Southern California Earthquake Center

2004 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 third year of SCEC2. The report is organized into the following sections:

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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 presented in Figure II.1.

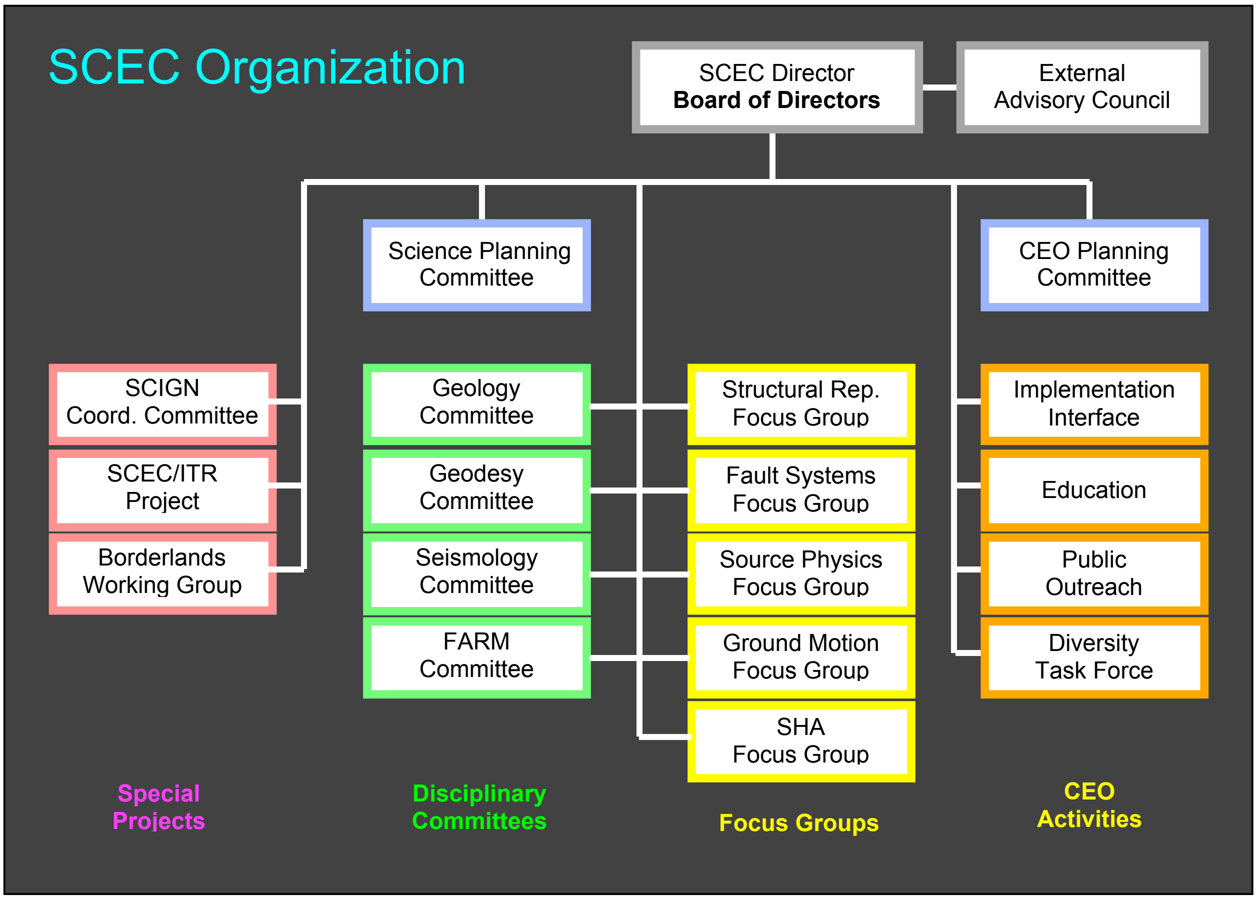

Figure II.1. Organization chart of the Southern California Earthquake Center

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 Riverside, one new U.S. participating institution (Woods Hole Oceanographic Institution) and five foreign institutions (ETH Zürich; Institute of Earth Sciences, Academia Sinica/Taiwan; National Central University; National Chung Cheng University; National Taiwan University). The SCEC membership now comprises 15 core institutions and 39 participating institutions. One measure of the growing size of the SCEC community is the attendance at its Annual Meeting (September 18-23, 2004), which rose to >400 people—the largest group in the history of the Center.

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. Dr. Jim Dieterich, now a Profesor at UC-Riverside, is our newest board member. Earlier in 2004, Emily Brodsky replaced David Jackson as the board member from UCLA. The15 members of the Board are listed in Table II.1. *Ex officio* members include the SCEC Deputy Director, Prof. Ralph Archuleta; the Associate Director for Administration, Mr. John McRaney, who also serves as Executive Secretary to the Board; the Associate Director for Communication, Education and Outreach, Mr. Mark Benthien, and the SCEC IT Architect, Mr. Phil Maechling.

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
Emily Brodsky	University of California Los Angeles
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)

* Executive Committee members

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. Dr. Sean Solomon of the Carnegie Institution of Washington replaced Bob Smith as Chair of the AC in 2004. Bob had been chair since 1997; serving in the period of transition from SCEC1 to SCEC2. The current AC members are: Sean Solomon (Chair/Carnegie Institution of Washington), Jeff Freymueller (U. Alaska), Raul Madariaga (Ecole Normale Superieure), Jack Moehle (PEER), Farzad Naeim (John A. Martin & Associates), Garry Rogers (Geological Survey Of Canada), Chris Rojahn (Applied Technology Council), Robert Smith (U. of Utah), Haresh Shah (RMS, Inc.), Ellis Stanley (LA Emergency Preparedness Department), and Susan Tubbesing (EERI). The terms of Madariaga, Naeim, Shah, and Tubessing end on January 31, 2005 and we will be seeking replacements for them. 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 year, several changes were made in the membership of the PC. Mike Oskin replaced Doug Burbank as the co-chair of Geology; Judi Chester replaced Jim Dieterich as co-chair of FARM; Jeroen Tromp replaced Rob Clayton as co-chair of Structural Representation; Jim Dieterich and Sally McGill replaced Charles Sammis as co-chairs of Fault Systems; David Oglesby replaced Greg Beroza as co-chair of Earthquake Source Physics; Rob Graves replaced Steve Day as co-chair of Ground Motions; and David Jackson replaced John Anderson as

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:	Tom Rockwell (chair)*
	Mike Oskin (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)
SCIGN Steering Committee:	Tom Herring (chair)*
SCEC/ITR Project:	Bernard Minster (liaison)*
Borderland Working Group:	Craig Nicholson (chair)*

* Science Planning Committee members

co-chair of Seismic Hazard Analysis. The net effect of these changes was to make the PC both more diverse and younger.

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 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).

SCEC continued as the parent organization for the Southern California Integrated GPS Network (SCIGN) in 2004, which has now has > 260 continuously monitoring GPS stations. We are now working with UNAVCO, the USGS, and the local surveying community to coordinate future maintenance of these stations with those of the Plate Boundary Observatory (PBO) of the EarthScope Project.

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 2004 began with the working-group discussions at the annual meeting in September, 2003. An RFP was issued in October, 2003, and 181 proposals (140 projects, considering collaborations) requesting a total of $5,663K were submitted in November, 2003. The 2004 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 met on January 19-20, 2004, 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 2-3, 2004. 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 14. Section III outlines the progress achieved in the 2004 research program.

In June, the Planning Committee met jointly with the Board of Directors and agency representatives for two full days to conduct a comprehensive review of the entire SCEC program. The leaders of all of the working groups summarized their accomplishments and plans, and there were vigorous discussions of how the current mix of science projects and other activities might be adjusted to better attain SCEC's five-year goals. Out of those sessions came the draft 2005 RFP that was put up for scrutiny at the 2004 annual meeting.

SCEC is coordinating its research program with the USGS through a Joint Planning Committee (JPC). For example, the USGS members of the JPC attended the proposal review meeting of the SCEC Planning Committee as non-voting participants, and they also attended the joint Board/PC meeting in June.

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 2004.

Disciplinary Activities

During this past year, the disciplinary committees reviewed the infrastructure elements in their disciplines that have been historically supported by SCEC and to assess how SCEC resources should be allocated to the disciplinary infrastructure in the future. The chairs and co-chairs of the disciplinary committees also participated in developing the program announcements and in the proposal review process to insure that the disciplinary elements of SCEC research remain strong. The following reports summarize the infrastructure activities and the discipline-oriented research.

Seismology

Four projects were funded in the Seismology Infrastructure focus group in 2003-2004. These were: (1) the Southern California Earthquake Data Center for $155K, (2) groups assembling waveform products and earthquake catalogs for $65K (several projects), (3) the Borehole Seismometer Network for $20K, and (4) the Portable Broadband Instrument Center (PBIC) for $40K. All these projects furthered the aims of the Southern California Earthquake Center and most are continuing in the coming years.

Southern California Earthquake Data Center (SCEDC)

The Archive (as of Sept. 13, 2004) has assembled 3.532 TB of waveform data. The SCEDC database contains 235,647,421 rows and 519,598 earthquakes (1932–present). In the first 6 months of 2004 the SCEDC exported 29.6 million waveforms (913 GB) via STP (i.e., 1.9 waveforms every second), archived 7,929 new events, and archived 2,010,709 seismograms.

The SCEDC has created a new website: http://www.data.scec.org, with improved navigation (fewer mouse clicks needed) and better documentation, which has generated more web traffic.

SCEDC's Seismic Transfer Program (STP) has been improved. Windows command-line and GUI clients are now available and XML output format may be generated for phase and event data. Two new commands are now available: 'altloc' to access to alternate location catalogs and 'coda' to access to coda measurements. A Programmatic Interface has been created that allows user-written programs to call data directly from the STP server, instead of having to download data beforehand. An application of this is the SAC2000 STP module, which allows the user to pull data into SAC memory using STP commands.

SCEDC has also implemented three critical IRIS products. SeismiQuery is a web-based program that provides users with pre-formatted queries concerning waveform data, instrument response, and channel information using point-and-click or form-based requests. NetDC is a system to enable data to be retrieved by other data centers and help users with "one-stop shopping" for seismic data. DHI (Data Handling Interface) can be thought of as an Application

Programming Interface (API) that can be used as a well-specified, standardized interface to any seismic data center.

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 a complete station history in the SEED volumes distributed by the SCEDC. Also, a clickable Station Map is available.

Catalogs available at the SCEDC include:

1932–present SCSN Searchable Catalog Page

Pre-compiled ASCII catalog files

Alternate Location Catalogs: SCEDC added two catalogs (Hauksson et al., 2004; Shearer et al., 2004) that use results from a SCEC-sponsored project that applies waveform cross-correlation to measure precise differential times among nearby events.

Searching tools available at the SCEDC include:

4-Point Polygon Catalog Search

Radius Catalog Search

Search by Event ID

Multiple-magnitude Catalog Search

New output format: XML

Caltech/UCSD Waveform Analysis Projects

Hauksson (Caltech) and 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 et al., 2004), the other uses source-specific station terms and a cluster analysis approach (Shearer et al., 2004). Both reveal more fine scale fault structure than previous catalogs. 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 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 planned to isolate source spectra and estimate stress drop and radiated energy. These measurements will enable progress on a range of earthquake scaling issues.

Borehole Seismometer Network Activity

The Pinon Flat and Keenwild sensors have been replaced with Hyposensor packages. Bedrock borehole sites are being explored for source physics studies. Connections to ANZA/CISN/NEES through HPWREN wireless network (UCSD/NEES cost share) are being developed.

Primarily, the borehole network was in maintenance mode for 2004. We continued to take advantage of cost sharing with other agencies. The previously funded sites at Rinaldi (LADWP/CISN cost share), Bonds Corner (NSMP/ANSS cost share), and the telemetry at Superstition Mountain (UCSD/ANZA/HPWREN/NEES cost share) were completed.

SCEC/CISN Borehole stations were integrated into the UCSB NEES database and real-time processing software. We developed automated spectral fitting procedures for incorporation into routine processing and developed combined Wavelet/Spectral inversion techniques solving for attenuation and velocity structure (with postdoc and grad students).

2004 PBIC Activities

A major activity of the PBIC was the San Simeon earthquake rapid array mobilization program (RAMP). The deployment was coordinated with the Menlo Park branch of the USGS and Cal State Northridge. 15 stations were deployed for 3 months. Over 2700 events were recorded that associate with the NCDC catalog at just the SCEC/CSUN stations. UCSB now has copies of all portable data. A SCEC summer intern assisted with data processing using the Antelope software package and integrated the USGS and SCEC/CSUN data sets.

Two other projects used PBIC equipment in 2003/2004. Steve Day and Frank Vernon (SDSU/UCSD) recorded receiver functions to delineate crustal structure across the Peninsular Ranges. The equipment was also deployed to quantify wave energy at the shoreline and understand coastline evolution (UCSC, P. Adams, R. Anderson, J. Revenaugh).

Geodesy

In 2004 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 earthquakes), and new data from various sources, mostly ones that would usually be inaccessible to the academic community (Caltrans surveys). The cost of adding these data is about 1% of the cost of collection, the latter not being borne by SCEC. The CMM group also focused on improved analysis of data from 1990-1991, an important period because it defines pre-Landers deformation; and on improved time-series modeling of postseismic signals. A major extension to the CMM coverage was provided by SCEC having added a group at UC Berkeley, who have been preparing result from the San Francisco Bay area, to extend the CMM seamlessly along the San Andreas fault. The 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, which did not show any unusual events during the year. The primary activity of the SCIGN network, also, was to continue to monitor long-term deformation. Parts of this network have been upgraded to record GPS data at 1 Hz; fortunately this included the stations around Parkfield, thus providing a high-rate GPS dataset for the earthquake there in September 2004. Finally, SCEC continued to provide some support for the WInSAR archive during 2004.

Analysis of these data included several activities not mentioned above. The WInSAR data were used to examine deformation in the western Salton Trough, showing deformation related to the Superstition Hills fault, and local groundwater withdrawal. A stack of a large number of InSAR scenes in the Eastern California Shear Zone shows ongoing deformations from both hydrologic and tectonic forcing; in particular, this analysis confirms earlier estimates for high slip rates on the Blackwater fault. It also suggests a number of locations for fault deformation controlled by decreased modulus along the fault zone. SCEC has also supported analysis of postseismic deformation from the Landers and Hector Mine earthquakes, for which the relative roles of bulk relaxation (linear or not), fault slip, and poroelastic effects are still being worked out. Finally, SCEC is supporting two projects that invert the CMM velocity field to estimate slip on the complete fault system in southern California: slip rates that are fundamental to the overall SCEC goal of estimating seismic hazard. The models developed so far have provided results that are both as expected (highest slip on the San Andreas) and also novel (significant temporal variations in slip rate). Comparisons between models are ongoing, to produce the most robust and reliable results possible.

Geology

SCEC efforts related to geology in 2004 fall into five principal areas: 1) directed geologic studies and compilation efforts that contribute to the Community Fault Model (CFM); 2) geologic, geomorphic and paleoseismic studies in the LA Basin, Eastern California Shear Zone (ECSZ), and southern San Andreas fault system, with emphases on: a) acquisition of long records to understand recurrence models and the constancy of strain release; b) efforts related to resolving differences between geologic and geodetic rates and the possible role of off-fault deformation in the southern San Andreas system and the ECSZ; and c) chronologic efforts to precisely date past earthquakes and develop a catalog of probability density functions for large prehistorical earthquakes for the RELM project; 3) activities related to the Fault Activity Database (FAD and Fault Information System (FIS); 4) development of a vertical motion database and Community Vertical Motion Map (VMM) for southern California; 5) other geologic studies that relate to rock mechanics, issues in source physics, etc. This summary will focus primarily on those elements not covered elsewhere, which are new advances in paleoseismic, geomorphic and slip rate studies, the vertical motion database, and the geochronologic efforts.

New Geologic, Paleoseismic and Geomorphic Results

Several studies were funded by SCEC that deal directly or indirectly with paleoseismic issues, in addition to the funding supplied to LLNL and Lewis Owen for dating paleoseismic events. Each area is discussed briefly.

Eastern California Shear Zone – Two new paleoseismic studies are underway this year in the ECSZ, both related to understanding the current high rate of strain identified by GPS across the central Mojave. Specifically, 12-14 mm/yr of strain appears to be concentrated over the Calico-Blackwater fault zones, although geologic and geomorphic evidence for high rates is lacking (Oskin, 2004). Trenches are being emplaced across the Calico (Seitz) and Blackwater (Madden) faults to establish their Holocene earthquake history and compare the intermediate Holocene rate to the long-term geologic rate (<1 mm/yr) and the GPS rate. The fieldwork should be completed by the end of 2004, and dates of events will be available in early 2005. Chronologic funding was also supplied for other projects – the completion of the Pinto Mountain fault study (Cadena et al) and for the western Garlock fault (Madden and Dolan).

San Andreas System Faults – The Work Continues- Four projects were funded that deal either directly with paleoseismic studies on the San Andreas fault system, or with issues of improving event correlations. Biasi and Weldon are working on modeling strategies for southern San Andreas earthquake ruptures, in association with the RELM effort, and Rockwell is working on a similar project for the San Jacinto fault. McGill and Weldon are working to improve slip per event information for the San Andreas along the San Bernardino segment. All of these studies are being incorporated into the RELM.

The excavations at Hog Lake in the Anza seismicity gap (Rockwell, Seitz, Dawson) were very successful at acquiring a deeper and longer record. After draining the 2002 trenches of water, the excavation was substantially enlarged and deepended to about 6 m (twice the original depth, revealing evidence for an additional 5-6 events (see Figure III.1). This makes the Hog Lake record the longest and most complete for any site along the San Jacinto fault, and similar to the Pallet Creek and Wrightwood records on the San Andreas fault. The most recent 6 events all occurred in the past 1000 years, but preliminary radiocarbon results for the deeper section show that the previous 5-6 events span an additional 2000 or more years, suggesting non-periodic recurrence. Further, The lull in seismic activity at Anza appears to correlate with the "flurry" of earthquakes documented for the San Andreas fault at Wrightwood. The work continues (in spite of early winter rains) to attempt acquisition of a 15 event record spanning the past 3-4 ka.

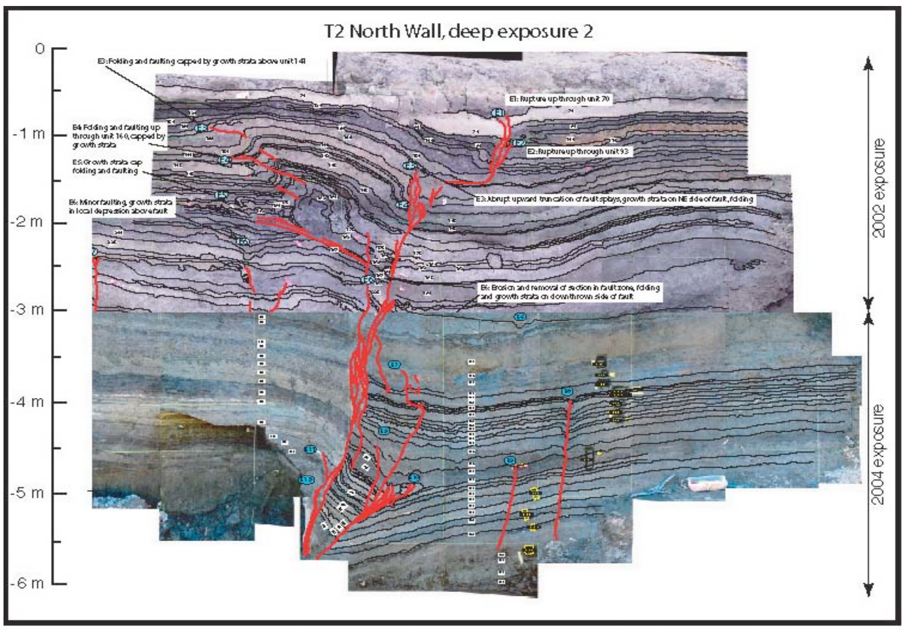

Figure III.1. Los Angeles Basin and Western Transverse Ranges – Two studies were funded that involve collection or compilation of data on vertical motions in LA Basin (Mueller) and the region from Ventura Basin to LA Basin (Neimi and Oskin). Mueller's study involves compilation of aquifer data to provide deformation surfaces for inclusion in the CFM and vertical motion data to be included in the Vertical Motion Database and Mapping effort (discussed below). The Neimi and Oskin study involves a geomorphic analysis to determine uplift rates over a broad region, as high-lighted in the next section.

Geomorphic analysis - Active thrust faults and associated folds present challenges for seismic hazard assessment because slip rates are difficult to measure via traditional field investigations and may vary significantly along strike. Using empirical and theoretical relationships that relate rock uplift rate to stream power, Neimi and Oskin developed and applied a spatial analysis technique to extract relative uplift rates on blind faults by deriving power values of streams that overlie active folds. Morphologic measurements of catchment area and slope were derived for > 30,000 stream segments from 10 meter-resolution digital elevation models. They calibrated the stream power relationship by comparing analyses on structures with known uplift rates. Preliminary results indicate that stream power increases dramatically across the axes of active structures (see Figure III.2). Stream power values in the Ventura anticline, South Mountain, and Oakridge system support very high uplift rates in the Ventura basin, probably on the order of 5-6 mm/yr or greater, consistent with published rates. High stream power is also detected in the southeast Puente Hills, consistent with an erosion rate (a proxy for uplift rate) approaching 2 to 3 mm/yr. This region of potentially high uplift rate could not have been detected by other methods because Quaternary rocks are not well-preserved in the southeast Puente Hills. Distribution of stream power data in the Santa Ynez range indicates a clear decrease in uplift rate from east to west along the range crest. A lack of calibration sites for Paleogene strata presently limits an absolute determination of these uplift rates. Further work on this methodology, to be completed this winter, will include calibration of stream power rates to uplift rates for a variety of lithologic types, as well as inclusion of additional channel width measurements from the field. This project has shown that there is a strong correlation between stream power of small-order catchments and uplift rate of folds and faults, making such analyses a potentially useful tool for determining the seismic hazard of blind structures.

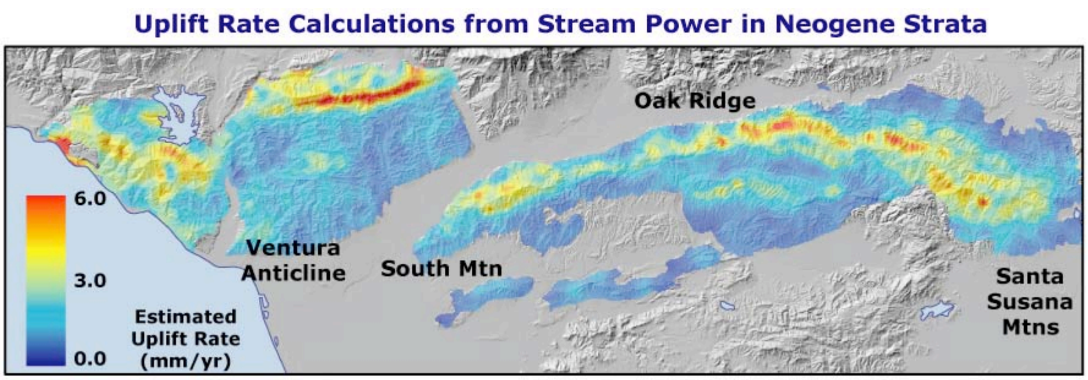

Figure III.2

Vertical Motion Database and Map - The vertical motion database for Southern California is a compilation of geologic data, reference frame information, and processing tools to determine vertical crustal motions at 10^4 – 10^6 year time-scales. All original data, reference frames, and processing information are encapsulated within a PostgreSQL object-relational database. Querying data proceeds interactively with the database through three steps: (1) select data points, optionally filtered by location and data type, (2) select appropriate reference frame for each data type in selected set, and (3) process the data points into vertical motion rates. Correlations between data points are preserved in the data set and are followed via recursive queries (implemented in PL/pgSQL) to produce vertical motion results. Data compilation efforts are now largely complete for marine terraces from central California to the border with Mexico. The majority of these data are for terraces formed 80 – 120 ka near the present coastline, with a few older points inland. Thermochronology data available for the Transverse Ranges have been compiled to provide exhumation rates (a proxy for uplift rates) at million-year time scales (Figure III.3). Aquifer elevations that map basin subsidence rates, provided by K. Mueller, have also been incorporated into the database. River terrace, Quaternary stratigraphy, and river gradient indices are in the proto-type stage of database development. Significant challenges remain in defining appropriate reference frames for these interior data sets. Through collaboration with the SCEC Community Modeling Environment program, the vertical motion database will soon be available alongside other SCEC spatial data through a geographical data server located at scecdata.usc.edu.

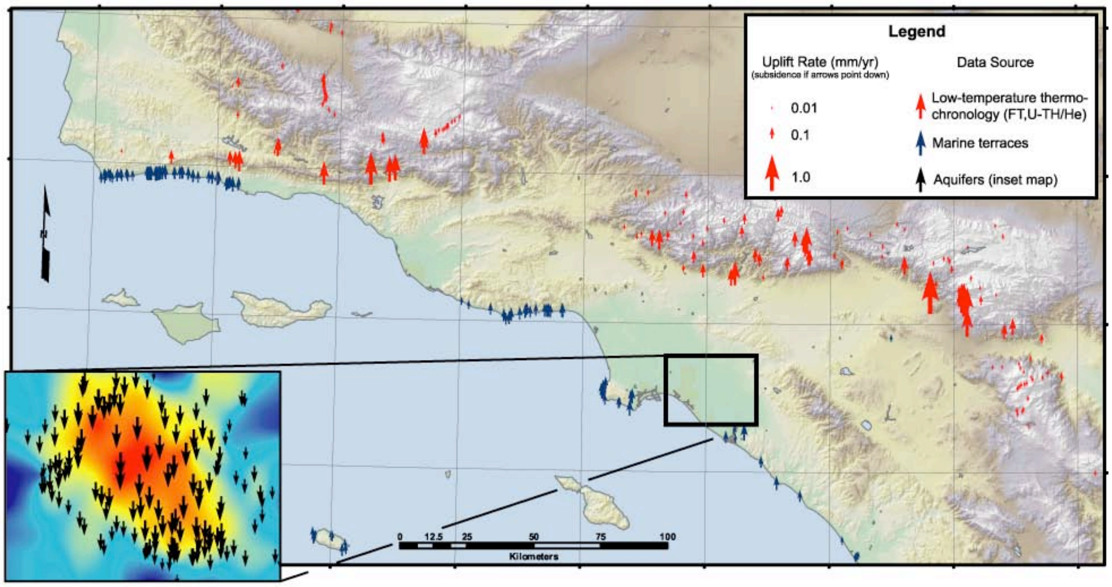

Figure III.3

Paleoseismic Chronologic Effort

The consolidation of geochronologic efforts, principally in radiocarbon dating, has had a dramatic affect in improving earthquake chronologies on the San Andreas, San Jacinto, Mojave, and LA basin faults. The obvious benefit is the ability to focus on dating the sections that have both the resolution of earthquake history (good stratigraphy) and the abundance of excellent, dateable material. The product has been a large increase in both accuracy and precision of paleo-earthquake events dates, with the production of probability density functions (PDF's) of many past events on the San Andreas, San Jacinto, and ECSZ faults. This now allows for more formal testing of event correlations between sites, which is important in constructing earthquake rupture models for individual faults, as well as understanding long-term local and regional patterns of seismic production. The majority of radiocarbon effort in 2004 has been for the San Andreas fault (Weldon, Shearer), the San Jacinto fault (Rockwell, Seitz, Dawson), and the Eastern California Shear Zone (Khatib and Rockwell, Seitz (pending), Madden (pending)), including the Garlock fault (Madden and Dolan) and Pinto Mountain fault (Cadena and Ruebin). In addition, Optical dates were run for the stratigraphy in the Pinto Mountain trench project.

Fault and Rock Mechanics

Many things came together this year for the FARM group and valuable progress was made in several areas. The connections between the studies and progress in these different areas are particularly notable. They highlight the fact that the SCEC collaboration leads to more rapid advances than would be the case without SCEC.

Field studies of exhumed fault zones by Jim Evans and his student Joe Jacobs from Utah State University show that there is no correlation between the thickness of the fault core and the fault slip. This suggests that the core thickness is established early and that this initial localization controls the location of subsequent slip. During subsequent slip the surrounding damage zone does increase in thickness, even though the core does not. Detailed studies have been made by Judi Chester of Texas A&M University of the total surface area of fractures on all scales within the damage zone, the fault core, and in particular the ultracataclasite along the principal slip surface within the core of the Punchbowl Fault (see Figure III.4). These show that the total fracture surface area within the very find grained ultracataclasite is about the same as that in the rest of the fault zone, the total surface area being about 5×10^7 m^2 per m^2 of the macroscopic fault surface. Nevertheless, this large surface area can only account for a small fraction of the energy budget of earthquakes.

Experimental studies of weakening at high slip speeds have been made by David Goldsby and Terry Tullis of Brown University. They find two high speed weakening mechanism, one due to the formation of silica gel that acts as a lubricating layer and one due to local or "flash" melting at asperity contacts. Chemical analysis of the thin gel layer has shown that it does indeed contain hydrogen as expected for a gel. It behaves as a thixotropic material, becoming weak only at high deformation rates. David and an undergraduate student from the University of Puerto Rico, Carla Roig Silva, find that the amount of weakening at a given slip velocity increases as the SiO_2 content of the rock increases, further supporting the gel-weakening hypothesis. The flash melting mechanism occurs at higher sliding velocities, and requires much less displacement for weakening, than does the gel weakening. The weakening agrees well with theoretical predictions for flash melting made by Jim Rice of Harvard University and Nick Beeler of the USGS (Figure III.5).

Although natural fault cores are meters thick, detailed microstructural studies by Judi Chester and others demonstrate that the zone of active shear during a slip event is even more localized, on the order of a few mm thick or less. This characteristic of natural fault zones is compatible with mechanisms of fault weakening activated in laboratory studies at high slip speeds that require extreme localization of slip, such as flash heating, lubrication by formation of silica gel, and thermal pressurization.

Theoretical analysis of weakening due to thermal pressurization due to shearing on a surface or in a think layer has been studied by Jim Rice, transferring the important field observations into theoretical analysis that can be used in dynamic rupture models. Nadia Lapusta of California Institute of Technology and Jim Rice have developed numerical models of earthquake cycles and dynamic rupture that use rate and state friction and include strong dynamic weakening such as are seen with flash melting or thermal pore fluid pressurization.

Their dynamic rupture models show that most of the slip can occur with a very low dynamic stress, can involve a low static stress drop, and rupture can propagate with a tectonic stress that is much smaller than the static strength, as long as the rupture initiates at some location where the tectonic stress and the static strength become equal. This behavior could be the solution to the "low stress" or "heat flow paradox" on faults that slip primarily via earthquakes. Because the stress difference need not be large between the initial and the dynamic values of stress on the fault, the mechanism should not produce accelerations that would exceed those observed for earthquakes.

Exploratory friction experiments have been made by Vikas Prakash of Case Western Reserve University using an experimental apparatus, the torsional Kolsky bar, that shows promise for collecting high speed friction data in a range of slip speeds and normal stresses that are similar to those occurring earthquakes. Furthermore it involves slip displacements up to 10 mm, much higher than the slip attainable by the pressure-shear impact friction experiments Vikas has previously explored as part of the SCEC program. Not only have the initial friction experiments using the torsional Kolsky bar shown its promise for more investigation, they have shown friction values on a novaculite of about 0.2, a value that is similar to those seen in the experiments of Goldsby and Tullis.

In summary the results of the FARM investigators working on field studies, laboratory experiments, and theoretical modeling are showing consistent results. The progress in each area has benefited from better communication between the research scientists that has been fostered by SCEC. The collective results suggest that fault slip is localized, that frictional resistance at high slip speeds can be quite low, and that dynamic rupture models with such resistance can be useful in simulating earthquake sources. This should allow creating more rigorously physics-based earthquake scenarios than are presently in use. Although much work still needs to be done, these results are laying out a path to follow in order to attain one important SCEC goal, that of going from a physics-based understanding of the processes that occur on faults during the earthquake cycle to realistic and accurate models of ground motions that can lead to implementation of better building design.

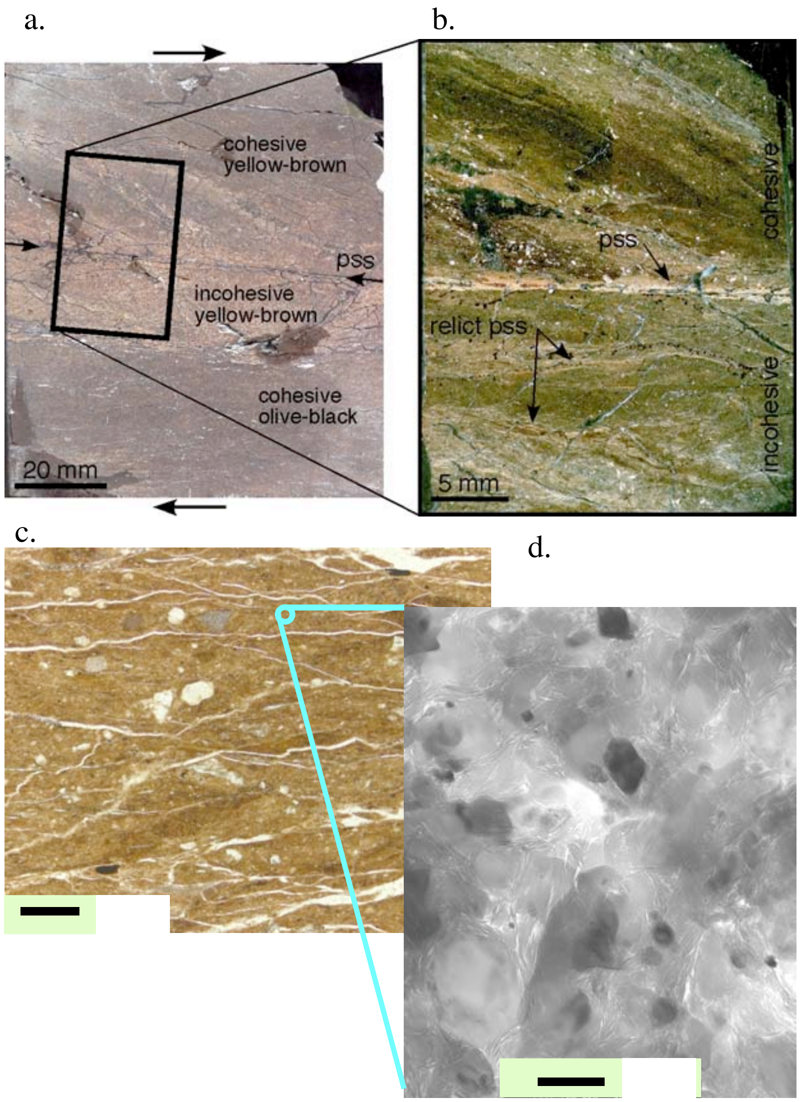

Figure III.4. Progressively magnified views of the ultracataclasite layer in the core of the Punchbowl Fault. a) Block of ultracataclasite containing a portion of the continuous, relatively planar principal slip surface mapped in outcrop exposures and interpreted as the site of most recent fault displacement; b) Cross polarized light image of a petrographic section across the slip surface showing that the slip surface is distinct in texture and approximately 1 mm thick; c) Ultracataclasite matrix in plane polarized light. Scale bar 200 μm; d) Bright-field TEM image of ultracataclasite layer showing crystalline nature of nanoscale particles. Scale bar 100 nm.

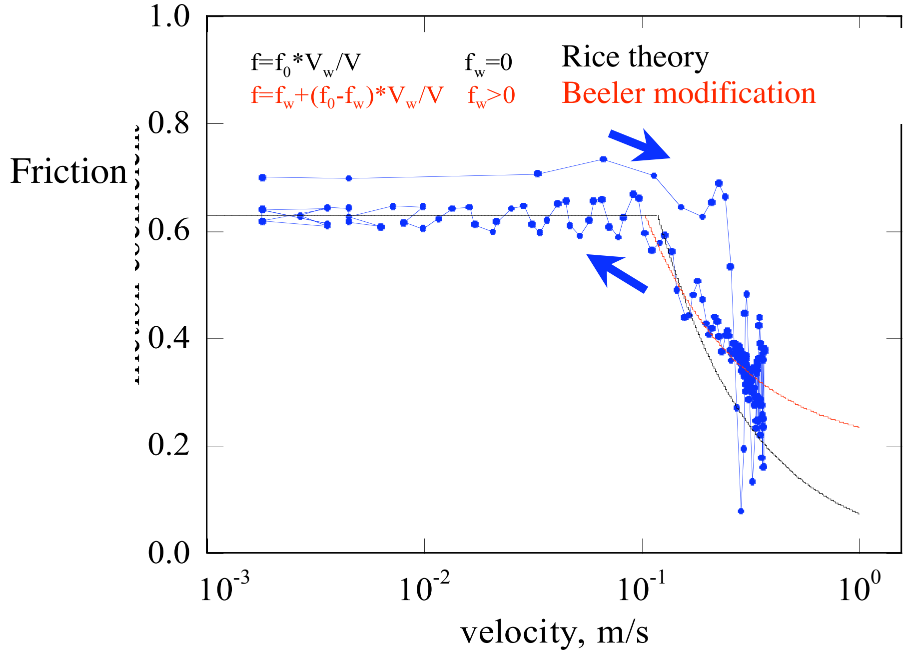

Figure III.5. Experimental data on novaculite, a pure quartz rock, showing dramatic weakening at high slip velocity that matches theoretical predictions for weakening due to flash melting at asperity contacts. As predicted for flash weakening, the weakening requires less than 2 mm of slip, much less than the several hundred mm of slip required to cause weakening by the gel mechanism. Similar weakening is seen for all silicate rocks tested, including gabbro that shows no weakening by the gel mechanism.

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

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 fault systems analysis, 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. Highlights of this past year's activities include construction and delivery of an improved Community Fault Model (CFM version 2/Figure III.6), new alternative velocity models (CVM), and the first Community Block Model (CBM/Figure III.7).

The CFM is an object-oriented, 3-D representation of more than 140 active faults in southern California, defined by surface geology, earthquake hypocenters and focal mechanisms, well bore, and seismic reflection data. CFM version 2.0 includes more than 35 new fault representations (Plesch et al., 2004), guided by contributions from more than 20 SCEC investigators. The model, including its alternative fault representations, were evaluated and approved by the SCEC Community this year in a "virtual workshop," in which scientists used the LA3D software tool, developed by the SCEC Intern Program, to visualize and analyze the faults. Based on feedback from this evaluation, we defined the inventory of CFM version 2, and are in the process of establishing a set of viable alternative fault models to be used by RELM for earthquake hazards assessment.

The CVM is a 3D description of crustal and upper mantle velocity (v_P) structure, with derivative shear wave velocity and density models. The current CVM (Version 3.0) employs a rule-based approach for defining the velocity structure in sedimentary basins (Magistrale et al., 2000), which are embedded in regional tomographic (Hauksson, 2000) and 1D background models. The CVM continues to be widely used by SCEC investigators for numerical simulations of seismic wave propagation (including the TeraShake simulations; Olson et al., 2004), earthquake catalog relocations, and other efforts to characterize earthquake sources. This year, SCEC released a new, alternative velocity parameterization for the CVM, based on petroleum well and seismic reflection data (e.g., Suess & Shaw, 2003). Provision of this new model reflects the commitment of the USR Focus Area to deliver alternative structural representations that reflect epistemic uncertainties. Both models are already being used to generate synthetic waveforms, which compared with observations provide a basis for evaluating the models' relative performance and their impacts on strong ground motion prediction.

The next generation of SCEC models will provide these and other alternative velocity parameterizations in a framework that is compatible with the fault representations provided by the CFM. To accomplish this, SCEC developed a Community Block Model (CBM), which consists of major fault surfaces from the CFM extrapolated and connected with topographic, base-of-seismicity, and Moho surfaces, to define closed blocks. The CBM is currently being used to generate volumetric meshes that will be used by SCEC's Crustal Deformation Modeling Group through 3D quasi-static codes to model crustal motions. In addition, the CBM and additional geological surfaces will be used to define fault-bounded blocks in which one or more alternative velocity parameterization may apply, allowing users to develop new property models that are, by definition, compatible with the CFM fault representations. This framework, including fault surfaces and geologic horizons in the CFM and CBM, and compatible property models (CVM), will constitute the Unified Structural Representation.

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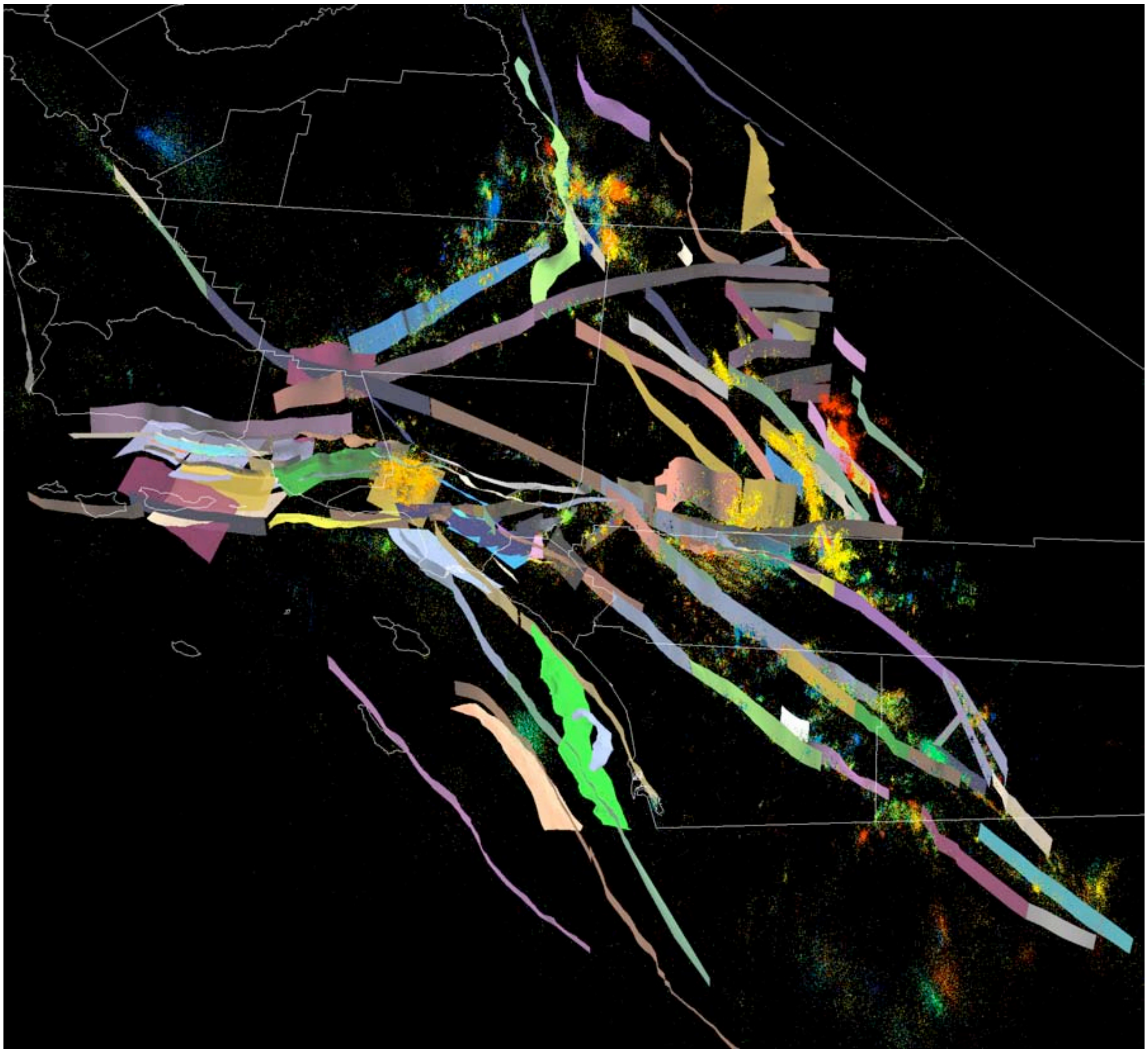


Figure III.6: Perspective view of the SCEC Community Fault Model (CFM version 2). Seismicity is from Hauksson (2000) and color-coded by year of occurrence.

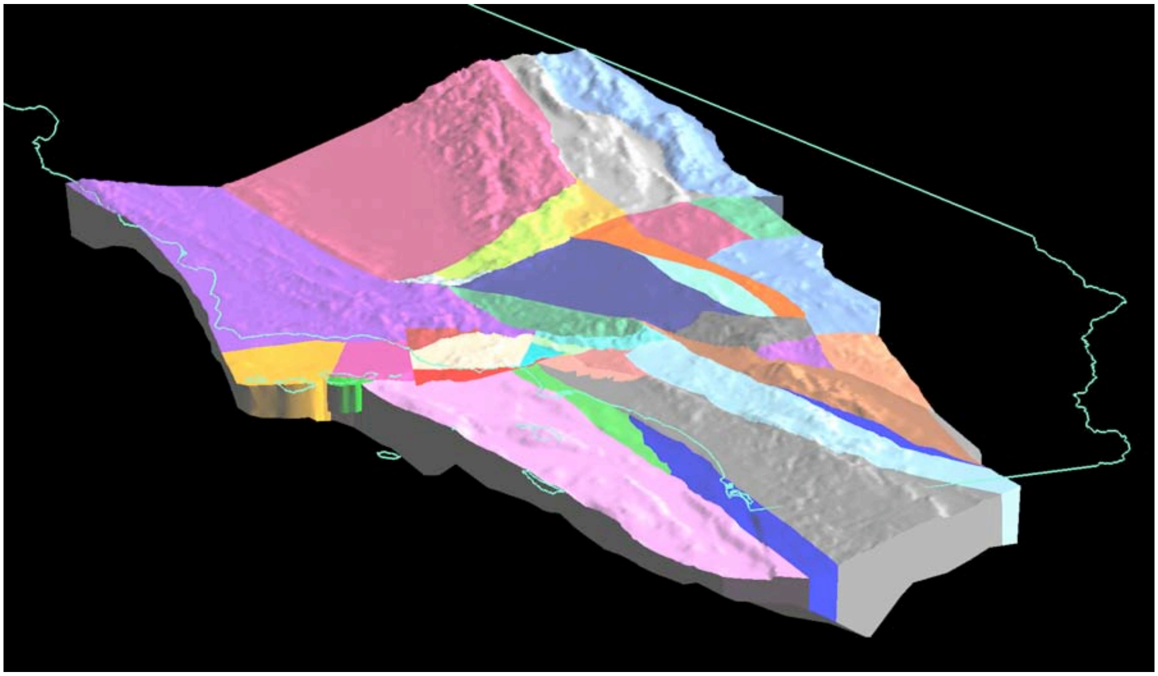


Figure III.7: Perspective view of the SCEC Community Block Model (CBM), which consists of more than 75 tectonic blocks bounded by major faults, derived from the CFM, and regional topography, base-of-seismicity, and Moho surfaces.

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 encompassed, 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.

A list of FSWG grant titles and PI's illustrates the scope of the effort. Scientific projects using the Systems approach include: Earthquake probabilities based on clustering and stress interactions (A. Helmstetter, Y. Kagan), Implementing and testing earthquake probability models (S. Wiemer, L. Jones, D. Jackson), Analysis & Integration of the Earthquake Stress Cycle Evolution & Pattern Informatics Techniques (K. Tiampo, C. Bowman), Emergent Modes on Earthquake Fault Systems (J. Rundle, W. Klein), Paleoseismic Constraints on Earthquake Simulation Models (S. Ward, L. Grant, T. Rockwell), Integrating Calibrated Triggered Seismicity with Fault Networks (D. Sornette), Structure and Mechanical Significance of Dynamically Generated Off-Fault Damage (C. Sammis), Discrete Element Simulations of Elasto-Plastic Fault Block Controls on Earthquake Distributions (J. Morgan), and Nonlinearity, Phase-Locking, and the Temporal Clustering of Large Earthquakes (C. Sammis). Crucial observations provided by Earthquake Geology include: Holocene and Late Quaternary slip rate of the San Bernardino strand of the SAF (S. McGill, R. Weldon), Constraints on clustering of earthquakes, ECSZ (C. Rubin), Prehistoric Earthquake Chronology of the SJF at Hog Lake (T. Rockwell), Mapping the Vertical Velocity Field in the LA Basin with Aquifers tied to Sea Level Change (K. Mueller), Paleoseismic Characterization of the Calico Fault (G. Seitz, T. Fumal), Timing and Displacement During Paleoearthquakes on the Garlock fault (E. Gath), and Timing of paleoearthquakes on the Blackwater fault (C. Madden).

Development of Community software is a high priority of FSWG: Development of Community Finite Element Models for Fault Systems Studies & Meshing the Community Block Model (C. Gable, B. Hager, M. Simons), Development of a parallelized 3-D finite element code for modeling deformation (C. Williams). Model-related studies include: Driving forces of crustal deformation (E. Humphreys), InSAR investigation of interseismic strain accumulation on faults in the ECSZ (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) Inferring Fault Slip and Crustal Motion from Joint Inversion of Geologic and Geodetic Data (B. Hager), Interpreting focal mechanisms in a heterogeneous stress field (T. Heaton), Modeling Geometrically Complex, Intersecting Faults Using the Finite Element Method (S. Kenner), The evolution of the brittle-ductile transition during the earthquake cycle (R. Burgmann), Community Fault Model validation with elastic models (M. Cooke, A. Meigs), Mapping groundwater-related subsidence with InSAR, western Salton trough (R. Mellors), Model of fault-zone properties from postseismic to pre-failure conditions. Application to full-cycle quasi-dynamic model of the Big Bend in the San Andreas Fault (N. Sleep), and Modeling the Mojave Lithosphere: New Approaches (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 August. This locale enables SCEC scientists to benefit from interaction with Lab experts. This year we leveraged SCEC funding with support from NSF EarthScope, 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 III.8).

Objectives for the Upcoming Year

• ***Fault-System Behavior:*** Assess the ways in which the system-level behavior of faults controls seismic activity and regional deformation; infer rates of change in stress from geodetic and seismic observations; compare and interpret quantitatively short-term geodetic rates of deformation, long-term geologic rates, and rates predicted by seismicity simulators; quantify the space-time behavior of the Southern California fault system in ways targeted to test models of earthquake occurrence and stress evolution; foster collaborations to obtain outside funding to support large, coordinated data-gathering efforts; determine how geologic deformation is partitioned between slip on faults and distributed off fault deformation and how geodetic strain is partitioned between long-term permanent and short-term elastic strain and on-fault slip or permanent distributed strain.

• ***Deformation Models:*** Develop, validate, and facilitate use of modular 3D quasi-static codes for simulating crustal motions utilizing realistic, highly resolved geometries and rheological properties (e.g., Burgers body viscoelasticity, rate-state friction, poroelasticity, damage rheology); develop continuum representations of fault system behavior on scales smaller than can be resolved as faulting; develop a closed volume representation of the Community Block Model (CBM) that unifies the geometric representations of CFM and the CVM and that serves as a basis for efficient meshing and remeshing of models; generate finite element meshes of the CBM; assess mechanical compatibility of CFM and how slip is transferred between recognized fault segments; develop a reference model of the time-dependent stress transfer and deformation associated with the 1992 Landers earthquake; extend models of time-dependent stress transfer and deformation of Southern California to cover multiple earthquake cycles addressing geologic slip rates, geodetic motions (including CMM 4.0), and earthquake histories; use these to infer fault slip, rheologic structure, and fault interactions through the transfer of stresses; couple numerical models of the interseismic period to quasi-static full-cycle fault models to better constrain stress transfer and conditions and processes at the start of dynamic rupture, including forcing by realistic coseismic displacements and dynamic stresses (with Source Physics); develop tectonic models that explain the inferred rates of fault slip; develop a plan for post-earthquake geodetic deployments.

• ***Seismicity Evolution Models:*** Determine the effects of fault system scale and resolution; develop and validate rapid simulation methods for modeling earthquakes in fault systems over a wide range of magnitudes (with Source Physics); develop, validate, and facilitate use of codes for ensemble models simulating earthquake catalogs using CFM, USR and CBM, as well as effects of faults not included in CFM; incorporate constraints (including data assimilation) from geologic slip rates, geodetic data, realistic boundary conditions, and fault rupture parameterizations, including rate-state friction and normal stress variations; assess the processes that control the space-time-magnitude distribution of regional seismicity; quantify sources of complexity, including geometrical structure, stress transfer, fault zone heterogeneity, and slip dynamics; assess the utility of these models in forecasting earthquakes; quantify signals in the space-time- magnitude distribution of seismicity and understand their physical origin.

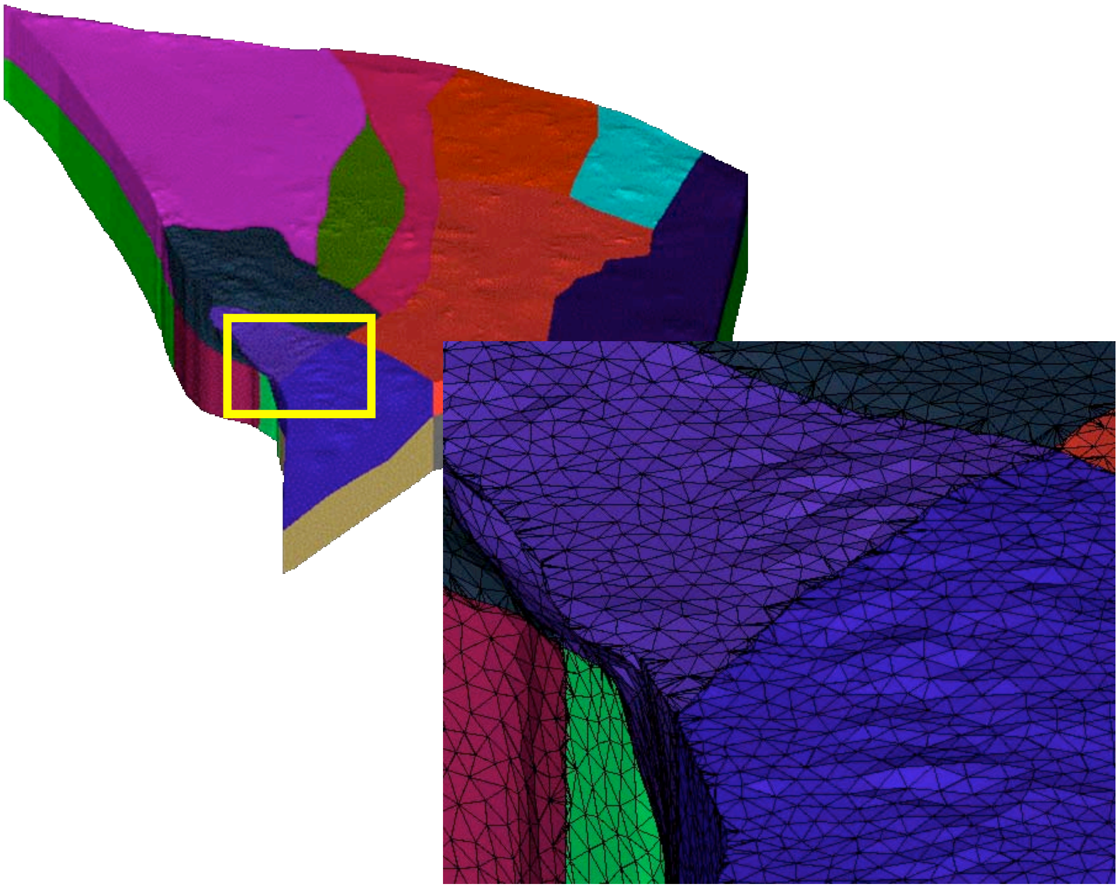


Figure III.8
Upper left: USR Community Block Model of the Mojave region, showing two layers of blocks.
Lower right: Zoomed view of mesh generated by Carl Gable using LAGriT.

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 FY2004 Earthquake Source Physics PI's tackled problems in 4 areas:

Computationally simulating rupture dynamics to elucidate earthquake physics

Rice/Dmowska (geometry, friction, lab)
Beeler & Tullis (lab)
Archuleta (energy)
Day & Harris (geometry, materials, friction)
Purvance/Anooshehpoor/Brune (lab)
Harris & Archuleta (code-comparison/validation workshop)
Harris/Aagaard/Ampuero/Andrews/Archuleta/Day/Dunham/Lapusta/Oglesby/Olsen/Pitarka (code-comparison/validation)
Lapusta (multi-cycle)
Oglesby & Xu (multi-cycle)
Shaw (multi-cycle)

Reference Earthquakes Database

Mai (many earthquakes)
Beroza & Olsen (Landers)

Investigating large- vs. small-earthquake physics

McGuire (rupture velocity)

Using earthquake triggering observations to decipher earthquake physics

Brodsky/Felzer (stress shadows)

Highlights from this research effort are as follows:

As part of our research into rupture dynamics, we in the Earthquake Source Physics Focus Group have 3 groups investigating the multi-cycle fault problem, where researchers are modeling the long-term dynamics of earthquakes over multiple earthquake cycles. 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. Our most visible current effort is our code validation/comparison exercise, which now involves more than 16 people, including a significant number of students and postdoctoral researchers. We hope to show that when we use similar assumptions about fault geometry, materials, friction, stress, we will produce the same earthquake source physics results, regardless of the computational method. 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 2 workshops (November 2003, >30 attendees; September 2004, >50 attendees), and our next meeting will be November 2004. We have compared results for two benchmark problems (The Problem, Versions 1 & 2), and are about to embark on The Problem, Version 3, before moving on to validation with both a foam rubber experiment (and other lab experiments as they become available) and Parkfield as 2005 goals. Our collaborative project has received worldwide attention, with scientists from other countries using our findings to benchmark their codes.

In ESP in 2004 we have had 3 groups comparing laboratory results with numerical simulations of dynamic rupture. These include the Brune group, which is simulating rupture in foam rubber that will be used as a validation exercise for the code-validation group; the Beeler/Tullis group, which is observing dynamic rupture in rock; and the Rice group, which is performing numerical simulations of the laboratory homolite rupture experiments of the Rousseau/Rosakis group. This is an exciting time in the overlap between lab and computational simulations of rupture dynamics.

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. PI Mai, on shoestring funding, put together the first part of this, with a web-accessible database on finite-source models from worldwide earthquakes.

In the coming year, FY05, our group hopes to continue some of these subprojects, all with the goal of deciphering earthquake source physics. The collaborative code validation exercise will expanding to include more PIs around the world (at negligible SCEC cost), and our group aims to participate in the NGA-H (see Implementation Interface section of this report) project when it comes on line. Our multi-cycle simulations show much promise, and the occurrence of the 2004 Parkfield earthquake should provide ESP with much eagerly anticipated data. The ESP group expects to benefit greatly from this earthquake, which is the best-recorded event in history.

FIGURES

Figure III.9.
Harris/Aagaard/Ampuero/Andrews/Archuleta/Day/Dunham/Lapusta/Oglesby/Olsen/Pitarka Rupture Dynamics Code Validation Exercise. The specific case of nucleation, followed by spontaneous rupture propagation on a vertical strike-slip fault in a homogeneous half-space. Shown are low-pass filtered synthetic seismograms of horizontal slip-rate at the epicenter. The simulations were done using 10 different spontaneous-rupture computer codes.

Figure III.10.
Comparison between numerical simulations of the Rice group and actual experiments by the Rousseau/Rosakis group of rupture on a bent fault in the material homalite.

Fig. III.9 Rupture Dynamics 10 Code Comparison - The Problem, Version 2

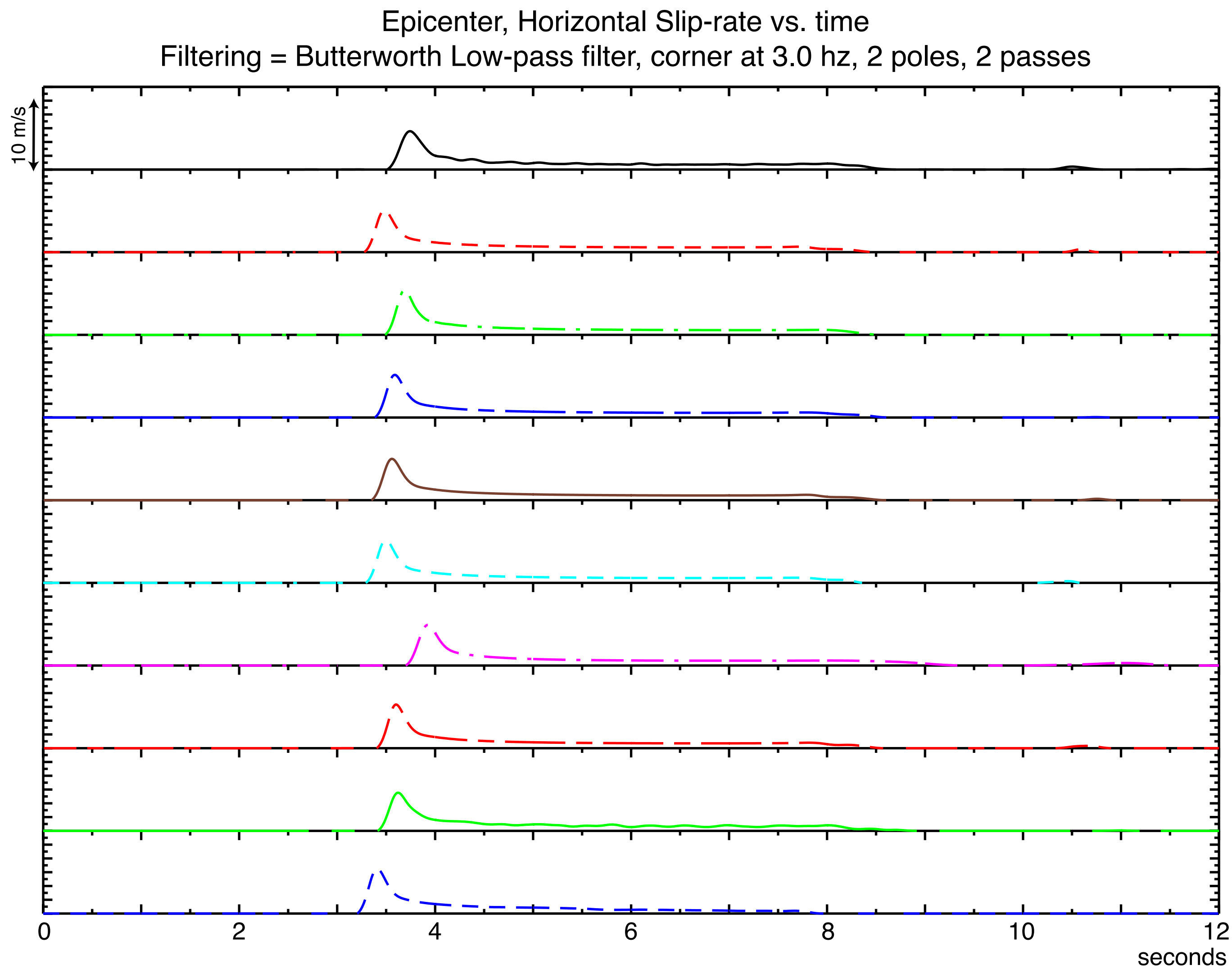


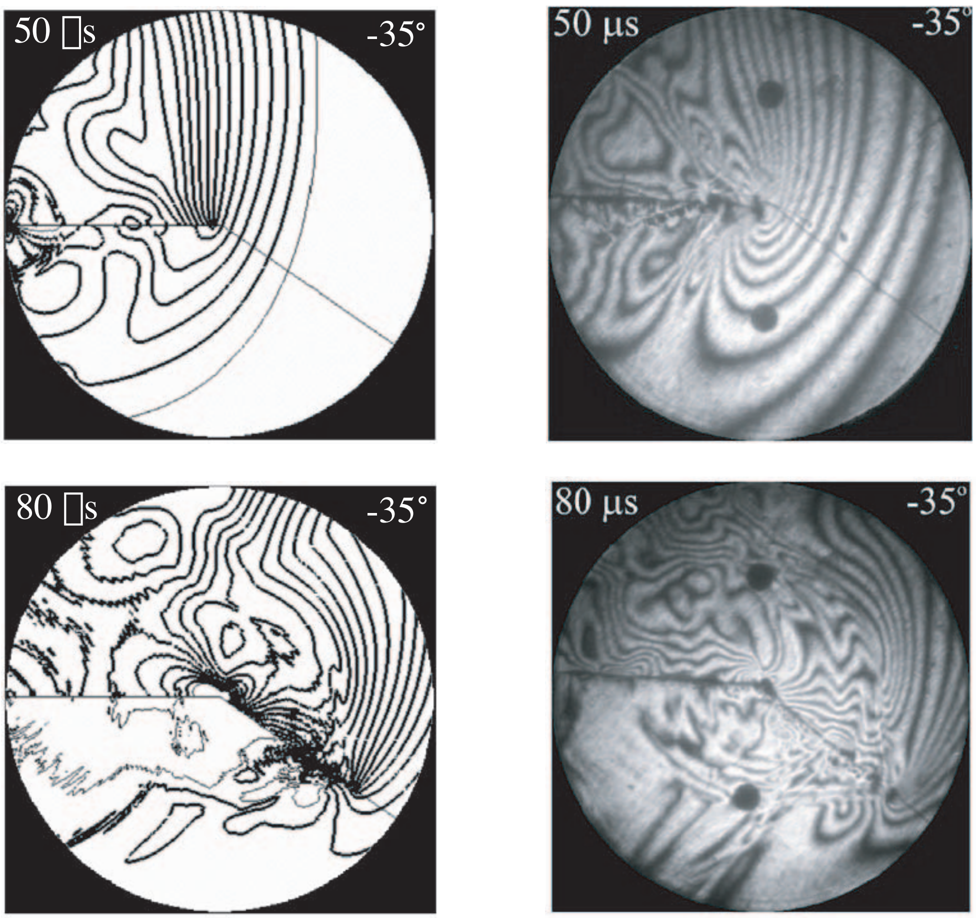
Fig. III.10. Comparison of numerical simulations (left) and lab experiment (right) of spontaneous rupture on a fault bend in homalite.

Templeton, Baudet, Bhat, Rice

Isochromatics comparison, *intersonic* simulation and *intersonic* experiment

Comparison of Isochromatic Fringe Patterns

Finite Element Results | Experimental Results



$V_{impact} = 32.6$ m/s

Comparison of the Isochromatic fringe patterns (experiments from Rousseau and Rosakis [JGR, 2003]), which are lines of constant difference between the maximum and minimum in-plane stresses, for a branch angle of -35 degrees. At 50 □s, the rupture has just reached the branch in the experiment and in the finite element results (with $C_p/(\square V c_p)= 0.024$). Both the experimental and finite element results predict an intersonic rupture velocity.

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 physical basis their reliability is in question. 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 (e.g., ESP, IIG, CVM, CFM, USR,CME).

Numerical Simulations

Probably the largest computation of ground motion to date was Terashake performed by the CME group using Kim Olsen's finite difference program. The southern California region was divided into 1.8 billion 200m cubes, and seismograms up to 0.5 Hz were generated from a Denali-type earthquake rupturing 230 km of the San Andreas fault. The calculation ran for four days on the San Diego DataStar supercomputer and generated 47 Tbytes of data (surely one for the Guinness book of world records). The spectacular movies of surface ground motion were shown at the SCEC annual meeting with vivid depiction of effects of directivity, fault segmentation, scattering, trapping of basin waves and generation of long term coda (Figure III.11).

A number of different methods have been implemented to model the high frequency part of seismograms. Yehua Zeng uses a combination of rough source, randomly distributed scatterers and reverberations in near surface layering. Arben Pitarka and Rob Graves add a stochastic component to low frequency deterministic calculations. Tom Heaton adds high frequency data from nearby strong motion instruments to wavefields calculated using Jeroen Tromp's spectral element method. Kim Olsen uses finite differences to model low frequencies and ray synthetics to deterministically model high frequencies with sources constrained by pseudo dynamics. The method claims smoother phase transitions across the spectral band. The same source model is used and a weighted superposition is used to combine the low and high frequency bands. The optimal method continues to be an area of active enquiry.

The ground motion group were active participants in the PEER-USGS-SCEC sponsored NGA-E (Next Generation Attenuation) project that has now been funded directly by NSF for a 3-year project. The SCEC research involves comparison of broadband simulations against data from large earthquakes (See IIG report). The NGA modeling effort presents an essential conduit through which SCEC research flows to practical use.

Modeling and Observations

The foam rubber test-bed in Jim Brune's lab has been used to validate Steve Day's dynamic rupture code. At low frequencies the comparison is excellent (Figure III.12), but at high frequency the smooth numerical model does not capture the high amplitude accelerations that develop in the vicinity of the fault (Figure III.12). This observation, also seen in earthquake records, is referred to as the roughness ratio, RR (high-f to low-f acceleration, RR~3). It suggests that, even in a nominally smooth physical model, the dynamics introduces rough behavior, possibly due to interface chatter, such as opening and closing modes, or dynamical effects causing variable friction. These observations reinforce the view that in order to understand high frequency ground motion it is critical to separate source and path effects. Comparisons between modeling and data have raised the following questions: (1) Why do the foam rubber models and numerical comparison over-predict directivity at high frequency in comparison with observations? (2) Why do they not exhibit along strike saturation; is this due to lack of asperities in rubber? (3) Why are high frequency accelerations several times low frequency accelerations? (4) Standard models find that spectral amplitudes increase with magnitude. However observations imply the near fault pulse is narrow band and period increases with magnitude. (5) Weaker ground motion is observed when faulting breaks the surface.

Work continues on finding geological constraints on historic strong ground motion by analyzing survivability of precariously balanced rocks. After the remarkable observation of a line of rocks mid-way between the Elsinore and San Jacinto faults, presumed to be located just far enough from each to survive historic shaking, a new reconnaissance study of the region between the San Andreas and San Jacinto is being undertaken. Further theoretical and observational work continues to quantify the observations.

Path and Scattering Effect*s*

Kim Olsen introduced an empirical Q model into the CVM, where Q was taken to be proportional to S wave speed. This resulted in significant variance reduction between theory and data. Peter Shearer and Egill Haukkson are inferring Q from local earthquake data. They use stacked spectra from hundreds of thousands of double difference-relocated events to isolate source, path, and site spectral response. At the SCEC meeting they presented a new Q model for the upper crust. Jamie Steidl and Pengcheng Liu have inverted for Q(z,f) at various depths in the SCEC borehole seismic array, and show that at high frequencies the last few hundred meters can be as attenuative as the remaining path. Ralph Archuleta is examining source, path and site effects on the 150 station Yokahama seismic array with the objective of explaining long durations and the various ground motion factors relative to the geology.

Rob Graves has compared Northridge earthquake synthetics from the SCEC velocity model and the Harvard velocity model (Figures III.13 and III.14). The models are generally similar in their representation of the basin structures. However, several key differences are apparent, particularly in the structure of the northern San Fernando basin. Both simulation models do reasonably well at reproducing the general characteristics (i.e., waveform and amplitude) of the observed time histories at these sites, with the exception of the Harvard model at **sylm**. The different simulation response at **sylm** is explained by the lack of basin structure at this site in the Harvard model. This work represents a start at reconciling the two models to arrive at an optimal CVM for ground motion predictions.

Engineering Applications

Tom Heaton leads an effort involving active collaboration between building and ground modelers to model the hazard presented by the newly discovered Puente Hills blind thrust. Ground motions up to 1.5 Hz are calculated using Tromp's spectral elements program, coupled with historic recordings of strong ground motion for higher frequencies. Programs written by (structural engineer) Hall's group have been used to model building response for (up to) 40-floor buildings. The simulations are used to identify times and locations of structural damage. The structure codes can take the buildings all the way to collapse. Various movies of building excitation were presented at the SCEC annual meeting with assessment of maximum damage presented in graphical form on the structural drawings.

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.

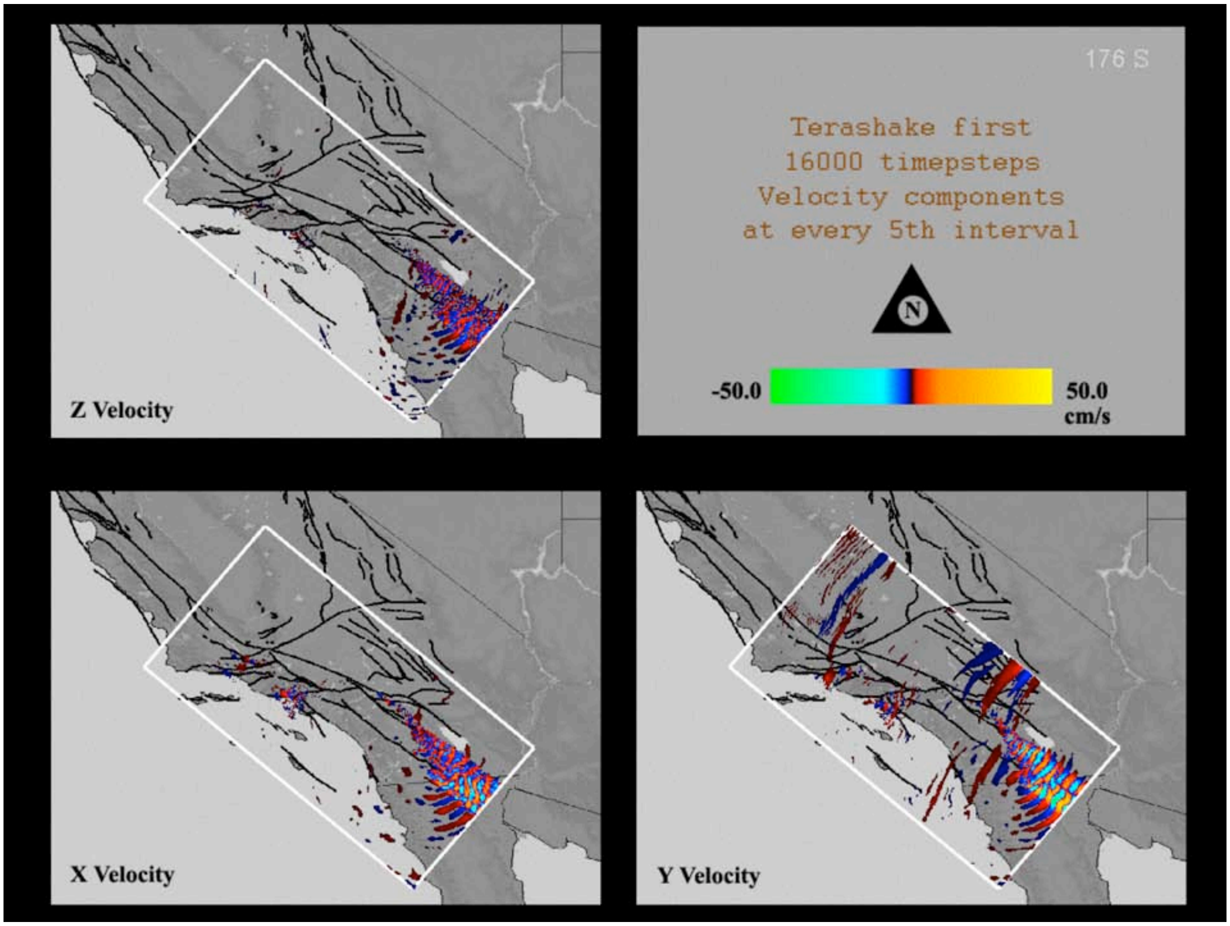


Figure III.11. Terashake movie frame. The rupture travels SE along the San Andreas fault. Note the directivity to the southeast, trapping of waves in the Los Angeles and Ventura basins and irregular shaking pattern from fault segmentation.

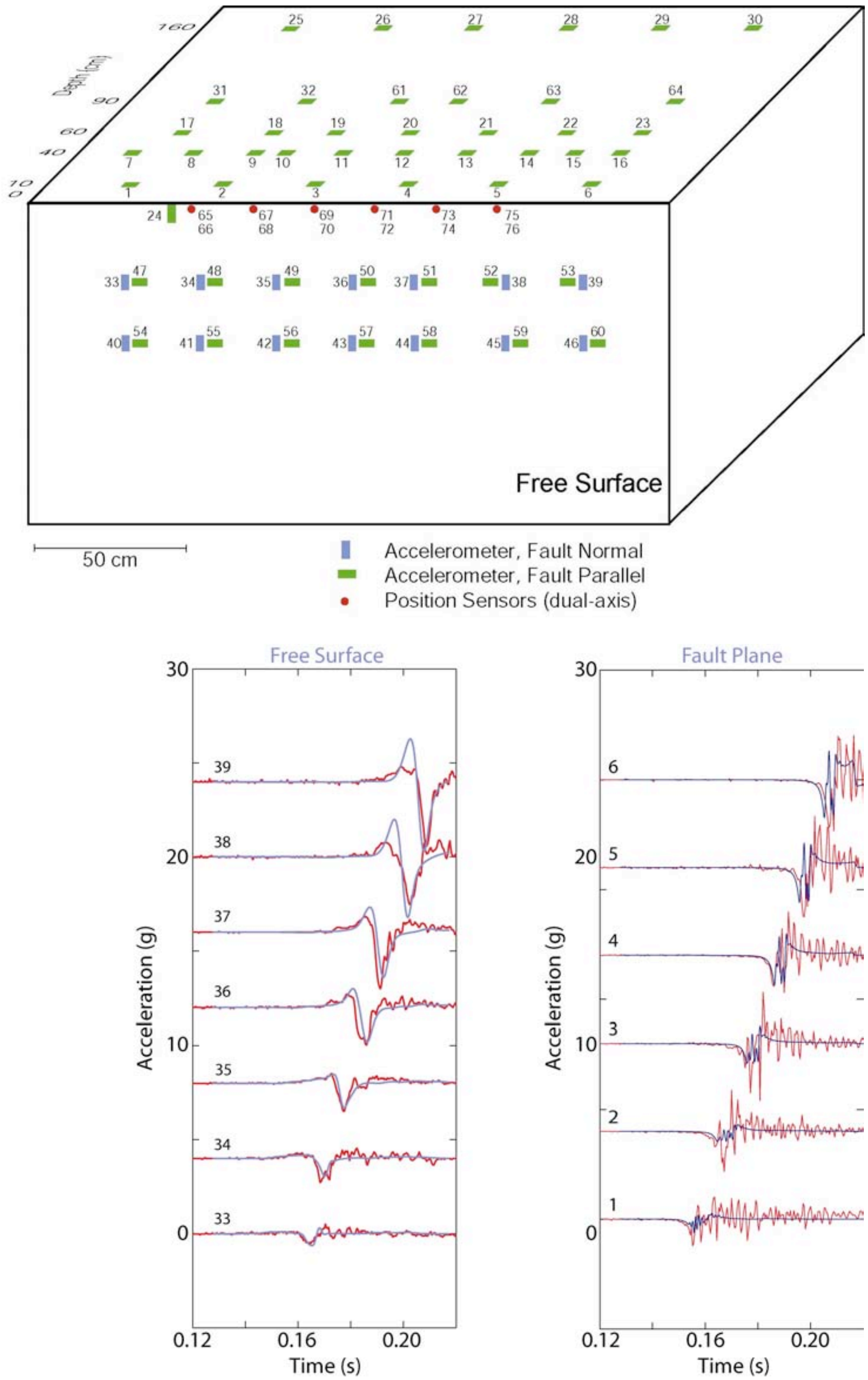


Figure III.12. Foam rubber simulations. The model is shown upper left. The data (red lines) is compared with Steve Day's dynamic rupture code, which matches low frequencies but not the high frequencies generated on the fault plane.

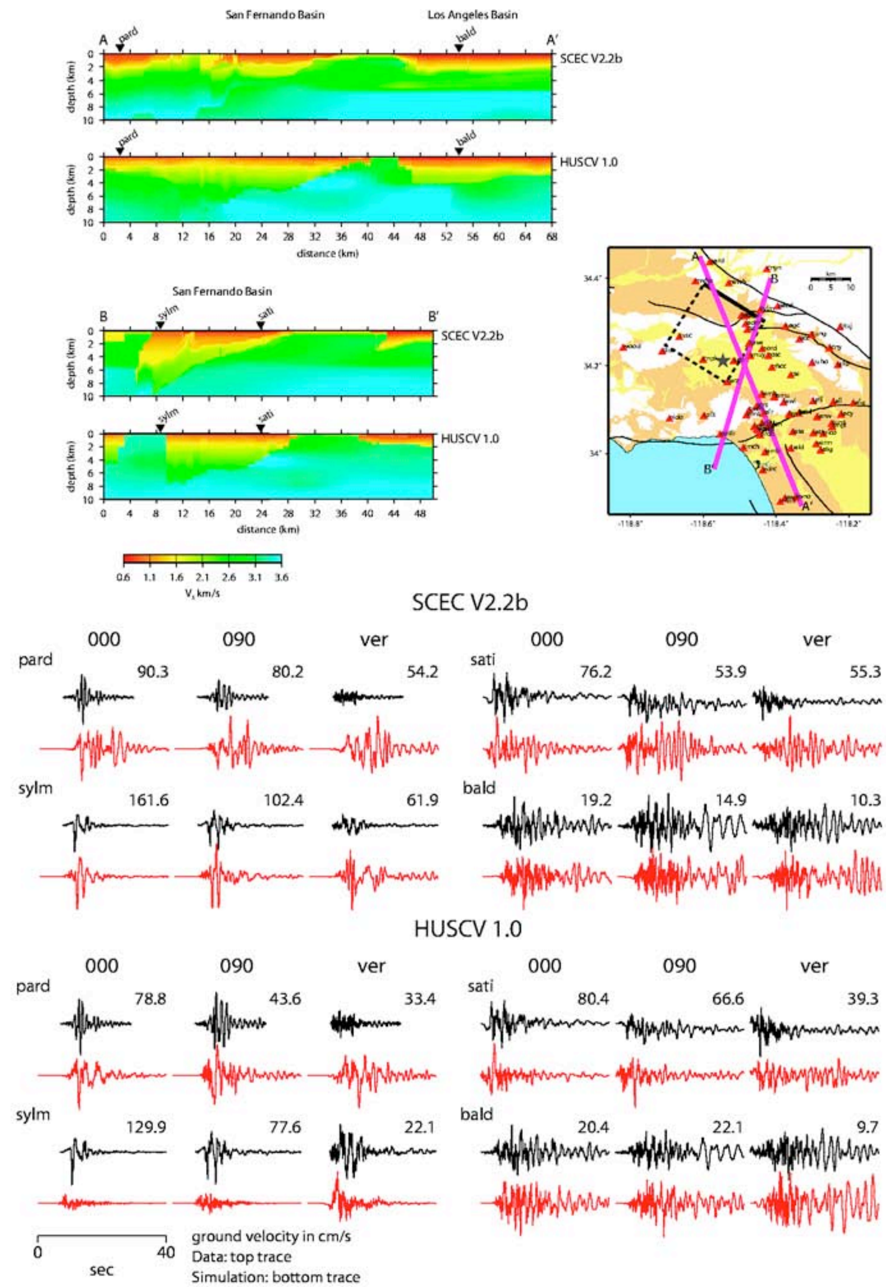


Figure III.13: Upper panels show shear wave velocity cross sections through the SCEC and Harvard 3D velocity models. Locations of the cross sections are indicated on the map. The models are generally similar in their representation of the basin structures; however, several key differences are apparent, particularly in the structure of the northern San Fernando basin. For both models, broadband (0-10 Hz) ground motion time histories were generated on a dense grid of points (16000 locations at 500 m spacing) throughout the near fault region for the Northridge earthquake. Details of the broadband simulation methodology are given in Graves and Pitarka (2004). Bottom panels compare recorded broadband ground velocity time histories at four selected sites for the Northridge earthquake with those simulated for the two 3D velocity structures. Both simulation models do reasonably well at reproducing the general characteristics (i.e., waveform and amplitude) of the observed time histories at these sites, with the exception of the Harvard model at **sylm**. The different simulation response at **sylm** is explained by the lack of basin structure at this site in the Harvard model (cross section B-B').

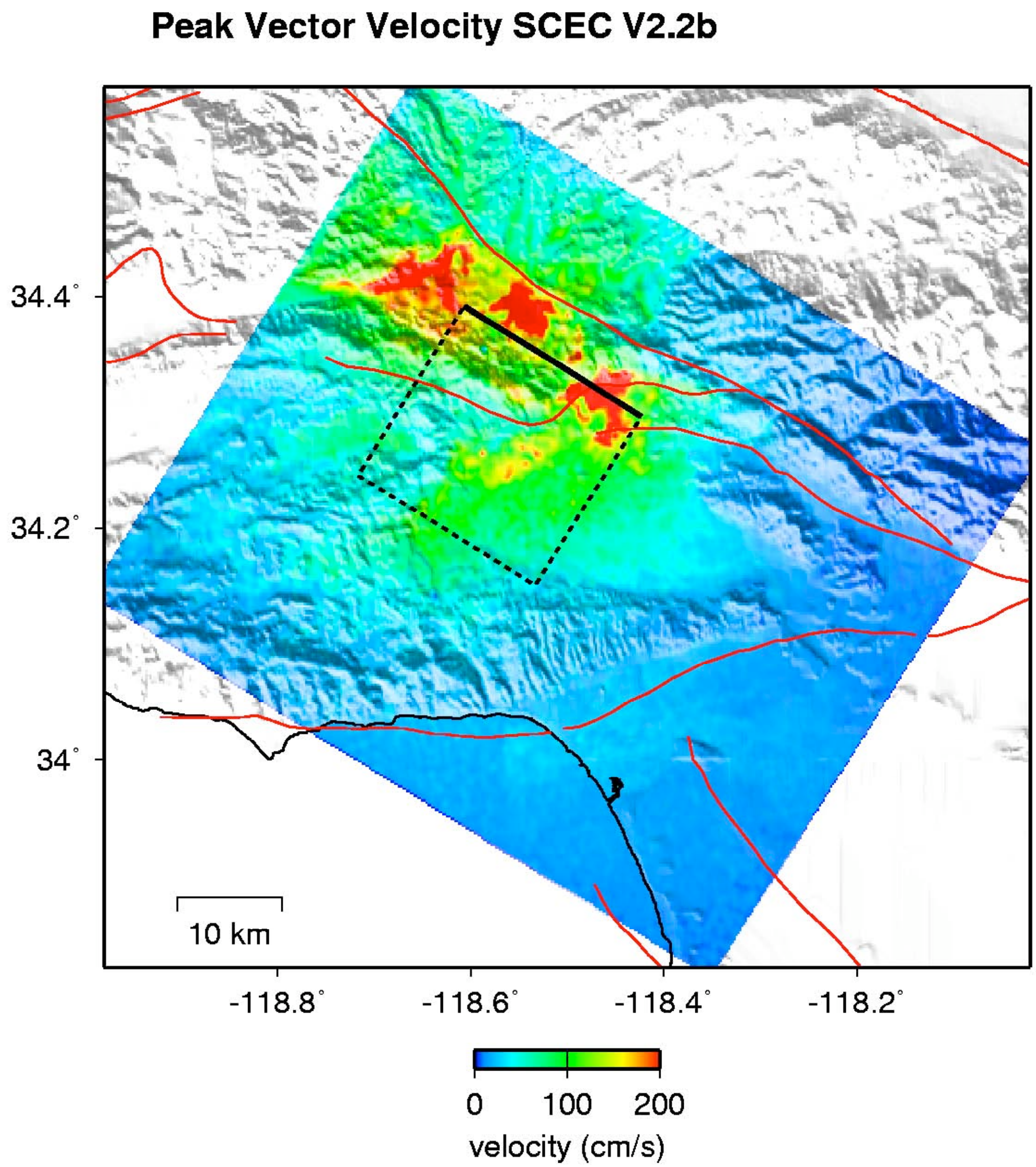


Figure III.14: Map of peak simulated ground velocity for the Northridge earthquake. This image is generated from a set of broadband (0-10 Hz), three component time histories that were computed at 16,800 locations in the near fault region using the hybrid simulation methodology of Graves and Pitarka (2004). At frequencies lower than 1 Hz, the simulation incorporates the detailed 3D velocity structure of this region using the SCEC Community Velocity Model (CVM).

Seismic Hazard Analysis

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 two major activities aimed at improving SHA: RELM (to develop alternative, physics-based ERFs), and OpenSHA (a community modeling environment for SHA). Both 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). The goal is to develop a variety of viable Earthquake-Rupture Forecasts (ERFs) rather than one consensus model (the latter being approach taken in previous working groups). 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. A list of models currently slated for publication can be seen by clicking "Models" at the RELM website given above.

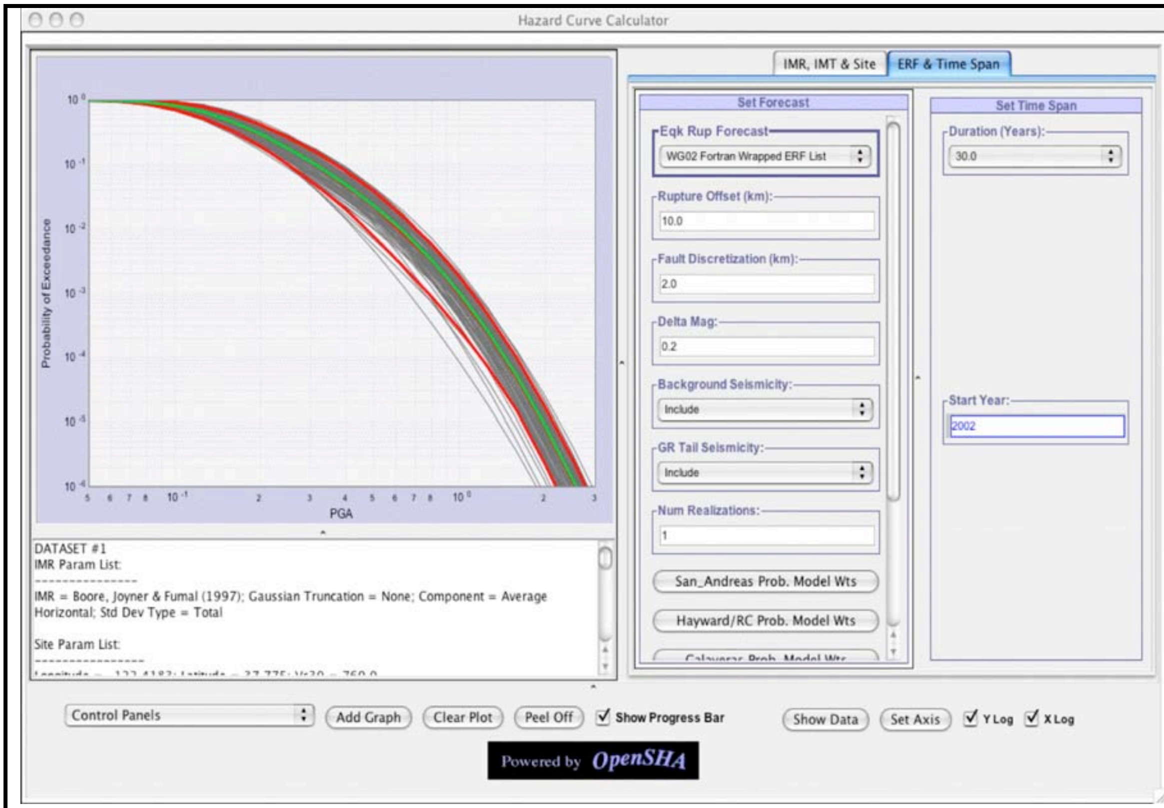
Part of the effort is to establish and implement formal test of each model (e.g., compare predicted earthquakes to those that actually occur). This activity has become particularly important in light of recent claims of success with respect to earthquake prediction. We also want to evaluate the hazard 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. Our web site (http://www.RELM.org) can be used to monitor progress in this ongoing effort.

OpenSHA:

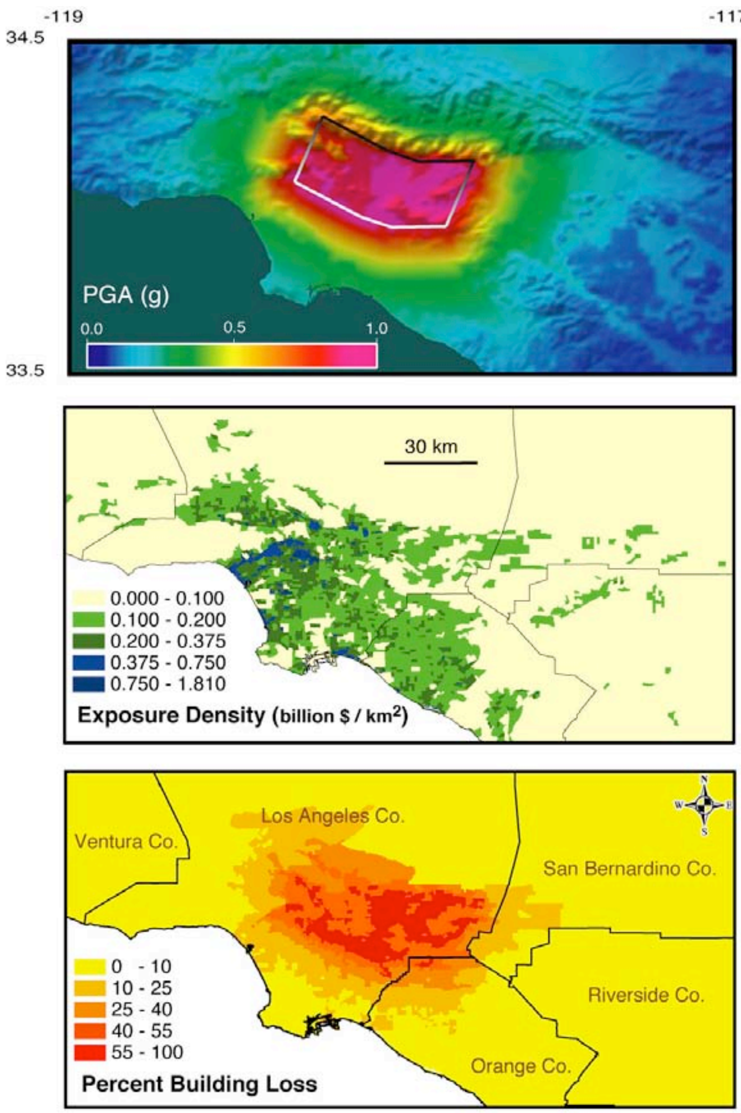
As discussed above, we need a computational infrastructure for SHA that can accommodate a rapid proliferation of new, alternative, and more physics-based models (e.g., new ERFs from RELM or new IMRs from the NGA effort mentioned above). Our answer to this need is OpenSHA (http://www.OpenSHA.org) – a 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.

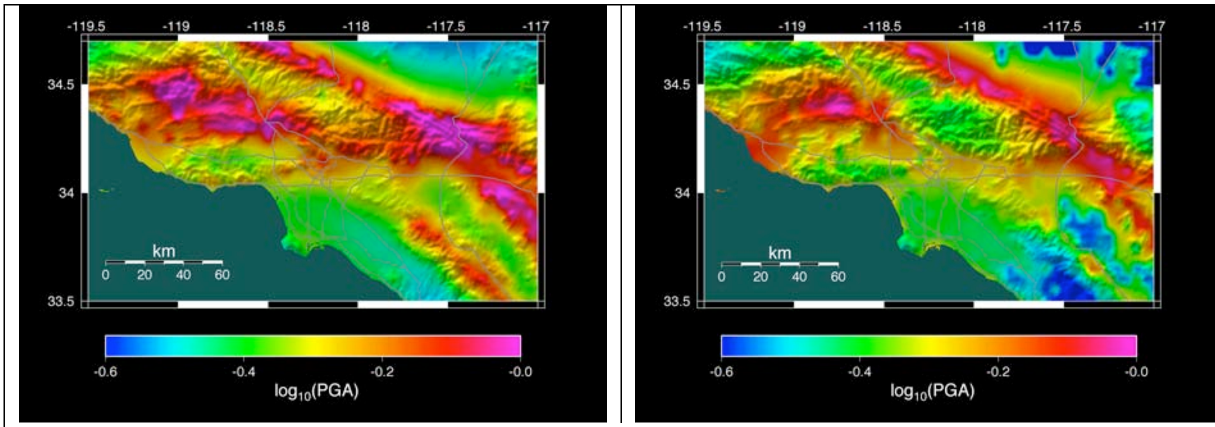
This community-modeling environment for SHA has benefited greatly by involvement in the SCEC Information Technology Research (ITR) collaboration. Specifically, this collaboration has enabled any of the model components (e.g., the ERFs) to be geographically distributed and runtime accessible over the 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.



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 red 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.



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 submitted for publication (Field et al., 2004, *Earthquake Spectra*)



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.

Special Projects

IMPLEMENTATION INTERFACE

SCEC's major Implementation Interface activity in 2004 was participation in the Next Generation Attenuation (NGA) Project. Ground motion attenuation relationships are the backbone of modern earthquake hazard assessment. These relationships are used in *all* earthquake hazard assessments ranging from the U.S. National and California seismic hazards maps, to site-specific assessments, both deterministic and probabilistic, used for specific facilities ranging from bridges to dams to power plants. Hazard assessment results are used to establish design strategies and details of the built environment and to predict their performance.

SCEC is a co-sponsor and co-participant with PEER-Lifelines and the USGS in NGA Project. The objective of the current phase of the NGA Project, NGA-E (Empirical), is to update existing ground-motion models for shallow crustal earthquakes in active tectonic regions derived from recorded strong motion data. The NGA-E Project consists of a set of 8 Tasks that are guided by 6 Working Groups, listed in Table III-1, which shows the relationships among them.

Table III-1. NGA-E Tasks, Working Groups, and their Relationships

Tasks	***W. Groups***
1. Database Development	1,2
2. 1-D Rock Simulation	3,4
3. Evaluation of Predictors	4
4. Site Classification and Site Effects	5
5. Site Response Analysis	5
6. Statistical Approaches	6
7. Simulation of 3-D Basin Response	4
8. Evaluation of Final NGA Models	

Working Groups	**Tasks**
1. Data Processing	1
2. Database Predictor Variables	1
3. Validation of 1-D Rock Simulation	2
4. Source/Path Effects	2,3,7
5. Site Classification and Site Effects	4
6. Statistical Modeling of Data	6

SCEC scientists participated in almost all of the tasks and working groups listed in Table III-1. 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.

SCEC work 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.

Examples of SCEC products for NGA-E are shown in Figures III-15 and III-16. Figure III-15 shows the results of extensive validation of a broadband simulation procedure against the recorded strong ground motions of five large earthquakes. The procedure was tested by examining residuals as a function of distance, magnitude, and directivity parameter for a wide range of periods. Figure III-16 shows the use of three broadband simulation procedures, including two from SCEC (UNR and URS), to model the magnitude scaling of ground motion response spectra for a range of periods.

Implementation of Research Products in Earthquake Engineering. NGA products will fulfill a clearly stated need of the industrial sponsors of PEER-LL (Caltrans, the California Energy Commission, and PG&E) for improved ground-motion prediction models. Potential user organizations include these sponsors and organizations (including ATC, BART, BSSC, CEA, CSSC, CUREE, DOE, DSOD, DWR, EBMUD, FEMA, FERC, LADWP, MAE, MCEER, NRC, NEES, OES, PEER, SCE, SEAOC.) that have an interest in improved earthquake hazard assessment and/or actively use attenuation relations in earthquake engineering practice.

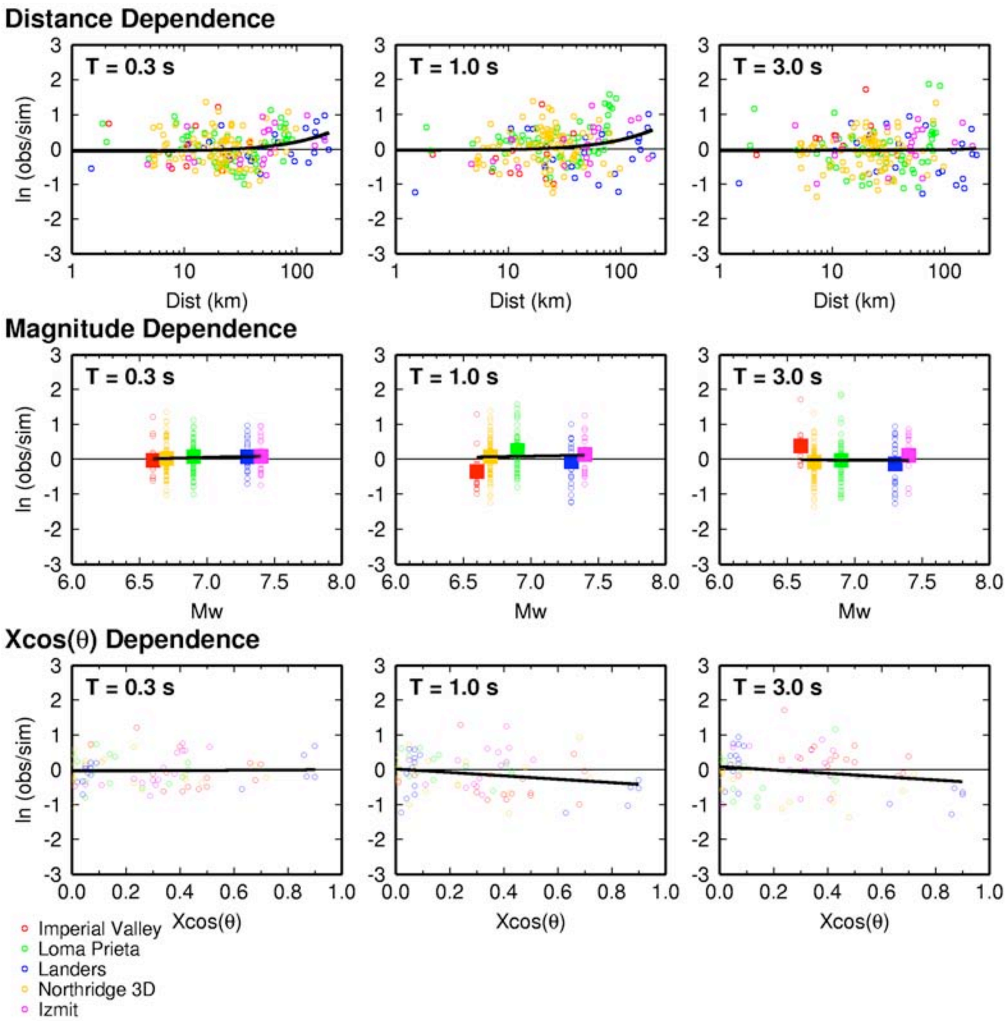


Figure III.15. Validation of the URS (Graves) broadband simulation procedure against recorded ground motions from five earthquakes. Goodness-of-fit is indicated by lack of trends in residuals against distance, magnitude and the directivity parameter Xcos(_).

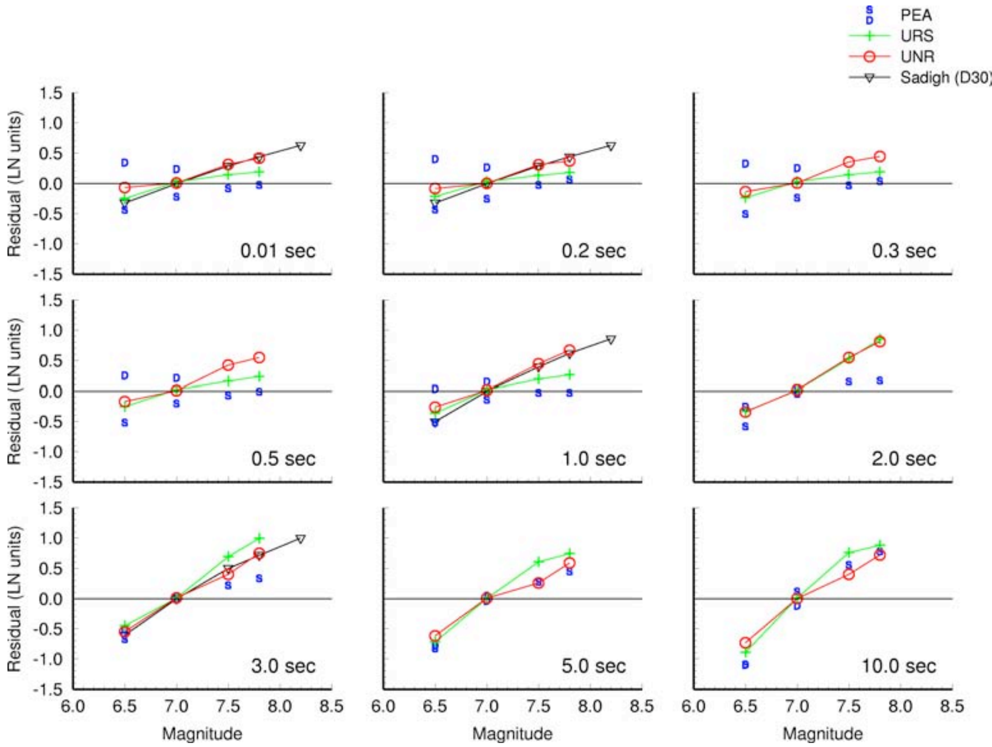


Figure III-16. Magnitude scaling of spectral acceleration for strike-slip earthquakes assuming constant stress drop scaling, normalized at M 7, compared with the Sadigh et al. (1997) empirical model.

SCEC/ITR Project

1. SCEC/CME Project Introduction

The SCEC/CME Project is a National Science Foundation Information Technology Research Project (ITR) that was funded in 2001 as a 5 year Geoscience and IT collaboration. The SCEC/CME Project brings together Geoscientists and Information Technology researchers in development of a computing environment that can be used to perform physics-based, systems-level, Seismic Hazard Analysis (SHA) research. Researchers from U.S. Geological Service, IRIS, U.C. San Diego, California State University San Diego, U.C. Santa Barbara, Carnegie Mellon University, and USC's Information Sciences Institute are collaborating with researchers from the Southern California Earthquake Center (SCEC) in the development of the SCEC/CME.

During SCEC/CME Project Year 3, our Project delivered a wide range of results. SCEC working groups performed innovative, leading-edge research in both Computer Science and the Geosciences. Project working groups have delivered original Information Technology software applications as well as innovative Geophysical simulation software. We have provided research opportunities for graduate and undergraduate research. Data products produced by the Project have been used in public Earthquake Information broadcasts. Project members presented their work at several scientific Conferences and published original research papers in both the Geosciences and Computer Science. And as continue to development new collaborations between our project Computer Scientists and Geoscientists.

This series of strong 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 12 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, which ensures that the Project is producing capabilities needed by working scientists.

2. Research and Cyberinfrastructure in the SCEC/CME Computational Pathways:

The SCEC/CME Project is a computing, and data management, environment in which earthquake simulation models are developed, documented, and maintained on-line for application by SCEC, earthquake researchers elsewhere around the world, and end-users of earthquake information. It has the potential to improve substantially the utilization of SHA in reducing earthquake losses.

The SCEC/CME development goals are formulated in terms of four Computational Pathways. The SCEC/CME Computational Pathways shown in III-17 represent increasingly more accurate, but also increasingly complex, approaches to improving Seismic Hazard Analysis results. This formulation of a graduated series of improvements to SHA science had provided a strong intellectual framework for the Project.

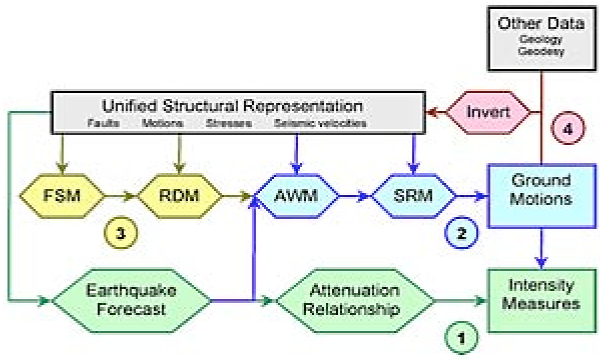


Figure III-17: SCEC/CME Computational Pathways represent a framework for integrating a more physics-based approach to Seismic

During SCEC/CME Project Year 3, SCEC/CME researchers have performed research and developed Cyberinfrastructure in all four of these computational pathways.

2.1. Pathway 1 Research and Cyberinfrastructure:

Our Pathway 1 working group, led by Edward Field (USGS) has continued development of a suite of Probabilistic Seismic Hazard Analysis tools called OpenSHA (www.opensha.org). In addition, Edward has applied these tools to his PSHA research.

The OpenSHA tools are the most mature, and most well-verified, software products in the Project. The Pathway 1 group has not only validated, and documented, existing OpenSHA capabilities, they continue to add capabilities such as support for new Earthquake Rupture Forecasts, and they continue to enhance their computational capabilities through IT technologies such as Grid Computing.

In one research effort, Field et al evaluated the National Seismic Hazard Mapping Project 2002 Earthquake Rupture Forecast (NSHMP-CA-2002 ERF). The power of the OpenSHA framework is the ability to combine elements of seismic hazard analysis, such as Earthquake Rupture Forecasts, Attenuation Relationships, and geological models such a site types, and velocity models. Previously, each combination was hand tailored. Now, with the OpenSHA tools, researchers can combine these elements quickly and easily, leading to new insights and better understanding of Seismic Hazards in California.

Figure III-18 shows an example of the OpenSHA capabilities. In this study, Field et al combined ruptures from the NSHMP-CA-2002 ERF with different attenuations and with different geological models. The variations in the maps indicate the need to improve the empirical attenuation relationships and the geological models used by the existing Probabilistic Seismic Hazard maps.

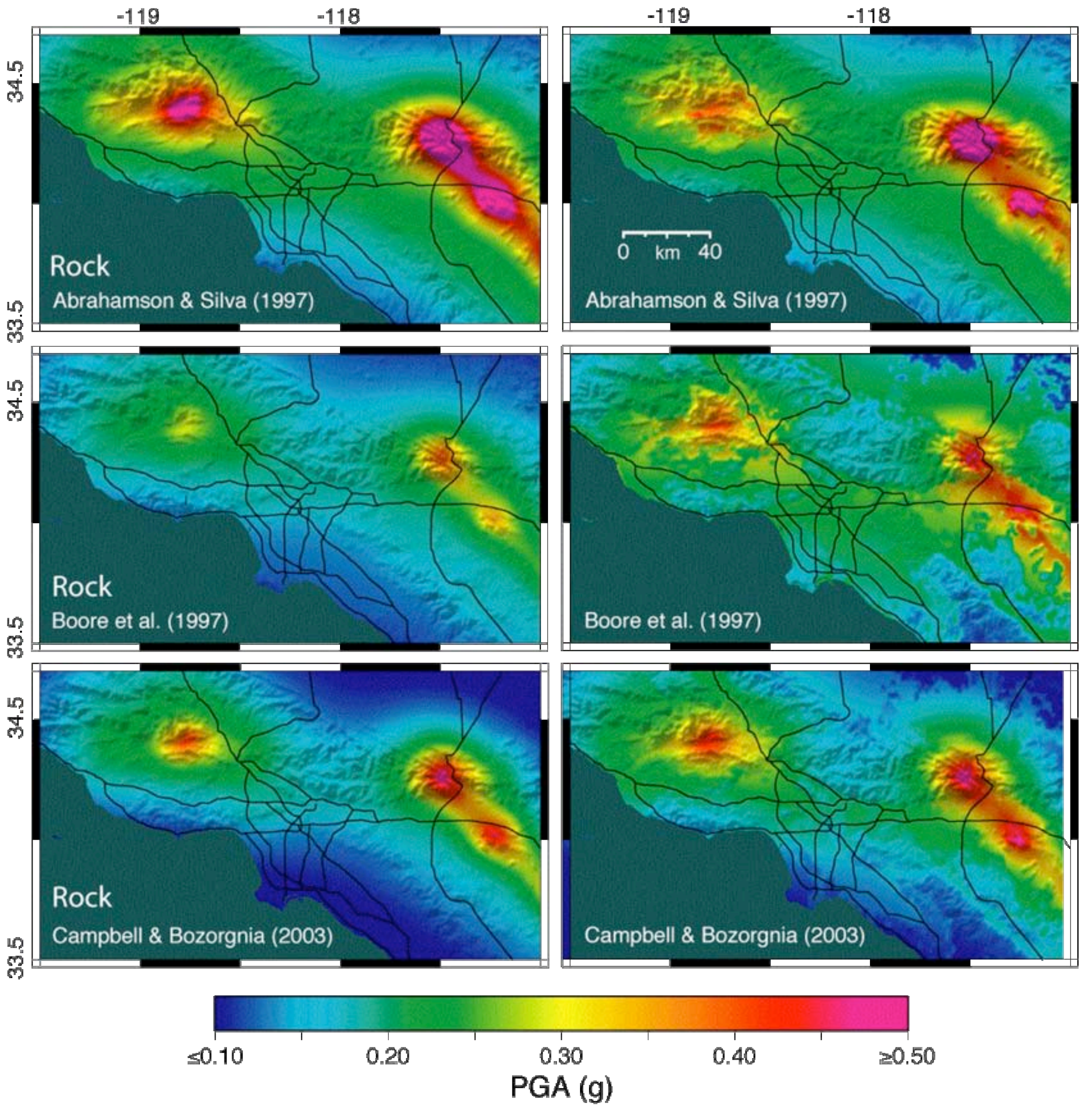


Figure III-18: Maps of the peak ground acceleration (PGA) that has a 50-percent chance of being exceeded in 50 years, computed using the different attenuation relationships as labeled. The maps on the left are for the entire region treated as rock (Wills et al. (2000) "BC" class), and those on the right include site effects as modeled by each attenuation relationship.

The OpenSHA software represents cyberinfrastructure developed on the SCEC/CME Project while the results of studies like this represent basic PSHA research being performed on the SCEC/CME Project.

2.2. Pathway 2 Research and Cyberinfrastructure:

Our Pathway 2 working group, including J. Bernard Minster (UCSD), Kim Olsen (SDSU), Steve Day (SDSU), and Ralph Archuleta (UCSB), Jacobo Bielak (CMU), and David Okaya (USC), has developed and validated suites of software for configuring, running, and analyzing Anelastic Wave Propagation software (AWM). Several of these codes are highly parallelizable, and run on Supercomputer class machines. In additional to using these codes for their research, they contributed their software to the SCEC/CME Project as Community Codes and they have provided the technical supported needed to train Project members on how to run simulations. This distribution of these complex codes is a significant advance toward a Community Modeling Environment in which scientist can use each other's codes without participating in the actual development of the software.

During this project year our Pathway 2 performed a large wave propagation simulation called TeraShake. TeraShake was a very large collaboration between Geoscientists and Computer Scientists. The TeraShake collaboration was an example of Big Science within the Earth Sciences. Over thirty people participated in the planning, test, execution, and analysis of the TeraShake simulations.

TeraShake was actually a series of simulation. The primary results are derived from two nearly identical simulations run at San Diego Supercomputer Center. Cumulative Peak Ground Velocity images from these simulations are shown in Figure III-19.

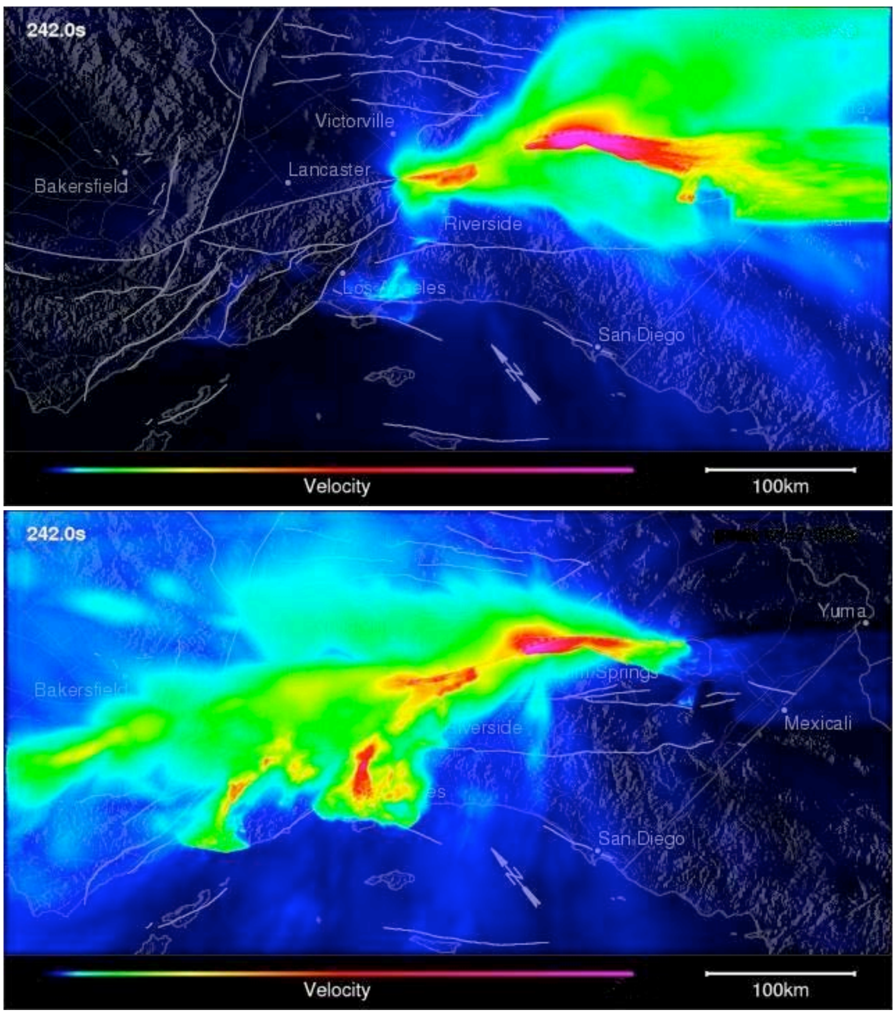


Figure III-19: Peak Ground Velocity Maps from the TeraShake simulations. The simulations that produced these maps were identical except for the rupture direction of the simulated Magnitude 7.7 earthquake.

The TeraShake simulations have generated new insights into the wave propagation characteristics of large earthquakes. In addition, the anelastic wave propagation software used in TeraShake has become a community cyberinfrastructure available to all members of SCEC.

2.3. Pathway 3 Research and Cyberinfrastructure:

Our Pathway 3 working group has developed rupture simulation software and is evaluating the accuracy of the ground motion predictions made by these codes. They have also prototyped the linking of codes that run on dissimilar meshes. This technique will be important as the modeler link rupture simulation code to wave propagation simulation codes.

SCEC/CME collaborators are working as a part of the larger SCEC research community in the performance of Rupture Dynamic simulation validation effort. Steve Day, Jacobo Bielak, and Kim Olsen are among the researcher participating in the SCEC sponsored rupture dynamics validation work. Given validated RDM codes, the SCEC/CME is prepared to host the codes and make them available for simulations.

2.4. Pathway 4 Research and Cyberinfrastructure:

Our Pathway 4 working group includes Thomas H. Jordan (USC), Li Zhao (USC), Po Chen (USC), Kim Olsen (SDSU), and Jacobo Bielak (CMU). This group has made significant progress in the calculation of Fréchet sensitivity kernels by applying the codes developed by our Pathway 2 group. This relationship between our Pathway 2 group and Pathway 4 group shows the strength of the incremental and cumulative computational pathway Project formulation.

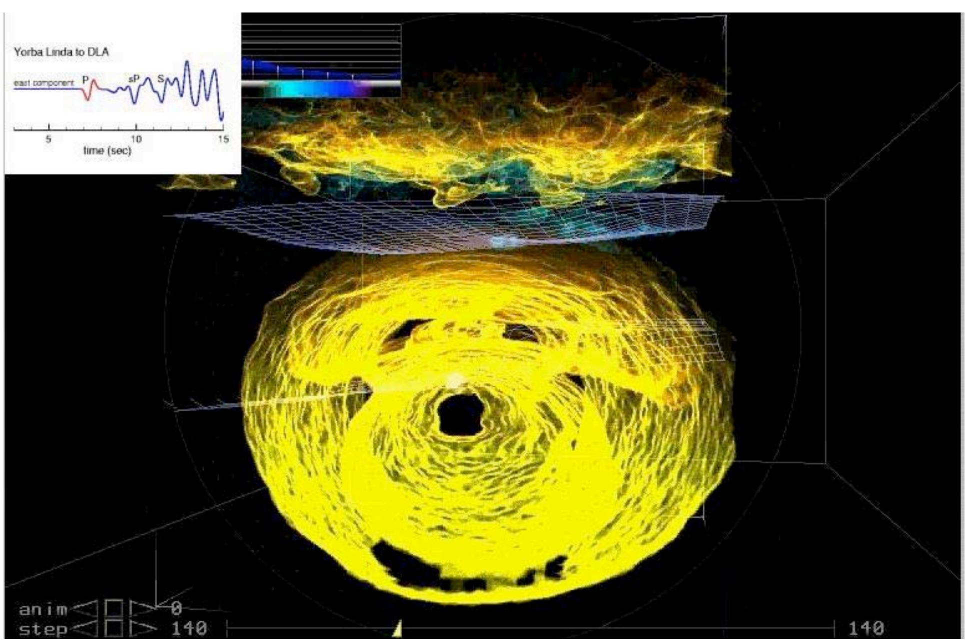


Figure III-20: This Fréchet Kernel visualization shows a characteristic doughnut shape for the P-phase arrival. The red segment in the seismogram indicates the phase for which the kernel image was produced.

The Pathway 4 goal is to run the inverse problem, to image and improve the geological structure by identifying differences between observed data and simulation results. Towards this end, the group has calculated a series of Fréchet sensitivity Kernels. An image from there calculation is shown in Figure III-20.

Our Pathway 4 working group has also ran a series of wave propagation simulations and used the results to calculate Greens Functions for many of the CISN broadband station sites in the Los Angeles area. This Green's Function library is part of the cyberinfrastructure created by the SCEC/CME Project.

3. Computer Science Research and Cyberinfrastructure:

3.1. Grid Computing and Workflow Tools:

An important computational capability developed over the last year is a grid-based workflow system.

The grid is a complex, distributed and heterogeneous execution environment. Running applications requires the knowledge of many grid services: users need to discover the available resources and schedule the jobs onto them, essentially composing detailed application workflow descriptions by hand. The goal of this work is to automate the workflow generation and execution process as much as possible. In particular we focus on developing and using workflow mapping and execution techniques to map and execute SCEC's Pathways 1 and 2 on the SCEC grid resources.

These pathways are represented as application workflows and are first generated using tools such as Composition Analysis Tool, an ontology-based workflow composition tool, or via a custom web interface. The workflows at this stage are named "abstract workflows" and refer only to the logical application components and the logical input data needed for the pathway's execution. The abstract workflows do not identify any of the resources or physical file locations needed to produce the desired data products.

To map and execute SCEC applications on Grid resources, technologies such as Pegasus and Condor's DAGMan can be used. Pegasus is a workflow management system developed at USC/ISI. DAGMan is a workflow execution and monitoring system developed at the University of Wisconsin Madison. In order to map the abstract workflows onto the Grid resources, Pegasus consults various Grid information service. It interfaces with the Globus Replica Location Service to determine the location of the input files and to register the locations of the data products that are generated during the execution of the workflow. It also queries the Globus Monitoring and Discovery Service to determine the available resources and their setup. Finally, Pegasus also consults a Transformation Catalog that holds information about the workflow executables and their locations on the grid. Using all this information Pegasus generates a concrete workflow that identifies the resources where the computation will take place, the data movement for staging data in and out of the computation, and registers the newly derived data products.

To date Pegasus has enabled SCEC applications to run on a variety of distributed resources such as individual machines, condor pools and parallel machines. The metadata of the products generated is being populated in the Metadata Catalog Service (MCS). The SCEC portal, which provides the user's interface, is now secured using MyProxy-based authentication that allows users to logon to the submission site using their grid credentials. This portal also enables the users to track the status of the jobs and to submit workflows on the grid.

3.2. Data Management Research and Cyberinfrastructure:

During Project Year 3, the SCEC/CME computers scientists have developed a digital library containing simulation results for 70+ Scenario Earthquake simulations. This collection contains data and metadata for each simulation. The collection is network accessible, and a variety of user interfaces have been developed, allowing users to choose how they access the data. Figure III-21 shows a web-based interface to a collection of over 70 ground motion simulations currently storage in the SCEC Digital Library.

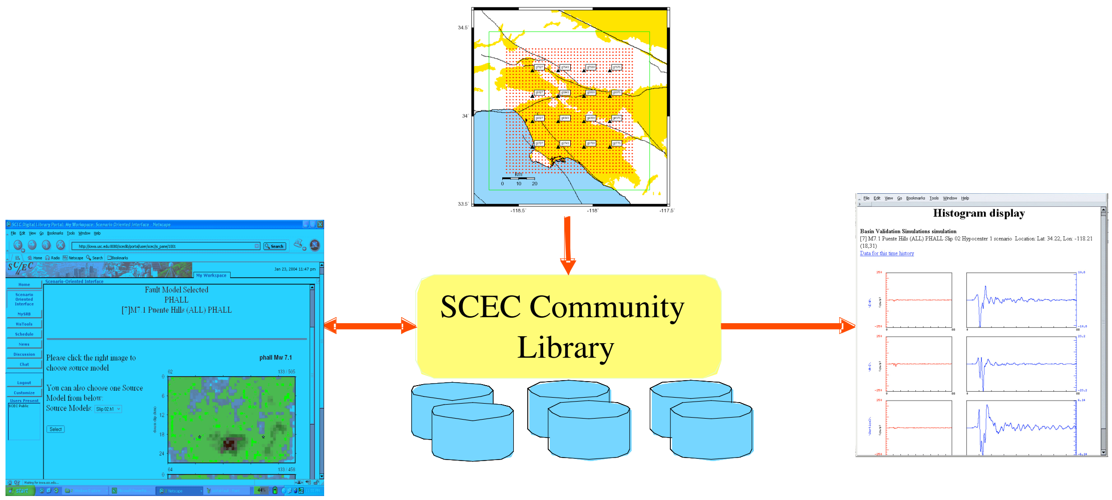


Figure III-21: SCEC Ground Motion Data Collections are accessible through a specially designed user Interface that allows scientists to view the collection as a set of Scenario Events.

The data management challenges on the SCEC/CME project also include the data management for the TeraShake simulation. The TeraShake simulation output over 40 Terabytes of data in the 5 days. The San Diego Supercomputer Center collaborates managed the data transfers from DataStar local storage to the SCEC SRB digital library to support this very large, data intensive, simulation.

3.3. Knowledge Representation and Reasoning:

Computer scientists on the SCEC/CME Project are developing intelligent reasoners and interfaces that enable users to 1) publish implemented codes of earthquake simulation models and describe model constraints 2) access published simulation models and check constraint violations, and 3) interactively construct computational pathways. Our researchers have developed a novel approach to interactive pathway composition that uses knowledge bases to represent and reason about model constraints and planning approaches to reason about the relationships among components within an end-to-end pathway computation. We are also investigating how to model the grid execution environment so that the user can be isolated from the details of the execution of the pathway. We have developed CAT, Composition Analysis Tool, and used it with Pathway 1 components. Figure III-22 shows our initial interface developed to prototype and demonstrate CAT's capabilities.

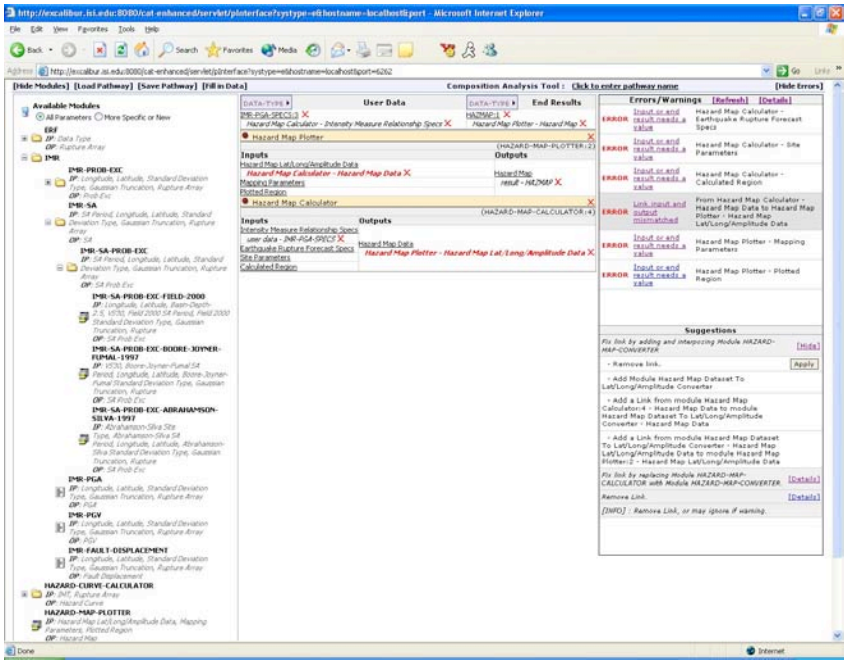


Figure III-22: Our Composition Analysis Tool proactively suggests useful next steps to the user and ensures that the final workflow is correct.

We are also investigating the use of planning techniques to reason about the grid execution environment and automatically generate executable workflows. CAT helps users create workflow templates, which then need to be instantiated with specific data. The result is an instantiated workflow. We have done some preliminary work in using query planning techniques to access metadata catalogs in the grid in the Artemis framework. Additional information needs to be added to these workflows about physical locations and computational and memory resources, resulting in an executable workflow that can be submitted to the grid for execution. This last step can be largely automated, and we are investigating this in the context of the Pegasus architecture.

4. Research Opportunities for Students:

During this Project Year 3, the SCEC/CME Project provided research opportunities for both graduate and undergraduate students.

4.1. SCEC Graduate Students

Several of the participating research organization including San Diego Supercomputer Center, USC, USC/ISI, CMU, UCSD, and UCSB, have provided research opportunities to graduates students through the SCEC/CME Project.

These graduate students have participated in geosciences research such as dynamic rupture simulations as well as information technology research including semantic web technology.

4.2. SCEC IT Intern Program

During this year, the SCEC/CME Project supported two sessions of the SCEC IT Summer Intern program, one of which is currently underway. Our summer-time SCEC IT Intern Program is called the *Undergraduate Summers in Earthquake Information Technology* (UseIT) Program. The Summer-2003 SCEC UseIT Intern program involved 12 undergraduate students. The efforts of these interns were focused on the enhancements to the 3D Visualization software that they created last year.

In addition to the LA3D Geowall software, they have produced products such as print images, and broadcast quality videos, derived from the 3D seismic visualizations created by the Geowall system, which were distributed throughout Southern California as part of SCEC's E&O program for the 10th-year anniversary of the Northridge earthquake.

In 2004, the SCEC UseIT Intern program built upon and expanded beyond its initial success. During the school year, our team-based, undergraduate research program comprises up to a dozen USC students. Funding for these students includes both SCEC/CME Project funds as well as additional funds from the USC Undergraduate Research program, and the USC College of Engineering.

In the summer of 2004, USC/SCEC became recognized as an NSF Research Experience for Undergraduates (REU) site, co-funded by the CISE and GEO directorates. This allowed us to expand the program to include 21 students from around the country. The SCEC UseIT Interns are expanding the datasets and capabilities of their interactive, open-source, 3D visualization software, dubbed "LA3D." They have added to the visual ontology in LA3D by creating a new representation of earthquake focal mechanisms. At the request of the SCEC Community Fault Model (CFM) leaders, the interns created an executable distribution of LA3D for use as a CFM fault viewer. SCEC's fault geologists are now using this fault viewer in order to evaluate CFM and propose changes.

Multiple IT interns presented different aspects of their work at regional and national meetings, including the SCEC annual meeting, the GSA Cordilleran Section, AGU and SSA. The group also participated in the Northridge 10 year Anniversary earthquake awareness fair at Caltech, displaying LA3D images on their Geowall projection system, and won first place, interdisciplinary, at the USC undergraduate research symposium.

5. Summary:

The SCEC/CME Project progress is a result of several factors including the very strong collaboration that was established during the formation of the project, a set of well focused Project objectives, as well as the innovative and hard work performed by our working groups throughout this reporting period.

In addition to meeting specific SCEC/CME system requirements, we believe the SCEC/CME ITR Project is meeting many of the goals NSF set for the ITR program including inter-disciplinary teams working on socially useful science, leading-edge research in both the Geosciences and Computer Science, and research opportunities for graduate and undergraduate students.

We would also like to recognize that the SCEC/CME Project is reaping significant benefits by our location within the existing SCEC scientific community. This co-location of core SCEC geoscientists and SCEC ITR scientists is producing benefits to both groups. The SCEC geoscientists are providing outstanding knowledge, guidance, and insight on the geosciences problems that the SCEC/CME Project is facing. And, conversely, the SCEC/CME project is anticipating the needs of SCEC scientists. Time, and again, we have found that the scientific programs, and the IT technologies, in use by the SCEC/CME Project are applicable and useful to SCEC scientists working outside the Project. We anticipate that this synergy between scientific groups will continue to grow during the life of the SCEC/CME Project.

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 and made it an official part of the organizational structure of SCEC in June 2002. 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. An extended white paper on the objectives, goals, and research priorities of the SCEC Borderland Working Group can be found at the website (http://www.scec.org/borderland) and is based largely on the results of a workshop held in March 2002 on Santa Catalina Island.

The Borderland Working Group recognizes that much of the support, data and facilities needed for offshore research must come from external sources and funding agencies, such as NOAA, NSF, NURP and ONR. The Borderland Working Group has thus been working to identify fundable research problems for which the offshore Borderland provides a particularly useful, unusual or outstanding natural laboratory to study.

In 2004, various Borderland projects were conducted or initiated, of which two received some support from SCEC. NSF funded Kennett, Nicholson, and Sorlien (UCSB)—in collaboration with Normark and Fisher (USGS)—to test the viability of extending the high-resolution climate record in Santa Barbara Basin. The project uses high-resolution seismic stratigraphy to map 3D structure and the location of where older stratigraphic sequences crop out along the Mid-Channel Trend (*Hopkins et al.,* 2004). These older sequences will then be sampled by piston core in August 2005. In addition to climate studies, this project will help to quantify patterns and rates of offshore late-Quaternary faulting and folding in the Santa Barbara Channel.

In 2004, SCEC helped support Sorlien (UCSB) to conduct continued analysis of active fault systems in Santa Monica Bay (Figure III-23-1). This includes the Palos Verdes, San Pedro Basin and Shelf Projection Blind 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 (*Sorlien et al.,* 2004a). This work led to the identification and preliminary mapping of the low-angle Shelf Projection blind fault beneath the Palos Verdes anticlinorium (*Sorlien et al.,* 2004b) that may be the offshore extension of the Compton blind fault in the Los Angeles basin. This project, in collaboration with colleagues at USGS and LDEO, mapped stratigraphic reference horizons to document amounts of deformation absorbed by fault slip, folding and rotation (Figure III-23-1b), and contributed several new 3D fault surfaces to the SCEC Community Fault Model.

In 2003 and 2004, as part of a tectonic and marine habitat program, NOAA and NURP funded Goldfinger (OSU) to conduct high-resolution multibeam, chirp, and submersible dive studies of submerged marine terraces and Pleistocene lowstand shorelines (*Meiner et al.,* 2004) around the Northern Channel Islands and Pilgrim Banks. SCEC partially supported this program by providing funds to date recovered marine fossils, thereby helping to quantify rates of offshore vertical motion associated with the deformation of these paleo-sealevel reference surfaces.

In 2004, USGS personnel continued work on offshore stratigraphy (*Normark et al.,* 2004) and the analysis of high-resolution multibeam, Huntec, chirp and multichannel seismic data to document the location, geometry, and timing of near-shore faulting (*Ryan et al.,* 2004) and submarine landslide (*Fisher et al.,* 2004) hazards.

Besides these major on-going projects, progress continues on obtaining extensive grids of existing high-quality multichannel seismic (MCS) reflection data collected by the industry for hydrocarbon exploration. Much of these data are high-quality and, in some cases, irreplaceable as the data extend into areas (National Marine Sanctuaries, State Water, etc.) where such marine seismic acquisition is now precluded by law. Several of these industry data sets, including data from Western GeCo and Chevron-Texaco, extend along the entire western margin of the continental Unites States, making them excellent data resources for use by both SCEC and EarthScope. Negotiations with Chevron-Texaco, Western GeCo, Venoco, and Heck-Ogle Petroleum have begun and preliminary agreements made to transfer and archive the offshore MCS data with USGS, IRIS, and SCEC, if funding sources for the tape transcription costs can be found. Jon Childs (USGS) has negotiated contracts for the data transfer and tape transcription with Western GeCo, and the USGS has some initial funding to begin this data rescue and archiving process. Members of the Borderland Working Group are currently working with NSF, IRIS and industry to identify and provide matching support for the USGS effort, and to support initial analyses of the MCS data. If these additional necessary funds are found, substantial progress can be made in investigating the active deformation and hazard potential of the offshore Continental Borderland.

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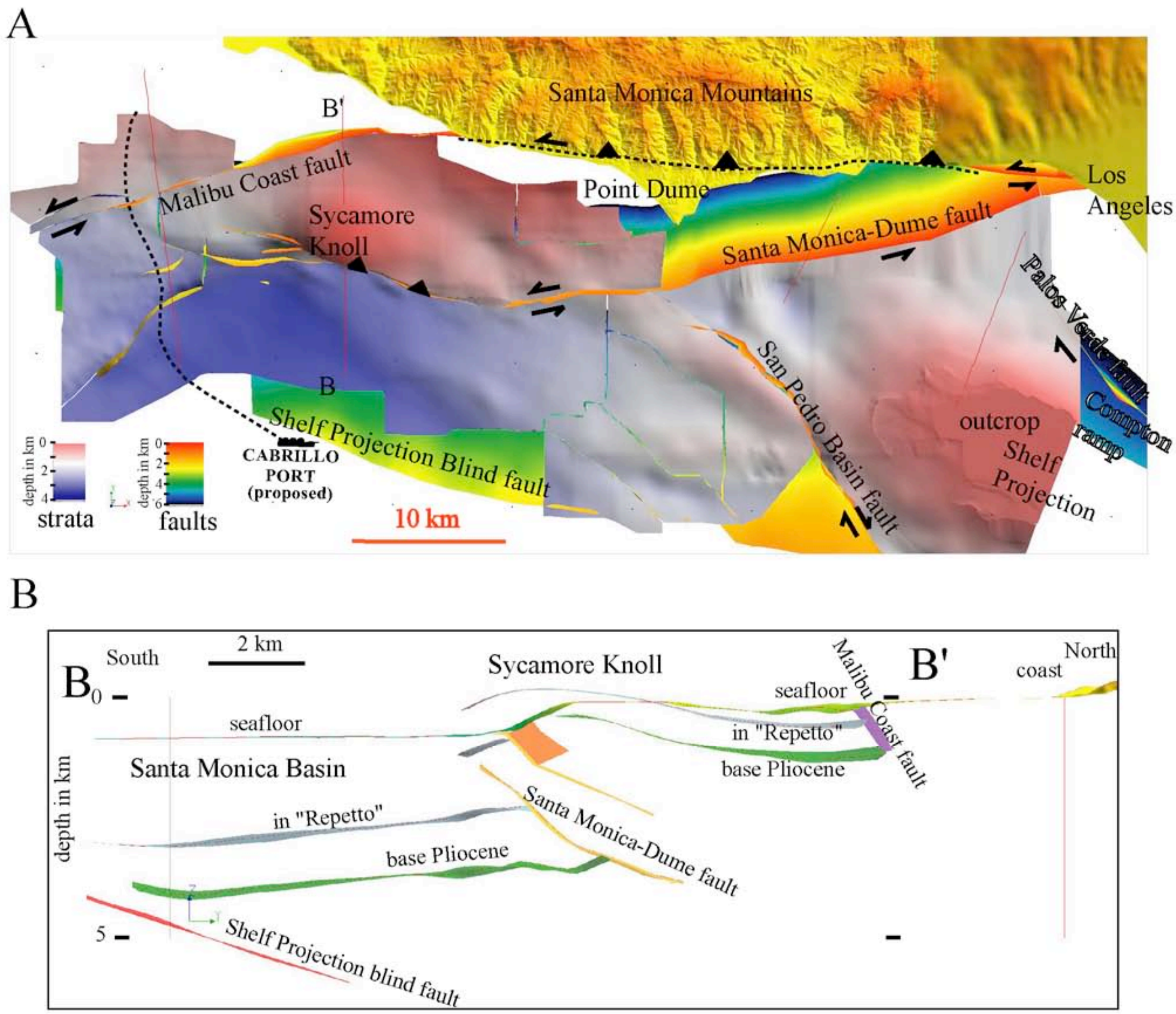

Figure BWG-1. a) Map view of offshore stratigraphic horizons and active offshore faults in the Santa Monica Bay area (*Sorlien et al.*, 2004a). Depth of "strata" and "faults" given by legends in lower left. A ~4 Ma horizon was mapped west of the San Pedro Basin fault and the base Pliocene was mapped east of that fault. Seafloor is shown in an area of Miocene outcrop along the Shelf Projection-Palos Verdes anticlinorium (red area in lower right). Compton ramp and other faults at east edge of figure are from SCEC Community Fault Model. Preferred location of a planned floating liquefied natural gas terminal (Cabrillo Port), along with its pipeline route towards shore, is shown. b) Depth cross section along B-B' through gOcad model of 3D fault surfaces and stratigraphic reference horizons. The three north-dipping faults shown all converge downdip towards the hypocenter of the 1973 Pt. Mugu earthquake. Middle and late Miocene strata are largely missing beneath base Pliocene in Santa Monica basin, consistent with the footwall of the Santa Monica-Dume fault being high-standing during Miocene extension. Sycamore Knoll is an inverted Miocene basin above the active Santa-Monica Dume fault.

Fault Information System (FIS)

New Databases and Integration of Existing Databases Within the SCEC Fault Information System

The SCEC Fault Information System (FIS) was established as a clearinghouse for fault related data and models, enabling users to discover and acquire products of interest. In 2004, its mission evolved to include prototyping for a national FIS. This year, principal FIS projects have been the development of the SCEC Reference Geologic Fault Parameter database (Ref Db), and the forging of an ever-stronger alliance with the USGS-Golden to provide users with the most complete and accurate data collections. The first data collection accessible via the FIS was the SCEC Fault Activity Database (FAD), which compiles published observational data in numeric fields keyed to faults, references, and study sites. The second data product is a cross-correlation of fault data and models that are available among the USGS National Quaternary Fault and Fold Database (NQFFD), the FAD, the input parameters to the 2002 and 1996 USGS National Seismic Hazard Maps, and fault representations in SCEC's Community Fault Model (CFM). We are working with the NQFFD to make the FAD numeric entries available to users of the comprehensive text commentaries of the NQFFD. Concurrently, we are working with the CA Geological Survey, which is tasked with the CA portion of the NQFFD, to develop a database maintenance procedure so that researchers may add their latest data, using a form adapted from the FAD Web submission form.

Once FAD and NQFFD data came on line in 2003, the gaps and variation among published data made it clear that best, current, expert opinion was still needed to provide modelers with complete and consistent input data. In order to establish the next generation of consensus data, the Ref Db will take as a starting point the input parameters to the 2002 USGS National Seismic Hazard maps, then augment the data and data fields using the latest understanding of SCEC field geologists. The first user will be the SCEC – Earthquake Rupture Forecast (ERF), which started within the Regional Earthquake Likelihood Models (RELM) project but may now be expanded to a statewide rupture forecast. Eventually, the Ref Db will be administered with a collection of fault related databases at the USGS-Golden, and available for the next generation of National Seismic Hazard Maps.

Southern California Integrated GPS Network (SCIGN)

SCEC has served as the managing organization of SCIGN since 1996. The network was completed in 2001 and we have been actively pursuing a long-term strategy for the maintenance of the SCIGN network and the archiving and availability of the data for basic and applied research applications. In 2004, a long-term strategy was developed by SCEC/SCIGN in collaboration with UNAVCO/PBO and other western US geodetic networks.

The plan will include the transfer of maintenance of 125 SCIGN stations to UNAVCO/PBO by 2007. The USGS will continue to maintain 95 stations in the array from its Pasadena office. The remaining 30+ stations will be maintained by UCSD through funding provided by the California Spatial Reference Center (CSRC) and by local county surveying agencies in Orange, Riverside, and San Diego counties.

SOPAC (Scrips Orbit and Permanent Array Center at UCSD) provides ongoing infrastructure support for geodetic studies of crustal deformation in southern California under the umbrella of SCIGN. They have responsibility for archiving SCIGN GPS data and data products, parallel responsibility (with JPL) for generating daily position time series, and responsibility for maintaining 20% of SCIGN sites (the other 80% maintained by the USGS). We highlight 2004 highlights in the areas of archive, web applications and cyberinfrastructure, fieldwork, and data gathering and analysis at SOPAC.

Archive

- Retrieval of data from the SOPAC archive, including SCIGN data, continued to increase. In 2003, about 20M files were transferred by ftp (about 90% of the transfers were RINEX files). Of these, more than 3M were SCIGN data files. Up to the end of October, more than 18.2M files have been retrieved in 2004. In 2003, we identified about 2300 unique host addresses and 52 client domains retrieving SCIGN data. More extensive statistics can be found on the SOPAC homepage (http://sopac.ucsd.edu).
- Archived on-line 1 Hz raw receiver data (and instantaneous positions) from 40 SCIGN stations (see ftp/http://garner.ucsd.edu/pub/highrate/). In terms of storage requirements this is equivalent to 1200 sites at a 30 s sampling rate. Real-time data streams through TCP/IP are available for all stations except the 13-station Parkfield network, which does not have a fast Internet link. Latency of the data streams is a fraction of a second on a wired connection and 1-2 s for cellular modem connections used by surveyors and others for network RTK.
- Connected a redundant 1GB fiber link between SOPAC’s computer room and SIO's network switch. The SCIGN archive is now only three hops from the Internet and has two separate gigabit wide area connections to the outside world, providing redundancy and increased bandwidth.

Web Applications and Cyberinfrastructure

- SOPAC developed an XML for Geodesy webpage and completed the schema definition for site log metadata (see http://sopac.ucsd.edu/projects/xml/).
- Initiated participation in the five-year NASA REASoN project “GPS Products for the Solid Earth Sciences.” SOPAC’s primary responsibilities are to design, develop, and implement the

SCIGN cyberinfrastructure, including redesign of the SCIGN web page (http://reason.scign.org), and participate in the production of higher-level data products.

- Improved the design and utility of the SOPAC Online Map Interface (SOMI) (http://sopac.ucsd.edu/maps/). We added a query and export feature and a velocity toolbox to display velocity vectors in various reference frames.
- Created a new Java based application to view coordinate time series (http://sopac.ucsd.edu/cgi-bin/refinedJavaTimeSeries.cgi). The oldest time series now span nearly 14 years.
- Enhanced the SECTOR application http://sopac.ucsd.edu/processing/coordinates/ for determining epoch ITRF coordinates.

Field Work

- Upgraded SCIGN stations in four southern California counties (Imperial, Orange, Riverside and San Diego) and the Parkfield Network to real-time (<1 sec latency) high-rate (1 Hz) operations to support traditional geodetic, as well as seismic applications (see next section). There are now 40 upgraded stations with the distribution as follows: Parkfield Network (14), Imperial County (5), Orange County (10), Riverside County (8), San Diego County (3), and all remaining SCIGN sites in the four counties are in the active upgrade queue (. In the Parkfield network and Orange County we've installed a dedicated radio communications network. In Imperial, Riverside, and San Diego Counties we are using UCSD's HPWREN communications backbone and ROADNet infrastructure, and the backbone of the three counties and the Metropolitan Water District of Southern California (MWD). See a map of upgraded stations at http://sopac.ucsd.edu/cgi-bin/somi3i?cx=-117.6&cy=32.3&scale=7000000&file=master.map.

Data Gathering and Analysis

- Computed, analyzed (and archived) instantaneous relative positions (*Bock et al*., 2000) for 40 SCIGN stations (http://garner.ucsd.edu/pub/highrate/cache/solutions/).
- Recorded teleseismic waves from the 3 November 2002 Mw 7.9 Denali fault earthquake with 1 Hz data from the Orange County Real Time Network (*Bock et al*., 2004). Our experience with the Denali fault earthquake confirmed the detection of seismic waves by *Nikolaidis et al.* [2001] based on 30 s SCIGN data collected during the 1999 Hector Mine earthquake.
- Recorded the 22 December 2003 Mw 6.5 San Simeon earthquake with 1 Hz data from the Parkfield network. The closest site to the earthquake was CRBT (35 km away). These data were used to detect seismic motion and model fault slip (*Hardebeck et al*., 2004; *Ji et al*., 2004).
- Characterized the errors in instantaneous positions and the sensitivity to the detection of fault slip and seismic displacements (*Langbein and Bock*, 2004).
- Characterized signal and noise in daily coordinate time series (*Williams et al*., 2004).
- Recorded 1 Hz data for the 28 September 2004 Mw 6.0 Parkfield earthquake.
- Published a global plate motion model (Prawirodirdjo and Bock, 2004) and updated this model once per month (http://sopac.ucsd.edu/cgi-bin/poleRotationValues.cgi).

SCIGN Network Coordinator Report

Real Time

SCIGN is currently upgrading stations to real time high rate data collection in partnership with county and city agencies. The Los Angeles City Surveyor, the Port of Los Angeles and Metropolitan Water District have agreed to fund upgrades of 9 SCIGN stations to support real time data streaming back to the US Geological Survey office. Their contribution will be used to purchase hardware for SCIGN stations and to fund continued development of SCIGN real time software. Also, the US Geological Survey will leverage these contracts to upgrade several other stations in SCIGN in the Los Angeles basin and surrounding areas.

Site Status

The extremely durable building procedures used in SCIGN have given the stations extreme longevity and little troubles with much of the equipment. Failures in equipment boxes and other metallic parts have been most notable in sites in the Channel Islands. Also, the Ashtech Z12 receivers currently used in SCIGN are againg and we have noticed an increase rate of receiver failures. We have sent all of our receivers for repair by the manufacturer before the official end-of-life date for the equipment. From this point on, none of the Z12 receivers will be repairable.

Most of the problems with the stations have centered around communication issues such as phone lines or radio problems. We have been aggressive in trying to remove phone line telemetry within SCIGN and work with our stations hosts to use existing ethernet telemetry or to install more reliable radio telemetry. The majority of the SCIGN stations have little to no problems and the majority of the stations with problems we are able to repair quickly and completely.

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) served 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's tradition of community service continued in 2004, playing the key role in four important meetings/workshops. First, SCEC hosted the annual meeting of the Seismological Society of America in April 2004 in Palm Springs, CA. This meeting was attended by 385 seismologists from around the world and served as an important outreach effort for our center. SCEC organized and hosted the Pacific Natural Hazards Laboratory Workshop in Maui in May. This workshop brought together scientists from countries around the North Pacific Rim to discuss mutual interests and collaboration in natural hazards. SCEC coordinated the participation of the 30 US scientists in the 2004 ACES workshop and field trips in China in July. Finally, in the continuing effort to organize the SAR community and convince the US government of the need for an InSAR mission (the 4th leg of EarthScope), SCEC organized and hosted an international InSAR science workshop (attended by 225 scientists) in Oxnard, California in October 2004.

SCEC assisted the community in three other activities in 2004. We hosted a meeting of the NSF Cyber Infrastructure Committee in February, co-hosted (with the USGS) the US/Japan Natural Resource Council Meeting in October, and helped organize several symposia at the December, 2004 AGU Meeting in honor of SCEC's first Director, Kei Aki. Aki received the highest honor of AGU in 2004, the Bowie Medal.

We hosted several workshops addressing center research activities. Individual reports on those workshops follow. All center workshops are open to all interested scientists.

SCEC 3nd Annual Crustal Deformation Modeling Workshop
Los Alamos National Laboratory, August 16-18, 2004

The Crustal Deformation Modeling subset of the Fault Systems Working Group is putting together a Community Finite Element Modeling (FEM) package for studies of crustal deformation in Southern California. Carl Gable, Brad Hager, and Mark Simons organized the third annual "Workshop on Community Finite Element Models for Fault Systems and Tectonic Studies," a three-day workshop which took place August 16 - 18 at Los Alamos National Laboratory (LANL). The purpose of the workshop was to serve as a venue to discuss progress in numerical modeling of lithospheric deformation, benchmark existing codes, and define the challenges that need to be met for future software development. Particular attention was placed on issues associated with meshing of complex domains, solution methods well adapted to MPI environments, and to the definition of rigorous benchmarks. Daily activities were partitioned between formal presentations/discussions and informal time for hands-on tinkering with codes. Partial financial support was provided by SCEC, LANL IGPP, NSF EarthScope, and NASA. 30 scientists from 12 universities, the USGS, JPL, Los Alamos National Laboratory, and Sandia National Laboratory participated in the workshop. The agenda, participant list, and group mission statement, are appended. Web site: http://geoweb.mit.edu/fe

Los Alamos National Laboratory was chosen to as the locale in order to enable SCEC scientists to benefit from attendance by Lab experts, particularly those with expertise in meshing. The workshop also introduced SCEC Fault Systems efforts to LANL physics/computational groups, sowing the seeds for future collaborations. By leveraging SCEC, NSF EarthScope, NASA, and LANL support, we were able to increase the number of students and senior researchers attending. Because members of the NASA-sponsored Quakesim group participated in the workshop, there was significant interchange of ideas and codes. Part of the group effort is aimed at verifying code accuracy, so significant effort was spent on refining the preliminary benchmark problems that were developed at last year's workshop. Efficient and accurate meshing of complex geologic structures is a very high priority, and meshing tutorials from scientists from LANL (LaGriT) and Sandia (Cubit) were very informative.

This workshop had a "hands-on" emphasis. The goals of the workshop were 1) to leave the workshop knowing how to do more with basic tools than before the workshop; 2) to use Southern California and Benchmarks as convenient and important examples for developing the next generation of crustal deformation modeling tools; 3) to focus on the meshing problem, learning how to use LAGriT; and 4) to learning to use GeoFest and Lithomop - what does it take to get these up and running, what can they do, how can they be modified. The goals were met and the Community looks forward with enthusiasm to next year's workshop, where increasingly realistic problems will be tackled, including the Landers reference earthquake.

**2004 Workshop on Community Finite Element Models for
Fault Systems and Tectonic Studies**

Goals of the workshop

1) Leave the workshop knowing how to do more with basic tools than before the workshop – a hands on emphasis

2) Use Southern California and Benchmarks as convenient and important examples for developing the next generation of crustal deformation models

3) The meshing problem: From geology, to blocks, to meshes
   a. Understand the geologic model and influence its development
   b. Understand discretization requirements imposed by physics
   c. Understand discretization requirements imposed by software choices/options
   d. Understand pros/cons of different meshers

4) From meshes to physical models
   a. Learning to use a couple of codes: GeoFest and Lithomop + ????. What does it take to get these up and running, what can they do, how can they be modified

b. Other solvers (explicit codes?)

5) Progress on benchmark definition and obtaining of results

(Benchmark descriptions can be found at: www-gpsg.mit.edu/fe)

Fault Systems Crustal Deformation Working Group: Mission Statement

1) Build tools to understand the response to single earthquakes, and make geodetic comparisons, infer rheology, and constrain structures
2) Build tools to simulate fault system interaction, regional strain and stress field evolution. Produce results that would assist in the estimation or modeling of fault slip and constrain physics
3) Develop understanding of transient stress interaction among faults
4) Determine realistic predictions of geologic features (e.g., topography, fault slip)

Agenda
Monday

Morning

8:00-8:30 Coffee, Breakfast, LANL Badges

8:30-8:50 Welcome and logistics - Carl Gable

8:50-9:00 Terry Wallace – EES Div Director, Welcome to LANL

9:00-9:10 Statement of Goals and Directions for Workshop (Simons)

9:10-10:20 Introductions, everyone (~ 5 min) what science I do or plan to do, what tools I use or plan to use, and what I hope to get out of the workshop.

10:20-10:30 *Break*

10:30-12:00 Modeling Workflow, Panel (10 min / panel member) + Group Discussion

a) Conceptual Model (Fialko)
b) Geologic Characterization (Shaw)
c) Mesh Generation (Gable)
d) Available Solvers (Hager)
e) Conclusion, insight, return to (a) and iterate

Panel/Group discussion to talk about how we work now, what are the pros and cons, what are the bottlenecks in the process, what tools or infrastructure would increase our time spent in (e) and reduce the time and effort required for (a)-(d).

12:00-1:00 Lunch, LANL Cafeteria, reserved side room A

Afternoon

1:00-2:00 The SCEC CFM, CBM, and USR – what has been done, what is planned, and what the questions are for the FEM users. Includes discussion of the Mojave block model (Shaw & Plesch)

2:00-3:00 LaGriT example work through (Carl Gable)
BM5
MicroLA – issues
Mojave – Example

Same thing for Cubit

3:00-3:15 *Break*

3:15-4:15 Status of Benchmarks, why are they important (Hager)

4:15-5:15 Group Discussion, Logistics, Computer Set-up

Tuesday

Morning

Comparison of solvers, using mesh created (beforehand) for BM5. Install & run software.

8:00-8:30 Coffee, Breakfast

8:30-9:30 Geofest (Lyzenga and Parker)

9:30-10:30 Lithomop (Williams)

10:30-10:45 *Break*

10:45-12:00 Other solvers that are available for people to use (?)

12:00-1:00 Lunch, Hot Rocks Cafe

Afternoon

Hands on experience meshing

1:00-1:30 Bleeding Edge Scientific Computing at LANL (White)

1:30-2:30 Hands on meshing of BM5

2:30-2:45 *Break*

2:45-4:30 Realistic example – meshing part of Mojave block model

6:30 Dinner at the Cayote Café in Santa Fe

Wednesday

Morning

8:30-9:00 Current developments with an explicit code (SNAC) with application to crustal deformation problems– Mike Gurnis

Hands on experience with Solvers and meshers – individual choice
Suggested problems: Benchmarks, Mojave

Afternoon

Continued work on problems: meshing, running codes, benchmarks

Late afternoon

Benchmark discussion; status of meshing; plans for next year

Table 1: 42 Registered Attendees (as of August 12, 2004) (* students or post-docs)

Caltech: Christopher DiCaprio*, Michael Gurnis, Ravi V.S. Kanda*, Mark Simons
Harvard University: Andreas Plesch, John H. Shaw
MIT: Lori Eich*, Bradford Hager, Eric Hetland*
Purdue University: Andy Freed
Rensselaer Polytechnic Institute: Charles Williams
University of British Columbia: Elizabeth Harding Hearn
UC Berkeley: Frederique Rolandone*
UC Los Angeles: Peter Bird, David D. Jackson
UC San Diego: Yuri Fialko, Bridget Smith*
University of California, Santa Barbara: Shuo Ma*
University of Kentucky: Shelley Kenner
University of Miami: Peter C. La Femina*, Rocco Malservisi, Gina Schmaizle*
University of Oregon: Noah Fay*
University of Southern California: Boris Kaus, Philip Maechling
Woods Hole Oceanographic Institution: Laurent Montesi
LANL: Christopher R. Bradley, Mingjie Chen*, David Coblentz, Svyatsky Davill, William R. Dearholt, Wesley G. Estill, Carl W. Gable, Andrew Newman, Bryan Travis
JPL: Gregory A. Lyzenga, Jay Parker
USGS: Brad Aagaard, Michael Barall, Oliver Boyd, Fred Pollitz, William Z. Savage, Robert L. Wesson

A Collaborative Project:
3D Rupture Dynamics, Validation of the Numerical Simulation Method
Coordinating Principal Investigator:
Ruth Harris (USGS)
Co-Principal Investigators:
Ralph Archuleta (UCSB)
Brad Aagaard (USGS)
Dudley Joe Andrews (USGS)
Steven Day (SDSU)
Eric Dunham (UCSB)
Nadia Lapusta (Caltech)
David Oglesby (UCR)
Kim Olsen (SDSU)
Arben Pitarka (URS)
Allan Rubin/Jean Paul Ampuero (Princeton)

AND FOR

3D Rupture Dynamics Code Validation 2004 Workshop
Co-Principal Investigators:
Ruth Harris (USGS) and Ralph Archuleta (UCSB)

This progress report is for the collaborative spontaneous-rupture-dynamics code validation exercise, and for the related two workshops that were held on September 19, 2004 and November 8, 2004. In 2004 the code-validation efforts were funded in 2 separate proposals, 1 proposal for the workshop(s), and 1 proposal for modeler salary support (mostly to support the students/postdocs). In 2004, 16 SCEC researchers numerically simulated earthquakes in the code-validation exercise, including the 7 SCEC-funded Principal Investigators, the 3 USGS Principal Investigators, 1 SCEC-institution visiting researcher from Japan, 2 SCEC institution postdocs, and 4 SCEC institution students.

The benchmarks tackled in 2004 were 3D simulations of spontaneous rupture propagation on a vertical strike-slip fault in a homogeneous medium. This simple scenario was the basis of our comparisons since it enabled the most types of codes (finite-difference, finite-element, boundary integral, spectral-element) to be included. Future efforts, with more complex parameterizations, will only be doable by a subset of these methodologies. In 2004 we tackled two benchmarks, The Problem, Version 2 (TPV2), and The Problem, Version 3 (TPV3). TPV2 is a slight modification of the instantaneous-nucleation The Problem, Version 1, that was simulated for the November 2003 SCEC workshop. TPV2 is the case of spontaneous rupture following slip-weakening nucleation on a vertical strike-slip fault in a homogeneous half-space (see figure 1). The objective was for each SCEC researcher's code to produce matching synthetic seismograms both on the synthetic earth's surface and at depth on the fault plane, in addition to matching rupture behavior. TPV3 (see figure 2) is a slight modification of TPV2 in that it has the same parameters as TPV2, except that it occurs in a fullspace rather than in the halfspace of TPV2.

During the summer and fall of 2004, 6 new codes came to the table and were implemented to tackle the benchmarks. These included the Boundary Integral code by Nadia Lapusta (TPV2 and TPV3), the spectral-element code by Jean-Paul Ampuero (TPV2), a discrete element code by Steve Day's postdoc Luis Dalguer, (TPV2 and TPV3), a finite-difference code by visiting Japanese researcher Yuko Kase (TPV2 and TPV3), and 2 variations of a boundary integral code by Eric Dunham (TPV3).

A discovery during 2004 is that the "fat fault" formulations may not lead to the same results as the "thin fault" or split-node fault approximations used by most of the other codes. Tests are being performed by Luis Dalguer to determine if there is a possibility of convergence between the "fat" and "thin" fault approximations if the nodes in the "fat fault" are brought close together, relative to the rest of the node spacing in the finite-difference grids. In 2005 we hope to arrive at convergence on this issue since otherwise it appears that the 2 types of codes produce divergent results, and thereby different synthetic seismograms.

During the September 2004 workshop we observed that many of the split-node codes are producing similar results, at least for the simple vertical strike-slip fault case of The Problem, Version 2. At our November 2004 workshop we compared our findings of the fullspace case (TPV3) with those of "rigorous" BIM simulations (the code of Nadia Lapusta), and also tested the effect of different node-spacings/element-sizes in the models. At the November workshop we found that for 100 m element-size/node-spacing, many of the codes agreed, whereas for coarser element-size/node-spacing, there was less of a convergence. It was decided that the differences might be due to how the element-size/node-spacings related to the slip-weakening breakdown distance, but this issue was not fully resolved.

During the September 2004 workshop Rasool Anooshehpoor and Jim Brune presented the Rasool/Matt/Jim results from foam rubber simulations that we were thinking of using as a validation exercise. (To this date we have been involved in comparison, rather than validation.) Discussion among the modelers and audience members at the September workshop proposed that our simulation of the foam rubber exercise might not be a new step forward for us since we would just be showing that we could match the Day and Ely [BSSA, 2002] studies of rupture in foam rubber, thereby demonstrating that we could match Steve's code's simulations of rupture. This discussion did move forward to the possibility that perhaps we could instead compare our simulations with new lab experiments on dynamic rupture in rock, such as is currently being undertaken by the Beeler/Junger/Tullis group. We will consider this issue further in 2005, including discussion with the SCEC ground motions and implementation interface groups about which would be our optimal validation test.

Part of the November 2004 workshop also consisted of discussion of FY05 problems to tackle (discussed in detail in the FY05 collaborative and workshop proposals). These will include rupture of an asperity away from the nucleation zone, a topic of specific interest to the ground motion modelers, and rupture of a weak patch. We also plan to tackle the sub-shear to supershear transition, to understand its physics better and see if it looks the same in all of the codes. The subshear/supershear topic is under more discussion in the seismological community than in the past, now that supershear rupture has been clearly inferred for a number of worldwide large earthquakes.

IT items that we plan to work on in 2005 include a better way to do the actual comparisons, and a place to host the simulations. Now that we have a large number of simulations being performed (see Table 1), there needs to be a better way to compare the results, which are currently undertaken by the coordinating-PI (RAH). This topic will be investigated by one of our co-PI's in the collaborative proposal for FY05.

2004 SCEC Publications directly related to this SCEC collaborative exercise:

EOS Article:

Harris, R.A., and R.J. Archuleta, Earthquake Rupture Dynamics: Comparing the Numerical Simulation Methods, EOS, vol. 85, No. 34, page 321, August 24, 2004.

Abstract for 2004 Fall AGU meeting:

Harris, R.A., R. Archuleta, B. Aagaard, J. P. Ampuero, D.J. Andrews, L. Dalguer, S. Day, E. Dunham, G. Ely, Y. Kase, N. Lapusta, Y. Liu, S. Ma, D. Oglesby, K. Olsen, A. Pitarka, The Source Physics of Large Earthquakes – Validating Spontaneous Rupture Methods, AGU Fall 2004 abstracts meeting volume.

AGENDA

2004 SCEC 3D Rupture Dynamics Code Validation Workshop

Sunday September 19, 2004 at the SCEC Meeting Hotel in Palm Springs

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8:00-8:15	Coffee, etc.
8:20	**Workshop Introduction** (*Ruth Harris/ Ralph Archuleta*)
8:40-12:00	**Presentations explaining the codes**
8:40	*David Oglesby*
9:00	*Shuo Ma*
9:20	*Brad Aagaard*
9:40	*Jean Paul Ampuero*
10:00	Break
10:30	*Nadia Lapusta / Yi Liu*
10:50	*Arben Pitarka*
11:10	*Kim Olsen*
11:30	*Luis Dalguer/ Steve Day*
11:50	*Eric Dunham/ Morgan Page*
12:10 -1:30	Lunch
1:30-1:50	**Presentations explaining the codes**
1:30	*Yuko Kase*
1:50-2:10	**Presentation showing lab experiments to simulate**
1:50	*Rasool Anooshehpoor/Matt Purvance/Jim Brune*
2:10-3:00	**The Problem, Version 2 Comparisons** *(Ruth/Ralph)*
3:00-3:15	Break
3:15-4:30	**Group Discussion (Everyone)**

2004 SCEC 3D Rupture Dynamics Code Validation Workshop
Sunday September 19, 2004 at the SCEC Meeting Hotel in Palm Springs
<u>52 WORKSHOP ATTENDEES:</u>
Ruth Harris
Ralph Archuleta
Brad Aagaard
Jean-Paul Ampuero
Rasool Anooshehpoor
Annemarie Baltay
Yehuda Ben-Zion
Greg Beroza
Harsha Bhat
Jacobo Bielak
Julia Brinkman
Jim Brune
Susana Custodio
Luis Dalguer
Paul Davis
Steve Day
Derek Desens
Benchun Duan
Eric Dunham
Geoff Ely
Marcio Faerman
Karl Fuchs
Tom Heaton
Carlos Huerta-Lopez
Larry Hutchings
Tom Jordan
Yuko Kase
Nadia Lapusta
Daniel Lavallee
Guoqing Lin
Pengcheng Liu
Shuo Ma
Phil Maechling
Martin Mai
John McRaney
Bernard Minster
Thomas Morbitzer
David Oglesby
Kim Olsen
Morgan Page
Brandee Pierce
Arben Pitarka
Matt Purvance
Leonardo Ramirez-Guzman
Jim Rice
Zheqiang Shi
Seok Goo Song
Elizabeth Templeton
Terry Tullis
Jack Tung
Nicholas Vaughn
Michael Vredevoogd

AGENDA
2004 SCEC 3D Rupture Dynamics Code Validation Workshop
Monday November 8, 2004 at SCEC/USC

10:30 Workshop Introduction *(Ruth Harris/Ralph Archuleta)*

10:40-11:40 Presentations Explaining Codes
10:40 *Elizabeth Templeton*
11:00 *Leo Ramirez-Guzman*
11:20 *Geoff Ely*

11:40 Presentation Demonstrating new IT Visualization Tool
11:40 *Kim Olsen*

12:00-1:00 Lunch

1:00-2:15 The Problem, Version 3 Comparisons (*Ruth/Ralph*)

2:15-2:30 Break

2:30-4:30 Group Discussion, Plans for FY05 Proposal (*Everyone*)

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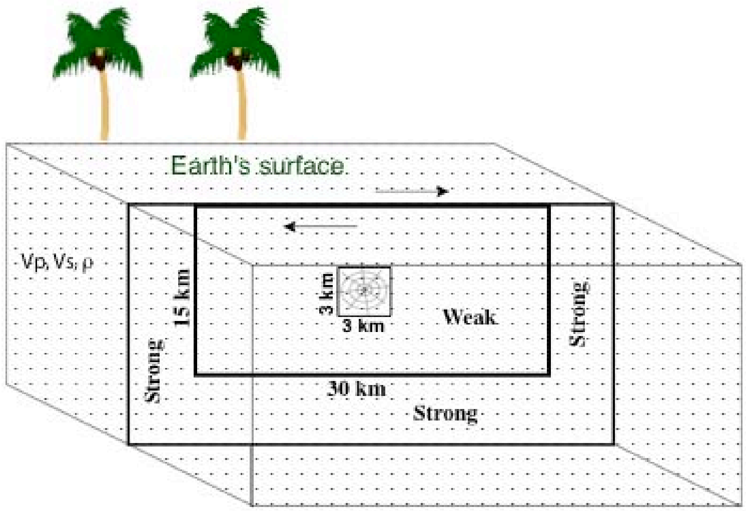
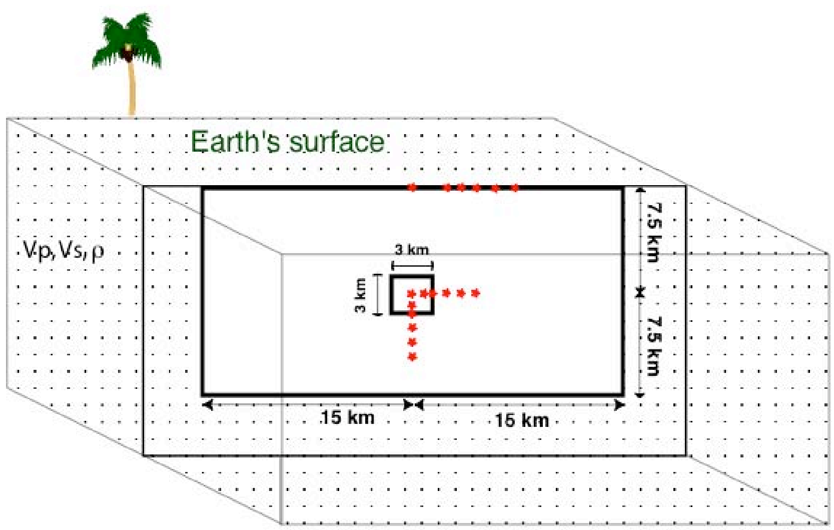
21 WORKSHOP ATTENDEES:

Ruth Harris
Ralph Archuleta
Brad Aagaard
Jean Paul Ampuero
Luis Dalguer
Steve Day
Eric Dunham
Geoff Ely
Yuko Kase
Nadia Lapusta
Daniel Lavallee
Pengcheng Liu
Yi Liu
Shuo Ma
David Oglesby
Kim Olsen
Morgan Page
Arben Pitarka
Leonardo Ramirez-Guzman
Otilio Rojas
Elizabeth Templeton

Figure 1a showing setting of The Problem, Version 2 (TPV2), the case of rupture on a vertical strike-slip fault in a homogeneous halfspace (top), and the locations of the stations for the synthetic seismograms (bottom).





Station Locations

Earth's surface: **epicenter,** **2.5, 3.5, 4.5, 6.0, 7.5 km along strike from the epicenter**

Deeper: **hypocenter, 1.0, 1.5, 2.5, 3.5, 4.5 km along-strike from the hypocenter,**

1.0, 1.5, 2.5, 3.5, 4.5 km down-dip from the hypocenter

Figure 1b showing physics for The Problem, Version 2 (TPV2)

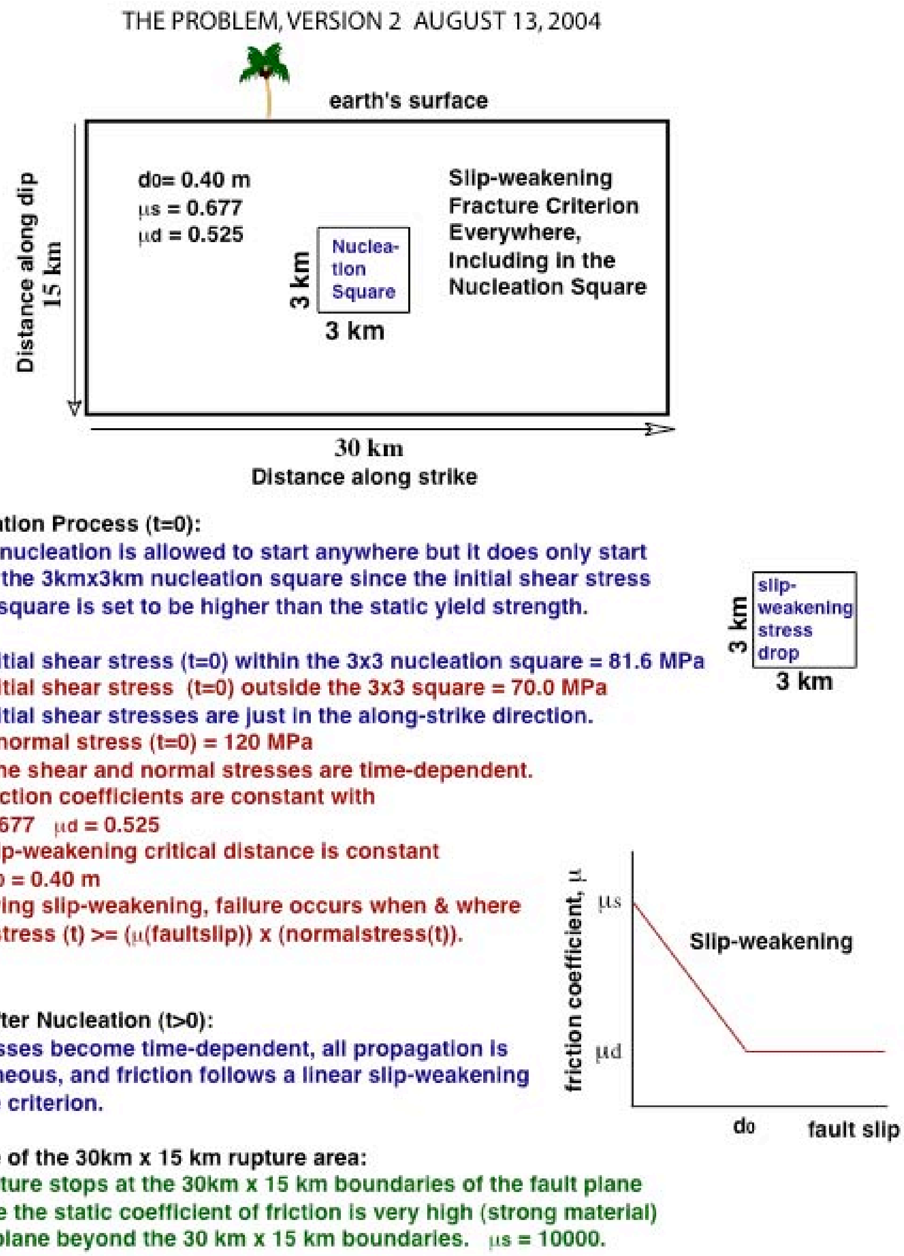


Figure 1c showing some results for The Problem, Version 2 (TPV2) at 1 station

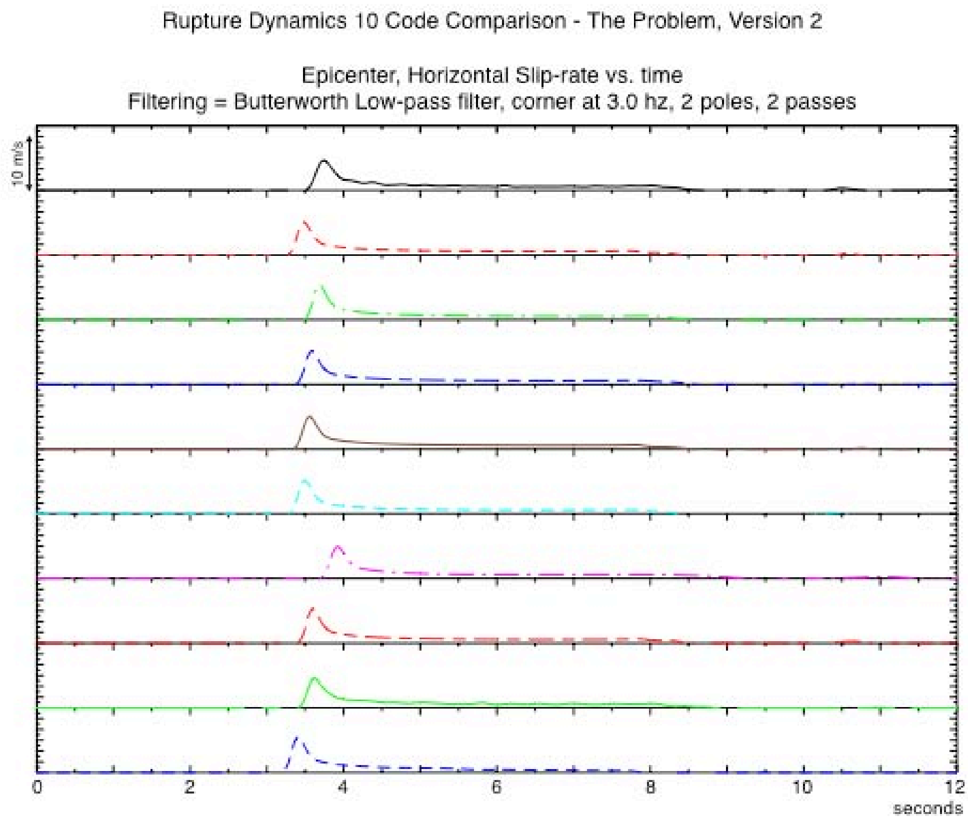
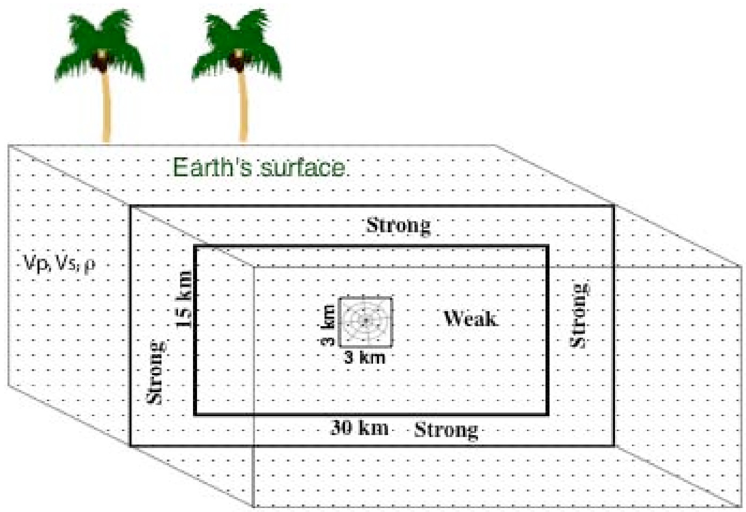


Figure 2a showing setting of The Problem, Version 3 (TPV3), the case of rupture on a vertical strike-slip fault in a homogeneous fullspace (top) and the locations of the stations for the synthetic seismograms (bottom).



10 Stations

0, 4.5, 7.5, and 12.0 km along-strike from the top center, 1.5 km down-dip from the top of the fault,
0, 4.5, 7.5, and 12.0 km along-strike from the top center, 7.5 km down-dip from the top of the fault,
0 km along-strike from the top center, 12.0 km down-dip from the top of the fault,
0 km along-strike from the top center, 13.5 km down-dip from the top of the fault

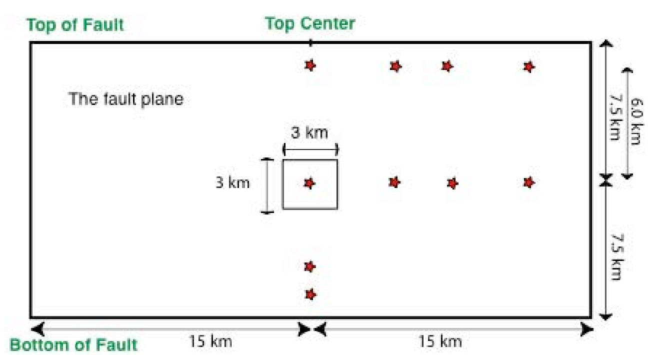


Figure 2b showing physics for The Problem, Version 3 (TPV3)

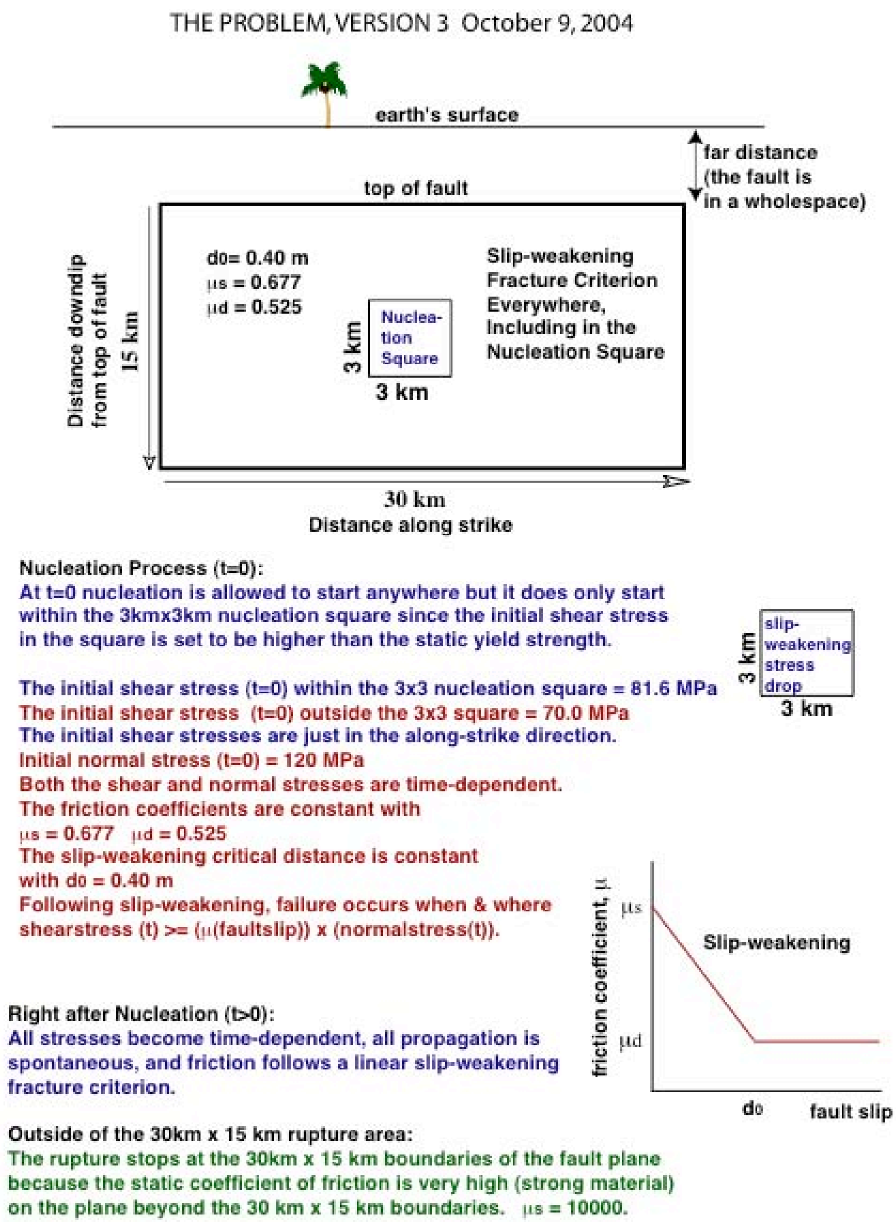


Figure 2c showing some results from The Problem, Version 3 (TPV3) at 1 station.

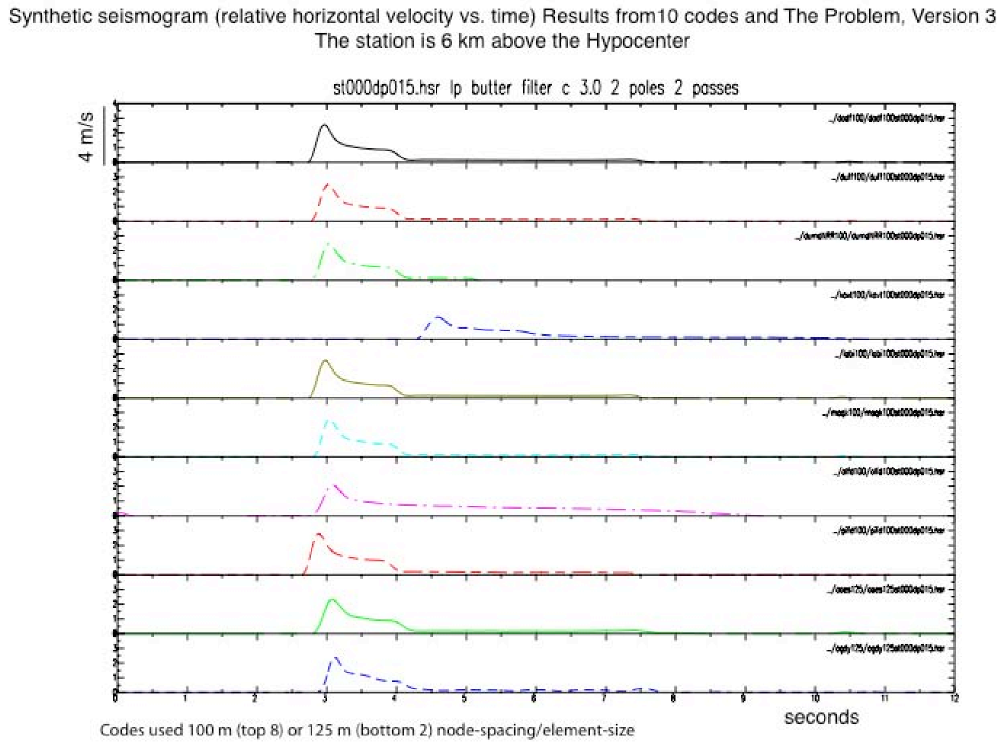


Table 1 showing the number of simulations done for The Problem, Version 3. Each calculation listed below was done for all of the stations depicted in Figure 2a.

The Problem, Version 3 Simulations (Oct. – Nov. 2004)

Code Abbreviation	Code User	Element/Node Spacing (m)	Code Description
labi	Lapusta/Liu	100	Lapusta Spectral Bounday Integral
		250	
		300	
maqk	Ma	100	Ma Finite Element
		250	
		300	
kavt	Kase	100	Kase Finite Difference
		250	
		300	
dadf	Dalguer	100	Day Finite Difference
		250	
		300	
duff	Dunham	100	Favreau Finite Difference No Rake Rotation
		150	
		300	
dumdNRR	Dunham	100	Dunham Spectral Bounday Integral No Rake Rotation
		150	
		300	
pifd	Pitarka	100	Pitarka Finite Difference Finite Fault Zone Width
		250	
		300	
olfd	Olsen	50	Olsen Finite Difference Finite Fault Zone Width
		100	
ogdy	Oglesby	125	Oglesby Finite Element
		167	
		250	
		300	
aaes	Aagaard	125	Aagaard Finite Element
		250	
		300	
lude	Dalguer	250	Dalguer Discrete Element Finite Fault Zone Width
		300	
dumdRR	Dunham	300	Dunham Spectral Bounday Integral Rake Rotation

2004 FARM WORKSHOP REPORT

Workshop on the Science, Status, and Future Needs of Experimental Rock Deformation

PI's: Terry E. Tullis, Brown University,
Thomas H. Jordan, University of Southern California
Robert C. Liebermann, SUNY, Stony Brook

SUMMARY

This was a workshop to assess the status of the field of experimental rock deformation and consider what actions might be taken to move the science and the field forward. Although it was originally conceived as a way to focus attention on possible needs for complex new experimental facilities to measure frictional resistance at seismic slip speeds, it became apparent that this could only be discussed in the context of the status and needs of the entire community. This scientific question was in fact listed as one of the most important by many of the participants, those working in the ductile field as well as the brittle field, but at least two other interesting and important questions that appear to require considerable apparatus design were also identified. The entire day and a half was taken up with discussion involving the whole group that was guided by the issues raised in the responses to an online questionnaire that all attendees were required to fill out prior to the conference. The workshop was very successful in beginning a dialog on important issues facing the field, and it is apparent that this workshop has started a discussion and process that are likely to lead to changes of many types that will be beneficial to the science, the scientists, and the infrastructure of the field as well as the many areas of earth and materials science that want and need results from this community.

Pre-workshop Publicity and Questionnaire

The announcement of the workshop and description of its purpose and logistics was made to the SCEC community, make available on the SCEC web site, and was widely circulated in the rock mechanics community, both to all those who had expressed interest in participating in the Rock Deformation Gordon Research Conference and the many people who receive email from the PPEM (Physical Properties of Earth Materials) committee affiliated with the Rock and Mineral Physics Committee of AGU.

Announcement

Third FARM Workshop:

Workshop on the Science, Status, and Future Needs of Experimental Rock Deformation

Terry Tullis, Brown University
Tom Jordan, SCEC
Robert Liebermann, COMPRES

Dates: August 13 and 14, 2004
Location: Mount Holyoke, Massachusetts, USA

The field of laboratory experimental rock deformation provides data that are critical to understanding earthquake mechanics, flow of the Earth's crust, and convection of the mantle. However, in all of these areas data are needed that are beyond the capabilities of present experimental equipment and laboratories. For example, it is not presently possible to conduct experiments that allow us to determine the mechanical behavior during coseismic slip on a crustal fault, during fluid-enhanced metamorphic reactions in the lower crust, or during high strain flow of high pressure phases in the deep mantle. In addition, the present way in which most data are collected, namely by isolated labs funded by modest grants to individual PIs, may not be capable of moving to the next generation of facilities that may be needed to answer the increasingly complex questions that the field is asking and being asked. The startup funds needed to establish a new lab are daunting, as is the cost of the technical personnel needed to keep a lab functioning. This means that few new labs are started by universities, the government, or industry, making it unclear what employment options exist for the next generation of scientists. In addition many of those responsible for running existing laboratories are approaching retirement age and it is not clear that these laboratories will continue when these people retire.

We will hold a one and half day workshop immediately following this year's Rock Deformation Gordon Conference to access 1) the scientific problems that a broad cross-section of the Earth science community feels are important and that may be addressable by laboratory experimental rock deformation studies, 2) the status of existing lab equipment and whether new equipment design and construction is needed to address the scientific questions, 3) the number and nature of existing personnel trained to conduct lab studies, the prospects for training future personnel, and the employment opportunities for existing and future personnel, and 4) whether existing organizational structures are adequate or new ones are needed to solve the scientific questions, run and create the necessary equipment, and employ the needed personnel. We have limited funds from both SCEC and COMPRES to support the incremental costs for attending this workshop by those who are already at the Gordon Conference, and to pay the travel and lodging expenses of any additional people who wish to attend. If you will not be attending the Gordon conference and decide that you need to rent a car from Logan airport, try to arrange to join with others in sharing the car to keep costs down.

The workshop itself will primarily consist of discussion, stimulated by a few carefully chosen presentations. The sessions will be organized around themes similar to those numbered 1-4 above as well as specialized breakouts on subdivisions of some of these, such as science questions focused on shallow crustal brittle deformation, deeper crustal flow, and mantle flow. In order to make the discussions at the workshop more efficient, there is a comprehensive web-based survey that participants are required to answer in order to have their workshop expenses covered. Others who are interested, but cannot attend the workshop, are strongly encouraged to respond to the survey. If possible, the survey should be filled out by July 20, and it must be filled out by workshop participants by August 1 if they wish to have their workshop expenses paid. Results of the responses will be available after July 20.

The workshop will start at 8:30 AM, Friday morning August 13, 2004 and end at noon on Saturday, August 14. Lodging will be in the rooms at Mount Holyoke used for the Gordon Conference. We hope to arrange bus transportation to Logan airport in Boston on Saturday afternoon. Registration for the workshop must be done on the workshop page at the SCEC website.

Web-based Survey

An extremely comprehensive questionnaire was prepared in consultation with some of the leaders of the Gordon Conference and of PPEM, was transferred to electronic form through the hard work of John Marquis at SCEC, and hosted on the SCEC website. The questionnaire will not be reproduced here due to its length, but is still available at the following URL: http://www.scec.org/workshops/WSSFNERD/. As it turned out it was more time consuming to convert the questionnaire to electronic form than anyone anticipated and as a result it was not possible to have it finished in time for everyone to fill it out completely and get the results summarized on the schedule anticipated in the above announcement. Nevertheless, John Marquis was able to create the tools necessary for the results in each category to be collected together and summarized, so the results of the questionnaire were extremely useful in guiding the discussions at the workshop. A summary of the survey results is attached as an Appendix to this report.

Detailed Agenda

Friday, August 13th

7:30 am - 8:30 am *Breakfast*

9:00 - 9:20 **Introduction and background**

Distribute compilations of responses to questionnaires
Origin of workshop idea
Brief description of SCEC and COMPRES

9:20 - 10:00 **Discussion of what we will do during the workshop and our objectives:**

Review suggestions from questionnaire on topics to discuss
Brief airing of people's concerns for our field and hopes for workshop
Do we want to add any to the distributed list?
Adoption of tentative schedule

10:00 - 10:30 *Coffee Break*

10:30 - 11:15 **Discussion of science problems**

Do we want to try to select a few as being "most important?"
Look over list from questionnaire

11:15 - 12:00 **Discussion of apparatus development**

What are the needs in order to solve scientific problems?
What are the barriers and possible solutions to overcoming them?

12:00 - 1:00 *Lunch*

1:30 - 2:15 **Discussion of future of existing labs**

Are they likely to continue when people retire?
Should they?
If so, what might be done to encourage their continuation?

2:15 - 3:00 **Discussion of opportunities for young scientists**

Is it a problem any more than for other fields?
What might be done to increase opportunities?

3:00 - 3:30 *Break*

3:30 - 4:15 **Discussion of connections to other communities**

Do other Earth science disciplines want our contributions?
Do we need to take a more active role in self-promotion?
If so, how can that be done?

4:15 - 5:00 **Discussion of funding**

Is it getting worse or better or no change?
Is it adequate?
If not, what can be done to increase it?

6:00 - 7:00 *Dinner*

Saturday, August 14th

Sat. 7:30 - 8:30 *Breakfast*

8:30 - 9:00 *Checkout*

9:00 - 10:00 **Organizational structures, USA and internationally**

Is cooperation adequate?
How might it be improved?

Are new structures needed to do the needed science, including building and running the machines?

10:00 - 10:30 *Coffee Break*

10:30 - 11:15 **Actions to consider**

What do we do next beside writing and distributing a report?

Can we use everything we gathered in the survey and how? Should more people be encouraged to fill it out? What do we do with it?

11:15- 12:00 **Revisit selected items**

Revisit topics on which we spent inadequate time

participants

Below is a list of the 36 participants and email addresses. A few others attended part of the time.

Name	Email address	Name	Email address
Boettcher, Margaret	mboettcher@whoi.edu	Liebermann, Robert	Robert.Liebermann@stonybrook.edu
Boroughs, Lydia	Lydia_Boroughs@brown.edu	Lockner, David	dlockner@usgs.gov
Cooper, Reid	Reid_Cooper@brown.edu	Milsch, Harald	hmilsch@ldeo.columbia.edu
Dresen, Georg	dre@gfz-potsdam.de	Mitchell, Tom	t.mitchell@liv.ac.uk
Durham, William	durham1@llnl.gov	Montesi, Laurent	lmontesi@whoi.edu
Faulkner, Dan	faulkner@liverpool.ac.uk	Muto, Jun	mutoh@mail.tains.tohoku.ac.jp
Fitzenz, Delphine	fitzenz@usgs.gov	Paterson, Mervyn	mervyn.paterson@anu.edu.au
Fountain, David	dfountai@nsf.gov	Renner, Joerg	renner@geophysik.ruhr-uni-bochum.de
Chester, Fred	chesterf@geo.tamu.edu	Rybecki, E.	UDDI@GFZ-POTSDAM.DE
Gratier, Jean-Pierre	Jean-Pierre.Gratier@obs.ujf-grenoble.fr	Skemer, Philip	philip.skemer@yale.edu
Green, Harry	harry.green@ucr.edu	Spiers, Chris	cspiers@geo.uu.nl
Heilbronner, Renee	renee.heilbronner@unibas.ch	Stipp, Michael	michael.stipp@geologie.uni-freiburg.de
Hirth, Greg	ghirth@whoi.edu	Tullis, Terry	Terry_Tullis@brown.edu
Holyoke, Caleb	Caleb_Holyoke_III@brown.edu	Wang, Yanbin	wang@cars.uchicago.edu
Jung, H.	hjung@citrus.ucr.edu	Weidner, David	dweidner@sunysb.edu
Karner, Stephen	karner@geo.tamu.edu	X. Xiao	xhxiao@mit.edu
Keulen, Nynke	nynke.keulen@unibas.ch	Zhou, Yongsheng	zhouysh@163bj.com
Kronenberg, Andreas	a-kronenberg@tamu.edu	Zhu, Wenlu	wzhu@whoi.edu

Summary of Results

This workshop has made and will continue to make a big difference in the experimental rock deformation community and the science it will do. It has gotten the community thinking and talking about some important issues that it faces, and there will be follow-up activities of many types. Although the workshop initially grew out of SCEC needs for more data on high velocity friction, it came at a time when many in the community were thinking that an assessment of many issues was needed. The issues include what the important science questions are, what new generations of laboratory equipment might be needed to answer them, what might be done to strengthen existing labs and create new ones so that the community has access to the facilities it needs, how to foster more cooperation among all the labs and workers so that the exiting facilities are used most effectively by many, and how to create more opportunities for employment as well as access to labs for young scientists.

An interesting development is that a number of international experimentalists attended, since the meeting occurred at the end of the Rock Deformation Gordon Conference. As a result of the discussions at the workshop, the very active European experimental community is going to have a similar workshop as part of one of their upcoming meetings in order to organize themselves for more collaborative interactions of the type we were discussing.

An interesting development is the beginning of an effort to catalog and publicize what equipment may no longer be needed by existing labs, for example when personnel and/or needs of their home institutions change, and what new locations might be found for this equipment, especially where young scientists are trying to set up new facilities.

Work is continuing among many in the community as we think about models of what might make sense for future organizational structures and laboratory facilities to promote improvements in the research climate for experimental rock deformation. The participants were universally enthusiastic about the workshop. All agreed that at least one more workshop, perhaps funded by NSF, is needed to further refine thinking on many of the topics discussed and to generate subsequent plans for how to implement some of the consensus recommendations that would emerge. The perspective and active participation of David Fountain from NSF was a very valuable contribution.

Workshop: Rationale for a
SCEC III Tectonophysics Focus Group

The over-riding objective of a Tectonophysics focus group in SCEC would be to use the geodynamical history of Southern California to infer the present day boundary conditions, inherited structures and rheologies that give rise to the surface deformation field, and the generation of earthquakes.

Under the section *Long-Term Research Goals* for the SCEC II Science Plan: '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 goals and key questions for basic research are summarized in these six problem areas.' The first area listed: Plate-Boundary Tectonics had as a ***'Long-Term Goal:*** To determine how the relative motion between 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:

1. 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? Why is plate motion being transferred to the Eastern California Shear Zone?
2. 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?
3. 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?
4. 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?
5. 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?

Central Product of the Working Group

A guiding theme for the Tectonophysics group will be the construction of a 3D geodynamical model for S. California that covers the last 30 Myrs. The initial state of the system will be inferred from geological reconstructions of the crust at 30 Ma. The evolution of the system with time has been estimated by several groups who have produced "movies" of the boundary as it evolves from subduction, to transtension, to its final transpression state. The movies will form the top boundary condition of the system. Estimating the current state of the system is goal of the Earthscope project, and we will use these results in the model. The challenge will be to find a model that can transform the system from an estimated initial condition, to an estimated final condition, subject to the surface boundary condition provided by the reconstruction movies.

A central product will give the group a focus in selecting specific projects to pursue both within SCEC itself and with external programs such as Earthscope and Continental Dynamics. The detail on the central product is:

(a) Products/Goals:
1) Community 3D tectonic reconstruction model (like other SCEC models)
2) 3D geology, viscosity, stress maps
3) development of shear zones over long time intervals (gouge width, damage zone, etc)
4) 4D geodynamical models

(b) Ingredients:
1) geology
2) topo/bathy
3) fault slip, rotation histories
4) basin volumes
5) paleo-strain
6) temperature/thermal history/water content
7) magmatic activity
8) density, viscosity, gravity, anisotropy, attenuation
9) global plate motions

(c) Reconstruction times:
1) pre 30 Ma state at post-Laramide
2) 30 Ma, collision
3) 20 micro-plate capture
4) 12 Ma Baja capture, triple junction
5) 6 Ma Opening of Gulf of Calif, SAF
6) 3 Ma NE shortening event
7) 1.5 Ma Pasadenan Orogeny, San Jacinto Fault
8) present

Table 1. Overview of the approach for the SCEC tectonophysics working group.

Timeliness

The stage has been set for SCEC to incorporate tectonophysics into its program. The NSF Earthscope initiative is clearly directed to supplying the observations necessary to determine the current state of the system. In particular, has started its seismic component in S. California by utilizing 35 stations from the Southern California Seismic Network and enhancing it with a few additional stations. The flexible array, consisting of 200 broadband portable stations, along with 2000 short-period stations will be available for focused studies. The geodetic component will build on the SCIGN network with XX additional sites, and will also include a few strainmeters. A SCEC-Earthscope workshop held in Oct, 2003 indicated a high-level of interest is utilizing the Earthscope project for the questions posed above. The key for success will be in integrating the efforts of many researchers together, and we are proposing the SCEC3 can provide that coordination.

The geophysics community has now adopted the idea of building dynamical models of tectonic systems. NSF has recently funded the CIG (Computational Infrastructure for Geophysics) initiative to provide the software to do this, and it is anticipated that this provide the impetus to model several plate boundaries. The key to making this work will be in building a good model, and in a sense, building this model is the next logical step beyond the velocity, fault and block models that were developed under SCEC II. The software developed under CIG is designed to run at multiple scales, which is ideal for the problem of coupling the short-term crustal process (such as earthquakes) to the longer-term driving forces of the system (such as would be the focus of the Tectonophysics group).

Workshops

In Oct, 2003, a SCEC sponsored workshop was held to develop a plan to respond to the Earthscope program that was starting in 2004. The consensus of that workshop was to develop a group within SCEC that would be the home for efforts to plan surveys under the Earthscope program that would benefit the earthquake and tectonophysics science in S. Calif. A special session at the 2004 Annual SCEC meeting reinforced this desire. In Nov, 2004, a workshop was held at Caltech to identify the main tectonophysics issues that need to be addressed in S. Calif. The participants at this workshops represented the overall community interested in the tectonics of S. Calif., and at least half of the attendees and speakers are not currently affiliated with SCEC. There was consensus on the science questions listed at the beginning.

Background (from the Nov. Workshop)

In order to model how the overall relative plate motion is accommodated we need to know how and where plate-like block motion makes the transition to distributed shear and how the shear is distributed across and within the margin. The model will need to describe the transition from undeforming Pacific plate lithosphere (e.g. the Patton escarpment) to undeforming North America lithosphere (Colorado Plateau) as well as the constitutive properties of the intervening region to depths in the mantle likely to be subjected to significant strain (200 km). The fact that constitutive properties are so highly dependent on temperature and water content persuades us that placing the geologic reconstructions in a physics-based model provides a useful framework for interpretation of present day data sets.

The southern California region has undergone a complex history, but considerable progress has been made in unraveling the major tectonic events that have shaped the geological structures and the rheology. Most of the effort has gone into reconstructing the surface geology. Jason Saleeby (Fig.1) describes the long-term history of the margin. He suggests an oceanic plateau collided with N America 80 Ma. and caused the subduction to be shallow, forcing the compression associated with the Laramide Orogeny. Then the slab broke off and rolled back pulling the Salinia-Mojave block outwards to eventually be captured by the Pacific plate and transported northwards. The resulting gap in the batholithic structures between the southern Sierra Nevada and the Peninsular Ranges is explained by this mechanism. The intervening region is an extended metamorphic core complex abutting oceanic lithosphere with accreted wedge material on top. Saleeby has suggested delamination of mantle lithosphere in the southern Sierras can explain xenolith properties and evolution of the geologic structures, a mirror image of the proposed delamination beneath the San Gabriels.

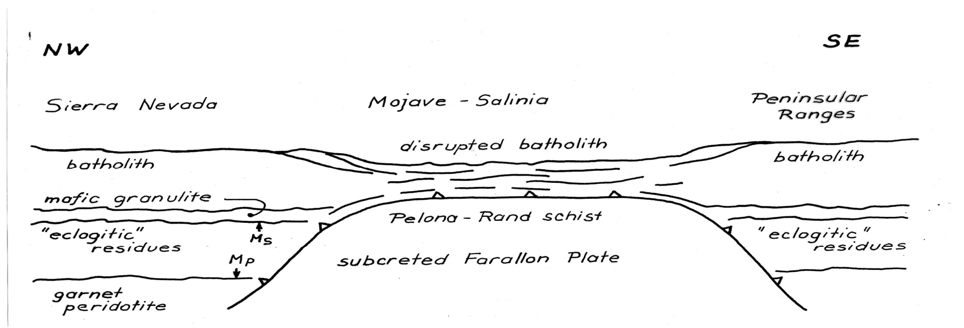


Fig. 1 After Saleeby. Major architecture of Southern California, north of the Peninsular Ranges.

Post-Laramide, the transition from a subduction boundary to the plate capture sequence (Fig.2) has been described by numerous authors largely from the UC Santa Barbara group (Atwater, 1970; 1989, Nicholson et al., 1997, Wilson, 2005 , Ingersoll and Rumelhart, 1999). At a recent (SCEC-sponsored) workshop the latest versions of these reconstructions were portrayed in several movies. Various strategies have been employed in the reconstructions, paleomagnetism, plate circuits, structure, rock-type associations, history of magmatism and affinity of volcanic products. There is general first order agreement on the history of events but as the details become more refined some differences remain. Of particular note is Wilson's (2005) model, based on volcanic products, that has a more extreme big bend in the past.

In terms of the geophysics, at about 30 Ma subduction ceased as a ridge collided with North America. Thus well-watered mantle wedge would have been underlain by young oceanic lithosphere. In the process of capturing plates (20 Ma) and rotation of the Transverse Ranges it has been hypothesized that offshore extension was so extreme that new ocean floor was generated (tenBrink et al., 2000). That and the regional volcanism suggest a slab window fed the volcanism. However there is some controversy as to what happened to the Farallon slab. Some interpretations have it accreted beneath the margin.

Others have it delaminating. While others suggest it continued downwards with the Farallon plate leaving a slab window.

As the margin has cooled the transform motion has moved further inland. Pre 12 Ma most motion was offshore as plates rotated. From about 12 to 6 Ma. the San Gabriel,-Cristianitos-Chino Hills faults were active and the margin became a pull-apart giving rise to the LA, and Ventura basins. At 6 Ma the transform motion has moved largely to the San Andreas and the margin became transpressive. The transpression thickened the crust forcing up the San Gabriels, and possibly caused the mantle lithosphere to thicken and delaminate. The current fault activity in the California shear zone is part of this inland-directed trend.

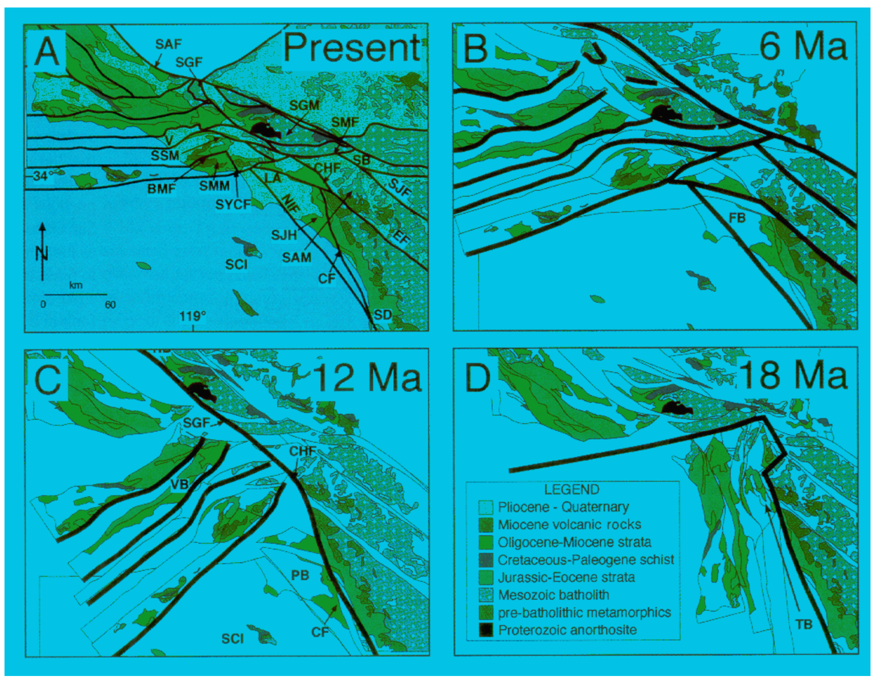


Fig. 2. After Ingersoll and Rumelhardt (1999) showing snapshots in geological time of reconstruction of the margin.

From a geophysical perspective this last transition has been subjected to most scrutiny. A high P-wave velocity anomaly (Fig.3) in the mantle to a depth of 200 km (Humphreys and Clayton 1988; Kohler, 2003) has been interpreted as delaminated lithopshere (drip), possibly accreted Farallon plate that became unstable (Kohler et al., Billen and Houseman 2002). Recent strong P-S conversions seen in receiver functions (Jamai and Clayton 2004) at a depth of 70 km supports this interpretation. Another option is that North American mantle lithosphere, on thickening, became unstable and sank (Fig.4) as a Rayleigh Taylor instability (Kohler, 1999; Kohler et al. 2003; Billen and Houseman 2002).

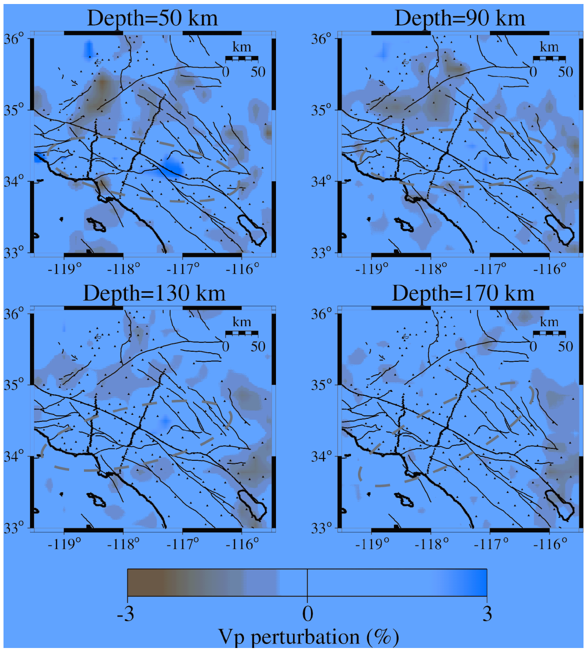


Fig 3. P-wave tomographic anomalies (after Kohler et al., 2003).

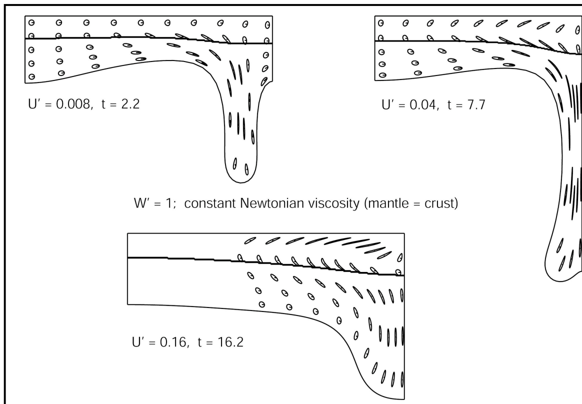


Fig. 4 After (Houseman et al., 2000) Theoretical mantle lithosphere (drip) instabilities under San Gabriel Mts.

The question then arises does the flow associated with the drip load the surface tectonics? Humphreys argues it does, but most models ignore its effect. The traction depends on the interpretation as to what it is, the flow geometry, and viscosities involved. The morphology of the high velocity zone under the transverse ranges shows that it appears to rotate anticlockwise with depth (Fig.3). This could be explained by Wilson's model of a bigger bend in the past or it may be due to flow in the mantle into which the anomalous material is sinking.

Teacher Workshop at the Visualization Center at Scripps Institution of Oceanography

Project Summary

SCEC funds were used to help offset the cost of our 2nd annual teacher workshop held on 11 August 2004 (see http://www.siovizcenter.ucsd.edu/workshop/index.html) at the Scripps Institution of Oceanography's Visualization Center (Figure 1; see Appendix A for the full workshop agenda). Thirty teachers signed up for this workshop, yet only fourteen attended due to last minute cancellations. Similar to the 2003 Teacher Workshop, the 2004 Workshop was a collaborative effort that included members from various sub-disciplines and seven institutions including:

- Southern California Earthquake Center (SCEC)
- U.S. Geological Survey (USGS)
- Scripps Institution of Oceanography's (SIO)
- Institute of Geophysics and Planetary Physics (IGPP)
- San Diego State University (SDSU).
- Birch Aquarium at Scripps (BAS)
- San Diego Supercomputer Center (SDSC)

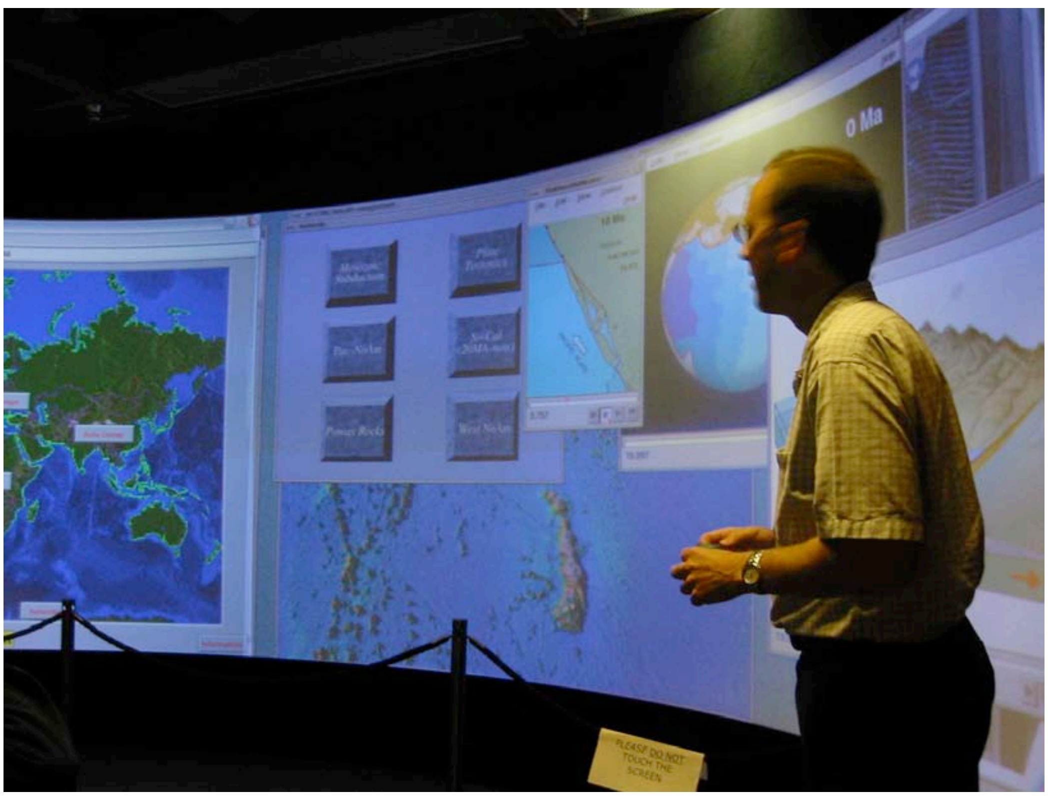


Figure 1. 2004 Teacher Workshop at the Scripps Institution of Oceanography's Visualization Center. Demonstrating some of the downloadable quick time movies Dr. Robert Mellors (SDSU) made us of the wall sized screen in the SIO Visualization center to simultaneously show multiple movies and how one can move from a large scale (global) to a small scale (local to the San Diego region). Jokingly, Dr. Mellors noted: location, location, location.

The SIO 2004 workshop differed from the 2003 workshop in that we included: an Earthquakes 101 lecture by Illene Cooper (SCEC), inclusion of information on the upcoming *Earthquake: Life on a restless planet* exhibit at the Birch Aquarium at Scripps (BAS), and, thanks to Robert DeGroot (SCEC) we were able to provide take-home street maps of the San Diego region that could be used to highlight local faults (Figure 2).

Figure 2. Pens, pencils and marking tools were on hand so that the teachers could immediately jot down important facts, highlight fault traces and jot down noteworthy information during the workshop on provided maps and handouts.

The teaching tools that we introduced at the 2004 SIO workshop included QuickTime movies, which can either be downloaded to local computers or displayed directly over the internet, as well as iView3-D 'scene files.' These 3-D interactive 'scene files' can be viewed using the freeware program iView3-D (http://www.ivs.unb.ca/products/iview3d/). This software runs on multiple platforms (Windows NT, Mac OSX, SGI, Sun, PC Windows2000 and PC Linux), and is easy to use and install (installation time is typically 5-10 minutes).

Additional Photos From the 2004 SIO Teacher Workshop can be Found at: http://www.siovizcenter.ucsd.edu/workshop/TW04/TW04.html.

1.0 The 2004 Teacher Workshop at SIO

One goal of the 2004 Teacher Workshop at the SIO Visualization Center was to help serve the needs of teachers in the San Diego region in their professional development. This workshop empowered teachers with the appropriate Earth science background to teach Earth Science in ways that were engaging and effective. Furthermore, the teachers gained pedagogical skills and resources required to convey concepts that are inherently 3-D in nature in ways that can be internalized by students. This expanded the teachers current repertoire of limited 2-D representations (map or cross sectional views) of concepts like fault plans and subduction zones to include 3-D interactive visualizations using current-day data that can be manipulated and viewed interactively (Figure 3). This provided the much needed content knowledge for K-12 Earth Science teachers and introduced teachers, and in turn their students, to freeware 3-D technological tools for use at home and in the classroom.

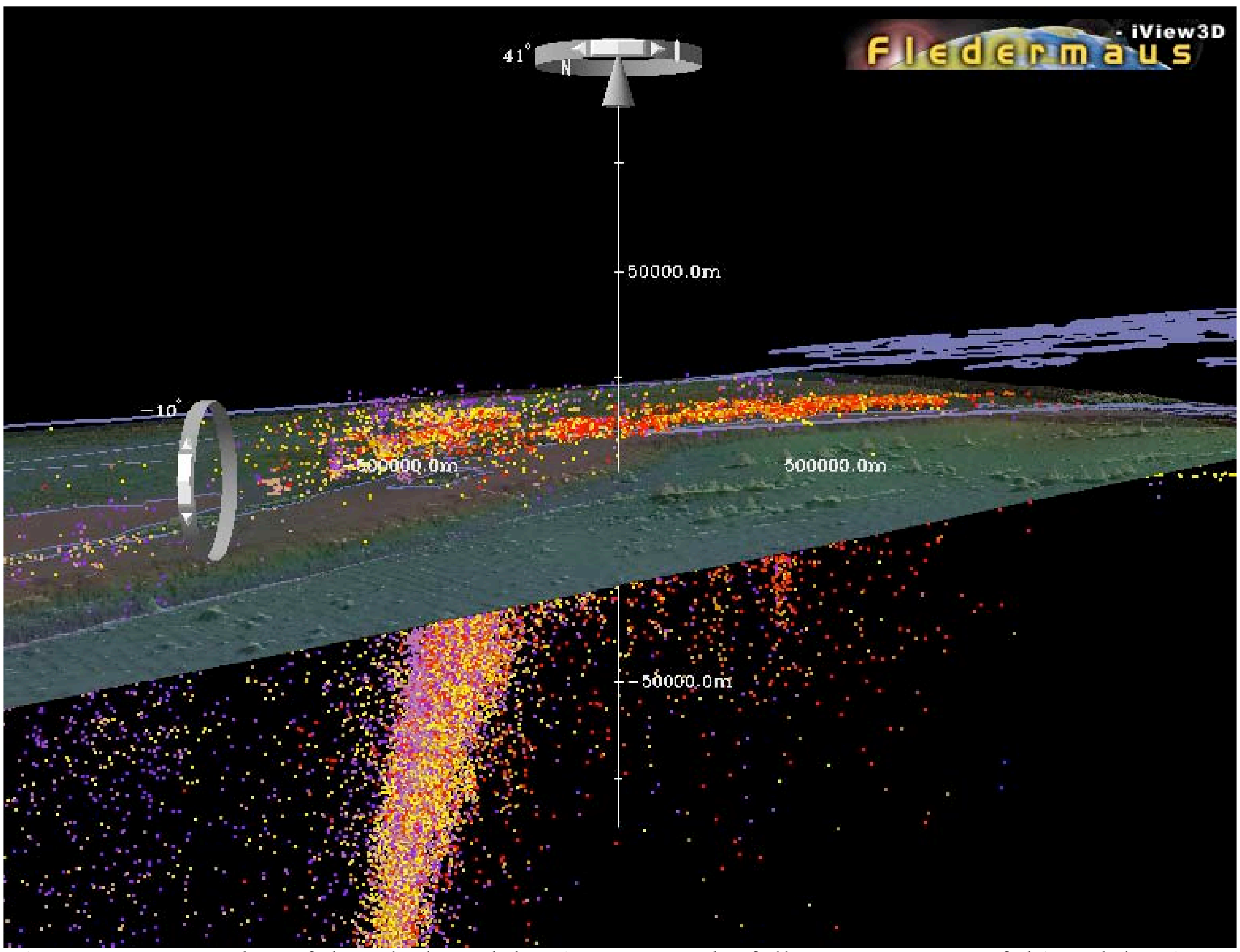


Figure 3. A snapshot of the Alaska subduction zone. The full 3-D structure of this subduction zone is best understood through interactive exploration of the data using the freeware iView3D (see http://www.siovizcenter.ucsd.edu/library/objects/index.php).

The SIO Visualization Center uses state-of-the-art computer hardware and software tools for presenting and manipulating very large datasets (http://www.siovizcenter.ucsd.edu). The center is powered by a SGI® Onyx 3400 graphics supercomputer that can incorporate and process large amounts of data that are impossible to render on the smaller systems. Using the technology at our center, we can render 3-D interactive data modules “visual objects” that can be exported to almost any system (Windows NT, Mac OSX, SGI, Sun, PC Windows2000 and PC Linux). This allows access to high quality 3-D interactive teaching tools, yet reduces hardware costs for an in-class visualization system to the cost of a low-end laptop (~$1,000). One of the beauties of using the VizCenter for these workshops is that the center’s wall sized (~9’ x 29’) curved screen is simultaneously viewable by up to ~40 people.

Through our 2003 and 2004 Teacher Workshops we found 3-D interactive teaching materials key in conveying the nature of 3-D data. However, a common problem is that the technologies to display and explore 3-D data are frequently developed without consulting classroom teachers. As teachers’ time becomes more and more valuable and the technology rapidly advances, the gap between development and practicum increases. The wall sized screen in the SIO Visualization Center allowed us to demonstrate the use of 3-D interactive visualizations, while at the same time obtaining feedback directly from the group teachers (Figure 4). This allowed us to identify the needs of the teachers on the spot and immediately try and problem-solve.

Figure 4. Robert DeGroot (SCEC) discusses the ROOTS earthquake preparedness handbook that was distributed to all participants at the 2004 SIO workshop (see http://www.scec.org/resources/catalog/roots.html)

Figure 5. Hands-on activities at the 2004 SIO Workshop. (a) When Robert DeGroot (SCEC) led the 'brick-slider' lesson he was peppered with questions such as: Where did you get that, how did you make that, and why did you use that material? (b) The always popular 'Plate Tectonic puzzle' led be Ilene Cooper (SCEC) was a big hit at the 2004 SIO workshop. One of the most frequently asked questions, both during the wrkshop and in post workshop emails was: 'Is it possible for me to get an extra tectonic plate puzzle map?'. When possible we made every effort to meet these requests.

2.0 The 16 June 2004 magnitude 5.4 earthquake near Rosarito, Mexico

Mother Nature's contribution to the 2004 Teacher Workshop was a magnitude 5.4 earthquake on June 16th, 2004 that was felt by many of the participants at the SIO 2004 workshop. We were able to discuss this earthquake in detail and explore the data interactively in 3-D (Figure 6). We explained how the same type of exploration could be done at home or at school with just a base laptop after downloading the required dataset and freeware program (see http://eqinfo.ucsd.edu/special_events/2004/167/a/index.shtml). In this way, the workshop participants learned how to explore not only this earthquake but also learned how to acquire information about earthquakes in near-real time through web links such as:

- http://pasadena.wr.usgs.gov/recenteqs/latest.htm
- http://eqinfo.ucsd.edu/dbrecenteqs/anza/AZ_R2_map.html
- http://www.iris.edu/seismon/
- http://www.eqinfo.ucsd.edu/

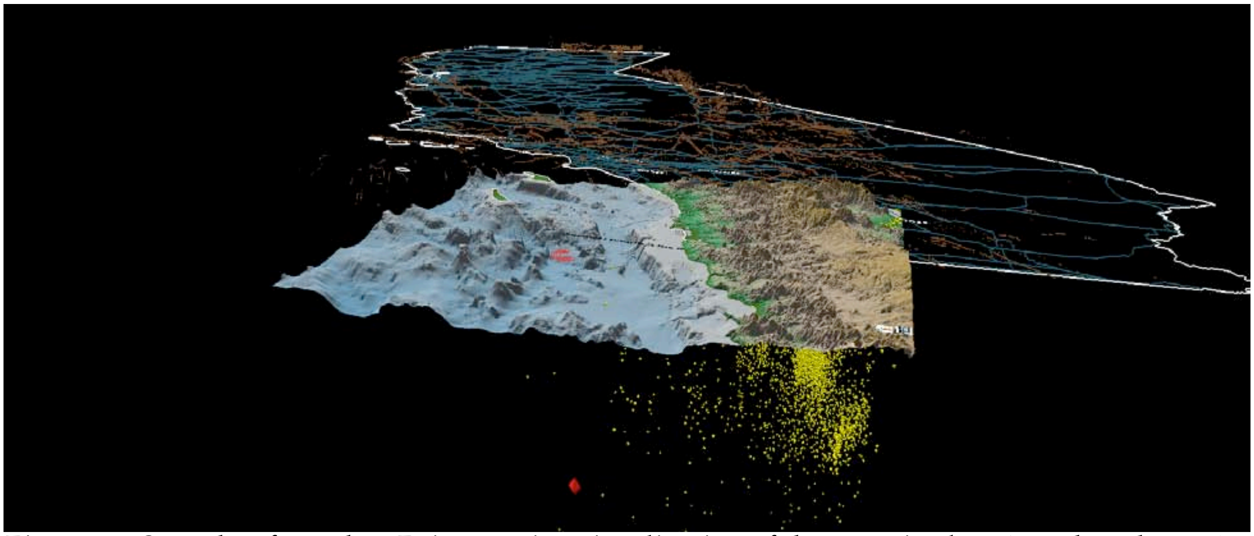


Figure 6. Snapshot from the 3D interactive visualization of the magnitude 5.4 earthquake on 16 June 2004 near Rosarito Mexico (red diamond denotes the earthquake hpyocenter). See http://eqinfo.ucsd.edu/special_events/2004/167/a/index.shtml; and Spanish Version http://eqinfo.ucsd.edu/special_events/2004/167/a/espanol.shtml.

3.0 Lessons Learned

We found a drastic difference between the 2003 and the 2004 SIO Teacher Workshops. We primarily attribute these differences to the timing of when the workshop was advertised and when the workshop was held. The spring 2003 workshop was better attended than the summer 2004 workshop. We expect this is due to the simple fact that teachers are typically 'off' in the summer, away from email and in general focusing on aspects other than the classroom. Presumably because of this, the primary makeup of the 2004 teacher workshop was from more affluent teachers in the higher end school districts. In general, the 2004 group were more timid during the workshop, preferring to ask questions at the breaks or in post-workshop emails, whereas the 2003 group were more vocal during the workshop and had minimal post-workshop requests and contact. We expect these differences stem from the fact that the 2004 group had, relatively speaking, more 'free time' to devote to increasing their bag-of-tricks for teaching Earth Science. A more in depth analysis of the pre/post survey and test and additional workshop questionnaires, which will be conducted by Ilene Cooper and Robert DeGroot, might help us better understand these differences. One consistency between the two workshops was that many participants listed the shake table demonstration as one of their favorites (Figure 7).

Similar to the 2003 workshop, the 2004 teacher workshop put us in one-on-one contact with the San Diego educators. In particular, an email correspondence was established between Debi Kilb (SIO) and at least 5 teachers who attended the 2004 workshop. These contacts greatly helped us understand the needs of the San Diego teacher community and try and establish ways to accommodate these needs. Most notable was a request by 6th teacher Theresa Williams to have her 'all girls science class' visit the SIO Visualization center. At the time of the request we did not have the proper funding to have the class visit, but in partnership with Dr. Helen Fricker (SIO) and E/O funds in her NSF grant plans are underway to bring the all girls class to the SIO VizCenter on November 9th, 2004. These connections could not have been made with out the initial SCEC funding for our 2004 SIO teacher workshop.

Figure 7. Wendy Shindle (USGS) led the shake table contest, which is a favorite not only among the workshop participants but also among the instructors. The goal is to design a building, using limited resources, which will withstand numerous tests on the shake table.

4.0 Future Directions & Long term goals

Our long-term goal is to annually hold collaborative (e.g., SCEC, USC, USGS, SIO, IGPP, BAS, SDSU and SDSC) Earth science teacher workshops at the SIO Visualization Center with the aim of introducing the next generation of teachers and students to visualization tools that can improve their ability to understand multidimensional datasets and concepts (Figure 6). This will provide teachers not only with standard images, global topography maps, and earthquake distribution maps, but also information on seismic tools and techniques, access to real-time seismic data, information on visualization tools available online, and access to visual objects (http://www.siovizcenter.ucsd.edu/library/objects/index.html). Our aim is to enable teachers with the technical capabilities to use our products and after the usefulness of our products are established to reassess and update our goals to meet the changing needs of educators in the San Diego community. Through these interactions we found it essential to have a balance between hands-on learning activities (e.g., Figure 5a-b) and learning activities that used computer graphics (e.g., Figures 1 and 3). These efforts are ongoing. To ensure our workshop participants receive continued access to some of the workshop's resources, we maintain a list of relevant websites (http://www.siovizcenter.ucsd.edu/workshop/materials.html). This information is also freely available to those who were not able to attend the workshop (see http://www.siovizcenter.ucsd.edu/workshop/resources.html)

Figure 6. Sample "graduation photos" from the 2004 workshop (top row) and the 2003 workshop (bottom row) teacher workshop held at the SIO Visualization Center. The "graduation ceremony" included a presentation of a course completion certificate, a number of different take-home maps, books, and teaching products to be used in the classroom.

Relevant References:

Kilb, D.L., R.L. Newman, F.L. Vernon, J.A. Eakins, L. Ziegler, J. Bowen, J. Otero, "Education and Outreach Based on data from the ANZA Seismic Network in Southern California" *Seis. Res. Lett.* V. 74, no. 5, p. 522-528, 2003.

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Kilb, D., I. Cooper, R. de Groot, W. Schindle, R. Mellors, M. Benthien, Using 3d Interactive Visualizations In Teacher Workshops, AGU, 2004.

Kilb, D., Bowen, J., Eakins, J., Lindquist, K., Martynov, V., Newman, R. L., Otero, J., Prieto, G., Vernon, F.L., Ziegler, L., Generation of 3D interactive visualization tools pertaining to significant earthquakes in southern California & noteworthy global earthquakes, SCEC, 2004.

Appendix A

Earthquake Education Workshop - Agenda - 11 August 2004

8:30-9:00am Check-in/Coffee/Pastries

9:00-9:20am Welcome, Overview of the center & introduction of key people (Debi)

9:20-9:40am Group introductions & Ball toss (Wendy)

9:40-10:40am Earthquake's 101 (Ilene/Debi)

10:40-10:55am Mention Pre/Post tests & Standards (Bob)

10:55-11:05am BREAK

11:05am-12:35pm Activities Set I

- Tectonic Plate Puzzle (Ilene)
- Tecno-tectonics
  - Tanya Atwater animations (RobM)
- Earthquakes
  - Earthquakes from around the world - 3D exploration (Debi)
  - Ilan Jones program (Debi)
  - Quick description of plotting earthquake epicenters (Wendy

12:35-1:30pm Catered Lunch on the Ocean-View Veranda

1:30-4:30pm Activities Set II

- Finish activities from Set I if needed
- Trip to balcony to see Mt. Soladad – how was it formed? (Bob)
- Quick description of ...
  - 3D earth structure model w/Clay (Cheryl)
  - Peanut Butter and Jelly" earth Layers (Bob)
  - A voyage through time: tectonic flipbook (Ilene)
- Slink Waves (Wendy)
- Human Waves on balcony (Ilene)
- BREAK (10)
- Available resources & future direction
  - Earthquake! Exhibit at BAS (Cheryl/DebbieZ)
  - Roots/Earthquake Country (Bob)
  - E3 (Ilene)
  - ANZA seismic data (Jose/Debi)
  - USGS learning web (Wendy)
  - SIO Visual Objects (Debi)
  - CUBES: 3D Q/A (Debi)
- GEON (Cindy)
- Milky Way Tectonics (Ilene)
- Brick/Slider Demo (Bob)
- Shake table contest (Wendy)

4:30-4:45pm Post-test (Bob)

4:45-5:00pm Workshop Wrapup

- Complete Evaluation Forms
- Certificate Awards Ceremony

5:00pm Adjourn

The Southern California Earthquake Center

IV. Communication, Education and Outreach

SCEC Communication, Education and Outreach (CEO) program

SCEC is a community of over 500 scientists, students, and staff from over 50 academic institutions across the United States, in partnership with many other science, engineering, education, and government organizations worldwide. To develop 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. These objectives set the programmatic milestones for the Center's internal assessments, guide the development of research results needed for effective education and outreach, and identify priorities for information technology and other resources.

CEO Focus Area Objectives

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

E1. Develop innovative earth-science education resources
E2. Interest, involve and retain students in earthquake science
E3. Offer effective professional development for K-12 educators

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

P1. Provide useful general earthquake information
P2. Develop information for the Spanish-speaking community
P3. Facilitate effective media relations
P4. Promote SCEC activities

Knowledge Transfer (activities with engineers and other scientists, practicing professionals, risk managers, and government officials.

I1. Engage in collaborations with earthquake engineering researchers and practitioners via the SCEC *Implementation Interface*
I2. Develop useful products and activities for practicing professionals
I3. Support improved hazard and risk assessment by local government and private industry
I4. Promote effective mitigation techniques and seismic policies

SCEC Community Development (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

CEO Management Objectives

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

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 K-12 and college-level education in Earth science. During SCEC2 many new educational products and services have been developed, and several activities from SCEC1 have been continued and in most cases expanded. In general, SCEC endeavors to more effective use of (a) the intrinsic interest of students in their natural environment, including the "teachable moments" when earthquakes happen, and (b) the scientific and educational expertise available from SCEC core and participating institutions.

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

Electronic Encyclopedia of Earthquakes (E3). This digital library of educational resources and information is connected with the Digital Library for Earth System Education (DLESE) and the National Science Digital Library (NSDL). E3 is a collaborative project of SCEC, the Consortia of Universities for Research in Earthquake Engineering (CUREE) and the Incorporated Research Institutions for Seismology (IRIS). When complete, information and resources for over 500 earth science and engineering topics will be included, with connections to curricular materials useful for teaching and learning about earth science, engineering, physics and mathematics. The purpose of the E3 collection is to support high-quality K-12 and undergraduate education by providing educators and students with a comprehensive library of tools and resources for instruction and research. E3 is also a valuable portal to anyone seeking up-to-date earthquake information and authoritative technical sources.

E3 is a unique collaboration among earthquake scientists and engineers to articulate and document a common knowledge base with a shared terminology and conceptual framework. It is a platform for cross-training scientists and engineers in these complementary fields and will provide a basis for sustained communication and resource building between major education and outreach activities. For example, the E3 collaborating organizations have leadership roles in the two largest earthquake engineering and earth science projects ever sponsored by NSF: the George E. Brown Network for Earthquake Engineering Simulation (CUREE) and the EarthScope Project (IRIS and SCEC). The E3 vocabulary and definitions are also being connected to a formal ontology under development by the SCEC/ITR project for knowledge management within the SCEC Collaboratory.

A very 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 system is now fully operational, and several hundred entries are being developed by ten faculty-student teams (four CUREE teams, two IRIS teams, and four SCEC teams). SCEC teams are led by Sally McGill, Sue Owen, Gerry Simila, and Jan Vermilye.

Scientists, engineers, and educators who have suggestions for content can visit www.scec.org/e3 now to complete the "Suggest a Web Page" form.

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. (http://www.kidzone.org)

SCEC Undergraduate Internship Program. (http://www.scec.org/internships) SCEC has supported over 130 students to date (including over 60 women and over 40 minority students) to work alongside over 60 SCEC scientists since 1994. The program has expanded in recent years: in 2004, SCEC supported 35 undergraduate students (22 IT interns at USC, 12 science interns and 1 CEO intern). SCEC's mission spans a broad range of expertise and applicants from all disciplines are welcomed. 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.

Each summer since 1994, the *SCEC Summer Undergraduate Research Experience (SCEC/SURE)* has supported students with a broad array of backgrounds and interests to work one-on-one as student interns with the world's preeminent earthquake scientists and specialists. Students participate in interdisciplinary, system-level earthquake science, and SCEC-funded activities throughout the summer. 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, affects that earthquakes have on natural resources (such as groundwater), science education, earthquake engineering, and many other areas. In 2002, the program expanded to include an Information Technology component, which has evolved into the SCEC/USEIT program.

The *SCEC Undergraduate Studies in Earthquake Information Technology (SCEC/USEIT)* program unites undergraduates from across the country to participate in a leading-edge program at the University of Southern California (USC). This NSF REU Site is co-funded by two directorates in the National Science Foundation, CISE (Computers, Information Science, and Engineering) and Geo (Geoscience). Additional funding is provided the USC College of Letters, Arts, and Sciences, the USC School of Engineering, and the SCEC Community Modeling Environment, a large-scale NSF IT Research project.

SCEC's mission spans a broad range of expertise and so does USEIT. While the majority of our interns have considerable computer science skill or aptitude, we welcome applicants from all disciplines. We are particularly interested in additional students with strong graphics, visualization, and cinema experience. About 50 students in computer science, engineering, geoscience, cinema, economics, mathematics, architecture, communications and pre-law participated since 2002. SCEC/USEIT interns interact in a structured yet flexible, team-oriented research environment and interact with some of the nation's most distinguished geoscience and computer science researchers. Students share their diverse skills and interests with their peers, and students mentoring students creates a powerful synergy. The goals of the program are: (1) to allow undergraduates to use, hands-on, the advanced tools of information technology (IT) to solve important problems in interdisciplinary earthquake research; (2) to close the gap between two fields of undergraduate study--computer science and geoscience--by cross-training students in the modes of understanding distinct to these disciplines; and (3) to engage non-geoscience majors in the application of earth science to the practical problems of reducing earthquake risk, and thereby inform students with diverse backgrounds how their classroom skills can be applied to significant social issues.

SCEC/USEIT interns have developed a new visualization platform dubbed "**LA3D**." This interactive, object-oriented, open source, internet-enabled system, written entirely in Java and based on the Java3D toolkit, is rapidly becoming the platform of choice for SCEC researchers interested in displaying objects that represent the complex subsurface structure of Southern California. The interns have not just created another visualization system; they are also 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 LA3D, so that we can tell *visual stories* about earthquakes and faults. These stories are often the best way to communicate the results of SCEC system-level research, not only among the scientists, but also to the general public.

Each term, a team of interns focuses on using intern software such as LA3D, plus some professional editing tools, to craft movies that communicate important earth science and earthquake hazard reduction concepts. Other teams specialize in bringing in new datasets that will be of particular interest for research or outreach. Interns are always encouraged to surprise us, however, and additional, intern-generated projects are encouraged. Some of the most exciting results of past terms have come from projects devised by the interns.

Summer Activities. **Participants of both intern programs come together several times during the summer, in much the same way that SCEC scientists work collaboratively. Near the beginning of the summer a SCEC Intern retreat (in a remote location) is held. Interns learn about SCEC, the schedule for the summer, and our expectations regarding intern work and conduct. Students also briefly describe their anticipated projects and have a chance to get acquainted with each other. Then, the group departs for several short excursions to experience some of southern California's active -- and exciting -- geology. The next all-intern activity, mid summer, comprises a pizza party and Research Colloquium at USC. Here, intern researchers present research status reports (15 - 20 minutes each). The interns have a chance to discuss any problems or breakthroughs they may be experiencing, to get feedback from the others, and thus improve aspects of their projects. At the conclusion of the summer, students present their research in posters at the SCEC Annual meeting and enjoy a reunion with fellow interns and mentors.**

USC Science Education Collaborative. In 2003 SCEC has taken advantage of the environment around the University of Southern California (USC) to form various partnerships and collaborations in order to increase earthquake awareness in the local community:

- One of our new partnerships is with USC's Joint Education Project (JEP). The JEP service learning program sends USC students into local schools to teach eight one hour lessons pertaining to what they are learning in their general education classes. SCEC has many educational resources that are made available to the USC students to take into the classrooms; they are also able to get advice from a SCEC educational specialist.

- Another partnership SCEC has begun is with the Education Consortium of Central Los Angeles (ECCLA). ECCLA funds inter-session (like summer school, but for year round schools) programs for elementary schools in the central Los Angeles region. They had an earthquake curriculum, which SCEC revised, reorganized and added to. SCEC also provided educational materials, and arranged for guest speakers and field trips for the students. The field trips included trips to SCEC, the California Science Center, the Los Angeles Emergency Operations Center, and City Hall. A SCEC education specialist met with the teacher and maintained contact throughout the session as both a content and pedagogical resource.
- Several teachers at Weemes elementary school are coordinating a Science for Parents Night, where parents will come with their children and learn about science. SCEC has been an active participant in the planning of this event, ranging from providing the teachers with ideas for engaging activities to background content information.
- SCEC has partnered with JEP, USC Mission Science, USC Sea Grants and the Jet Propulsion Laboratory (JPL) in creating hands on workshops for teachers at schools in the neighborhood surrounding USC. These workshops focus on the interdisciplinary nature of science. Future workshops are planned to expand to include teaching science as inquiry.

Teacher Workshops. CEO offers 2-4 teacher education workshops each year in partnership with the U.S. Geological Survey (USGS) Pasadena Outreach and Education office. The workshops provide a direct connection between scientists and developers of earthquake education resources and those who use these resources in the classroom.□The workshops include content and pedagogical instruction, ties to state standards, and materials teachers can take back to their classrooms. Many of the materials for the workshops are provided by the Incorporated Research Institutions for Seismology (IRIS). SCEC is also coordinating a college instructor version of the workshop in southern California, based on a program also designed by IRIS. In 2003 SCEC CEO began a partnership with Scripps Institute of Oceanography (SIO) Visualization Center to develop teacher workshops that take advantage of the facilities at SIO. Two workshops have now been held with SIO, and a third is planned for summer 2005.

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. [managed by Bob Yeats, Oregon State University] This project will develop 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. The initial resources to be developed will be a prototype Web-based course on the societal implications of earthquake science. The plan for this year is to develop the Web-based course from an existing in-residence course taught annually at OSU, which is based on the concepts contained in Yeats' (1998) textbook, course, *Living with Earthquakes in the Pacific Northwest*. With this template, we will modify the course to be Southern California-specific, based on Yeats' (2001) textbook, *Living with Earthquakes in California – A Survivor's Guide* (developed with financial help from SCEC), with the ultimate goal of wide dissemination to the SCEC community, college and university teachers, and others.

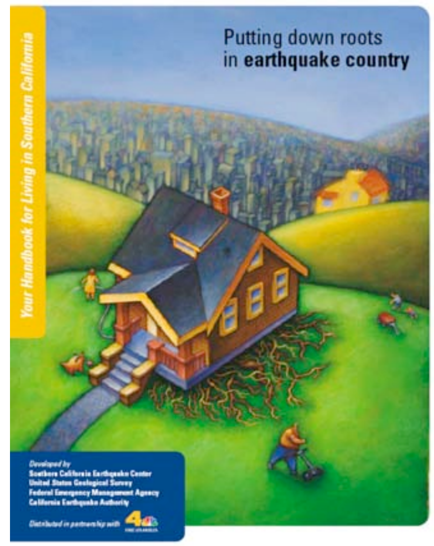
Public Outreach Activities

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.

The SCEC2 objectives for the Public Outreach 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.

SCEC Webservice and SCEC News. 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 1500 people have subscribed to e-mailed news "bytes" which announce new articles. (www.scec.org)

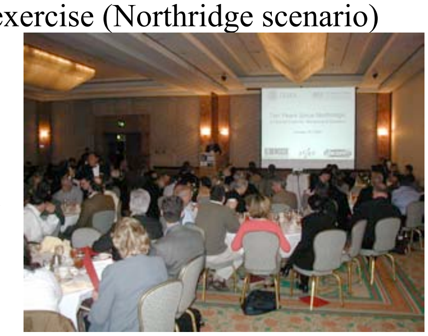
Putting Down Roots in Earthquake Country. To answer the growing concern regarding the implications of the Northridge earthquake and other recent seismic events in southern California, in 1995 the U.S. Geological Survey and SCEC developed a graphically illustrated, 32-page color handbook on earthquake science, mitigation and preparedness. The new version features current scientific understanding of when and where earthquakes will occur in Southern California, and how the ground will shake as a result. Updated maps of earthquakes, faults, and potential shaking are included as well as instructions on how to get information after earthquakes. 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, and to survive and recover from a damaging earthquake. 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 the CEA, USGS, Edison, Amgen, Quakehold, and others. Copies of the document are distributed at home improvement centers, via the American Red Cross, and many others. The updated handbook is now at www.earthquakecountry.info and a Spanish version and Northern California version are in development. Both versions will also be translated into Spanish, and versions for other regions may be created.



Earthquake Country Alliance and the Northridge Ten-year anniversary. 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." This group has been organized to present common messages, to share or promote existing resources, and to develop new activities and products. The group includes earthquake scientists and engineers, preparedness experts, response and recovery officials, news media representatives, community leaders, and education specialists.

The Alliance has been meeting monthly since June 2003 to develop plans. Fortunately this planning has resulted in a complementary set of activities (planned by the Alliance or by individual organizations) that commenced in January and continued throughout the year, as follows:

- Jan. 7: "Earthquakes 101." A seminar for the news media, 8 am to noon, Caltech
- Jan. 13: California Emergency Services Association special seminar at CSUN. Speakers included Don Manning, Lucy Jones, and Tom Heaton
- Jan. 15: City of Los Angeles annual emergency response exercise (Northridge scenario)
- Jan. 15-16: Multidisciplinary Center for Earthquake Engineering Research (MCEER) Annual Meeting, at the New Otani Hotel in downtown Los Angeles.
- Jan. 15: Meeting of the California Seismic Safety Commission, Pasadena.
- Jan. 16: "10 years since Northridge: A Special Event for Movers and Shakers." An invite-only luncheon hosted by the Multidisciplinary Center for Earthquake Engineering



Research (MCEER), the Southern California Earthquake Center (SCEC), and the Business and Industry Council for Emergency Planning and Preparedness (BICEPP). FEMA and the National Center For Crisis and Continuity Coordination (NC4) sponsored the event. Speakers discussed what has been learned since Northridge and what should be known in the near future.
- Jan. 17: "Northridge Earthquake 10th Anniversary: Learning from the Past, Planning for the Future." Beckman Auditorium on the Caltech Campus, 9 am to 3:30 pm. Lectures, movies, displays and activities about earthquakes, for the general public.
- Feb. 4-8: EERI Annual Meeting, Omni Hotel, downtown Los Angeles. Sessions presented what has been learned since Northridge, and several tours to downtown landmarks were offered.
- **Other conferences throughout the year are also commemorating the anniversary, such as Seismological Society of America annual meeting in April (Palm Springs) and the National Earthquake Conference (FEMA, USGS, and many other earthquake organizations) in September (St. Louis, MO).**

In addition to these activities, several products have been developed:
- A major update of *Putting Down Roots in Earthquake Country,* the 32-page earthquake science and preparedness handbook first published in 1995. SCEC, USGS, FEMA, and the California Earthquake Authority (CEA) sponsored the revision (see full description above). An online version is at www.earthquakecountry.info/roots.
- A web portal, www.earthquakecountry.info, has been established with answers to frequently asked questions and descriptions of other resources and services that Earthquake Country Alliance members provide. The portal uses technology developed for the E^3 project (see above).

- "Written in Stone: Earthquake Country- Los Angeles" video produced by Pat Abbott, SDSU. This documentary style 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. SCEC is also developing curricular kits for school and community groups to accompany the video, which will be duplicated in large quantities with funding from the California Earthquake Authority.

The Earthquake Country Alliance 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.

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)

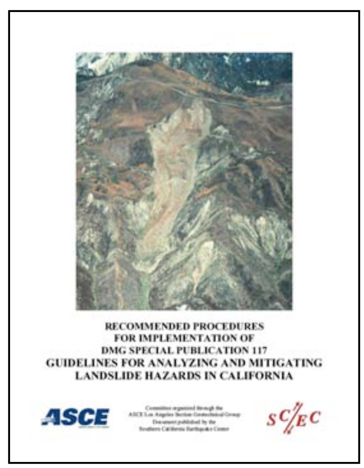
Media Relations. SCEC has successfully engaged local, regional and national media organizations (print, radio and television) to jointly educate and inform the public about earthquake-related issues. The goal has been to communicate clear, consistent messages to the public–both to educate and inform and to minimize misunderstandings or the perpetuation of myths. 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)

Knowledge Transfer Activities

This Focus Area includes activities with engineers and other scientists, practicing professionals, risk managers, and government officials, with the following objectives: 1) engage in collaborations with earthquake engineering researchers and practitioners via the SCEC *Implementation Interface*, (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.



Landslide Report and Workshops. In August 1998, a group of geotechnical engineers and engineering geologists with academic, practicing, and regulatory backgrounds was assembled to form 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 was recently published and is available on the Southern California Earthquake Center's (SCEC) 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.

HAZUS. CEO is coordinating the development and activities of the Southern California HAZUS Users Group (SoCalHUG) with the Federal Emergency Management Agency (FEMA) and the California Office of Emergency Services (OES). HAZUS is FEMA's earthquake loss estimation software program. 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 also considering how it can improve the data and models that HAZUS uses in its calculations. SCEC CEO has organized three general meetings of the user group and in July 2001, a HAZUS training was held at California State University Fullerton for 23 Geographic Information System professionals employed by local governments, utilities, universities, and corporations. Funding for the training was provided by FEMA in response to a proposal by the SCEC and the OES. SCEC is also promoting the improvement of USGS ShakeMap (to include results of SCEC Research) for use in HAZUS scenarios. In summer, 2004, Benthien used HAZUS to provide earthquake hazard and loss scenarios to the City and County of Los Angeles for use in FEMA-required Local Hazard Mitigation Plans. (www.hazus.org)

EERI Southern California Chapter. SCEC has hosted 6 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."

Implementation of SCEC Research in Earthquake Engineering Research and Practice [managed by Dr Paul Somerville, URS Group]

The development of new knowledge about earthquakes and their effects is an important role of SCEC, but not its only role. Because earthquakes have major impacts on society, SCEC must also transfer knowledge about earthquakes and their effects for use in earthquake risk mitigation. This includes the transfer of knowledge to organizations involved in earthquake engineering research, and organizations that have special responsibilities for earthquake safety because they operate lifeline systems. The role of the SCEC Implementation Interface is to implement SCEC research in earthquake engineering research and practice through information transfer and collaborative research. Table 1, from the 2004 SCEC Program Announcement, lists the collaborative research projects that have been developed during 2002 and 2003 between SCEC investigators and investigators from organizations involved in earthquake engineering research or practice.

Table 1. 2002-2003 SCEC Advanced Implementation Interface Projects

THEME	PROJECT	INVESTIGATORS	SPONSORS
Ground-Motion Prediction using Rupture Dynamics	Pseudo-Dynamic Modeling Project	Beroza, Guatteri	PEER-Lifelines, SCEC
Ground-Motion Simulation Code Validation	3D Basin Code Validation Project	Day, Bielak, Dreger, Graves, Larsen, Olsen, Pitarka	PEER-Lifelines, SCEC
	Foamquake Data Interp. Project: Phase 1: Modeling of directivity Phase 2: Validation of source inversion	Day, Graves, Pitarka, Silva, Zeng	PEER-Lifelines, via SCEC
Probabilistic Seismic Hazard Analysis	Object Oriented PSHA Framework Project (Open-PSHA)	Field	SCEC
	PSHA Code Validation Project	Field used results to validate Open-PSHA	PEER-Lifelines
	Surface Faulting Hazard	Rockwell	PEER-Lifelines
	Vector-Valued Hazard Project	Somerville, Thio	SCEC, PEER
Ground-Motion Time Histories	Time Histories for PEER Performance-Based Earthquake Engineering Testbeds	Somerville	PEER, SCEC
Ground-Motion Prediction Model	**Next Generation Attenuation Project**	Archuleta, Anderson, Campbell, Beroza, Day, Field, Graves, Somerville, Zeng	PEER-Lifelines, SCEC
Interface	**Workshop on the interface between SCEC and earthquake engineering research and practice**	Somerville	SCEC
Loss Estimation	Loss Estimation Methodology for Evaluating Societal Impacts of Alternative Seismic Hazard Models	Campbell	SCEC

Workshop on Implementation of SCEC Earthquake Hazard Research Results in Earthquake Engineering Research and Practice, October 22, 2003, Oakland, California. Somerville organized this workshop with the assistance of Mark Benthien. The objective of this Workshop was to expand the interface between the Southern California Earthquake Center (SCEC) and organizations that can use SCEC knowledge in their research and practice in earthquake engineering and related disciplines. The workshop was designed to identify what kinds of scientific knowledge about earthquake hazards are useful to this community, to identify problems/ issues/ needs/ opportunities that lie at the interface, and to identify how SCEC can engage in collaborative research with this community to produce useful knowledge. Information technology is an important component of this interface.

The workshop participants included representatives of Federal and State government agencies that sponsor and use research in earthquake science and engineering (FEMA, FHWA, NSF, USGS; CEA, CGS, COES, CSSC); earthquake engineering organizations, consortia and centers (CUREE, EERI, MAE, MCEER, NEES, PEER, PEER-Lifelines), as well as practicing engineers and SCEC and USGS scientists.

The morning plenary session included presentations on key problems, issues, needs, and opportunities at the interface between earthquake science and earthquake engineering. Much of the presentation and discussion was focused on optimizing the parameters (intensity measures) that are used to describe earthquake ground motions for input into seismic response analysis of soils and structures. This discussion took place within the framework of Performance Based Seismic Engineering, whose ongoing development and application in practice were described. Interface projects that are currently underway, that have been proposed for funding, and that are solicited in the 2004 SCEC RFP, were summarized, and the OpenSHA project was described in some detail.

In the afternoon, breakout discussions focused on identification of potential collaboration projects, and on potential strategies for organizing and funding collaboration. Key issues at the interface include the optimal selection of ground motion intensity measures, and the scaling of ground motion time histories used in structural response analyses. The deployment of instruments on the ground and in structures in the ANSS (Advanced National Seismic System) was identified as a key need and opportunity for collaboration at the interface. The growing need for suites of ground motion time histories for experimentation (e.g. by NEES, the Network for Earthquake Engineering Simulation) and for design by practitioners was recognized. Analysis of the system response of spatially distributed systems such as lifelines requires spatial descriptions of ground motion scenarios, providing an important computational challenge and opportunity to earthquake scientists.

One of the key suggestions for collaboration was for end-to-end simulation from the earthquake source through to structural response ("rupture to re-bar"). This would require coordination of existing simulation and information technology capabilities in earthquake science and earthquake engineering. Another key suggestion for collaboration was to use a suite of Index Buildings that would help quantify the changing levels of seismic risk that accompany real or perceived changes in the seismic hazard as represented for example in time-dependent hazard estimates and building code revisions. The SAC steel moment frame buildings and the PEER Testbed buildings and bridges are examples of such Index Buildings.

An agenda of the workshop, list of participants, presentations that were made, and summaries of the ensuing discussions, can be found on the SCEC Website, and a list of the participants and their affiliations is given in Table 2.

Table 2. List of Participants in SCEC Implementation Interface Workshop

Acronym	Name	Role	Participant
ATC	Applied Technology Council	Consensus formation for building code writing	Chris Rojahn
USBR	US Bureau of Reclamation	Dam safety	
Caltrans	California Department of Transportation	Highway infrastructure	Brian Chiou Cliff Roblee
CEA	California Earthquake Authority	Insurance	Tim Richison
CGS	California Geological Survey	Mapping seismic hazards in California	Mike Reichle Chris Wills
COES	California Office of Emergency Services	Emergency Response	Richard Eisner
CSSC	California Seismic Safety Commission	Legislation	Bob Anderson
CUREE	Consortium of Universities for Research in Earthquake Engineering	Research	Robert Reitherman Andrew Whittaker
DOE	U.S. Department of Energy	Energy	
DWR	California Department of Water Resources	Dam safety	Les Harder David Gutierrez
EERI	Earthquake Engineering Research Institute	All aspects of the impact of earthquakes on society	Craig Comartin
FEMA	Federal Emergency Management Agency	Emergency response and disaster mitigation	Mike Mahoney Jeffrey Lusk
FHWA	Federal Highway Administration	Highway safety	Roland Nimis
MAE	Mid America Earthquake Engineering Center	Research and Outreach	Amr Elnashai
MCEER	Multidisciplinary Center for Earthquake Engineering Research	Research and Outreach	Andrew Whittaker
NIST	National Institute of Standards and Technology	Building standards	

NEES	Network for Earthquake Engineering Simulation	Research facilities and collaboratory	Ian Buckle Robert Nigbor
NSF	National Science Foundation	Research	Steve McCabe Joy Pauschke
PG&E	Pacific Gas & Electric	Power Utility	Norm Abrahamson
PEER	Pacific Earthquake Engineering Research Center	Research and Outreach	Jack Moehle Greg Deierlein Allin Cornell Jon Bray Helmut Krawinkler
PEER-Lifelines	Directed Research Program on Lifelines	Sponsored by Caltrans, Cal. Energy Commission, and PG&E	Brian Chiou Cliff Roblee
SEAOC	Structural Engineers' Association of California	Professional Practice Organization	Craig Comartin Joe Maffei Charlie Kircher
SCEC	Southern California Earthquake Center	Earthquake Research and Outreach	John Anderson Ralph Archuleta Mark Benthien Greg Beroza Ken Campbell Steve Day Tom Heaton Tom Jordan Paul Somerville
USGS	U.S. Geological Survey/ SCEC	Earthquake Research and Outreach	Bill Ellsworth Ned Field Ruth Harris Mark Petersen Woody Savage Rob Wesson

Next Generation Attenuation (NGA) Project. SCEC's major Implementation Interface activity in 2004 was participation in the Next Generation Attenuation (NGA) Project. Ground motion attenuation relationships are the backbone of modern earthquake hazard assessment. These relationships are used in *all* earthquake hazard assessments ranging from the U.S. National and California seismic hazards maps, to site-specific assessments, both deterministic and probabilistic, used for specific facilities ranging from bridges to dams to power plants. Hazard assessment results are used to establish design strategies and details of the built environment and to predict their performance.

SCEC is a co-sponsor and co-participant with PEER-Lifelines and the USGS in NGA Project. The objective of the current phase of the NGA Project, NGA-E (Empirical), is to update existing ground-motion models for shallow crustal earthquakes in active tectonic regions derived from recorded strong motion data. The NGA-E Project consists of a set of 8 Tasks that are guided by 6 Working Groups, listed in Table 3, which shows the relationships among them.

Table 3. NGA-E Tasks, Working Groups, and their Relationships

Tasks	***W. Groups***		**Working Groups**	**Tasks**
1. Database Development	1,2		1. Data Processing	1
2. 1-D Rock Simulation	3,4		2. Database Predictor Variables	1
3. Evaluation of Predictors	4		3. Validation of 1-D Rock Simulation	2
4. Site Classification and Site Effects	5		4. Source/Path Effects	2,3,7
5. Site Response Analysis	5		5. Site Classification and Site Effects	4
6. Statistical Approaches	6		6. Statistical Modeling of Data	6
7. Simulation of 3-D Basin Response	4			
8. Evaluation of Final NGA Models				

SCEC scientists participated in almost all of the tasks and working groups listed in Table 3. 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.

SCEC work 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.

NGA products will fulfill a clearly stated need of the industrial sponsors of PEER-LL (Caltrans, the California Energy Commission, and PG&E) for improved ground-motion prediction models. Potential user organizations include these sponsors and organizations (including ATC, BART, BSSC, CEA, CSSC, CUREE, DOE, DSOD, DWR, EBMUD, FEMA, FERC, LADWP, MAE, MCEER, NRC, NEES, OES, PEER, SCE, SEAOC.) that have an interest in improved earthquake hazard assessment and/or actively use attenuation relations in earthquake engineering practice.

Effective Risk Mitigation for SCEC Target Audiences. [Lisa B. Grant (PI), with Eric E. Runnerstrom (Graduate student researcher) and Kristen Iriarte (SCEC Intern)]

Introduction. The moderate magnitude (M6.7) Northridge earthquake in 1994 was the most expensive natural disaster in U.S. history, with total losses up to $46 Billion (CDMG, 2000). Despite significant efforts by the scientific research and hazard mitigation communities, the risk from potential future earthquakes in the U.S. continues to rise as population and exposure increase in tandem. The House Committee on Science (2003) estimated that a major earthquake in a U.S. urban area could cause as much as $200 Billion in losses. Such large losses could have a significant negative impact on the U.S., especially if accompanied by casualties, and therefore seismic hazard and risk are problems of national importance.

Earthquakes, however, are *local* phenomena that have the greatest impact on specific areas or regions. *Many elements of hazard mitigation and risk reduction must be conducted at local levels to be effective* because a substantial amount of policy implementation, compliance and enforcement occurs at municipal and county levels (Mileti, 1999). Unfortunately, adoption and implementation of local seismic mitigation policies is difficult because the problem is generally perceived as a low priority for local governments (Berke and Beatley, 1992). Past research has demonstrated that technical aspects of earthquake mitigation are more advanced than implementation by governments (Berke and Beatley, 1992), and this may be especially true at the local level. Better understanding of this problem could lead to more effective seismic hazard risk communication for target audiences at the local level.

Purpose. The Southern California Earthquake Center (SCEC) is positioned to advance knowledge transfer and risk communication about seismic hazard. To strengthen risk communication between SCEC and target audiences, such as local governments, it is necessary to establish a baseline understanding of current efforts and their effectiveness at risk communication and risk mitigation In this report, we describe preliminary results of a baseline study to document the utilization of seismic hazard data and research products by local government in Orange County, one of the highest risk counties in California and the country.

Orange County Cities. Our study is 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. Orange County is one of California's geographically smaller counties, yet its population (2.8 million) and total personal income ($99.5 million) rank 2nd out of the state's 58 counties. Approximately 40% of Orange County's housing stock was built before 1970, which is prior to substantial upgrades in seismic building practices. Using HAZUS methodology, the CDMG (CGS) estimated Orange County's expected annualized total loss due to earthquake activity to be among the highest in the state.

Our study focuses on cities because they represent a key component of risk communication and mitigation. A substantial amount of policy implementation, compliance, and enforcement occurs at the municipal government level, so it is important to understand how cities utilize seismic hazard information to mitigate risk. In particular, we focus on the direct use of SCEC products by local-level policy-makers and staff. As opposed to state and federal level, we expect to find the greatest amount of variation in the use of SCEC products at the local level. By understanding this variation in the use of SCEC products, we expect that effective areas or targets within cities for risk communication should emerge.

SCEC and Research Communication. An objective of SCEC is to "…communicate the results of their research with the multiple millions of citizens who live and work in this seismically active region" (SCEC website). One mechanism designed to achieve this objective is SCEC's Communication, Education, and Outreach (CEO) program. There are multiple modes of communication. Communication occurs among multiple stakeholder groups and at various levels of government. SCEC products, based on SCEC-funded research, can traverse multiple paths toward advancing science or improving seismic safety. These paths are not mutually exclusive. SCEC products may affect one communication node, which then impacts another node, creating a web of indirect influences. For example, empirical relationships described by Wells and Coppersmith (1994; SCEC #178) are used by HAZUS' software methodology to compute fault rupture length in order to estimate ground motions. Ground motions are used to calculate estimations of losses by social systems due to scenario earthquakes. HAZUS runs are being integrated into geotechnical background reports, which then influence policies of cities' safety elements. To track every SCEC product in order to measure direct and indirect influences on cities' seismic mitigation practices is beyond the scope of this study. We have focused on Safety Elements and related documents (Technical Background Reports, EIRs and MEAs) for Orange County's 34 cities. These documents identify hazards to public welfare and provide guidance for local decisions on zoning, subdivisions and permitting.

Planning and Seismic Safety. Within California's ~477 cities, planning is performed using three basic tools:

- the general plan
- the zoning ordinance
- the Subdivision Map Act.

These planning tools are fundamental to California's planning system. "Over the past twenty years, the general plan has emerged as the most important document in local planning in California" (Fulton, 1991). General plans were required of counties and cities by the California legislature beginning in 1937, but were not taken seriously until after a legislative milestone in 1971 that required consistency among the general plan, zoning ordinances, and subdivision procedures within a jurisdiction (§65300.5).

A general plan consists of text containing objectives, principles, standards, and plan proposals, as well as maps and diagrams. Together, these constituent parts illustrate a picture of the community's future development. Most jurisdictions select 15 - 20 years as the long-term horizon for the general plan, but are encouraged to revise every 5 years.

In statute, the general plan is organized as a collection of seven "elements" (see §65302): land use, circulation, housing, conservation, open-space, noise, and safety. The level of discussion given to each issue in the local plan depends upon local conditions and the relative local importance of that issue. Seismic hazards are included in the Safety Element.

The Safety Element establishes policies and programs to protect the community from risks associated with seismic, geologic, flood, and wildfire hazards. The safety element's identification of hazards and hazard abatement provisions are a guide to local decisions related to zoning, subdivisions, and entitlement permits. The element should contain general hazard and risk reduction strategies and policies supporting hazard mitigation measures. Policies should address hazard avoidance and risk reduction.

Geotechnical data and analyses are important to the preparation of the plan because the information establishes a context for objectives and policies, but can obscure the primary purpose of the plan (to be a statement of policies) with an abundance of pages. Consequently, the Governor's Office of Planning and Research recommends that technical background documents be provided in appendices or as separate documents.

The process of adopting or amending a general plan encourages public participation. Cities and counties must hold public hearings for such proposals. Advance notice of the place and time of the hearing must be published in the newspaper or posted in the vicinity of the site proposed for change. Prior to approval, hearings will be held by the planning commission and the city council or board of supervisors. General plans are available for anyone to study or review.

Findings. Since the founding of SCEC in 1991, 28 out of 34 Orange County (O.C.) cities have revised or created their Safety Elements. We have obtained and reviewed all available Safety Elements and supporting technical background documents for all 34 O.C. cities, and compared references with the database of over 650 SCEC publications. Directly cited SCEC products are listed below, with the citing document.

<u>Brea (Map Credit) Geotechnical Background Report 2002</u>

- Southern California Earthquake Center (SCEC) January 1932 to November 21, 2001 adapted for "Earthquake Map of the Brea Planning Area"

<u>Rancho Santa Margarita (Map Credit) Geotechnical Background Report 2002</u>

- "Earthquake Map of the Rancho Santa Margarita Planning Area" Scientists of the USGS and the Southern California Earthquake Center, 1994; Science, October 21, 1994 Figure 1

<u>San Juan Capistrano Technical Background Report 1999</u>

- Grant, L. B., K. J. Mueller, E. M. Gath, H. Cheng, R. L. Edwards, R. Munro and G. L. Kennedy, Late Quaternary uplift and earthquake potential of the San Joaquin Hills, southern Los Angeles basin, California, Geology, 27, pp. 1031-1034, 1999.
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- McNeilan, T., T. K. Rockwell and G. Resnick, Style and Rate of Holocene Slip, Palos Verdes Fault, Southern California, Journal of Geophysical Research, 101, no. B4, pp. 8317-8334, 1996.
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Implications. "Like other social problems, the earthquake hazard will not be addressed adequately until we understand both the social processes that produce earthquake vulnerability and the policy steps that need to be taken to reverse those processes." -- Chris Arnold, Earthquake Engineering Research Institute, Testimony before the House Committee on Science, Subcommittee on Basic Research, 2/23/1998

Our preliminary analysis of the data suggests that SCEC products are underutilized for local planning and seismic hazard mitigation. We are evaluating alternative explanations such as nested references, and other use of SCEC products without direct citation

We have also found that nearly all cities in O.C. relied on planning and/or geotechnical firms to prepare technical reports or Safety Elements. Therefore, these consultants would be excellent targets for more effective seismic risk and hazard communication by SCEC.

Looking ahead. New opportunities to establish linkages between seismic hazards and other natural hazards may emerge due to the requirements of FEMA's new Pre-Disaster Mitigation Program. On average, cities are unaware of documentation that outlines the ways SCEC can improve hazard and risk assessment by local government. In some circumstances, SCEC products and research are nested within other resources that are non-exclusive to SCEC (e.g., HAZUS). Consequently, some substantial SCEC contributions are not easily recognized by end-users. For the cities that are using SCEC for seismic hazard mitigation, we expect that the types of products and extent of usage will be better understood following our analysis of geotechnical background reports to safety elements. To date, our review of refereed literature suggests that this methodology will contribute to a better understanding of risk communication between a scientific center and non-technical government decision-makers.

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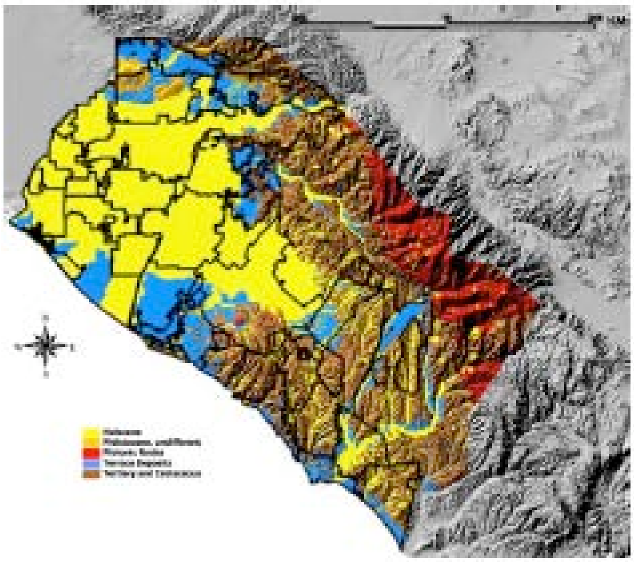

Figure 1: Multiple geologic, topographic, and seismic conditions are represented in the relatively small geographic area of Orange County, CA (see area of color) and vicinity (see area of grayscale). The county's 34 cities are indicated by black outlines. Orange County's physiographic includes mountains, flood plains, coastal bluffs, soft soils, liquefaction and landslide hazard, surface rupture potential, and sources of potentially strong ground shaking such as the Newport-Inglewood, Whittier - Ellsinore, Palos Verdes, San Joaquin Hills and San Andreas faults.

SCEC Community Development Activities

The foundation of SCEC CEO is our partnerships and participation in many communities in each of the previous Focus Areas. Supporting our own community from within is parallel activity that bolsters our ability to reach out to others. This Focus Area includes activities and resources relevant to SCEC scientists and students, with objectives 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.

SCEC Diversity Issues and Possible Activities for a Diversity Task Force. The participants in SCEC represent a diverse array of ethnicities and a mix of genders. Nonetheless within this array there are perceived to be certain issues related to diversity. Among these perceptions are:

- The leadership of SCEC, including the Officers and the Board, is dominantly white and male.
- The Planning Committee has significant power in SCEC II 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.
- The current situation is not unique to SCEC, but reflects historical trends in the earth and physical science communities.

Possible Activities: An important first step in planning for the diversity effort at SCEC is to decide at what scale to address these perceived issues and to scope the effort. There seem to be several classes of activities that could be undertaken to address the concerns listed above. It would seem appropriate for the Board to consider which of the following classes of activities it wishes to pursue, and then to assign the responsibility for developing the activities to either a Diversity Task Force, or to specific individuals:

- Goal Setting—Does the SCEC Board want to establish a written statement of diversity goals? The goals could be cast in several ways. The goals need not necessarily be numerical, but rather could be aimed at processes.
- Analysis of statistics of past activities and maintenance of statistics on future activities—What are the actual statistics on interns, graduate students, pistols, Pin's, project awards, etc.? How have these statistics changed with time? Considerable care must be taken in analyzing these statistics because the rules at some institutions (e.g. Harvard) require that a P.I. be a faculty member. This requirement may conceal a greater diversity than may be at first apparent.
- Establishing policy guidelines for the selection of individuals for "stepping stone" opportunities—SCEC could develop a policy of announcing the availability of opportunities for roles within SCEC leading to increased responsibility and/or visibility. Such opportunities might include speakers at the annual meeting, workshops and retreats, and committee assignments. By asking for volunteers and nominees for these opportunities, SCEC leadership could assure that qualified, interested individuals are not being overlooked.
- Sounding board—There may be significant diversity-related perceptions within the SCEC community that are not currently obvious to the leadership. Actions aimed at elucidating these might include the appointment of one or more diversity contacts who could serve as informal counselors, and/or holding an evening session at the annual meeting where diversity issues could be aired.
- Mentoring program—SCEC could develop a mentoring program. The program could be developed at a variety of scales, but perhaps the most critical need might be at the graduate student, post doc and junior faculty levels. The program could try to match volunteer senior faulty/researchers with younger individuals who request a mentor.
- Placement assistance—SCEC could develop a program aimed at assisting graduate students and postdocs find successor positions.
- Enhanced intern and community-based programs for involving undergraduates—SCEC I was active in involving women and minority students through internships and other activities. These programs could be continued and enhanced.
- Benchmarking—SCEC could undertake to learn what activities other large science and/or NSF-funded centers and consortia have done to achieve diversity goals and consider adoption of the most successful and appropriate of these.
- Multi-year plan—The SCEC Board could ask an individual or the Diversity Task Force to propose a 2 to 5 year plan for developing the activities the Board considers most appropriate.
- Seeking Support for Diversity Activities—SCEC could investigate additional opportunities for supporting diversity-related activities from NSF-education or other sources.
- Periodic self-analysis and reflection—The SCEC Board could hold a discussion, perhaps on an annual basis, of how SCEC is doing on diversity issues, perhaps receiving a report from the Diversity Task Force, if one is established.

SCEC Community Information System (SCECCIS). SCEC CEO 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, but will soon be expanded to generate a web page for each SCEC scientist that will provide access to their past and current SCEC-funded projects, published research, outreach activities, etc. This system will also allow SCEC CEO to better track research projects with potential CEO applications. Contact information will be accessible by

members of the SCEC community after signing in with a password. As a service for other communities associated with SCEC, similar interfaces have been developed. Such communities include the California Post Earthquake Information Clearinghouse, the Earthquake Country Alliance, the U.S. Educational Seismology Network, and others.

CEO Management Activities

Recruit CEO Advisory Panel. 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.

Develop strategic plan. 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) E&O 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 20, 2004, by the Center Director, Tom Jordan

This is the third community-wide gathering since SCEC was reconfigured as a free-standing center on February 1, 2002. Here in Palm Springs, you will be joined by more than 360 of your colleagues—the largest attendance in the history of the Center. The agenda features some outstanding science presentations, an impressive set of science posters, important working group meetings, and panoply of IT demonstrations, education & outreach activities, and social gatherings. I look forward to your participation in all of these events. In this brief report, I will summarize some of the major activities and touch on several issues relevant to our future. I would especially like to solicit your participation in an activity prominent on the agenda and central to our goals: the formulation of the SCEC3 proposal. A special section at the end of my report is devoted to this important topic.

Organization and Leadership

SCEC is an institution-based center, governed by a Board of Directors who represent its members. The number of participating institutions continues to grow. During the past year, the Board approved the admission of four new U.S. participating institutions—Case Western Reserve University, Rensselaer Polytechnic University, University of Kentucky, Woods Hole Oceanographic Institution—as well as six foreign participating institutions: ETH (Zürich, Switzerland), Institute of Earth Sciences of Academia Sinica (Taiwan), National Chung Cheng University (Taiwan), National Taiwan University (Taiwan), National Central University (Taiwan), and the University of Western Ontario (Canada). The institutional membership now comprises 14 core institutions and 37 participating institutions.

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 Prof. Emily Brodsky, who was appointed by UCLA to replace David Jackson. (Dave has taken on new duties as department chair, but he will continue to be a SCEC leader as the new co-chair of the Seismic Hazard Analysis focus group.) The other 15 members of the Board are Greg Beroza (Vice-Chair/Stanford), 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 (see table below).

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	
SCIGN Steering Committee:	Thomas Herring (chair)*
SCEC/ITR Project:	Bernard Minster (liaison)*
Borderland Working Group:	Craig Nicholson (chair)*

* Planning Committee members

During the past year, a number of rotations in the PC membership brought new blood into the SCEC leadership. Mike Oskin was appointed as co-chair of the Geology disciplinary committee, Judi Chester as co-chair of the Fault & Rock Mechanics disciplinary committee, Jeroen Tromp as co-leader of Structural Representation focus group, Sally McGill and Jim Dieterich as co-leaders of Fault Systems focus group, Dave Oglesby as co-leader of Earthquake Source Physics focus group, Paul Davis as leader and Rob Graves as co-leader of Ground Motion focus group, and Dave Jackson as co-leader of the Seismic Hazard Analysis focus group. We are fortunate that such accomplished and energetic scientists are willing to participate as SCEC leaders, and I look forward to their insights about how we might best move forward toward SCEC3. I also want to take this opportunity to thank all the retiring members for their excellent service during the past 2 years.

Advisory Council. The Center's external Advisory Council is charged with developing an overview of SCEC operations and giving advice to the Director and the Board. We have been very fortunate to have Prof. Bob Smith as the AC chair for the past 5 years. Bob's leadership during the transition from SCEC1 to SCEC2 was especially important to me personally as I assumed the duties of SCEC director in 2002. Bob is stepping down as chair, but he has graciously agreed to remain a member of the AC, so we will continue to receive his unique insight. On behalf of the SCEC Board of Directors, I would like to thank Bob for his great service to the SCEC Community.

I am very pleased to announce that Dr. Sean Solomon has agreed to be the next chair of the AC, beginning at this meeting. Sean's outstanding accomplishments as a geoscientist and his broad perspectives as an international scientific leader are superb qualifications for this key position. I am confident that he will continue the tradition of strong AC leadership demonstrated by all the chairs over the past 13 years (Barbara Romanowicz, John Rundle, and Bob Smith).

The AC's yearly report, which was issued in November, 2003, focused on several key issues that are now being addressed by the SCEC leadership team. This report can be downloaded from our document website as part of our 2003 report (http://www.scec.org/aboutscec/documents/).

The AC's assessments and advice will be especially important as we enter the planning phase for SCEC3. I urge all attendees to use this meeting as an opportunity to communicate their views to the Council. The current members are: Sean Solomon (Chair/ Carnegie Institution of Washington), Jeff Freymueller (U. Alaska), Raul Madariaga (Ecole Normale Superieure), Jack Moehle (PEER), Farzad Naeim (John A. Martin & Associates), Garry Rogers (Geological Survey Of Canada), Chris Rojahn (Applied Technology Council), Haresh Shah (RMS, Inc.), Robert Smith (U. Utah,), Ellis Stanley (LA Emergency Preparedness Department), and Susan Tubbesing (EERI).

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*, *geodesy*, *geology*, and *fault and rock mechanics*. 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.

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.

An “Earthquake Country Alliance” has been organized to coordinate activities for the 10-year anniversary of the Northridge Earthquake in 2004, and beyond. 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. (This popular guide will soon be published in Spanish language edition.) The group includes earthquake science and engineering researchers and practicing professionals, preparedness experts, response and recovery officials, news media representatives, and education specialists. A web portal, www.earthquakecountry.info, has been established with links to web pages and descriptions of resources and services that the Alliance members provide. 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.

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, 35 students have participated in the program, including 13 students working with scientists throughout SCEC and 22 students enrolled in the USC-based Undergraduate Summer in Earthquake Information Technology (UseIT) intern program.

Center Budget and Project Funding

The 2004 base funding for the Center is $2,760K from the National Science Foundation and $1,100K from the U.S. Geological Survey. The base budget approved by the Board of Directors for this year allocates $2,725K for science activities managed by the SCEC Planning Committee; $385K for communication, education, and outreach activities, managed by the CEO Associate Director, Mark Benthien; $170K 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 $150K 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

$228K from NSF's National Science, Technology, Engineering, Mathematics, and Education Digital Library (NSDL) program for the Electronic Encyclopedia of Earthquakes. The project managers for the ITR and NSDL grants are Phil Maechling and Mark Benthien, 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 2004 began with the working-group discussions at our last annual meeting in September, 2003. An RFP was issued in October, 2003 (see Appendix A), and 176 proposals (147 projects, considering collaborations) requesting a total of $5,370K were submitted in November, 2003. 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 19-20, 2004, 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 2-3. 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 20.

On June 7-8, the SCEC/USGS Joint Planning Committee, which includes several USGS program leaders, met with the Board of Directors and agency representatives to conduct a comprehensive review of the entire SCEC2 program and to initiate the planning process for SCEC3. The leaders of all of the working groups summarized their accomplishments and plans, and there were vigorous discussions of how the current mix of science projects and other activities might be adjusted to better attain SCEC2's five-year goals and feed into SCEC3.

After these sessions, the PC began the processes of formulating the 2004 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 volume, and others will be discussed in the working-group sessions throughout the annual meeting. Rather than attempt a summary, I will simply list several documents which you can download from the web to find detailed reports. Of course, you can find a lot more information about SCEC activities through our webportal (http://www.scec.org).

SCEC 2003 Annual Report (December, 2003). This large, comprehensive document (155 pp., 3.6 MB) can be downloaded from our website (http://www.scec.org/aboutscec/documents/). 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 2004 RFP

SCEC/CME 2004 Annual Report (June, 2004). 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 third annual report on the CME (92 pp.) can be downloaded from the CME website (http://epicenter.usc.edu/cmeportal/documents.html).

Site Review Report of the SCEC/CME Project (March, 2004). On March 2-5, 2004, NSF convened a panel of geoscientists and computer scientists at USC to conduct a comprehensive mid-term (2.5-yr) evaluation of the SCEC/CME Project. Their report (9 pp., 112 KB) to the NSF is included as Appendix B to this meeting volume.

***Putting Down Roots in Earthquake Country* (January, 2004)**. The new edition of this widely distributed public-information document was released by SCEC and the USGS on the anniversary of the Northridge earthquake. 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 by Mark Benthien and hosted by SCEC. A second printing of *Roots* is being sponsored in large part by the California Earthquake Authority, and a Spanish-language edition is being prepared.

The SCEC3 Planning Process

The current phase of the Center (SCEC2) extends for five years, until January 31, 2007. Our principal funding agencies, the National Science Foundation and the U.S. Geological Survey, have requested that we submit a five-year renewal proposal on or around March 1, 2005. The nearly two-year lead period will permit a thorough evaluation of the proposal (up to the highest agency levels), as well as sufficient time for the SCEC Community to adjust to any funding discontinuities, up or down. That means that this 3rd annual meeting of the SCEC2 collaboration will be our last before we submit the SCEC3 proposal. (Can you believe it?)

In early June, more than 40 members of the SCEC2 leadership team—the Board of Directors, the leaders and co-leaders of the working groups, and the USGS/SCEC Joint Planning Committee—met for two days with agency representatives to review progress and discuss other issues relevant to a SCEC renewal, including the possibility of *not* submitting a proposal. A detailed rationale for continuing the collaboration was articulated by the leadership team, and it received a strong endorsement from our agency partners. A decision to submit was unanimously approved by the Board.

The plan hammered out at this meeting will the subject of my presentation at 1:30 pm on Monday, Sept 20. Let me summarize it here by listing an approximate timetable for the SCEC3 renewal process:

June 8, 2004	SCEC3 planning process initiated at Oxnard meeting
Sept 1	Director describes process in email to SCEC community and solicits input, including 1-page "science nuggets" that describe the results of SCEC2 projects
Sept 19-22	Working-group discussions of SCEC3 proposal at Annual Meeting
mid-Nov	Deadline for science nuggets from SCEC investigators (along with 2004 progress reports)
Jan 1, 2005	Draft 1 of SCEC3 proposal posted for comment
early Feb	BoD/PC meeting to review Draft 2
Mar 1	SCEC3 proposal submitted to NSF & USGS
Summer	Site review
Fall	Decision from funding agencies

You will notice that all members of the community are invited to participate in several stages of the process, beginning at this annual meeting. In particular, I hope you will participate in the working-group sessions to formulate the directions that SCEC3 should take, engage your colleagues, especially the leadership team, in vigorous hallway and beverage-centric discussions of what SCEC3 should look like, and participate in the Wednesday morning synthesis of a community consensus about SCEC3.

The discussions at the annual meeting will address the following four questions:

1. *What will be the major accomplishments of SCEC2?*
   - Basic science
   - Data and modeling products
   - Information technology
   - Service to scientific community
   - Partnerships with other organizations
   - Implementation of science for hazard assessment and risk reduction
   - Service to end-user communities
     - Education and outreach

2. *How shall we describe these accomplishments?*
   - 1-page "science nuggets" from investigators describing project results
   - Reports from the working groups
   - Special volume of research papers
   - Overview publication on SCEC2
   - Formal assessments from SCEC participants and customers

3. *What will be the goals of SCEC3?*
   - Basic science goals
   - New product goals
     - system-level models of the SoCal natural laboratory
     - hazard and risk models
   - Time-dependent earthquake forecasting
     - earthquake prediction
   - End-to-end ("rupture-to-rafters") simulation
   - SCEC collaboratory (Community Modeling Environment)

4. *What structural changes should be made to prepare for SCEC3?*
   - How to transition WInSAR and SCIGN to the PBO era
   - New working groups for EarthScope and/or Tectonophysics
   - Encourage participation/collaboration by foreign institutions
   - Major new partnerships with NEES, the EERCs, and other organizations
   - Leadership transitions

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. Professor Robert Smith, who chaired the SCEC Advisory Council since 2000, stepped down as chair in January, 2004. Sean Solomon is the new AC chair, effective January, 2004. The Advisory Council convened at the SCEC Annual Meeting in September 2004, and their report is reproduced verbatim below.

Table VI.1. SCEC Advisory Council for 2004

Sean SOLOMON (Chair), Carnegie Institution of Washington, Washington, DC
Jeff FREYMUELLER, University of Alaska, Geophysical Institute, P.O. Box 757320, Fairbanks, AK 99775-7320
Raul MADARIAGA, Laboratoire de Geologie, Ecole Normale Superieure, 24 Rue Lhomond, Cedex 05, 75231 Paris, FRANCE
Jack MOEHLE, Pacific Earthquake Eng. Research Center, 1301 S. 46th St., Bldg. 451, Richmond, CA 94804-4698
Farzad NAEIM, John A. Martin & Associates, 1212 S. Flower St., Los Angeles, CA 90015
Garry ROGERS, Geological Survey of Canada, Box 6000, Sidney, V8L 4B2, BC, Canada
Chris ROJAHN, Applied Technology Council, 555 Twin Dolphin Dr., Ste. 550, Redwood City, CA 94065
Haresh SHAH, RMS, Inc., 149 Commonwealth Dr., Menlo Park, CA 94025
Robert SMITH , University of Utah, Department of Geology and Geophysics, Salt Lake City, UT 84112-1183
Ellis STANLEY, City of Los Angeles, Emergency Preparedness Department, 200 N. Main Street, Room 1500, Los Angeles, CA 90012
Susan TUBBESING, EERI, 499 14th St., Suite 320, Oakland, CA 94612-1902

Report of the Advisory Council
Southern California Earthquake Center
September 2004 Meeting

Introduction

The Advisory Council of the Southern California Earthquake Center (SCEC) met during the 2004 SCEC Annual Meeting, held in Palm Springs, California, on 19-23 September 2004. The principal meeting of the Council was during the evening of 22 September; an earlier executive session of the Council was held prior to the start of the Annual Meeting on 19 September to outline areas of focus. A report of the principal findings and recommendations was made orally to those attending the Annual Meeting during the closing session on the morning of 23 September.

Prior to the Annual Meeting the SCEC Director circulated to Advisory Council members a three-page list of issues warranting Council attention. Those issues included assessments of SCEC's system-level approach to earthquake science; SCEC's partnership activities; the geographic scope of SCEC's focus; the goals and objectives for the next proposed phase of the Center (so-called SCEC3); and the membership, agenda, and meeting schedule of the Council. For each major issue, the SCEC Director posed a series of specific subsidiary questions.

After some general comments, we group the bulk of our discussion and recommendations below in line with those five issues and the corresponding subsidiary questions.

General Impressions and Recommendations

Because the members of the Advisory Council are not also members of SCEC, the Annual Meeting is of particular importance as a measure of annual progress on the goals and programs of the Center. One metric on that progress is meeting attendance, which continues to grow and reached an all-time high at this year's meeting. Another is the range of topics on which new results were presented and engaging discussions ensued. Even compared with one year earlier, the diversity of subjects treated and the maturity of much of the Center's highest-priority work have advanced noticeably.

Presentations on two topics made particularly positive impressions on Advisory Council members. The first is the Community Modeling Environment, the managed computational facility for validating and inter-comparing numerical codes for fault rupture, wave propagation, and other elements of the seismic hazard analysis problem. The combination of state-of-the-art information technology tools for computation and visualization together with the integrative, open approach promises to provide a critical resource both to seismologists and to the engineering and management user communities.

The second is the TerraShake simulation of ground motions from a specified model of fault rupture within a three-dimensional representation of the fault system and seismic velocity structure of Southern California. This computational tour de force, with its compelling visualization of wave propagation and ground accelerations, provided dramatically graphical lessons concerning the effects of rupture directivity and the focusing of energy by sediment-filled basins and other structures. The promise of such simulations for understanding seismic hazards, and for pointing in directions where improved observations or better models would be most worthwhile, is enormous.

On the basis of all of the presentations and discussions at the Annual Meeting, the Advisory Council has several general recommendations to offer.

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.

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.

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.

SCEC's System-level Approach

A primary goal of SCEC during its second phase as a Center (so-called SCEC2) has been to develop a system-level approach to earthquake science that can improve seismic hazard analysis and contribute to a reduction in earthquake risk. The Advisory Council was specifically asked:

a. *Has this approach been successful in advancing earthquake science? Will it lead to substantial improvements in seismic hazard analysis?*
b. *Is it an appropriate basis for continuing the SCEC collaboration?*
c. *Do [SCEC's] accomplishments on this problem warrant the continuation of the program into the next 5-year phase (SCEC3)?*

In response to these queries, the Advisory Council affirms that the system-level approach to earthquake science that SCEC has pioneered is novel, appears to be demonstrating substantial progress, and is the type of integrative effort most appropriate for a multi-institutional, mission-focused Center. The approach that SCEC has taken in its system-level representation of tectonic elements and seismic structure in Southern California — including the Community Velocity Model, the Community Fault Model, the Community Crustal Motion Map, the Community Block Model, and the Unified Structural Representation — integrates all available observations through an open process that involves all interested members of the community. In parallel with the development of regional models, through the Community Modeling Environment SCEC has developed a system-level approach to the management of simulations and visualizations and the curation of data products. Most importantly, the well-documented SCEC approach stands as an exemplary model on which similar efforts for other earthquake-prone regions can build.

As noted above, end-to-end simulations of ground motion from specific fault rupture scenarios presented at the Annual Meeting constitute compelling evidence that SCEC's system-level approach promises to provide a capability for substantial improvements to ground motion estimation and seismic hazard analysis. Whether that capability will modify current methods for such analysis is less clear at present. In large measure, the success of SCEC's effort to improve the state of seismic hazard analysis will depend on the extent to which the user community adapts SCEC's tools and methodology into standard practice.

SCEC's system-level approach to earthquake science is nonetheless a clearly appropriate basis for continuing the SCEC collaboration. The community models and modeling environment are just now reaching levels of maturity to test diverse scenarios for Southern California fault behavior. Further, as mentioned earlier, these models should provide a clear basis for deciding where new observations and observational approaches are needed to fill gaps in knowledge or to foster new monitoring tools. Finding an optimum balance between system-level and observational approaches will be a high priority for SCEC throughout the lifetime of the Center.

The answer to the final question above should be obvious. SCEC's accomplishments to date readily warrant continuation of the Center's programs into another 5-year phase (SCEC3). Proposals to federal, state, and private organizations for support of such an endeavor should be prepared as opportunity permits.

SCEC's Partnership Activities

To accomplish its goal of reducing earthquake risk, SCEC has sought a range of partnerships in earthquake engineering, emergency management, and public outreach and education. The Advisory Council has been asked:

a. *How effective has SCEC been in creating and managing its partnerships?*
b. *In particular, how would [the Council] evaluate SCEC's Implementation Interface activities?*
c. *What new partnerships should be considered for SCEC3 to improve [the Center's] impact on risk reduction?*
d. *Is there too much or too little emphasis on practical products for seismic hazard analysis and risk reduction?*

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 Pacific Earthquake Engineering Research Center (PEER)-Lifelines/SCEC/U.S. Geological Survey (USGS) New Generation Attenuation Project and the end-to-end ("Rupture to Rafters/Rivets") simulation initiative. As part of SCEC's Communication, Education, and Outreach Program, partnered activities include the SCEC/CUREE/IRIS Electronic Encyclopedia of Earthquakes and the web portal managed by the Earthquake Country Alliance. 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's Geographic Scope

SCEC has a natural and appropriate focus on Southern California as a laboratory for earthquake science and hazards. Nonetheless, seismology is informed by insight gained from earthquakes throughout the globe. The Advisory Council was therefore asked:

a. *What is the appropriate geographic scale for SCEC science? Should it remain a regional Center?*
b. *Are [SCEC's] initiatives to form other regional partnerships an appropriate way to diversify the study of earthquake systems?*
c. *Would [the Council] encourage [SCEC] to put forward an international Center-based initiative to the NSF Office of International Science and Engineering? What are the pace and selection issues associated with such an initiative?*

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. A large fraction of SCEC members are from institutions within Southern California, which can most readily maintain local geological and seismological field programs. The enormous investment by SCEC to date in understanding the tectonics and structure of Southern California provides additional rationale to continue such a focus.

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.

Goals and Objectives for SCEC3

Plans for the next 5-year phase of SCEC received an understandably large share of attention during the Annual Meeting, as SCEC leadership and membership wrestle with the question of how best to prioritize goals for SCEC3. The Advisory Council was specifically asked to comment on the following questions:

a. *What will be the goals and objectives of SCEC3? Basic science goals? New product goals (e.g., system-level models of the Southern California laboratory; hazard and risk models)? Time-dependent earthquake forecasting (earthquake prediction)? End-to-end ("rupture to rafters") simulation? SCEC collaboratory (Community Modeling Environment)?*
b. *What structural changes should be made to prepare for SCEC3? How to transition WInSAR and SCIGN to the PBO era? New working groups for EarthScope and/or Tectonophysics? Move forward on international collaborations? Major new partnerships and/or other organizations? Leadership transitions?*

By the end of SCEC2, several of the Center's activities will still be underway, and some will have considerable scientific momentum. Activities during SCEC3 that harvest such momentum can therefore be anticipated. Nonetheless, to present a compelling vision for continued funding, SCEC3 should offer several new initiatives — directions in earthquake science beyond those now being pursued by the community.

Without prejudging the selection of what those initiatives should be, the Advisory Council recommends that those initiatives should satisfy several criteria. They should be sharply focused. They should be based firmly on fundamental questions in basic science. They should address goals that are achievable only by a multi-institutional Center. And those goals should be attainable within a 5-year time frame.

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.

Within SCEC, a Tectonophysics Focus Group is warranted on scientific grounds; some rebalancing of assignments among working groups may be needed as a consequence. As noted above, carefully selected international collaborations make sense as a means to broaden the sweep of natural laboratories and enhance the opportunity for important lesson-forming events.

SCEC has made visible effort to promote early-career scientists to leadership positions within Center activities. This laudable effort takes optimum advantages of the energy and ideas of younger members of the community, offers opportunities to enhance the diversity of SCEC leadership, and builds a cadre of younger leaders to whom the Center and the community can turn when transitions in senior leadership are needed.

Advisory Council Issues

The structure and charter for the Advisory Council should be devised so as to provide the most effective and constructive feedback for the Center on a regular basis. Specific questions posted to the Council included the following:

a. *Should [SCEC] consider new appointments or rotations, especially given the difficulty some members have had in attending AC meetings? Should [SCEC] add expertise in other areas, such as IT?*
b. *What should be the focus of the AC during the SCEC3 planning process? A SCEC3 proposal will require external assessments, probably at several levels. Should the AC configure a formal assessment process?*
c. *What should be the AC's meeting schedule? Thus far in SCEC2, the AC has met yearly at the Annual Meeting. Should a mid-year meeting be added, which was the tradition in the early days of SCEC1?*

To provide the continued infusion of fresh ideas to SCEC planning efforts, the Center should consider instituting a formal rotation of Advisory Council members. The earliest rotations should be for those members whose schedules make it difficult for them to participate in SCEC Annual Meetings.

As new appointments are made to the Advisory Council, the expertise represented should be broadened over that of the current Council membership. Adding an expert in Information Technology should be a top priority.

The Advisory Council will assist in the preparation of the proposal for SCEC3 by providing a review of a pre-submission proposal draft. The Council is willing to add a mid-year meeting to enable such a review.

Concluding Comments

The Advisory Council is pleased to provide continued assistance to SCEC in its efforts to formulate and accomplish its major goals. The Council invites comments, criticism, and advice from the seismological community, including those both inside and outside SCEC membership, on how best to provide that assistance.

The Advisory Council looks forward to working with SCEC leadership to craft a compelling scientific and societal rationale for the continuation and expansion of SCEC activities.

VII. Financial Report

Table VII.1 gives the breakdown of the SCEC 2004 budget by major categories. The list of individual projects supported by SCEC in 2004 can be found on the website http://www.scec.org/research/2003research/index.html.

Table VII.1 2004 Budget Breakdown by Major Categories

Total Funding (NSF and USGS):	$3,910,000
Budgets for Infrastructure:	$ 1,185,320
Management	280,000
CEO Program	385,000
Annual, AC, Board, and PC Meetings	150,320
Information Architect	170,000
Director's Reserve Fund	150,000
SCEC Summer Intern Program	50,000
Budgets for Disciplinary and Focus Group Activities: (including workshops)	$ 2,724,680
Earthquake Source Physics and FARM	502,700
Ground Motions	170,000
Velocity Structure and Seismology	549,700
Seismic Hazard Analysis	286,580
Fault Systems	543,000
Geodesy	607,700
Workshops	65,000

VIII. Report on Subawards and Monitoring

The process to determine funding for 2004 began with discussions at the SCEC annual meeting in Oxnard in September, 2003. An RFP was issued in October, 2003 and 181 proposals were submitted in November, 2003. Proposals were then sorted and sent out for review in mid-December, 2003. 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 19-20, 2004 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 2004 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 2-3, 2004. The board voted 15-0 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 20034 was $3.91M. The board approved $280K for administration; $385K for the communications, education, and outreach program; $150K for workshops and meetings; and $170K for the information technology program. We also received a $50,000 supplement from NSF for a 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 ($150,000) fund for supporting projects at his discretion. This funding was used to provide additional workshop support, RELM activities, send two students to a meeting in Japan, NGA-H work, and a project on velocity attenuation.

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 2004 are shown in the table below for both the USGS and NSF components of SCEC funding.

Table VIII.1 SCEC Subcontracts for 2004

USGS Funds

ABS Consulting	15,000	
Boston U	10,000	
Cal State-Fullerton	10,980	
Caltech	155,000	Data Center Only
ECI	17,000	
Harvard	138,000	
LANL	27,500	
LLNL	45,000	
Oregon	38,500	
Oregon State	31,500	
San Diego State	10,000	
Stanford	43,500	
UCI	5,000	
UCLA	30,000	
URS	126,000	
Utah State	13,000	
Texas	5,000	
Western Ontario	21,000	
WHOI	15,000	

NSF Funds

British Columbia	15,000	
Brown	37,700	
Caltech	183,300	Science only
Cal State, San Bernardino	29,400	
Case Western	40,000	
Colorado	16,000	
Kentucky	20,000	
LDEO	45,000	
MIT	82,500	
North Carolina	22,300	
Princeton	15,000	
RPI	30,000	
Rice	15,000	
SDSU	221,500	
Texas A&M	20,000	
U Mass	17,500	
UCB	38,000	
UCD	10,000	
UCLA	161,400	
UCR	41,000	
UCSB	236,200	
UCSC	15,000	
UCSD	171,300	
UNR	87,000	

Report on 2004 SCEC Cost Sharing

The University of Southern California contributes substantial cost sharing for the administration of SCEC. In 2004, USC provides $280,000 for SCEC administration costs, waived $671,000 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.

SCEC Management Cost-Sharing Report for 2004

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

Institution	**Amount**	**Purpose**
USC	$213,400	Salary Support of Jordan, McRaney, S. Henyey
	$10,000	Report Preparation and Printing
	$11,000	Meeting Expenses
	$7,500	Office Supplies
	$5,000	Computers and Usage Fees
	$8,500	Administrative Travel Support for SCEC Officers
	$5,600	Postage
	$21,000	Telecommunications
	$280,000	Total

2. USC waives overhead on subcontracts. There are 41 subcontracts in 2004.

$1,075,000	Amount Subject to Overhead (43 * $25,000)
0.625	USC Overhead Rate
$671,875	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 2004.

Institution	SCEC Cost-Sharing for 2004 Amount	Purpose
USC	$12,000	Student Support
	$3,000	Research Support/Supplies
	$5,000	Visitor Support Geoff King and Matt Holschneider
	$15,000	Research Faculty Salary Support
	$35,000	Total
Harvard	$6,412	Staff Salaries and Benefits
	$3,831	SCEC-Related Travel
	$24,487	Equipment and Research Supplies
	$34,730	Total
UCSD	$15,000	Pinon Flat Observatory Operation
	$15,000	Software Development
	$10,000	WiNSAR Archive
	$10,000	Hardware Maintenance/Supplies
	$50,000	Total
Columbia/LDEO	$1,673	Administrative Salary Support
	$1,412	Travel for James Gaherty
	$33,746	Salary Support for Leonardo Seeber
	$36,831	Total
UCSB	$2,022	Salary Support for Visiting Faculty
	$2,248	Student Salary
	$6,385	Travel Support
	$2,821	Supplies and Expenses
	$3,500	Staff Salary
	$16,000	SCEC Postdoc
	$2,000	Equipment
	$34,976	
Stanford	$35,000	Graduate Student Fellowship
	$18,190	Graduate Student/Post-Doc Travel
	$53,190	Total
UCLA	$21,774	Salary Support for Research Personnel
	$11,857	Supplies
	$1,369	Travel
	$35,000	Total

MIT	$46,711	Computer Cluster Purchase
	$24,210	Graduate Student Fellowship
	$6,900	Geophysics Field Camp
	$77,821	
SDSU	$5,118	Software Licenses and Support
	$4,041	Equipment
	$12,925	Staff Salary
	$11,774	PI Salary
	$1,142	Supplies
	$35,000	Total
UNR	$24,701	Salary for Research Faculty Rasool Anooshehpoor
	$11,262	Salary for Research Faculty Zeng Su
	$8,400	Salary for PhD Student Aasha Pancha
	$44,363	Total
Caltech	$26,058	Two Gutenberg Graduate Student Fellowships
	$47,569	Moore/Richter Graduate Student Fellowship
	$43,218	Housner Graduate Student Fellowship
	$116,845	Total
USGS/Pasadena	$350,000	Support for SCIGN (Salaries and Materials)
	$127,000	Support for RELM (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	7	16	35	27	17
Black	1	0	1	1	0
White	30	123	82	151	43
Native American	0	3	6	1	0
Pacific Islander	0	0	1	0	1
Ethnicity					
Latino	1	5	9	7	4
Not Latino	33	118	84	148	49
No information	3	15	18	24	7
Withheld	2	3	11	5	4
Gender					
Female	16	21	46	50	28
Male	22	119	75	133	35
Withheld/No Info	1	1	1	1	1
Citizenship					
US	35	109	58	124	54
Other	2	11	45	28	2
No information	2	8	12	15	6
Resident	0	13	3	16	2
Withheld	0	0	4	1	0
Disability Status					
None	32	108	78	139	51
No information	7	30	45	40	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 two international members of our Advisory Council. They are Raul Madariaga of Ecole Normale Superieure, Paris and Garry Rogers of Geological Survey of Canada, Sydney.

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. 30 U.S. scientists (most affiliated with SCEC) participated in the ACES biennial meeting in July, 2004 in Beijing, China. There were 95 international participants (15 from Australia, 50 from China, 1 from New Zealand, 2 from Mexico, 2 from Germany, and 25 from Japan).

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 network has stations in Baja California and on Isla Guadalupe. Scientists from CICESE in Ensenada, Mexico participate in the SCIGN program.

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 2004 annual meeting from China, Japan, India, Mexico, Canada, France, Switzerland, Germany, Russia, and New Zealand.

10. International Participating Institutions. ETH/Zurich, CICESE/Mexico, and 4 institutions from Taiwan (Academia Sinica; National Central University; National Chung Cheng University; National Taiwan University) are participating institutions in SCEC. Tom Jordan and Jeroen Tromp gave seminars at a workshop in Taiwan in April, 2004.

11. Pacific GeoHazards Laboratory. Scientists from Russia, Japan, Canada, Mexico, China and the U.S. participated in this workshop.

12. US/Japan Natural Resources Council Meeting. This meeting was attended by 20 scientists from Japan and 30 from the U.S.

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, 2003 and December, 2004.

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767. Anderson, John G., QUANTITATIVE MEASURE OF THE GOODNESS-OF-FIT OF SYNTHETIC SEISMOGRAMS, Proceedings, 13th World Conference on Earthquake Engineering, in review, 2003.

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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 (<□00 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. 2005 PROGRAM ANNOUNCEMENT
FOR THE SOUTHERN CALIFORNIA EARTHQUAKE CENTER

I. INTRODUCTION

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

II. GUIDELINES FOR PROPOSAL SUBMISSION

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

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

C. Formatting Instructions.

- ***Cover Page:*** Should begin with the words "2005 SCEC Proposal," the project title, Principal Investigator, institution, proposal categories (from types listed in Section IV, including the new SCEC Intern Support category), and the disciplinary committee(s) and focus group(s) that should consider your proposal. Indicate if the proposal should also be identified with one or more of the SCEC special projects (see Section VII) or advanced Implementation Interface projects (see Section VIII for examples). Collaborative proposals involving multiple investigators and/or institutions should list all principal investigators. Proposals do not need to be formally signed by institutional representatives, and should be for one year, with a start date of February 1, 2005.
  - ***Technical Description:*** Describe in **five pages or fewer (including figures)** the technical details of the project and how it relates to the short-term objectives outlined in the SCEC Science Plan (Section VII).
  - ***Budget Page:*** Budgets and budget explanations should be constructed using NSF categories. Under guidelines of the SCEC Cooperative Agreements and A-21 regulations, secretarial support and office supplies are not allowable as direct expenses. Budgeted matching funds for SCEC interns will only be awarded if a PI for the project is paired with a student intern.
  - ***Current Support:*** Statements of current support, following NSF guidelines, should be included for each Principal Investigator.
  - ***2004 Annual Report:*** Scientists funded by SCEC in 2004 must submit a report of their progress with the 2005 proposals. 2005 proposals lacking 2004 reports (which may cover 2003 to mid-year 2004 results) will neither be reviewed nor will they be considered for 2005 funding. Reports should be up to five pages of text and figures.
  - ***Science Nuggets:*** All SCEC2 PI's must submit "science nuggets" that highlight their research findings in SCEC2. Nuggets that highlight interdisciplinary work are especially important. These nuggets will be needed for the preparation of the SCEC3 proposal. Instructions for submitting these nuggets are at the proposal web site.

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

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

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

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

III. SCEC ORGANIZATION

A. **Mission and Science Goal.** SCEC is an interdisciplinary, regionally focused organization with a mission to:

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

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

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

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

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

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

IV. Proposal Categories

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

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

C. Workshops. SCEC participants who wish to host a workshop between February 2005, and February 2006, should submit a proposal for the workshop in response to this RFP. Workshops in the following topics are particularly relevant:

- Organizing collaborative research efforts for the five-year SCEC program (2002-2007). In particular, interactive workshops that engage more than one focus and/or disciplinary group are strongly encouraged.
- Engaging earthquake engineers and other partner and user groups in SCEC-sponsored research.
- Participating in national initiatives such as EarthScope, the Advanced National Seismic System (ANSS), and the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES).

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

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

V. Evaluation Process and Criteria

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

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

- All research proposals will be evaluated by the appropriate disciplinary committees and focus groups, the Science Planning Committee, and the Center Director. CEO proposals will be evaluated by the CEO Planning Committee and the Center Director.
- The Science Planning Committee is chaired by the Deputy Director and comprises the chairs of the disciplinary committees, focus groups, and special projects. It is responsible for recommending a balanced science budget to the Center Director.
- The CEO Planning Committee is chaired by the Associate Director for CEO and comprises experts involved in SCEC and USGS implementation, education, and outreach. It is responsible for recommending a balanced CEO budget to the Center Director.
- Recommendations of the planning committees will be combined into an annual spending plan by the Executive Committee of the SCEC Board of Directors and forwarded to the Board of Directors for approval.
- Final selection of research projects will be made by the Center Director, in consultation with the Board of Directors.
- The review process should be completed and applicants notified by the end of February, 2005.

VI. Coordination of Research between SCEC and USGS-ERHP

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

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

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

The EHRP web page, http://erp-web.er.usgs.gov/, describes program priorities, projects currently funded, results from past work, and instructions for submitting proposals. The EHRP external funding cycle is several months offset from SCEC's, with the RFP due out in February and proposals due in early May. Interested PI's are encouraged to contact the USGS regional or topical coordinators for Southern California, Earthquake Physics and Effects, and/or National (PSHA) research, as listed under the "Contact Us" tab.

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

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

VII. Research Objectives

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

A. Disciplinary Activities

The Center will sustain disciplinary science through standing committees in *seismology*, *geodesy*, *geology*, and *fault and rock mechanics*. These committees will be responsible for planning and coordinating disciplinary activities relevant to the SCEC science plan, and they will make recommendations to the SCEC Planning Committee regarding the support of disciplinary infrastructure. High-priority disciplinary objectives include the following tasks:

1. Seismology

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

Other activities might include seed money for design of future experiments such as dense array measurements of basin structure and large earthquake properties, OBS deployments, and deep basement borehole studies.

• ***Data Products:*** Improve the ability of users to retrieve seismograms and other seismic data and enhance the usefulness of data products, such as catalogs of earthquake parameters, arrival time and polarity information, and signal-to-noise measures. An important SCEC resource is the

Southern California Earthquake Data Center (SCEDC), whose continued operation is essential to deciphering Southern California seismicity, crustal and fault structure.

Enhancements to the SCEDC are encouraged that will extend its capabilities beyond routine network operations and waveform archiving, and assist researchers in using more of the data.

Desirable improvements include support hardware and software enhancements, better integration with data centers in other regions, and expansion of catalogs, including the offshore region. Specific goals include: 1) Developing the ability to preview seismograms and directly load waveforms into programs, 2) Implementing software that permits access to both northern and southern California data with a single data request, and 3) Incorporating first motion and moment tensors as they become available.

2. Tectonic Geodesy

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

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

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

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

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

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

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

3. Earthquake Geology

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

• ***Data Products:*** Integrate field and laboratory efforts to date geologic samples and events, including standardized procedures for field documentation, sample treatment, dating methodologies, and data archiving and distribution (FAD); produce long-term rupture histories for selected fault systems in Southern California, with specific interest in the Los Angeles, Mojave, and southern San Andreas systems; address the GPS/geology discrepancy for some faults; construction of a community vertical motions map (10^5 year timescale).

4. Fault and Rock Mechanics

• ***Data Gathering:*** Areas of FARM research include fault modeling, laboratory studies, field studies of exhumed faults, and studies of faults from drill cores. While all areas of FARM research in support of the interdisciplinary working groups will be considered, greatest emphasis will be given to research that can increase our understanding of fault behavior during dynamic earthquake slip and thereby provide useful input for models of dynamic rupture propagation. In particular, emphasis will be given to: 1) pilot studies designed to develop and test new techniques, or to develop a new facility, to measure sliding resistance of faults at seismic slip rates, 2) detailed characterizations of natural slip surfaces and the products of high-speed deformation experiments to identify the structures diagnostic of dynamic slip and to test hypotheses of dynamic weakening, 3) modeling activities to predict fault behavior during dynamic slip with extreme weakening, 4) field studies geared towards developing a model of the 3D structure of a fault zone, particularly to define and quantify geometric and material property variations that influence rupture propagation, 5) developing a database for large strike-slip faults world-wide that could serve as analogs to the seismogenic depth range of the modern San Andreas fault in Southern California and that includes information about tectonic setting and history, depth of exhumation, locations, quality and extent of exposures, and an annotated bibliography for each fault including any relevant fault and rock mechanics research, 6) modeling fault behavior on the San Andreas near the EarthScope SAFOD site and collaborative studies of the structure and properties of material recovered during SAFOD drilling, and 7) cataloging of and studies of existing industry core material crossing significant faults in Southern California in order to address fault zone process questions. Also of importance, but of lower priority, is to conduct coordinated field, laboratory and theoretical studies to determine the time evolution of physical parameters during the inter-seismic period that might control the onset and characteristics of earthquake faulting. Such parameters might include those controlling fault/fluid interactions and frictional properties.

• ***Data Products:*** Assess information and products from rock-mechanics experiments and fieldwork that will be most useful in SCEC studies of earthquake source physics and fault-system dynamics; develop an IT framework for an open database of experimental, model, and field results and expand upon existing databases.

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

B. Interdisciplinary Focus Areas

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

1. Structural Representation

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

• ***Community Fault Model (CFM):*** Improve and evaluate the CFM, placing emphasis on: a) defining the geometry of major faults that are incompletely, or inaccurately represented in the current model; b) producing alternative fault representations; and c) providing more detailed representations of fault terminations and linkages. Emphasis will be placed on evaluating CFM 2.0 and its alternative fault representations.

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

2. Fault Systems

• ***Fault-System Behavior:*** Investigate the system-level architecture and behavior of fault networks to better understand the cooperative interactions that take place over a wide range of scales, assessing the ways in which the system-level behavior of faults controls seismic activity and regional deformation; infer rates of change in stress from geodetic and seismic observations; compare and interpret quantitatively short-term geodetic rates of deformation, long-term geologic rates, and rates predicted by seismicity simulators; quantify the space-time behavior of the Southern California fault system in ways that are targeted to test models of earthquake occurrence and stress evolution; foster collaborations to obtain outside funding to support large, coordinated data-gathering efforts; determine how geologic deformation is partitioned between slip on faults and distributed off fault deformation and how geodetic strain is partitioned between long-term permanent and short-term elastic strain and on-fault slip or permanent distributed strain.

• ***Deformation Models:*** Develop, validate, and facilitate use of modular 3D quasi-static codes for simulating crustal motions utilizing realistic, highly resolved geometries and rheological properties (e.g., Burgers body viscoelasticity, rate-state friction, poroelasticity, damage rheology); develop continuum representations of fault system behavior on scales smaller than can be resolved as faulting on computationally feasible meshes; develop a closed volume representation of southern California (Community Block Model—CBM) that unifies the geometric representations of CFM and the CVM and that serves as a basis for efficient meshing and remeshing of models; generate finite element meshes of the CBM; assess mechanical compatibility of CFM and how slip is transferred between recognized fault segments; develop a reference model of the time-dependent stress transfer and deformation associated with the 1992 Landers earthquake; extend models of time-dependent stress transfer and deformation of Southern California to cover multiple earthquake cycles addressing geologic slip rates, geodetic motions (including CMM 4.0), and earthquake histories; use these models to infer fault slip, 3D rheologic structure, and fault interactions through the transfer of stresses; couple numerical models of the interseismic period to quasi-static full-cycle fault models to better constrain stress transfer and conditions and processes at the start of dynamic rupture, including forcing by realistic coseismic displacements and dynamic stresses (with Source Physics); develop tectonic models that explain the inferred rates of fault slip; develop a plan for post-earthquake geodetic deployments.

• ***Seismicity Evolution Models:*** Determine the effects of fault system scale and resolution in models of geometrically complex fault systems; develop and validate rapid simulation methods for modeling earthquakes in fault systems over a wide range of magnitudes (with Source Physics); develop, validate, and facilitate use of codes for ensemble models simulating earthquake catalogs using CFM, USR and CBM, as well as effects of faults not included in CFM; incorporate constraints (including data assimilation) from geologic slip rates, geodetic data, realistic boundary conditions, and fault rupture parameterizations, including rate-state friction and normal stress variations; assess the processes that control the space-time-magnitude distribution of regional seismicity; quantify sources of complexity, including geometrical structure, stress transfer, fault zone heterogeneity, and slip dynamics; assess the utility of these models in forecasting Southern California earthquakes; search for statistically significant signals in the space-time- magnitude distribution of seismicity and understand their physical origin.

3. Earthquake Source Physics

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

- Conduct numerical simulations of dynamic rupture nucleation, propagation, and termination that include known or realistic complexity in fault geometry, material properties, stress state, and constitutive relations. Compare results with source and fault zone observations. Use this information to test hypotheses or develop new testable hypotheses about earthquake source physics.
- Explore what aspects of the source generate high-frequency waves.
- Explore what aspects of the source and fault zone determine propagation direction (directivity).
- Use numerical simulations results to guide seismic hazards analysis (Joint with SHA Focus Group), such as quantifying fault-to-fault rupture probabilities for earthquake forecasting.
- Participate in the code validation exercises for 3D spontaneous rupture simulations (also Pathway 3 of the SCEC ITR) by performing benchmark tests and comparing results with the rest of the ESP and Pathway 3 community. As part of this exercise, use the M6.0 2004 Parkfield earthquake as a validation test. (Joint with GM Focus Group).
- Bridge the interface between Earthquake Source Physics and Fault Systems by conducting physics-based fully dynamic multi-earthquake-cycle simulations, and by determining if simpler, quasi-dynamic or quasi-static simulations may suffice as a proxy for full dynamic simulations in long-term fault-systems simulations. (Joint with FS Focus Group)
- Participate in NGA-H. Investigate particular problems of interest to NGA-H, including the observation that ground-rupturing earthquakes produce smaller ground motion than buried earthquakes.

See Section VIII, Part A4 – Implementation Interface Focus Area – for more information on the NGA-H Program.

• ***Reference Earthquakes***
Building on efforts started in 2004, continue construction of a database that includes geodetic, geologic, and seismological data (and metadata), as well as models derived from them. The goal is to facilitate comparison of different models and analysis of multiple datasets. The reference earthquake database will be used for testing/validation of earthquake physics concepts and modeling techniques, and will serve as a template for additional reference earthquakes.

• ***In-Situ Studies of Fault-Zones (Exhumed Faults & Deep Cores)***
Examine and document features of fault zones in Southern California, including the San Andreas fault system, Parkfield, and the SAFOD site, that reveal the mechanical, chemical, thermal, and kinematic processes that occur during dynamic rupture.□nclude measurements and inferences of on-fault and near-fault stress, slip-zone thickness, fine-scale fault-zone geometry, adjacent damage, and fluid content at seismogenic depths. (Joint with Geology and FARM Discipline Groups)

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

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

• ***Earthquake Interaction as an Approach to Explain Earthquake Physics***
Use observations of earthquake triggering or suppression to test models of earthquake interaction and constrain the physics of earthquake rupture nucleation, propagation, and arrest.

4. Ground Motions

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

• ***Inversion and CVM Testing:*** Use data from well-recorded earthquakes to assess wavefield simulations based on the CVM. Identify regions where CVM fails to predict ground motion.

Develop methods to invert ground motion data for source and path effects, their resolution and uncertainties. Improve the S-wave velocity structure in the CVM and the Harvard model by inversion of waveform data.

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

• ***Non-Linear Site Response*****:** Develop methods for incorporating nonlinear site response for large amplitude ground motion events in Southern California. Ideas that improve our understanding of linear site response should lead to a new understanding of how site response varies spatially. Investigate soil- (building) structure interaction and its effect on ground response including nonlinear effects.

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

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

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

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

5. Seismic Hazard Analysis

• ***OpenSHA*****:** Contribute to the Community Modeling Environment for Seismic Hazard Analysis (known as OpenSHA; www.OpenSHA.org). This is an open-source, object oriented, and web-enabled framework that will allow various, arbitrarily complex (e.g., physics based) earthquake-rupture forecasts, ground-motion models, and engineering response measures to plug in for SHA. Part of this effort is to use information technology to enable the various models and databases they depend upon to be geographically distributed and run-time accessible. Contributions may include: 1) implementing any of the various components (in Java or other language), 2) testing any of the various components/applications, 3) extending the existing framework to enable other capabilities, such as vector-valued hazard analysis, to interface with existing risk/loss estimation tools, or to web-enable the testing of the various RELM forecast models, and 4) conducting outreach activities (e.g., workshop) with potential user groups.

• ***Regional Earthquake Likelihood Models (RELM):*** Via the RELM working group, develop, submit (for testing and SHA), and publish viable earthquake-forecast models for southern California or the entire state (the more physics based approaches should be developed in coordination with the Fault Systems focus group). Of particular interest are simulations methods to extend "next-event" forecasts to forecasts of all possible sequences of events. Continue the development of shared data resources needed by the RELM working group, especially in terms of making them on-line and machine readable. These should be coordinated with other focus/disciplinary groups as appropriate (e.g., the needed quantification of alternative, internally-consistent fault-system representations should be coordinated with the CFM effort). Establish and implement quantitative tests of the various forecast models using observed seismicity, precarious-rock constraints, historically observed intensity levels, or other viable approaches. Conduct workshops to facilitate the various RELM activities (e.g., to establish standards for testing the models).

• ***Contribute to SCEC's System-Level Earthquake Rupture Forecast Model:*** We encourage development of a system-level earthquake forecast employing relevant information from geology, seismology, and geodesy, comparable in scope to those reported by the Working Group on California Earthquake Probabilities. See http://www.RELM.org/models/scec_erf for details. The structure of this model is necessarily object oriented, enabling different groups to develop the different modular components separately, as well as enabling alternative components (e.g., with more or less physics) to be swapped in or added later. Proposals will be considered for participation in the following tasks: 1) quantify alternative, complete, viable fault models (CFMs); 2) compile paleoseismic data for these faults; 3) develop regional deformation models (slip and loading rates on and off faults) by combining geologic and geodetic constraints with the fault models; 4) develop models of the rate and/or probability of earthquake rupture on the fault(s) (e.g., based on a synoptic view of paleoseismic data; with or without fault segmentation); 5) help constrain fault-to-fault rupture probabilities using dynamic-rupture modeling (or by compiling previous results thereof) 6) develop stress-change-dependent probability models; 7) develop stress-change monitors or calculators that provide the average stress change on an arbitrary surface caused by an arbitrary rupture (e.g., using Coulomb or viscoelastic models, or by inversion of observed seismicity using rate and state), 8) develop methods of adding foreshock/aftershock statistics to the model.

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

C. Special Projects

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

1. SCIGN (www.scign.org)

Southern California now benefits from a state-of-the-art geodetic array for monitoring earthquake-related crustal deformation, and we encourage use of these data in support of the SCEC science goals and mission. The Southern California Integrated GPS Network (SCIGN), an array of 250 continuously operating GPS stations and one long-baseline laser strainmeter, tracks regional strain changes with unprecedented precision. Scientists of organizations participating in SCEC designed and manage SCIGN; SCEC also played a vital coordinating role in making SCIGN possible. The array is now operational and is already providing horizontal station velocities good to within 1 mm/yr for most stations. SCIGN maintenance is now funded by PBO/UNAVCO (which will maintain 125 sites), the USGS (which will maintain 90+ sites) and southern California counties (which will maintain the remaining sites). The SCIGN network provides data with which to improve seismic hazard assessments, through the innovation of new methods as part of the SCEC seismic hazard analysis efforts. SCIGN will also enable us to quickly measure the larger displacements that occur during and immediately after earthquakes, and it is important that these static deformation data are integrated with other intensity measures for use by emergency responders and the engineering community, through SCEC's Implementation Interface efforts. SCEC encourages proposals that make innovative use of the openly available data from this unique array to further any of the short or long-term scientific goals of SCEC, and in any of the interface areas that will potentially foster greater use of SCIGN data throughout an even wider range of applications.

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

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

To address these issues, new methods, new datasets, and in some cases new technology may need to be developed and/or acquired. This includes the re-examination and analyses of newly released grids of industry seismic data to better quantify the location, subsurface geometry and late-Quaternary history of active offshore structures. More comprehensive detailed mapping of active offshore faults will likely require complete coverage of the Borderland with high-resolution multibeam bathymetry or other high-resolution seafloor imaging systems. Development of high-resolution techniques for conducting paleoseismology in a submarine environment will require innovative multidisciplinary techniques for imaging, sampling, and dating. Long-term monitoring of earthquake activity and geodetic strain in the Borderland will require the establishment of seafloor observatories. Such efforts may be best developed in collaboration with other disciplines (climate, oceanography, marine habitat studies, etc.), programs (EarthScope) and agencies (NOAA, NSF, NURP, etc.). SCEC wishes to encourage and endorse cooperative and collaborative projects that promote these objectives.

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

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

VIII. SCEC Communication, Education, and Outreach Plan

SCEC is a community of over 500 scientists, students, and staff from 50 institutions across the United States, in partnership with many other science, engineering, education, and government organizations worldwide. To facilitate applications of the knowledge and scientific products developed by this community, SCEC maintains a *Communication, Education, and Outreach* (CEO) program with four long-term goals:

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

Short-term objectives are outlined below. Many of these objectives present opportunities for members of the SCEC community to become involved in CEO activities, which are for the most part coordinated by CEO staff. To support the involvement of as many others as possible, budgets for proposed projects should be on the order of $3,000 to $7,000 (Implementation Interface research proposals excluded). Hence proposals that include additional sources of support (cost-sharing, funding from other organizations, etc.) are highly recommended. Those interested in submitting a CEO proposal should first contact Mark Benthien, director for CEO, at 213-740-0323 or benthien@usc.edu.

A. CEO Focus Area Objectives

1. SCEC Community Development and Resources ***(activities and resources for SCEC scientists and students)***
   SC1 Increase diversity of SCEC leadership, scientists, and students
   SC2 Facilitate communication within the SCEC Community
   SC3 Increase utilization of products from individual research projects

2. Education ***(programs and resources for students, educators, and learners of all ages)***
   E1 Develop innovative earth-science education resources
   E2 Interest, involve and retain students in earthquake science
   E3 Offer effective professional development for K-12 educators

3. Public Outreach ***(activities and products for media reporters and writers, civic groups and the general public)***
   P1 Provide useful general earthquake information
   P2 Develop information for the Spanish-speaking community
   P3 Facilitate effective media relations
   P4 Promote SCEC activities

4. Implementation Interface ***(activities with engineers and other scientists, practicing professionals, risk managers, and government officials.***
   I1 Engage in collaborations with earthquake engineering researchers and practitioners
   I2 Develop useful products and activities for practicing professionals
   I3 Support improved hazard and risk assessment by local government and industry
   I4 Promote effective mitigation techniques and seismic policies

B. Implementation Interface Program

1. Earthquake Engineering Research and Professional Practice Organizations: The purpose of the Advanced Implementation Interface is to implement knowledge about earthquake hazards developed by SCEC into research and practice. This is done by fostering collaboration between SCEC scientists and partners that are involved in research or practice in earthquake engineering, or other earthquake-related technical disciplines. Individual SCEC investigators or groups of SCEC investigators are encouraged to identify collaborative projects with individuals or groups of investigators from other organizations. SCEC investigators should request funding within SCEC Focus Groups, especially Earthquake Source Physics and Ground Motions, and describe how the project will relate to projects with partners, such as those listed in the table below. Engineers and other potential partners should seek funding from their own organizations.

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

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

Table 2 lists current potential future project topics that could involve collaboration between SCEC and earthquake engineering organizations. Among these topics, those shown in boldface are components of the new three-year NSF grant described above. Table 2 lists other topics for potential future collaboration between SCEC and earthquake engineering organizations, which are identified in the table as potential co-sponsors of collaborative implementation-oriented work. The identification of these other potential collaborative projects and potential co-sponsors does not imply a commitment on the part of these organizations to co-fund projects. These organizations have their own internal processes for reviewing and approving projects, whose schedules are not necessarily synchronous with the SCEC schedule. Accordingly, the topics not in boldface in Table 2 should be viewed as a preliminary identification of potential mutual interests that could be pursued with additional discussion. Table 2 does not preclude other ideas for collaboration with these or other earthquake engineering organizations.

Table 1. Summary of NSF Project on Implementation Interface

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

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

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