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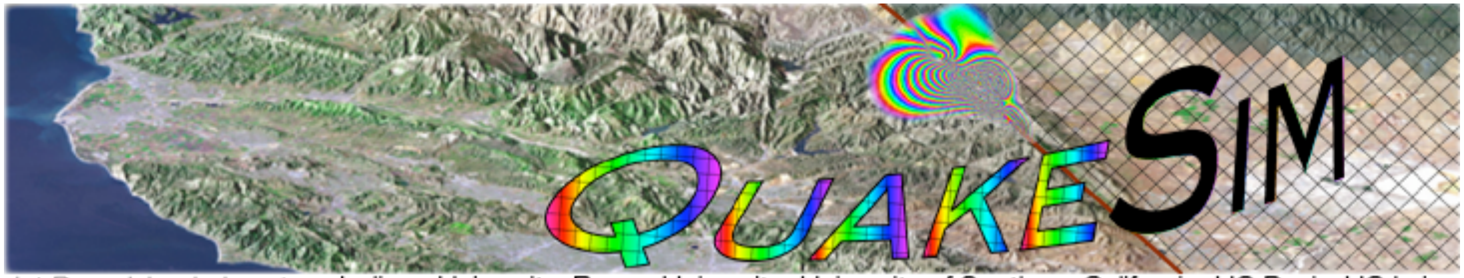

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An Overview of NASA Earthquake Research and the QuakeSim Project

Maggi Glasscoe

5th UJNR Earthquake Research Panel Meeting

October 13-15, 2004

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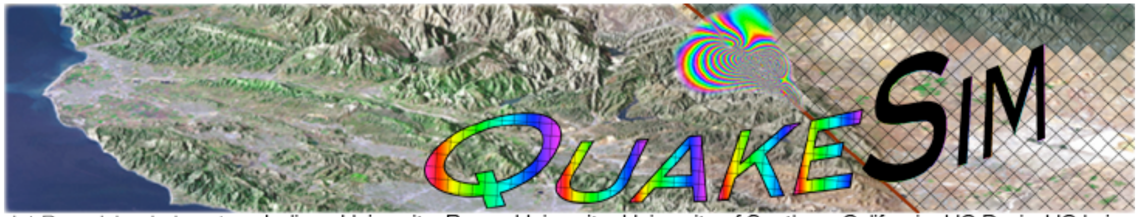

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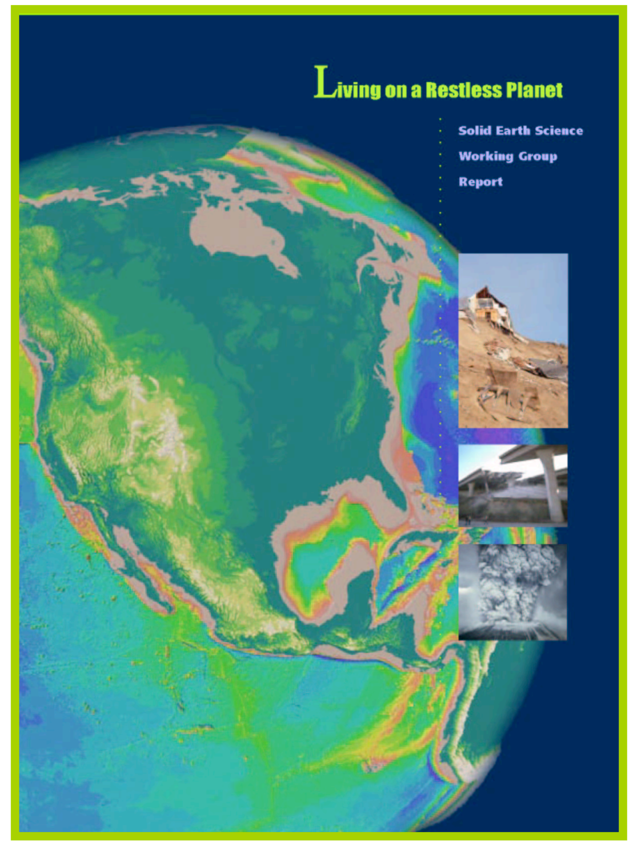
Acknowledgments

- Andrea Donnellan (PI), Jay Parker, Greg Lyzenga, Charles Norton, Teresa Baker, John Rundle, and the rest of the QuakeSim team
- Gilles Peltzer, Janet Harvey, Simon Hook (MASTER fault mapping)
- Nevin Bryant and others (thermal anomalies)
- Scott Hensley and others (UAVSAR)
- Frank Webb, Sharon Kedar, and others (SCIGN)

NASA's vision for solid Earth science

- In 2000, NASA formed the Solid Earth Science Working Group (SESWG)
- In 2002,they published *Living on a Restless Planet*
- This report outlined the vision for solid Earth science within NASA for the next 25 years



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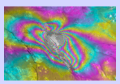
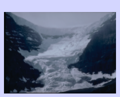
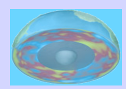
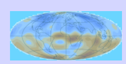
Motivating Challenges

1.  **What is the nature of deformation at plate boundaries and what are the implications for earthquake hazards?**
2.  **How do tectonics and climate interact to shape the Earth's surface and create natural hazards?**
3.  **What are the interactions among ice masses, oceans, and the solid Earth and their implications for sea level change?**
4.  **How do magmatic systems evolve and under what conditions do volcanoes erupt?**
5.  **What are the dynamics of the mantle and crust and how does the Earth's surface respond?**
6.  **What are the dynamics of the Earth's magnetic field and its interactions with the Earth system?**

From NASA's Solid Earth Science Working Group Report, *Living on a Restless Planet,* Nov. 2002

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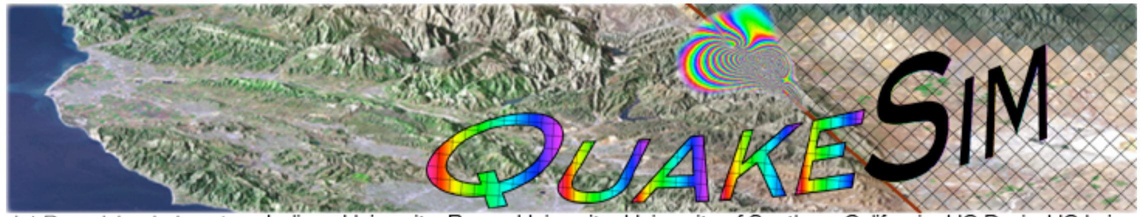

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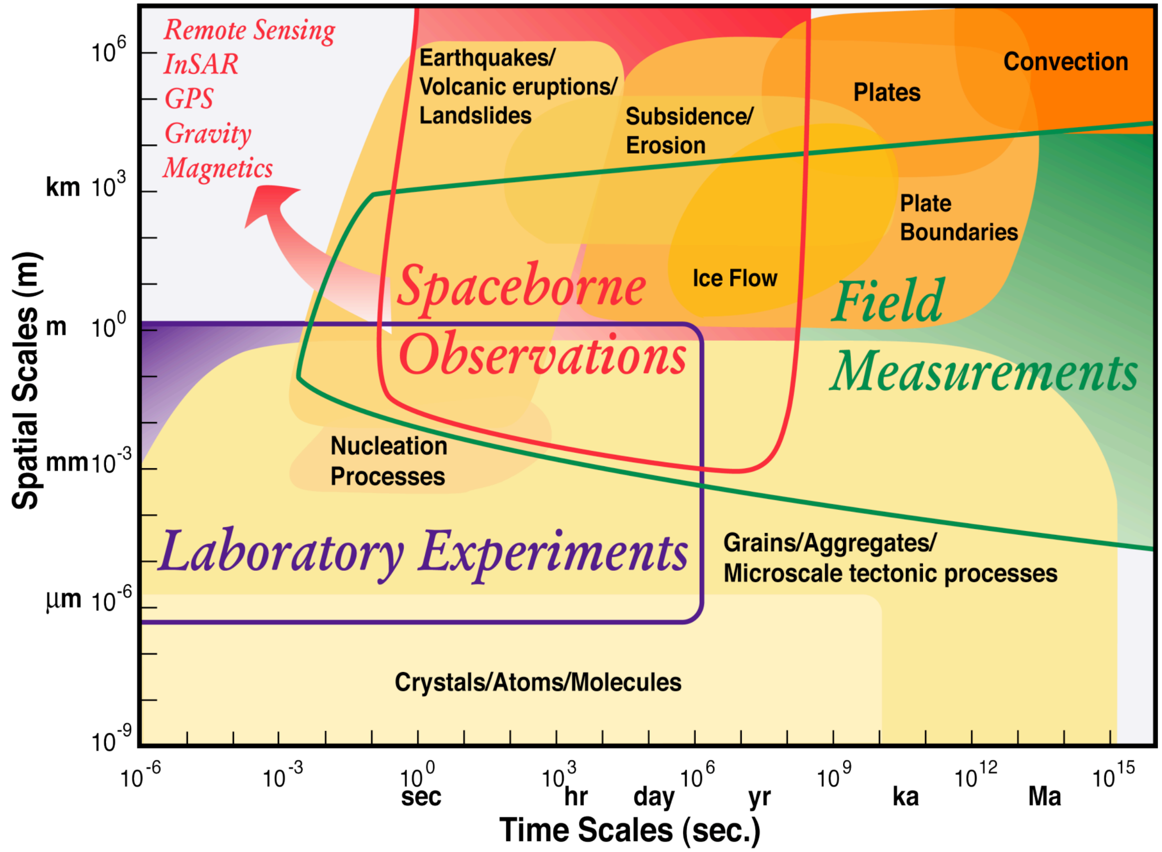
Characteristics of Solid Earth and Earthquake Sciences

- Widely distributed heterogeneous datasets
- Multiplicity of time and spatial scales
- Decomposable problems requiring interoperability for full models
- Distributed models and expertise



Enabled by Grids and Networks

NASA's Observational Strategies

To address the six cross-cutting scientific challenges, SESWG identified a suite of high-priority observational strategies.

1. **Surface deformation**
2. **High-resolution topography**
3. **Variability of Earth's magnetic field**
4. **Variability of Earth's gravity field**
5. **Imaging spectroscopy of Earth's changing surface**
6. **Space geodetic networks and the ITRF**
7. **Promising techniques and observations**

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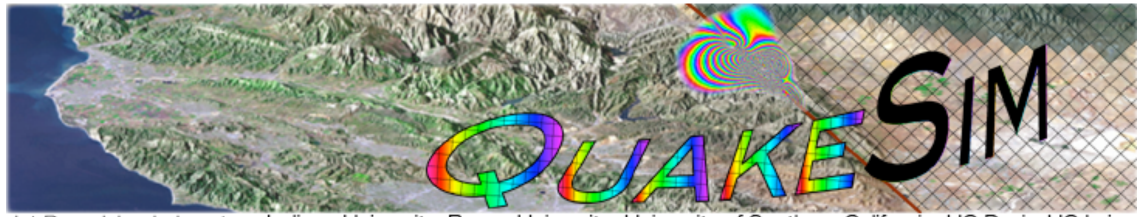

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Recent advances in NASA earthquake research

- Aerial mapping of faults
  - Using thermal mapping from airborne instruments to locate faults (MASTER)
- Thermal anomalies
  - Temperature increases prior to and just after earthquakes may indicate precursory signal
- UAVSAR
  - Autonomous airborne SAR
- Geohazards Natural Laboratory
  - Expanding several international Solid Earth programs into the larger framework for the Asia Pacific Arc and Western North America
- IT Developments
  - SCIGN
  - QuakeSim

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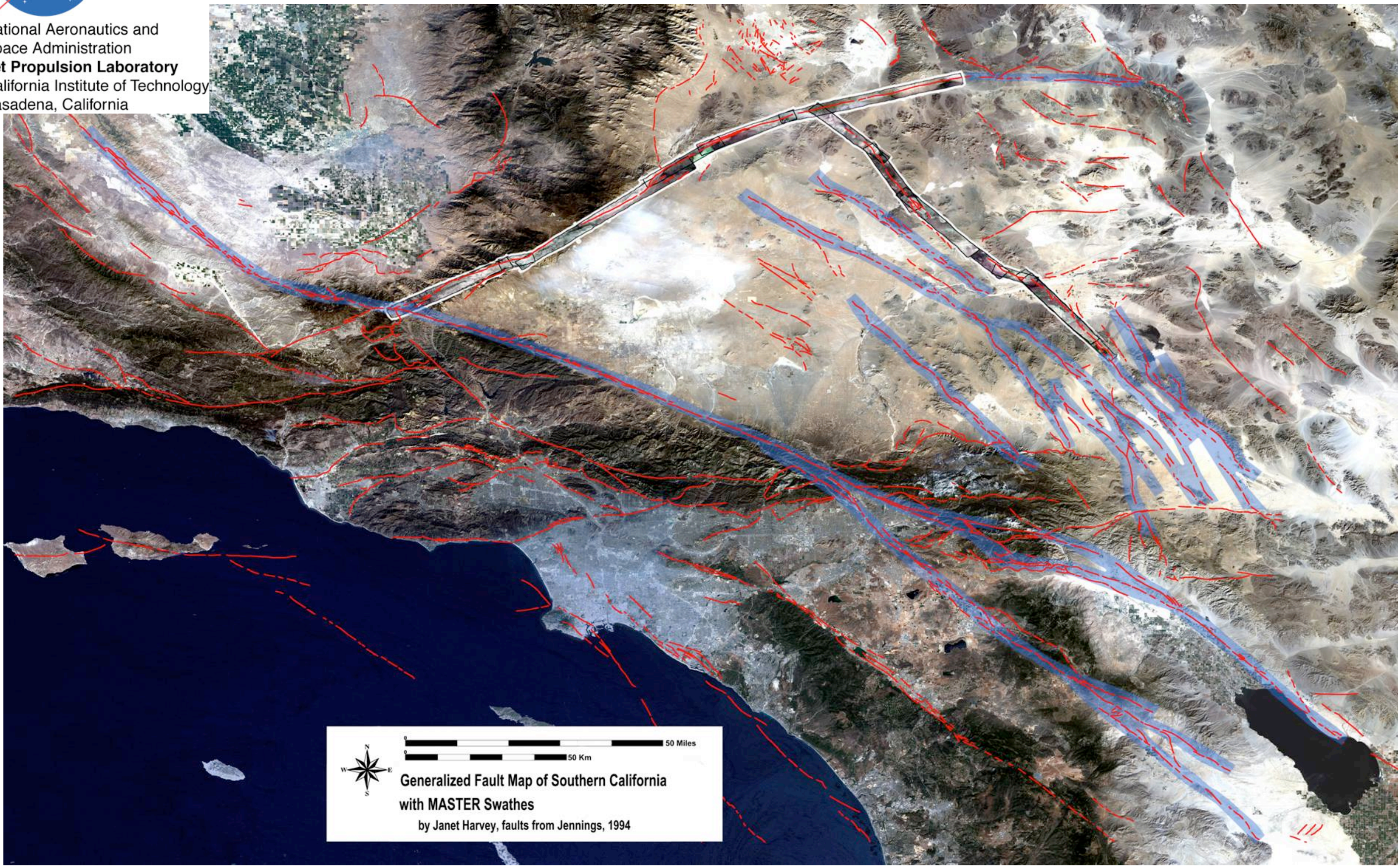
MASTER Mapping of Faults



Major Southern California Faults in Red
October, 2003 MASTER Data Acquisition displayed as Thermal Infrared Band Images
August, 2004 Data Acquisitions displayed in Blue
Landsat Background

Janet Harvey, Gilles Peltzer, UCLA
Simon Hook, JPL

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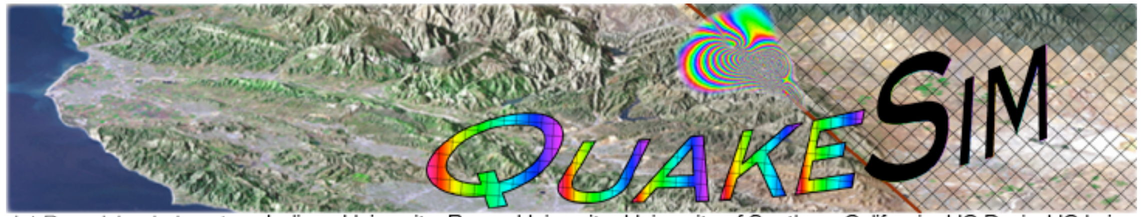

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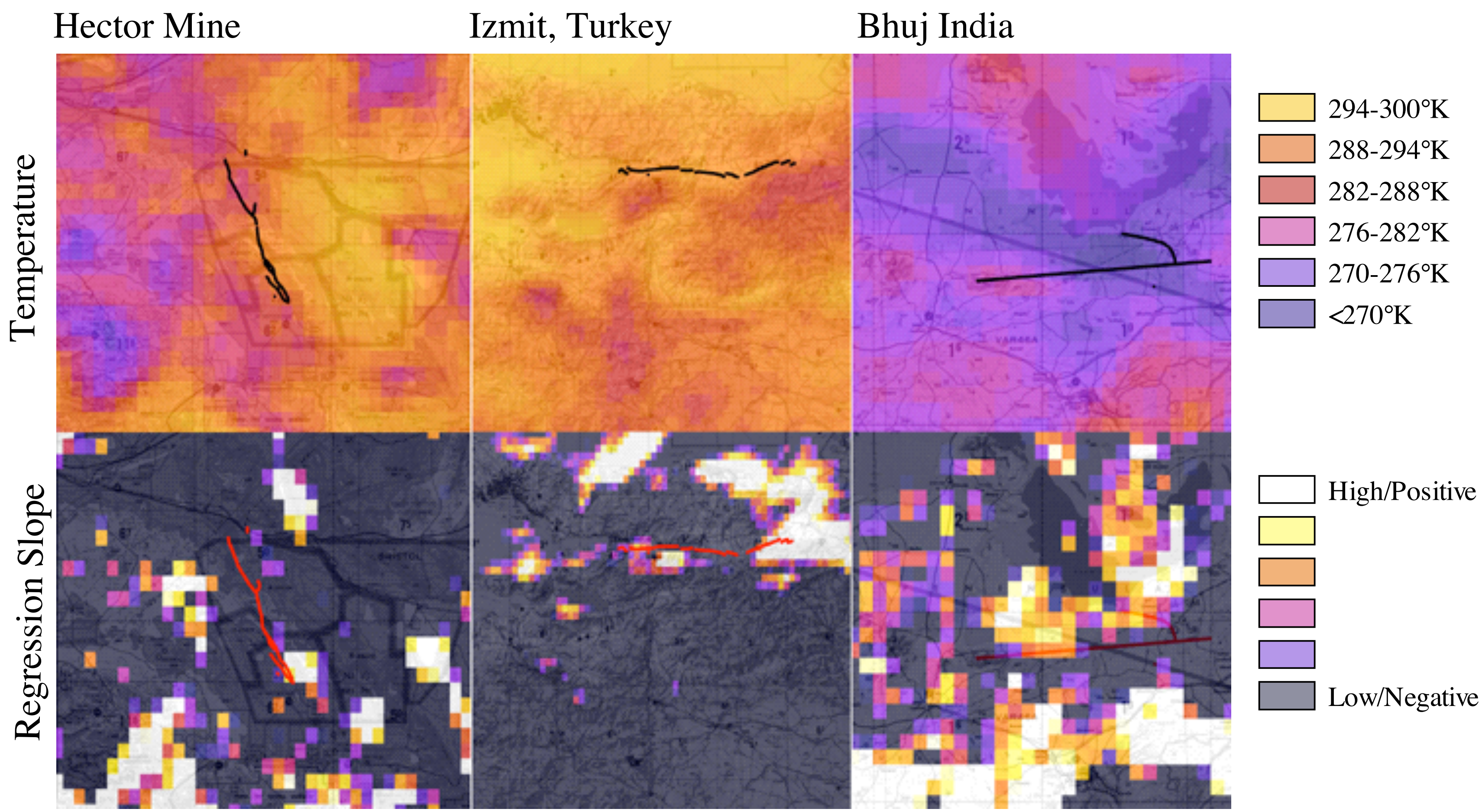
Temperature and Regression Slope Maps of Three Earthquake Events

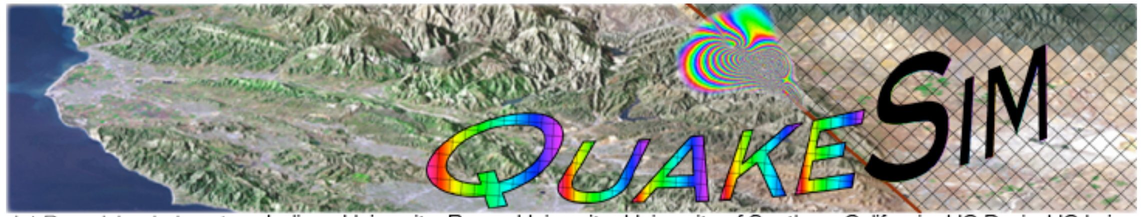


UAVSAR

- Generate fine resolution, accurate observations of crustal deformation resulting from natural hazards at hourly intervals
- Airborne InSAR can contribute to local measurements of rapidly evolving surfaces
- L-Band, repeat pass, satellites cannot provide adequate coverage at necessary temporal and spatial scales
- First flight in Jul-Oct ‘06
  First repeat pass Jan-Jun ‘07
  Deformation science demonstration Jun ‘07- Jul ‘08

Geohazards Natural Laboratory

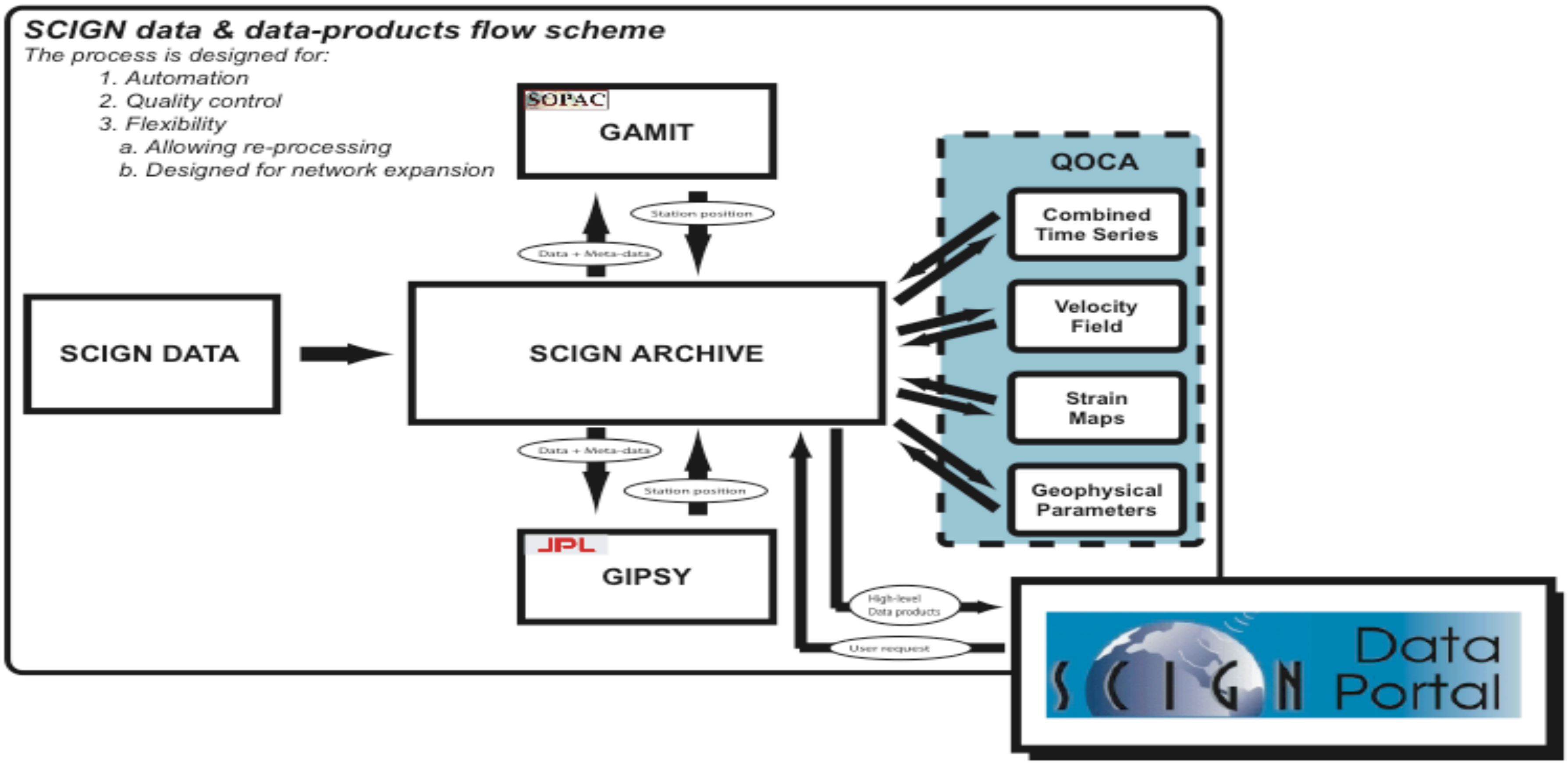
- The Earth Science Natural Laboratories (ESNL) concept provides a unifying theme under which research on earthquake, volcano and landslide geo-hazards may be studied
- An ESNL is a geographical region designated for the study of Earth processes through detailed field observations and *in situ* measurements
- The global nature of the problem makes satellite remote sensing uniquely suited to contribute to ESNL research through:
  - long-term site-specific monitoring
  - broader regional characterization
  - globally synoptic studies of comparable environments
- Also identified a need for quick-response, high spatial resolution data, as might be provided by airborne systems



Geohazards Natural Laboratory

- Data
  - Archives
  - New missions
- Development of standards, software and systems to promote the effective transfer and utilization of remote sensing data with the objective of near real-time data access to new data acquisition and archived data sets alike
- Development of a distributed computing environment and analysis capability to effectively synthesize and understand the ground and remotely sensed data sets

SCIGN Data and Data Products



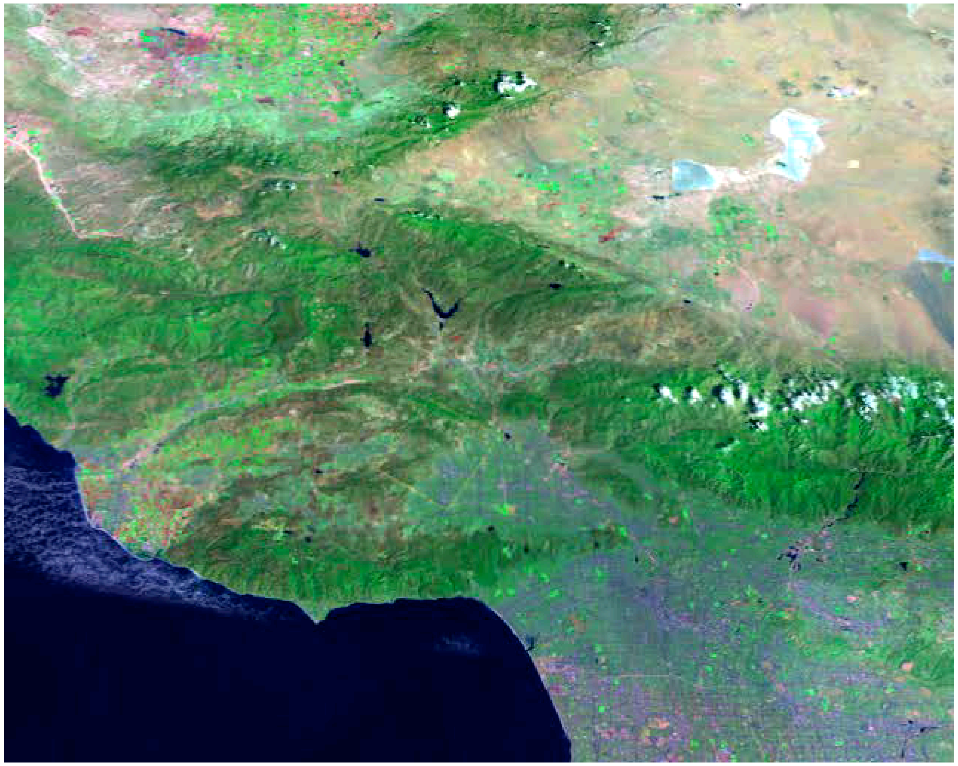
QuakeSim:

Simulation and analysis tools for creating a solid Earth science framework for understanding and studying active tectonic and earthquake processes

Objective

Develop the first real-time, large-scale, data assimilation grid implementation for the study of earthquakes that will:

- Assimilate distributed data sources and complex models into a parallel high-performance earthquake simulation and forecasting system
- Simplify data discovery, access, and usage from the scientific user point of view
- Provide capabilities for efficient data mining



Simulation of Northridge earthquake deformation and relaxation 500 years following the earthquake. InSAR fringes are equivalent to C-Band, 5.6 cm per fringe

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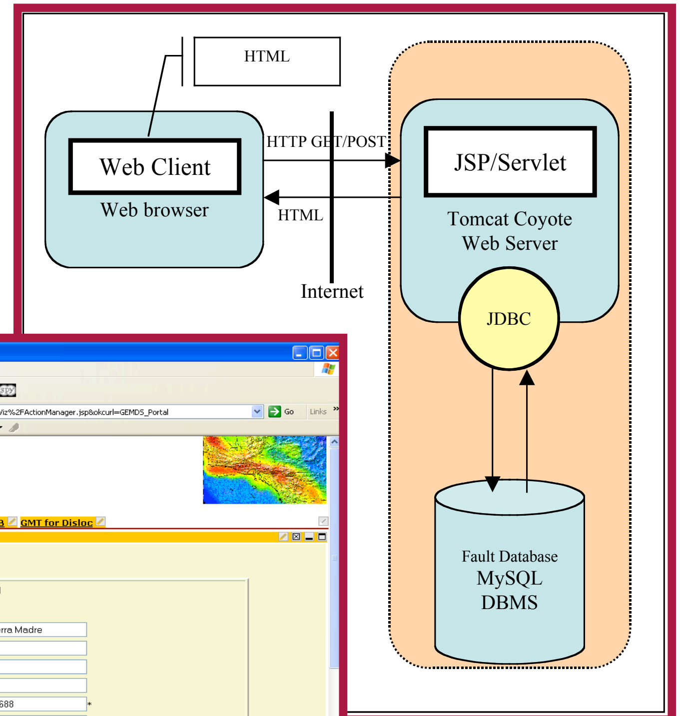
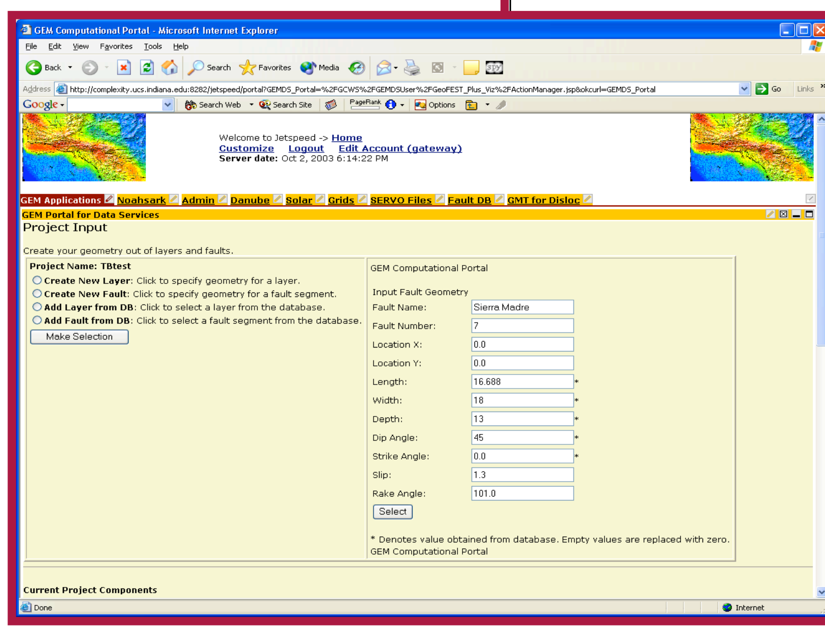
Information Systems

Computational Priorities
Advances in inversion methods, 3D modeling, data assimilation and pattern recognition all require high- performance computing.

Distributed Receiving and Processing Systems
The creation of distributed centers for processing and storing and comparing complementary data sets is important for interdisciplinary research.





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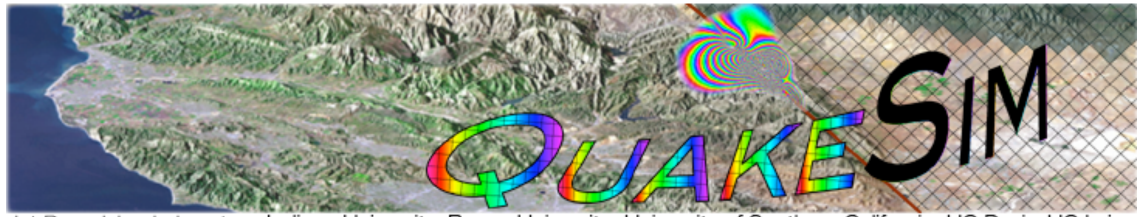

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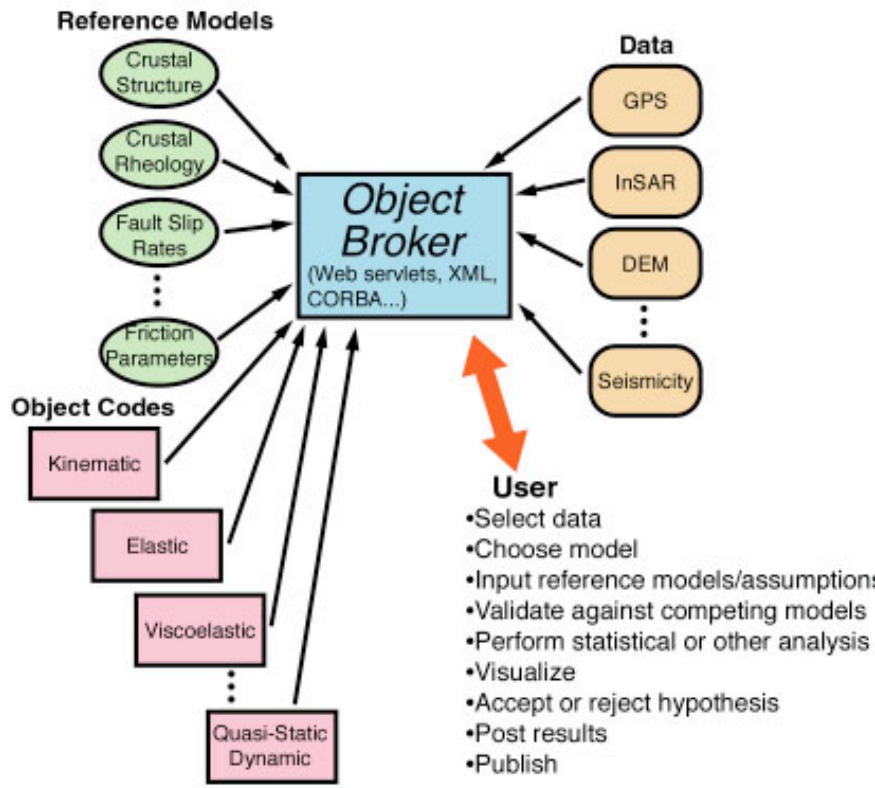
The QuakeSim Portal Interoperability Concept

- Reference models and material, simulation codes, data sources are internet objects.
- Design, maintenance, improvements at home institution
- Access for broad community through browser portal (PSE)
- Facilitates research with many tools, intercomparisons.



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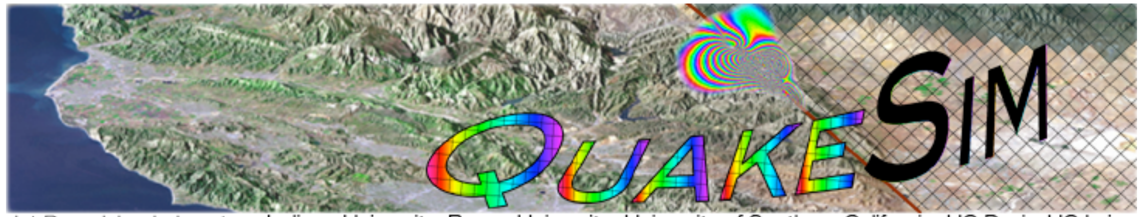

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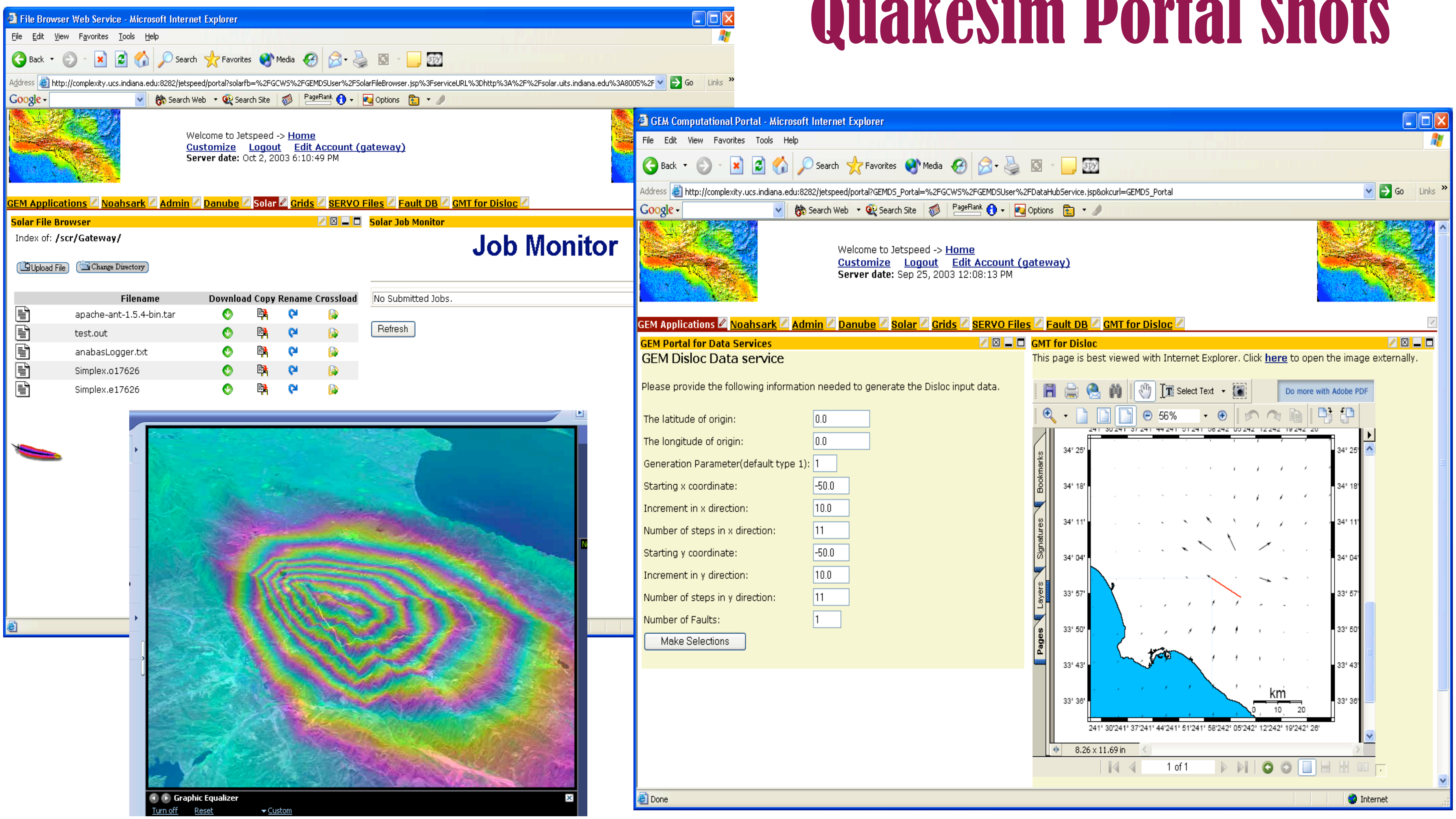
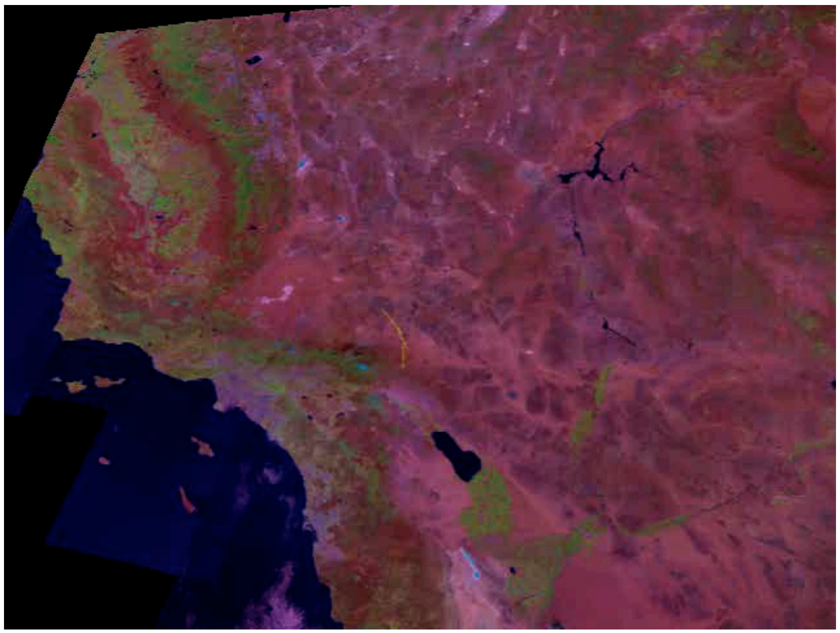
QuakeSim Portal Shots



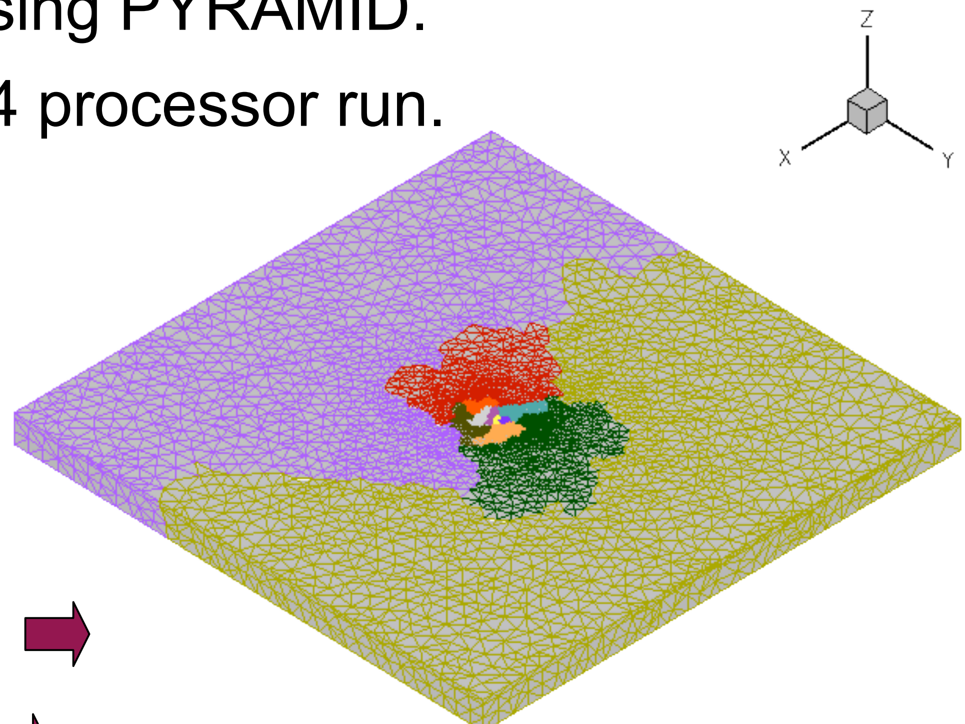
GeoFEST FEM and Mesh Decomposition



Simulation of Landers earthquake deformation and relaxation 500 years following the earthquake. InSAR fringes are equivalent to C-Band, 5.6 cm per fringe

1992 Landers earthquake finite element mesh decomposed using PYRAMID.

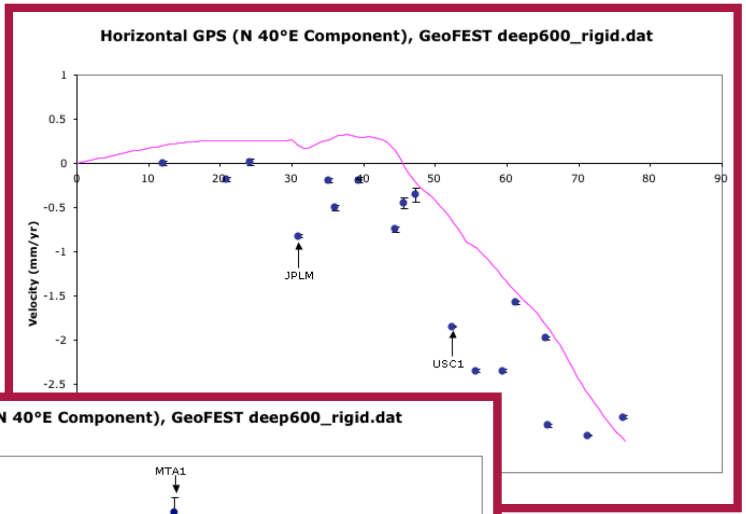
64 processor run.

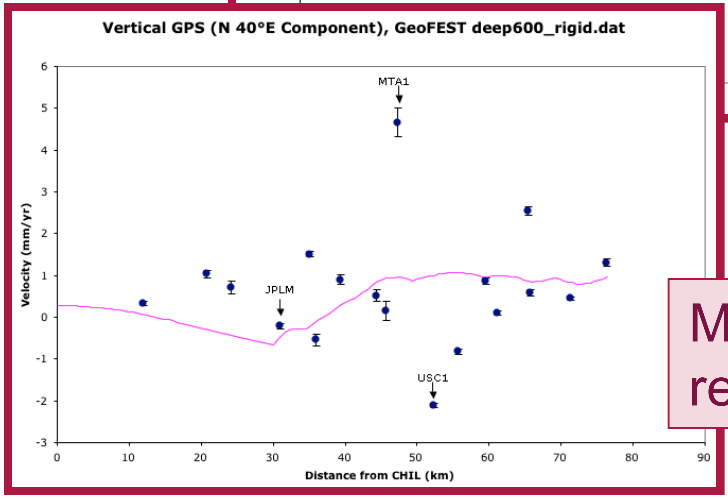


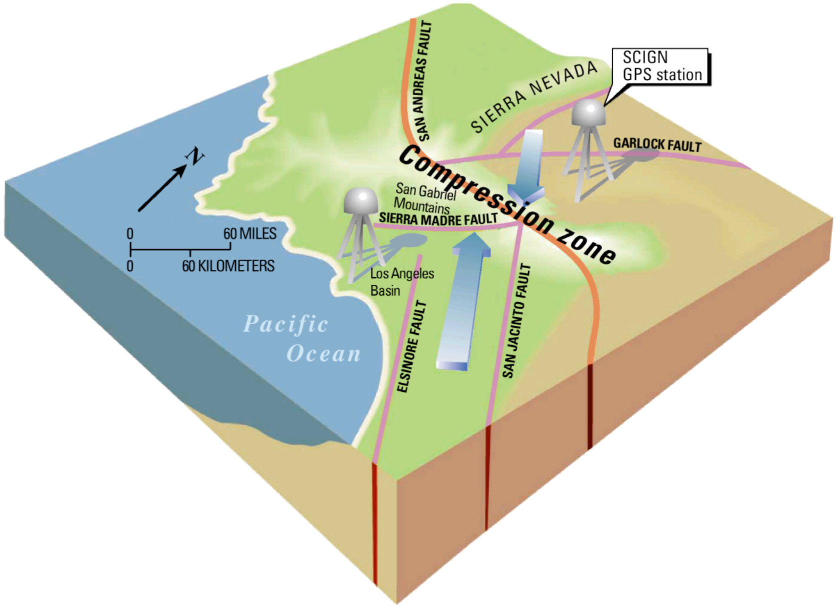
Model → Generate Mesh →

Refine Mesh → Run model → Interpret/visualize

Interacting Faults in the Los Angeles Basin







More than one fault is required to match the data.

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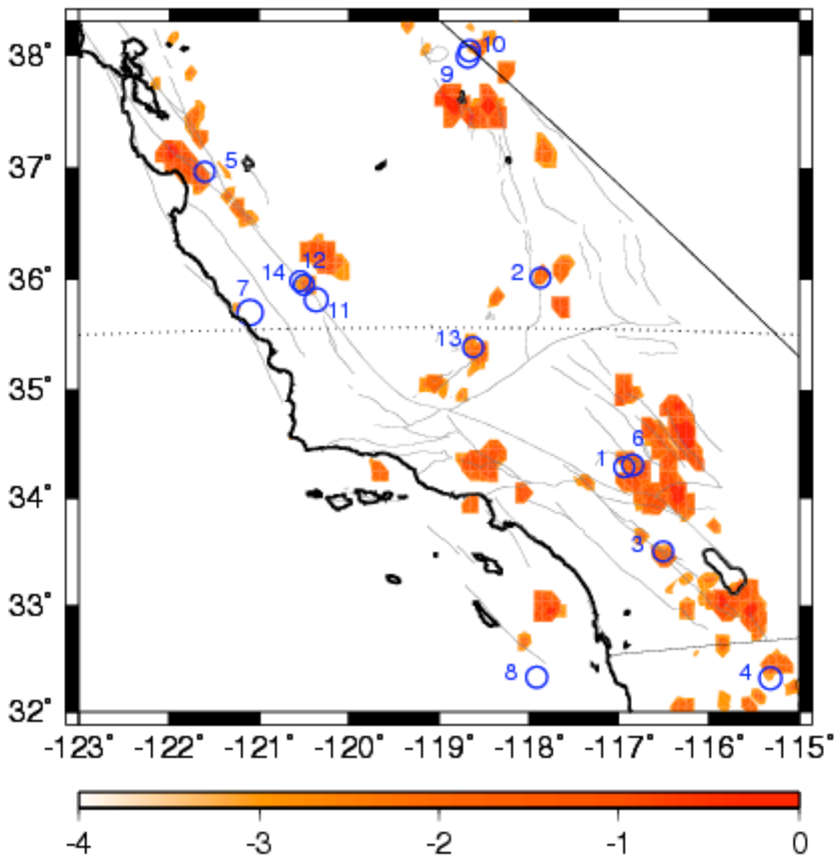
Real-time Earthquake Forecast



Plot of Log_{10} (Seismic Potential)

Increase in Potential for large earthquakes, M ≥ 5, ~ 2000 to 2010

Fourteen large events (blue circles) with M ≥ 5 have occurred on Central or Southern California on anomalies, or within the margin of error (+/- 11 km; Data from S. CA. and N. CA catalogs):

1. Big Bear I, M = 5.1, Feb 10, 2001
2. Coso, M = 5.1, July 17, 2001
3. Anza, M = 5.1, Oct 31, 2001
4. Baja, M = 5.7, Feb 22, 2002
5. Gilroy, M=4.9 - 5.1, May 13, 2002
6. Big Bear II, M=5.4, Feb 22, 2003
7. San Simeon, M = 6.5, Dec 22, 2003
8. San Clemente Island, M = 5.2, June 15, 2004
9. Bodie I, M=5.5, Sept. 18, 2004
10. Bodie II, M=5.4, Sept. 18, 2004
11. Parkfield I, M = 6.0, Sept. 28, 2004
12 Parkfield II, M = 5.2, Sept. 29, 2004
13 Arvin, M = 5.0, Sept. 29, 2004
14 Parkfield III, M = 5.0, Sept. 30, 2004

JB Rundle, KF Tiampo, W. Klein, JSS Martins, PNAS, v99, Supl 1, 2514-2521, Feb 19, 2002;
KF Tiampo, KF Tiampo, JB Rundle, S. McGinnis, S. Gross and W. Klein, Europhys. Lett., 60, 481-487, 2002

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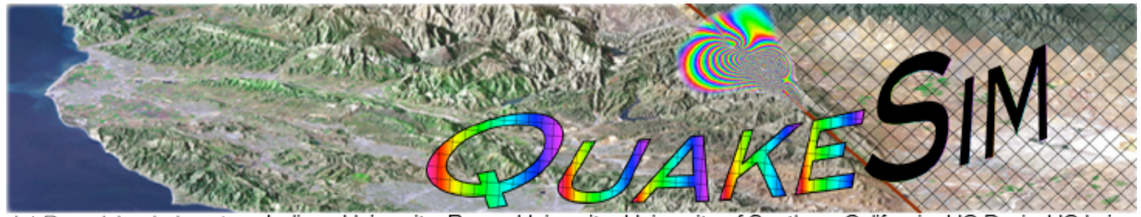

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Solid Earth Research Virtual Observatory (SERVO)

- Web-services (portal) based Problem Solving Environment
- Couples data with simulation, pattern recognition software, and visualization software
- Enable investigators to seamlessly merge multiple data sets and models, and create new queries.

<u>Data</u>

- Spaced-based observational data
- Ground-based sensor data (GPS, seismicity)
- Simulation data
- Published/historical fault measurements

<u>Analysis Software</u>

- Earthquake fault
- Lithospheric modeling
- Pattern recognition software

- SESWG and other materials
  - http://solidearth.jpl.nasa.gov
- QuakeSim website
  - http://quakesim.jpl.nasa.gov
- SCIGN
  - http://www.scign.org
  - http://reason.scign.org
- MASTER
  - http://masterweb.jpl.nasa.gov