Improving GNSS for Future Natural Disaster Reduction:

Earthquakes & Tsunamis

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U. S. Geological Survey

GNSS Science & Technology Applications

ICG-3

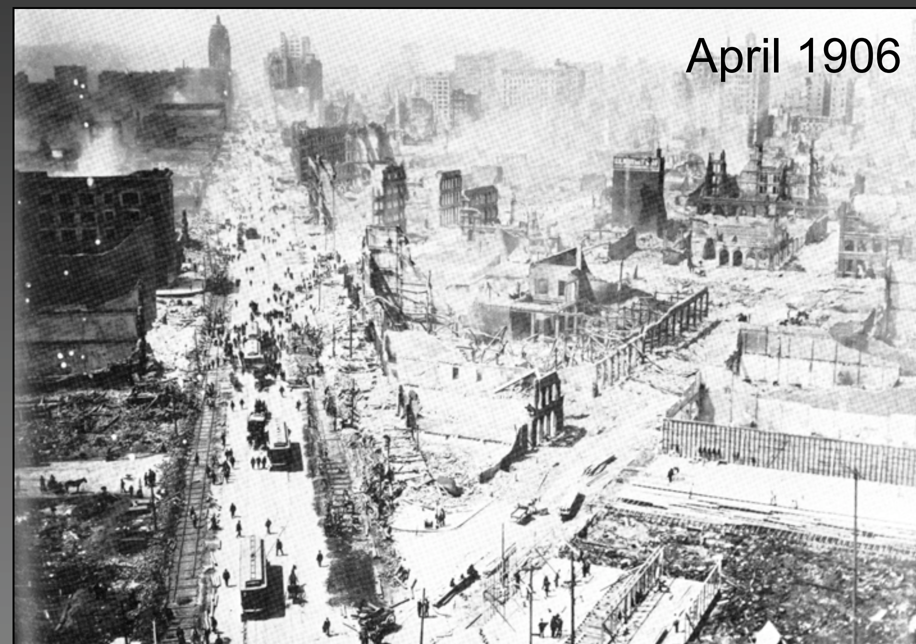
December 9, 2008

Pasadena, California

USGS
science for a changing world

San Francisco - 5:12 AM on April 18, 1906…


May 1900

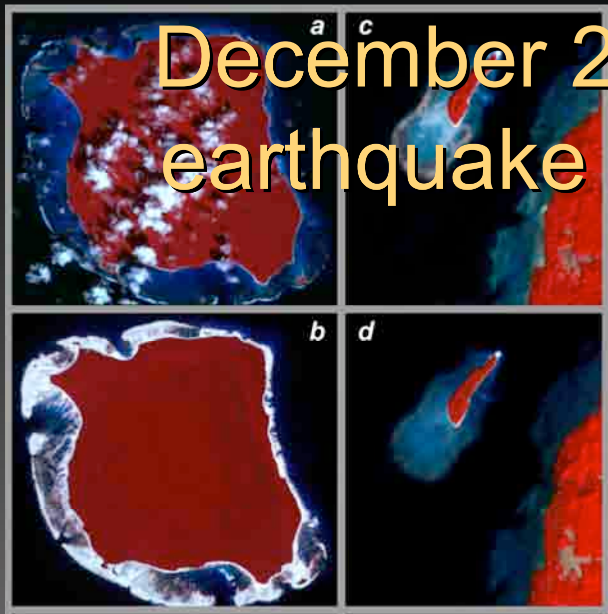

April 1906

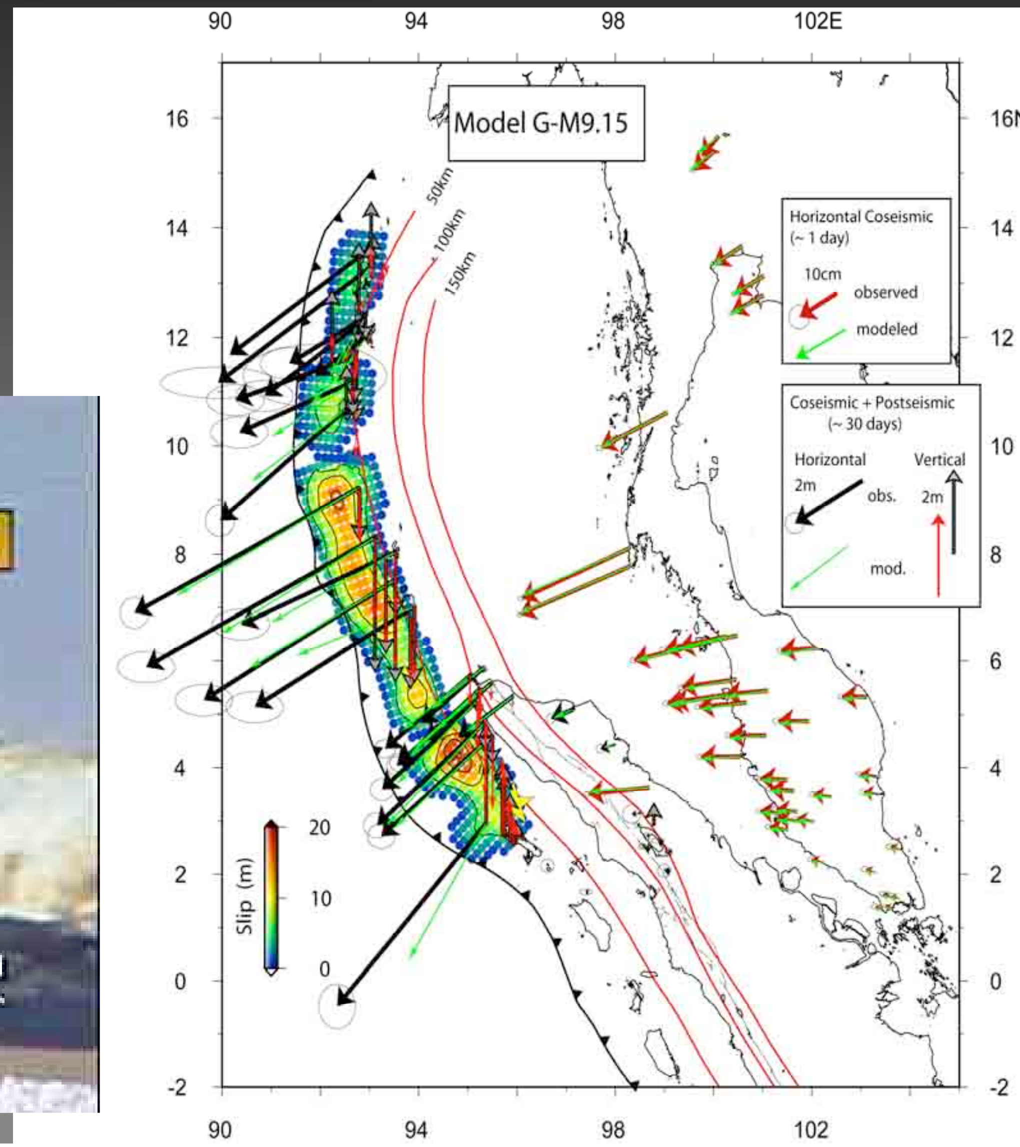
Photos courtesy Carol Prentice, USGS

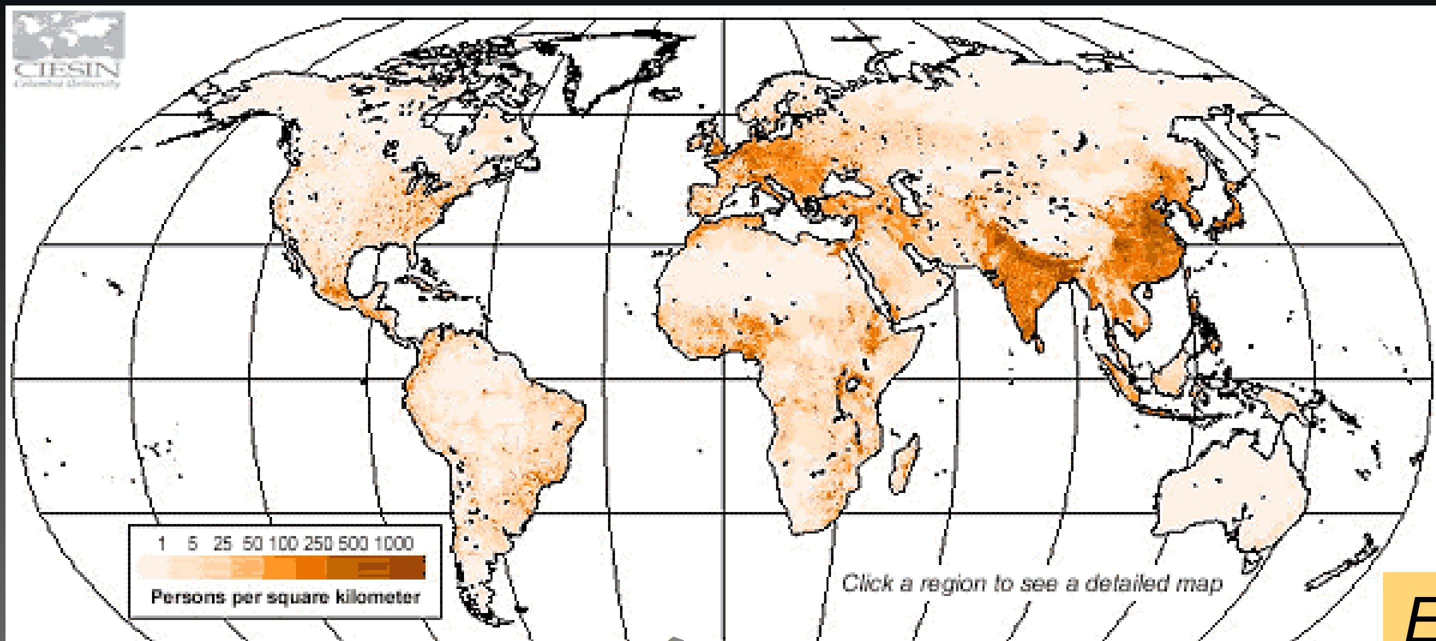
3000 people were killed; 225,000 of the 400,000 living in San Francisco were left homeless. Much of the city was in ruins.

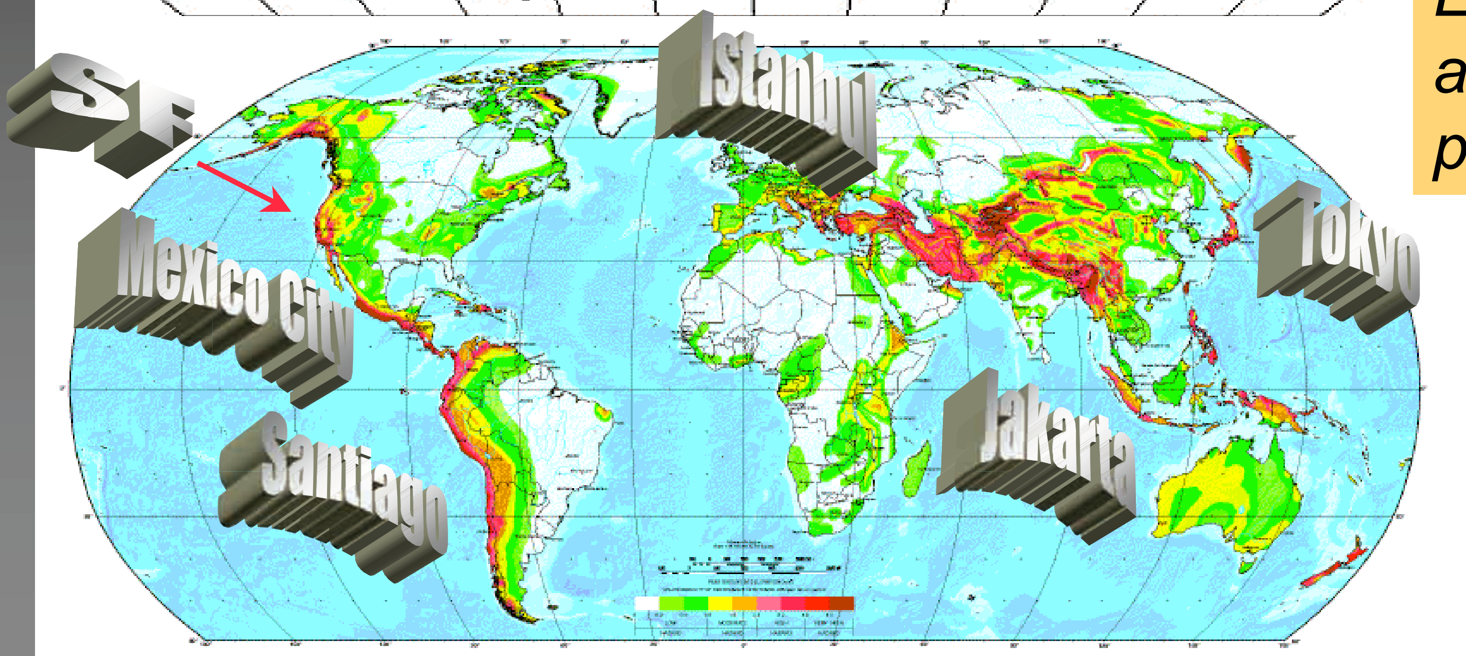
100 years ago

December 26, 2004 Sumatra-Andaman earthquake and Indian Ocean Tsunami



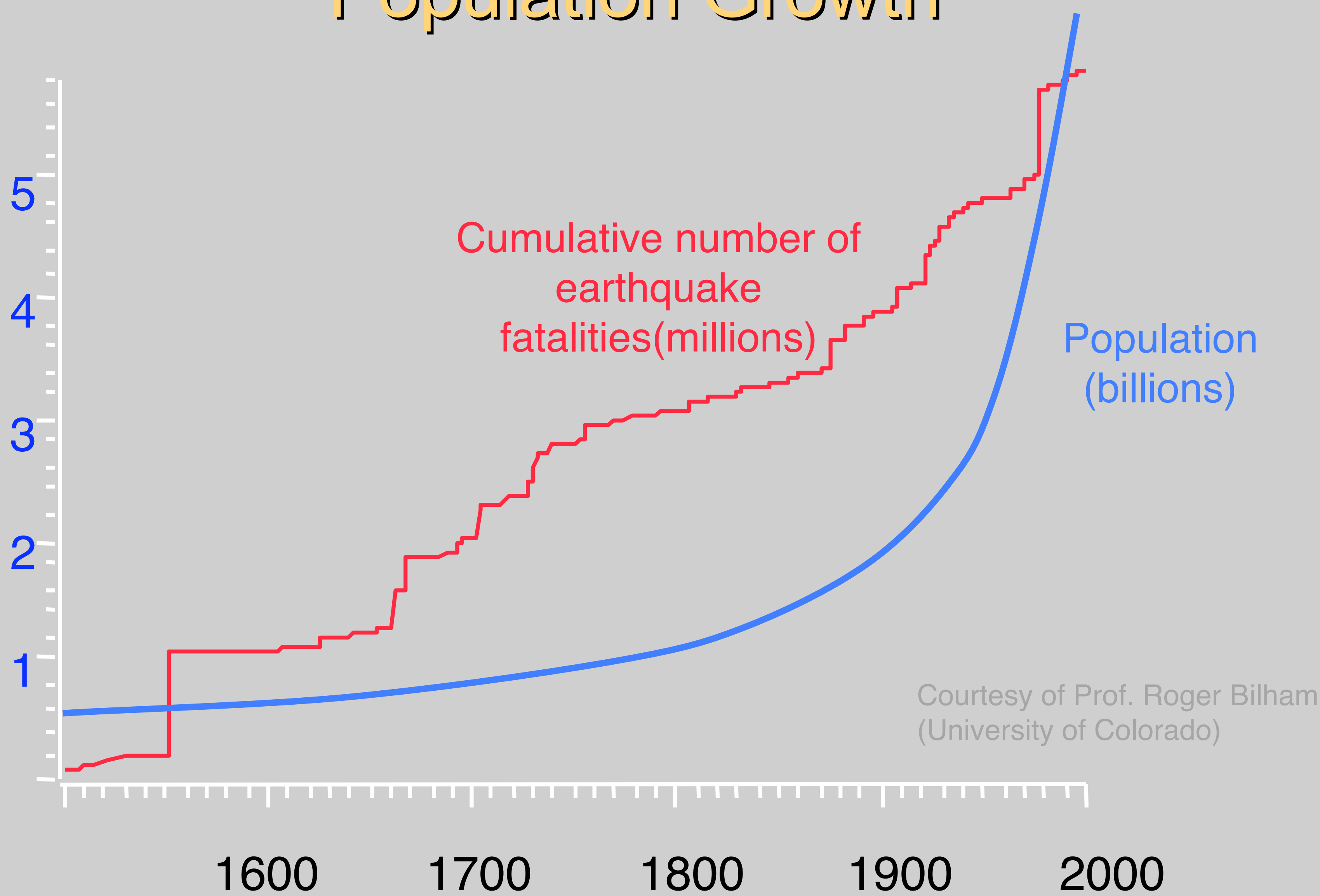




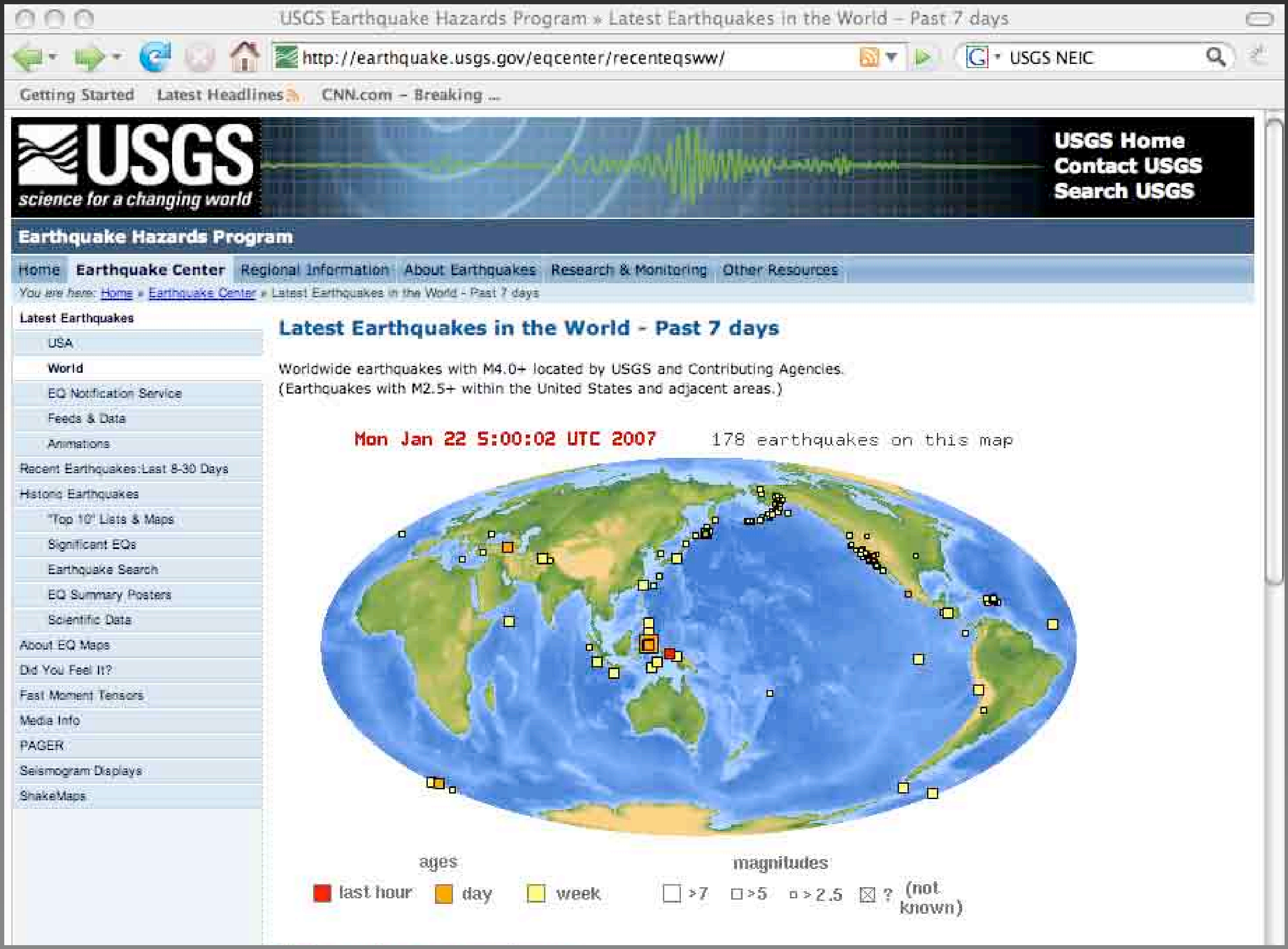


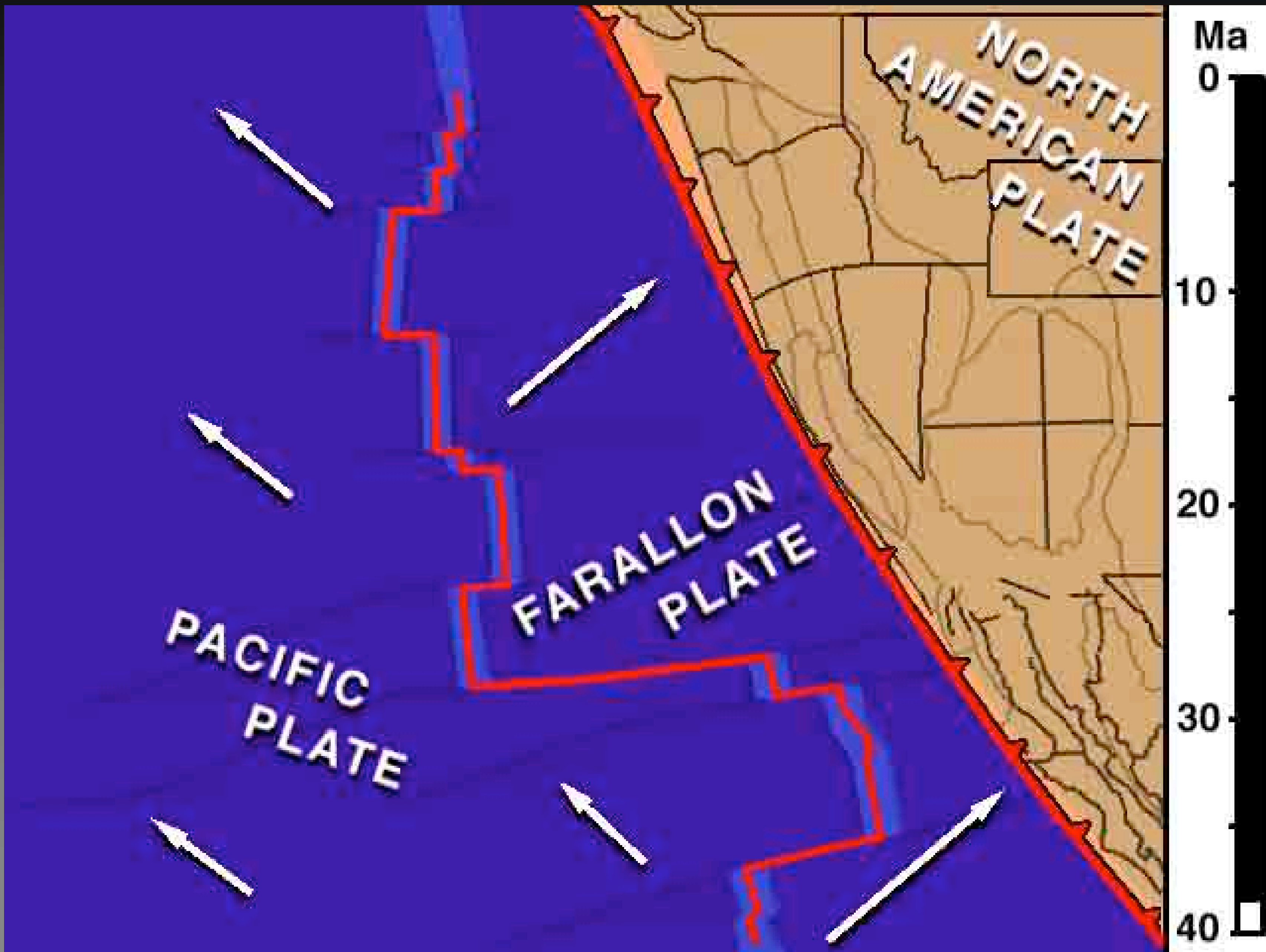
Earthquakes are a global problem

Earthquake Fatalities and Population Growth

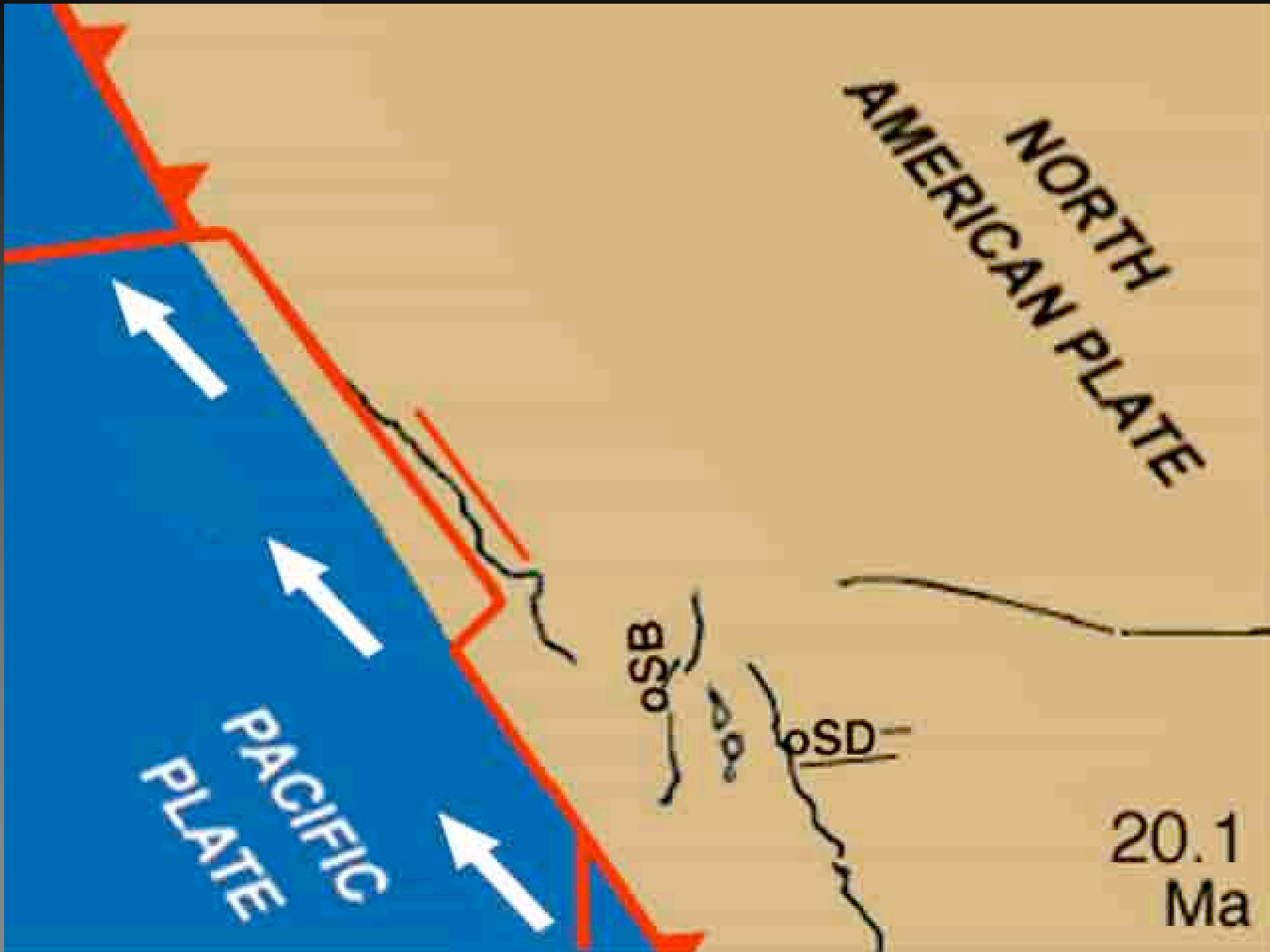


GNSS timing for precise earthquake location worldwide - also vital for tsunami alerts





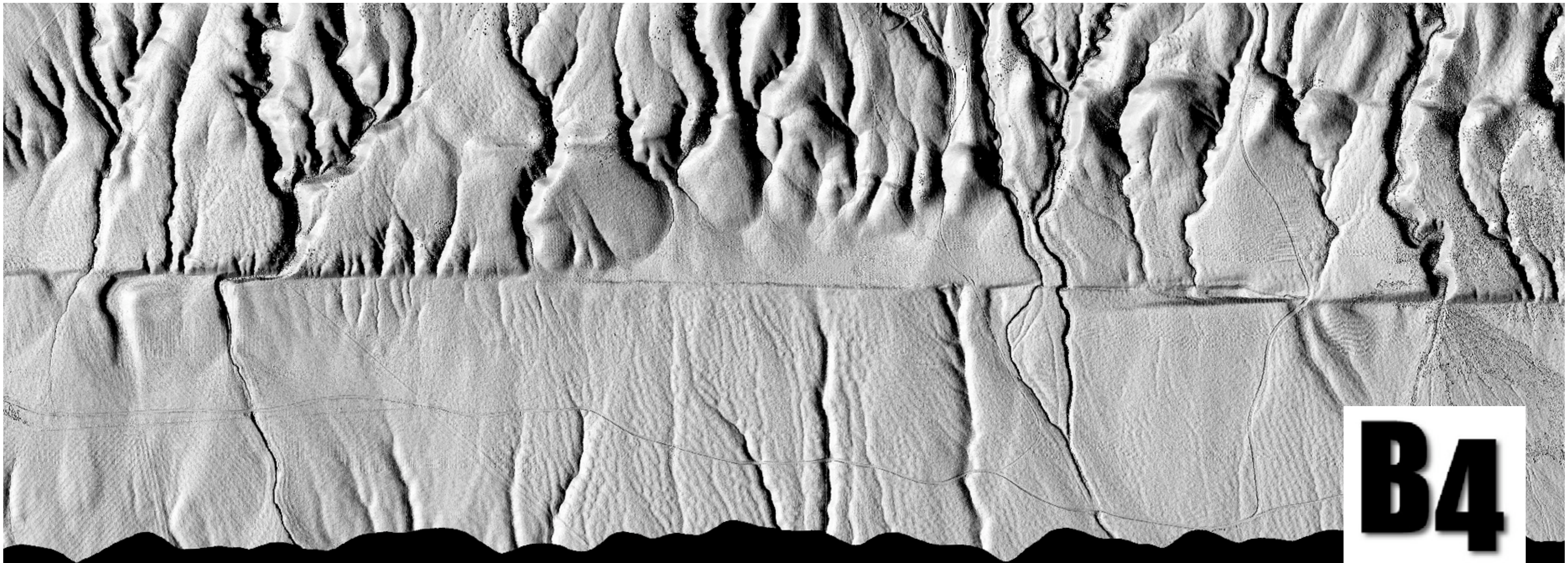
Courtesy of Prof. Tanya Atwater, UCSB

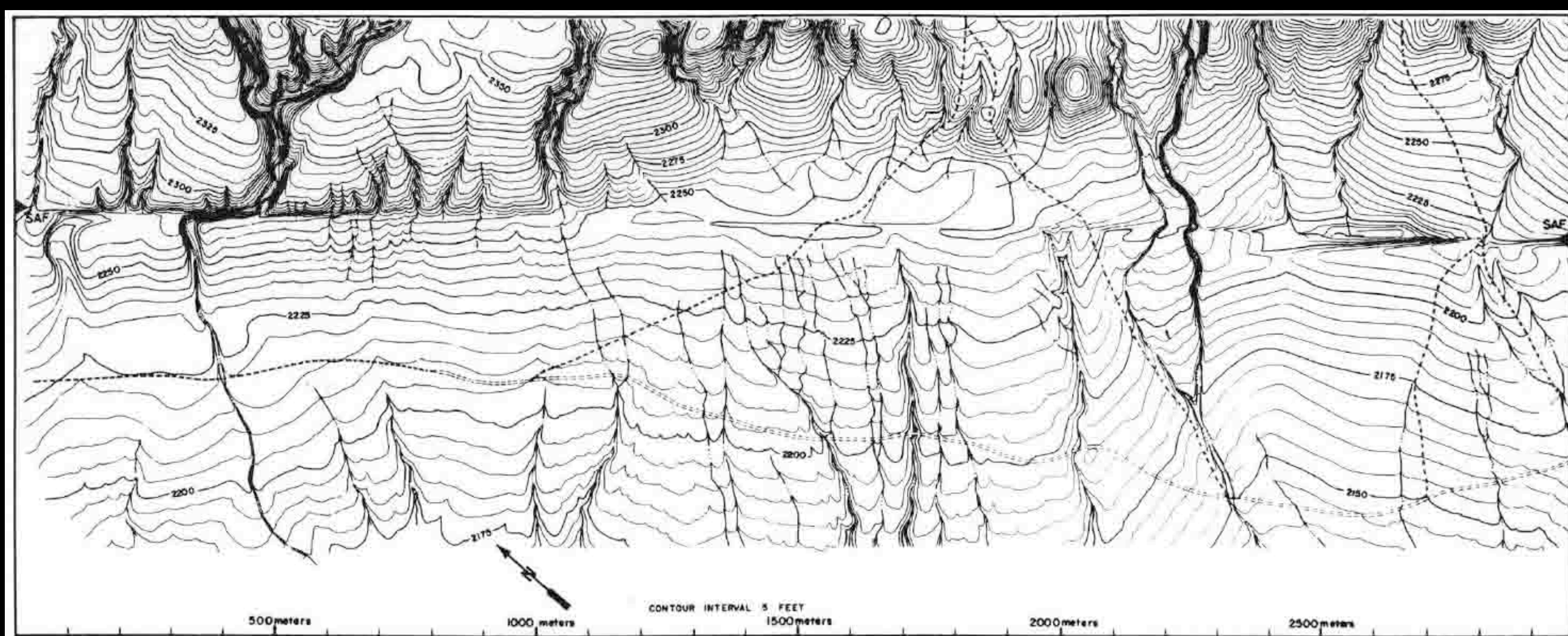


Courtesy of Prof. Tanya Atwater, UCSB

San Andreas fault

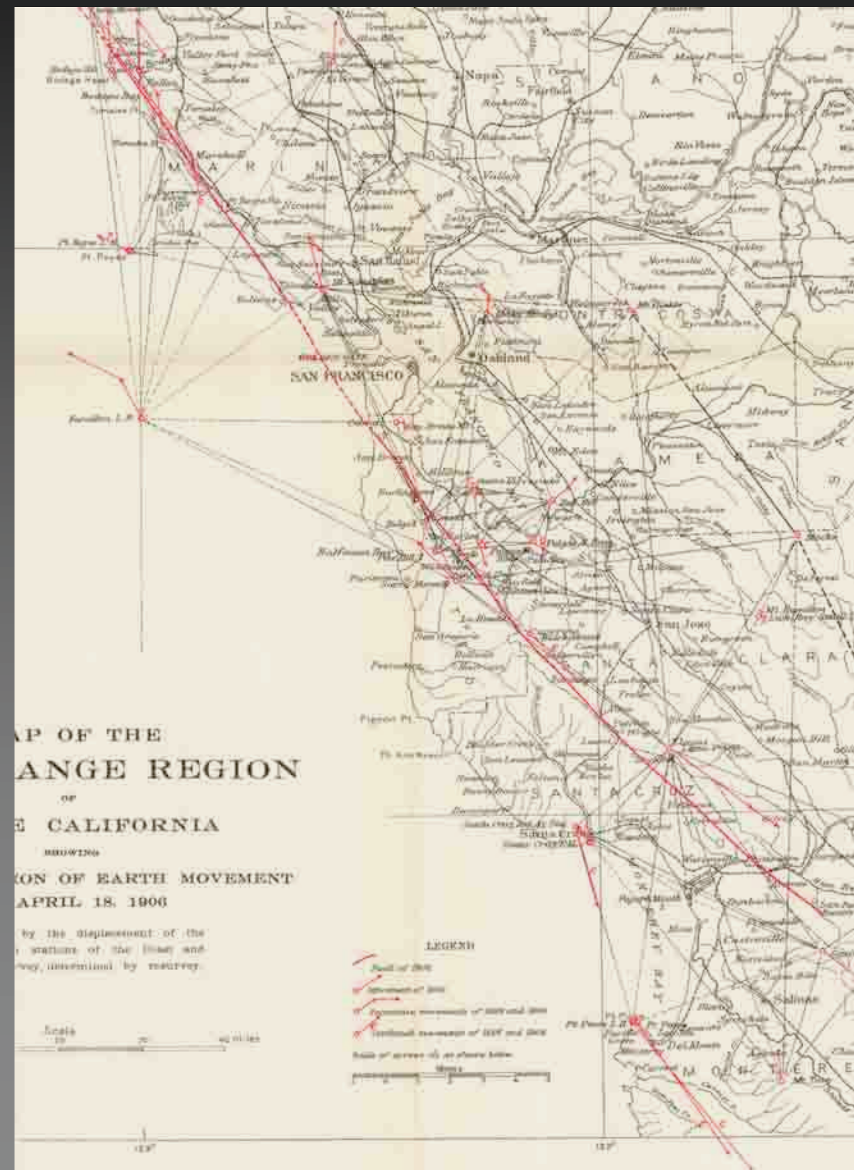
- 35 mm/yr slip rate;
  - >70% of plate motion
  - 1685, 1812, 1857 eq's
- Big Bend compression
  - 1971 Sylmar (M 6.7)
  - 1994 Northridge (M 6.7)
- California is now very heavily 'wired' with many GPS stations
- GPS measures plate motion strain accumulation and large earthquake displacements
- 'Natural laboratory' to study future 'Big Ones'
- B4 - Imaged by airborne LiDAR - *GPS was crucial!*


B4

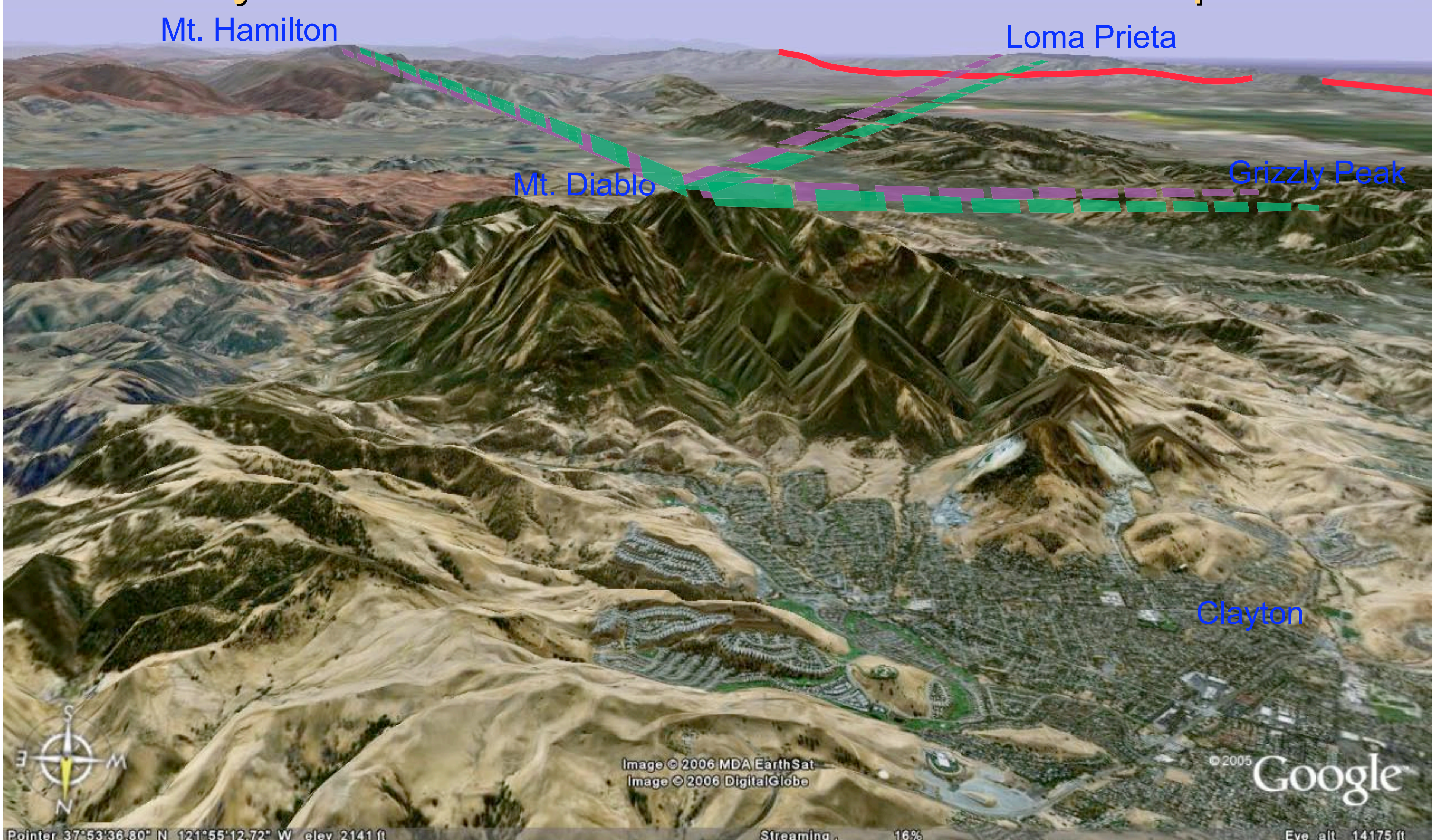

SAF
SAF
CONTOUR INTERVAL 5 FEET
500 meters
1000 meters
1500 meters
2000 meters
2500 meters

Reid's theory of "Elastic Rebound"

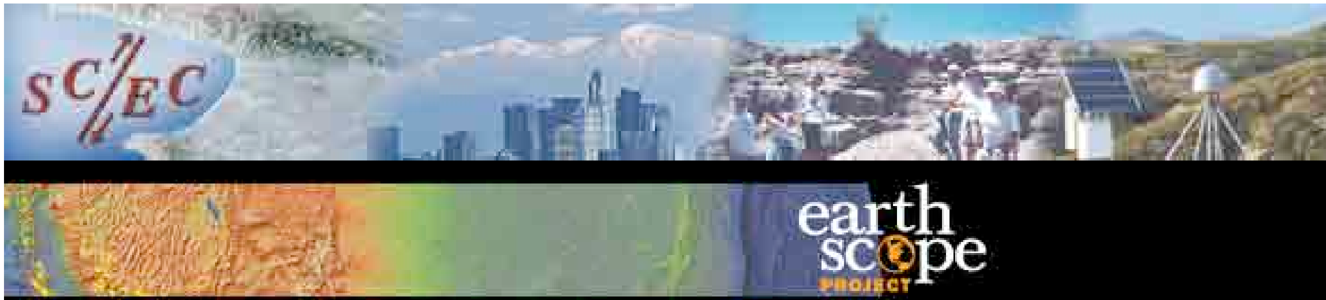
Triangulation networks were resurveyed in the 15 months following the 1906 earthquake.



Surveyors measure the location of mountain peaks



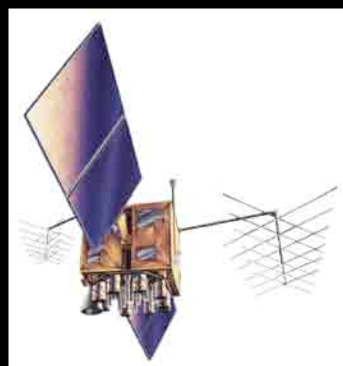
Pre-earthquake Post earthquake



SCIGN

SOUTHERN CALIFORNIA INTEGRATED GPS NETWORK

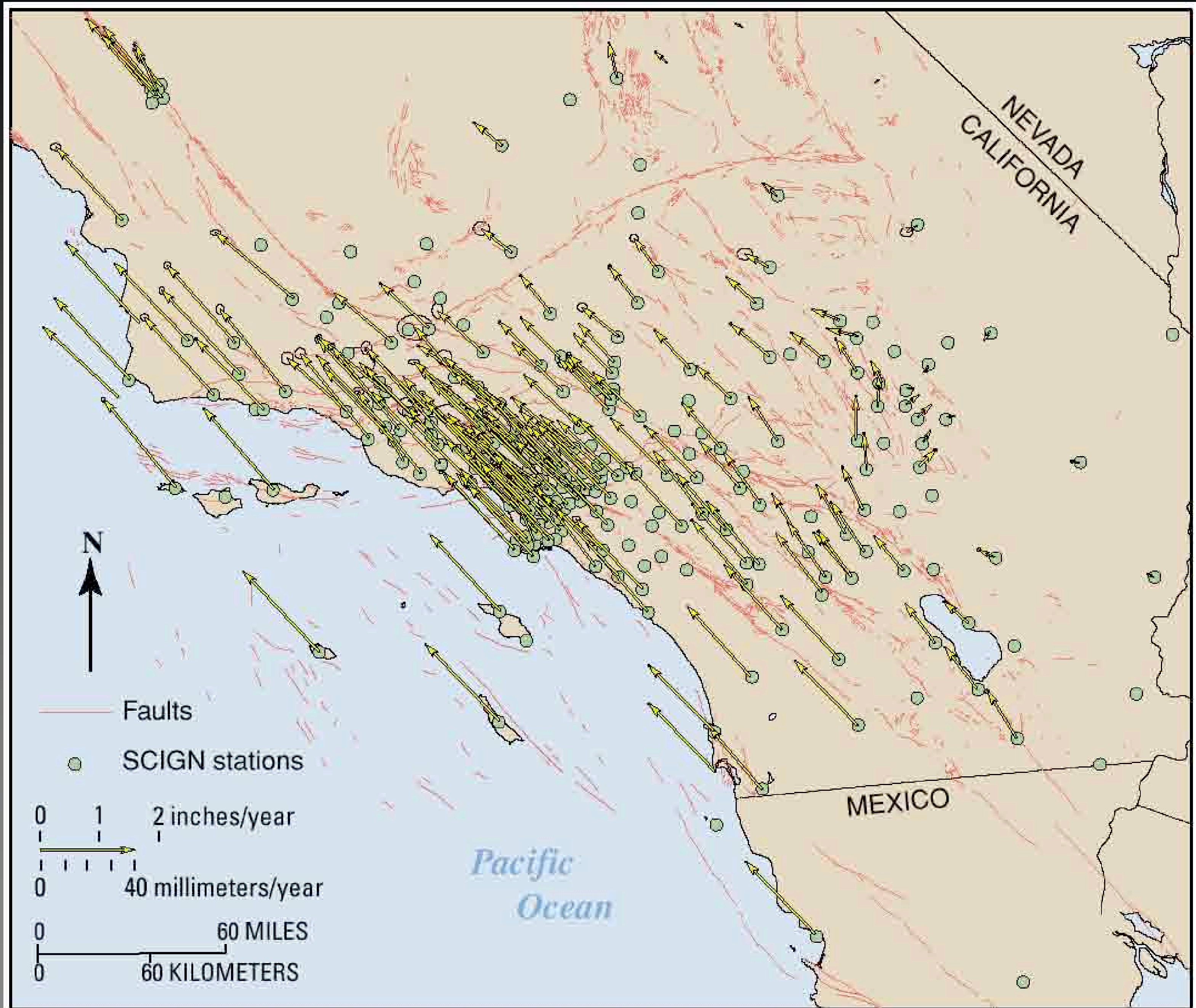
GPS



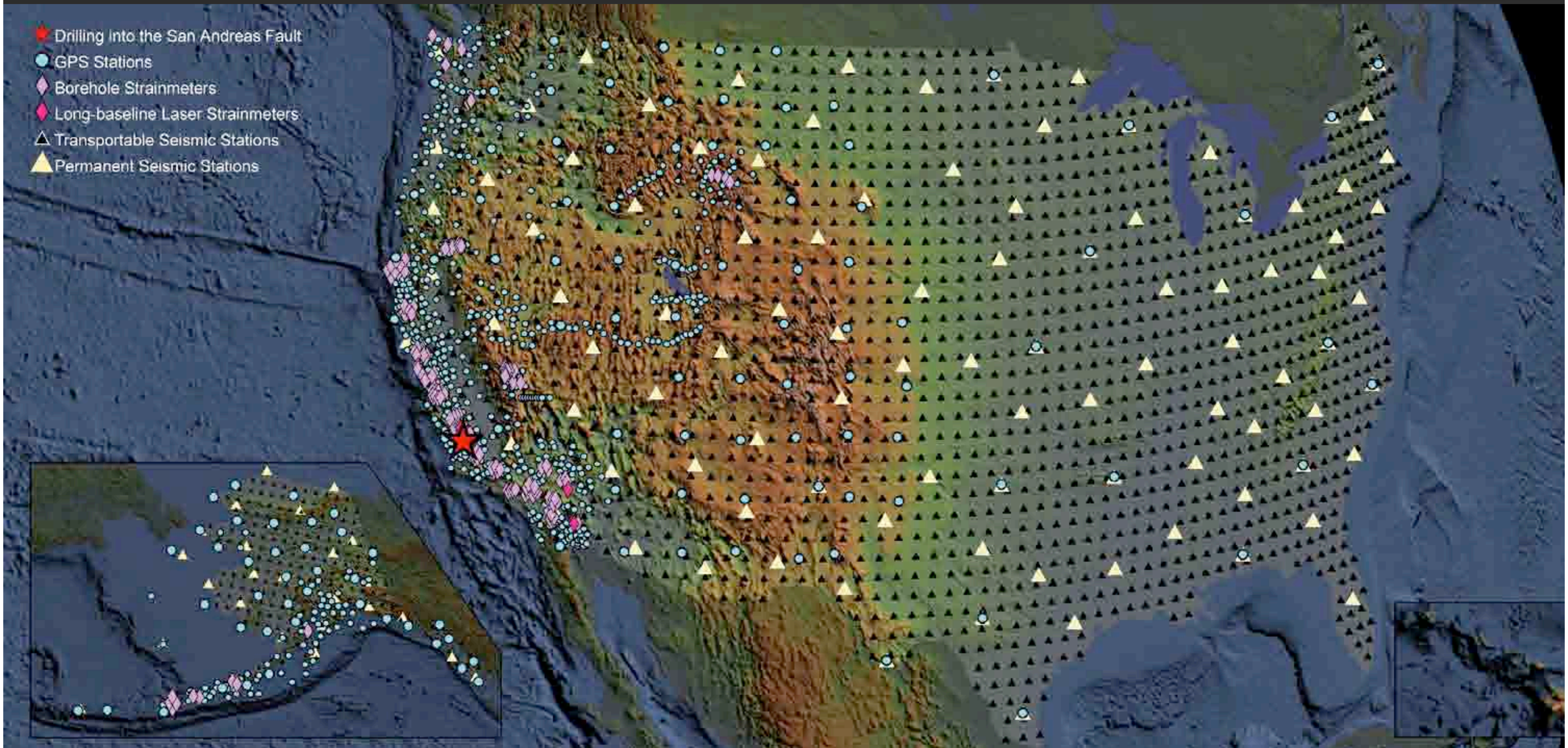
GPS network measures plate tectonic motions to an accuracy of better than 1 mm/yr

We can see whether the motion is ‘slow and steady,’ or perhaps more interestingly it may sometimes accelerate or decelerate

W. M. Keck Foundation · NASA · NSF · USGS science for a changing world


NEVADA
CALIFORNIA
MEXICO
N
Faults
SCIGN stations
0 1 2 inches/year
0 40 millimeters/year
0 60 MILES
0 60 KILOMETERS
Pacific Ocean

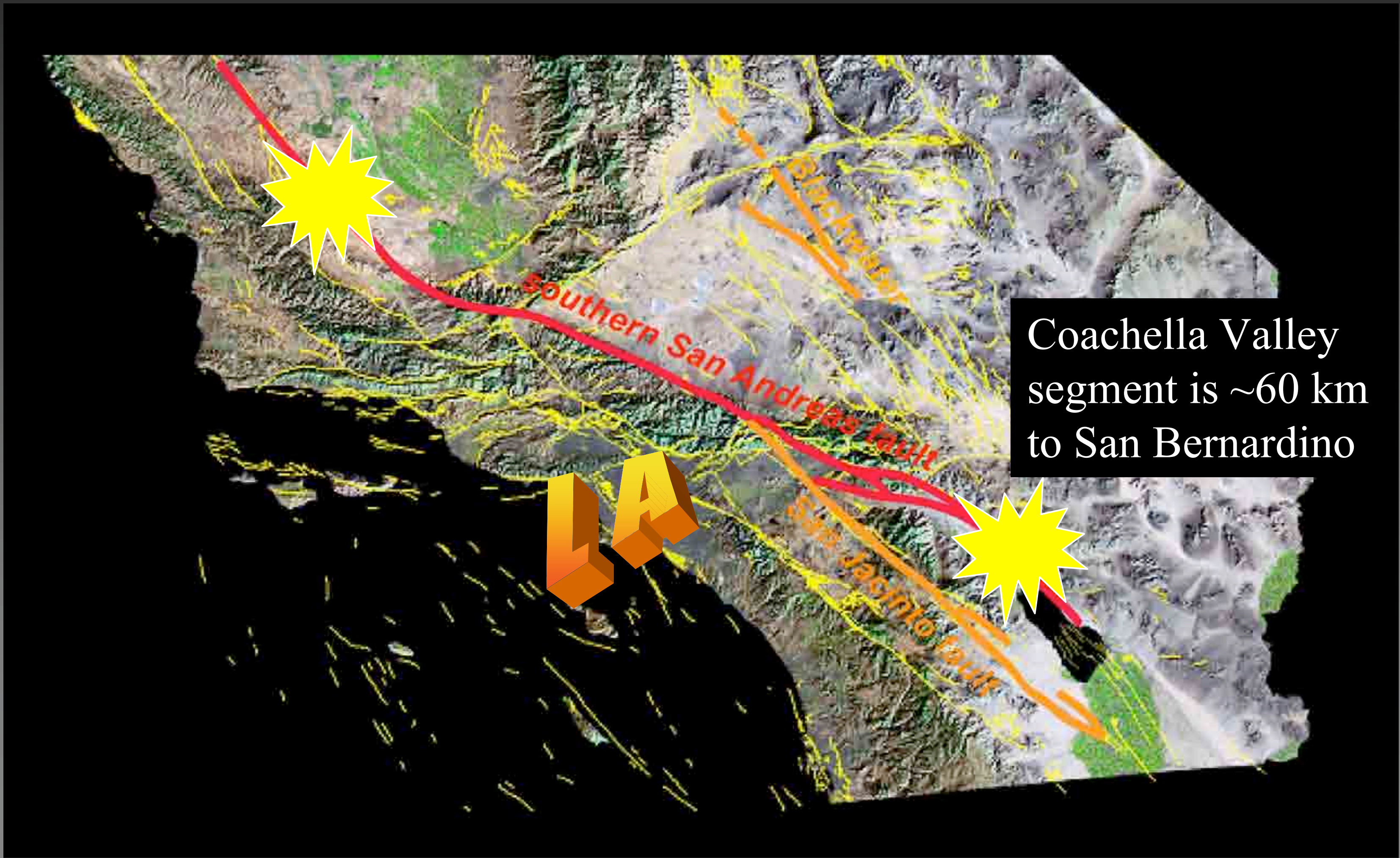
earthscope PROJECT



National Science Foundation
WHERE DISCOVERIES BEGIN

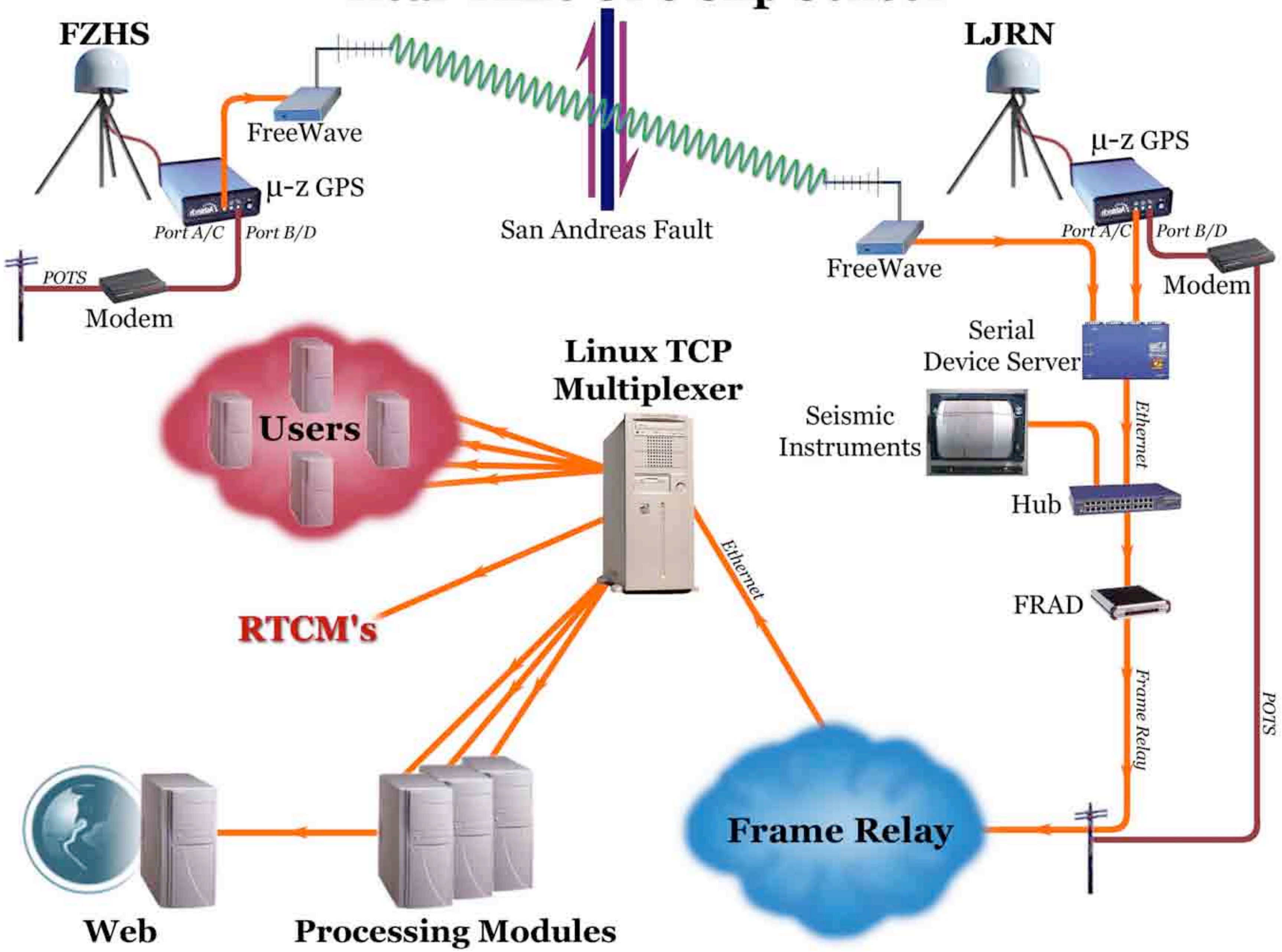
San Andreas - place two bets

both ~120 km from Los Angeles (LA)



Coachella Valley segment is ~60 km to San Bernardino

Real-Time GPS Slip Sensor



Lone Juniper Ranch and Frazier Park High School

Prototype GPS fault slip sensor;
up to 10 Hz

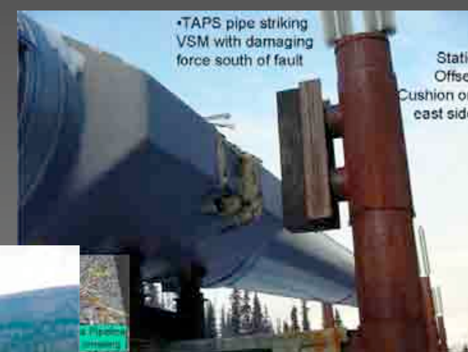
Spans the San Andreas fault near Gorman, California

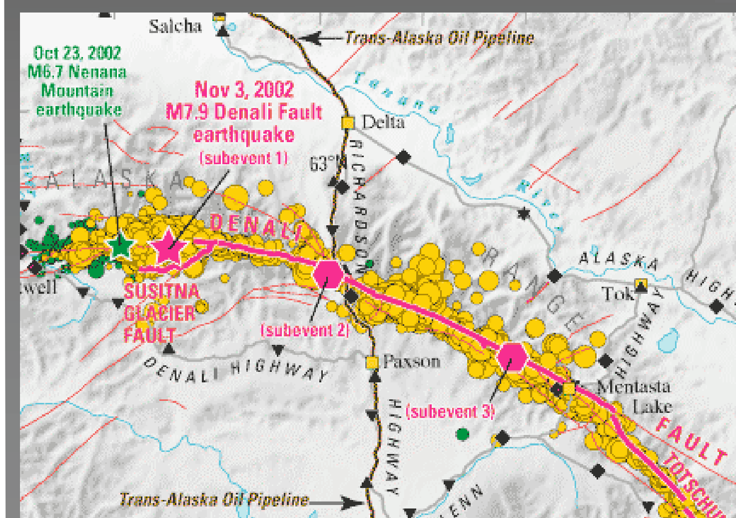
"Good science, when applied in the way that the people of Alaska have done, made the difference between an emergency and a tragedy."

Charles Groat, Director, United States Geological Survey

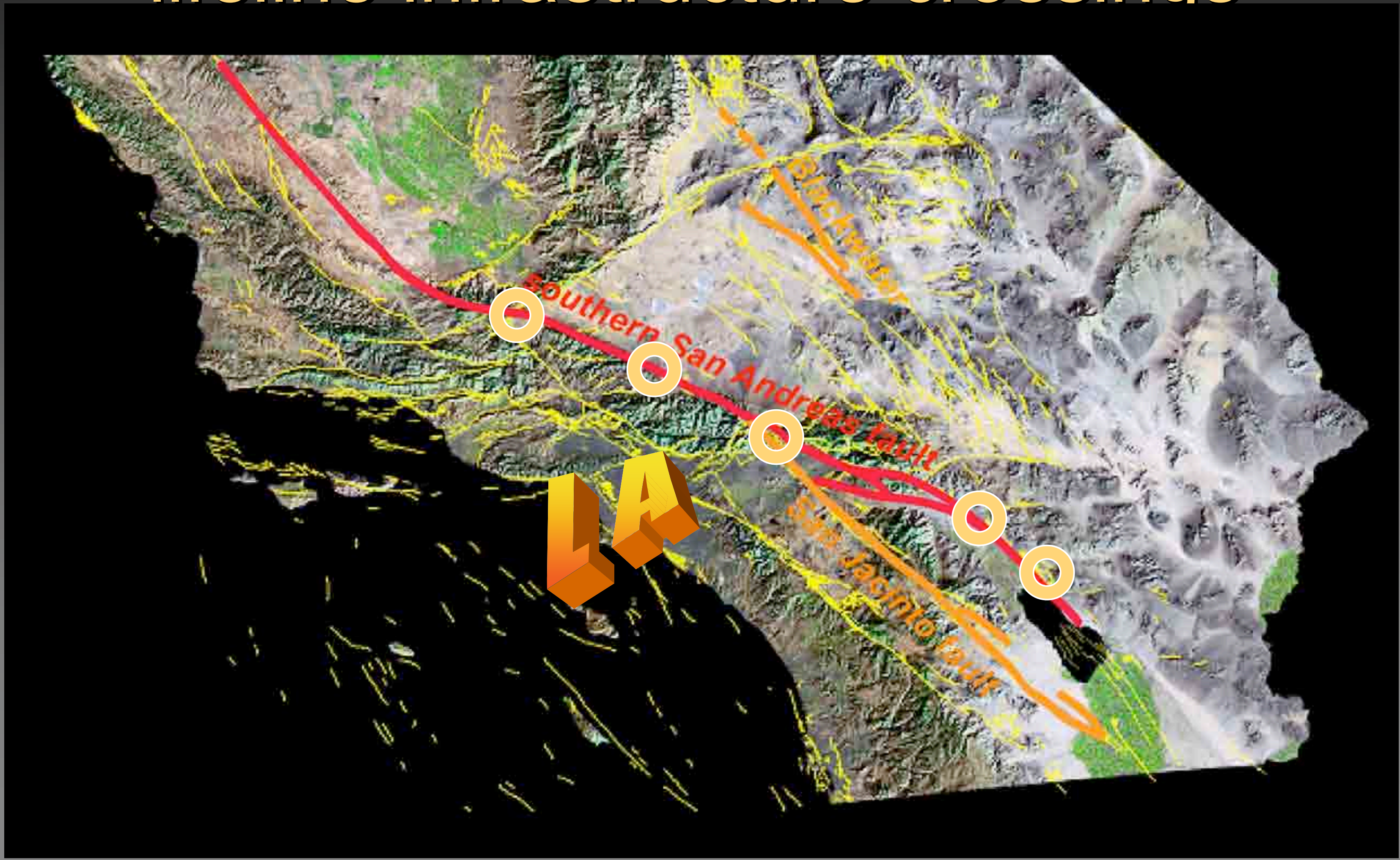
Each day, the Trans-Alaska oil pipeline carries one million barrels of oil, about 17% of the domestic oil supply for the United States, valued at about $25 million. If the pipeline had ruptured during the 2002 Denali earthquake, the lost revenue and cost of repair and environmental cleanup would have been incalculable.

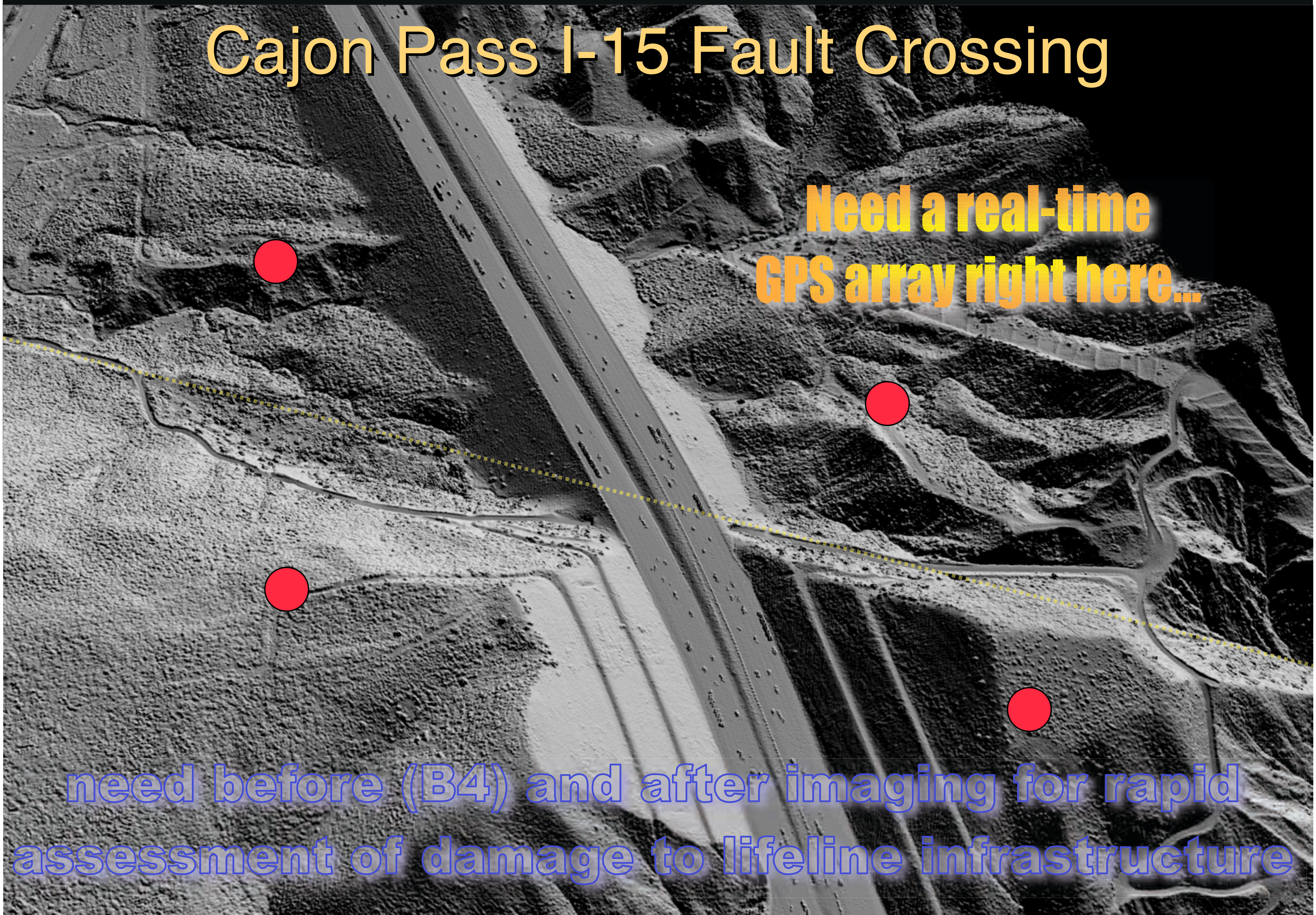
M 7.9 - similar to the anticipated San Andreas fault 'Big One'





San Andreas - instrument major lifeline infrastructure crossings




Cajon Pass I-15 Fault Crossing
Need a real-time
GPS array right here...
need before (B4) and after imaging for rapid
assessment of damage to lifeline infrastructure

Earthquake Early Warning

Tangshan, China

1976 - M 7.5

255,000

people died

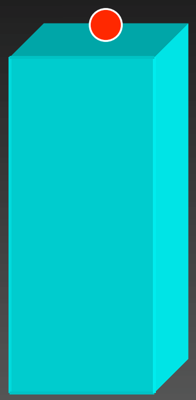
(official)

Northridge, CA
1994 - it *can*
happen here

Earthquakes Don't Kill People, Buildings Do...

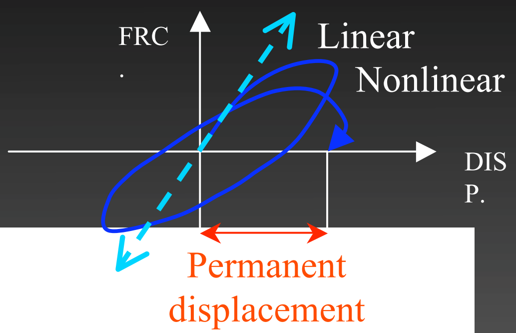
Turkey 1999

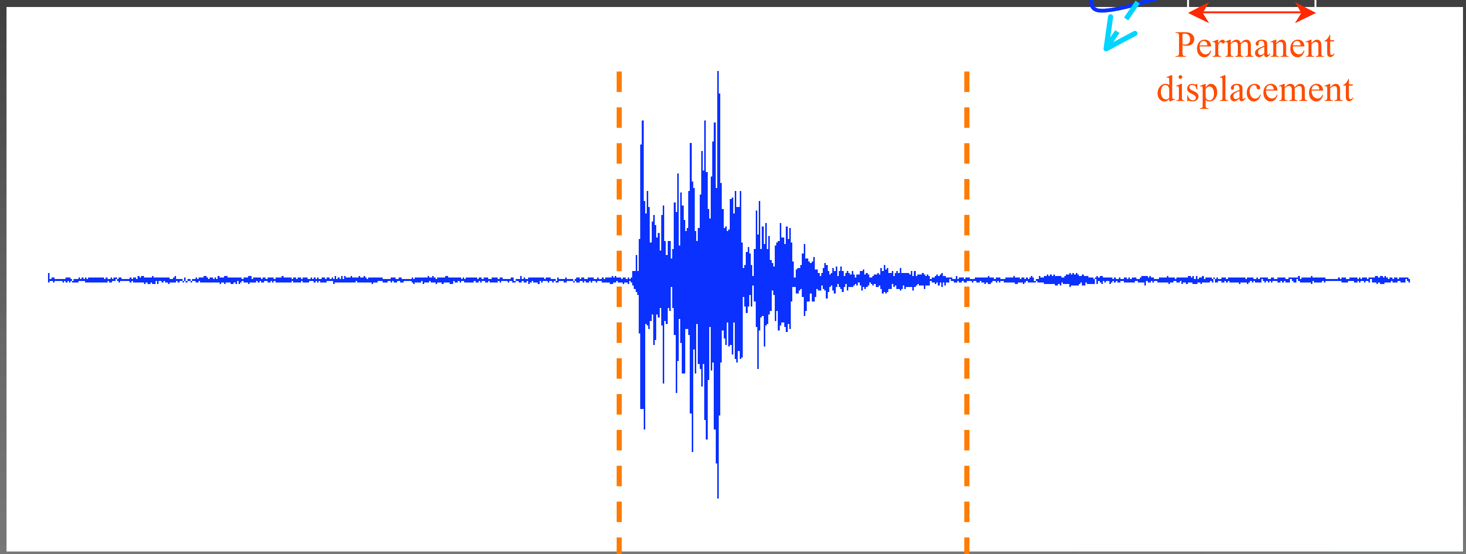
Automated Tagging and Real-Time Damage Distribution Maps



Multiple sensor package:

- Acceleration / Velocity
- Displacement (GPS)
- Rotation (tilt-meter)





Pre-earthquake:

- Reference static displacement
- Reference static rotation
- Mean and variance of dynamic characteristics

During earthquake:

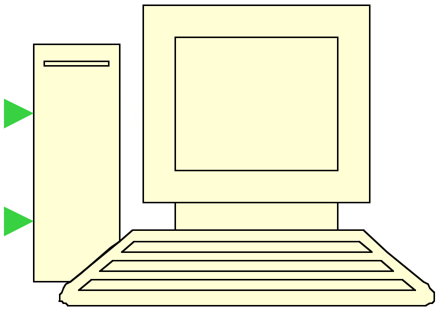
- Changes in dynamic characteristics
- Hysteretic behavior
- Damage initiation

Post-earthquake:

- Permanent static displacement
- Permanent static rotation
- Mean and variance of dynamic characteristics

REAL-TIME DAMAGE ASSESSMENT

- Satellite
- Telemetry
- Internet



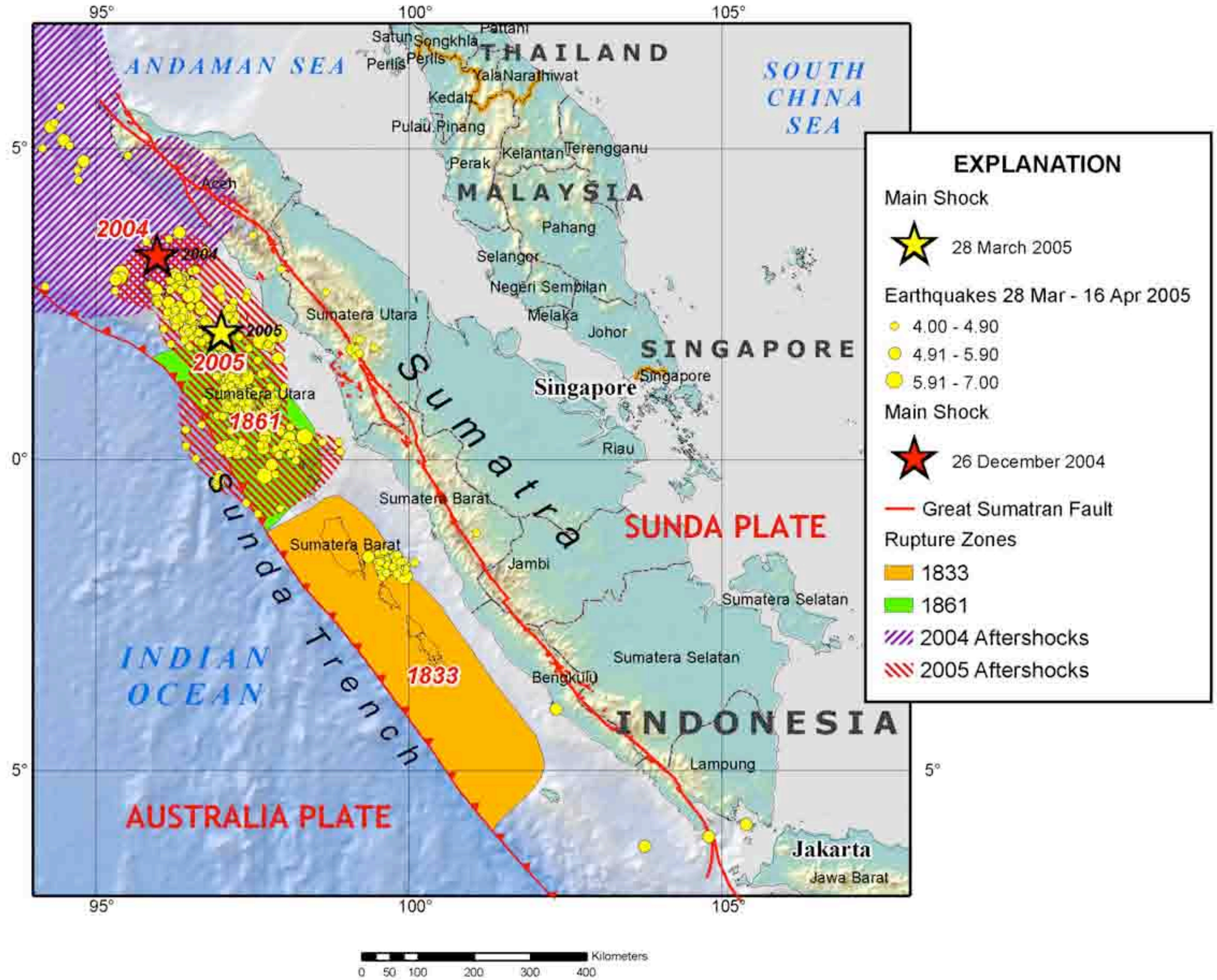
Courtesy of
Erdal Safak (USGS)

SENSOR PACKAGE

- -Accelerometer
- -Tiltmeter
- -GPS sensor

USGS

Northern Sumatra Earthquake of 28 March 2005



18 April 2005 @ 1000 MDT

Caltech Tectonic Observatory GPS Array: *SuGAr*
USAID funds to upgrade to real-time GNSS

The helicopter, the people, and the antenna at the Simuk Island GPS station.

USAID
FROM THE AMERICAN PEOPLE

On-land GPS stations are essential for real-time detection of large slip:

Blewitt et al. (GRL, 2006)

GNSS buoy systems

- NOAA DART buoys are expensive and require regular maintenance
- GPS buoys developed by GFZ and Univ. Tokyo groups
- GPS can be used for large numbers of low-cost buoys to complement existing system
- NavCom-AXYS contract for US Navy (NAVOCEANO);

  2 cm inshore, 10 cm offshore
- NOAA-USGS testing program for warning application (MBARI)
- Tie in with existing earthquake and weather monitoring and alerts

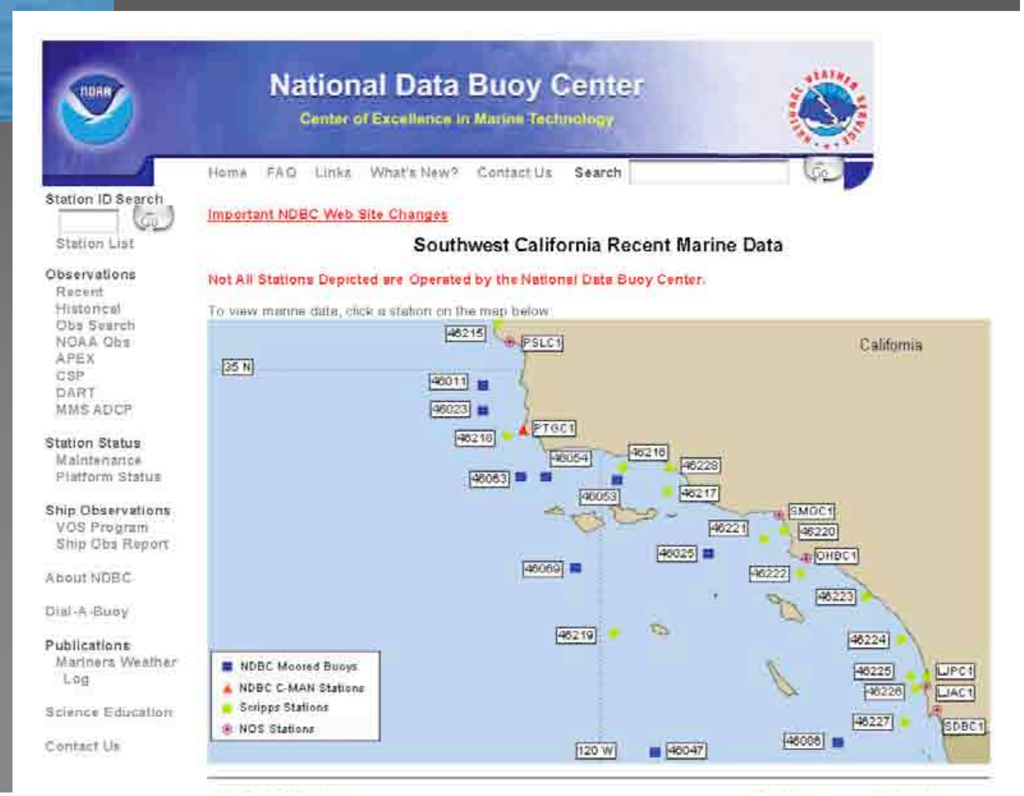
Padang - what to do?

Photo by John Galetzka
Caltech Tectonic Observatory

Inexpensive package of GPS/INS can be added (after R&D and testing) to existing NOAA buoys offshore of So. Calif. to complement other Instrumentation for earthquake and tsunami early warning systems

Photo by John Galetzka
Caltech Tectonic Observatory

SoCal - What to do?



GNSS Benefiting Humanity: Earthquake and Tsunami safety

- Global earthquake observation and tsunami alerts (ANSS)
- Airborne imagery positioning for fault zone characterization and damage assessment (B4)
- Tracking plates and strain accumulation and release (PBO)
- Earthquake early warning & rapid slip observation at lifeline fault crossings (Gorman SAF)
- Building monitoring and damage assessment; automatic ‘tagging’ (Factor Building)
- Fault displacement (SuGAr) and tsunami buoy measurement (MBARI)

Nearly everything we do is helped by GNSS

- GNSS will become even better than it is currently for these applications:
  - GPS L2C, L5 and L1C will improve over current capabilities (e.g., tri-laning)
  - GLONASS, QZSS, Galileo and other GNSS will help (e.g., increased coverage)
- GNSS could be improved beyond currently planned system enhancements:
  - Aiding through internet or wireless will enhance real-time precise results
  - Added signals could nearly eliminate the real-time ambiguity resolution problem