SCEC Community Modeling Environment

A Collaboratory for System-Level Earthquake Science

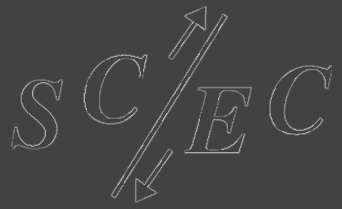
Tom Jordan

Director, Southern California Earthquake Center

University of Southern California

UJNR Meeting

October 15, 2004

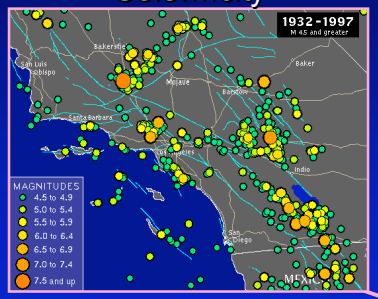


Topics

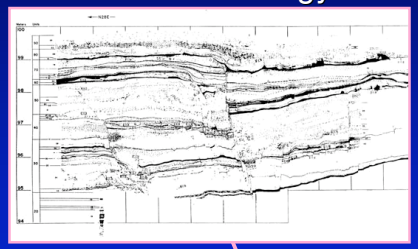
- Overview of the Earthquake Center
  - Structure of SCEC2
- Community Modeling Environment (SCEC/CME)
  - The SCEC “Collaboratory”
- Plans for the Future
  - SCEC3 initiatives for March 1, 2005 proposal
- An Invitation to our Japanese colleagues
  - to joint SCEC and its agency partners (USGS, CGS, NSF) in coordinating common efforts in system-level earthquake science

Seismic Hazard Analysis is a System-Level Problem

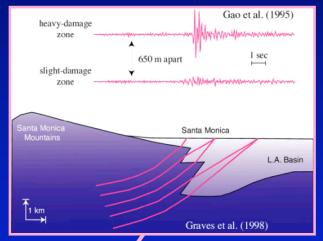
Seismicity



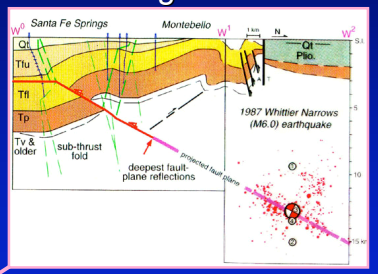
Paleoseismology



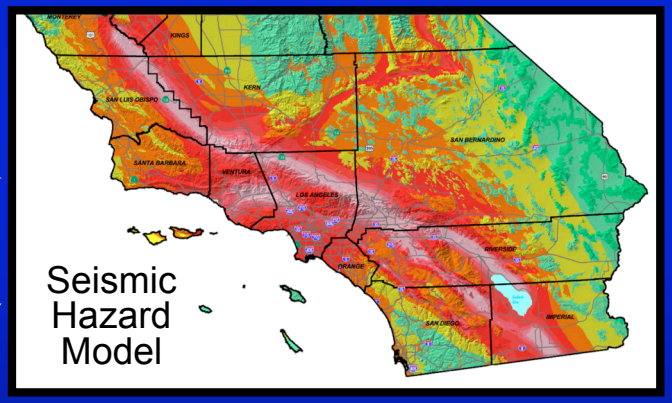
Local site effects

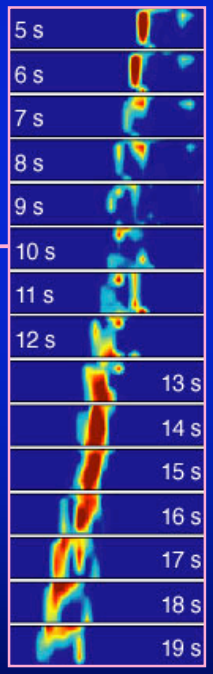


Geologic structure

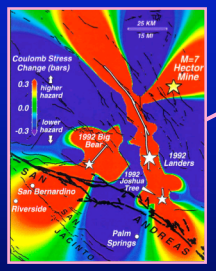


Faults

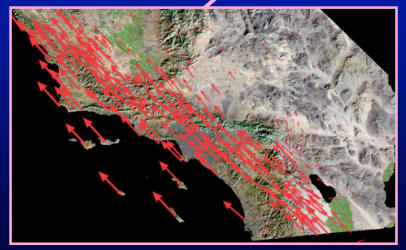




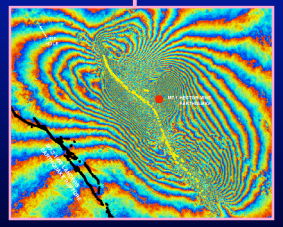
Rupture dynamics



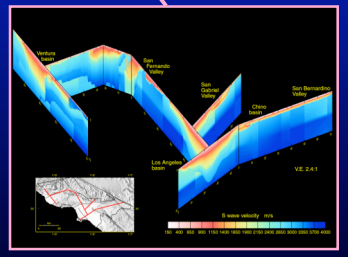
Stress transfer



Crustal motion



Crustal deformation



Seismic velocity structure

Goals of a Regional Earthquake Collaboratory

- To gather all types of information about earthquakes in the region
- To integrate this information into a comprehensive, physics-based, predictive understanding of earthquake phenomena
- To communicate this understanding to the population as useful knowledge for reducing earthquake risks

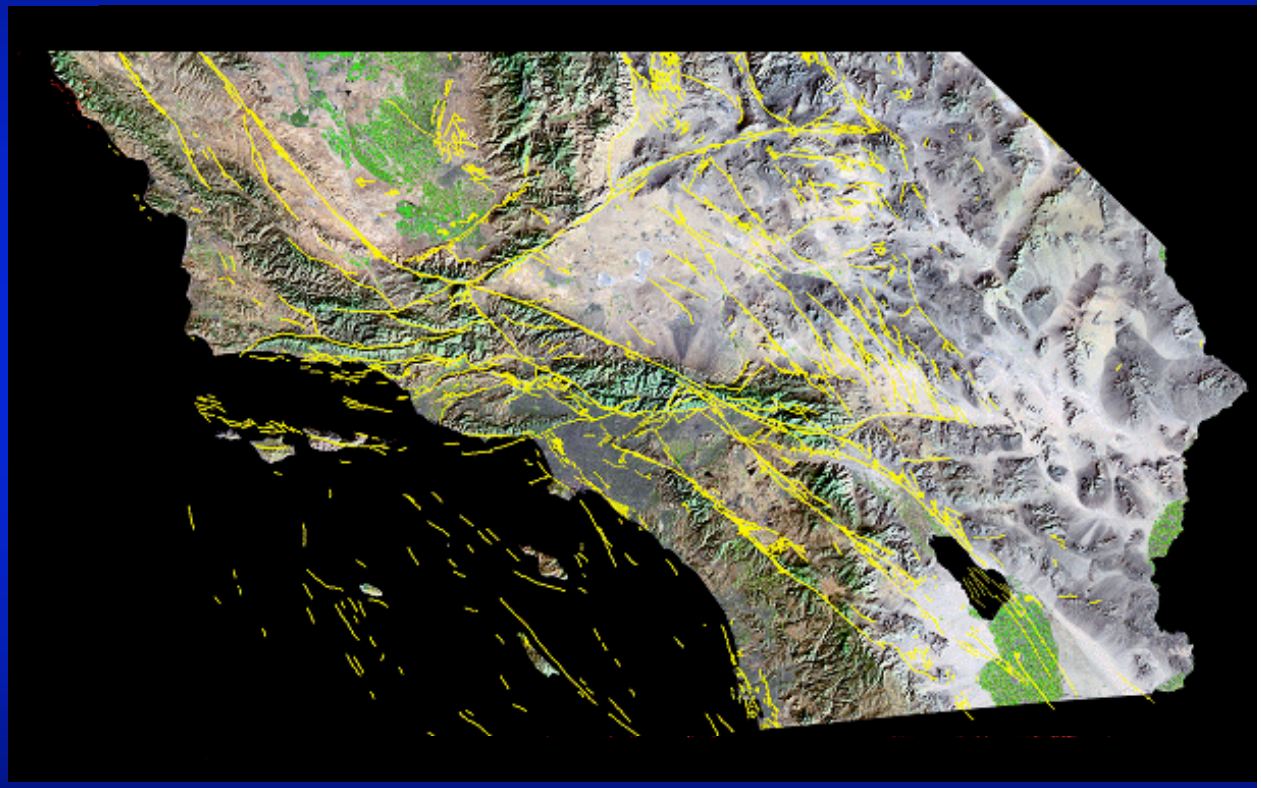
Multidisciplinary, multi-institutional collaboration

IT- enabled, system-level science

Strategic partnerships for communication, education and outreach

Southern California: a Natural Laboratory for Understanding Seismic Hazard and Managing Risk

- Tectonic diversity
- Complex fault network
- High seismic activity
- Excellent geologic exposure
- Rich data sources
- Large urban population with densely built environment ⇒ high risk



- Extensive research program coordinated by Southern California Earthquake Center (SCEC) under NSF and USGS sponsorship

Southern California Earthquake Center

15 Core Institutions

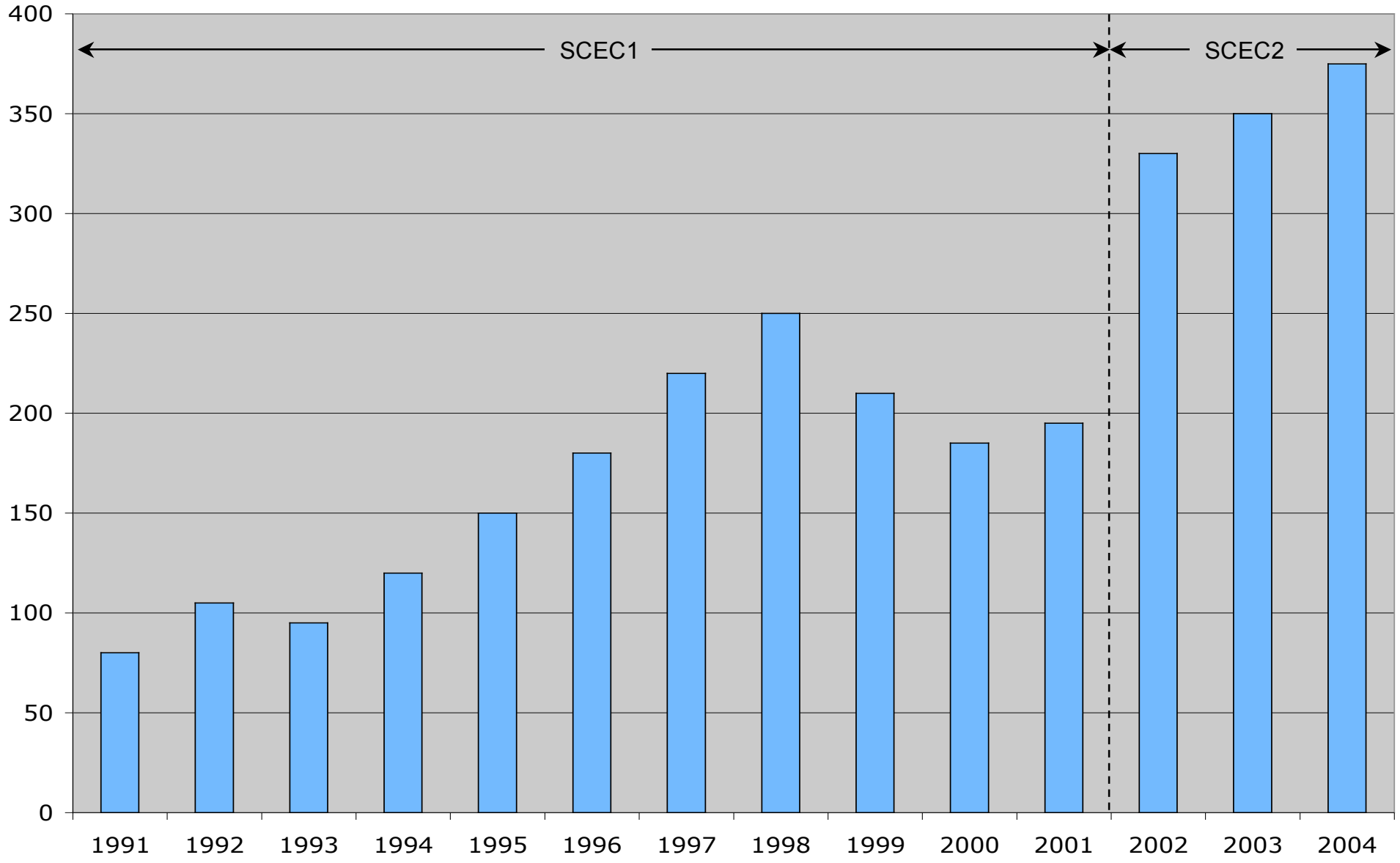
California Institute of Technology
Columbia University
Harvard University
Massachusetts Institute of Technology
San Diego State University
Stanford University
U.S. Geological Survey, Golden
U.S. Geological Survey, Menlo Park
U.S. Geological Survey, Pasadena
University of California, Los Angeles
University of California, Riverside
University of California, San Diego
University of California, Santa Barbara
University of Nevada, Reno
University of Southern California (lead)

+ 40 Participating Institutions Worldwide

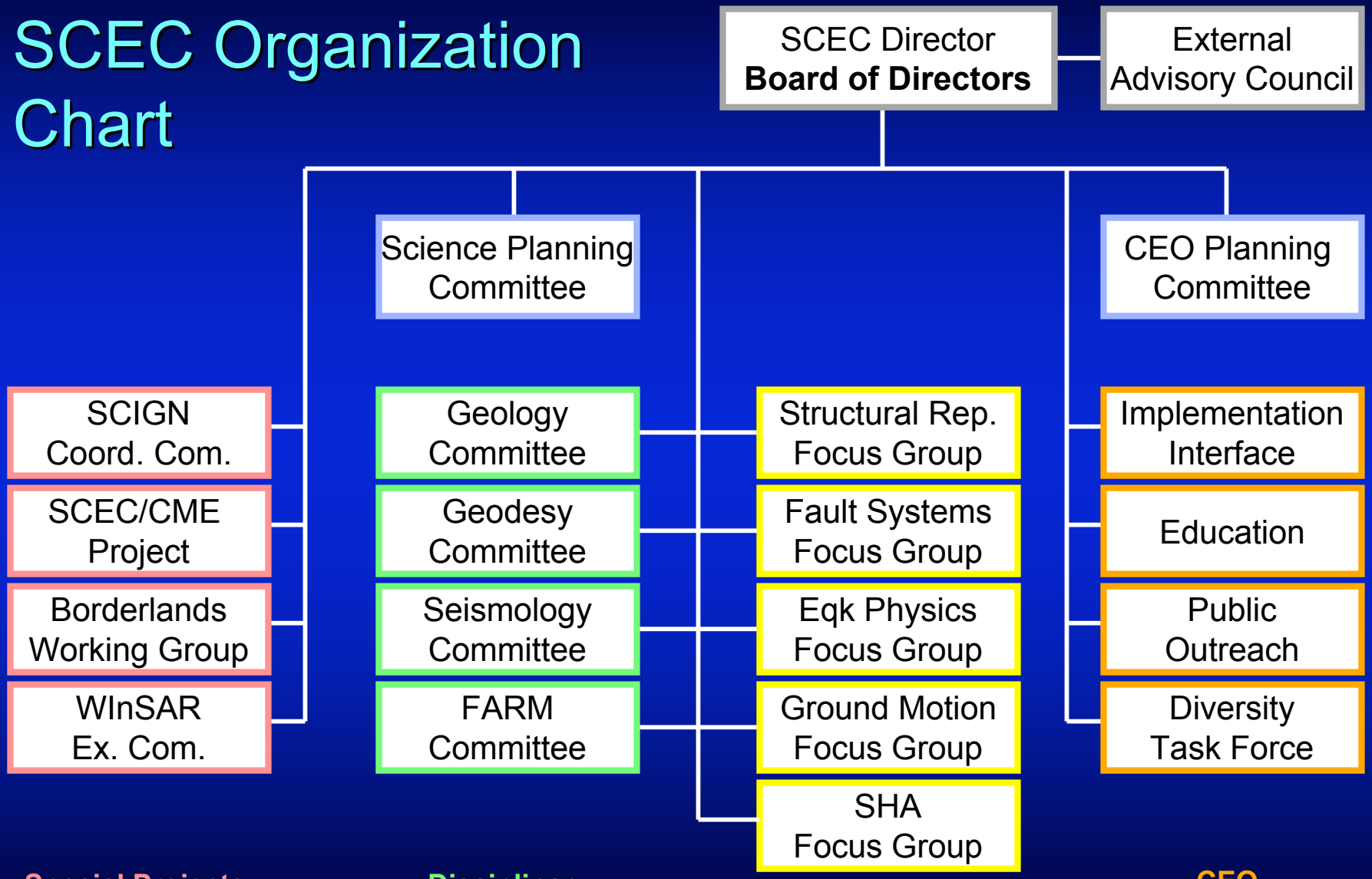
- Consortium of 14 core institutions and 35 participating organizations, founded in 1991
- Co-funded by NSF and USGS under the National Earthquake Hazards Reduction Program (NEHRP)
- An open but structured collaboration, organized through a series of focused studies, including
  - **Phase I**: Future Seismic Hazards in Southern California, Implications of the 1992 Landers Earthquake Sequence
  - **Phase II**: Seismic Hazards in Southern California: Probable Earthquakes, 1994 to 2024
  - **Phase III**: Accounting for Site Effects in Probabilistic Seismic Hazard Analyses of Southern California
  - **Phase IV**: Regional Earthquake Likelihood Models

http://www.scec.org

Participation in SCEC Annual Meeting



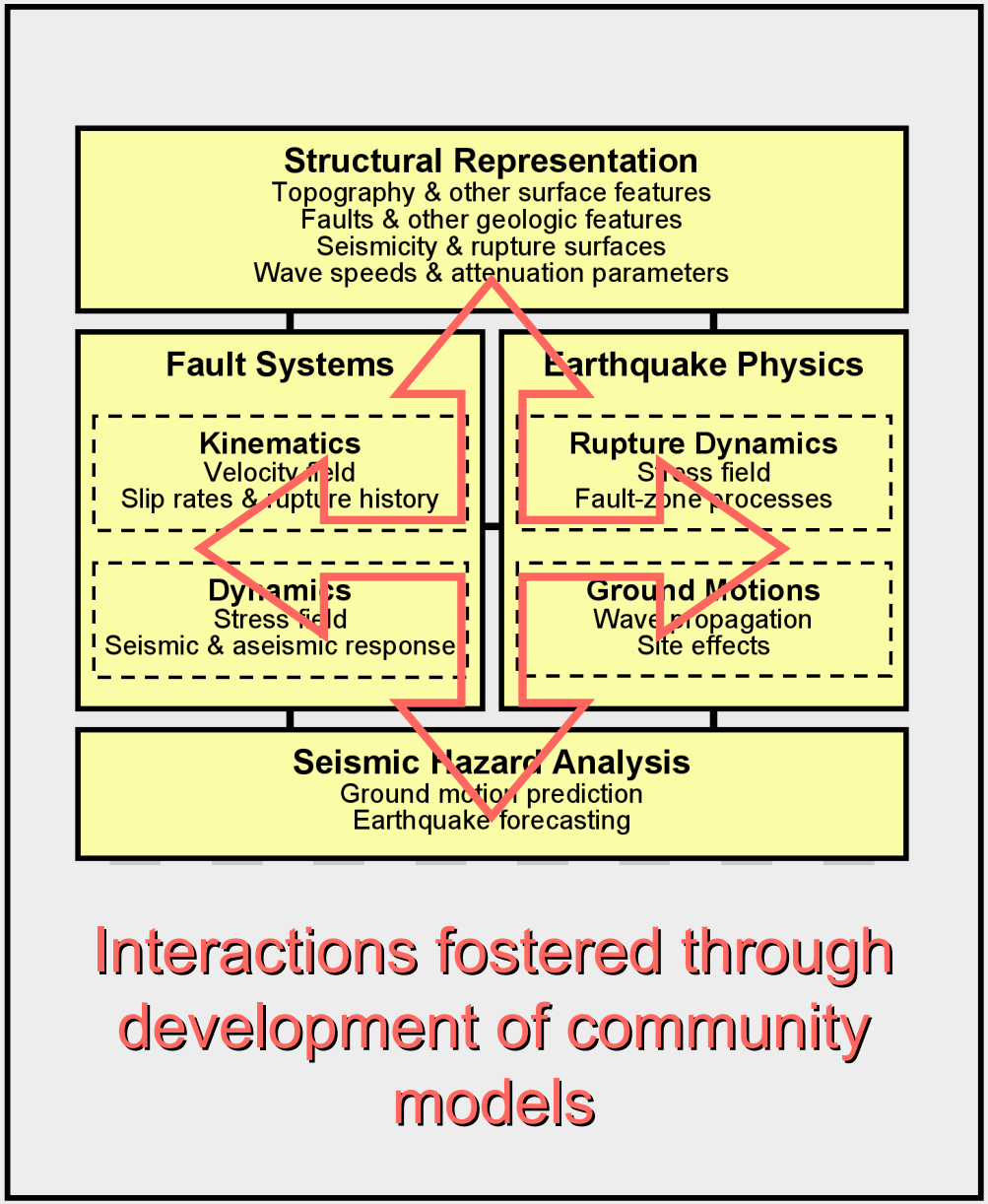
SCEC Organization Chart



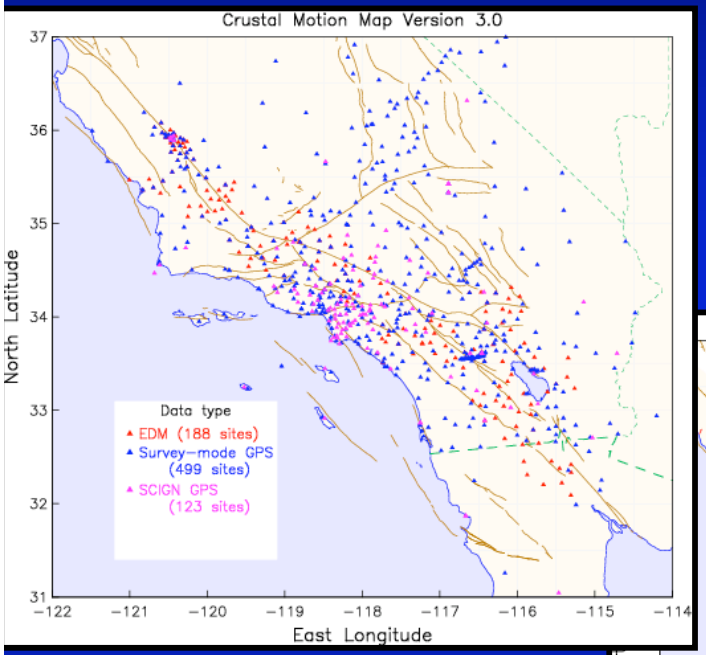
Interdisciplinary Framework

Major focus areas

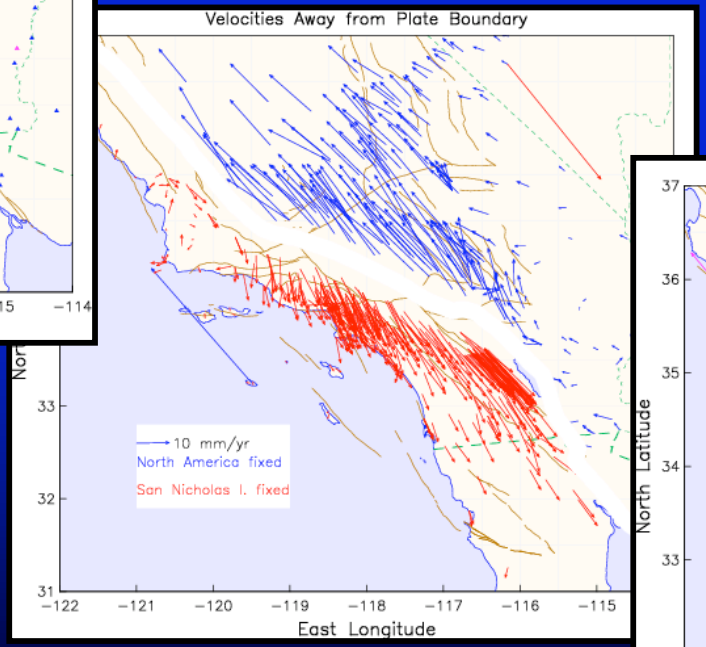
- Structural Representation
- Fault Systems
- Earthquake Source Physics
- Ground Motions
- Seismic Hazard Analysis

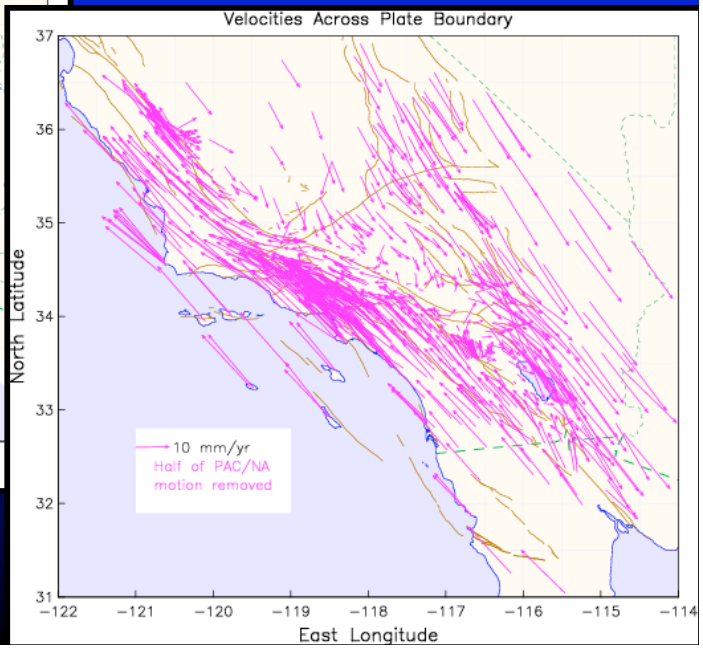


SCEC Crustal Motion Map



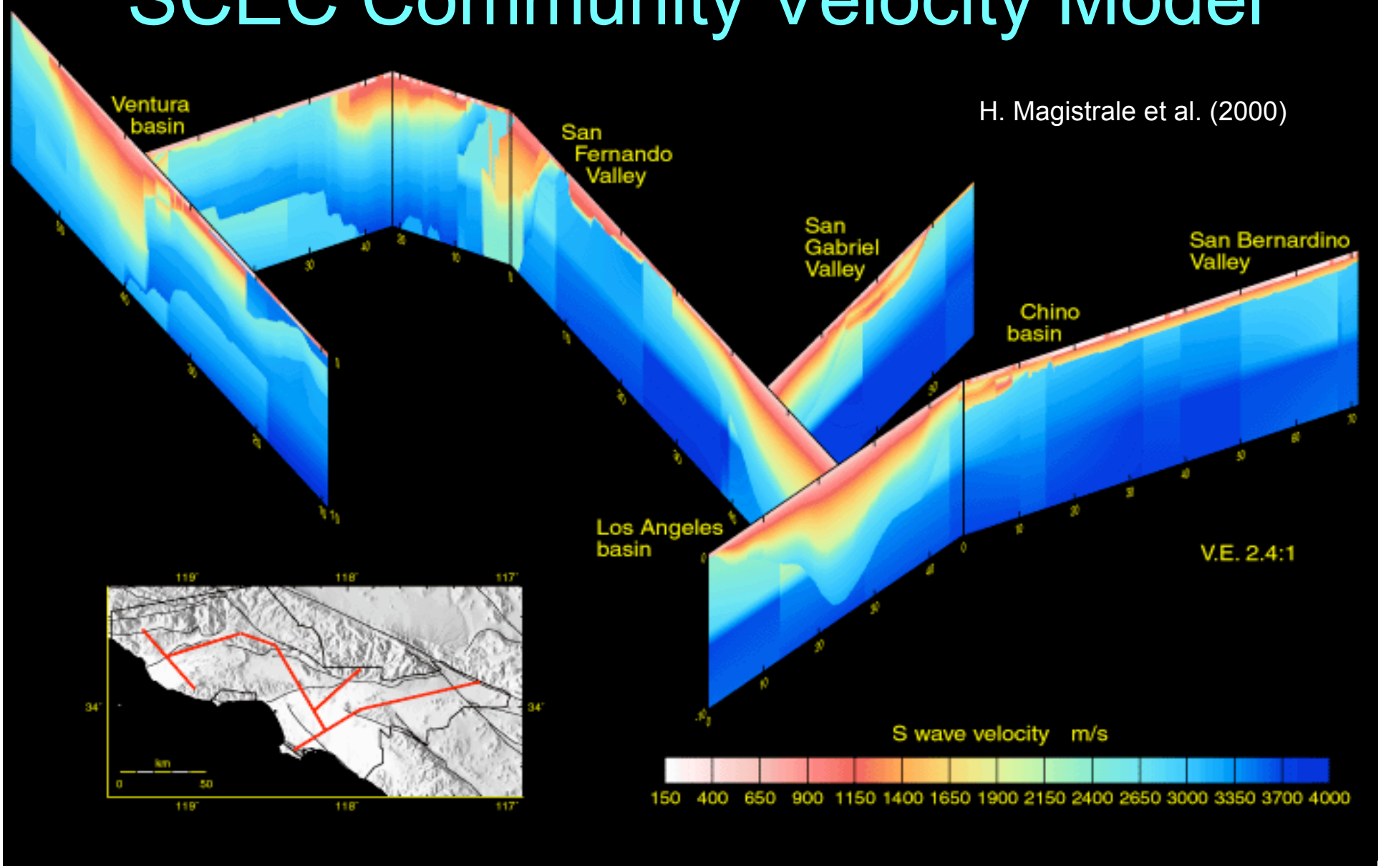
- 833 crustal velocity estimates at 762 points
- Co-seismic offsets for the Landers, Northridge & Hector Mine earthquakes
- Data from SCIGN



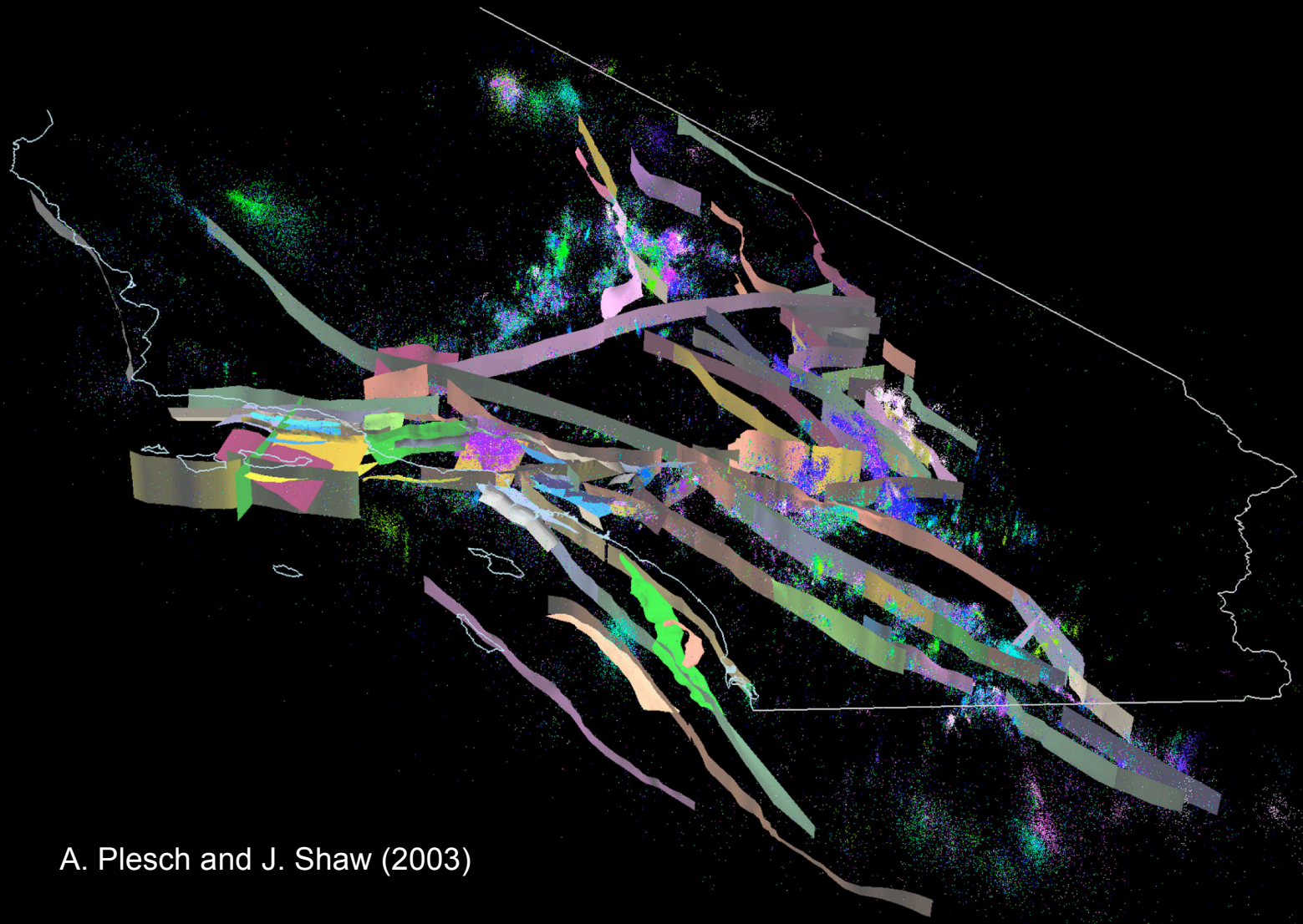


CMM.3.0.1 (Agnew et al., 2003)

SCEC Community Velocity Model

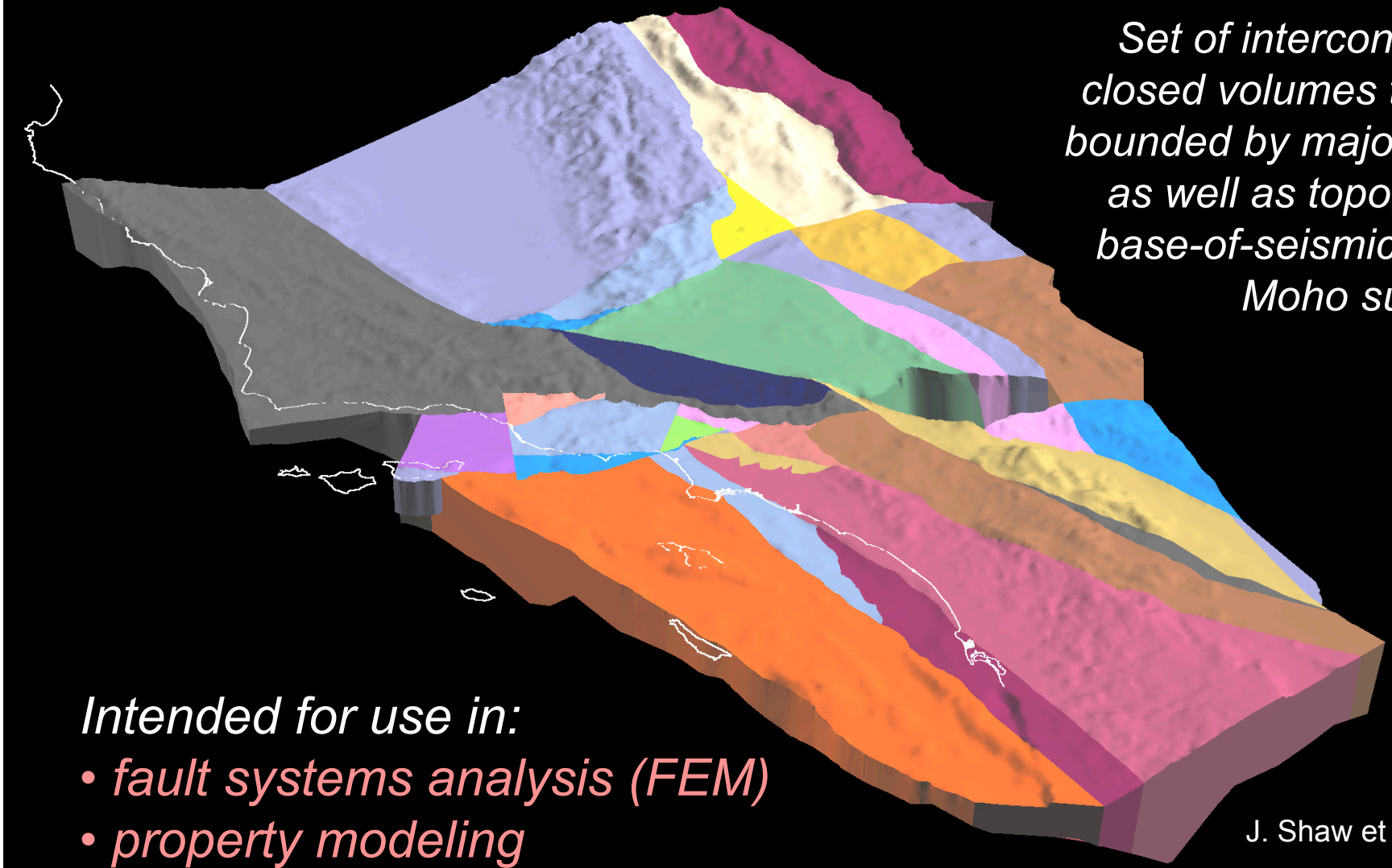


SCEC Community Fault Model



A. Plesch and J. Shaw (2003)

SCEC Community Block Model



Set of interconnected, closed volumes that are bounded by major faults, as well as topography, base-of-seismicity, and Moho surfaces.

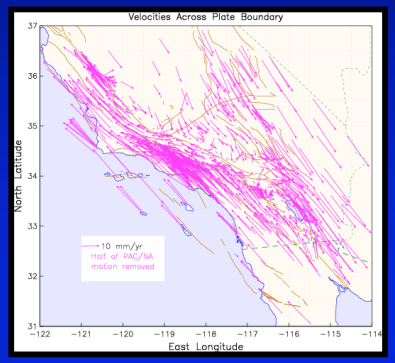
Intended for use in:

- *fault systems analysis (FEM)*
- *property modeling*

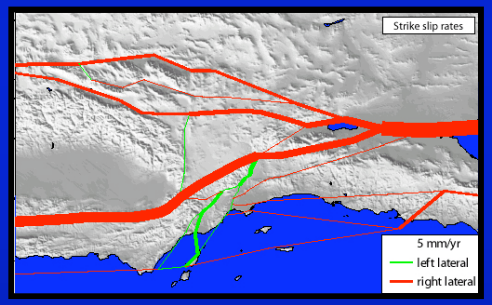
J. Shaw et al. (2004)

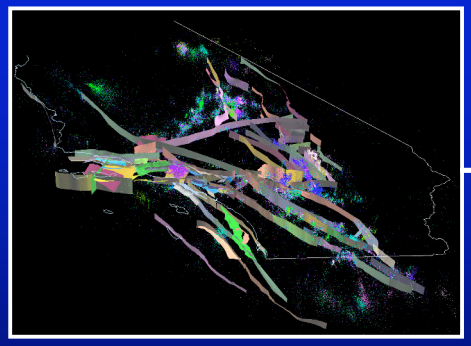
Unified Structural Representation

Crustal Motion Map

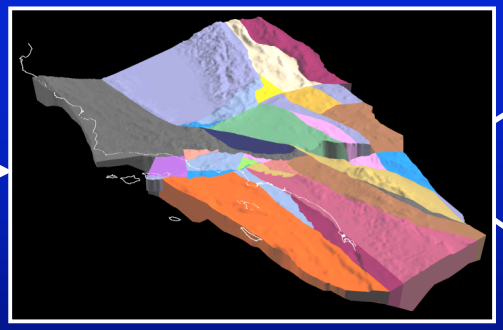


Tectonic models

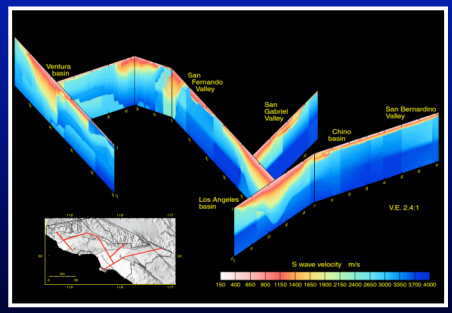




Community Fault Model



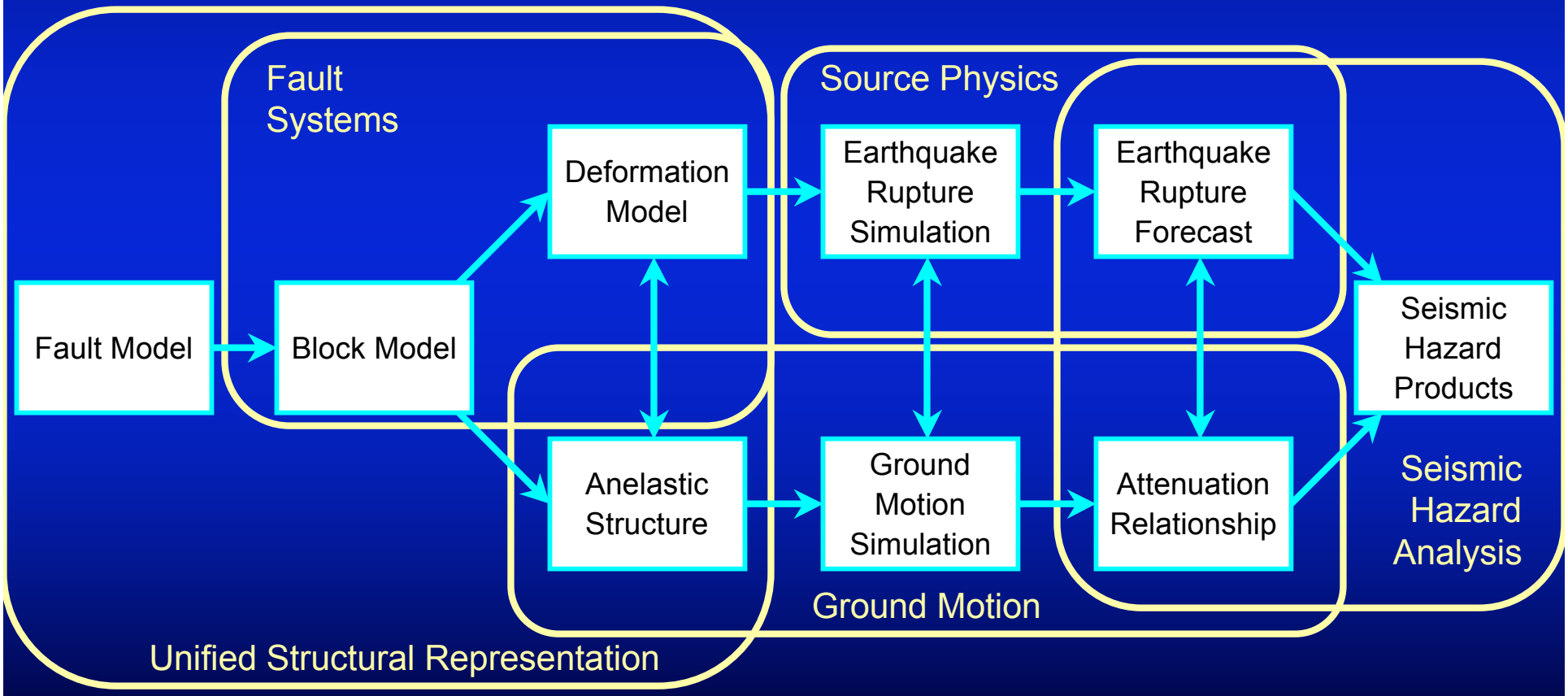
Community Block Model



Structural models

SHA Computational Pathways

System-Level Integration by SCEC Focus Groups

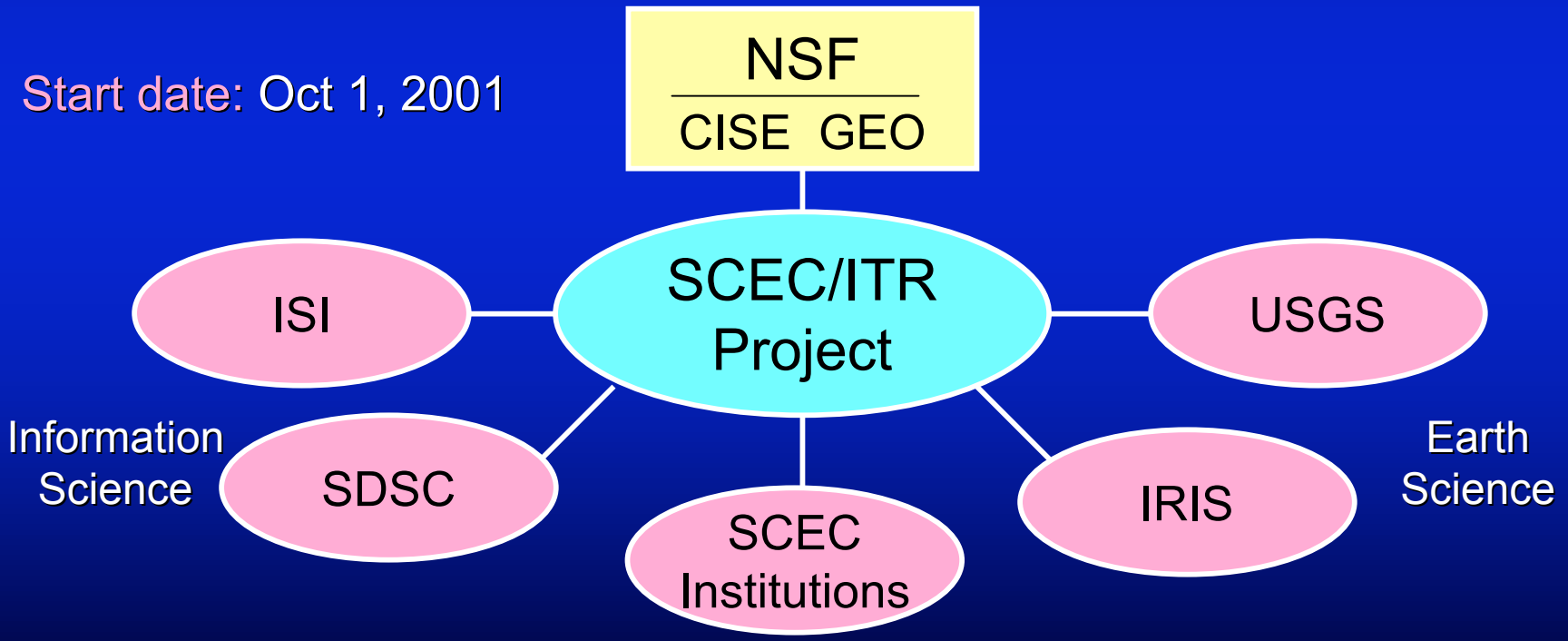


SCEC/CME Project

Goal: To develop a cyberinfrastructure that can support system-level earthquake science – the SCEC Community Modeling Environment (CME)

Support: 5-yr project funded by the NSF/ITR program under the CISE and Geoscience Directorates

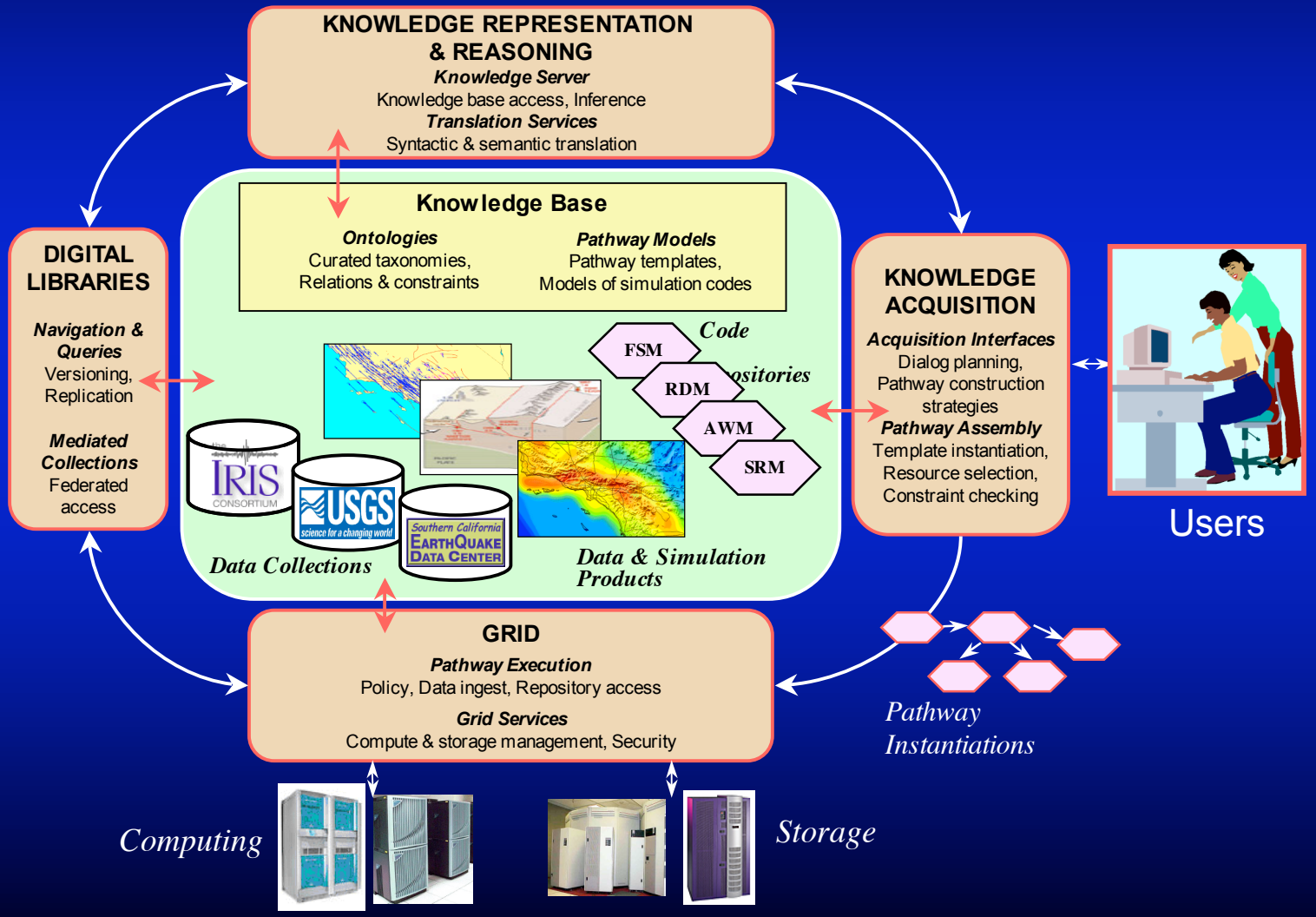
Start date: Oct 1, 2001



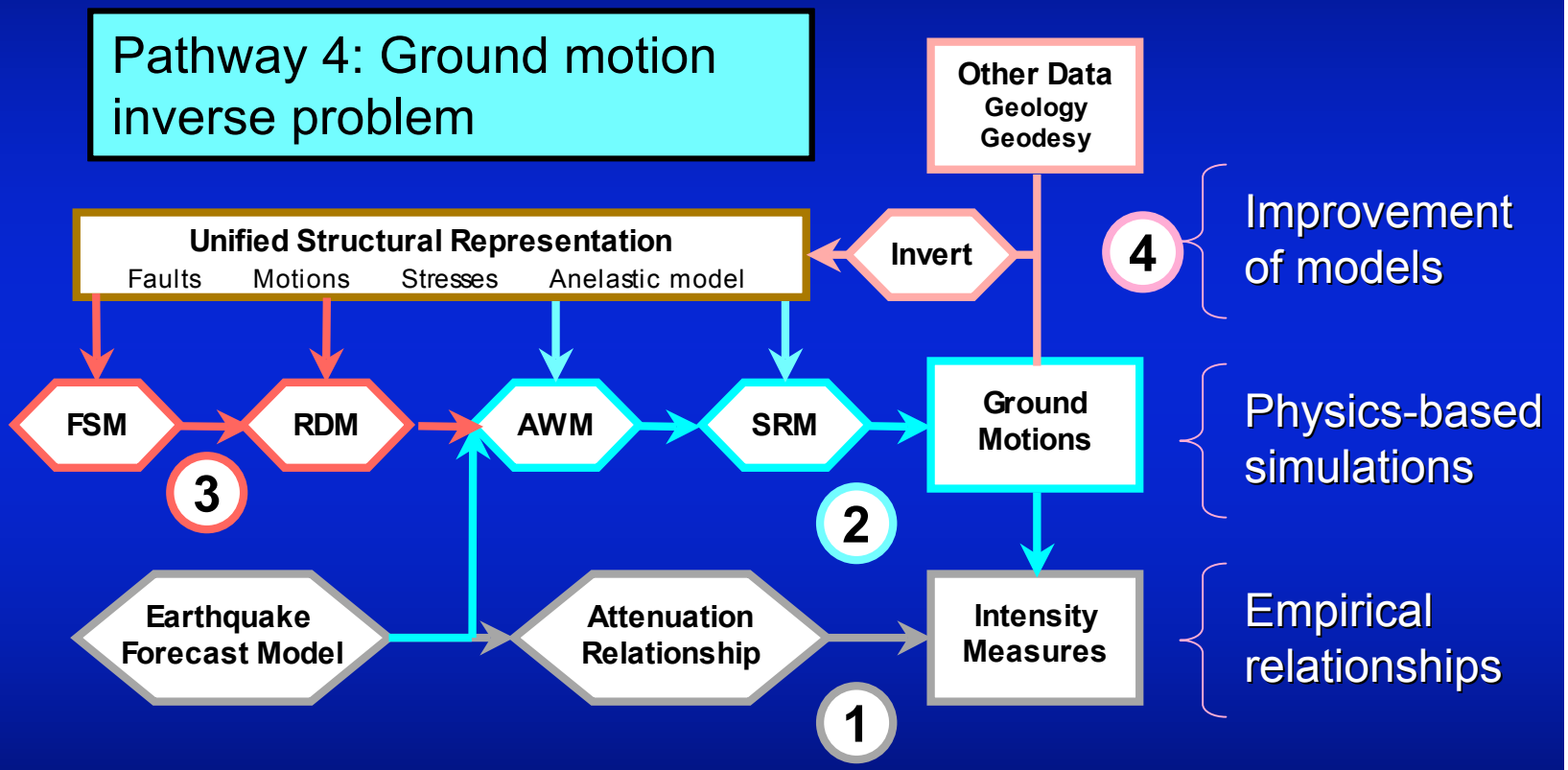
www.scec.org/cme

SCEC Community Modeling Environment

A collaboratory for system-level earthquake science



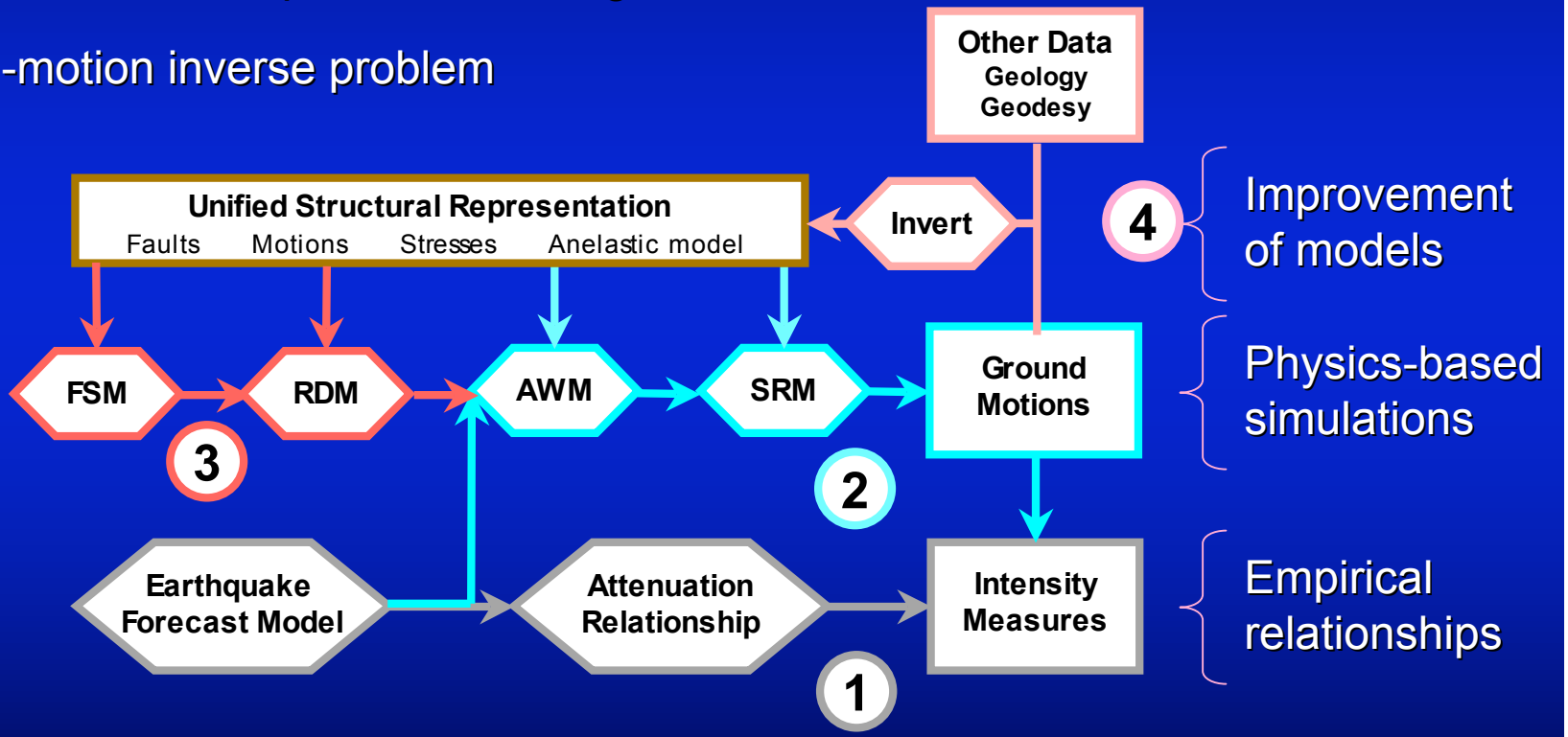
SHA Computational Pathways



FSM = Fault System Model
RDM = Rupture Dynamics Model
AWP = Anelastic Wave Propagation
SRM = Site Response Model

SHA Computational Pathways

1. Standardized Seismic Hazard Analysis
2. Ground motion simulation
3. Physics-based earthquake forecasting
4. Ground-motion inverse problem



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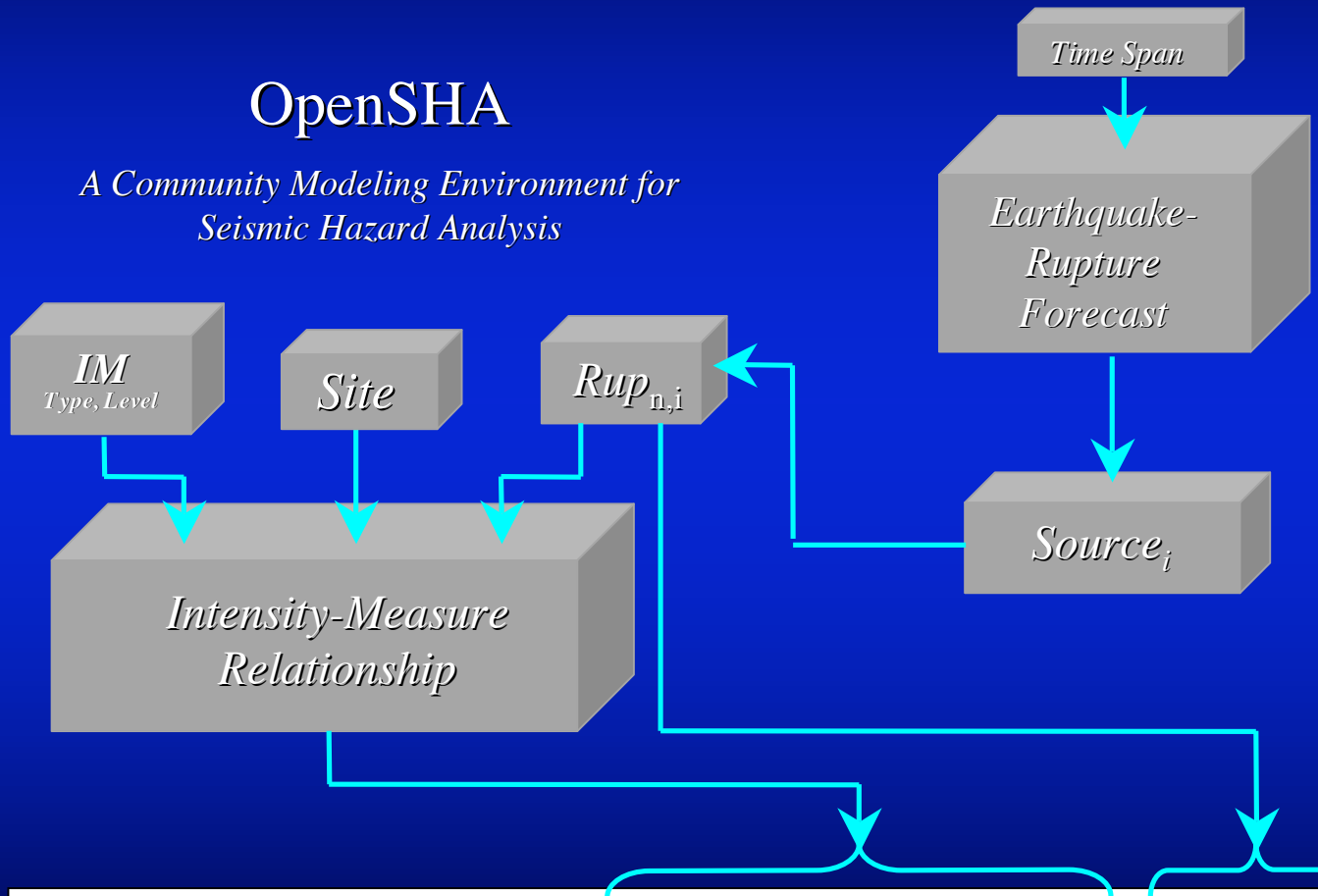
Pathway 1: OpenSHA

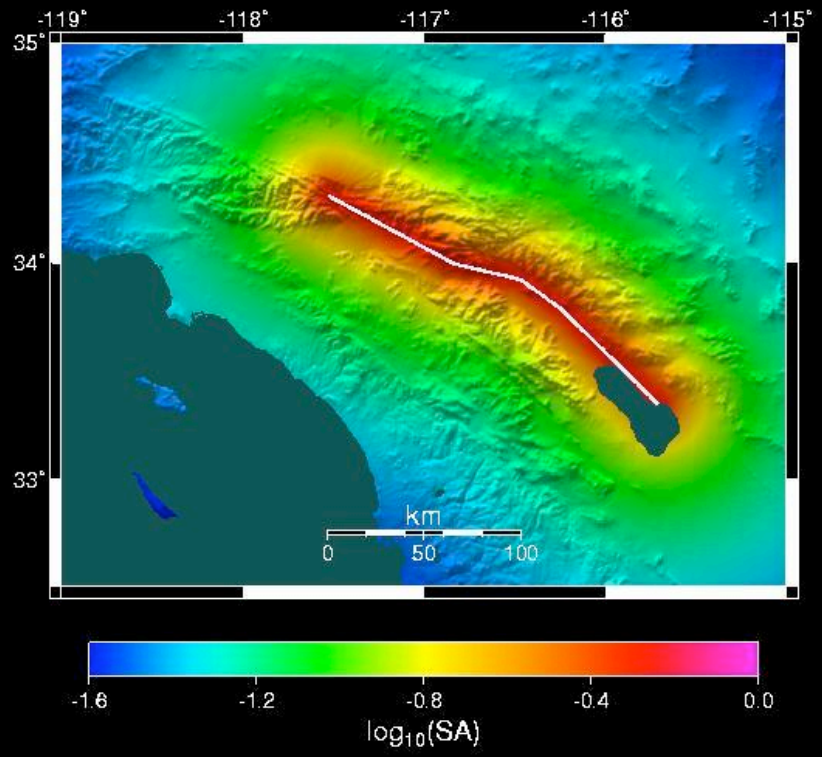


$$\text{Prob}(IMT \geq IML) = 1 - \prod_{i=1}^{I}\left(1 - \sum_{n=1}^{N(i)}\left[\text{Prob}(IMT \geq IML, Site \mid Rup_{n,i}) * \text{Prob}(Rup_{n,i})\right]\right)$$

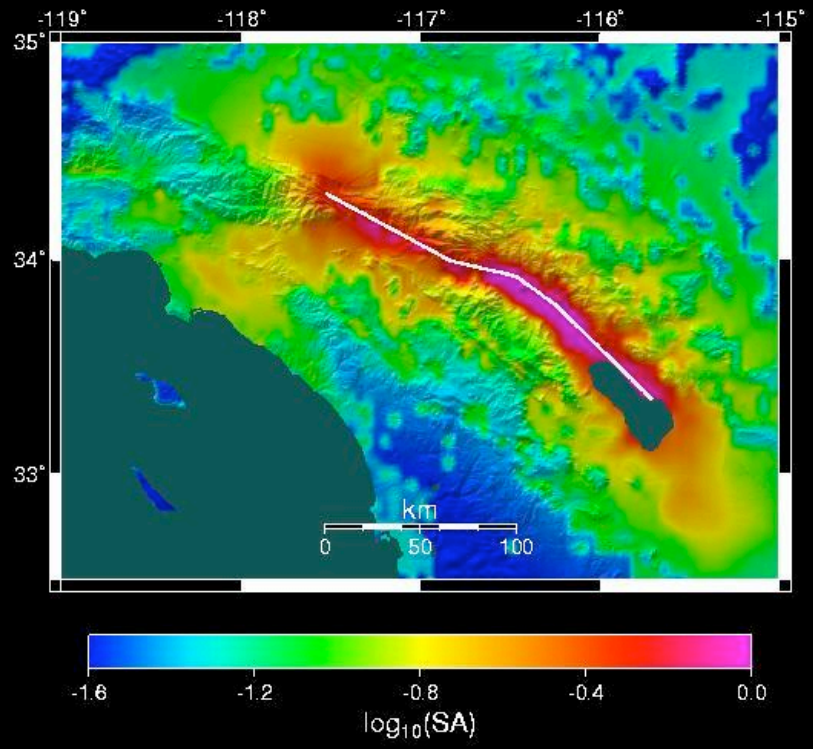
Field, Jordan & Cornell (2003)

Scenario ShakeMaps for M 7.7 Southern San Andreas Rupture

Without soil & basin effects

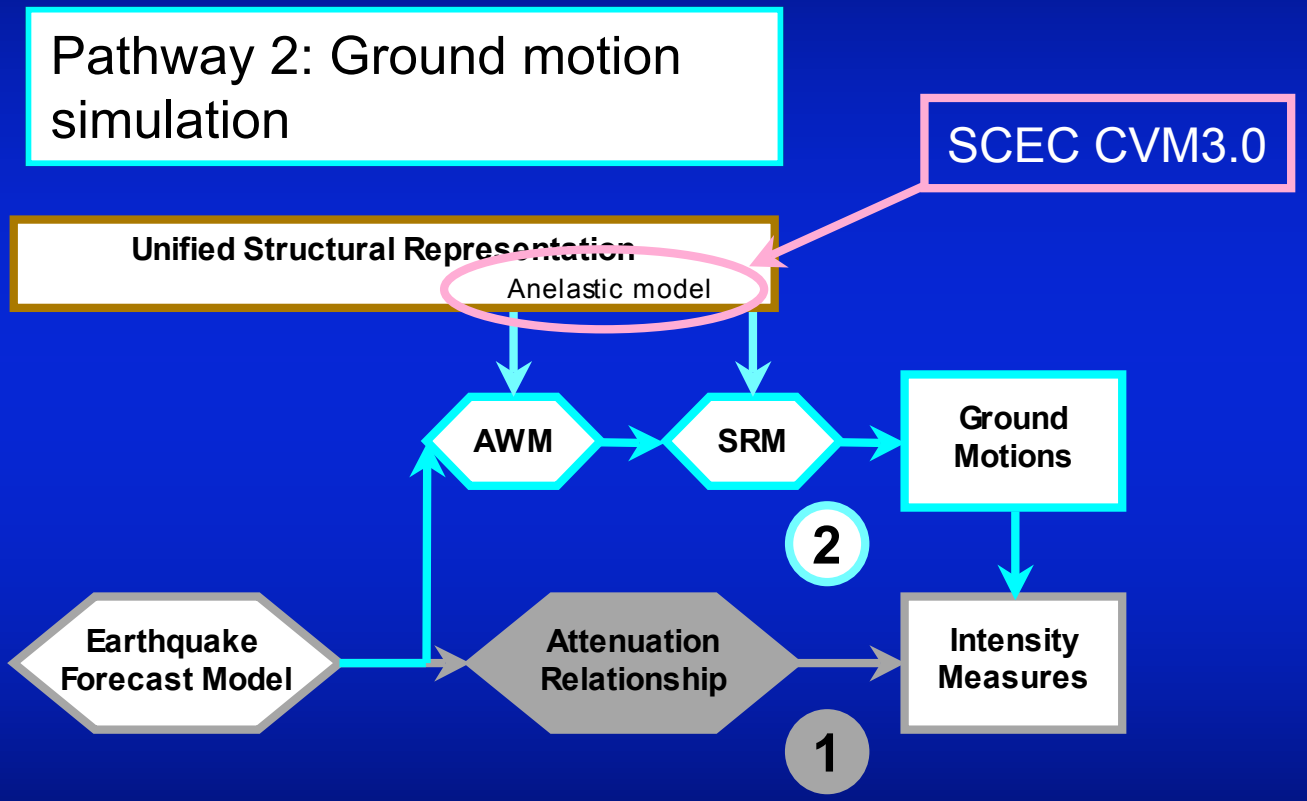


With soil & basin effects

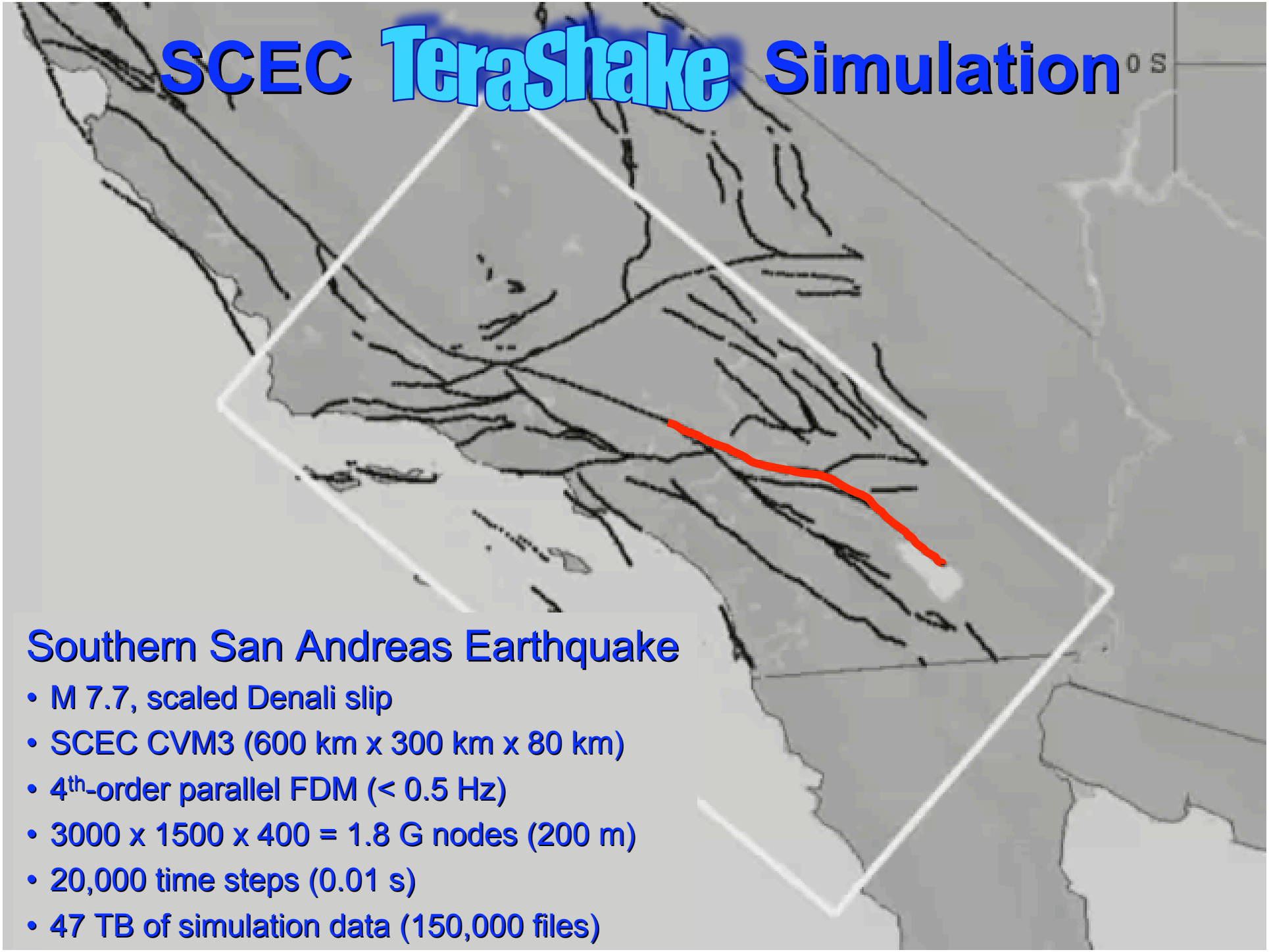


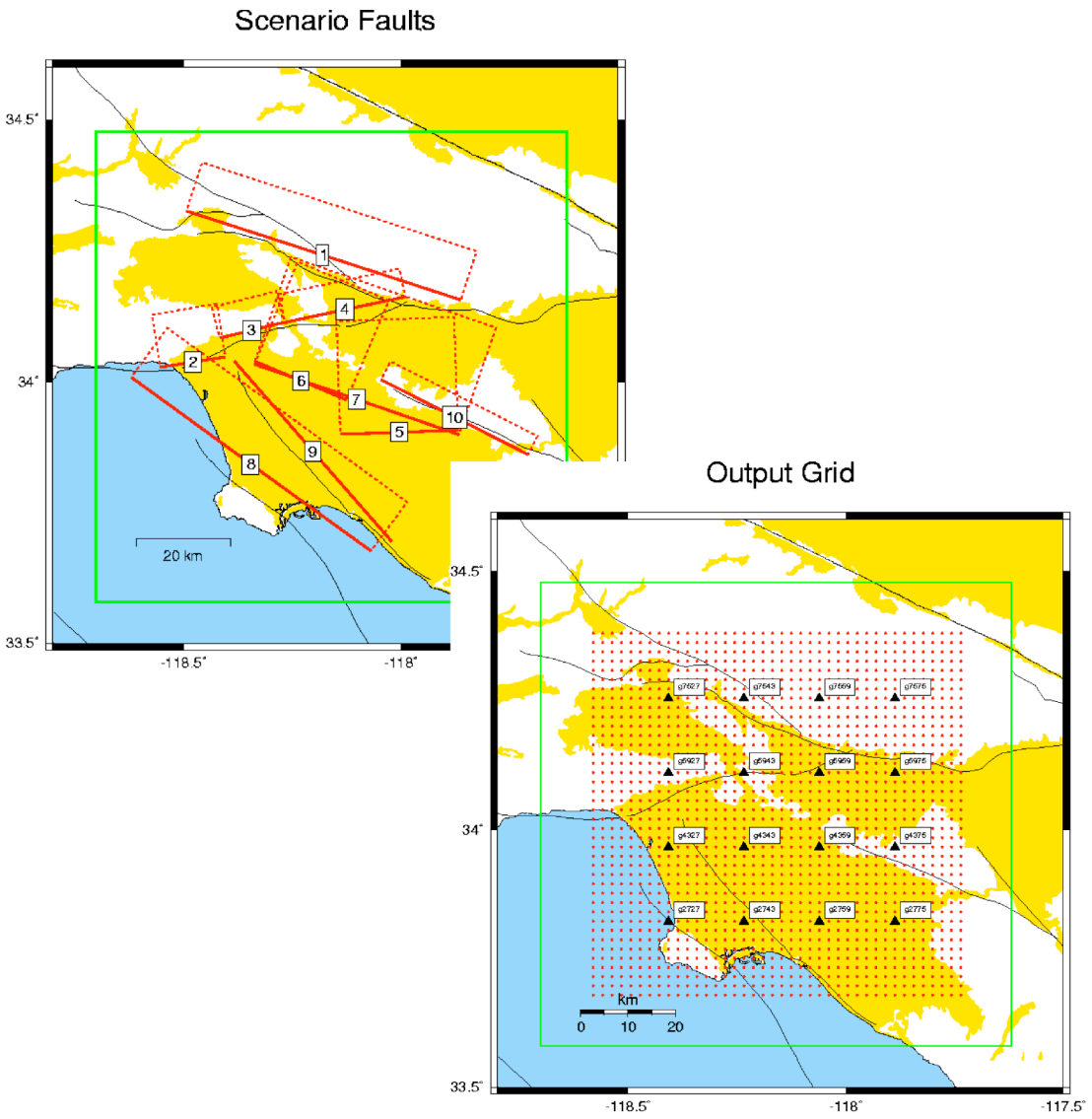
Ned Field, USGS, Pasadena

SHA Computational Pathways



AWP = Anelastic Wave Propagation
SRM = Site Response Model

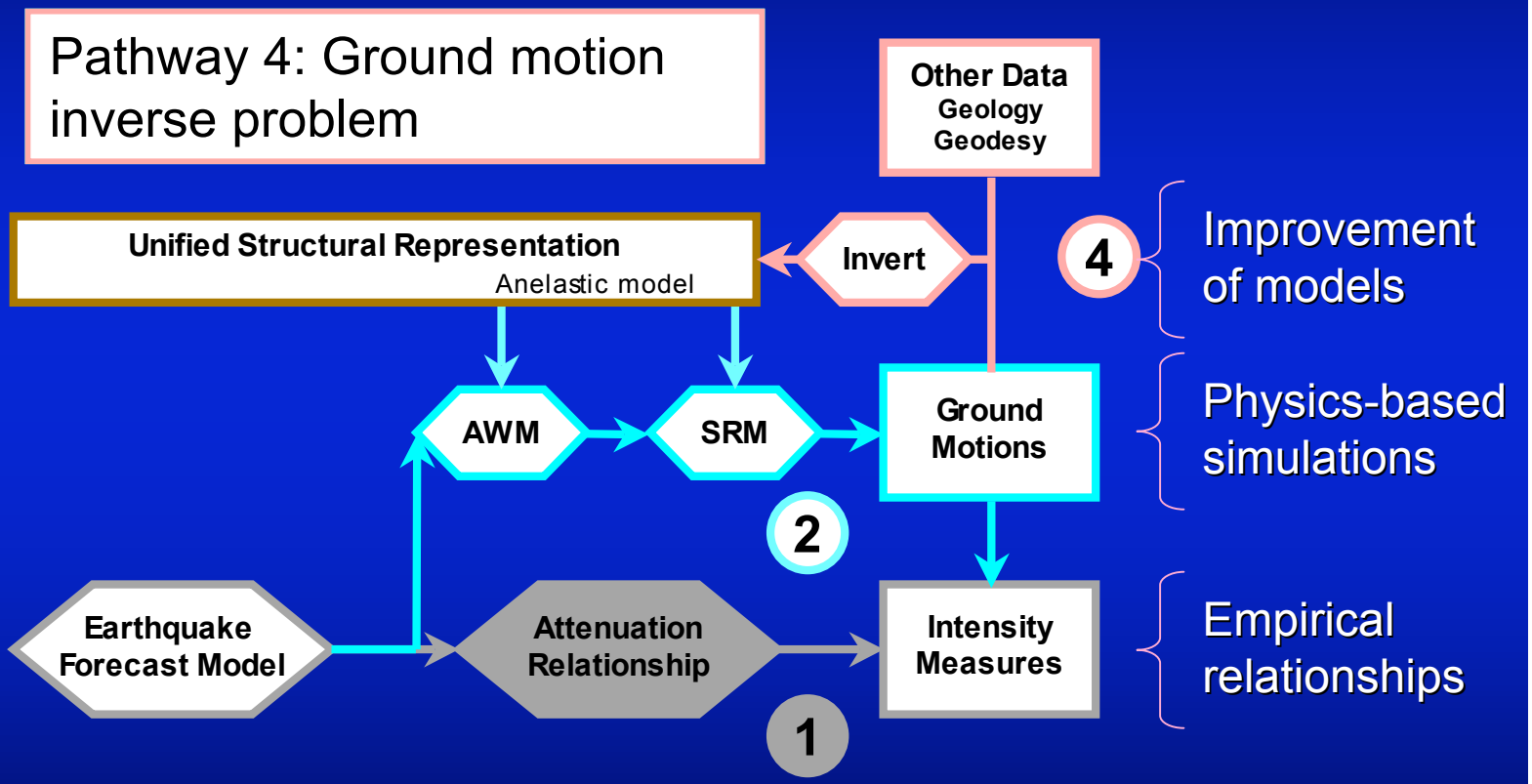

SCEC TeraShake Simulation
Southern San Andreas Earthquake
• M 7.7, scaled Denali slip
• SCEC CVM3 (600 km x 300 km x 80 km)
• 4th-order parallel FDM (< 0.5 Hz)
• 3000 x 1500 x 400 = 1.8 G nodes (200 m)
• 20,000 time steps (0.01 s)
• 47 TB of simulation data (150,000 files)



Pathway 2 Verification

- Co-supported by SCEC, SCEC/CME, PEER-Lifelines
- Participation by 5 groups developing FD and FE codes
- Validation through hierarchy of standardized test cases
- Production of 96,000 synthetic seismograms for 6 earthquake scenarios on each of 10 faults
- SRB archive now available in CME
- Results are being analyzed to improve attenuation relationships

SHA Computational Pathways



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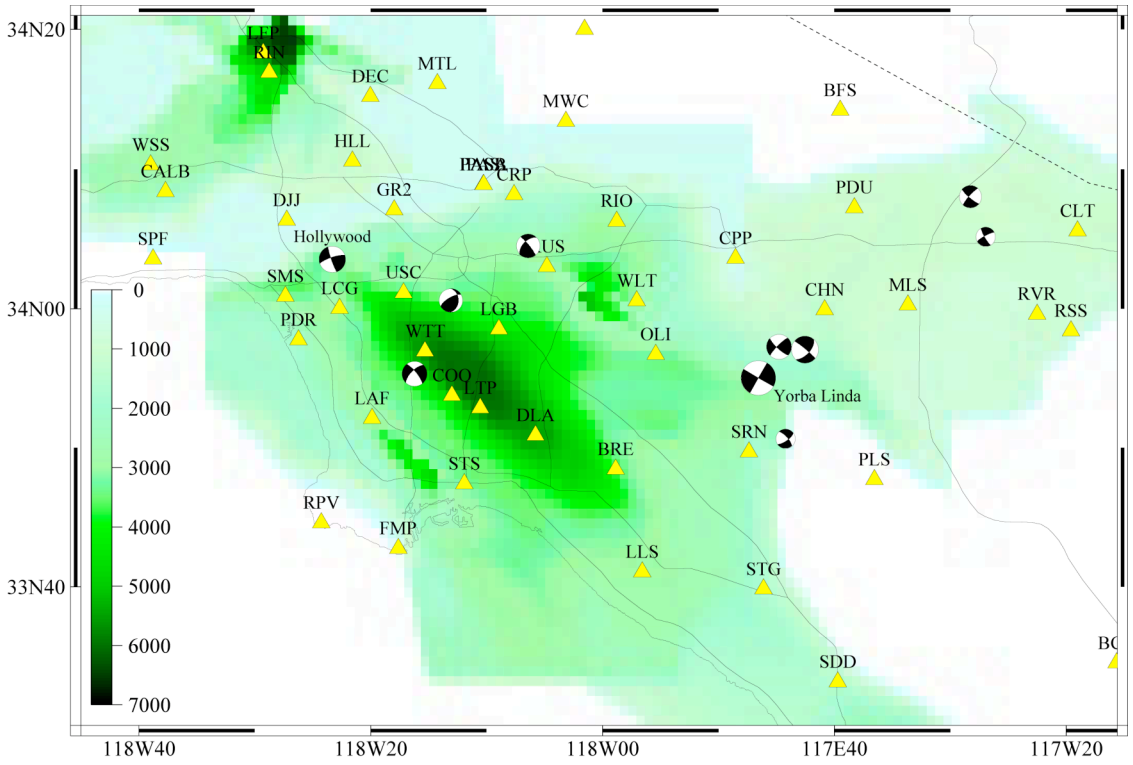
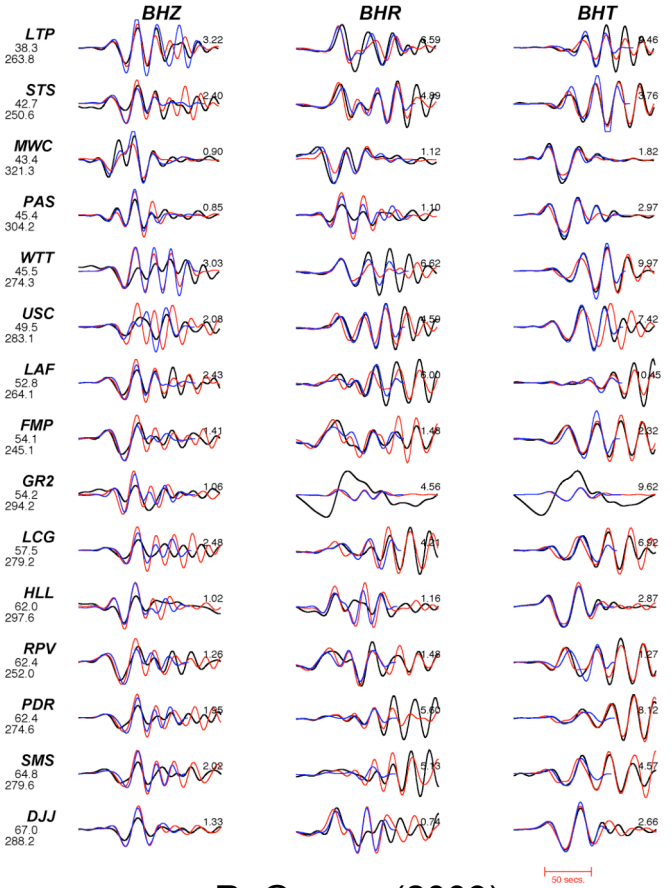
Pathway 4: Data Inversion & Assimilation

Pathway 4 inversions techniques are used to update the geological models needed for simulations in the other pathways





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R. Graves (2003)

Pathway 4: Data Inversion & Assimilation

Perturbation Theory

$$F_i(\mathbf{m}) = d_i, \quad i = 1, 2, \ldots, N$$

$$\mathbf{m} = \mathbf{m}_0 + \delta\mathbf{m}$$

$$\int_V K_i(\mathbf{r}, \mathbf{m}_0)\,\delta\mathbf{m}(\mathbf{r})\,dV(\mathbf{r}) = \delta d_i$$

FRÉCHET KERNEL

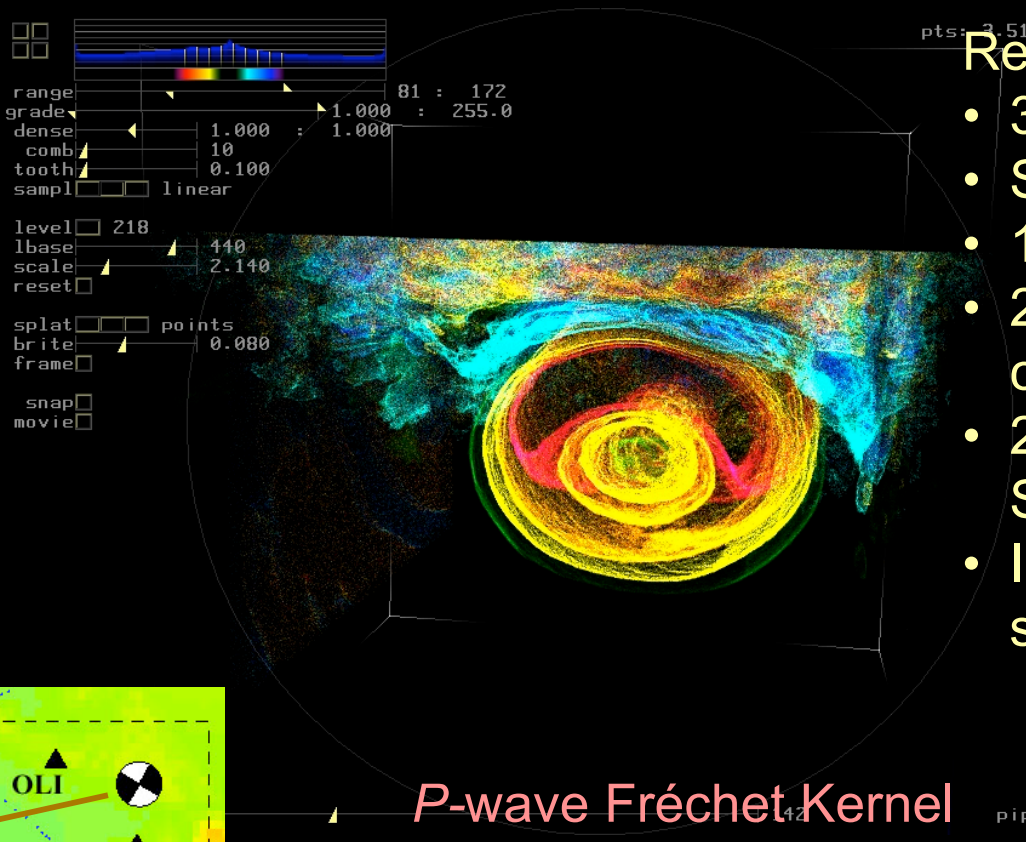
REFERENCE MODEL

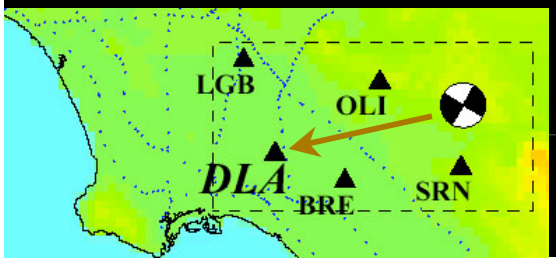
PERTURBATION

Structural inverse problem has 3 types of spatial dimensionality. For regional applications all need to be 3D.

Pathway 4: Data Inversion & Assimilation

Pathway 4 inversions techniques are used to update the geological models needed for simulations in the other pathways





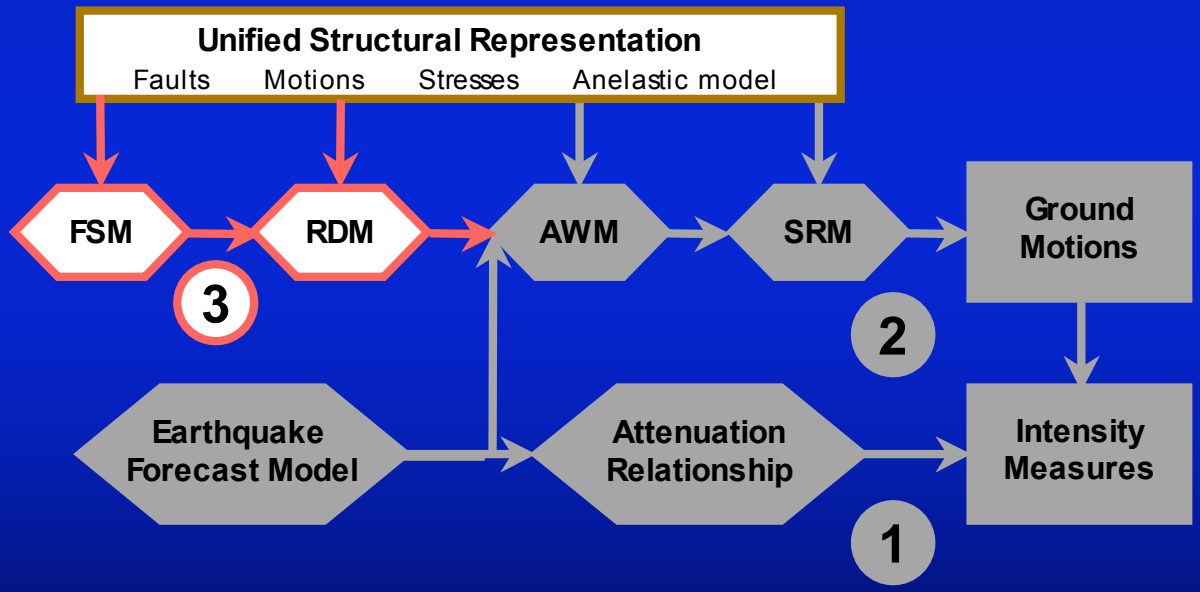
P-wave Fréchet Kernel
09/04/02 Yorba Linda Earthquake

Receiver Green Functions

- 33 CISN BB stations
- SCEC CVM3.0
- 180-m, .01-s resolution
- 20 days on 60-node cluster
- 27 TB data stored in SCEC digital library
- In use for CMT & FMT source inversions

SHA Computational Pathways

Pathway 3: Physics-based earthquake forecasting



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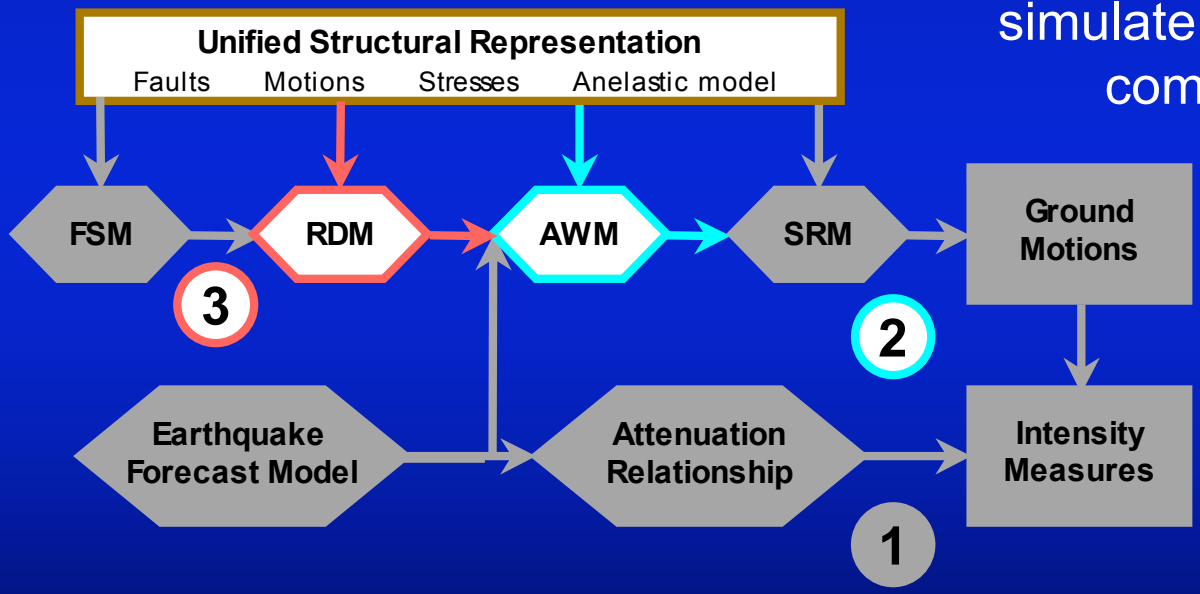
SHA Computational Pathways

Pathway 3: Physics-based earthquake forecasting



3D Rupture Dynamic Models are being coupled Anelastic Wave Models to simulate earthquake complexity.

FSM = Fault System Model
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Pathway 3 Verification

- Supported by SCEC/ESP Focus Group
- Hierarchy of problems of increasing complexity
- Workshops held in November, 2003 and September, 2004
- Validation using reference earthquakes (e.g. Parkfield)
- Results to be archived and subset of codes to be registered into SCEC/CME

Nucleation Process:
At t=0, a sudden stress drop occurs over the entire 3 km x 3 km zone.
This stress drop is from the static yield strength of 81.24 MPa down to the dynamic friction stress of 63.00 MPa, for a total stress drop of 18.24 MPa.

Outside of the nucleation zone, the rupture is allowed to propagate spontaneously and friction follows a linear slip-weakening law.

Initial shear stress (t=0) = 70 MPa
Initial normal stress (t=0) = 120 MPa
Both the shear and normal stresses are time-dependent.
The friction coefficients are constant with
$\mu_s = 0.677$ $\mu_d = 0.525$
The slip-weakening critical distance, d_0, is constant with $d_0 = 0.50$ m

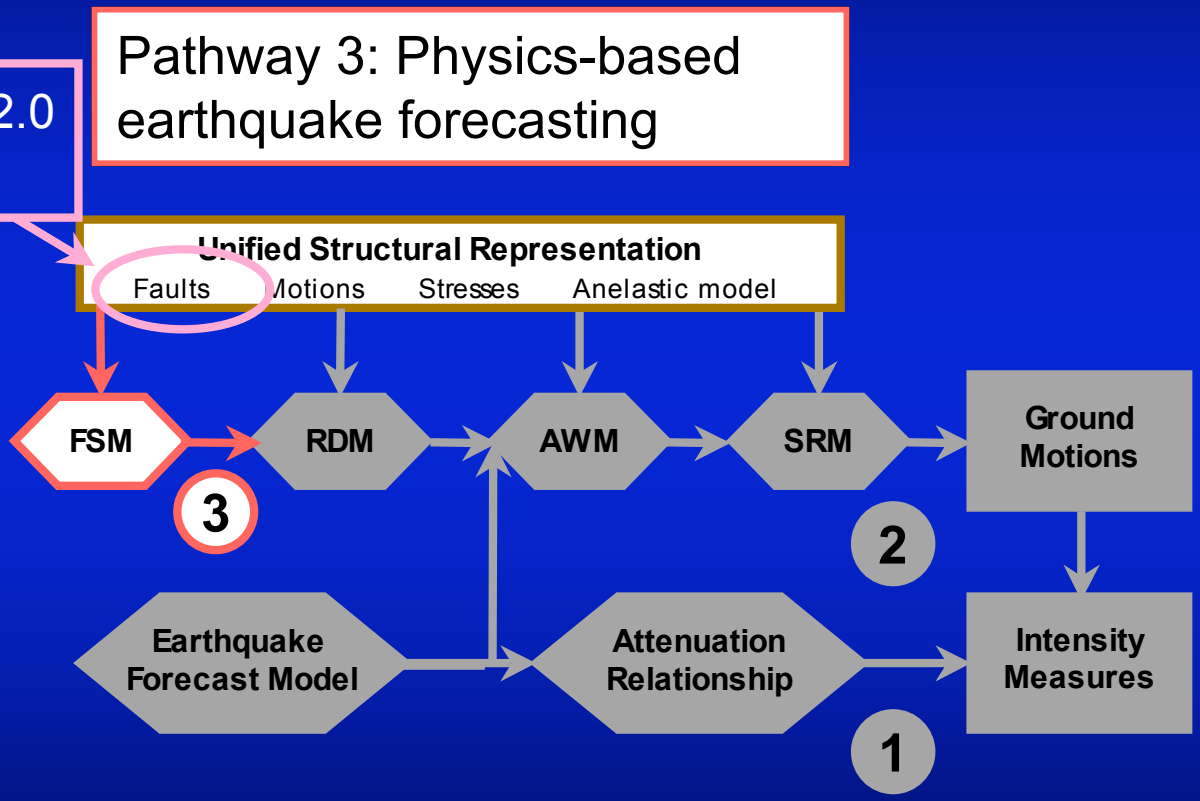
Following slip-weakening, failure occurs when & where shearstress (t) >= (μ(faultslip)) x (normalstress(t)).

Outside of the 30km x 15 km rupture area,
the rupture stops at the 30km x 15 km boundaries of the fault plane because the static coefficient of friction is very high (strong material) on the plane beyond the 30 km x 15 km boundaries. $\mu_s = 10000$.

SHA Computational Pathways

SCEC CFM2.0 & CBM1.0

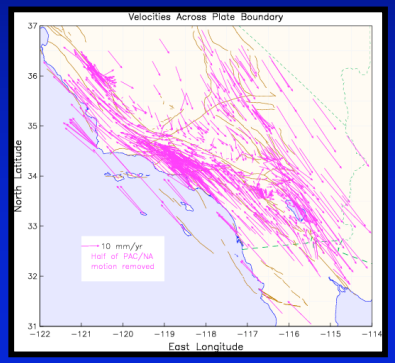
Pathway 3: Physics-based earthquake forecasting



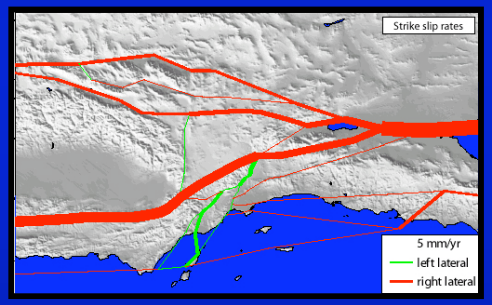
FSM = Fault System Model
RDM = Rupture Dynamics Model
AWP = Anelastic Wave Propagation
SRM = Site Response Model

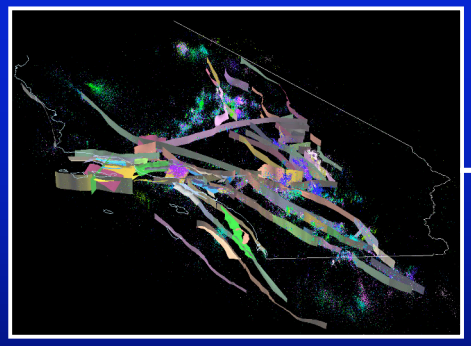
Unified Structural Representation

Crustal Motion Map

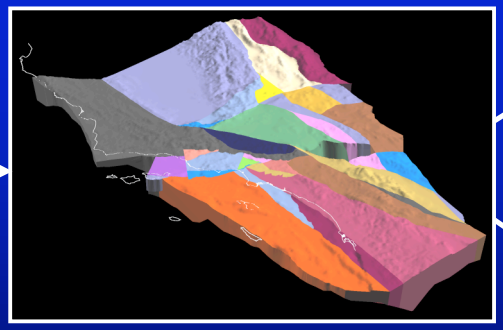


Tectonic models

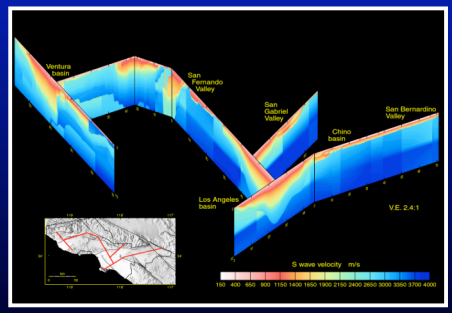




Community Fault Model



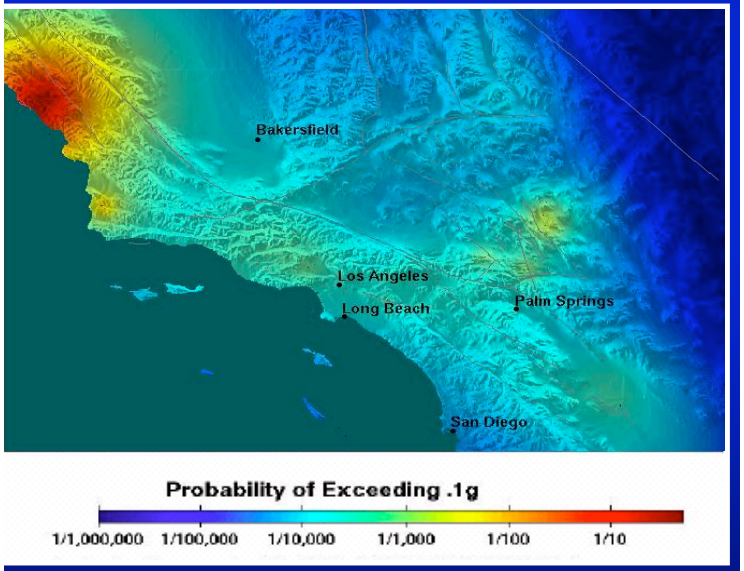
Community Block Model



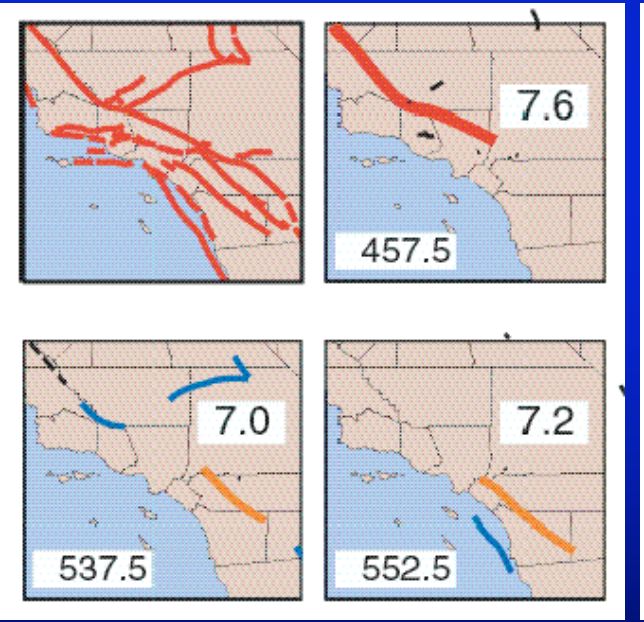
Structural models

SCEC/USGS Working Group for the Development of

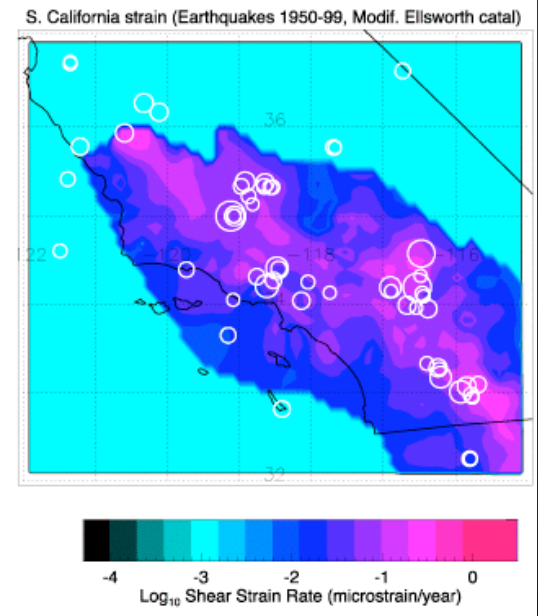
Regional Earthquake Likelihood Models (RELM)



STEP - Seismicity-based
(Wiemer & others)



Fault-Based Simulation
(Ward)



GPS Strain Model
(Jackson & others)

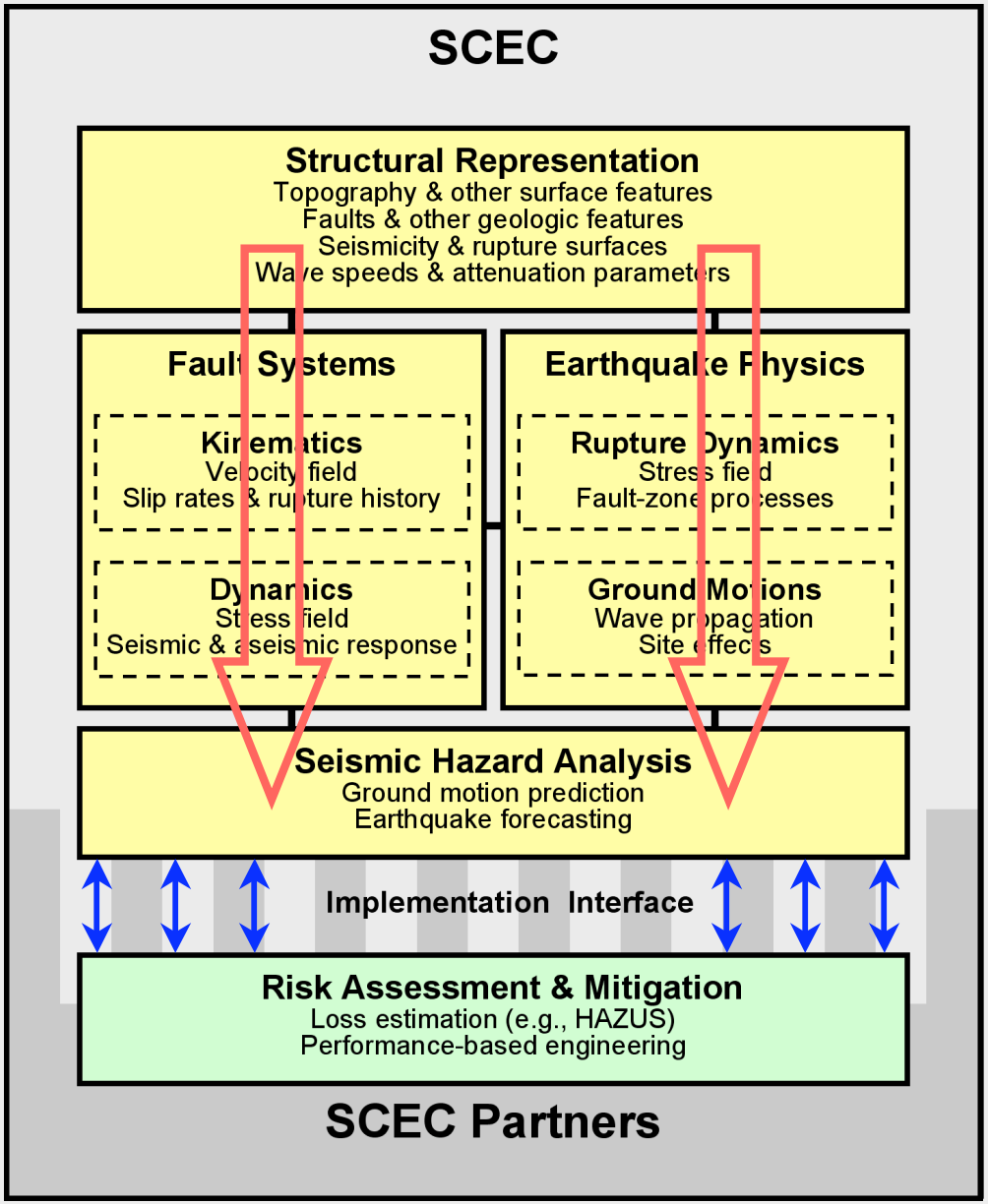
Interdisciplinary Framework

Major focus areas

- Structural Representation
- Fault Systems
- Earthquake Source Physics
- Ground Motions
- Seismic Hazard Analysis

Implementation interface

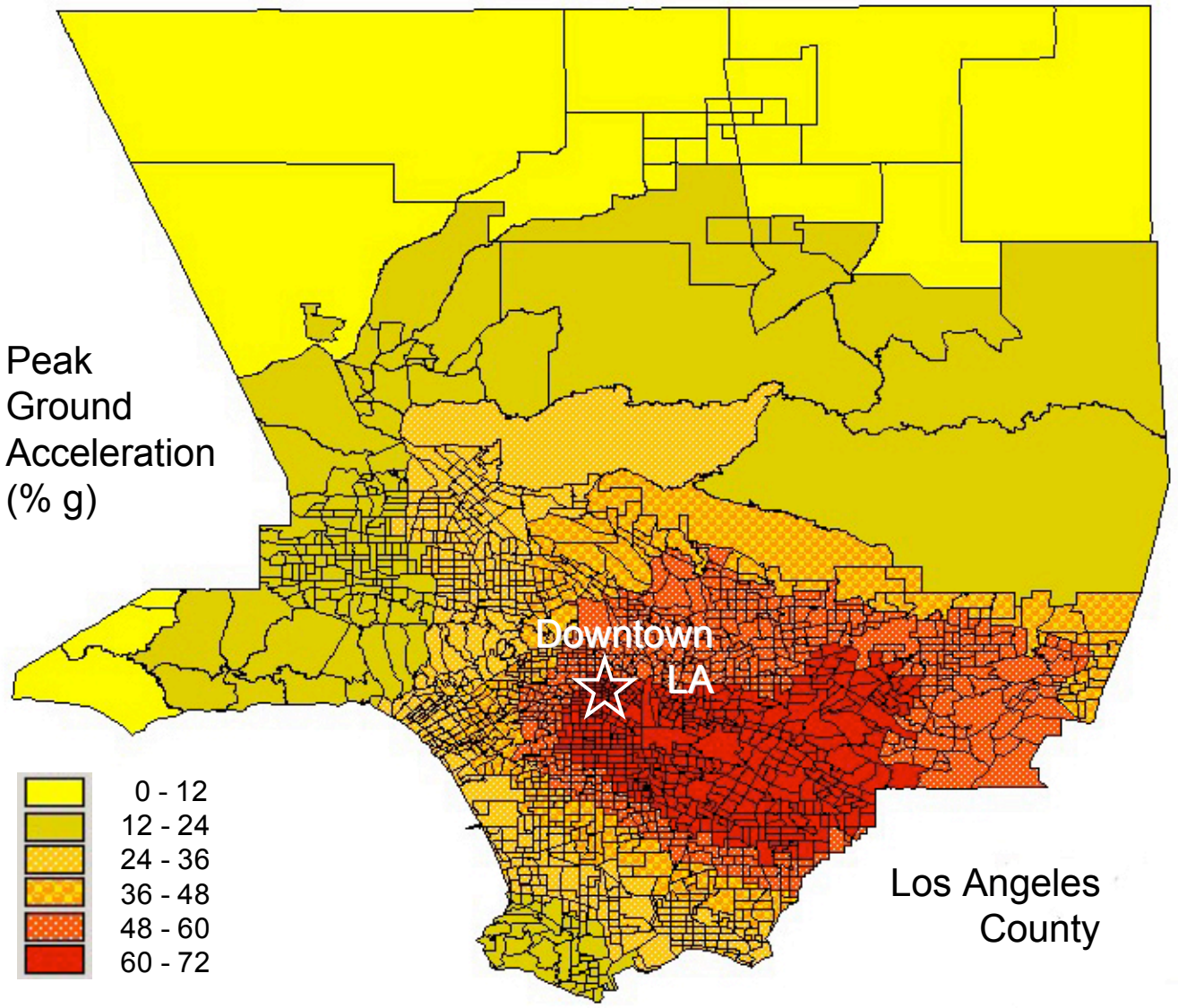
- Partnerships for Risk Assessment & Mitigation



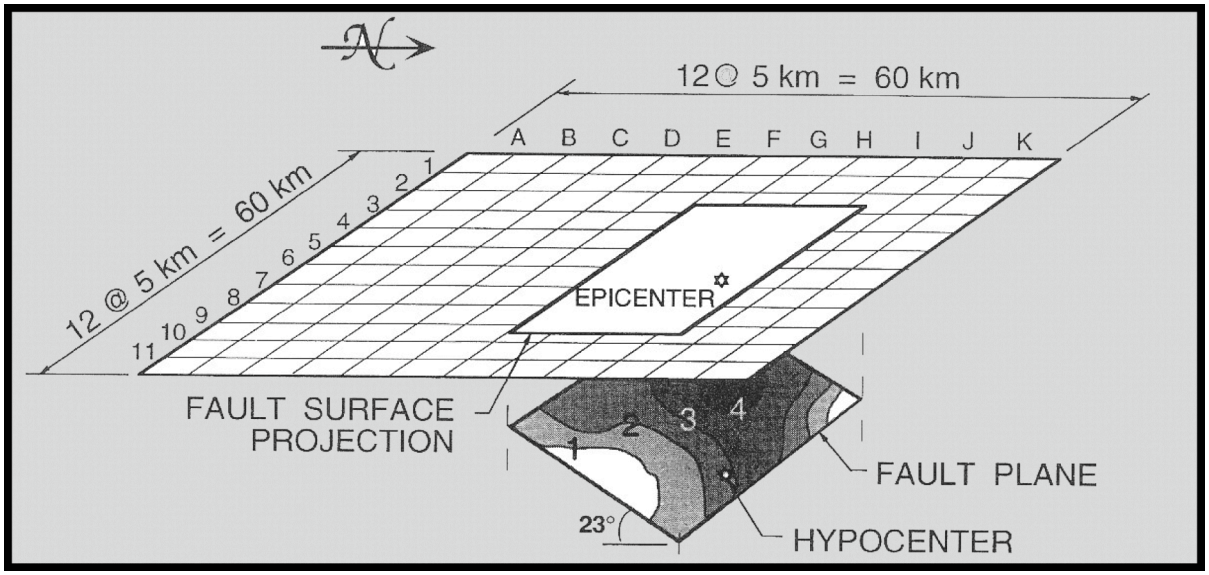
SCEC Collaborations with Earthquake Engineers

- Open-source, object-oriented framework for probabilistic seismic hazard analysis (OpenSHA)
  - SCEC development
  - Verification in collaboration with PEER-Lifelines
- Next Generation Attenuation Program (PEER-LL/SCEC/USGS)
  - NGA-E (empirical) phase to be completed in Summer, 2004
  - NGA-H (hybrid) phase to be initiated in Fall, 2004
- Ground-motion time histories for use in performance-based earthquake engineering
  - Emphasis on broad-band synthetic seismograms
  - Time histories for PEER testbeds
- End-to-end (“rupture-to-rivets”) simulations of scenario earthquakes in Southern California

Puente Hills M 7.1 Scenario

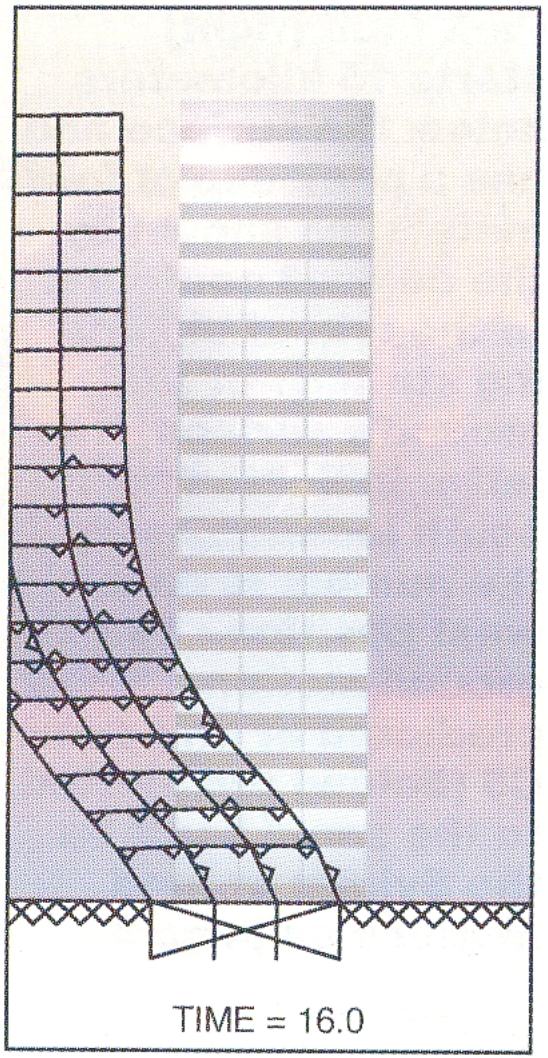


Displacement Pulse from an M7 Blind-Thrust Earthquake Beneath Los Angeles

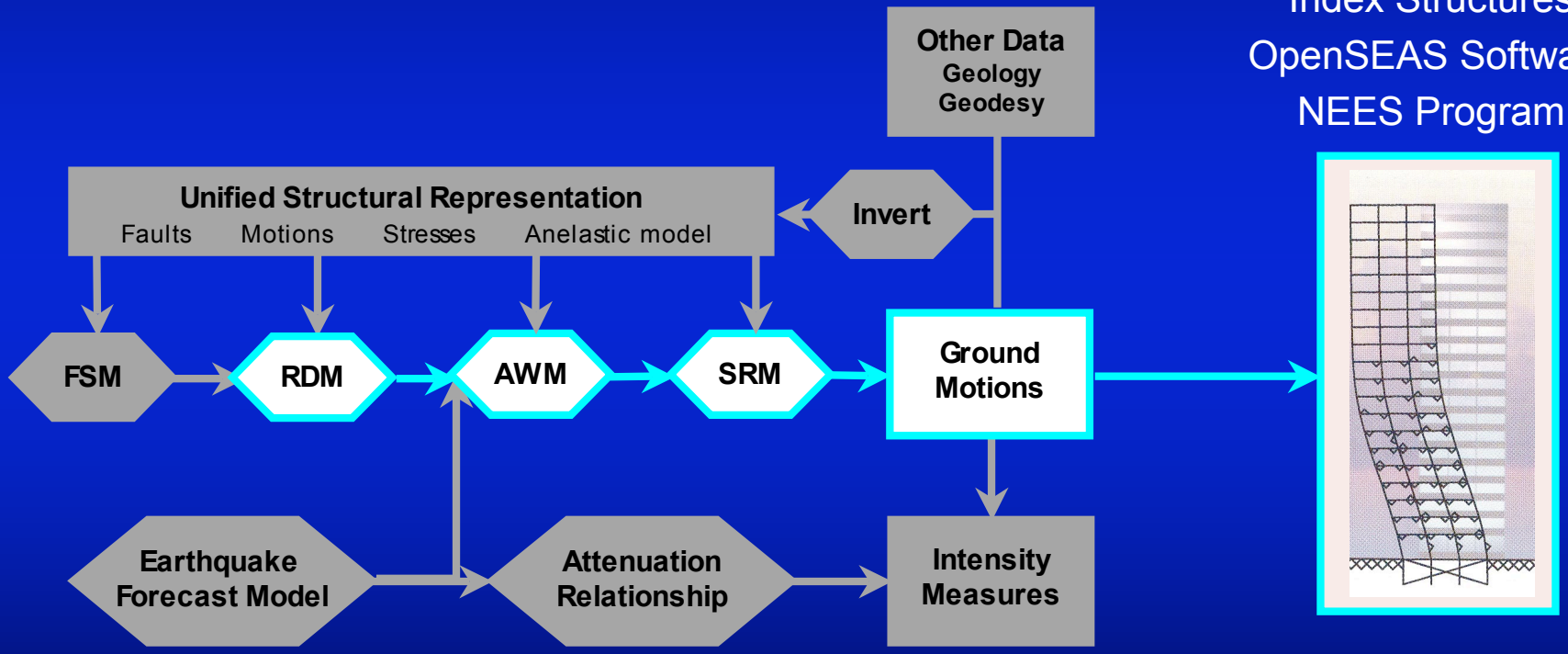


Simulation by
Hall, Heaton, Wald, and Halling

By t=16 seconds, the building is hopelessly overbalanced and on its way to oblivion.



End-to-End Simulation "Ruptures to Rivets"



Index Structures
OpenSEAS Software
NEES Program

RDM = Rupture Dynamics Model

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SCEC3 Initiatives

- End-to-end simulations
  - "Ruptures-to-rivets" collaboration with engineering community
- Collaboratory for the Study of Earthquake Predictability
  - Rigorous environment for registering & evaluating prediction experiments
- International Partnerships for System-Level Earthquake Science
  - With other countries that have earthquake collaboratories similar to SCEC

End