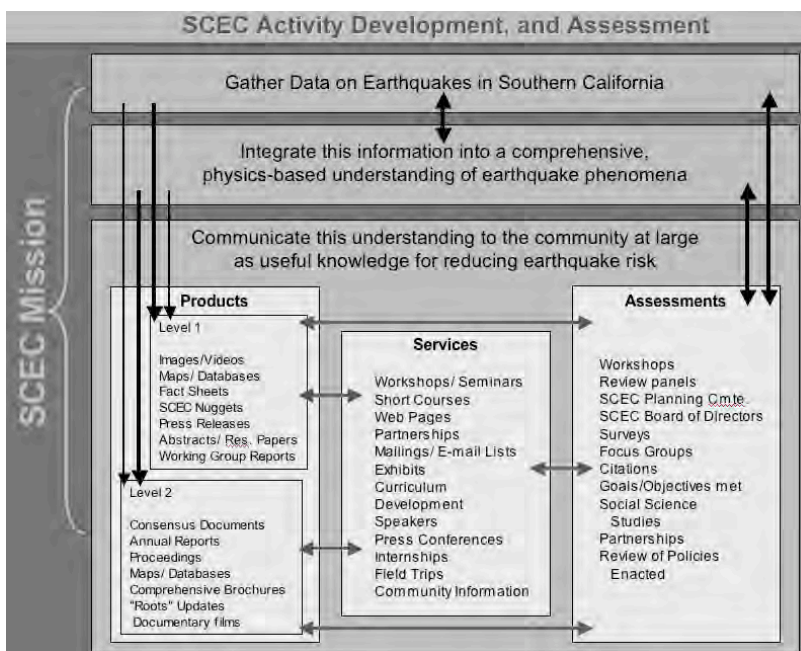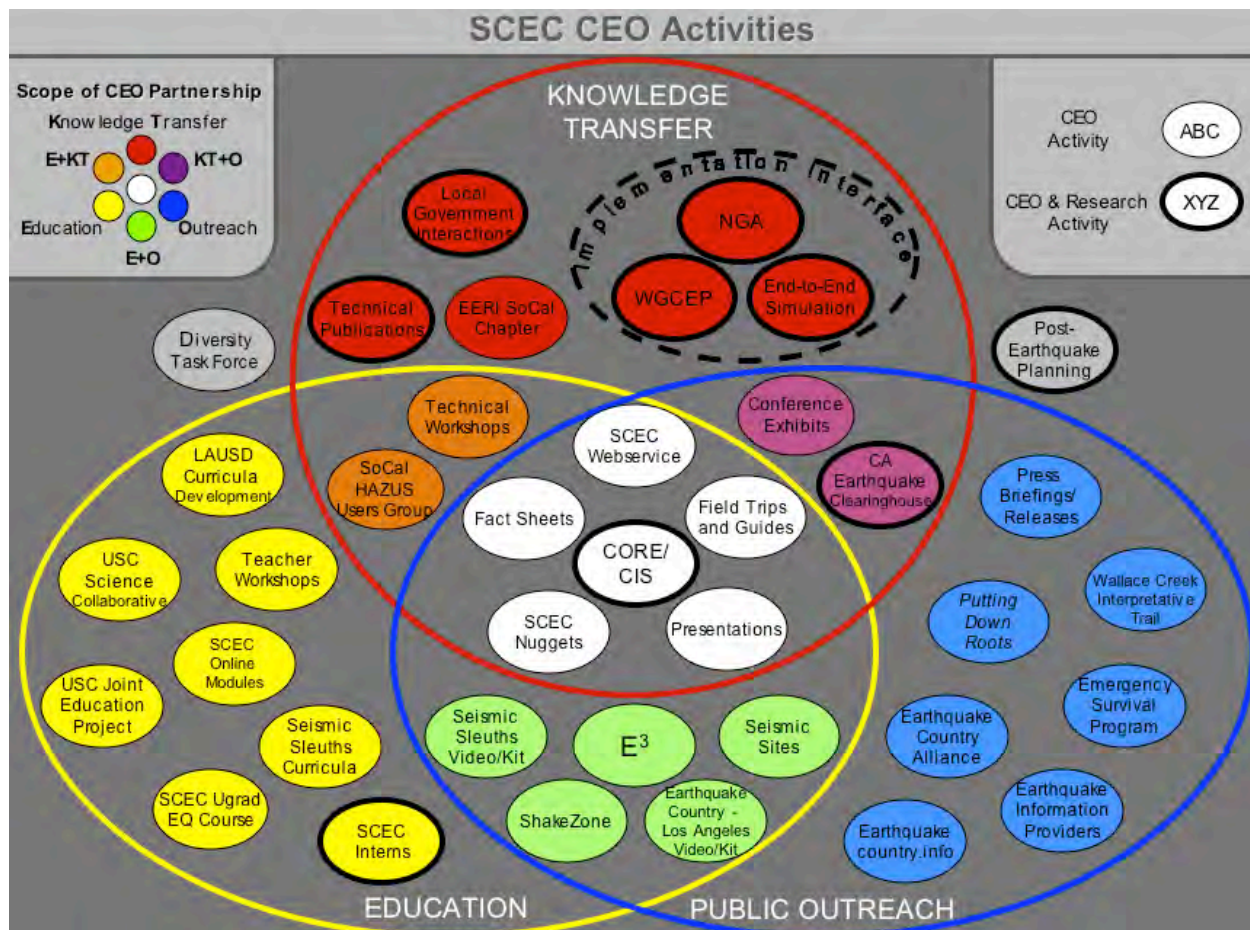
SCEC CEO Activities, showing how many activities span more than one CEO focus area. Activities within the SCEC Community Development focus area are shown outside the three circles, though have connections to many of the activities shown.

SCEC CEO Team

Staff
Mark Benthien, director
John Marquis, digital products manager
Bob de Groot, education specialist
Sue Perry, earthquake information technology student programs manager

Student Employees
Ilene Cooper, education specialist
Brion Vibber, web specialist
Monica Maynard, education specialist and Spanish translator

Consultant
Paul Somerville, Implementation Interface project manager

Education Activities

SCEC and its expanding network of education partners are committed to fostering increasing earthquake knowledge and science literacy at all educational levels, especially K-12 and college-level education in Earth science. In addition to activities described below, SCEC CEO also is developing an undergraduate earthquake course with new visuals and online interactive modules, revising the *Seismic Sleuths* earthquake curricula, supporting activities at the SCEC-developed *ShakeZone* museum exhibit, and working with the Los Angeles Unified School District on a sixth grade earth sciences unit which will include SCEC images and videos.

Objectives

The SCEC2 objectives for the Education focus area are to (1) interest, involve and retain students in earthquake science, (2) develop innovative earth-science education resources, (3) offer effective professional development for K-12 educators.

Results

<u>SCEC Undergraduate Internship Program.</u> SCEC has supported over 160 students to date (including over 70 women and over 50 minority students) to work alongside over 65 SCEC scientists since 1994. The program has expanded in recent years: in 2004, SCEC supported 34 undergraduate students. SCEC interns are paid a stipend of $5000 over the summer with support from the NSF REU program. SCEC offers two summer internship programs, SCEC/SURE, and SCEC/USEIT. These programs are the principal SCEC *framework* for undergraduate student participation in SCEC, and have common goals of increasing diversity and retention. In addition to their research projects, participants come together several times during their internship for orientations, field trips, and to present posters at the SCEC Annual meeting. Students apply for both programs at http://www.scec.org/internships.

Each summer since 1994, the *SCEC Summer Undergraduate Research Experience (SCEC/SURE)* has supported students to work one-on-one as student interns with SCEC scientists. The goals of SCEC/SURE are (1) to provide hands-on experiences for undergraduates and expand student participation in the earth sciences and related disciplines, (2) to encourage students to consider careers in research and education, and (3) to interest, train, and retain talented students, including women, members of underrepresented minorities, persons with disabilities, and students outside the earth sciences. SCEC/SURE has supported students to work on numerous issues related to earthquake science including the history of earthquakes on faults, risk mitigation, seismic velocity modeling, science education, and earthquake engineering.

The *SCEC Undergraduate Studies in Earthquake Information Technology (SCEC/USEIT)* program, unites undergraduates from across the country in an NSF REU Site at USC. 64 students in computer science, engineering, geoscience, cinema, economics, mathematics, architecture, communications and pre-law majors have participated since Summer 2002. SCEC/USEIT interns interact in a team-oriented research environment with some of the nation's most distinguished geoscience and computer science researchers. The goals of the program are: (1) to allow undergraduates to use advanced tools of information technology to solve important problems in interdisciplinary earthquake research; (2) to close the gap between two fields of undergraduate study--computer science and geoscience; and (3) to engage non-geoscience majors in the application of earth science to the practical problems of reducing earthquake risk.

SCEC/USEIT interns have developed the "LA3D" and "SCEC-VDO" (Visual Display of Objects) visualization platforms, object-oriented, open source, and Internet-enabled systems. These tools are being used by SCEC researchers interested in displaying objects that represent the complex subsurface structure of Southern California. The interns are encoding visualization objects, creating a *visual vocabulary* comprising earthquake-related objects that are interconnected into a new *visual ontology*. In addition, the interns have built scripting capabilities into the tools, to allow the creation of *visual stories* that communicate the

results of SCEC system-level research.

Electronic Encyclopedia of Earthquakes (E3). SCEC is developing this digital library of educational resources and information with CUREE and IRIS, with funding from the NSF National Science Digital Library (NSDL) initiative. When complete, information and resources for over 500 earth science and engineering topics will be included, with links to curricular materials useful for teaching and learning about earth science, engineering, physics and mathematics. E3 is also a valuable portal to anyone seeking up-to-date earthquake information and authoritative technical sources, and is a platform for cross-training scientists and engineers and will provide a basis for sustained communication and resource building between major education and outreach activities. Scientists, engineers, and educators who have suggestions for content can visit www.scec.org/e3 now to complete the "Suggest a Web Page" form.

E3 is now the primary SCEC *framework* for presenting extensive earthquake science and engineering information, including curricular materials and technical information organized by topical areas. E3 is used to organize materials for SCEC teacher workshops, field trips, exhibits, and other SCEC activities. A sophisticated information system for building and displaying the E3 collection and web pages has been developed, now called the SCEC Community Organized Resource Environment (SCEC/CORE). This content development and management system has now been used to create many other web *and print* resources, such as the main SCEC website and the new version of the *Putting Down Roots in Earthquake Country* brochure.

SCEC's Regional Seismicity and Geodesy Online Education Modules. These interactive online learning resources are based on seismic data from the SCEC data center, and geodetic data from the Southern California Integrated GPS Network (SCIGN). The modules are used by high school and undergraduate students and teachers, and will be integrated with the Electronic Encyclopedia of Earthquakes) (http://www.scecdc.scec.org/Module and http://scign.jpl.nasa.gov/learn). A new project is underway with Lisa Grant (UCI), Ralph Archuleta (UCSB) and Debi Kilb (Scripps) to work with SCEC staff to update functionality and content of several activities within the Seismicity module.

Seismic Sleuths Revision. SCEC is revising the AGU/FEMA Seismic *Sleuths* middle school earthquake curriculum to reflect advances in science and technology since the last update in 1995. The objectives are to promote and improve natural hazard education for students; to foster preparedness for natural hazards through empowerment and encouraging personal responsibility; to provide an updated and redesigned learning tool that can be easily integrated into a curriculum based on national standards; and to provide constant updates in science content, pedagogy, and resource information through an interactive website. Each unit has been streamlined and can stand-alone in print or on the Internet in order to be used in a variety of environments. In addition, a television special (*Earthquakes: Seismic Sleuths*) based on the series has been created and aired worldwide, made possible by funding from the California Department of Insurance, the Institute for Business and Home Safety, and SCEC. The hour-long video was first broadcast on "Assignment Discovery" in spring, 2001. The video can be used by teachers as an excellent advance organizer, or viewed by interested citizens who want to learn more about earthquakes, the destruction they can cause, the scientists and engineers who study them, and what they can do to prepare. (http://school.discovery.com/lessonplans/programs/earthquakes-gettingready/q.html)

ShakeZone. In partnership with the Riverside County Children's Museum ("KidZone"), the CUREE-Caltech Woodframe Project and UC Riverside, SCEC created an educational, family-oriented exhibit on earthquakes ("ShakeZone") that opened in January 2002. The mission of the exhibit is to reach the local community, particularly the 20,000 elementary school children who visit KidZone each year, with positive messages about studying the Earth and preparing for earthquakes. The exhibit presents information about science, engineering, safety and mitigation. A shake table, an interactive computer display, and wall displays teach the visitors about the tools and techniques of earth scientists, engineers and emergency services personnel. The initial exhibit closed in fall 2005, and SCEC is working with the museum to develop a smaller but updated exhibit. Much of the new exhibit will feature materials and displays provided by the Scripps Institution of Oceanography Birch Aquarium, at the completion of their temporary earthquake exhibit in October 2005. (http://www.kidzone.org)

Teacher Workshops. SCEC offers teachers 2-3 full-day professional development workshops each year. The workshops provide a connection between developers of earthquake education resources and those who use these resources in the classroom. The workshops include: content and pedagogical instruction; ties to national and state science education standards; and materials teachers can take back to their classrooms. Activities include: the Dynamic Plate Puzzle; Seismic Waves with Slinkys; Brick and Sandpaper Earthquake Machine; and a Shake Table Contest. At the end of the day teachers receive an assortment of free materials provided by IRIS, including posters, maps, books, slinkys, and the binders with all the lessons from the workshop included.

In 2003 SCEC began a partnership with the SIO Visualization Center to develop teacher workshops. Facilities at the Visualization Center include a wall-sized curved panorama screen (over 10m wide). This allows the workshop participants to be literally immersed in the images being discussed. For example, when the traditional 2D maps of earthquake epicenter data were viewed in 3D, the teachers immediately understood that the faults depicted by the earthquake locations were 3D planes, not 2D lines. Three workshops have now been held with SIO, and will continue each summer. (www.scec.org/education)

USC Science Education Collaborative. Since 2003, SCEC has greatly increased engagement with the inner-city neighborhoods around USC to form various partnerships in order to improve science education and increase earthquake awareness in the local community:

- One of these partnerships is with USC's Joint Education Project (JEP), which sends USC students into local schools to teach eight one-hour lessons pertaining to what they are learning in their classes. SCEC, in partnership with the USC department of Earth Sciences, now provides educational resources to JEP students in several earth-science courses, and trains the students how to use the resources in their lessons.

- Another USC-area related partnership is with the Education Consortium of Central Los Angeles (ECCLA), which funds three-week intersession programs in inner-city Los Angeles. SCEC revised and added additional materials to their existing earthquake curriculum, which was renamed "Earthquake Explorers." SCEC also provided educational materials, and arranged guest speakers and field trips.

SCEC has also partnered with JEP, USC Mission Science, USC Sea Grants and the Jet Propulsion Laboratory (JPL) to create hands-on workshops for teachers at schools in the neighborhoods surrounding USC.

National Association of Geoscience Teachers Far Western Section 2004 Annual Meeting. SCEC hosted this meeting with the USC Earth Science Department the last weekend of February 2004. The teachers in attendance ranged from elementary school teachers up through community college professors. A reception for the teachers began the meeting on Friday evening, which was followed by talks given by Tom Henyey and Tom Jordan, past and present directors of SCEC. On Saturday, teachers chose one of three all day field trips: Faults of Los Angeles, led by James Dolan, The Geology of the Palos Verdes Peninsula, led by Tom Henyey, and Oceanography and Coastal Geography led by Steve Lund. The meeting banquet was held Saturday evening with Lucy Jones as keynote speaker. Dr. Jones spoke about earthquake prediction, followed by a question and answer session for the teachers. On Sunday the teachers had a choice of an all day earthquake education workshop or one of three half day field trips: The La Brea Tar Pits, Southern California Integrated GPS Network, or the California Institute of Technology Seismology Lab.

Teaching Aids for University and College Level Classes: Visual Objects and QuickTime Movies [managed by Debi Kilb, UCSD/IGPP] As proposed teaching modules have been specifically designed to meet the needs of faculty members at SCEC based institutions that can be used in undergraduate and graduate classes and provide an introduction to 3D interactive exploration of data. At the 2003 SCEC meeting many of the visual objects were previewed and netted a favorable response (12 people asked for follow up information). To date Kilb has either discussed and/or ported products to 28 people from ~20 different institutions and discussions to improve and augment these teaching tools are ongoing. Due to current space limitations only some of the end products (e.g., QuickTime movies, interactive 3D data sets, image galleries) are currently accessible through a web-based digital library interface (http://www.siovizcenter.ucsd.edu/library.shtml) at the Visualization Center at Scripps Institution of Oceanography. There have been 550 unique visitors to these pages within the last 6 months. Plans are also in place to integrate many of the images and visual objects that we developed into the Electronic Encyclopedia of Earthquakes website (http://www.scec.org/e3/)
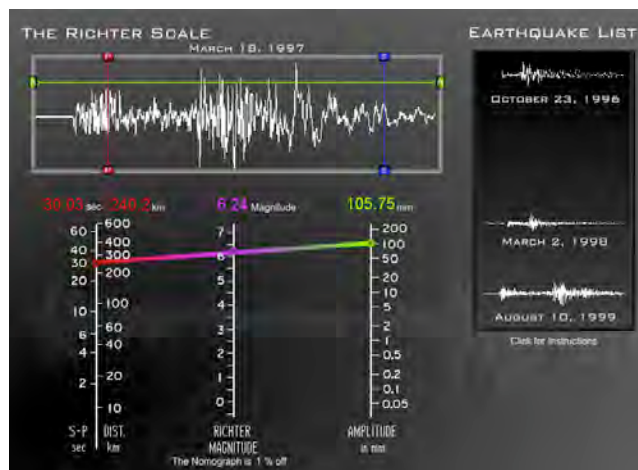
Teaching Aids for University and College Level Classes: Online Course development. This project is developing resources for undergraduate general education earthquake courses. Materials will include online PowerPoint files for lectures, portable demonstrations, and interactive online exercises for use in the classroom or by students at home. The online materials will be freely available to instructors at any school. The project may lead to the development of a consensus-based course that could allow interaction between students and faculty at separate institutions, with the ultimate goal of wide dissemination to the SCEC community, college and university teachers, and others.

Assessment

Education programs in SCEC2 have greatly expanded the Center's ability to provide earthquake information and resources for students and teachers. By the beginning of SCEC3, these activities will be even further developed, especially the *Electronic Encyclopedia of Earthquakes*.

The SCEC2 Intern programs have grown each year, and with the advent of the SCEC/UseIT program, SCEC2 has brought students to research and/or the earth sciences who had no previous interest. Also, of the 73 SCEC2 interns (SURE and USEIT combined): 29 were female; 7 were Hispanic, 1 was African American, and 1 was Pacific Islander. Of the 2004 interns, 7 were first-generation college students and 6 were from schools without research opportunities (this is the first year this information was tracked). In terms of attracting more students to the earth sciences, one student changed from an astrophysics major to a geology major, and two computer science undergraduates are now pursuing graduate degrees in geophysics. Through extensive recruitment activities in 2005 and beyond, we hope to continue to offer research opportunities to well-qualified and diverse students from around the country.

However, due to a focus on public outreach activities during the past few years (see next section), less time has been available to offer additional teacher workshops, develop as many curricular materials as originally planned, and establish partnerships with educational organizations on the same scale as our partnerships in other CEO focus areas. Building upon the resources developed in SCEC2, and expanding their geographic reach, must be a priority of the SCEC3 education effort.

Public Outreach Activities

This Focus Area involves activities and products for media reporters and writers, civic groups and the general public, and has been a high priority during SCEC2. Much of 2003 was focused on planning activities and developing products for the 10-year anniversary of the Northridge earthquake in January 2004. These activities have continued into 2005 with product revisions and continue interactions with public outreach partners.

Objectives

The SCEC2 objectives for the Public Outreach Focus Area are to (1) provide useful general earthquake information, (2) develop information for the Spanish-speaking community, (3) facilitate effective media relations, and (4) promote SCEC activities.

Results

<u>SCEC Webservice and SCEC News</u>. SCEC's webservice presents the research of SCEC scientists, provides links to SCEC institutions, research facilities, and databases, and serves as a resource for earthquake information, educational products, and links to other earthquake organizations. In 2000 SCEC introduced SCEC News to provide a source of information in all matters relevant to the SCEC community – to disseminate news, announcements, earthquake information, and in-depth coverage of earthquake research, in a timely manner via the World Wide Web. Since its inception in March 2000, over 1800 people have subscribed to e-mailed news "bytes" which announce new articles. (www.scec.org)

Earthquake Country Alliance. To coordinate activities for the 10-year anniversary of the Northridge Earthquake in January 2004 (and beyond), SCEC led the development of the "Earthquake Country Alliance" (ECA). This group has been organized to present common messages, to share or promote existing resources, and to develop new activities and products. The ECA includes earthquake scientists and engineers, preparedness experts, response and recovery officials, news media representatives, community leaders, and education specialists. The ECA is now the primary SCEC framework for maintaining partnerships and developing new products and services for the general public.

The ECA first met in June 2003 to begin making plans for the Northridge earthquake anniversary. This planning resulted in a complementary set of activities (planned by the ECA or by individual organizations). The ECA will continue to coordinate public awareness efforts in southern California through these and additional products and activities over the next year and beyond. In 2006, the centennial anniversary of the 1906 San Francisco earthquake will be commemorated and the Alliance will participate in educational activities and events with partners in the Bay Area.

Putting Down Roots in Earthquake Country. In 1995 SCEC, USGS, and a large group of partners developed a 32-page color handbook on earthquake science, mitigation and preparedness. For the 10-year anniversary of the Northridge earthquake, a new version was produced by SCEC and the newly-formed ECA. The updated handbook features current understanding of when and where earthquakes will occur in Southern California, how the ground will shake as a result, and descriptions of what information will be available online. The preparedness section has been completely reworked and is now organized according to the "Seven Steps on the Road to Earthquake Safety." These steps provide a simple set of guidelines for preparing and protecting people and property. 200,000 copies were printed in January 2004, with funding from the California Earthquake Authority (CEA) and FEMA, and another 150,000 copies were printed in September 2004, with funding from CEA, USGS, Edison, Amgen, Quakehold, and others. In Spring 2005 a further revision was printed (60,000 copies) with coupons for home mitigation products. Copies of the document have been distributed at home improvement centers (on tables with preparedness products), by the American Red Cross (at neighborhood safety trainings), and by many others. The updated handbook is now at www.earthquakecountry.info/roots.

Putting Down Roots is the principal SCEC framework for providing earthquake science, mitigation, and preparedness information to the public. The "Roots" framework extends beyond the distribution of a printed brochure and the online version. For example, the Birch Aquarium in San Diego developed an earthquake exhibit which featured a "Seven Steps" display, and the Emergency Survival Program (managed by LA County) will be basing it's 2006 campaign around the "Seven Steps." In October 2004 over 15,000 copies were included in the Earth Science Week packets distributed to science teachers and others nationwide. In early 2006 the first-ever Spanish version of the document will be distributed in Southern California, and will be followed by a Spring 2006 english edition with many updates.

The new version of *Putting Down Roots* was designed to allow other regions to adopt its structure and create additional versions. The first is a Northern California version produced

by a partnership led by the USGS with SCEC, local and state emergency managers, the Red Cross and many other organizations. The handbook was revised with Bay Area hazards and a new section called "Why Should I Prepare?" was added that includes scenarios for likely damage, casualties, etc., and how life will change during a large earthquake in the region. Over 750,000 copies were printed in September, 2005, with funding from the California Earthquake Authority, USGS, FEMA, Red Cross, OES, CGS, and several others). 500,000 of these copies (with an inserted coupon for furniture straps and other mitigation products) were distributed in the San Francisco Chronicle. The handbook is available at home improvement stores throughout the Bay Area, and is being distributed by the Red Cross and USGS. Because of high demand a second printing in October, 2005, produced another 130,000 copies for distribution by the USGS and in stores.

Earthquake Country Alliance Website. SCEC hosts this new web portal (www.earthquakecountry.info.), which provides answers to frequently asked questions and descriptions of other resources and services that ECA members provide. The portal uses

technology developed for the E^3 project (see above). Each ECA member can suggest links to their organization's resources as answers to questions listed on the site. The structure is set up very similarly to the new *Putting Down Roots:* sections include "what should I know?" "why should I care?" "what should I do before?" and "what should I do during and after?"

The site is set up separately from the main SCEC web pages (though has attribution to SCEC) so that all members of the ECA see the site as their own and are willing to provide content. The site features the online version of *Putting Down Roots* and special information pages that all groups can promote, such as a special page about the "10.5" miniseries and a page about the "Triangle of Life" controversy (see assessments below).

Earthquake Country- Los Angeles. This video was produced by Dr. Pat Abbott of SDSU as the second in his "Written in Stone" series. The video tells the story of how the mountains and valleys of the Los Angeles area formed, including the important role of earthquakes. The video features aerial photography, stunning computer animations, and interviews with well-known experts. The video features 3D fault animations produced by SCEC's "LA3D" visualization system. In addition to conducting several focus groups with teachers and preparedness experts where the video was evaluated, SCEC is also developing curricular kits for school and community groups to accompany the video, and has added captions in both English and Spanish. These kits will be duplicated in large quantities with funding from the California Earthquake Authority. The Los Angeles Unified School District has asked SCEC to train teachers how to use these curricular kits, and may include the video in a new sixth-grade Earth science curricula soon to be adopted district wide.

Emergency Survival Program SCEC serves on the Coordinating Council of the Los Angeles County-led *Emergency Surival Program*, with emergency managers from all southern California counties, many large cities, the American Red Cross, and Southern California Edison. The primary role of the program is to develop a series of public information materials including monthly Focus Sheets, newsletter articles, and public service announcements related to a yearly theme. In 2006 the program is focusing on earthquakes, with seven of the monthly focus sheets based on the "seven steps to earthquake safety" in *Putting Down Roots in Earthquake Country*.

EqIP. CEO participates in the EqIP (Earthquake Information Providers) group, which connects information specialists from most earthquake-related organizations. EqIP's mission is to facilitate and improve access to earthquake information through collaboration, minimize duplication of effort by sharing information through individual personal contact, joint activities and projects, group annual meetings and biennial forums, and electronic communication. SCEC's former

CEO director was among the founding group members and managed the initial development of EqIP's website which provides a database of descriptions of over 250 organizations with links to their websites. SCEC's current director for CEO is now the Chair of this group. (www.eqnet.org)

Media Relations. SCEC engages local, regional and national media organizations (print, radio and television) to jointly educate and inform the public about earthquake-related issues. The goal has been to communicate clear, consistent messages to the public–both to educate and inform and to minimize misunderstandings or the perpetuation of myths. . For example, at the SCEC 2004 Annual Meeting a multi-topic press conference was held to provide SCEC's perspective on recent earthquake predictions, discuss large earthquakes on the San Andreas fault, and announce new results from the SCEC TeraShake project. In May 2005, CEO organized a major press briefing to announce the results of a study of losses expected from a range of earthquakes on the Puente Hills fault (www.scec.org/puentehills) which received broad regional, national, and international coverage. SCEC CEO encourages scientists who are interested in conducting interviews with media reporters and writers to take advantage of short courses designed and taught by public information professionals.

Wallace Creek Interpretive Trail. In partnership with The Bureau of Land Management (BLM), SCEC designed an interpretive trail along a particularly spectacular and accessible 2 km long stretch of the San Andreas Fault near Wallace Creek. Wallace Creek is located on the Carrizo Plain, a 3-4 hour drive north from Los Angeles. The trail opened in January 2001. The area is replete with the classic landforms produced by strike-slip faults: shutter ridges, sag ponds, simple offset stream channels, mole tracks and scarps. SCEC created the infrastructure and interpretive materials (durable signage, brochure content, and a website with additional information and directions to the trail). BLM has agreed to maintain the site and print the brochure into the foreseeable future. (www.scec.org/wallacecreek)

SCEC Publication Distribution. Copies of SCEC's field trip guides, technical reports (Phase I & II reprints, Liquefaction and Landslide Mitigation Guidelines reports, etc.), and *Putting Down Roots in Earthquake Country* general public handbook (see below) are widely distributed at workshops, earthquake preparedness fairs, and through the SCEC website. (www.scec.org/resources/catalog)

Assessment

The public outreach products developed, updated, and maintained during SCEC2 represent a new capacity for providing earthquake-related information and services. Over the next few years and into SCEC3, these resources will allow SCEC and our partners to provide continually updated information in a broad assortment of venues and mechanisms. For example, because of the ECA, a coordinated response was possible during 2004 to several public awareness threats: a mini-series about a "10.5" magnitude earthquake, a widely-reported prediction for an a 6.5 magnitude earthquake in southern California, and a mass-email campaign promoting a (dangerous) alternative to the "drop, cover, and hold on" position all preparedness groups endorse. ECA members were able to direct their audiences to a common webpage for information, rather than creating their own response. The ECA e-mail list has provided a way for members to communicate with a larger group of their peers, and meetings have brought together existing partners and new allies.

During SCEC2 the news media has become increasingly aware and interested in SCEC research and now look to SCEC as an international source of information about earthquakes. After significant earthquakes and major earthquake-related news stories, reporters from around the world call SCEC for interviews. It is essential to carefully manage SCEC's media presence and we plan to continue to build awareness of SCEC as a media resource.

Knowledge Transfer Activities

There is a widely perceived gap between basic earthquake science and its implementation in risk mitigation. SCEC's mission dictates that it work to close this implementation gap with engineers, emergency managers, public officials, and other users of earthquake science. The Knowledge Transfer focus area coordinates these activities.

Objectives

The SCEC2 objectives for the Knowledge Transfer focus area are to (1) Engage in collaborations with earthquake engineering researchers and practitioners, (2) develop useful products and activities for practicing professionals, (3) support improved hazard and risk assessment by local government and private industry, and (4) promote effective mitigation techniques and seismic policies.

Results.

Implementation Interface. A goal of SCEC2 has been to establish a closer working relationship with the earthquake engineering community that would be more effective in implementing physics-based hazard and risk analysis. We therefore established a new working group, the *SCEC Implementation Interface* (P. Somerville, leader; R. Wesson, co-leader), as a funded component of the Center's program to promote these partnerships. It coordinates activities with all other SCEC working groups, particularly the Seismic Hazard Analysis focus group (N. Field, leader; D. Jackson, co-leader), which is responsible for developing earthquake forecasting models (with the ESP and Fault Systems groups) and intensitymeasure relationships (with the Ground Motions
group).

The objectives of the Implementation Interface are to (1) integrate physics-based seismic hazard analysis (SHA) developed by SCEC into earthquake engineering research and practicethrough two-way knowledge transfer and collaborative research, (2) provide a flexible computational framework for system-level hazard and risk analysis through the OpenSHA platform and the Community Modeling Environment, and (3) interface SCEC research with major initiatives in earthquake engineering, such as the Next Generation Attenuation project and the NSF-sponsored George E. Brown Network for Earthquake Engineering Simulation (NEES).

The first initiative was to set up a research partnership with the Pacific Earthquake Engineering Research (PEER) Center and its companion PEER-Lifelines Program. Several efforts were jointly funded by SCEC and PEER, including a large collaboration to study basin effects through wavefield modeling, led by S. Day (see Fig. 2.16), and a collaboration between A. Cornell and P. Somerville to develop vector-valued probabilistic seismic hazard analysis (VPSHA; Bazzuro and Cornell, 2002). The latter led to a novel application of VPSHA to the use of precariously balanced rocks in PSHA by Purvance et al. (2004) (see Fig. 2.20).

The partnership with PEER continues to develop through the Next Generation Attenuation (NGA) Project, a major collaboration involving SCEC, the PEER-Lifelines Program, and USGS, which has been sponsored by the California Department of Transportation, the California Energy Commission, and PG&E. In its current phase, NGA-E (for *empirical*), SCEC scientists have used validated broadband ground motion simulation techniques to investigate features of attenuation models poorly constrained by currently available strong motion data, including rupture directivity effects, footwall vs. hanging wall effects for dipping faults, depth of faulting effects (buried vs. surface rupture), static stress drop effects, and depth to basement and basin effects. SCEC work has involved the use of results from dynamic rupture models and foam experiments to shed light on the physics of rupture directivity and shallow/deep faulting effects on strong ground motion; the development of pseudodynamic models to facilitate the representation of the physics of these phenomena in earthquake source models; and kinematic ground-motion simulations of these effects using pseudodynamic source models to guide the development of

functional forms of ground-motion models representing these effects. The new set of attenuation models produced by the NGA-E project will be finalized in Spring, 2005. These models will significant change hazard estimates at short distances from seismic sources and how such estimates depend on magnitude.

The activities of the Implementation Interface were broadened through a workshop held in October 2003, which identified end-to-end simulation from the earthquake source through to structural response ("rupture-to-rafters") as a key area for SCEC collaborations with the engineering community. This idea is the focus of a major SCEC3 initiative that will involve partnerships with PEER and CUREE (§III.C.5).

A collaboration between SCEC and the USGS has developed OpenSHA (Field et al., 2003), an open-source, object-oriented, web-enabled software integrated into the SCEC Community Modeling Environment that provides a very flexible platform for seismic hazard analysis. OpenSHA allows investigators to easily perform strong motion simulations and seismic hazard analyses, accounting for multiple earthquake potential models and multiple approaches to ground motion prediction, including physics-based simulation approaches as well as conventional attenuation relation approaches. The OpenSHA group has participated in the formal PSHA-validation exercises sponsored by the PEER-Lifelines Program, and the software is gaining wide acceptance as the platform-of-choice for PSHA calculations.

Open-Source Risk Assessment Workshop To discuss if the open-source concept (a key complement of OpenSHA) is appropriate for risk assessment software, SCEC co-sponsored a workshop in March, 2005. Participants included scientists and engineers involved with earthquake, wind, and flood modeling, individuals from reinsurance and commercial risk model companies, and other parties interested in catastrophe risk modeling. Presentations and discussions focused on the need and potential uses for an open-source risk model, on ongoing efforts in earthquake, wind, and flood communities, and on potential next steps. The result was the formation of a new community, organized at http://www.open-risk.org/ and a white paper was produced that ouitlines next steps.

HAZUS Activities. SCEC is coordinating the development and activities of the Southern California HAZUS Users Group (SoCalHUG) with the Federal Emergency Management Agency (FEMA) and the California Office of Emergency Services (OES). HAZUS (www.hazus.org) is FEMA's earthquake loss estimation software program. SoCalHUG brings together current and potential HAZUS users from industry, government, universities, and other organizations to (a) train GIS professionals in HAZUS earthquake loss estimation software, (b) improve earthquake databases and inventories, and (c) develop and exercise emergency management protocol. SCEC is considering how it can improve the data and models that HAZUS uses in its calculations, and sees this community as an important audience for SCEC research results. SCEC CEO has organized four general meetings of the user group and several HAZUS trainings. The most recent was held in June, 2005, at SCEC headquarters at USC, with ten participants trained to be HAZUS "vendors" in the region. The training was preceeded by a User Group meeting, and will be repeated in 2006. (www.hazus.org)

Landslide Report and Workshops. In 1998, a group of geotechnical engineers and engineering geologists with academic, practicing, and regulatory backgrounds was assembled under SCEC auspices as a committee (chaired by Thomas Blake) to develop specific slope stability analysis implementation procedures to aid local southern California city and county agencies in their compliance with review requirements of the State's Seismic Hazard Mapping Act. The work of that committee resulted in the development of a relatively detailed set of procedures for analyzing and mitigating landslide hazards in California (edited by T. Blake, R. Hollingsworth, and J. Stewart), which SCEC published in 2002 and is available on SCEC's web site (www.scec.org/resources/catalog/hazardmitigation.html). In June 2002, over 200 geotechnical

engineers, practicing geologists, government regulators and others attended a two-day SCEC workshop that explained the Landslide document. Because of the outstanding response to the sold-out workshop, a second workshop was held in February 2003 for those who were unable to attend the first. The course materials (now available for order) include extensive printed materials including all PowerPoint presentations, and two CDs with software tools and PDF files of all presentations and printed materials. As a bonus, the CD includes PDF files of the presentations given at the 1999 SCEC Liquefaction workshop and both the Landslide and Liquefaction Procedures documents. Plans are now being discussed to offer these workshops in Northern California in 2005.

EERI Southern California Chapter. Since 2003, SCEC has hosted the bi-monthly meetings of the southern California chapter of the Earthquake Engineering Research Institute. These meetings include a speaker on a particular topic of interest to the attendees, typically civil, structural, and geotechnical practicing engineers. For example, on November 19, 2003, over 40 people attended a meeting with a speaker addressing new research on "Assessment and Repair of Earthquake Damage in Woodframe Construction," and on January 19, 2005, 20 EERI members attended a briefing on the recent Sumatran earthquake and Indian Ocean Tsunami.

International Earthquake Mitigation and Preparedness SCEC participates with the City of Los Angeles in the international *Earthquakes and Megacities Initiative,* as part of the Americas Cluster which includes Los Angeles, Mexico City, Bogota, and Quito. Each city is represented by emergency managers and academic representatives. The goal of the initiative is to promote the sharing of best practices for earthquake mitigation and preparedness and to develop common resources and joint projects. In addition to developing partnerships with other cities, participation in this program has also strengthened SCEC's ties with the City of Los Angeles.

Assessment

Much of the SCEC2 knowledge transfer effort to date has been focused on developing partnerships with research and practicing engineers, and educating the users of technical products. By the end of SCEC2, new resources such as OpenSHA and the SCEC Community Modeling Environment will greatly expand the services SCEC can provide. SCEC partnerships with earthquake engineering organizations are now very strong, and we expect will continue to develop significant results through joint research projects. These results may lead to safer buildings through improved modeling of ground motions and improved engineering design to accommodate these ground motions. However, such improvements will only become implemented if building codes are updated and local governments regulate construction accordingly. To truly achieve its mission of reducing earthquake risk, SCEC must work at all levels of implementation, from basic research to enforcement of building codes at the local level.

To identify how to strengthen risk communication between SCEC and local governments, L. Grant and E. Runnerstrom of UC Irvine were supported by CEO to study the utilization of seismic hazard data and research products by cities in Orange County, CA. The study focused on evaluating the effectiveness of previous SCEC activities and products in communicating seismic risk at the municipal level. Orange County is well suited for this study because it contains diverse sociologic, geologic, and seismic conditions. In particular, the study looked at the direct use of SCEC products by local-level policy-makers and staff. By understanding the variation in the use of SCEC products, effective areas or targets within cities for risk communication should emerge. Preliminary analyses of the data suggest that SCEC products are underutilized for local planning and seismic hazard mitigation. This may be partly because of nested references within other resources that are non-exclusive to SCEC, and other use of SCEC products without direct citation. The study focused on Safety Elements and related documents (including Technical Background Reports) for Orange County's 34 cities and found that nearly all cities in Orange County relied on planning and/or geotechnical firms to prepare technical reports or Safety Elements. Therefore, these consultants would be excellent targets for seismic risk and hazard communication by SCEC.

SCEC Community Development

The foundation of SCEC CEO is our partnerships and participation in many communities in each of the previous focus areas. Supporting the SCEC community from within is a parallel activity that bolsters our ability to reach out effectively to others. This focus area includes activities and resources relevant to SCEC scientists and students.

Objectives

The SCEC2 objectives for the SCEC Community Development focus area are to (1) increase the diversity of SCEC leadership, scientists, and students, (2) facilitate communication within the SCEC Community, and (3) increase utilization of products from individual research projects.

Results

SCEC Diversity Issues and Possible Activities for a Diversity Task Force. SCEC is committed to supporting the participation of a diverse community of scientists, students, and staff and others. At the beginning of SCEC2, a Diversity Task Force of the Board of Directors was established to identify policies for increasing diversity. This Task Force began by identifying several issues:

- The leadership of SCEC, including the Officers and the Board, is predominantly white and male.
- The Planning Committee has significant power in SCEC2 and serves as a stepping-stone to leadership. It would be desirable for the planning committee to be significantly diverse.
- Although many women and minority students are involved in intern and other programs at the undergraduate level, successively smaller numbers of women and minorities are involved at the graduate student, post doctoral, junior faculty and senior faculty levels.
- SCEC is a consortium of institutions and as an organization has very little control in hiring scientists and staff, and in admitting students. Diversity goals can be encouraged but not mandated.
- The current situation is not unique to SCEC, but reflects historical trends in the earth and physical science communities.

Several activities to address these issues have been identified, including improved demographic assessments of SCEC participants (for a baseline understanding of diversity in SCEC), establishing goals for increasing the numbers of women and under-represented minorities at all levels of SCEC leadership (Board, Planning Committee, etc.), and establishing policy guidelines for the selection of individuals for "stepping stone" opportunities, including speaking at SCEC meetings, and membership on SCEC committees. These activities have been implemented. For 12 years, the SCEC intern program has given research opportunities to studens with diversity as a goal, and long-term tracking shows that many of the under-represented students that participated are still in science careers.

Of the 580 participants throughout SCEC2 (some of which no longer are involved), diversity at various levels seems to reflect historical trends, with much greater diversity among students than senior faculty. In terms of gender, women account for 42% of SCEC undergraduates, 36% of graduate students, 27% of non-faculty researchers, 42% of administrative staff, and 15% of faculty researchers. SCEC has increased the representation of women on its Board of Directors (2 of 15), though board members are appointed by institutions and not selected by SCEC leadership. Three women now participate in the SCEC Planning committee, and SCEC hopes to continue to identify women within each working group willing to take on leadership roles.

Participation of under-represented minorities in SCEC also reflects general Earth science levels, and is generally much lower than preferred at this time. Overall, of the 580 SCEC2 participants, 25 are latino, 10 are Native American, 3 are black, 2 are Pacific Islander, 105 are asian, 413 are white, and 32 are unknown.

Other plans that have been discussed include the establishment of a "sounding board" (a committee of SCEC participants who could serve as informal counselors), holding an evening session at the annual meeting where diversity issues could be aired, developing a mentoring program at a variety of scales (especially at the graduate student, post doc and junior faculty levels), and identifying successful diversity practices of other large science organizations. These

and other activities are being considered to continue to support the career trajectories of all members–and potential members– of the SCEC community

<u>SCEC Community Information System (SCEC/CIS)</u>. SCEC has developed a new online database system, using technology developed as part of the Electronic Encyclopedia of Earthquakes project. This system was first implemented to facilitate registration for the 2002 SCEC Annual Meeting, and has since been used for registration for most SCEC workshops and meetings, for tracking SCEC publications, for submitting and reviewing SCEC proposals each year, maintaining demographic information, managing e-mail lists, and for providing access to contact information for each of the 750+ members of the SCEC Community. This system also allows SCEC CEO to better track research projects with potential CEO applications.

As a service for other communities associated with SCEC, similar interfaces have been developed using the same system. Such communities include the California Post Earthquake Information Clearinghouse, the Earthquake Country Alliance, the Earthquake Information Providers (EqIP), and soon others. Members of multiple communities only need to remember a single password and update their information in one location, to keep their information current for all communities.

Assessment

This is a new area of organized attention in SCEC2, and the structures and mechanisms for achieving the objectives listed above are still in development. Still, SCEC has made progress already in increasing diversity in the community, such as improved representation of women in SCEC leadership positions. The issue of diversity in the sciences extends far beyond SCEC, however since SCEC is a sufficiently large community with significant representation at the nation's leading research institutions, there is an opportunity for SCEC to make a difference.

The objective of increasing the utilization of products from individual research projects (as opposed to products developed from overall SCEC system-level results) has not yet been sufficiently addressed. One new mechanism for promoting awareness of these projects is "SCEC Nuggets," 1-2 page summaries basic research results that were requested for the first time in late 2004. These summaries will also allow SCEC CEO to better identify research projects with potential educational or technical products.

CEO Management Activities

<u>Recruit CEO Advisory Panel.</u> To expand participation by partners and recipients of SCEC CEO activities, a small advisory panel will be recruited to help review progress and provide suggestions for opportunities that might otherwise be unknown.

<u>Develop strategic plan</u>. Continue development of long-term strategic plan, with a focus on evaluation strategies. The CEO advisory panel will be instrumental in providing guidance for evaluation priorities. Careful assessment must be conducted at every stage of program development in order to ensure that the program can be responsive to audience needs and effective in achieving its goals:
1) Stakeholder needs assessment will determine a base level of knowledge among various audiences and identify specific needs to be addressed. This information will be gathered through document reviews and interviews with representatives of the key targets audience groups.
2) Evaluation design will consider the types of evaluation methodologies and logic models SCEC CEO will employ, based on decisions of what should be evaluated (quality and/or quantity of products? Usefulness of services? Cost-effectiveness?) and why the

evaluation is needed (improve the discipline of E&O? Accountability to agency management and stakeholders? Improve service delivery and program effectiveness?)

3) Performance measurement of product development and implementation will involve collecting accountability information for stakeholders, tracking intended and unintended outcomes of the program, and providing information vital to program improvement in order to achieve pre-established goals. This information can be useful for management of activities, resources, and partnerships.

4) Programmatic assessment of the overall success in achieving SCEC's stated goals and identification of what was successful, what failed, and why. This step is broader than performance measurement as it addresses the long-term, overall affect of the CEO program as a whole, and has implications for other large-scale E&O programs.

Represent SCEC as Member of:
- Network for Earthquake Engineering Simulation (NEES) EOT Committee
- Earthquake Information Providers (EqIP) group (Benthien is Chair)
- Earthquakes and Mega Cities Initiative (Los Angeles representative)
- Western States Seismic Policy Council
- California Post-Earthquake Technical Information Clearinghouse (Benthien is chair of Information Technology workgroup)
- Emergency Survival Program Coordinating Council
- Southern California HAZUS Users Group (Benthien is project lead)
- EERI Southern California Chapter (SCEC hosts bimonthly meetings)
- EERI Mitigation Center So. Cal. Planning Committee
- City of Los Angeles Local Hazard Mitigation Grant Advisory Committee
- County of Los Angeles Local Hazard Mitigation Grant Advisory Committee

Document and Report on CEO activities. Each year many presentations and reports are prepared to describe the activities of the CEO program. In 2003 a paper was published in a special issue of Seismological Research Letters focused on education and outreach.

V. Director's Management Report

The following report was presented at the SCEC Annual Meeting on September 12, 2005, by the Center Director, Tom Jordan

I welcome you all to the 2005 Annual Meeting in Palm Springs. This will be the fourth community-wide gathering since SCEC was reconfigured as a free-standing center on February 1, 2002. The past year has been exceptionally active, and the meeting agenda is chock full of sessions where the results of your efforts will be presented and discussed. A particularly notable accomplishment was the submission of the SCEC3 proposal to the National Science Foundation and U.S. Geological Survey, which maps out the Center's plans for 2007-2012. As of this writing, we have not received official word about the status of our proposal, but the site review in early June seemed to go very well, and I am optimistic that our plan will be accepted by both agencies. I will summarize elements of the SCEC3 plan in my report below.

In addition to the working group sessions, the agenda features some outstanding science presentations, an outstanding set of science posters, as well as a variety of IT demonstrations, education & outreach activities, and social gatherings. I look forward to participating with you in all of these events.
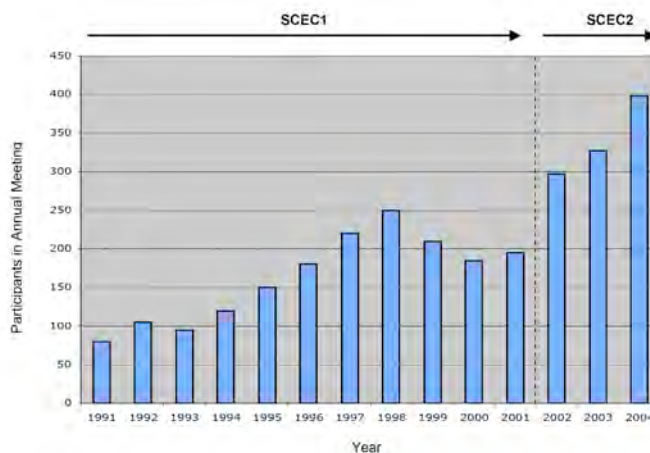
Figure 1. Registrants at SCEC Annual Meetings, 1991-2004.

Organization and Leadership

SCEC is an institution-based center, governed by a Board of Directors who represent its members. Over the past year, UC Riverside became a core institution, and two new organizations, the University of Utah and the Institute of Geological and Nuclear Sciences (New Zealand), joined as participating institutions, raising the membership to 15 core institutions and 40 participating institutions (Table 1). A January, 2005, census indicated that 565 scientists and other experts are involved in active SCEC projects, which makes SCEC one of the largest

collaborations in all of geoscience. Another measure of SCEC involvement—registrants at our annual meetings—is shown for the entire history of the Center in Figure 1.

Table 1. SCEC Member Institutions (September 1, 2005).

Core Institutions (15)	Participating Institutions (40)
California Institute of Technology 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 Nevada, Reno University of Southern California (lead)	Arizona State University; Boston University; Brown University; Cal-State, Fullerton; Cal-State, Northridge; Cal-State, San Bernardino; California Geological Survey; Carnegie Mellon University; Case Western Reserve University; Central Washington University; CICESE (Mexico); ETH (Switzerland); Institute of Earth Sciences of Academia Sinica (Taiwan); Institute of Geological and Nuclear Sciences (New Zealand); Jet Propulsion Laboratory; Lawrence Livermore National Laboratory; National Chung Cheng University (Taiwan); National Taiwan University (Taiwan); National Central University (Taiwan); Oregon State University; Pennsylvania State University; Rensselaer Polytechnic University; Rice University; SUNY Stony Brook; Texas A&M University; UC, Berkeley; UC, Davis; UC, Irvine; UC, Santa Cruz; University of Colorado; University of Kentucky; University of Massachusetts; University of New Mexico; University of Oregon; University of Utah; University of Western Ontario (Canada); URS Corporation; Utah State University; Whittier College; Woods Hole Oceanographic Institution

Board of Directors. Under the SCEC2 by-laws, each core institution appoints one board member, and two at-large members are elected by the Board from the participating institutions. This year we welcome to the Board Prof. Jim Dieterich, who now represents our newest core institution, UC Riverside. The other 16 members of the Board are Greg Beroza (Vice-Chair/Stanford), Emily Brodsky (UCLA), Jim Brune (UNR), Doug Burbank (UCSB), Steve Day (SDSU), Bill Ellsworth (USGS-Menlo Park), Lisa Grant (At-Large), Tom Heaton (Caltech), Tom Herring (MIT), Lucy Jones (USGS-Pasadena), Bernard Minster (UCSD), Jim Rice (Harvard), Bruce Shaw (Columbia), Terry Tullis (At-Large), Rob Wesson (USGS-Golden), and myself (Chair/USC). John McRaney continues to act with his characteristic efficiency and effectiveness as Executive Secretary to the Board.

Planning Committee. One of our most important organizations is the SCEC Planning Committee, which is chaired by Ralph Archuleta, SCEC's Deputy Director. 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 membership includes the leaders of the major SCEC working groups—disciplinary committees, focus groups, and special project groups (Table 2).

Table 2. SCEC Working Group Leadership

Disciplinary Committees

Seismology:	John Vidale (chair)*
	Peter Shearer (co-chair)
Geodesy:	Duncan Agnew (chair)*
	Mark Simons (co-chair)
Geology:	Tom Rockwell (chair)*
	Mike Oskin (co-chair)
Fault & Rock Mechanics:	Terry Tullis (chair)*
	Judith Chester (co-chair)

Focus Groups

Structural Representation:	John Shaw (leader)*
	Jeroen Tromp (co-leader)
Fault Systems:	Brad Hager (leader)*
	Sally McGill (co-leader)
	James Dieterich (co-leader)
Earthquake Source Physics:	Ruth Harris (leader)*
	David Oglesby (co-leader)
Ground Motions:	Paul Davis (leader)*
	Robert Graves (co-leader)
Seismic Hazard Analysis:	Ned Field (leader)*
	David Jackson (co-leader)
Implementation Interface:	Paul Somerville (leader)*
	Robert Wesson (co-leader)

Special Project Groups

SCEC/ITR Project:	Bernard Minster (liaison)*
Borderland Working Group:	Craig Nicholson (chair)*
WInSAR Working Group	Mark Simons (chair)*

* Planning Committee members

Advisory Council. The Center's external Advisory Council 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's 2004 report focused on several key issues regarding the formulation of the SCEC3 proposal, and its analysis influenced how the proposal was constructed in a very positive way. A verbatim copy of this report is included in this meeting volume. In February, 2005, the Council reviewed an intermediate draft of the SCEC3 proposal, and they rendered advice which proved very valuable in finalizing the document.

AC members serve three-year terms. During this past year, five members rotated off the Council: Raul Madariaga (Ecole Normale Superieure), Farzad Naeim (John A. Martin &

Associates), Haresh Shah (RMS, Inc.), Robert Smith (U. Utah,), and Susan Tubbesing (EERI). We thank them for their distinguished service. We note that one of the retiring members, Bob Smith, who served as AC Chair from 2000-2004, will remain involved in SCEC as the representative for one of our new institutions, the University of Utah. (Remember, Bob, you can check out any time you want, but you can never leave!)

The current members of the Advisory Council are: Sean Solomon (Carnegie Institution of Washington), who took over as chair of the AC last year, Jeff Freymueller (U. Alaska), Jack Moehle (PEER), Garry Rogers (Geological Survey Of Canada), Chris Rojahn (Applied Technology Council).

Added to their ranks are five new members, whom we welcome to the AC at this meeting: Gail Atkinson, Carlton University), Lloyd Cluff (Pacific Gas and Electric Co.), Patti Guatteri (Swiss Reinsurance), Kate Miller (University of Texas at El Paso), and John Rudnicki (Northwestern University). We are very fortunate to have such an exceptional group of experts providing the Center with advice.

Working Groups. The SCEC organization comprises a number of disciplinary committees, focus groups, and special project teams. These working groups are the engines of its success, and the discussions they organize at the annual meeting provide critical input to our reporting and planning processes.

The Center sustains disciplinary science through its standing committees in *Seismology*, *Tectonic Geodesy*, *Earthquake Geology*, and *Fault and Rock Mechanics* (a.k.a. the FARMers). These committees are responsible for coordinating disciplinary activities relevant to the SCEC science plan, and they make recommendations to the Planning Committee regarding the support of disciplinary activities and infrastructure.

Interdisciplinary research is organized into five science focus areas: *Structural Representation*, *Fault Systems*, *Earthquake Source Physics*, *Ground Motion*, and *Seismic Hazard Analysis*. The focus groups are the crucibles for the interdisciplinary synthesis that lies at the core of SCEC's mission. For that reason, a substantial fraction of this annual meeting will be devoted to reviewing the focus-group activities and discussing their plans.

SCEC activities classified under special projects include *Southern California Integrated GPS Network* (SCIGN), the *WInSAR Consortium*, the *Borderland Working Group*, and the *Community Modeling Environment* (CME), which is being developed under the SCEC/ITR project.

Following the recommendation of the SCEC Advisory Council in their 2004 report, the SCEC Board of Directors formed a subcommittee to review the future of the SCIGN organization as a standing committee of SCEC.

SCEC's role in oversight of SCIGN began in 1996, primarily to insure that adequate funding could be found to build the array of 250 continuous GPS stations in Southern California and to monitor the construction of the network. With the completion of the SCIGN array in 2002 and a long-term plan in place by 2004 to maintain the stations through a combination of support through PBO/UNAVCO/NSF, the USGS office in Pasadena, and the surveying community through UCSD, SCEC had completed its objectives. In the light of these developments, particularly the initiation of the EarthScope Project, the Board subcommittee recommended that SCEC disband the SCIGN board as a standing committee of SCEC and that all future geodetic activities in SCEC be coordinated by the Tectonic Geodesy disciplinary committee.

The recommendation of the subcommittee was approved by the Board, the director, and by agency officials of NSF and the USGS. The director notified the SCIGN group of the decision in late June, 2005. The SCEC administration will continue to assist the group in the array maintenance transition.

The WInSAR standing committee is now seeking offers for a new host institution as it hopes to renew itself as a global SAR archive.

Interdisciplinary research in risk assessment and mitigation is a primary subject for collaboration between SCEC scientists and partners from other communities—earthquake engineering, risk analysis, and emergency management. These partnerships are facilitated by an *Implementation Interface*, a structure based within the CEO program and designed to foster two-way communication and knowledge transfer. Representatives from a number of partnering organizations will be attending this meeting, and we should use this opportunity to discuss how our efforts toward implementing science for public benefit can be improved.

Communication, Education, and Outreach. Through its CEO Program, SCEC offers a wide range of student research experiences, web-based education tools, classroom curricula, museum displays, public information brochures, online newsletters, and technical workshops and publications.

Much progress has been made on the development of the *Electronic Encyclopedia of Earthquakes* (E3), a collaborative project with CUREE and IRIS. The E3 development system is now fully operational, and a number of encyclopedia entries are in the pipeline. When complete, E3 will include information and resources for over 500 Earth science and engineering topics, with connections to curricular materials useful for teaching Earth science, engineering, physics and mathematics.

The "Earthquake Country Alliance," organized to coordinate activities for the 10-year anniversary of the Northridge Earthquake in 2004, has continue to work together. The Alliance presents common messages, shares and promotes existing resources, and develops new activities and joint products, such as the new version of *Putting Down Roots in Earthquake Country*, now in distribution. It can be downloaded from www.earthquakecountry.info/roots/. Earthquakecountry.info is a multi-organizational collaboration to inform the public about earthquake hazards and safety, organized and hosted by SCEC. In 2005 SCEC worked with a large group of Bay Area scientists, engineers, and emergency managers, led by the USGS, to create the first Bay Area version of *Roots* (soon available through the www.earthquakecountry.info/roots/ website also) and a Spanish-language edition is being prepared for printing in late 2005. A new video, *Written in Stone: Earthquake Country – Los Angeles*, has been produced and will be distributed in curricular kits to schools and community groups. The Los Angeles Unified School District plans to include the video in a new sixth-grade science unit, in every school in the district.

SCEC's Summer Intern program has grown to a new level and now has a year-round counterpart with students working on IT projects at USC and other institutions. Since last summer, 33 students have participated in the program, including 11 students working with scientists throughout SCEC and 22 students enrolled in the USC-based Undergraduate Studies in Earthquake Information Technology (UseIT) program.

Center Budget and Project Funding

The 2005 base funding for the Center is $2,622K from the National Science Foundation and $1,100K from the U.S. Geological Survey. The NSF funding was 9.3% below SCEC's expected allocation and 5% less than last year, owing to budgetary problems within EAR. The base funding of $3.722M was augmented with $60K from the California Earthquake Authority and $50K held over from 2004 for the NGA-H initiative.

The base budget approved by the Board of Directors for this year allocated $2,750K for science activities managed by the SCEC Planning Committee; $380K for communication, education, and outreach activities, managed by the CEO Associate Director, Mark Benthien; $142K for information technology, managed by Information Architect, Phil Maechling; $280K for administration and $150K for meetings, managed by the Associate Director for Administration, John McRaney; and $130K for the director's reserve account. In addition, the Center received $2,000K from NSF's Information Technology Research (ITR) Program for continuing development of the SCEC Community Modeling Environment, and $511K from NSF's Engineering program for the SCEC research in seismic risk reduction. The project managers for the ITR and Engineering grants are Phil Maechling and Paul Somerville, respectively.

I will use the opportunity to review how science projects have been funded as part of the SCEC collaboration, since this ongoing process will be a major concern of the annual meeting. The process of structuring the SCEC program for 2005 began with the working-group discussions at our last annual meeting in September, 2004. An RFP was issued in October, 2004, and 149 proposals (128 projects, considering collaborations) requesting a total of $4,520K were submitted in November, 2004. All proposals were independently reviewed by the director and deputy director. Each proposal was also independently reviewed by the chairs and/or co-chairs of three relevant focus groups or disciplinary committees. (Reviewers were required to recuse themselves when they had a conflict of interest.) The Planning Committee met on January 17-18, 2005, and spent two long days discussing every proposal. The objective was to formulate a coherent, budget-balanced science program consistent with SCEC's basic mission, short-term objectives, long-term goals, and institutional composition. Proposals were evaluated according to the following criteria:

a. Scientific merit of the proposed research.
b. Competence and performance of the investigators, especially in regard to past SCEC-sponsored research.
c. Priority of the proposed project for short-term SCEC objectives.
d. Promise of the proposed project for contributing to long-term SCEC goals.
e. Commitment of the P.I. and institution to the SCEC mission.
f. Value of the proposed research relative to its cost.
g. The need to achieve a balanced budget while maintaining a reasonable level of scientific continuity given the very limited Center funding.

The recommendations of the PC were reviewed by the SCEC Board of Directors at a meeting on February 7-8. The Board voted unanimously to accept the PC's recommendations, pending a final review of the program by the Center director, which was completed on February 25.

On June 7, the SCEC Planning Committee met after the SCEC3 site visit and began the processes of formulating the 2005 RFP, and their draft will being put up for scrutiny at this annual meeting. I urge you to participate fully in these discussions. Based on the community input, the PC will modify their draft, and the final RFP will be released in October.

Accomplishments

Many of the scientific results of the SCEC collaboration are detailed in the abstracts of presentations and posters included in this Meeting Volume, and others will be discussed in the working-group sessions throughout the Annual Meeting.

This was an exceptional busy year in terms of SCEC initiatives. For example, we developed a plan in collaboration with the USGS and CGS for a new Working Group on California Earthquake Probabilities, which has been chartered to produce a time-dependent uniform California earthquake rupture forecast by 2007. WGCEP'07, which is led by Ned Field, will report to a management oversight committee (MOC) chaired by the SCEC director.

The California Earthquake Authority (CEA) has allocated $1.75 million for the project, which will be managed by SCEC through the MOC. The CEA has also funded SCEC projects in ground motion attenuation studies and end-to-end ("ruptures-to-rafters") simulations.

Plans were also formulated for a set of international collaborations under the new Multinational Partnership in Earthquake System Science (MPRESS), a new Collaboratory for the Study of Earthquake Predictability (CSEP), and several other initiatives. These are outlined in the SCEC3 proposal (see the SCEC3 Proposal Summary below).

Rather than attempt a synopsis of the many projects that SCEC is coordinating, I will simply list several documents which you can download from the web to find detailed reports (http://www.scec.org/aboutscec/documents/). Of course, you can find a lot more information about SCEC activities through our main webportal (http://www.scec.org).

SCEC 2004 Annual Report (December, 2004). This large, comprehensive document (188 pp., 8.1 MB) provides an excellent snapshot of the Center's 2004 activities. It comprises following sections:

I. Introduction
II. Planning, Organization, and Management of the Center
III. Research Accomplishments
IV. Communication, Education, and Outreach Activities
V. Director's Management Report
VI. Advisory Council Report
VII. Financial Report
VIII. Report on Subawards and Monitoring
IX. Demographics of SCEC Participants
X. Report on International Contacts and Visits
XI. Publications
Appendices: Long-Term Research Goals, By-Laws, and 2005 RFP

SCEC/CME 2004 Annual Report (June, 2005). In 2001, SCEC was funded by NSF's ITR Program for a large project ($10M for 5 yr) to develop a new information infrastructure for earthquake science—the SCEC "Community Modeling Environment" (CME). The fourth annual report on the CME (89 pp., 6.3 MB) can be downloaded from the SCEC document website. Further information, including a wide variety of products, capabilities, and reports can be found on the CME website (http://epicenter.usc.edu/cmeportal/).

Putting Down Roots in Earthquake Country **(2005).** The new edition of this widely distributed public-information document was released by SCEC and the USGS on the anniversary of the Northridge earthquake and has been updated twice since. It can be downloaded from the new website (www.earthquakecountry.info/roots/). Earthquakecountry.info is a multi-organizational collaboration to inform the public about earthquake hazards and safety, organized and hosted by SCEC. In 2005 SCEC worked with a large group of Bay Area scientists, engineers, and emergency managers, led by the USGS, to create the first Bay Area version of *Roots* (soon available through the www.earthquakecountry.info/roots/ website also) and a Spanish-language edition is being prepared for printing in late 2005.

The SCEC3 Proposal

The current phase of the Center (SCEC2) extends for five years, until January 31, 2007. In early March, 2005, we submitted the SCEC3 proposal to NSF and the USGS, which lays out our plans to extend Center operations for the 5-year period 2007-2012. The construction of this proposal was a truly collaborative enterprise that stretched over a nine-month period and involved the Board of Directors, Planning Committee, Advisory Council, the entire SCEC staff, and many, many SCEC participants. I want to express my deepest gratitude to all of you for your outstanding efforts on behalf of the Center.

The results were a truly impressive document. I urge all SCEC participants to download it from the SCEC documents webpage (http://www.scec.org/aboutscec/documents/) and read it. The proposal was sent out for mail reviews and, in early June, a group of experts assembled by NSF and the USGS convened for a panel review at USC. We hope to receive word on the status of this proposal by the Annual Meeting. Reproduced below is the Proposal Summary.

SCEC3 Proposal Summary

The Southern California Earthquake Center was created as a Science & Technology Center in 1991 by NSF and the USGS. SCEC was renewed in 2002, and its size has since expanded to 54 institutions involving over 560 scientists. The core institutions, currently 15, are committed to SCEC's mission and offer sustained support for its programs; the participating institutions, currently 40, are self-nominated through their members' participation.

The Center is open to any credible scientist from any research institution interested in collaborating on the problems of earthquake science. However, its program is structured to achieve prioritized science objectives within the Southern California Natural Laboratory, and resources are allocated accordingly. Research projects are supported on a year-to-year basis by a

competitive, collaboration-building process that involves extensive interactions among 14 working groups, a Joint Planning Committee with the USGS, the SCEC Board of Directors, and an External Advisory Council. In 2005, SCEC will sponsor 123 projects by 156 principal investigators at 51 institutions. The overall program includes a number of additional USGS investigators, as well as many collaborators supported by SCEC's partner organizations.

Science Goal and Mission. SCEC's basic science goal is to understand the physics of the Southern California fault system and encode this understanding in a system-level model that can predict salient aspects of earthquake behavior. Southern California's network of several hundred active faults forms a superb natural laboratory for the study of earthquake physics. Its seismic, geodetic, and geologic data are among the best in the world. Moreover, Southern California contains 23 million people, so that high seismic hazard translates to nearly one-half of the national earthquake risk.

The Center's tripartite mission statement emphasizes the connections between information gathering, knowledge formulation through physics-based modeling, and public communication of hazard and risk. An important part of SCEC's mission is to increase the diversity of its scientific workforce; it values diversity in all aspects of its activities.

Mission Statement

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

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Intellectual Merit of the Proposed Research. Earthquakes are one of the great unsolved puzzles of science. The study of earthquakes concerns the two basic geophysical problems: (a) the *dynamics of fault rupture*—what happens on a time scale of seconds to minutes when a single fault breaks during a given earthquake—and (b) the *dynamics of fault systems*—what happens within a fault network on a time scale of hours to centuries to generate a sequence of earthquakes. These highly nonlinear problems are coupled to one another through the complex processes of brittle and ductile deformation. No theory adequately describes the basic features of dynamic rupture, nor is one available that fully explains the dynamical interactions among faults, because we do not yet understand the physics of how matter and energy interact during the extreme conditions of rock failure. The major research issues of earthquake science are true *system-level problems*—they require an interdisciplinary, multi-institutional approach that considers the nonlinear interactions among many fault-system elements. SCEC will advance earthquake science through a comprehensive program of system-specific studies in Southern California.

Broader Implications of the Proposed Research. Earthquakes pose the greatest natural threat to the built environment of California and other seismically active regions. Probabilistic seismic hazard analysis (PSHA) is the primary methodology used to ensure the public's seismic safety. SCEC research will incorporate physics-based methods into PSHA, which will provide better earthquake forecasts and better estimates of strong ground motions. The Center will extend this research beyond Southern California through its national and international research collaborations. Through partnerships with earthquake engineers, it will also generalize the natural system under consideration to include built structures, thereby extending its seismic hazard analysis to earthquake risk. Through its Communication, Education & Outreach (CEO) Program, it will provide society at large with useful knowledge for reducing earthquake risk.

Accomplishments. SCEC scientists engaged in data collection have come together with theoreticians and numerical modelers in a collaborative process that has greatly accelerated the understanding of seismic hazards in Southern California and elsewhere. The results have been incorporated into practical products, including the National Seismic Hazard Maps of 2002 and the new seismic attenuation relations developed by the Next Generation Attenuation Project. SCEC's achievements contributed to the launching of NSF's EarthScope initiative in 2003. For example, the Center developed the 250-station Southern California Integrated GPS Network (SCIGN), the largest outside of Japan, which has served as a prototype for EarthScope's Plate Boundary Observatory.

This proposal highlights scientific accomplishments in six problem areas central to the earthquake system science.

Fault mechanics. New types of laboratory experiments have elucidated on the frictional resistance during high-speed coseismic slip, and these data have been combined with field studies on exhumed faults to develop better models of dynamic rupture.

Earthquake Rupture Dynamics. Codes for 3D dynamic rupture simulation have been validated by cross-comparison exercises; they are being verified by comparisons with laboratory experiments and real earthquakes and coupled with anelastic wave propagation models to investigate strong ground motions.

Structural Representation. The Community Velocity Model (CVM) has been improved by extending and refining its 3D elastic structure and incorporating attenuation parameters; a new Community Fault Model (CFM) representing more than 140 active faults has been developed and extended to a Community Block Model (CBM), and a prototype Unified Structural Representation (USR) is merging the CVM into the CBM structural framework.

Fault Systems. New deformation signals have been discovered by InSAR and GPS, and new data from SCIGN and GPS campaigns have been incorporated into the Crustal Motion Map (CMM). The geologic record of fault-system behavior has been significantly expanded; tectonic block models have been created for physics-based earthquake forecasting, and finite-element codes have been developed for a new CBM-based deformation model that will assimilate the CMM and geologic data.

<u>Earthquake Forecasting</u>. New paleoseismic data and data-synthesis techniques have been used to constrain earthquake recurrence intervals, event clustering, and interactions among faults. Relocated seismicity has mapped new seismogenic structures and provided better tests of earthquake triggering models. Regional earthquake likelihood models have been formulated for use in PSHA and earthquake predictability experiments, and they are being tested for prediction skill using a rigorous methodology.

<u>Ground Motion Prediction</u>. Earthquake ground motions have been simulated using the CVM, realistic source models, and validated wave-physics codes; high-frequency stochastic methods have been combined with low-frequency deterministic methods to attain a broadband (0-10 Hz) simulation capability; broadband predictions have been tested against precarious-rock data; and simulations have been used to improve attenuation relationships and create realistic earthquake scenarios.

The CEO program has expanded SCEC partnerships in science, engineering, risk management, government, business, and education; increased earthquake knowledge and science literacy at all educational levels; worked with partners to improve earthquake hazard and risk assessments; and promoted earthquake preparedness, mitigation, and planning. An *Implementation Interface* has been constructed to integrate physics-based SHA into earthquake engineering research and practice through collaborations with PEER, CUREE, and the Next Generation Attenuation (NGA) Project; it has provided a flexible computational framework for system-level hazard and risk analysis through the OpenSHA platform, and it is developing an interface between SCEC and the NSF Network for Earthquake Engineering Simulation (NEES).

CEO highlights include a very successful new intern program Undergraduate Studies in Earthquake Information Technology (UsEIT); the development of the *Electronic Encyclopedia of Earthquakes* as part of the NSF National Science Digital Library; the establishment of the Earthquake Country Alliance to present consistent earthquake information to the public; and a new edition of *Putting Down Roots in Earthquake Country* in both English and Spanish.

Science Plan. The SCEC3 Science Plan is articulated in terms of four basic science problems that organize the most pressing issues of earthquake system science.
A. <u>Earthquake Source Physics</u>: to discover the physics of fault failure and dynamic rupture that will improve predictions of strong ground motions and the understanding of earthquake predictability.
B. <u>Fault System Dynamics</u>: to develop representations of the postseismic and interseismic evolution of stress, strain, and rheology that can predict fault system behaviors.
C. <u>Earthquake Forecasting and Predictability</u>: to improve earthquake forecasts by understanding the physical basis for earthquake predictability.
D. <u>Ground Motion Prediction</u>: to predict the ground motions using realistic earthquake simulations at frequencies up to 10 Hz for all sites in Southern California.
In each problem area, we state the research issues, identify specific objectives, and assess the requisite research activities and capabilities. Based on this assessment, we formulate a new working-group structure to enact the Science Plan.

The SCEC3 Science Plan motivates eight initiatives that will augment the basic research program.

1. <u>Networks as Research Tools</u>: to foster innovations in network deployments and data collection that can provide researchers with new information on earthquake phenomena. Plans include a real-time demonstration project in seismic early warning in partnership with CISN.

2. <u>Southern San Andreas Fault</u>: to mobilize a major effort on the collection and interpretation of geologic data to understand the earthquake history of the SSAF system.

3. <u>Working Group on California Earthquake Probabilities</u>: to develop in partnership with the USGS and CGS a uniform California earthquake rupture forecast by combining new information with the best available methodologies for time-dependent forecasting.

4. <u>Next Generation Attenuation Program</u>: to produce in partnership with PEER-Lifeline and the USGS more reliable ground motion attenuation models that are based on physics as well as data.

5. "<u>Rupture to Rafters</u>": to develop in partnership with earthquake engineers a capability for the end-to-end simulation of earthquake processes, including embedding built structures in geologic models. This analysis will be used in new types of risk assessment.

6. <u>Collaboratory for the Study of Earthquake Predictability</u>: to provide a stable environment for registering earthquake predictions and conducting long-term predictability experiments that are properly characterized and can be properly evaluated.

7. <u>National Collaborations Through EarthScope</u>: to apply SCEC's system-level approach to other fault systems in the United States and collaborate on a national scale in comparative studies of fault system dynamics and earthquake behavior.

8. <u>International Collaboration</u>s: to develop multinational partnerships that will promote comparative studies of fault systems and international cooperation in earthquake system science.

We outline the objectives of each initiative, its resource requirements, the participants and organizational partners, and the mechanisms that we will pursue to obtain additional resources. The latter is critical, because the ambitious research program proposed for SCEC3, particularly in the realm of applied studies, will require other sources of funding than the Center base budget proposed here.

The CEO program is an essential component of the Science Plan through its management of external partnerships that foster new research opportunities and its delivery of research and educational products to society at large.

In SCEC3, the Center will expand its CEO activities through partnerships with new groups, such as the EarthScope Education & Outreach Program and the NEES Education, Outreach & Training Program. The CEO focus areas will include partnerships in seismic hazard & risk analysis, primarily with research engineers; knowledge transfer partnerships and programs for technical professionals and government officials; education programs and products for students and educators; and public outreach to the general public, civic and preparedness groups, and the news media. As in SCEC2, CEO will organize community development programs for SCEC participants.

Management Plan. SCEC3 will continue to operate under the lean, flexible, and very successful management structure developed for SCEC2. However, to implement the Science Plan, we will make significant changes in the organization of the working groups, as shown on the SCEC3 organization chart.
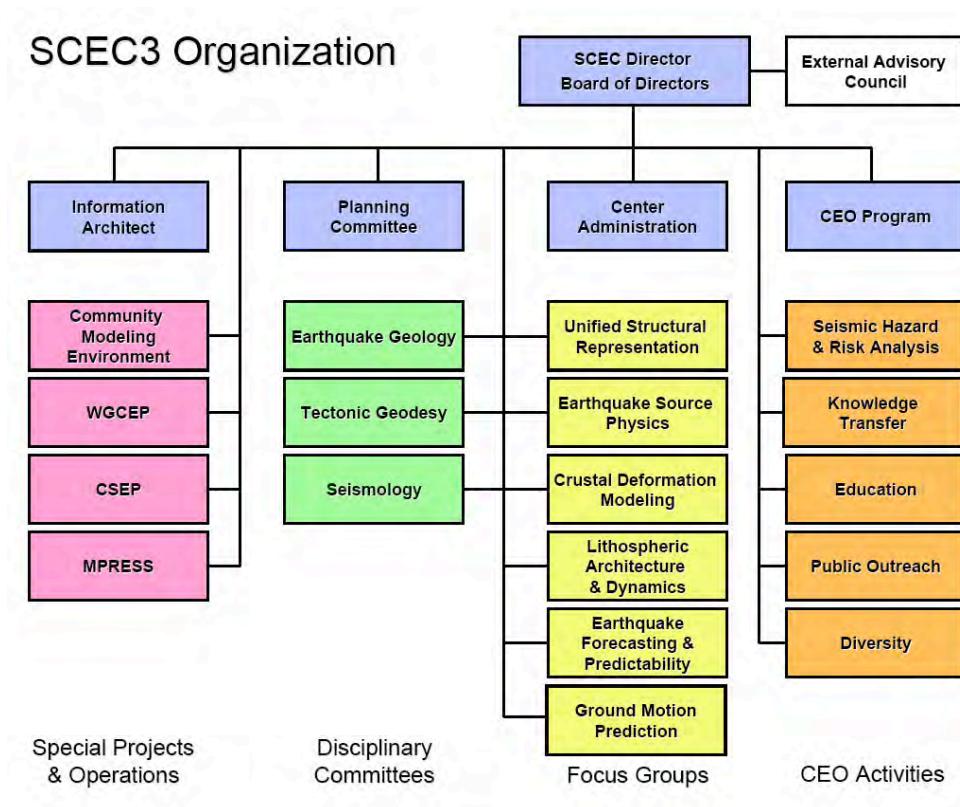
Recognizing that diversity is a long-term issue that requires continuing assessments and constant attention by the leadership, the Center has taken a number of concrete steps to assess the diversity of its workforce and to develop policies for increasing diversity. Tangible progress has been made in populating SCEC leadership positions with outstanding women and minority scientists, and a long-term plan has been enacted to make further improvements. A key pipeline strategy is to recruit minority students into the SCEC intern programs and encourage them to pursue research careers at SCEC institutions. These recruitment and retention activities will be expanded in SCEC3.

In closing, I want to express my thanks to all of you for your attendance at the meeting and your sustained commitment to the SCEC collaboration. Please do not hesitate to contact me personally if you have questions or comments about our activities, accomplishments, and plans.

VI. Advisory Council Report

The membership of the SCEC External Advisory Council is listed in Table VI.1. Sean Solomon continues as the very effective chair of the council. AC chair. The Advisory Council assisted in reviews of drafts of the SCEC3 proposal and convened at the SCEC Annual Meeting in September 2005, and their annual report is reproduced verbatim below.

Table VI.1. SCEC Advisory Council for 2005

Sean SOLOMON (Chair), Carnegie Institution of Washington, Washington, DC

Gail ATKINSON, Carleton University, Ottawa, Ontario, Canada

Lloyd CLUFF, Pacific Gas and Electric Company, San Francisco, CA

Jeff FREYMUELLER, University of Alaska, Fairbanks, AK

Patti GUATTERI, Swiss Re-Insurance, New York, NY

Kate MILLER, University of Texas-El Paso, El Paso, Texas

Jack MOEHLE, Pacific Earthquake Eng. Research Center, Richmond, CA

Garry ROGERS, Geological Survey of Canada, Sidney, BC, Canada

Chris ROJAHN, Applied Technology Council, Redwood City, CA

John RUDNICKI, Northwestern University, Evanston, Illinois

Ellis STANLEY, City of Los Angeles, Emergency Preparedness Department, Los Angeles, CA

Report of the Advisory Council
Southern California Earthquake Center
September 2005 Meeting

Introduction

The Advisory Council of the Southern California Earthquake Center (SCEC) met during the 2005 SCEC Annual Meeting, held in Palm Springs, California, during 11-14 September 2005. The principal meeting of the Council was during the evening of 13 September; an earlier session was held prior to the start of the Annual Meeting on 11 September to outline areas of focus. The Council chair summarized the principal Council findings and recommendations in an oral report delivered during the closing session of the Annual Meeting on the morning of 14 September.

On 7 September the SCEC Director had circulated to Advisory Council members a copy of his "State of SCEC, 2005" report to the SCEC community as well as a separate report to the Council. The latter report summarized how SCEC responded to Advisory Council recommendations from last year and presented a number of new issues warranting Council attention. Those new issues included how best to sustain SCEC's Community Modeling

Environment (CME); whether there should be further change to SCEC's management structure; an evaluation of SCEC's plan for enhancing diversity of the SCEC community; and overall assessments of scientific progress, financial support, the internal proposal process, and the geographic focus of SCEC research efforts.

After a few general remarks, we comment on the responsiveness of SCEC to last year's Advisory Council recommendations. We then align the remainder of our discussion and recommendations with the issues and corresponding subsidiary questions raised by the Director in his 7 September mailing.

Some General Impressions

Because the members of the Advisory Council are not also members of SCEC, the Annual Meeting provides a critical opportunity for Council members to assess annual progress on the goals and programs of the Center. The 2005 meeting and associated workshops proved again to be impressive demonstrations of the energy and enthusiasm of the SCEC community.

The Advisory Council lauds the membership of SCEC for the selfless community spirit with which everyone has worked constructively to develop system-level representations that are advancing the goal of end-to-end simulation of earthquake ground motions. SCEC is to be commended for continuing to highlight the most exciting Center-fostered work at the Annual Meeting, particularly the work of early-career scientists. The Advisory Council also applauds SCEC's developing partnerships with the earthquake engineering community, notably the Next Generation Attenuation (NGA) modeling effort with the Pacific Earthquake Engineering Research Center (PEER).

The most heartening news from the Annual Meeting was the report that the proposal for a third phase of SCEC (SCEC3) would be supported by the National Science Foundation (NSF) and United States Geological Survey (USGS). Although details on support levels were not available at the time of the meeting, the announcement ensured that SCEC will continue as a center for earthquake science for another 5 years beyond January 2007.

Outside Communication

In its 2004 report the Advisory Council made the following recommendation with respect to the communication of SCEC-sponsored science to the broader Earth science and earthquake engineering communities and to the public:

> "SCEC should enhance the communication of its activities, accomplishments, and plans to the greater Earth science and earthquake engineering communities and to the public. There is an enormous body of very exciting scientific work being carried out by SCEC members and through SCEC's partnerships with other organizations. It is the impression of Advisory Council members, however, that the broader community of Earth scientists and earthquake engineers are unfamiliar with much of this effort. SCEC should do more to publicize its work, through organized sets of presentations at professional meetings, publications in professional journals, targeted articles in the lay media, and

internet-based materials. Presentations and publications of SCEC-sponsored research should consistently give explicit credit to such sponsorship. Regular updates to SCEC's web site (including pages currently 'under construction') would also serve to enhance the Center's visibility as a focus of community-directed activity."

It is clear that in the intervening year SCEC has made a concerted effort to present its accomplishments to these audiences by means of presentations at national meetings, peer-reviewed publications, targeted articles in the lay media, and internet-based materials. Nonetheless, much of the excitement within SCEC — excitement particularly evident at the Annual Meeting — is not visible to most of the rest of the Earth science and earthquake engineering communities.

The Advisory Council recommends, as one means to enhance communication with both the outside professional community and the public, that SCEC recruit and support a cadre of speakers who can represent the SCEC membership and demonstrate by personal example the excitement that characterizes SCEC programs. Speakers for such a program should include early-career scientists and perhaps even graduate students. The program should target a range of audiences and should endeavor to convey the groundbreaking work that the Center has engendered.

In his response to the 2004 Advisory Council recommendation, the Director described difficulties that have been encountered with the peer review of papers describing SCEC's system-level approach. An example given was a multi-authored paper on the Community Fault Model, which was reviewed by three journals (*Nature, Geology*, and the *Bulletin of the Seismological Society of America*), each of which decided not to publish the article. Some of these negative decisions appeared to reflect the fear that more documentation would be required to back up such a paper than would be permitted by journal space constraints. Some reviewers may not understand the value of the system-level approach.

As a vehicle for publishing SCEC's overall system-level framework for improving our understanding of earthquake physics, the Center is considering the possibility of preparing a special bound volume of technical papers on the accomplishments of the second phase of Center activities (SCEC2). One model for such a volume is the monograph series of the American Geophysical Union (AGU).

The Advisory Council was asked by the Director to offer an opinion on whether such a publication constitutes an appropriate investment of time and other resources. There is broad support within the Council for such an effort. *A monograph, published by AGU or another reputable publisher, would provide both an archival volume to document SCEC's system-level approach to earthquake science and a showcase for exciting new results that have been enabled by that approach.*

In parallel with preparing a monograph, SCEC should consider the possibility of self-publishing an on-line library of technical reports in pdf format. A formal review process and a consistent report style could be established to demonstrate appropriate standards and to encourage citation. The library could be readily reached though the SCEC home page, and the

arrival of new reports to the library could be announced to the community through the news column in *Seismological Research Letters* (SRL) and the newsletter of the Earthquake Engineering Research Institute (EERI). A regular SCEC column in SRL is a further option that might be discussed with that journal's editor. The audience that could be reached with such an on-line library might exceed that of a printed monograph by a considerable degree, and the regular updates to reports in the series would ensure that the library would remain timely long beyond the lifetime of a print volume.

Planning for a Southern California Earthquake

In its 2004 report the Advisory Council recommended that SCEC expand its planning for Center activities in the event of a large southern California earthquake:

"SCEC should develop a plan for how it will coordinate, in partnership with relevant federal and state agencies, a science community response to a large earthquake in southern California. The need for such a plan was underscored by the Parkfield, California, earthquake of 28 September, just one week after the Annual Meeting. As a multi-institutional Center for earthquake science, society will look to SCEC to provide scientific leadership in the immediate aftermath of any large seismic event in the southern California region. SCEC should have a clear protocol for how it will provide that leadership."

In response, SCEC reviewed its earthquake-response plans and prepared an updated and expanded outline of those plans as part of the SCEC3 proposal process. The plans appropriately emphasize the gathering of critical information and the rapid electronic communication of that information to the USGS and emergency response organizations. The Advisory Council regards those plans as an excellent first step, but more steps are needed. In particular, *SCEC's proposal to establish a satellite phone system should be put into operation. Planning exercises for specific earthquake scenarios, emphasizing the most devastating plausible events, should be carried out and procedures developed to assign responsibilities for post-earthquake activities and communications.*

Success Metrics for SCEC

In its 2004 report the Advisory Council advised SCEC to set well-defined milestones for progress to be made on each of its major programs:

"SCEC has set out ambitious goals and several milestones to be attained in the pursuit of those goals. Building on those plans, SCEC should develop clear metrics for the successful achievement of its goals. These "success criteria" should be applied both to past activities — in the development of a rationale for continuing SCEC into its next phase — and to activities proposed by the SCEC3 era. The feasibility of satisfying those success criteria for planned efforts will enhance the case for SCEC3."

Although the SCEC3 proposal process has concluded successfully, this general advice is worthwhile. SCEC leadership has responded that their roadmap approach to the achievement of

scientific goals contains success metrics of the sort envisioned by the Council, but they expressed concern that in Communication, Education, and Outreach (CEO) activities the evaluation of progress toward metrics can consume a large fraction of available effort and allocated salaries.

It was not the intent of this recommendation by the Council that a large share of SCEC resources be devoted to evaluations of progress, in the CEO area or any other. Rather the intended goal was that *for each major activity SCEC should articulate a clear set of milestones, each cast in sufficiently specific terms with defined target dates so that evaluation is both straightforward and obvious to any objective observer*. The SCEC3 proposal has already provided a framework for assessing progress, and the CEO program is making reasonable efforts to assess its progress toward programmatic objectives. Continuing attention to the definition of milestones and the progress toward their achievement across all SCEC activities is nonetheless warranted.

Ties to Earthquake Engineering

In 2004 SCEC asked the Advisory Council to evaluate the effectiveness of its partnership activities, particularly in the areas of seismic hazard analysis and risk reduction. The Council advised:

> "SCEC has entered into a number of promising partnerships. The new Implementation Interface provides a focus for collaborations with the earthquake engineering community, exemplified by the PEER-Lifelines/SCEC/USGS New Generation Attenuation Project and the end-to-end ("Rupture to Rafters/Rivets") simulation initiative…In general, these partnerships provide an effective means for engaging the user community and for leveraging SCEC efforts. Nonetheless, there is more that can be done, particularly through partnerships with organizations that are now applying earthquake information. In particular, SCEC should enhance its awareness of current directions being taken by the engineering community to develop next-generation methods for performance-based design and to address the Los Angeles community's most pressing concerns regarding seismically hazardous structures. Open synergistic partnerships with organizations whose goals include the advancement of these causes are encouraged. The partnership with PEER is a laudable example of this type of collaboration, but others should be pursued as well."

SCEC responded that collaborations with professional engineers have steadily improved through several partnerships initiated during the development of the SCEC3 proposal, including those with NSF Earthquake Engineering Research Centers (EERCs), the Consortium for University Research in Earthquake Engineering (CUREE), and the George E. Brown Network for Earthquake Engineering Simulation (NEES), all managed under SCEC's Implementation Interface. Support for these partnerships has been provided by both SCEC base funds and additional resources obtained from the California Earthquake Authority and the Civil and Mechanical Systems (CMS) Division of the NSF Engineering Directorate.

The progress that SCEC has made in establishing working programs with the earthquake engineering community is laudable and warrants still further strengthening. It is the view of the Advisory Council that *SCEC should continue to seek partnership opportunities with research and practicing earthquake engineers by developing realistic earthquake simulation scenarios, reinforced by empirical ground motion data, aiming toward the adoption of performance-based engineering that will drive improved seismic safety decision-making in southern California*.

International Partnerships

In 2004 the Advisory Council was asked to comment on the appropriate geographic emphasis for SCEC's scientific activities. The Council replied:

"For several reasons, the regional scale adopted by SCEC to date is still highly appropriate. Southern California remains one of the best — arguably the best — natural laboratory for earthquake science because of the spatial and temporal coverage of diverse instrumentation, the variety of fault geometries and tectonic settings, and the large population of area residents for whom improved hazard analysis will enhance safety and reduce economic vulnerability…That said, ongoing SCEC initiatives to form regional partnerships are appropriate mechanisms to export SCEC products and to expand the suite of natural laboratories from which to gather information on earthquake physics. The Basin and Range working group sponsored by SCEC and the acceptance as SCEC Participating Institutions of seven foreign universities and research organizations to date are noteworthy examples of these initiatives. There are nonetheless real limits to the number and diversity of regional partnerships in which SCEC can maintain an active role at any one time. SCEC should therefore select its partnerships carefully, emphasizing those that can best advance overall SCEC goals."

In the SCEC3 proposal, and in a separate proposal to NSF for Multinational Partnerships in Earthquake System Science (MPRESS), the Center outlined a specific set of potential international partnerships carefully selected on the basis of geological complementarity with southern California and technical complementarity to SCEC activities. It is the view of the Council that *the international partnerships identified in the MPRESS proposal — including Japan, Taiwan, and Turkey — are well-chosen targets where exchanges of data and methodologies can advance substantially SCEC's long-range scientific goals*. It is therefore regrettable that the MPRESS was not funded, despite receiving excellent peer reviews, for lack of funds at NSF. The Council urges that *SCEC should continue to pursue aggressively the MPRESS proposal or an equivalent program of international partnerships*.

New Directions

In 2004 the Advisory Council recommended that SCEC develop, in preparation for SCEC3, several sharply focused initiatives in fundamental earthquake science. The Center responded with eight initiatives, each described in the SCEC3 proposal: (1) networks as research tools, (2) the southern San Andreas fault, (3) a Working Group on California Earthquake Probabilities, (4) the Next Generation Attenuation Program, (5) a "rupture to rafters" program, (6) a Collaboratory

for the Study of Earthquake Predictability, (7) national collaborations through the EarthScope Program, and (8) international collaborations.

With the approval of the SCEC3 proposal, the Center is now faced with the challenge of how best to allocate resources among these distinct but complementary initiatives, and the Advisory Council has been asked to evaluate these concepts with an eye on prioritization. The Council is willing to assist SCEC with such an assignment, but more time for discussion and evaluation is needed to do so than was available during Council sessions at the Annual Meeting. The Council plans to provide this advice after further discussions with SCEC staff, most likely at a dedicated Council meeting to take place during 2006.

SCIGN and WInSAR

In 2004, in anticipation of the transition between SCEC2 and SCEC3, the Advisory Council made several recommendations regarding potential organizational changes within the Center:

> "Several structural changes are appropriate in preparation for a transition from SCEC2 to SCEC3. SCEC's stewardship of SCIGN and WInSAR has been critical to date, but with the onset of the EarthScope program it is now timely to transfer these activities to appropriate alternative organizations. At the same time, explicit links with EarthScope should be strengthened through one or more SCEC organizational units."

SCEC followed the Council's advice regarding the Southern California Integrated GPS Network (SCIGN). A SCEC subcommittee formed early last year to review the issue recommended that SCEC disband the SCIGN board as a standing committee and coordinate all future geodetic activities within the Center through the Tectonic Geodesy disciplinary committee. SCEC's Board and Director approved the recommendation, as did the Center's sponsoring agencies, and the transition was effected in June 2005.

At the time of the Annual Meeting, the Western North America Interferometric Synthetic Aperture Radar (WInSAR) Consortium was seeking offers for a new host institution, and the Director asked the Council whether SCEC should offer to serve that role and, if so, under what conditions. In the view of the Council, *SCEC should choose carefully those community service tasks that it undertakes, and the principal selection criterion should be the advancement of one or more of the goals of the Center.* The timely transfer of SCIGN and WInSAR to other sponsors is in appropriate conformance with this guideline.

Following the Annual Meeting, the WInSAR Executive Committee voted to accept an offer from UNAVCO, Inc., to serve as its host institution. SCEC's commitment to effect a timely transition in the sponsorship of this important community activity during 2006 is laudable.

SCEC Working Groups

In 2004 the Advisory Council was asked about the value of adding formally a Focus Group in the area of tectonophysics and responded that

"Within SCEC, a Tectonophysics Focus Group is warranted on scientific grounds; some rebalancing of assignments among working groups may be needed as a consequence."

SCEC incorporated this recommendation into an organizational restructuring outlined in the SCEC3 proposal, and the Director asked the Council to comment on the proposed new structure.

In the view of the Council, *the new organization described in the SCEC3 documents appears to be a sensible alignment with the new scientific and programmatic directions and objectives. SCEC's organization should continue to adapt as necessary as the goals and programs of the Center evolve.*

Sustaining the CME

Foremost among the new issues for Advisory Council advice raised this year by the SCEC Director is the question of how to sustain the Center's Community Modeling Environment. The CME has been funded through a 5-year grant from the NSF Information Technology Research (ITR) Program, and that grant is due to expire at the end of September 2006. The ITR Program, however, is not accepting new or renewal proposals, and NSF has yet to announce a follow-on cyberinfrastructure program from which SCEC could seek a sustained continuation of support. The Earth Sciences (EAR) Division of NSF announced an opportunity for cyberinfrastructure proposals to its Instrumentation and Facilities Program, but the budget available would not permit the awarding of funds comparable to those now supporting the CME.

The Director specifically asked the Advisory Council whether SCEC should respond to the EAR announcement, as well as whether SCEC should submit a more comprehensive proposal to NSF's cyberinfrastructure initiative, once such a program has been organized to the point of accepting proposals. It is the view of the Council that *the CME is one of SCEC's most important and innovative initiatives and must be sustained beyond September 2006. SCEC should work with NSF, and in particular with EAR, to seek creative solutions to finding continued support for this endeavo*r.

SCEC Management Structure

The SCEC Director sought Advisory Council advice regarding the management structure for the Center. Noting that the budget for management has remained constant throughout the SCEC2 era despite growth in activities and staff compensation levels, the Director asked whether SCEC is spending too much or too little on management, whether the management team organization is optimum, and whether additional administrative personnel are needed.

It is the Council's view that *at current SCEC support levels the budget fraction allocated to management is more or less appropriate. In the SCEC3 era, new initiatives must be accompanied by the identification of, and budget for, the incremental management resources that will be needed to accomplish them.*

SCEC's Diversity Plan

   The SCEC Director sought Advisory Council feedback as well on its plan for enhancing diversity within the earthquake science community. This issue is a national one, underscored by the small fraction of most minority populations in this country who are electing to pursue careers in the sciences in general and Earth science in particular. It is the opinion of the Advisory Council that *SCEC's diversity plan constitutes a serious response to the challenge faced by the Earth science community in trying to improve the diversity of participation at all levels*. The intern program has successfully drawn women and minorities, and women are increasingly represented in leadership positions within SCEC committees. Sustained attention to diversification of the SCEC community is certainly warranted, but the pride that SCEC displays in its efforts toward building a diverse workforce are well justified, and its diversity plan is a showcase for other NSF-sponsored programs.

General Assessments of SCEC

   The SCEC Director raised for Advisory Council comment a number of additional questions regarding Center organization, including the following:

   • Is SCEC working under its current structure?

   • Should SCEC modify how they fund their science and infrastructure with regard to the dollar size of grants?

   • Is the SCEC proposal process adequate to safeguard against conflicts of interest?

   • Should SCEC become involved in projects beyond southern California, or is SCEC a *de facto* national center?

   These topics, although important, require more time for discussion than was available to the Council during the SCEC Annual Meeting. These issues will guide continuing discussions between the Council and SCEC management over the coming year.

Final Comments

   The Advisory Council is pleased to provide continued assistance to SCEC in its efforts to formulate and accomplish its major goals. At any time the Council will welcome comments, criticism, and advice from the seismological community, including individuals and groups inside and outside SCEC membership, on how best to provide that assistance.

   The Advisory Council looks forward to working with SCEC leadership to optimize the Center's transition to the SCEC3 era.

2 February 2006

SCEC Advisory Council

Sean C. Solomon, Carnegie Institution of Washington (Chair)*
Gail Atkinson, Carleton University*
Lloyd S. Cluff, Pacific Gas and Electric Company*
Jeffrey T. Freymueller, University of Alaska*
Mariagiovanna Guatteri, Swiss Reinsurance America Corporation
Kate C. Miller, University of Texas at El Paso*
Jack P. Moehle, Pacific Earthquake Engineering Research Center (PEER)**
Garry C. Rogers, Geological Survey of Canada*
Chris Rojahn, Applied Technology Council*
John Rudnicki, Northwestern University
Ellis M. Stanley, Sr., City of Los Angeles Emergency Preparedness Department

*Attended at least part of the 2005 Annual Meeting and Advisory Council sessions
** Represented by Yousef Bozorgnia, PEER

VII. Financial Report

Table VII.1 gives the breakdown of the SCEC 2005 budget by major categories. The list of individual projects supported by SCEC in 2005 can be found on the website http://www.scec.org/research/2005research/index.html.

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Table VII.1 2005 Budget Breakdown by Major Categories

Total Funding (NSF and USGS):	$3,797,000
Budgets for Infrastructure:	$ 1,107,000
Management	280,000
CEO Program	380,000
Annual, AC, Board, and PC Meetings	150,000
Information Architect	142,000
Director's Reserve Fund	130,000
SCEC Summer Intern Program	25,000
Budgets for Disciplinary and Focus Group Activities: (including workshops)*	$ 2,690,000
Earthquake Source Physics and FARM	495,000
Ground Motions	260,000
Velocity Structure and Seismology	555,000
Seismic Hazard Analysis	385,000
Fault Systems	490,000
Geodesy	420,000
Workshops	85,000

*Note: Includes $50K unspent in 2004.

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VIII. Report on Subawards and Monitoring

The process to determine funding for 2005 began with discussions at the SCEC annual meeting in Palm Springs in September, 2004. An RFP was issued in October, 2004 and 155 proposals were submitted in November, 2004. Proposals were then sorted and sent out for review in mid-December, 2004. Each proposal was independently reviewed by the Center Director Tom Jordan, the Deputy Director Ralph Archuleta, by the chair and co-chair of the relevant focus group, and by the chair and co-chair of the relevant disciplinary committee. Reviewers had to recuse themselves where conflicts of interest existed. Every proposal had from 4 to 6 reviews. Reviews were sent to John McRaney, SCEC Associate Director for Administration, who collated and tabulated them. The SCEC Planning Committee (chaired by Archuleta) met on January 17-18, 2005 and spent 25+ hours over two days discussing every proposal. The PC assigned a rating from 1-5 (1 being highest) to each proposal and recommended a funding level. Proposals were rated based on quality of science and the proposed research plan, their relevance to the SCEC 2005 science goals, and the amount of money available for the overall program.

The recommendations of the PC were reviewed by the SCEC board at a meeting on February 7-8, 2005. The board voted 16-0 to accept the recommendations of the PC, pending a final review of the program by the Center Director. The director did not make any changes in the proposed plan approved by the board. The board was given two days to comment on the final plan of Jordan.

SCEC funding for 2005 was $3.722M. The board approved $280K for administration; $380K for the communications, education, and outreach program; $150K for workshops and meetings; and $142K for the information technology program. We also received a $25,000 supplement from NSF for the summer undergraduate intern program.

The Center Director did not give specific targets for funding by infrastructure and science groups. Final funding for each disciplinary and focus group is shown in Table VII.I. Most research in SCEC involves aspects of several focus groups. The funding is shown by primary review group at the Planning Committee meeting.

The Center Director also was given a small ($130,000) fund for supporting projects at his discretion. This funding was used to provide additional workshop support, WGCEP activities, send students to meetings in Greece and Japan, the SCEC3 site review, and CEO activities.

Following this action, individual PI's were notified of the decision on their proposals. Successful applicants submit formal requests for funding to SCEC. After all PI's at a core or participating institution submit their individual proposals, the proposals are scanned and the institution's request is submitted electronically to NSF/USGS for approval to issue a subcontract. Once that approval is received, the formal subcontract is issued to each institution to fund the individual investigators and projects.

Scientific oversight of each project is the responsibility of the Center Director, Deputy Director, and focus/disciplinary group leaders. Fiscal oversight of each project is the responsibility of the Associate Director for Administration. Regular oversight reports go to the SCEC Board. Any unusual problems are brought to the attention of agency personnel.

Subcontracts issued in 2005 are shown in the table below for both the USGS and NSF components of SCEC funding.

Table VIII.1 SCEC Subcontracts for 2005

USGS Funds

ABS Consulting	25,000
Boston U	10,000
Cal State-Fullerton	32,000
Caltech	155,000 Data Center Only
ECI	10,000
Harvard	187,000
LANL	35,000
LLNL	92,000
Patrick Williams Associates	16,125
Oregon State	20,000
San Diego State	13,875
Stanford	61,580
UCI	5,000
Utah State	7,000
William Lettis Associates	15,000
Western Ontario	15,000
WHOI	15,000

NSF Funds

British Columbia	15,000
Brown	32,000
Caltech	154,500 Science only
Cal State, San Bernardino	28,380
Case Western	40,000
LDEO	45,000
Legg Associates	20,000
MIT	88,800
Minnesota	7,000
North Carolina	28,000
Oregon	83,000
Purdue	15,000
RPI	20,000
SDSU	86,000
Texas A&M	23,000
U Mass	10,000
UCB	35,000
UCD	10,000
UCLA	223,000
UCR	70,000
UCSB	225,000
UCSC	22,000
UCSD	148,000
UNR	55,000
URS	120,000

<center>**Report on 2005 SCEC Cost Sharing**</center>

The University of Southern California contributes substantial cost sharing for the administration of SCEC. In 2005, USC provided $280,000 for SCEC administration costs, waived $526,000 in overhead recovery on subcontracts, and provided nearly $100,000 in release time to the center director to work on SCEC. USC had previously spent $7,500,000 in 2002-2003 renovating SCEC space.

<center>**SCEC Management Cost-Sharing Report for 2004**</center>

1. USC annually provides $280,000 in cost-sharing for SCEC management (Direct Costs).

Institution	Amount	Purpose
USC	$222,000	Salary Support of Jordan, McRaney, S. Henyey
	$10,000	Report Preparation and Printing
	$8,000	Meeting Expenses
	$6,000	Office Supplies
	$2,000	Computers and Usage Fees
	$6,000	Administrative Travel Support for SCEC Officers
	$5,000	Postage
	$21,000	Telecommunications
	$280,000	Total

2. USC waives overhead on subcontracts. There are 43 subcontracts in 2005.

$843,000	Amount Subject to Overhead
0.625	USC Overhead Rate
$526,875	Savings Due to Overhead Waiver

3. SCEC Director receives a 50% release from teaching for administrative work.

$100,000	Cost Sharing for 2003-2004 Academic Year

$1,051,875	2003-2004 USC Cost-Sharing to SCEC

In addition to USC support of SCEC management activities, each core institution of SCEC is required by the by-laws to spend at least $35,000 in direct costs on SCEC activities at the local institution. These funds are controlled by the institution's participants in SCEC, not centrally directed by SCEC management. The following table shows how each core institution spent its funds in 2005.

Institution	SCEC Cost-Sharing for 2005 Amount	Purpose
USC	$24,000	Student Support
	$6,000	Research Support/Supplies
	$2,000	Visitor Support
	$3,000	Research Faculty Expenses
	$35,000	Total
Harvard	$25,000	Staff Salaries and Benefits
	$3,800	Student Salaries
	$800	SCEC-Related Travel
	$5,400	Computer Facilities Charges
	$35,000	Total
UCSD	$15,000	Pinon Flat Observatory Operation
	$6,000	CEO Education Workshop
	$20,000	GPS Research
	$9,000	Seismology Initiatives
	$50,000	Total
Columbia/LDEO	$6,715	Administrative Salary Support
	$7,900	Salary Support for Agnes Helmstetter
	$11,590	Salary Support for Felix Waldhauser
	$14,815	Salary Support for Bruce Shaw
	$9,680	Salary Support for Art Lerner-Lam
	$50,700	Total
UCSB	$17,100	Salary Support for Assimaki and Lavallee
	$14,100	Staff Salary Support for Martin (IT)
	$14,900	Student Salaries and Tuition
	$5,300	Supplies and Expenses
	$1,600	Travel
	$2,400	Equipment
	$54,400	
Stanford	$47,000	Graduate Student Fellowships
	$19,000	Graduate Student/Post-Doc Travel
	$66,000	Total

UCLA	$25,000	Salary Support for Research Personnel
	$3,000	Supplies
	$7,000	Travel
	$35,000	Total
MIT	$27,000	Graduate Student Fellowship
	$11,000	Computer Cluster Support
	$6,900	Geophysics Field Camp
	$44,900	
SDSU	$5,855	Computer Hardware
	$3,675	Travel
	$23,115	Student Salary
	$11,774	PI Salary
	$35,000	Total
UNR	$26,000	Salary for Research Faculty Rasool Anooshehpoor
	$12,000	Salary for PhD Student Aasha Pancha
	$38,000	Total
Caltech	$26,000	Two Gutenberg Graduate Student Fellowships
	$48,000	Moore/Richter Graduate Student Fellowship
	$43,000	Housner Graduate Student Fellowship
	$117,000	Total
UCR	$20,000	Computer Equipment
	$25,000	Student Salary Support
	$45,000	Total
USGS/Pasadena	$350,000	Support for SCIGN (Salaries and Materials)
	$127,000	Support for RELM/CSEP (Salaries and Materials)
	$477,000	
USGS/Golden	$150,000	Salary Support of RELM, OpenSHA, NGA Activities
	$10,000	Travel Support
	$160,000	
USGS/Menlo Park	$150,000	Salary Support of SCIGN, SCSN, FARM Activities
	$20,000	
	$170,000	

IX. Demographics of SCEC Participants

Center Database of SCEC Participants in 2004

	Administration/ Technical	Faculty Researcher	Graduate Student	Non-faculty Researcher	Undergraduate Student
Race					
Asian	8	16	34	28	13
Black	1	0	1	1	1
White	43	131	98	187	47
Native American	0	3	6	2	2
No Information	2	1	3	8	2
Ethnicity					
Latino	1	6	13	7	4
Not Latino	44	129	95	178	52
No information	1	11	21	31	6
Withheld	2	3	13	13	3
Gender					
Female	19	25	52	54	33
Male	34	123	84	169	32
Withheld/No Info	1	1	6	2	0
Citizenship					
US	45	116	68	160	54
Other	4	14	50	30	2
No information	5	6	15	15	8
Resident	0	13	4	19	1
Withheld	0	0	5	1	0
Disability Status					
None	43	123	102	177	52
No information	11	27	42	44	13
Hearing	0	1	0	0	0
Visual	0	0	0	2	0
Mobility	0	0	0	2	0

X. Report on International Contacts and Visits

1. SCEC Advisory Council. We have international members of our Advisory Council. TRaul Madariaga of Ecole Normale Superieure, Paris rotated off the council in August, 2005. Garry Rogers of Geological Survey of Canada, Sydney is now joined by Gail Atkinson of Carleton University, Ottawa.

2. ACES (APEC Cooperative for Earthquake Simulation). SCEC and JPL are the U.S. organizations participating in ACES. Information on ACES can be found at http://www.quakes.uq.edu.au/ACES/. Andrea Donnellan of SCEC/JPL is the U.S. delegate to the ACES International Science Board and John McRaney of SCEC is the secretary general. The next ACES workshop will be held in April, 2006 in Hawaii. Participants from Australia, China, Japan, and Canada have confirmed.

3. ETH/Zurich. Stefan Wiemar, Martin Mai, and Daniel Schorlemmer of ETH are participants in the SCEC/RELM project. ETH pays the salaries of the participants and SCEC pays their travel to meetings in the U.S.

4. IGNS/New Zealand. Mark Stirling of the Institute for Geological and Nuclear Sciences of New Zealand is involved in the RELM program.

5. University of Western Ontario/Canada. Kristy Tiampo of the University of Western Ontario in London, Ontario is funded through the Earthquake Source Physics Group.

6. University of British Columbia/Canada. Elizabeth Klein of UBC is funded through the Fault Systems Group.

7. SCIGN. The SCIGN standing committee was disbanded by SCEC in 2005. SCEC continues to work with UNAVCO to transition maintenance of 125 CGPS stations to be part of PBO. We expect this work to be completed in 2008.

8. SCEC Borderland Working Group. SCEC is developing plans to study the active tectonics of the California Borderland. Scientists from CICESE in Ensenada, Mexico are participating in this effort as the area of interest includes both U.S. and Mexican waters.

9. SCEC Annual Meeting. The SCEC annual meeting continues to attract international participants each year. There were participants in the 2005 annual meeting from China, Japan, India, Mexico, Canada, France, Switzerland, Germany, Russia, and New Zealand.

10. 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.

12. US/Japan Joint Workshop on Urban Hazards. A joint workshop was held at ERI-University of Tokyo in October, 2005. SCEC participants included Tom Jordan, Ralph Archuleta, Steve Day, Kim Olsen, Tom Heaton, and Greg Beroza.

XI. Publications

Note: Publication numbers listed here are continued from the SCEC list that was initiated in 1991. This list includes on research publications that had updates between November 1, 2004 and December, 2005.

809. Duan, B., and D. D. Oglesby, Multicycle dynamics of nonplanar strike-slip faults, Journal of Geophysical Research, 110, B03304, 2005.

810. Chen, P., T. H. Jordan and L. Zhao, Finite Moment Tensor of the 3 September 2002 Yorba Linda Earthquake, Bulletin of the Seismological Society of America, in revision, 2005.

811. Tiampo, K.F., Rundle, J.B., Klein, W., Premonitory seismicity changes prior to the Parkfield and Coalinga earthquakes in southern California, Tectonophysics, submitted, 2004.

812. Tiampo, K.F., Rundle, J.B., Klein, W., Stress shadows determined from a phase dynamical measure of historic seismicity, PAGEOPH, in review, 2004.

813. Tiampo, K.F., Rundle, J.B., Klein, W., Sá Martins, J.S., Ferguson, C.D., Ergodic Dynamics in a Natural Threshold Systems: A Study of Earthquake Fault Networks, Physical Review E, in preparation, 2004.

814. Tiampo, K.F., Bowman, D.D., Rundle, J.B., SAM and the PI index: Complementary approaches to earthquake forecasting, Seismological Research Letters, in preparation, 2004.

815. Toda, S., R. S. Stein, K. Richards-Dinger, and S. Bozkurt, Forecasting the evolution of seismicity in southern California: Animations built on earthquake stress transfer, Journal of Geophysical Research, doi:10.1029/2004JB003415, 2005.

816. Meade, B. J., and B. H. Hager, Block Models of Crustal Motion in Southern California Constrained by GPS Measurements, Journal of Geophysical Research - Solid Earth, accepted, 2004.

817. Zhang, C., D. D. Oglesby, and G. Xu, Earthquake nucleation on dip-slip faults with depth-dependent frictional properties, Journal of Geophysical Research, AGU, 109, 2004.

818. Brune, J. N., A. Anooshehpoor, M. D. Purvance, and R. J. Brune, A Band of Precariously Balanced Rocks Extending from Riverside, CA, to near Borrego Valley, CA, Halfway between the Elsinore and San Jacinto Faults: Constraints on Ground Motion for M~7 Earthquakes, Geology, submitted, 2005.

819. Field, E.H., N. Gupta, V. Gupta, M. Blanpied, P. Maechling, and T.H. Jordan, Hazard Calculations for the WGCEP-2002 Earthquake Forecast Using OpenSHA and Distributed Object Technologies, Seismological Research Letters, Susan Hough, SSA, accepted, 2005.

820. Hauksson, E. and P. Shearer, Southern California Hypocenter Relocation with Waveform Cross-Correlation: Part 1. Results Using the Double-Difference Method, Bulletin of the Seismological Society of America, in revision, 2005.

821. Kagan, Y. Y., Earthquake slip distribution: A statistical model, Journal of Geophysical Research, Joan Gomberg, AGU, 110, B5, 2005.

822. Kagan, Y. Y., D. D. Jackson, and Z. Liu, Stress and earthquakes in southern California, 1850-2004, Journal of Geophysical Research, Joan Gomberg, AGU, accepted, 2005.

823. Chester, J. S., F. M. Chester, and A. K. Kronenberg, Fracture Surface Energy of the Punchbowl Fault, San Andreas System, Nature, submitted, 2005.

824. Meade, B. J., and B. H. Hager, Spatial Localization of Moment Deficits in Southern California, Journal of Geophysical Research - Solid Earth, accepted, 2005.

825. Field, E.H., H.A. Seligson, N. Gupta, V. Gupta, T.H. Jordan, and K.W. Campbell, Loss Estimates for a Puente Hills Blind-Thrust Earthquake in Los Angeles, California, Earthquake Spectra, Farzad Naeim, accepted, 2005.

826. Shaw, B.E., Self-organizing fault systems and self-organizing elastodynamic events on them, Geophysical Research Letters, 31, L17603, 2004.

827. Shaw, B.E., Dynamic heterogeneities versus fixed heterogeneities in earthquake models, Geophysical Journal International, 156, 275, 2004.

828. Shaw, B.E., Variation of large elastodynamic earthquakes on complex fault systems, Geophysical Research Letters, 31, L18609, 2004.

829. Griffith, W.A., and M. L. Cooke, HOW SENSITIVE ARE FAULT SLIP RATES IN THE LOS ANGELES BASIN TO TECTONIC BOUNDARY CONDITIONS?, Bulletin of the Seismological Society of America, in revision, 2005.

830. Harris, Ruth A., Numerical simulations of large earthquakes: dynamic rupture propagation on heterogeneous faults, Pure and Applied Geophysics, 161, 2161-2171, 2004.

831. Harris, Ruth A., Stress triggers, Stress shadows, and Seismic hazard, International Handbook of Earthquake and Engineering Seismology, W.H.K. Lee, H. Kanamori, P. C. Jennings, C. Kisslinger, Chapter 73, 1217-1232, 2003.

832. Harris, Ruth A., J.F. Dolan, R. Hartleb, and S.M. Day, The 1999 Izmit, Turkey earthquake - A 3D dynamic stress transfer model of intraearthquake triggering, Bulletin of the Seismological Society of America, 92, 245-255, 2002.

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834. Harris, Ruth A., Earthquake stress triggers, stress shadows, and seismic hazard, Current Science, 79, 1215-1225, 2000.

835. Gomberg, J., P.A. Reasenberg, P. Bodin, and R.A. Harris, Earthquake triggering by seismic waves following the Landers and Hector Mine earthquakes, Nature, 411 , 462-465, 2001.

836. Dreger, D.S., D. D. Oglesby, R. Harris, N. Ratchkovski, and R. Hansen, Kinematic and dynamic rupture models of the November 3, 2002 Mw7.9 Denali, Alaska, earthquake, Geophysical Research Letters, 31, 20 February 2004, 2004.

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838. Harris, R.A., Forecasts of the 1989 Loma Prieta, California, Earthquake, Bulletin of the Seismological Society of America, 88, 898-916, 1998.

839. Eberhart-Phillips, D., and 25 others, including R.A. Harris, The 2002 Denali fault earthquake, Alaska: A large magnitude, slip-partitioned event, Science, AAAS, 300, 1113-1118, 2003.

840. Harris, R.A., Harris, R.A., Earthquake Seismology (1997 Geoscience Highlights), Geotimes, American Geological Institute, 43, 21-22, 1998.

841. Harris, R.A., Earthquake Seismology (1998 Geoscience Highlights Issue), Geotimes, American Geological Institute, 44, 21-22, 1999.

842. Harris, R.A., Earthquakes (1999 Geoscience Highlights Issue), Geotimes, American Geological Institute, 45, 15, 2000.

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Appendices

Appendix A. Long-Term Research Goals

This section outlines the SCEC science priorities for the five-year period from February 1, 2002, to January 31, 2007, as stated in *The SCEC Strategic Plan 2002-2007* (October, 2002). Additional material on the science and management plans for the Center can be found in the SCEC proposal to the NSF and USGS (http://www.scec.org/SCEC).

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

Plate-Boundary Tectonics

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

Key Questions:

- How does the complex system of faults in Southern California accommodate the overall plate motion? To what extent does distributed deformation (folds, pressure-solution compaction, and motions on joints, fractures and small faults) play a role within the seismogenic layer of the crust?

- What lateral tractions drive the fault system? What are the directions and magnitudes of the basal tractions? How do these stresses compare with the stresses due to topography and variations in rock density? Do they vary through time?

- What rheologies govern deformation in the lower crust and mantle? Is deformation beneath the seismogenic zone localized on discrete surfaces or distributed over broad regions? How are these deformations related to those within the seismogenic zone?

- What is the deep structure of fault zones? Are major strike-slip faults such as the SAF truncated by décollements or do they continue through the crust? Do they offset the Moho? Are active thrust faults best described by thick-skin or thin-skin geometries?

- How is the fault system in Southern California evolving over geologic time, what factors are controlling the evolution, and what influence do these changes have on the patterns of seismicity?

Fault Systems

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

Key Questions:

- What are the limits of earthquake predictability, and how are they set by fault-system dynamics?

- How does inelastic deformation affect strain accumulation and release through the earthquake cycle? Does inelastic deformation accumulated over repeated earthquake cycles give rise to landforms and geologic structures that can be used to constrain deformation rates and structural geometries on time intervals of thousands to hundreds of thousands of years?

- Are there patterns in the regional seismicity related to the past or future occurrence of large earthquakes? For example, are major ruptures on the SAF preceded by enhanced activity on secondary faults, temporal changes in b-values, or local quiescence? Can the seismicity cycles associated with large earthquakes be described in terms of repeated approaches to, and retreats from, a regional "critical point" of the fault system?

- What are the statistics that describe seismic clustering in time and space, and what underlying dynamics control this episodic behavior? Is clustering observed in some fault systems due to repeated ruptures on an individual fault segment, or to rupture overlap from multiple segments? Is clustering on an individual fault related to regional clustering encompassing many faults?

- What systematic differences in fault strength and behavior are attributable to the age and maturity of the fault zone, lithology of the wall rock, sense of slip, heat flow, and variation of physical properties with depth? Is the mature SAF a weak fault? If so, why? How are the details of fault-zone physics such as "critical slip distance" expressed at the system level?

- To what extent do fault-zone complexities, such as bends, changes in strength, and other quenched heterogeneities control the nucleation and termination of large earthquakes and their predictability? How repeatable are large earthquakes from event to event, both in terms of location and slip distribution? How applicable are the "characteristic-earthquake" and "slip-patch" models in describing the frequency of large events? How important are dynamic cascades in determining this frequency? Do these cascades depend on the state of stress, as well as the configuration of fault segments?

- How does the fault system respond to the abrupt stress changes caused by earthquakes? To what extent do the stress changes from a large earthquake advance or retard large earthquakes on adjacent faults? How does stress transfer vary with time? Does a more realistic lower-crustal rheology affect the spatial and temporal evolution of seismicity?

- What controls the amplitude and time constants of the post-seismic response, including aftershock sequences and transient aseismic deformations? In particular, how important are induction of self-driven accelerating creep , fault-healing effects, poroelastic effects, and coupling of the seismogenic layer to viscoelastic flow at depth?

Fault-Zone Processes

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

Key Questions:

- Which small-scale processes—pore-water pressurization and flow, thermal effects, geochemical alteration of minerals, solution transport effects, contact creep, microcracking and rock damage, gouge comminution and wear—are important in describing the earthquake cycle of nucleation, dynamic rupture, and post-seismic healing?

- What fault-zone properties and processes determine velocity-weakening vs. velocity-strengthening behavior? How do these properties and processes vary with temperature,

pressure, and composition? How do significant changes in normal stress modify constitutive behavior?

- How does fault strength drop as slip increases immediately prior to and just after the initiation of dynamic fault rupture? Are dilatancy and fluid-flow effects important during nucleation?

- What is the explanation of the discrepancy between the small values of the critical slip distance found in the laboratory (< 100 microns) and the large values (> 100 millimeters) inferred from the fracture energies of large earthquakes? What is the nature of near-fault damage and how can its effect on fault-zone rheology be parameterized?

- How does fault-zone rheology depend on microscale roughness, mesoscale offsets and bends, variations in the thickness and rheology of the gouge zone, and variations in porosity and fluid pressures? Can the effects of these or other physical heterogeneities on fault friction be parameterized in phenomenological laws based on rate and state variables?

- How does fault friction vary as the slip velocities increase to values as large as 1 m/s? How much is frictional weakening enhanced during high-speed slip by thermal softening at asperity contacts and by local melting?

- How do faults heal? Is the dependence of large-scale fault healing on time logarithmic, as observed in the laboratory? What small-scale processes govern the healing rate, and how do they depend on temperature, stress, mineralogy, and pore-fluid chemistry?

Rupture Dynamics

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

Key Questions:
- What is the magnitude of the stress needed to initiate fault rupture? Are crustal faults "brittle" in the sense that ruptures require high stress concentrations to nucleate, but, once started, large ruptures reduce the stress to low residual levels?

- How do earthquakes nucleate? What is the role of foreshocks in this process? What features characterize the early post-instability phase?

- How can data on fault friction from laboratory experiments be reconciled with the earthquake energy budget observed from seismic radiation and near-fault heat flow? What is explanation of short apparent slip duration?

- How much inelastic work is done outside a highly localized fault-zone core during rupture? Is the porosity of the fault zone increased by rock damage due to the passage of the rupture-tip stress concentration? What is the role of aqueous fluids in dynamic weakening and slip stabilization?

- Do minor faults bordering a main fault become involved in producing unsteady rupture propagation and, potentially, in arresting the rupture? Is rupture branching an important process in controlling earthquake size and dynamic complexity?

- Are strong, local variations in normal stress generated by rapid sliding on nonplanar surfaces or material contrasts across these surfaces? If so, how do they affect the energy balance during rupture?

- What produces the slip heterogeneity observed in the analysis of near-field strong motion data? Does it arise from variations in mechanical properties (quenched heterogeneity) or stress fluctuations left in the wake of prior events (dynamic heterogeneity)?

- Under what conditions will ruptures jump damaged zones between major fault strands? Why do many ruptures terminate at releasing step-overs? How does the current state of stress

along a fault segment affect the likelihood of ruptures cascading from one segment to the next?

- What are physical mechanisms for the near-field and far-field dynamical triggering of seismicity by large earthquakes?

Ground Motion

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

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

Seismic Hazard Analysis

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

Key Questions:
- What factors limit fault-rupture propagation? How valid are the cascade and characteristic-earthquake models? What magnitude distribution is appropriate for Southern California?
- How can geodetic (GPS and InSAR) measurements of deformation be used to constrain short- and long-term seismicity rates for use in seismic hazard assessment? How can geologic and paleoseismic data on faults be used to determine earthquake recurrence rates?

- What temporal models and distributions of recurrence intervals pertain to faults in Southern California? Under what circumstances are large events Poissonian in time? Can PSHA be improved by incorporating non-Poissonian distributions?

- Can physics-based scenario simulations produce more accurate estimates of ground-motion parameters than standard attenuation relationships? Can these simulations be used to reduce the high residual variance in these relationships ?

- What is the nature of near-fault ground motion? How do fault ruptures generate long-period directivity pulses? How do near-fault effects differ between reverse and strike-slip faulting? Can these effects be predicted?

- What are the earthquake source and strong ground motion characteristics of large earthquakes (magnitudes larger then 7.5), for which there are few strong motion recordings? Can the shaking from large earthquakes be inferred from smaller events?

- How does the nonlinear seismic response of soils depend on medium properties, amplitude, and frequency?

Appendix B. SCEC By-Laws

The by-laws given here were approved by the SCEC Board of Directors at its March 6, 2002, meeting.

By-Laws of the Southern California Earthquake Center (SCEC)
Effective February 1, 2002

PREAMBLE

The By-Laws of the Southern California Earthquake Center (SCEC) are adopted by the Board of Directors for the purpose of conducting SCEC business in a collegial manner. They should not be construed as overriding the standard responsibilities and prerogatives of Principal Investigators or their respective institutions. However, situations and issues may arise from time to time for which resolution through standard procedures cannot be achieved. Consequently, should the Center Director and the Board of Directors not be able to reach agreement on any given issue, the Center Director, as Principal Investigator on all Center grants/contracts, will ultimately retain full authority to make and implement decisions on Center programs and policies. These by-laws supercede those adopted by SCEC upon its founding on February 1, 1991 and revised in February, 1996.

ARTICLE I

Name

Section 1. The name of the Center is the Southern California Earthquake Center.

ARTICLE II

Member Institutions

Section 1. Core Institutions. The following named institutions shall be Core Institutions:

     * California Institute of Technology
     * Columbia University
        Harvard University
        Massachusetts Institute of Technology
        San Diego State University
        Stanford University
        United States Geological Survey, Golden
        United States Geological Survey, Menlo Park

* United States Geological Survey, Pasadena
* University of California, Los Angeles
* University of California, San Diego
* University of California, Santa Barbara
  University of Nevada, Reno
* University of Southern California

* The *founding* Core Institutions of SCEC.

Section 2. Obligations and Responsibilities of Core Institutions. SCEC Core Institutions are designated academic and Government research organizations with major research programs in earthquake science. Each Core Institution is expected to contribute a significant level of effort (both in personnel and activities) to SCEC programs, including the Communications, Education and Outreach Program. Core Institutions are obligated to contribute a yearly minimum of $35K of institutional resources as matching funds to Center activities. Each core institution shall appoint an *Institutional Director* to the SCEC Board of Directors, who shall represent the appropriate Dean, Office Chief, or higher officer as described in Article III.

Section 3. Addition of Core Institutions. Additional institutions that meet the requirements specified in Article I, Section 2 may become Core Institutions by a two-thirds affirmative vote of the entire Board of Directors.

Section 4. Removal of Core Institutions. Any Core Institution may resign as a Core Institution at any time by giving written notice from the appropriate Dean, Office Chief, or higher officer to the Center Director. Such resignation shall take effect at the time of receipt of the notice, or at any later time specified therein. Any Core Institution may be removed by affirmative vote of *N*–1 Directors, where *N* is the total number of Directors. Any Core Institution that fails to provide a qualified Institutional Director for a period exceeding one year shall be removed as a Core Institution.

Section 5. Participating Institutions. In addition to Core Institutions, SCEC membership shall be open to *Participating Institutions*. Eligible institutions shall include any organization (including profit, not-for-profit, domestic, or foreign) involved in a Center-related research, education, or outreach activity. Participating Institutions do not necessarily receive direct support from the Center. Each Participating Institution shall appoint a qualified *Institutional Liaison* to facilitate communication with the Center. The interests of Participating Institutions shall be represented on the Board of Directors by two Directors At-Large, elected as specified in Article III, Section IV.

Section 6. Election of Participating Institutions. Election to the status of Participating Institution requires a majority affirmative vote of the entire Board of Directors.

Section 7. Removal of Participating Institutions. Any Participating Institution may resign at any time by giving written notice to the Center Director. Such resignation shall take effect at the time of receipt of the notice, or at any later time specified therein. The status of Participating Institution may be withdrawn by a two-thirds affirmative vote of the entire Board of Directors.

Any Participating Institution that fails to provide a qualified Institutional Liaison for a period exceeding one year shall be removed as a Core Institution.

Section 8. Current roster of Core and Participating Institutions. The current list of Core and Participating Institutions shall be public and maintained in an accessible location, such as the Center web site.

ARTICLE III

Board of Directors

Section 1. Powers. The management of the affairs of the Center is vested in the Board of Directors. The Board of Directors shall have power to authorize action on behalf of the Center, make such rules or regulations for its management, create such additional offices or special committees, and select, employ or remove such of its officers, agents or employees as it shall deem best.

Section 2. Composition. The Board of Directors shall be composed of Institutional Directors from each of the Core Institutions and two Directors At-Large.

Section 3. Appointment of Core Institution Directors. The *Institutional Director* from each academic Core Institution shall be appointed by the appropriate Dean, or higher level officer, in a letter to the Center Director. The Institutional Director from the U.S. Geological Survey offices shall be appointed by the appropriate USGS official in a letter to the Center Director.

Section 4. Appointment of Directors At-Large. Two *Directors At-Large* shall be elected for two-year terms from a slate of three or more nominees proposed by a Nominating Committee of the Participating Institutions. The Nominating Committee will be appointed by the Center Director.

Section 5. Term of Office, Core Directors. Each Institutional Director of the Board of Directors shall continue in office until a successor is appointed; or until he or she dies, resigns or is replaced by the relevant officer of the Core Institution as specified in Article III Section 7; or until his or her institution is removed from the list of Core Institutions.

Section 6. Term of Office, Directors At-Large. Each Director At-Large shall serve a term of two years and may be reelected for up to two additional terms. The term of a Director At-Large may be terminated by a vote of $N-1$ of the entire board, where N is the total number of Directors.

Section 7. Resignation, Core Directors. Any Institutional Director may resign at any time by giving written notice to the Chairman of the Board of Directors and the appropriate academic dean or USGS official. Such resignation shall take effect at the time of receipt of the notice, or at any later time specified therein. Upon resignation of an Institutional Director, the Core Institution shall appoint a new Institutional Director within 30 days, or resign as a Core Institution.

Section 8. Resignation, Core Directors. Any Director At-Large may resign at any time by giving written notice to the Chairman of the Board of Directors. Such resignation shall take effect at the time of receipt of the notice, or at any later time specified therein. Upon resignation of an Director At-Large, the Board of Directors shall elect a new Director At-Large within 30 days.

Section 9. Alternate Members. Any Core Institution Director may appoint for a specified time interval, not to exceed one year, an Alternate Member from the same Core Institution to replace Core Institution Director in all of the activities during that interval. Such appointments must be transmitted in writing to the Center Director before taking effect.

Section 9. Salary Compensation. There shall be no salary compensation from Center funds for Institutional Directors and Directors-At-Large. The Center Director and/or Deputy Director may receive salary compensation from Center funds at a level approved by the Board and commensurate with administrative activities carried out on behalf of the Center.

ARTICLE IV

Meetings of the Board of Directors

Section 1. Annual Meeting. The Board of Directors shall hold at least one annual Board meeting at a time convenient for all members of the Board for the purpose of conducting center business.

Section 2. Special Meetings. Special meetings of the Board of Directors may be called by the Chair or Vice-Chair of the Board at any time.

Section 3. Place of Meetings. The Center Director shall designate the place of the annual Board meeting or any special meeting, which may be either within or without the State of California and which shall be specified in the notice of meeting or waiver of notice thereof.

Section 4. Notice of Meetings. Notice of such meeting of the Board of Directors shall be given to each Director by the Executive Secretary, or by an officer directed by the Chairman of the Board of Directors to give such notice by delivering to him or her personally, or by first-class mail or e-mail addressed to him or her at the address of his or her member institution, a written or printed notice not less than ten nor more than sixty days before the date fixed for the meeting. Notice of any meeting need not be given to any Director, however, who submits a signed waiver of notice, whether before or after the meeting. The attendance of any Director at a meeting without protesting the lack of notice thereof prior to the conclusion of the meeting, shall constitute a waiver of notice by him or her. When a meeting is adjourned to another place or time, it shall not be necessary to give any notice of the adjourned meeting if the time and place to which the meeting is adjourned are announced at the meeting at which the adjournment is taken.

Section 5. Quorum. Except as may be otherwise expressly required by law or these By-Laws, at all meetings of the Board of Directors or of any committee thereof, a majority of the Directors or members of such committee then serving in such position shall constitute a quorum. If a quorum is not present, a majority of the Directors present may adjourn the meeting without notice other than by announcement at said meeting, until a quorum is present. At any duly adjourned meeting at which a quorum is present, any business may be transacted which might have been transacted at the meeting as originally called.

Section 6. Executive Sessions. The Board of Directors may, at the direction of the Chairman of the Board of Directors, meet in executive session. At such executive session, the meeting will be open only to Directors, the Executive Secretary, and other persons specifically invited by the Chairman of the Board of Directors.

Section 7. Voting. Each Director shall be entitled to one vote. Except as otherwise expressly required by law, or these By-Laws, all matters shall be decided by the affirmative vote of a majority of the entire Board of Directors membership, if a quorum is then present. All votes shall be by voice vote, unless two members request a secret ballot.   Votes pertaining to elections are governed by Article VII.

Section 8. Action Without a Meeting. Any action required or permitted to be taken by the Board of Directors or any committee thereof, may be taken without a meeting if all members of the Board of Directors consent in writing or by e-mail to the adoption of a resolution authorizing the action. The resolution and the written consents thereof shall be filed with the minutes of the proceedings of the Board of Directors or the committee.

Section 9. Participation by Telephone or Televideo Conference. In any meeting of the Board of Directors or any committee thereof, any one or more Directors or members of any such committee may participate by means of a telephone or televideo conference allowing all persons participating in the meeting to hear and/or see each other at the same time. Participation by such means shall constitute presence in person at a meeting.

ARTICLE V

Officers

Section 1. Officers and Qualifications. The officers of the Center shall consist of a Center Director, a Deputy Director, an Executive Secretary, and other such officers as the Board of Directors may from time to time establish, deem qualified and appoint.

Section 2. Center Director. The *Center Director* is the Chief Executive Officer of the Center and Chairman of the Board of Directors. It shall be his or her duty, insofar as the facilities and funds furnished to him or her by the Center permit, to see that the orders and votes of the Board of Directors and the purposes of the Center are carried out. He/she must be a full-time faculty member at one of the Center's Core Institutions, and shall be the Principal Investigator on all proposals submitted by the Center to external agencies. He/she shall be the board member for

his/her home institution. The Center Director is the Center's official liaison to the rest of the world and, specifically, to the funding agencies. The Center Director will be the principal person for dealing with questions and concerns raised by members of the Center or from the outside. As Chairman of the Board of Directors, he/she shall call and preside at all meetings of the Board of Directors. He/she shall perform other such duties and exercise other such powers as shall from time to time be assigned by the Board of Directors. The Chairman shall have final authority for the science program, budget and financial obligations of the Center. The Chairman may appoint advisory committees or panels to assist in carrying out the business of the Center. The Center Director oversees, in consultation with the Board, the implementation of the Science Plan for the Center and will maintain day-to-day oversight of the science activities. Chairs of standing committees of the Board will report to the Chairman of the Board.

Section 4. Deputy Director. The *Deputy Director* of the Center will assist the Center Director in all his/her duties. He/she shall be nominated by the Center Director and elected by the entire Board of Directors. He/she shall serve as a non-voting *ex-officio* member of the Board of Directors. The Deputy Director will chair the Planning Committee described in Article VI, Section 4. He/she will oversee the CEO program, and will serve as liaison with SCEC partners.

Section 5. Vice-Chair of the Board of Directors. The Board of Directors will elect a *Vice-Chair* from among its members. He/she shall serve as chair of the Board of Directors in the absence of the Center Director.

Section 6. Associate Director for Administration and Executive Secretary to the Board. The *Associate Director for Administration* is the senior staff person to the Board of Directors, the Center Director, and the Deputy Director. He/she shall be nominated by the Center Director and confirmed by a vote of the Board of Directors. He/she reports to the Director and is Executive Secretary to the Board. The Executive Secretary shall give notice of meetings of the Board of Directors, shall record all actions taken at such meetings and shall perform such other duties as shall from time to time be assigned by the Board of Directors.

Section 7. Associate Director for Communication, Education and Outreach. The Center Director shall nominate an *Associate Director for Communications, Education, and Outreach* (CEO). The nominee will be confirmed by a vote of the Board of Directors. The Associate Director for CEO shall oversee the Center programs in communications, education, and knowledge transfer. He/she shall be a non-voting *ex-officio* member of the Board of Directors.

Section 8. Other Associate Directors. Other Associate Directors may be established through nomination by the Center Director for specific activities of the Center and approval by the Board.

Section 9. Resignation of Officers. Any officer may resign at any time by giving written notice to the Center Director, or the Executive Secretary of the Board of Directors. Such resignation shall take effect at the time of receipt of the notice, or at any later time specified therein.

Section 10. Vacancies of Officers. Any vacancy in any office may be filled for the unexpired portion of the term of such office by the Center Director with approval of the Board of Directors.

Section 11. Removal of Officers. Any officer may be removed at any time either with or without cause by affirmative vote of N–1 Directors, where N is the total number of Directors. Removal of the Center Director also requires the consent of funding agencies.

ARTICLE VI

Committees and Advisory Council

Section 1. Establishment of Committees of the Board of Directors. Committees of the Board of Directors may be established for specified terms. Actions by the Board of Directors to create Committees shall specify the scope of Committee activity. Committee members shall be appointed by the Chairman of the Board of Directors. Committee chairs shall be appointed by the Chairman of the Board of Directors from among members of the Center. Committees may not set policy nor take binding action nor publish documents without the consent of the Board of Directors. Committees may not create or appoint Subcommittees without consent of the Board of Directors.

Section 2. Executive Committee of the Board of Directors. The Board of Directors shall establish an *Executive Committee* to take care of the day-to-day business of the Center. The powers of the Executive Committee shall be established by a two-thirds affirmative vote of the entire Board. All actions taken by the Executive Committee must be reported to the full Board with ten business days. The Executive Committee shall consist of the Chairman and Vice Chairman of the Board and three other Board members elected for staggered three-year, renewable terms. The Executive Committee shall hold a business meeting, either in person or by electronic means at least once per quarter. The Executive Secretary of the Board shall serve as Secretary of the Executive Committee, and shall be responsible for transmitting minutes and actions of the Executive Committee to the entire Board.

Section 3. Standing Committees. The Board of Directors may designate one or more *Standing Committees* for each major scientific, educational or research program of the Center. Members of each such committee shall have only the lawful powers specifically delegated to it by the Board. Each such committee shall serve at the pleasure of the Board. Members of a Standing Committee are not required to hold a Director or officer position within the Center. Standing Committees shall prepare plans for the appropriate scientific, educational, or research programs of the Center. These plans shall be modified as appropriate and approved by the Center Director with the advice and counsel of the Board of Directors.

Section 4. Planning Committee. A *Planning Committee* shall be appointed by the Center Director with approval of the Board of Directors. The Planning Committee shall be responsible for conducting the annual proposal review process and constructing annual and long-term science and budget plans for consideration by the Board of Directors. It shall be chaired by the Deputy Director, and its membership shall be constituted to provide a balanced representation of the various disciplines and focus areas of the Center. Planning Committee meetings will be called by the Deputy Director.

Section 5. Advisory Council. The Board of Directors will establish an *Advisory Council* to serve as an experienced advisory body to the Board. The members of the Council shall serve for three-year rotating renewable terms (by thirds). The chair of the Advisory Council shall be appointed for a three-year term by the Center Director in consultation with the Board and may be reappointed for two additional terms. The size and responsibilities of the Council shall be determined by the Board of Directors to reflect current needs of the Center.

ARTICLE VII

Election Procedures

Section 1. Procedure. Officers may be elected by the Board of Directors at any meeting, in accordance with the procedures established in this Article.

Section 2. Election. Election shall be by written ballot, which may be cast in person by a Director at the meeting, or may be submitted by mail, facsimile, or e-mail if received by the Executive Secretary before the meeting. The Executive Secretary will treat all electronic ballots as secret ballots. Election shall be valid if ballots are received from two-thirds of the membership of the entire Board of Directors in accordance with this Article, even if a quorum is not present for the purpose of conducting other business.

Section 3. Method of Voting. In the election of officers, a valid ballot shall contain at most one vote for each office; election shall be decided in favor of the nominee receiving a majority of votes.

Section 4. Counting of Ballots. Ballots shall be counted by the Executive Secretary and the Chairman and Vice-Chairman of the Board of Directors, unless they have cause for recusal.

ARTICLE VIII

Amendments

Section 1. Amendment. All By-Laws of the Center shall be subject to amendment or repeal by the affirmative vote of two-thirds of the entire Board of Directors at any annual or special meeting, provided the notice or waiver of notice of said meeting shall have specified the proposed actions to amend or repeal the By-Laws.

Appendix C. 2006 PROGRAM ANNOUNCEMENT
FOR THE SOUTHERN CALIFORNIA EARTHQUAKE CENTER

I. INTRODUCTION

On February 1, 2002, the Southern California Earthquake Center (SCEC) changed from an entity within the NSF/STC program to a free-standing center, funded by NSF/EAR and the U. S. Geological Survey. This document solicits proposals from individuals and groups to participate in the fifth and final year of the SCEC2 program.

II. GUIDELINES FOR PROPOSAL SUBMISSION

A. Due Date: Monday, **November 14, 2005, 5:00 pm PST**. Late proposals will not be accepted.

B. Delivery Instructions. Proposals and annual reports must be submitted as <u>separate</u> PDF documents via the SCEC Proposal web site at <u>http://www.scec.org/proposals</u>. Submission procedures, including requirements for how to name your PDF files, will be found at this web site.

C. Formatting Instructions.
- *Cover Page:* Should begin with the words "2006 SCEC Proposal," the project title, Principal Investigator, institution, proposal categories (from types listed in Section IV, including the SCEC Intern Project category). List in order of priority three disciplinary and/or focus group(s) that should consider your proposal. Indicate if the proposal should also be identified with one or more of the SCEC special projects (see Section VII) or advanced Implementation Interface projects (see Section VIII for examples). Collaborative proposals involving multiple investigators and/or institutions should list all principal investigators. Proposals do not need to be formally signed by institutional representatives, and should be for one year, with a start date of February 1, 2006.

  - *Technical Description:* Describe in **five pages or fewer (including figures)** the technical details of the project and how it relates to the short-term objectives outlined in the SCEC Science Plan (Section VII). References are not subject to the five page limit.

  - *Budget Page:* Budgets and budget explanations should be constructed using NSF categories. Under guidelines of the SCEC Cooperative Agreements and A-21 regulations, secretarial support and office supplies are not allowable as direct expenses.

  - *Current Support:* Statements of current support, following NSF guidelines, should be included for each Principal Investigator.

  - *2005 Annual Report:* Scientists funded by SCEC in 2005 must submit a report of their progress **by 5 pm November 21, 2005**. 2006 proposals from scientists who do not submit all of their 2005 reports (which may cover 2004 to mid-year 2005 results) will neither be reviewed nor will they be considered for 2006 funding. Reports should be up to five pages of text and figures. Reports should include bibliographic references to any SCEC publication during the past year (including papers submitted and in review), including their SCEC contribution number. Publications are assigned numbers when they are submitted to the SCEC publication database at http://www.scec.org/research/scecnumber.

  - *Labeling the Submitted PDF Proposal:* PI's must follow the naming convention. Investigators must label their submitted proposals and their annual reports with their last name followed by 2006, e.g., Archuleta2006.pdf. If there is more than one, then the file would be labeled as follows: Archuleta2006_1.pdf (for the 1st proposal) and Archuleta2006_2.pdf (for the 2nd proposal).

D. Investigator Responsibilities. Investigators are expected to interact with other SCEC scientists on a regular basis (e.g., by attending workshops and working group meetings), and contribute data, analysis results, and/or models to the appropriate SCEC data center (e.g., Southern California Earthquake Data Center—SCEDC), database (e.g., Fault Activity Database—FAD), or community model (e.g., Community Velocity Model—CVM). Publications resulting entirely or partially from SCEC funding must include a publication number available at http://www.scec.org/research/scecnumber/index.html. By submitting a proposal, investigators are agreeing to these conditions.

E. Eligibility. Proposals can be submitted by eligible Principal Investigators from:
- U.S. Academic institutions
- U.S. Private corporations
- International Institutions (funding will mainly be for travel)

F. Collaboration. Collaborative proposals with investigators from the USGS are encouraged. USGS employees should submit their requests for support through USGS channels. Collaborative proposals involving multiple investigators and/or institutions are strongly encouraged; these can be submitted with the same text, but with different institutional budgets if more than one institution is involved.

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

III. SCEC ORGANIZATION

A. Mission and Science Goal. SCEC is an interdisciplinary, regionally focused organization with a mission to:
- Gather new information about earthquakes in Southern California;
- Integrate this information into a comprehensive and predictive understanding of earthquake phenomena; and
- Communicate this understanding to end-users and the general public in order to increase earthquake awareness, reduce economic losses, and save lives.

SCEC's primary science goal is to develop a comprehensive, physics-based understanding of earthquake phenomena in Southern California through integrative, multidisciplinary studies of plate-boundary tectonics, active fault systems, fault-zone processes, dynamics of fault ruptures, ground motions, and seismic hazard analysis. The long-term science goals are summarized in Appendix A.

B. Disciplinary Activities. The Center sustains disciplinary science through standing committees in *seismology*, *geodesy*, *geology*, and *fault and rock mechanics*. These committees will be responsible for planning and coordinating disciplinary activities relevant to the SCEC science plan, and they will make recommendations to the SCEC Planning Committee regarding support of disciplinary research and infrastructure. High-priority disciplinary activities are summarized in Section VII.A.

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

engineering, risk analysis, and emergency management. High-priority activities are listed for each of these interdisciplinary focus areas in Section VII.B.

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

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

IV. PROPOSAL CATEGORIES

A. **Data Gathering and Products.** SCEC coordinates an interdisciplinary and multi-institutional study of earthquakes in Southern California, which requires data and derived products pertinent to the region. Proposals in this category should address the collection, archiving and distribution of data, including the production of SCEC community models that are on-line, maintained, and documented resources for making data and data products available to the scientific community.

B. **Integration and Theory.** SCEC supports and coordinates interpretive and theoretical investigations on earthquake problems related to the Center's mission. Proposals in this category should be for the integration of data or data products from Category A, or for general or theoretical studies. Proposals in Categories A and B should address one or more of the goals in Section VII, and may include a brief description (<200 words) as to how the proposed research and/or its results might be used in an educational or outreach mode (see Section VII).

C. **Workshops.** SCEC participants who wish to host a workshop between February 2006, and February 2007, should submit a proposal for the workshop in response to this RFP. Workshops in the following topics are particularly relevant:
- Organizing collaborative research efforts for the five-year SCEC program (2002-2007). In particular, interactive workshops that engage more than one focus and/or disciplinary group are strongly encouraged.
- Engaging earthquake engineers and other partner and user groups in SCEC-sponsored research.
- Participating in national initiatives such as EarthScope, the Advanced National Seismic System (ANSS), and the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES).

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

E. **SCEC Intern Project**. Each year SCEC coordinates the SCEC Summer Undergraduate Research Experience (SCEC/SURE) program to support undergraduate student research with SCEC scientists. See the SCEC Internship website at <http://www.scec.org/internships> for

more information. Proposals are encouraged to specify a project for a student for Summer 2006. If a suitable applicant is found for the project, a $5000 stipend will be paid directly to the intern by SCEC. Proposals do not need to include intern funding in the proposed budget.

The project description should include a one-paragraph statement of the scientific problem, research location, intern responsibilities, necessary skills and educational preparation. 2006 SCEC projects that have specified intern components will be announced on the SCEC Internship web page (using the one paragraph statement) to allow applicants to identify their preferred projects.

V. EVALUATION PROCESS AND CRITERIA

- Proposals should be responsive to the RFP. A primary consideration in evaluating proposals will be how directly the proposal addresses the main objectives of SCEC. Important criteria include (not necessarily in order of priority):
    - Scientific merit of the proposed research
    - Competence and performance of the investigators, especially in regard to past SCEC-sponsored research
    - Priority of the proposed project for short-term SCEC objectives as stated in the RFP
    - Promise of the proposed project for contributing to long-term SCEC goals as reflected in the SCEC science plan (see Appendix A).
    - Commitment of the P.I. and institution to the SCEC mission
    - Value of the proposed research relative to its cost
    - Ability to leverage the cost of the proposed research through other funding sources
    - Involvement of students and junior investigators
    - Involvement of women and underrepresented groups
    - Innovative or "risky" ideas that have a reasonable chance of leading to new insights or advances in earthquake physics and/or seismic hazard analysis.

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

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

- The Science Planning Committee is chaired by the Deputy Director and comprises the chairs of the disciplinary committees, focus groups, and special projects. It is responsible for recommending a balanced science budget to the Center Director.

- The CEO Planning Committee is chaired by the Associate Director for CEO and comprises experts involved in SCEC and USGS implementation, education, and outreach. It is responsible for recommending a balanced CEO budget to the Center Director.

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

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

- The review process should be completed and applicants notified by the end of February, 2006.

VI. COORDINATION OF RESEARCH BETWEEN SCEC AND USGS-ERHP

Earthquake research in Southern California is supported both by SCEC and by the USGS Earthquake Hazards Reduction Program (EHRP). EHRP's mission is to provide the scientific information and knowledge necessary to reduce deaths, injuries, and economic losses from earthquakes. Products of this program include timely notifications of earthquake locations, size, and potential damage, regional and national assessments of earthquakes hazards, and increased understanding of the cause of earthquakes and their effects. EHRP funds research via its External Research Program, as well as work by USGS staff in its Pasadena, Menlo Park, and Golden offices. The EHRP also supports SCEC directly with $1.1M per year.

SCEC and EHRP coordinate research activities through formal means, including USGS membership on the SCEC Board of Directors and a Joint Planning Committee, and through a variety of less formal means. Interested researchers are invited to contact Dr. Lucy Jones, EHRP coordinator for Southern California, or other SCEC and EHRP staff to discuss opportunities for coordinated research.

The USGS EHRP supports a competitive, peer-reviewed, external program of research grants that enlists the talents and expertise of the academic community, State and local government, and the private sector. The investigations and activities supported through the external program are coordinated with and complement the internal USGS program efforts. This program is divided into six geographical/topical 'regions', including one specifically aimed at southern California earthquake research and others aimed at earthquake physics and effects and at probabilistic seismic hazard assessment (PSHA). The Program invites proposals that assist in achieving EHRP goals.

The EHRP web page, http://erp-web.er.usgs.gov/, describes program priorities, projects currently funded, results from past work, and instructions for submitting proposals. The EHRP external funding cycle is several months offset from SCEC's, with the RFP due out in February and proposals due in early May. Interested PI's are encouraged to contact the USGS regional or

topical coordinators for Southern California, Earthquake Physics and Effects, and/or National (PSHA) research, as listed under the "Contact Us" tab.

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

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

VII. RESEARCH OBJECTIVES

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

A. Disciplinary Activities

The Center will sustain disciplinary science through standing committees in *seismology*, *geodesy*, *geology*, and *fault and rock mechanics*. These committees will be responsible for planning and coordinating disciplinary activities relevant to the SCEC science plan, and they will make recommendations to the SCEC Planning Committee regarding the support of disciplinary infrastructure. High-priority disciplinary objectives include the following tasks:

1. Seismology

Data Gathering: Maintain and improve the ability of SCEC scientists to collect seismograms to further the goals of SCEC. Efforts may include:

- 1) Maintaining and adding to the network of borehole seismometers in order to improve resolution of earthquake source physics and the influence of the near-surface on ground motions, and

- 2) Maintaining and upgrading a pool of portable instruments in support of targeted deployments or aftershock response.

- Other possible activities include seed money for design of future passive and active experiments such as dense array measurements of basin structure and large earthquake properties, OBS deployments, and deep basement borehole studies.

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

- Enhancements to the SCEDC are encouraged that will extend its capabilities beyond routine network operations and waveform archiving, and assist researchers in using more of the data. Desirable improvements include support hardware and software enhancements, better integration with data centers in other regions, and extension of catalogs.

  Specific goals include:

- Developing the ability to preview seismograms and directly load waveforms into programs,

- Implementing software that permits access to both northern and southern California data with a single data request, and 3) Incorporating first motion and moment tensors as they become available.

2.   Tectonic Geodesy

Data Gathering:

In areas of special interest, support the collection of geodetic data to decrease error or increase site density in the CMM by reobserving sites using any appropriate geodetic method. The proposal should explain how the improvement is likely to occur. Observations that will help to clarify vertical motions are especially valued.

- Support the collection of data relevant to time-varying deformation.

- Proposals should describe how the proposed measurements relate to others, both existing (the CMM and SCIGN) and planned (PBO).

Data Products:

- Continue to assimilate newly acquired GPS data to update the Crustal Motion Map, in order to better describe postseismic and coseismic motions, vertical motion, and horizontal motions throughout California. The goal is to combine survey-mode and continuous GPS data into a seamless set of products.

- Support small-scale projects which use InSAR data, solely or combined with other measurements, to produce products for general use by the SCEC Community.

- If needed, provide support to ensure that data from all continuous GPS sites in Southern California are archived in ways that facilitate easy access, and that a unified set of time-series products are available for all such sites.

Analysis (with Fault Sytems):

- Investigate methods for using CMM/SCIGN/EarthScope products to estimate spatial and temporal variations in deformation rate, and compare these with related observations over different time scales.

- Examine the use of geodetic and other data to remove non-tectonic signals from deformation records.

3.   Earthquake Geology

The geology disciplinary committee fosters geologic measurements of active tectonics and direct observations of fault zones that further our understanding of earthquake recurrence processes. Specific research objectives in geology include the following foci:

Data Gathering
- Collect new information on fault slip rates, develop paleoseismic chronologies that span multiple recurrence cycles, and develop paleoseismic sites that define slip in past earthquakes.
- Develop methodology to test paleoseismic methodology and improve resolution of event chronologies.
- Foster analysis of subsurface fault systems and off-fault deformation, including the 3D configuration of emergent and blind thrusts.
- Compile and generate data on absolute and relative vertical motions in southern California, including development of deformed reference surface libraries.
- Investigate geologic archives of maximum seismic ground motions in southern California.
- Develop key examples of fault intersections, linkage zones, and stepovers that may affect dynamic rupture processes.
- Conduct detailed studies of fault zone materials and structures in and adjacent to exhumed faults that relate to the rupture processes, including fault zone signatures of damage and preferred rupture direction.
-

Data Products
- Integrate field and laboratory efforts to date geologic samples and events, including standardized procedures for field documentation, sample treatment, dating methodologies, and data archiving and distribution.
- Produce a paleoseismic event chronology with slip-per-event information for the past 2000 years for the southern San Andreas and San Jacinto fault system.
- Construct a community vertical motions map with emphasis on data that integrate motions over the 10^4 to 10^5 year timescales.
- Develop, build and contribute new and existing data to the Community Fault Model and to the Working Group on California Earthquake Probabilities.

The geology disciplinary committee also coordinates shared infrastructure for geology field research. At present, geology infrastructure supports shared geochronology resources. Estimated C-14, cosmogenic, and OSL geochronology requirements should be stated within individual proposals but not listed as part of the budget. *These estimates must be coordinated with the geochronology infrastructure proposal before the proposal submission deadline.*

4.   **Fault and Rock Mechanics**

Research under Fault and Rock Mechanics (FARM) is designed to support mechanics-oriented studies via the linked disciplines of experimental rock deformation, field observation, and modeling. Greatest emphasis will be given to research that can increase our understanding of fault behavior during nucleation and dynamic earthquake slip and thereby provide useful input for models of dynamic rupture.   This includes laboratory, modeling, and field studies aimed at determining the maximum possible ground shaking that can result from plausible extreme behavior at the earthquake source. Collaboration with SAFOD studies is strongly encouraged.

Also of importance, but of lower priority, is to conduct coordinated field, laboratory and theoretical studies to determine the time evolution of physical parameters during the inter-seismic period that might control the onset and characteristics of earthquake faulting. Such parameters might include those controlling fault/fluid interactions and frictional properties.

Laboratory Experimental Studies:
- Pilot studies designed to develop and test new experimental techniques, or to develop a new facility, to measure sliding resistance of faults at seismic slip rates
- Assess information and products from rock-mechanics experiments that will be most useful in SCEC studies of earthquake source physics and fault-system dynamics and develop an IT framework for an open database of experimental results; expand upon existing databases

Field Studies:
- Detailed characterizations of natural slip surfaces and the products of high-speed deformation experiments to identify the structures diagnostic of dynamic slip and to test hypotheses of dynamic weakening
- Field studies geared towards developing a model of the 3D structure of a fault zone, particularly to define and quantify geometric and material property variations that influence rupture propagation, and detecting possible thermal signatures of paleoearthquake slip
- Developing a database for large strike-slip faults world-wide that could serve as analogs to the seismogenic depth range of the modern San Andreas fault in Southern California and that includes information about tectonic setting and history, depth of exhumation, locations, quality and extent of exposures, and an annotated bibliography for each fault including any relevant fault and rock mechanics research
- Cataloging of, and/or studies of, existing industry borehole data (e.g. logs, stress measurements, core material) and products of other excavations crossing significant faults in Southern California in order to address fault zone process questions
- Assess information and products from fieldwork that will be most useful in SCEC studies of earthquake source physics and fault-system dynamics and develop an IT framework for an open database of field results; expand upon existing databases

Modeling Studies
- Modeling activities to predict fault behavior during dynamic slip, especially with extreme weakening
- Modeling fault behavior on the San Andreas fault near the EarthScope SAFOD
- Develop an IT framework for an open database of model results; expand upon existing databases

B.   Interdisciplinary Focus Areas

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

1.   Structural Representation

The Structural Representation group aims to develop unified, three-dimensional representations of active faults and earth structure (velocity, density, etc.) for use in fault-system analysis, ground-motion prediction, and hazard assessment. This year's efforts will focus on making improvements to existing community models (CVM, CVM-H, CFM, CBM) and evaluating alternative structural representations. We will also support the use of these models in various aspects of earthquake science by other working groups in SCEC.

- *Community Velocity Model (CVM):* Develop and implement improvements to the current SCEC velocity models, with emphasis on more accurate representations of Vs and density structure, basin shapes, and attenuation. Make the models compatible with fault positions and displacements as represented in the CFM. Evaluate the models with data (e.g., waveforms, gravity) to distinguish alternative models and quantify model uncertainties. Generate integrated northern and southern California models.

- *Community Fault Model (CFM):* Improve and evaluate the CFM, placing emphasis on: a) defining the geometry of major faults that are incompletely, or inaccurately represented in the current model; b) producing alternative fault representations; and c) providing more detailed representations of fault terminations and linkages. Evaluate the CFM with data (e.g., seismicity) to distinguish alternative fault models. Generate integrated northern and southern California models.

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

2.   Fault Systems

The fault systems group solicits proposals to investigate the system-level architecture and behavior of fault networks, assessing the ways in which the these control seismic activity and regional deformation.

Fault-System Behavior:

- Infer rates of change in stress from geodetic and seismic observations.

- Compare and interpret quantitatively short-term geodetic rates of deformation, long-term geologic rates, and rates predicted by seismicity simulators.

- Quantify the space-time behavior of the California fault system in ways that are targeted to test models of earthquake occurrence.

- Foster collaborations to obtain outside funding to support large, coordinated data- gathering efforts.

- Determine how geologic deformation is partitioned between slip on faults and distributed off-fault deformation.

• Determine how geodetic strain is partitioned between long-term permanent and short-term elastic strain and on-fault slip or permanent distributed strain.

• Determine the partitioning between seismicity on recognized faults and off-fault seismicity, and how each contributes to the GR relationship.

Deformation Models:

• Develop models to infer fault slip state-wide (see RELM and WGCEP components of Seismic Hazard Analysis section), and evolution of stress.

• Develop, validate and facilitate use of 3D quasi-static codes utilizing realistic geometries and rheological properties (e.g., 3-D elastic structure, Burgers body viscoelasticity, rate-state friction, plasticity, poroelasticity, damage rheology).

• Foster collaborations that will facilitate understanding of and address differences between model inferences (e.g., between various crustal deformation models or between those models and geology) by using common geometries (CFM, CBM, USR) and common data sets (CMM3, CMM4, FIS), and/or provide cleaned, documented data sets.

• Develop continuum representations of fault system behavior on scales smaller than can be resolved as faulting on computationally feasible meshes.

• Generate finite element meshes of the CBM and assess the trade-offs between resolution and accuracy in realistic geometries.

• Assess mechanical compatibility of the CFM and how slip is transferred between recognized fault segments.

• Develop a reference model of the time-dependent stress transfer and deformation associated with the 1992 Landers & 1999 Hector Mine earthquakes.

• Extend models of time-dependent stress transfer and deformation of California to cover multiple earthquake cycles addressing geologic slip rates, geodetic motions (including CMM 4.0), and earthquake histories, and use these models to infer fault slip.

• Couple numerical models of the interseismic period to quasi-static full-cycle fault models to better constrain stress transfer and conditions and processes at the start of dynamic rupture, including forcing by realistic coseismic displacements and dynamic stresses (with Source Physics).

• Develop tectonic models that explain inferred rates of fault slip and state of stress.

Seismicity Evolution:

• Search for statistically significant signals in the space-time- magnitude distribution of seismicity and understand their physical origin.

• Quantify sources of complexity, including geometrical structure, stress transfer, fault zone heterogeneity, rheology, and slip dynamics.

• Determine effects of computational mesh scale & resolution in geometrically complex models.

• Develop and validate rapid simulation methods for modeling earthquakes in fault systems over a wide range of earthquake magnitudes (with Source Physics).

• Incorporate constraints from geologic & geodetic data, realistic boundary conditions and fault rupture parameterizations, rate-state friction and normal stress variations.

• Assess the processes that control the space-time-magnitude distribution of regional seismicity.

• Assemble models simulating earthquake catalogs (not limited to CFM faults).

• Assess the utility of seismicity evolution models in forecasting earthquakes.

3. **Earthquake Source Physics**

Numerical Simulations Of The Earthquake Source And Earthquake Cycle

- Conduct numerical simulations of dynamic rupture nucleation, propagation, and termination that include known or realistic complexity in fault geometry, material properties, stress state, and constitutive relations. Compare results with source and fault zone observations. Use this information to test hypotheses or develop new testable hypotheses about earthquake source physics. Use this information to generate earthquake scenarios, especially for Southern California (*Joint with Ground Motions Group*).

- Explore what aspects of the source generate high-frequency waves. (*Joint with Ground Motions Group*)

- Explore what aspects of the source and fault zone determine propagation direction (directivity).

- Use numerical simulations results to guide seismic hazards analysis. Use dynamic rupture simulations to estimate probabilities of earthquakes rupturing multiple faults. (*Joint with SHA Group*)

- Participate in the code validation exercises for 3D spontaneous rupture simulations (also Pathway 3 of the SCEC ITR) by performing benchmark tests and comparing results with the rest of the ESP and Pathway 3 community. In addition to investigating basic earthquake source physics problems, target problems of specific interest to the Extreme Ground Motions, NGA-H, Terashake, and Cybershake projects. Develop a user-friendly web-based community IT tool to enhance code comparison and validation. Develop code performance metrics.

- Bridge the interface between Earthquake Source Physics and Fault Systems by conducting physics-based fully dynamic multi-earthquake-cycle simulations, and by determining if simpler, quasi-dynamic or quasi-static simulations may suffice as a proxy for full dynamic simulations in long-term fault-systems simulations. (*Joint with FS Focus Group*)

- Investigate how uncertainty in model parameters propagate into final results of dynamic faulting models.

- Participate in NGA-H. Investigate particular problems of interest to NGA-H. (*Joint with Implementation Interface Group*)

- Participate in YM Extreme Ground Motions Project. Investigate particular problems of interest to YM. (*Joint with Implementation Interface Group*)

Reference Earthquakes

- Building on efforts started in 2004, continue work on a database that includes geodetic, geologic, and seismological data (and metadata), as well as models derived from them. The goal is to facilitate comparison of different models and analysis of multiple datasets. The reference earthquake database will be used for testing/validation of earthquake physics concepts and modeling techniques, and will serve as a template for additional reference earthquakes.

In-Situ Studies Of Fault-Zones (Exhumed Faults & Deep Cores)

- Examine and document features of fault zones in Southern California, including the San Andreas fault system, Parkfield, and the SAFOD site, that reveal the mechanical, chemical, thermal, and kinematic processes that occur during dynamic rupture. Include measurements and inferences of on-fault and near-fault stress, slip-zone thickness, fine-scale fault-zone geometry, adjacent damage, and fluid content at seismogenic depths. (*Joint with Geology and FARM Groups*)

Earthquake Scaling

- Determine to what extent earthquake behavior depends on earthquake size.

- Determine if there are breaks or trends in scaling behavior of quantities, such as stress drop or radiated seismic energy. If so, determine how they can constrain models of the earthquake source.

Lab Studies Of The Earthquake Source (*Joint with FARM Group*)

- Carry out lab experiments on faults in rock or analog materials to determine shear resistance at high slip speeds (on the order of 1 m/s) and stress conditions at seismogenic depths (or appropriately scaled conditions for analog materials).

- Measure hydrologic properties of likely fault zone materials at high rates of deformation and fluid flow.

- Conduct theoretical studies of expected behavior for possible high-speed weakening mechanisms.

- Determine how changes in normal stress might affect shear resistance during dynamic rupture.

- Compare laboratory results with dynamic rupture source observations. Use this information to test proposed constitutive relations or develop improved constitutive relations. Use this information to test numerical spontaneous rupture simulations of the earthquake source.

Earthquake Interaction As An Approach To Explain Earthquake Physics

- Use observations of earthquake triggering or suppression to test models of earthquake interaction and constrain the physics of earthquake rupture nucleation, propagation, and arrest.

4.   Ground Motions

The primary long-term goal of the Ground Motion Focus Group is to understand and characterize seismic ground motion in urbanized Southern California well enough to predict the ground motions from specified sources at frequencies up to at least 1 Hz, and to formulate useful, consistent, stochastic models of ground motions up to at least 10 Hz. Accomplishing this goal requires knowledge of seismic source processes, geologic structure, anelastic wave propagation in heterogeneous media, and non-linear soil response. Thus, the Ground Motion Group relies heavily on interaction and collaboration with other SCEC groups, in particular, the Earthquake Source Physics Group (source rupture processes), the Structural Representation Group (CVM, CFM, USR), the Seismic Hazard Group (waveform-based hazard assessment), and the Implementation Interface (conduit to the engineering community). Projects funded within the Ground Motion Group need to directly address the long-term goal with the aim of providing usable results by the end of SCEC2, and need to clearly describe potential interactions/collaborations with other SCEC groups.

Specifically identified topics are listed below:

    • *Broadband Ground Motion Modeling Project*: Multiple groups/investigators will calculate synthetic seismograms up to 10Hz by combining deterministic and high frequency (stochastic or other) synthetics and comparing with observations. Validation of methodologies should use ground motions from pertinent earthquakes (e.g., Northridge, Landers, Hector Mine, Loma Prieta). Successful approaches will be used to extend existing 3D scenarios* to broadband by end of SCEC2, and may be used in the NGA-H Program, described in more detail in Section VIII, Part B –Implementation Interface.

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

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

    • *Non-Linear Site Response*: Develop methods for incorporating nonlinear site response for large amplitude ground motion events in Southern California. Ideas that improve our understanding of linear site response should lead to a new understanding of how site response varies spatially. Investigate soil- (building) structure interaction and its effect on ground response including nonlinear effects.

    • *High Frequency Wavefield:* Develop strategies/experiments to separate source and path effects in high frequency wavefields. This could include empirical Green's functions, results

from the scattering model, inversion. Develop hybrid models (e.g., 3D+asymptotic methods, 3D+2D, 3D+1D) to include higher frequencies. Evaluate basin-edge effects.

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

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

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

5.   Seismic Hazard Analysis

OpenSHA: Contribute to the Community Modeling Environment for Seismic Hazard Analysis (known as OpenSHA; www.OpenSHA.org). This is an open-source, object oriented, and web enabled framework that will allow various, arbitrarily complex (e.g., physics based) earthquake rupture forecasts, ground-motion models, and engineering response measures to plug in for SHA. Part of this effort is to use information technology to enable the various models and databases they depend upon to be geographically distributed and run-time accessible. Contributions may include:

- Implementing any of the various components (in Java or other languages)

- Testing any of the various components or applications

- Extending the existing framework to enable other capabilities, such as vector-valued hazard analysis, to interface with existing risk/loss estimation tools, or to web-enable the testing of the various RELM forecast models

- Developing and implementing waveform-on-demand capabilities (i.e., the generation of synthetic seismograms for an arbitrary earthquake rupture and site or grid of sites)

- Conducting outreach activities (e.g., workshop) with potential user groups or developing educational modules

Regional Earthquake Likelihood Models (RELM): Although RELM will be expanding into the Center for the Study of Earthquake Predictability (CSEP) over the next year, we nevertheless encourage the following contributions:

- Formally submit earthquake rupture forecast (ERF) models for testing and evaluation (5 year, 1-year, and 1-day forecasts are particularly desired)

- Develop physics-based simulation ERFs, which are desirable to both extend "next-event" forecasts to forecasts of all possible sequences of events, and to test probability models that might be applied in more empirically-based models

- Continue the development of shared data resources needed by forecast modelers,

especially in terms of making them on-line and machine readable.

- Establish and implement quantitative tests of the various forecast models using observed seismicity, precarious-rock constraints, historically observed intensity levels, or other viable approaches. This includes methods to test alarm-based forecasts

- Conduct workshops to facilitate the various RELM or CSEP activities (e.g., to establish standards for testing the models)

Contribute to the ongoing Working Group on California Earthquake Probabilities (WGCEP): We encourage contributions to the WGCEP's effort to develop a time-dependent Uniform California Earthquake Rupture Forecast (UCERF), which is being funded in part by the California Earthquake Authority for their use in setting earthquake insurance rates. Planned innovations include relaxing assumption of persistent rupture boundaries (fault segmentation), allowing fault-to-fault jumps, the use of kinematically consistent deformation models, and the inclusion of earthquake triggering effects. The model will be deployed in an adaptable and extensible framework whereby modifications can be made as warranted by scientific developments, the collection of new data, or following the occurrence of significant earthquakes. The model will be "living" to the extent that the update and evaluation process can occur in short order. The modular design means we can use a relatively simple versions of each component at first, and add more sophisticated components later. Specific information on the components and other potential contributions can be gleaned from material at http://www.relm.org/models/WGCEP (a temporary location). We specifically encourage the following:

- Compilation, analysis, or interpretation of paleoseismic data (fault slip rates, cumulative offsets, or dates of events inferred at fault locations)

- Refinement of 3D fault models (including those in N. California), coordinated with the Structural Representation group.

- Contribution of a statewide deformation models or the compilation of data used therein (e.g., GPS)

- Development of models or constraints on the long-term rate of all possible earthquakes throughout California (e.g., magnitude-area relationships, or constraints on the magnitude-frequency distribution of the region or on individual faults)

- Application of dynamic rupture modeling or paleoseismology to constrain fault segmentation or the probability of fault-to-fault jumps

- Application of physics-based earthquake simulations to test possible approaches for defining time-dependent probabilities

- Development of any type of viable, time-dependent probability model that can plug into our framework (e.g., renewal-type models where strict segmentation is relaxed, empirically based triggering models, or theoretically based stress-interaction models)

- Establishment of a standardized, community endorsed interface between SHA and loss modeling

- Help refine or constrain any of the following: Mag(Area) relationships, seismogenic depths, or aseismicity

C.   Special Projects

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

1.   Continental Borderland (www.scec.org/borderland)

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

• Analyses of newly released grids of industry seismic reflection data (available through the National Archive of Marine Seismic Surveys) to better quantify crustal velocities and the location, subsurface geometry and late-Quaternary history of active offshore structures;

• Mapping and dating of stratigraphic reference horizons in 3D to better define the near-surface deformation associated with blind faults, the timing and rates of fault and fold evolution, and the pattern of uplift and subsidence associated with offshore vertical motions;

• Development of high-resolution techniques for conducting submarine paleoseismology through innovative multidisciplinary techniques for identifying, imaging, sampling, and dating possible individual slip events on offshore faults;

• Waveform analyses of offshore earthquakes (both recent and historical) to invert for velocities and improve event locations, magnitudes, and focal mechanism solutions, etc.;

• Promote continued acquisition of high-resolution multibeam bathymetry data or other high-resolution seafloor imaging systems to provide more comprehensive mapping of active offshore faults and quantitative seafloor geomorphological studies;

Such Borderland efforts may be best developed in collaboration with other disciplines (climate, oceanography, marine habitat studies, etc.), programs (EarthScope) and agencies (NOAA, NSF, NURP, etc.). SCEC wishes to encourage cooperative and collaborative projects that promote these objectives.

2.   Information Technology (www.scec.org/cme)

SCEC needs to implement the tools of information technology (IT) to carry out its research agenda. A major collaboration involving SCEC scientists and IT researchers was recently funded by the NSF Information Technology Research Program to develop an advanced information infrastructure for earthquake science in Southern California (the SCEC Community Modeling Environment). The Center encourages participation by SCEC

scientists in its IT activities, either directly or as part of ongoing research projects. These include: 1) defining the data structures needed to exchange information and computational results in SCEC research, including implementing these data structures via XML schema for selected computational pathways in seismic hazard analysis and ground-motion simulation; 2) developing, verifying, benchmarking, documenting, and maintaining SCEC community models; 3) developing tools for visualizing earthquake information that improve the community's capabilities in research and education; and 4) organizing collections for, and contributing IT capabilities to, the *Electronic Encyclopedia of Earthquakes* (E^3).

VIII. SCEC COMMUNICATION, EDUCATION, AND OUTREACH PLAN

SCEC is a community of over 500 scientists, students, and staff from 50 institutions across the United States, in partnership with many other science, engineering, education, and government organizations worldwide. To facilitate applications of the knowledge and scientific products developed by this community, SCEC maintains a *Communication, Education, and Outreach* (CEO) program with four long-term goals:

- Coordinate productive interactions among a diverse community of SCEC scientists and with partners in science, engineering, risk management, government, business, and education.

- Increase earthquake knowledge and science literacy at all educational levels, including students and the general public.

- Improve earthquake hazard and risk assessments

- Promote earthquake preparedness, mitigation, and planning for response and recovery.

Short-term objectives are outlined below. Many of these objectives present opportunities for members of the SCEC community to become involved in CEO activities, which are for the most part coordinated by CEO staff. To support the involvement of as many others as possible, budgets for proposed projects should be on the order of $3,000 to $7,000 (Implementation Interface research proposals excluded). Hence proposals that include additional sources of support (cost-sharing, funding from other organizations, etc.) are highly recommended. Those interested in submitting a CEO proposal should first contact Mark Benthien, director for CEO, at 213-740-0323 or benthien@usc.edu.

A. CEO Focus Area Objectives

1. SCEC Community Development and Resources *(activities and resources for SCEC scientists and students)*
   SC1 Increase diversity of SCEC leadership, scientists, and students
   SC2 Facilitate communication within the SCEC Community
   SC3 Increase utilization of products from individual research projects

2. Education *(programs and resources for students, educators, and learners of all ages)*
   E1   Develop innovative earth-science education resources
   E2   Interest, involve and retain students in earthquake science
   E3   Offer effective professional development for K-12 educators

3. Public Outreach *(activities and products for media reporters and writers, civic groups and the general public)*
   P1   Provide useful general earthquake information
   P2   Develop information for the Spanish-speaking community
   P3   Facilitate effective media relations
   P4   Promote SCEC activities

4. Implementation Interface *(activities with engineers and other scientists, practicing professionals, risk managers, and government officials.*
   I1   Engage in collaborations with earthquake engineering researchers and practitioners
   I2   Develop useful products and activities for practicing professionals
   I3   Support improved hazard and risk assessment by local government and industry
   I4   Promote effective mitigation techniques and seismic policies

B. Advanced Implementation Interface Projects

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

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

Beyond this solicitation, SCEC is involved in four Auxiliary Projects in which participants have been or will be selected through other means. These projects are outlined below.

SOLICITED PROJECTS

Ground Motion Response

- Improved regional site response factors from detailed surface geology and from geotechnical borehole data bases; K-net and Kik-net (Japan). Potential co-sponsors: CGS, PEER-Lifelines

- Improved site response estimation in simulations for regions having soft soils e.g. Long Beach; soil failure. Potential co-sponsors: PEER-Lifelines

- Seismic velocity profiles from micro-tremor arrays for deep Vs profiles to complement SASW testing. Potential co-sponsors: PEER-Lifelines

- Data base of soil boring logs to augment ROSRINE. Potential co-sponsors: PEER-Lifelines

- Mapping of basin edge effects using geological data consistent with engineering model from the "Basins" project. Potential co-sponsors: CGS, PEER-Lifelines

Ground Motion Time Histories

- Selection, scaling and spectral matching of time histories. Potential co-sponsors: NEES, MAE, MCEER, PEER

- Validation of simulated ground motions for performance assessment of buildings and bridges, including site effects. Potential co-sponsors: MAE, MCEER, PEER

Relationship Between Ground Motion Characteristics, Building Response, and the Three Loss D's: Deaths, Dollars and Downtime

- Identify damaging characteristics of ground motions, and mapping of associated hazard intensity measures, including vector-valued hazard measures. Get feedback from engineers to seismologists identifying aspects of ground motions that are key to predicting damage. Potential co-sponsors: CUREE, MAE, MCEER, PEER

- Develop different fragility functions for different levels of aggregation (building-specific vs. census tract). Potential co-sponsors: CUREE, MAE, MCEER, NEES, PEER

- Investigage how ground motions enter low-rise buildings. Potential co-sponsors: CUREE, MAE, MCEER, NEES, PEER

- Initiate end-to-end simulations including long-span bridges. Potential co-sponsors: CUREE, MAE, MCEER, NEES, PEER

- Develop a database of model buildings. Potential co-sponsors: CUREE, MAE, MCEER, PEER

Societal Implications of Earthquake Hazard

- Risk and implications of earthquake hazards on distributed lifeline systems and regional economies – identify the real vulnerabilities. Potential co-sponsors: MAE, MCEER, PEER-Lifelines

Loss Estimation

- Develop loss estimation methodology for evaluating societal impacts of SCEC products such as alternative RELM fault models or alternative ground motion models. Potential co-sponsors: CUREE, MAE, MCEER, PEER

- Improve the interface between seismic hazard analysis and loss analysis (currently OpenSHA – HAZUS). Potential co-sponsors: CUREE, MAE, MCEER, PEER

- Contribute earthquake science components of a national disaster experience archive. Potential co-sponsors: USGS, EERI

Information Technology

- Exchange experience with use of information technologies. Potential co-sponsors: NEES
- Simulation and visualization of earthquake hazards, ground motions, geotechnical/structural response and damage. Potential co-sponsors: NEES, MAE, MCEER, PEER

AUXILIARY PROJECTS

Next Generation Attenuation Project (NGA)

- The purpose of this project is to contribute to the development of a set of ground motion prediction models that are based on validated ground motion simulations as well as on recorded strong ground motions. Multiple groups / investigators will calculate synthetic seismograms up to 10Hz by combining deterministic and high frequency (stochastic or other) synthetics and comparing them with observations. Co-sponsors are CEA, NSF, and PEER-Lifelines. The main SCEC focus groups involved in this project are Earthquake Source Physics, especially rupture dynamics, and Ground Motion

Extreme Ground Motion Project (XGM)

- The purpose of this project is seek physical limits on the amplitude of strong ground motion in rock, and is motivated by the issue of ground motion levels at very low probability levels at Yucca Mountain. SCEC held an initial workshop on this project just before the Annual Meeting (September 8 – 10, 2005) to discuss and make recommendations on a draft work plan. This project is sponsored by DOE. The main SCEC discipline and focus groups that will work on this project are Geology – especially fault zone geology; Fault and Rock Mechanics; Earthquake Source Physics, and Ground Motion.

End-to-End Simulation

- The purpose of this project is to foster interaction between earthquake scientists and earthquake engineers through the collaborative modeling of the whole process involved in earthquake fault rupture, seismic wave propagation, site response, soil-structure interaction, and building response. This project is sponsored by NSF (tall buildings) and CEA (woodframe buildings). The main SCEC discipline and focus groups working on this project are Geology, especially fault models; Unified Structural Representation; Earthquake Source Physics; Ground Motion; and CME – Terashake and Cybershake

Time Histories for Earthquake Engineering

- The purpose of this project is to provide ground motion time histories to earthquake engineering researchers and practitioners to use in experimental testing facilities and in non-linear time domain response analyses of structures. Many of the testing facilities are part of NEES – the Network for Earthquake Engineering Simulation. This project is sponsored by NSF. The main SCEC discipline and focus groups working on this project are Ground Motion and CME – Terashake and Cybershake