1: ShakeAlert

Earthquake Early Warning For the West Coast

Doug Given
USGS
Earthquake Early Warning Coordinator

NEPM Meeting
May 22, 2014

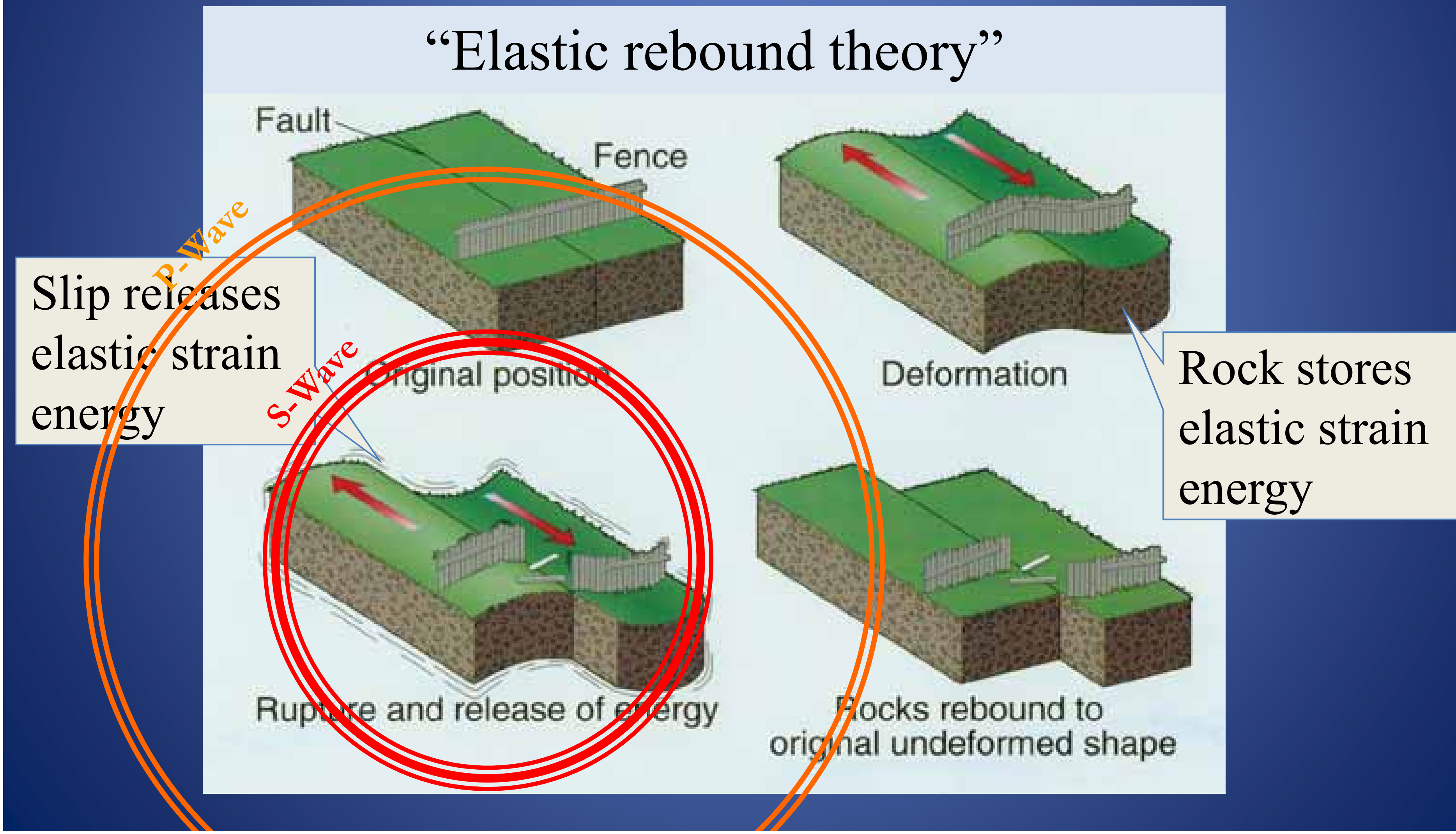
Principal EEW Collaborators

- ***USGS***
  Given, D., Cochran, E., Oppenheimer, D.
- ***Caltech***
  Heaton, T., Hauksson, E., Böse, M.
- ***UC Berkeley***
  Allen, R., Hellweg, P., Neuhauser, D.
- ***Swiss Seismological Service, ETH***
  Clinton, J., Behr, Y.
- ***U. of Washington***
  Vidale, J., Bodin, P.
- ***Moore Foundation***
  Chandler, V., Biggs, G.

Earthquake Hazards Program

What is a earthquake?

Sudden slip between two blocks of crust along a fault

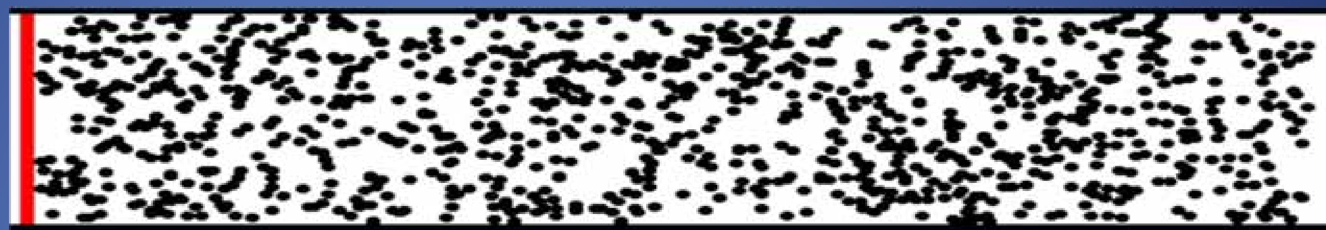


Earthquake Waves

“The P-wave carries information and the S-wave carries energy.” -Kanamori

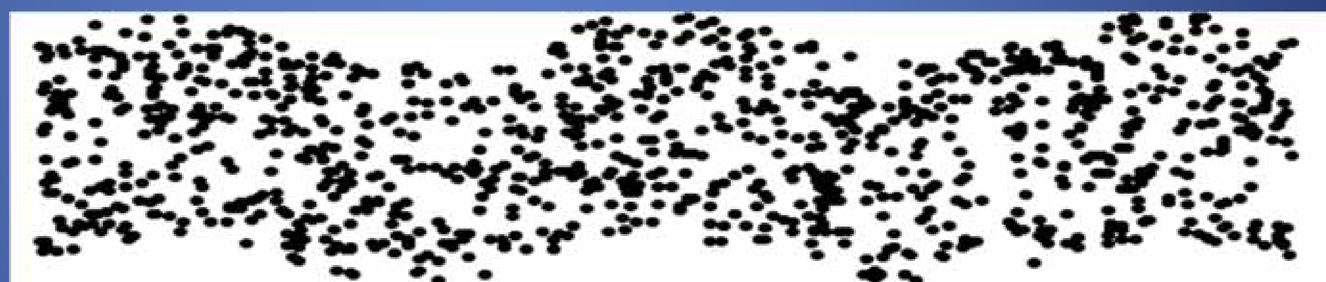
P-wave

~3.5 mi/sec



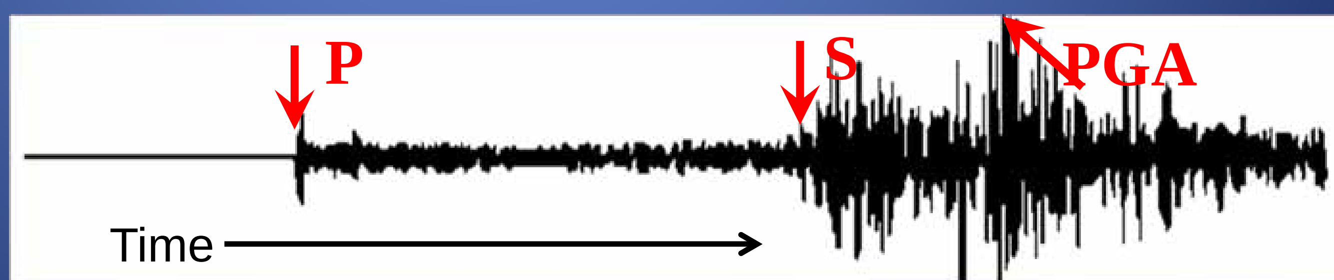
S-wave

~2 mi/sec



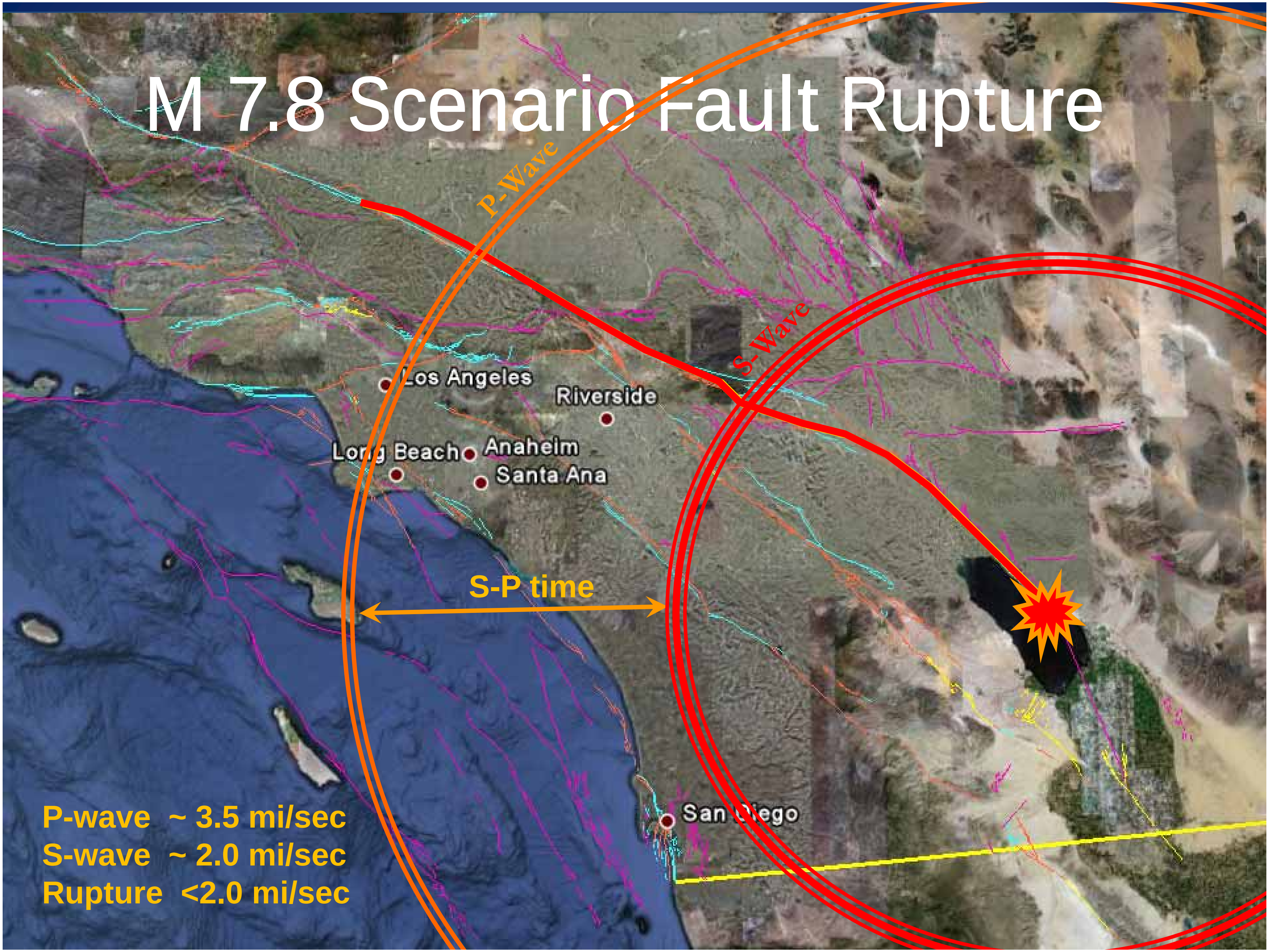
Seismogram

(ground motion)

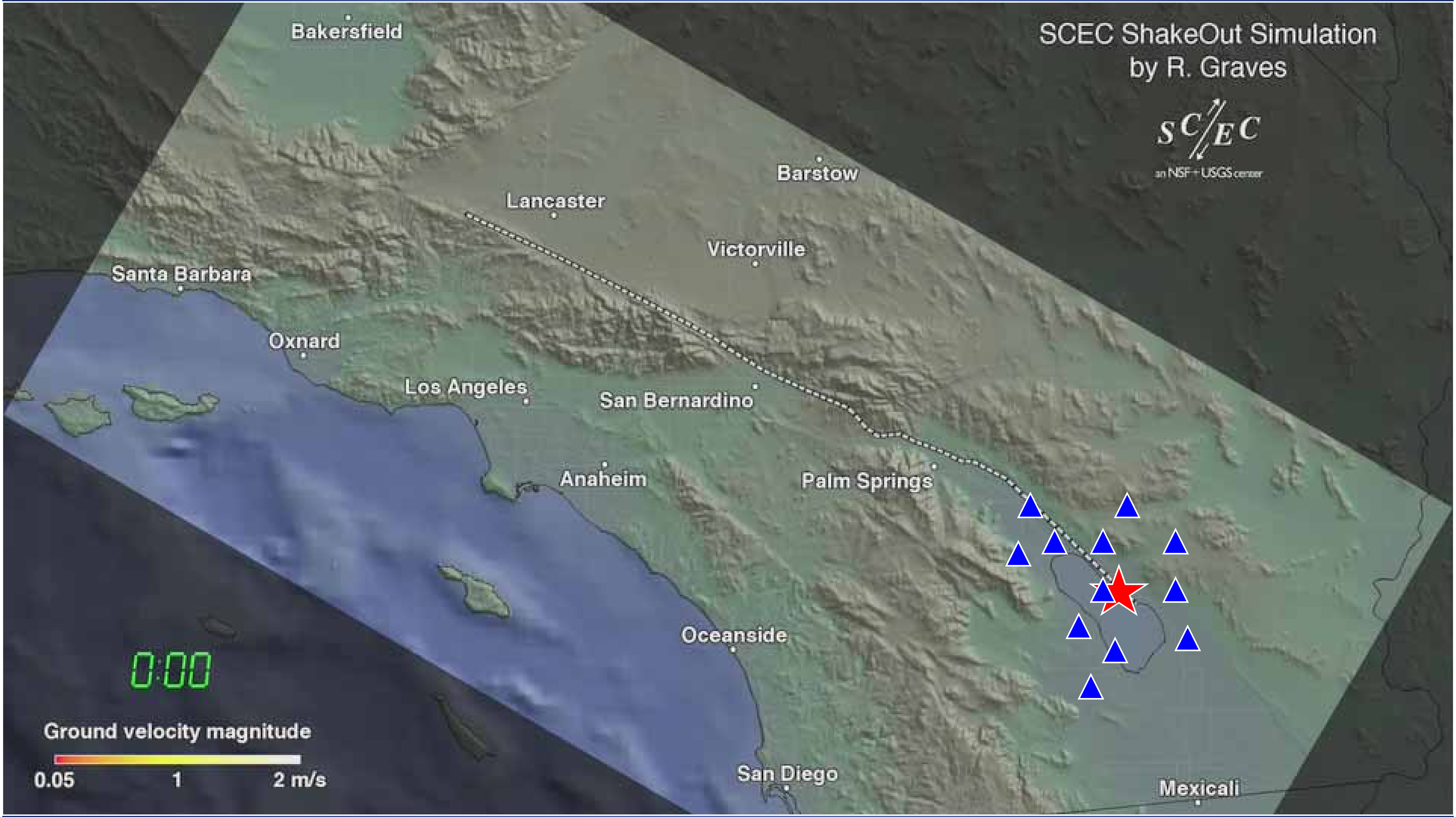


PGA = Peak Ground Acceleration

M 7.8 Scenario Fault Rupture

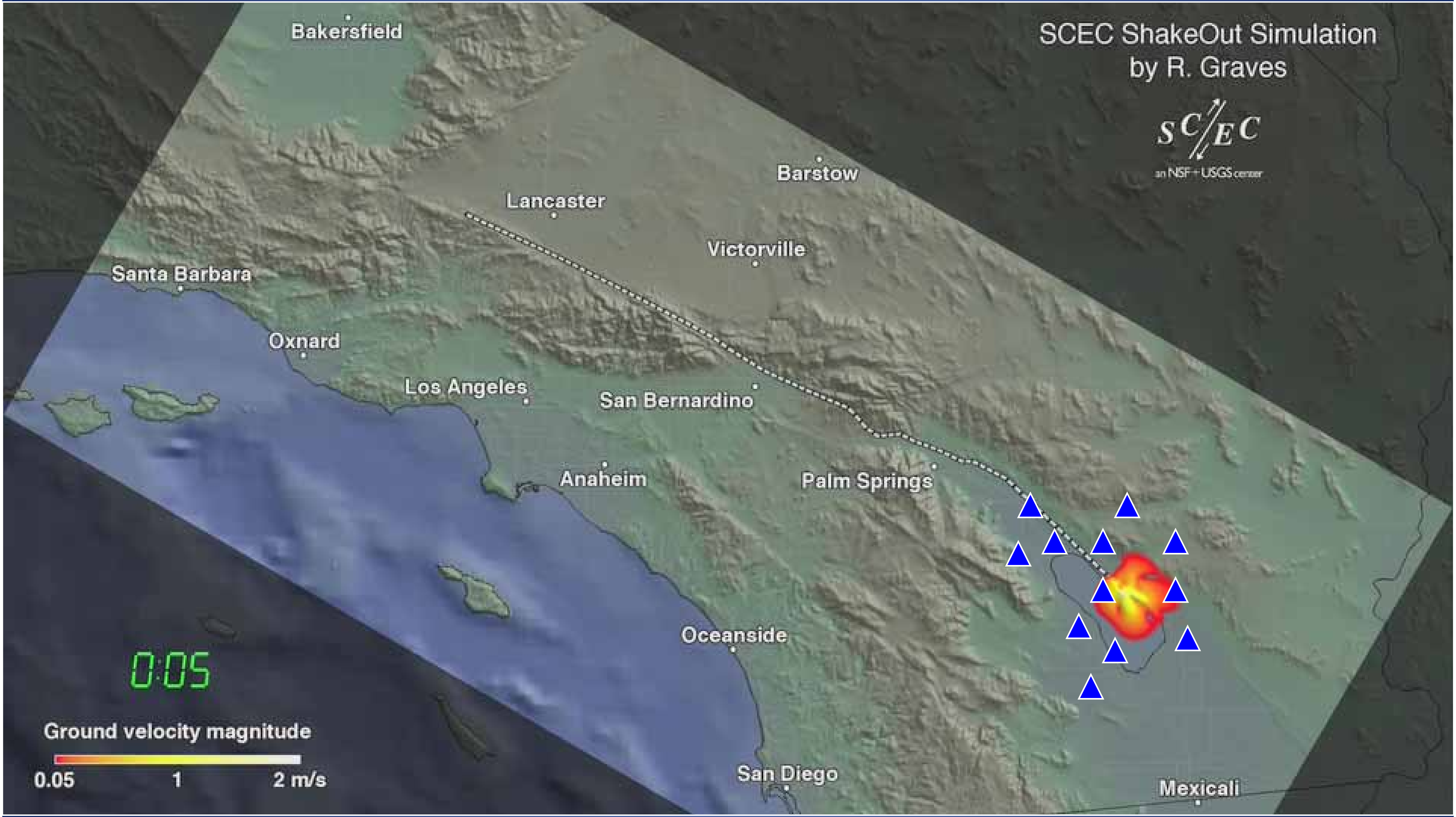


Earthquake Begins

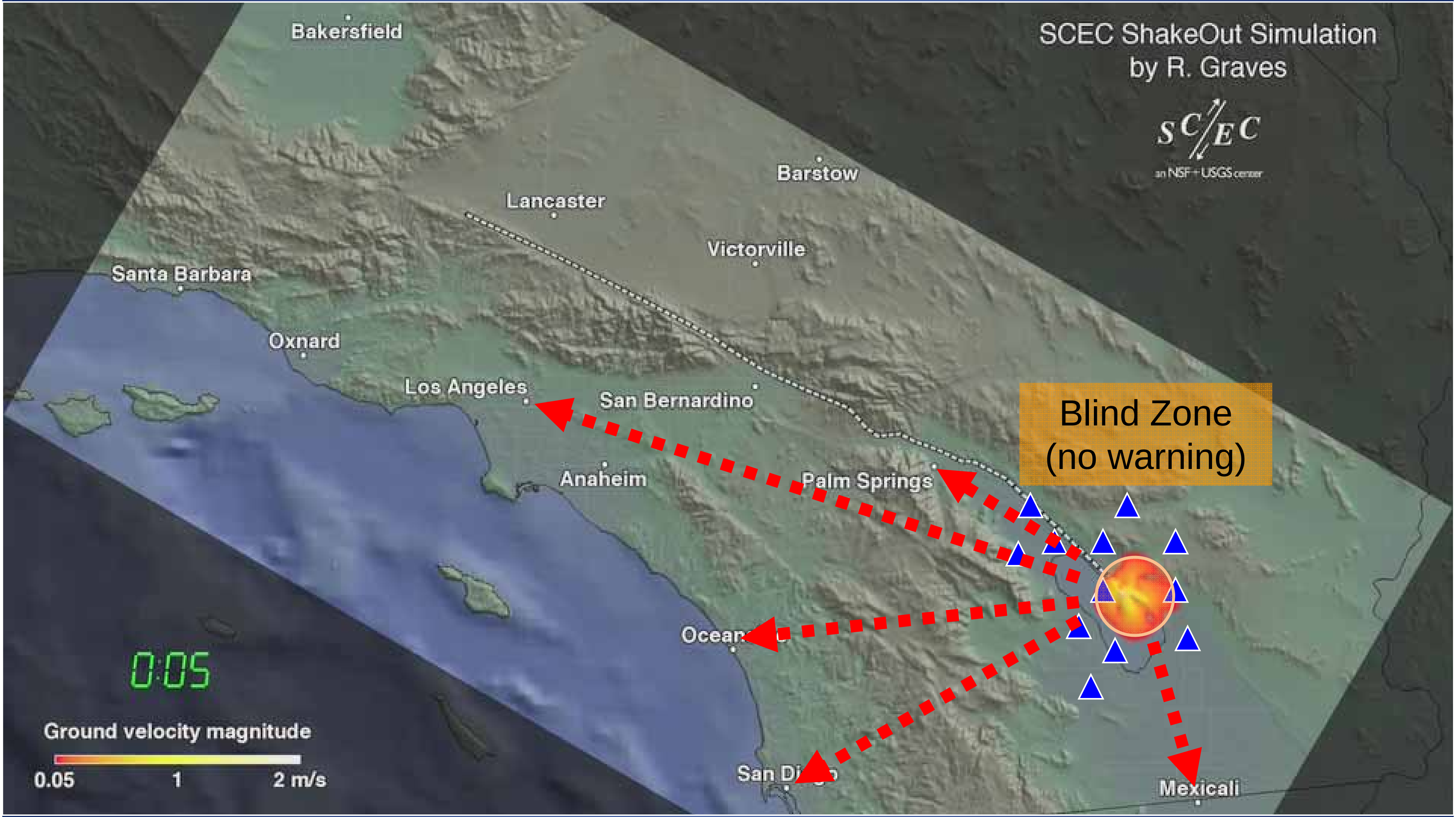


M7.8 SoSAFZ Scenario

Stations Sense Shaking

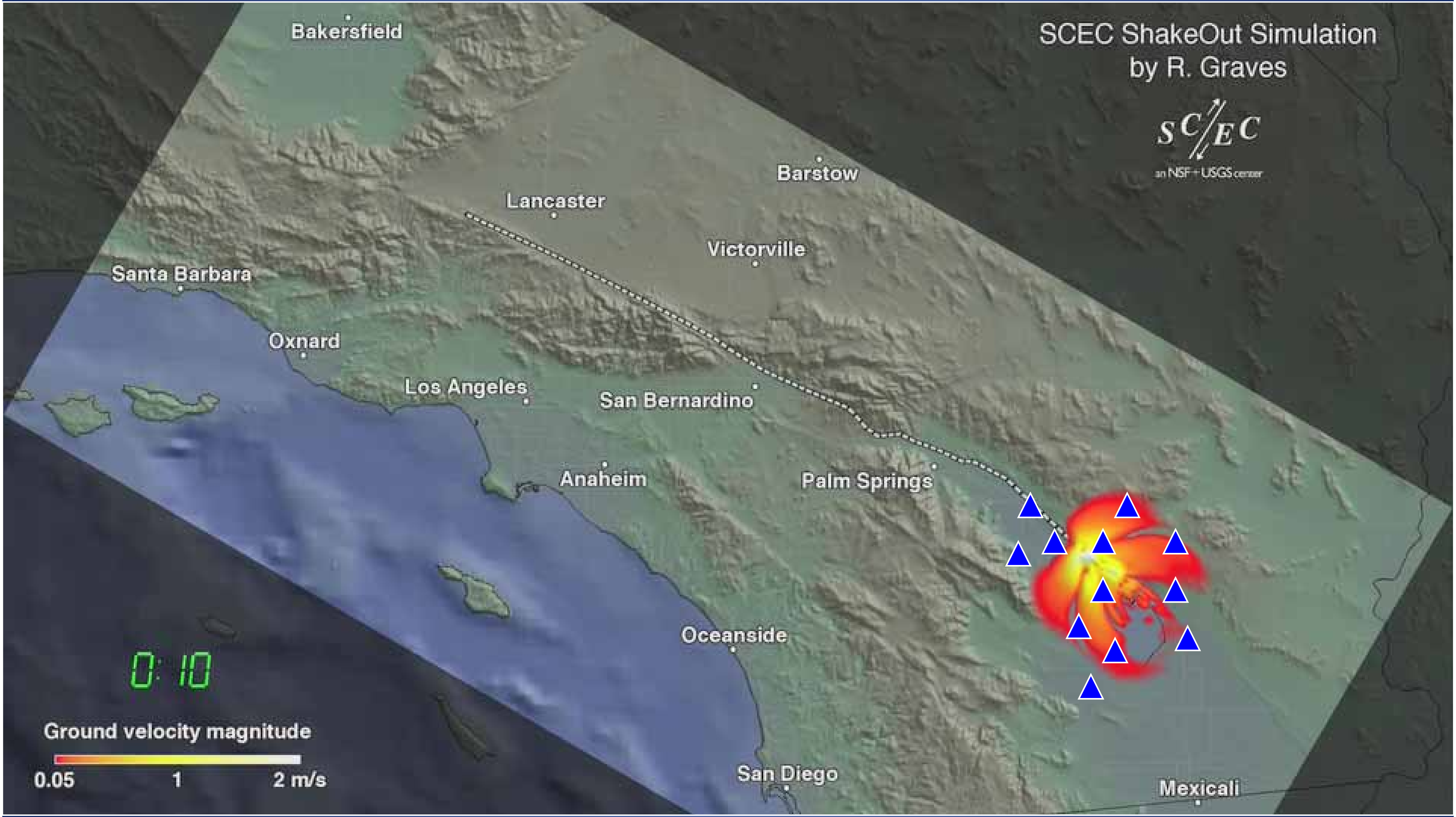


ShakeAlert Detects Event – Issues Alert

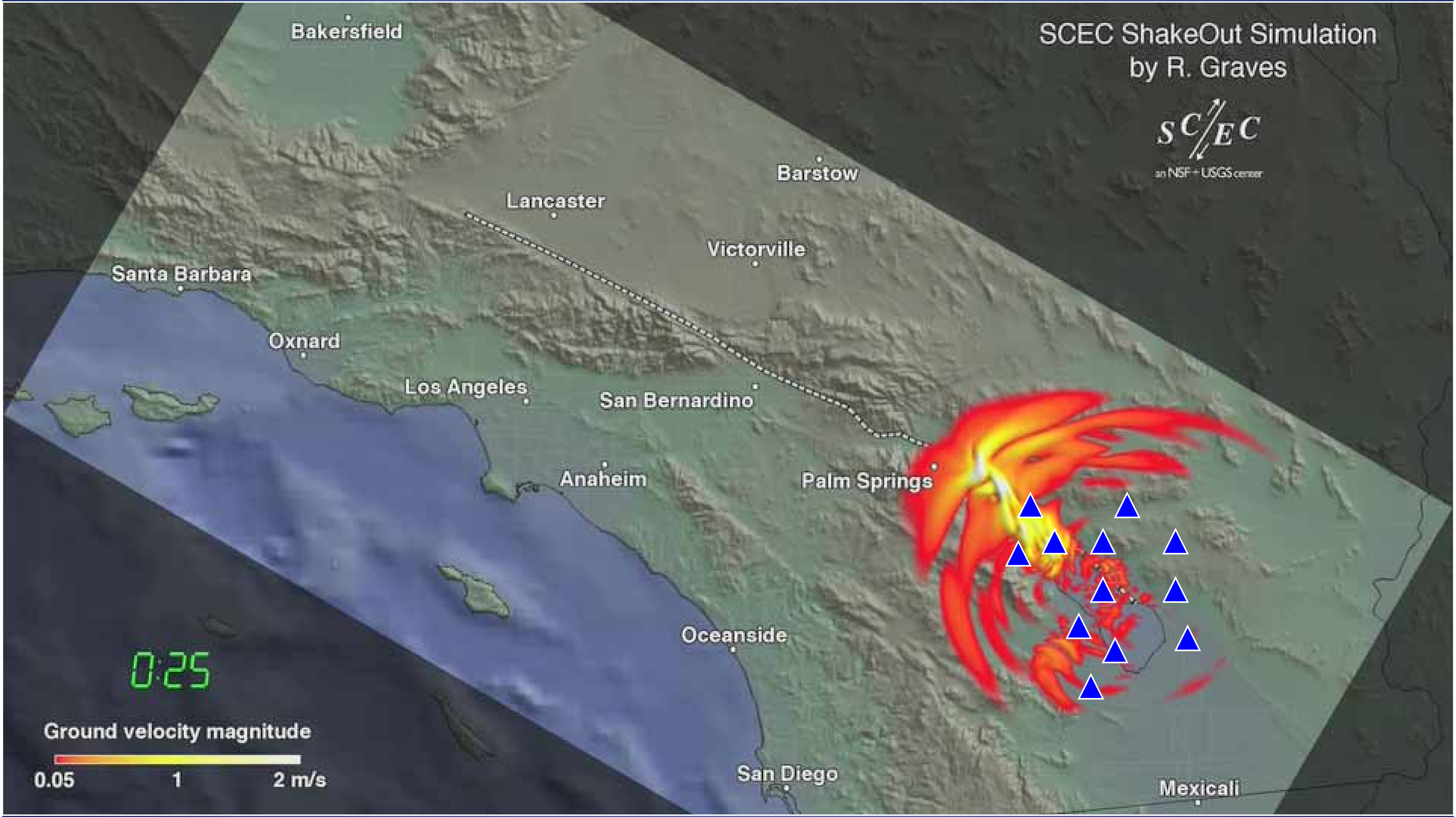


Up to 90 sec warning depending on distance.

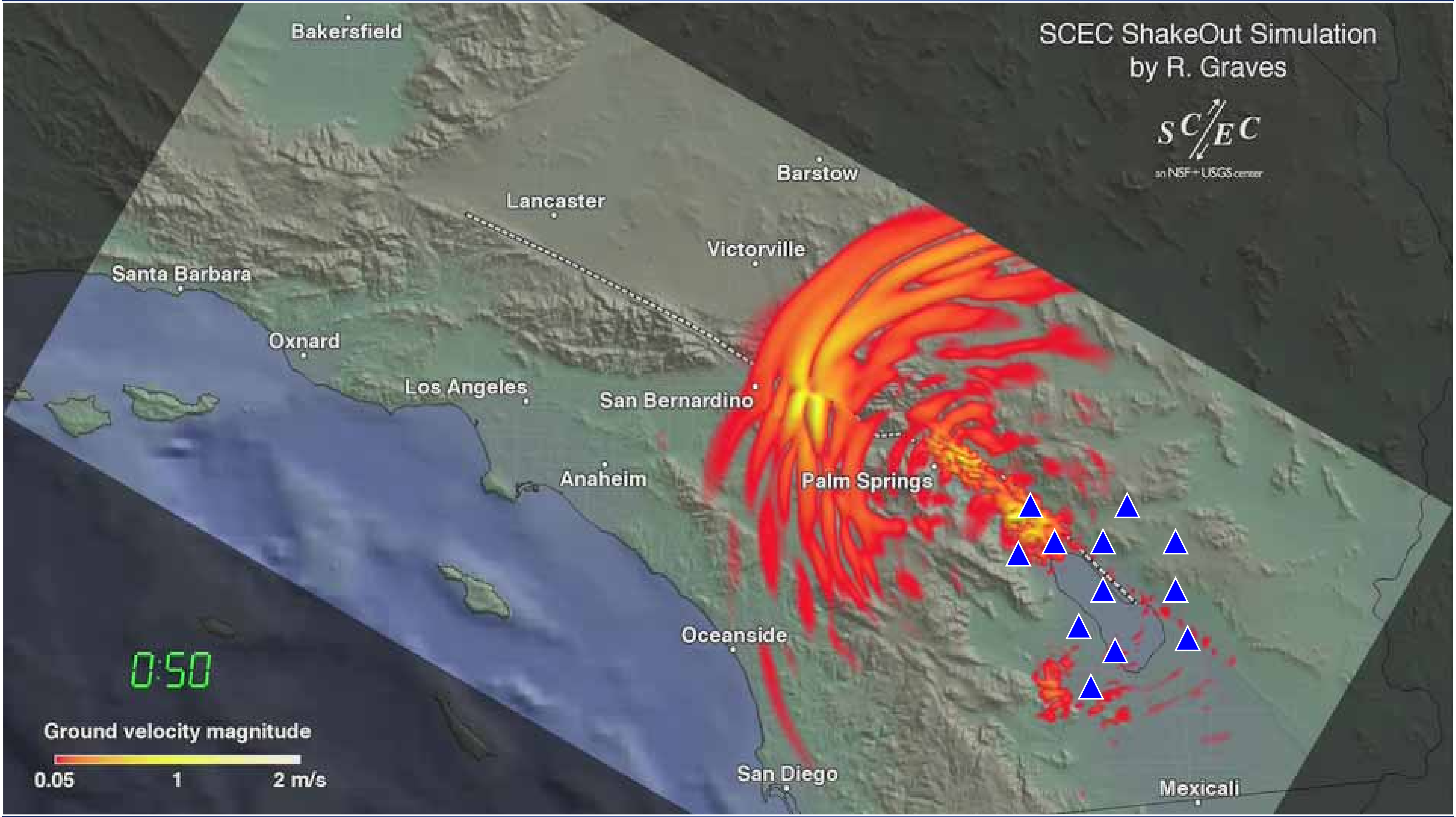
Rupture Moves Up Fault



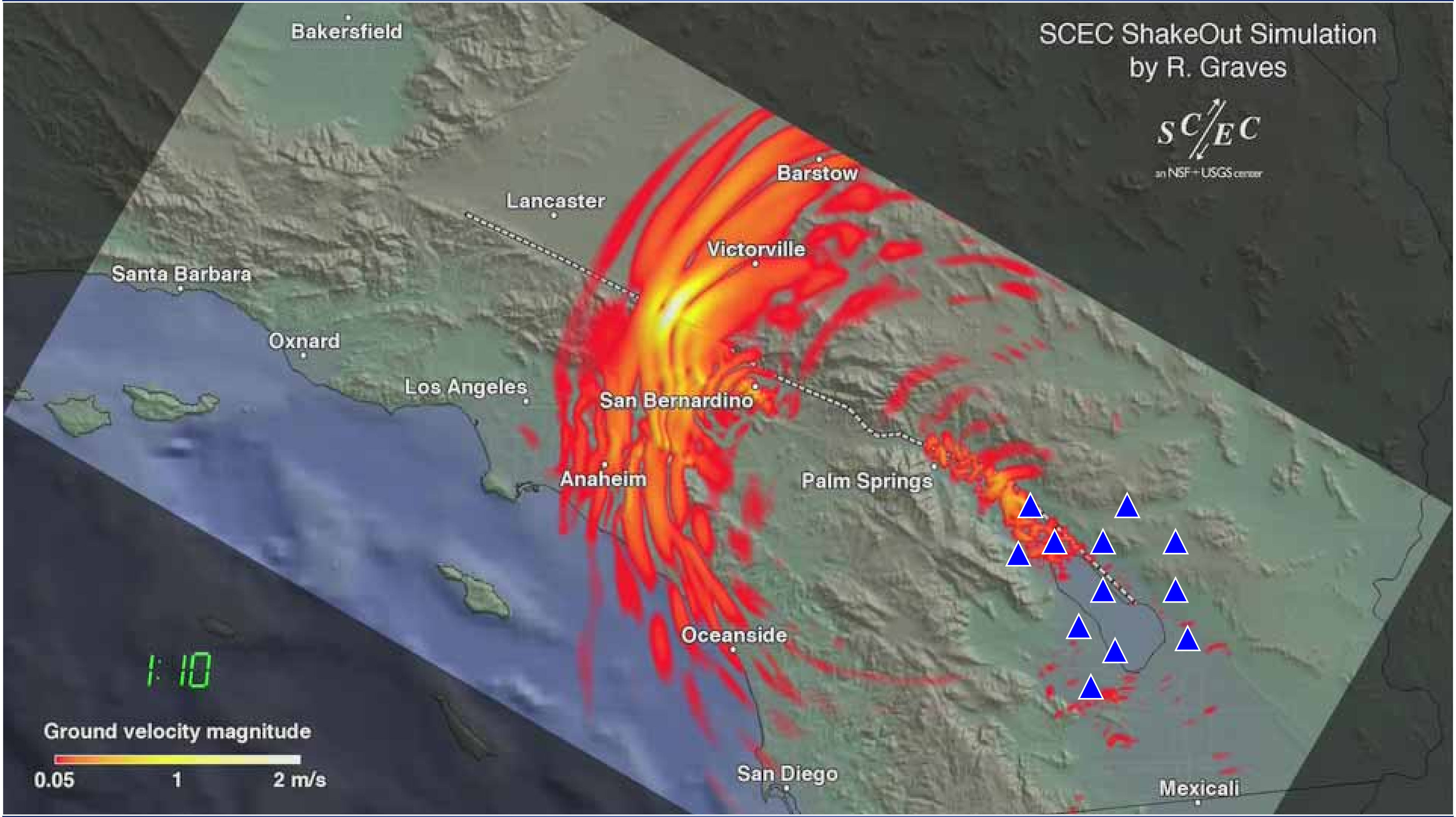
Strong Shaking Arrives – Palm Springs



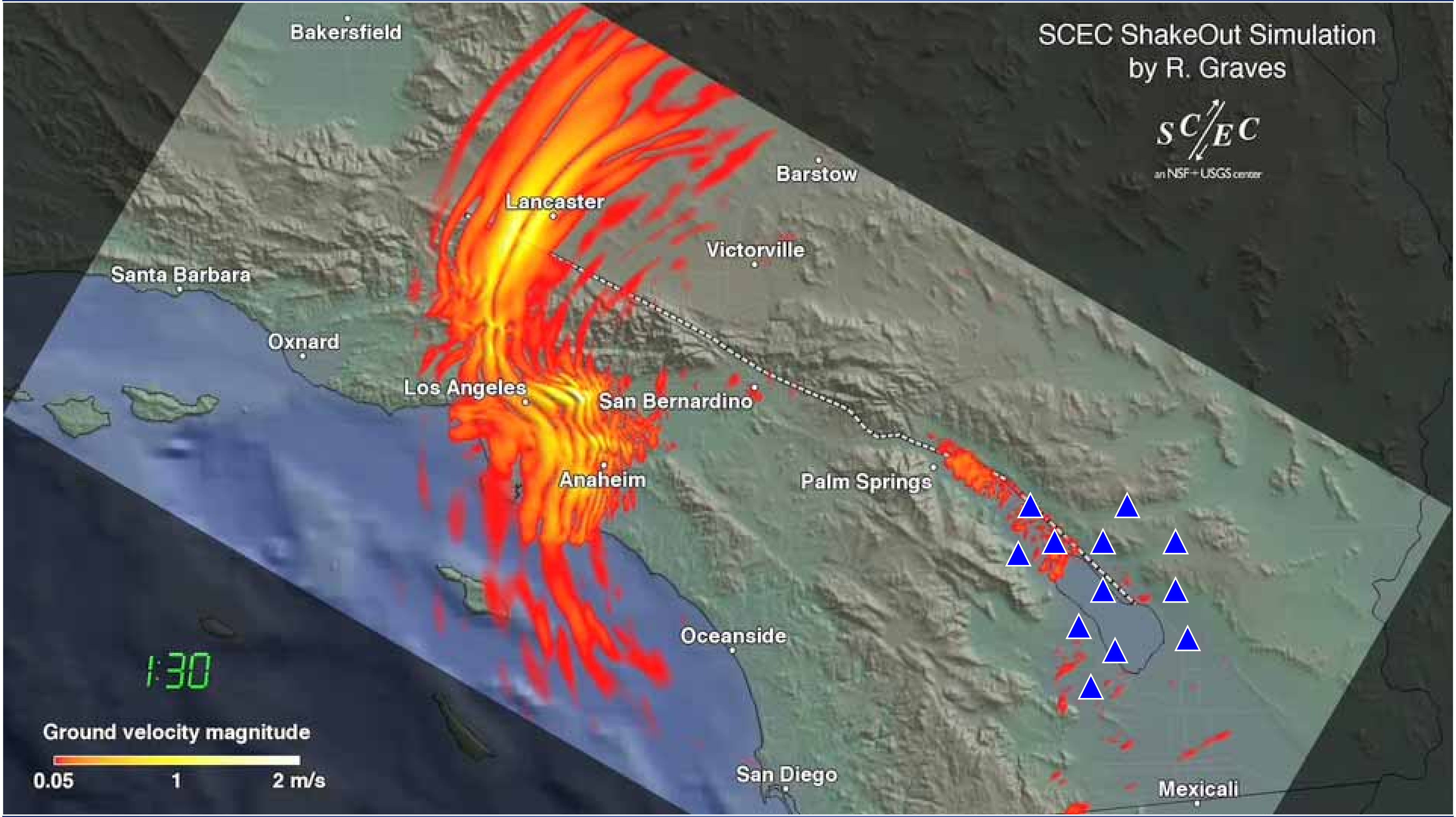
Strong Shaking Arrives – San Bernardino



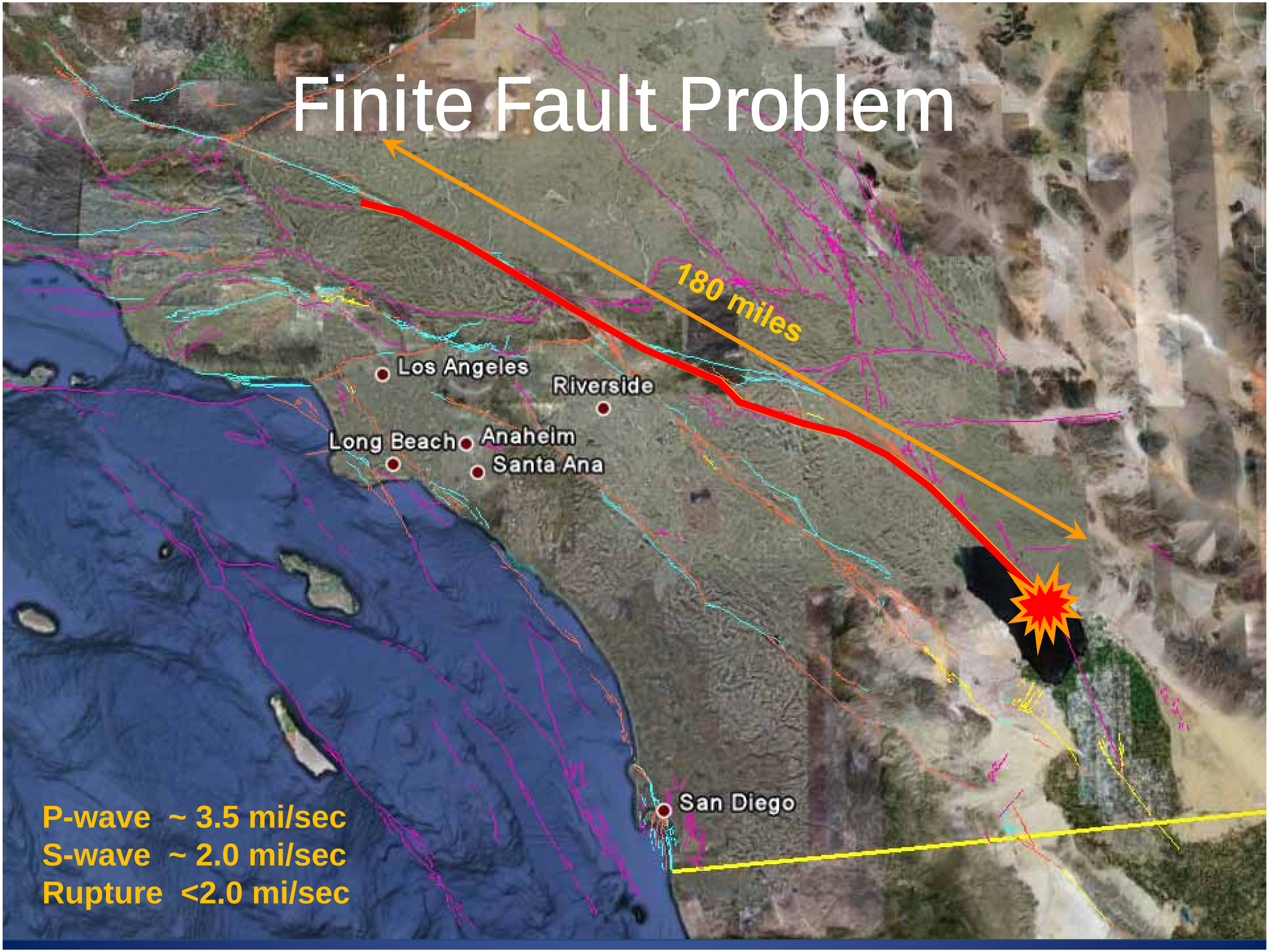
Strong Shaking Arrives – Orange Co.



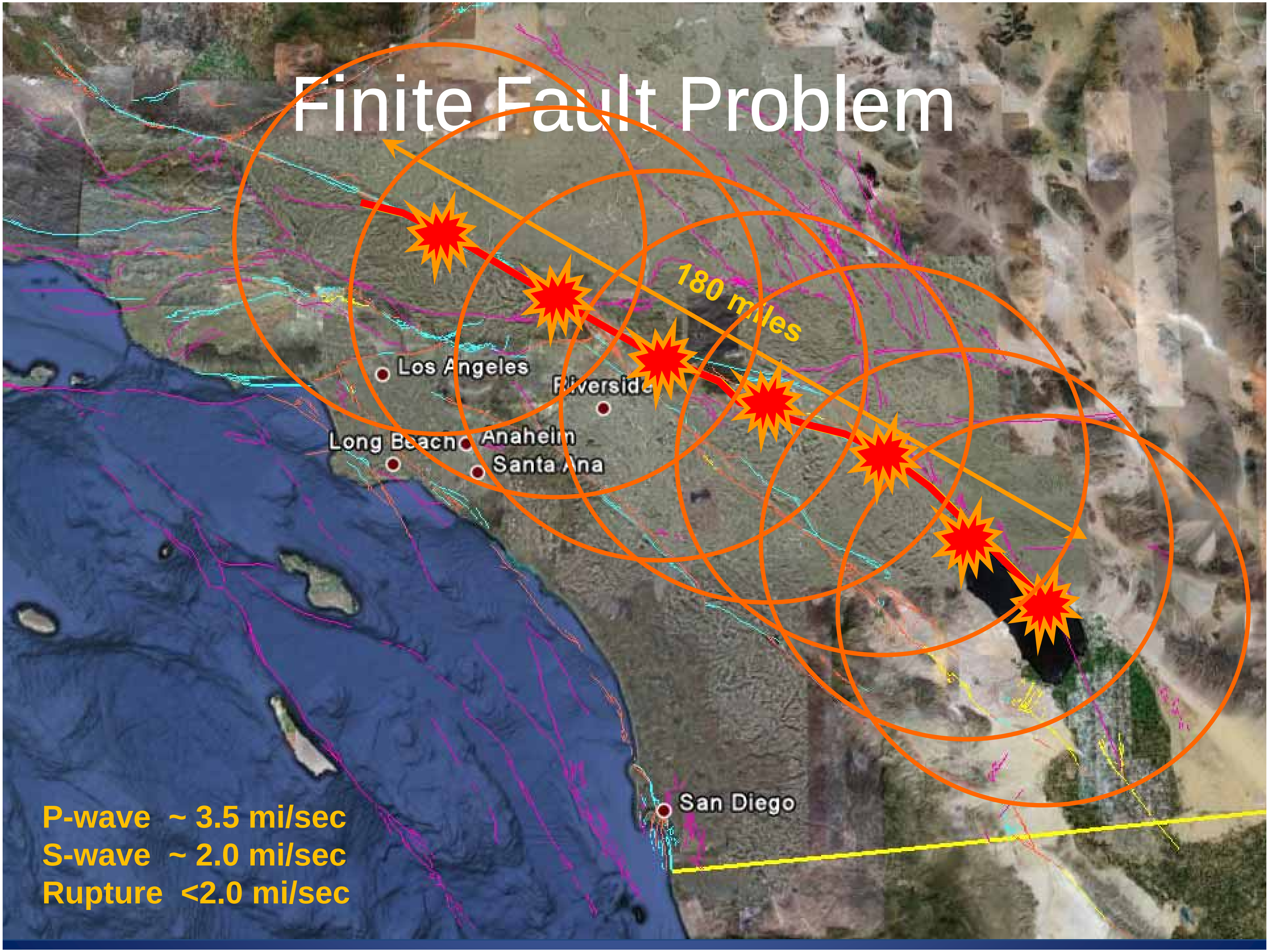
Strong Shaking Arrives – Los Angeles



Finite Fault Problem

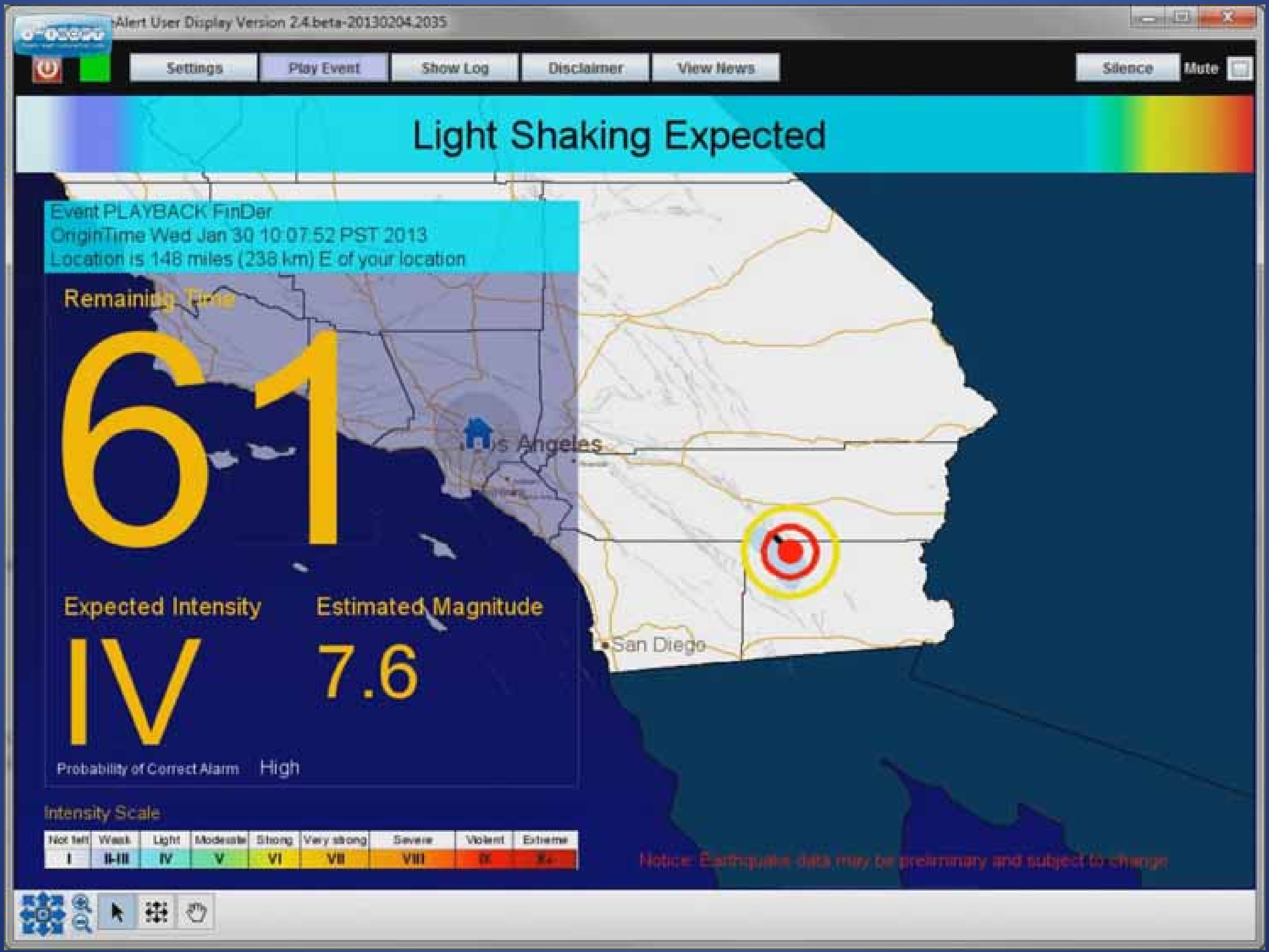


Finite Fault Problem



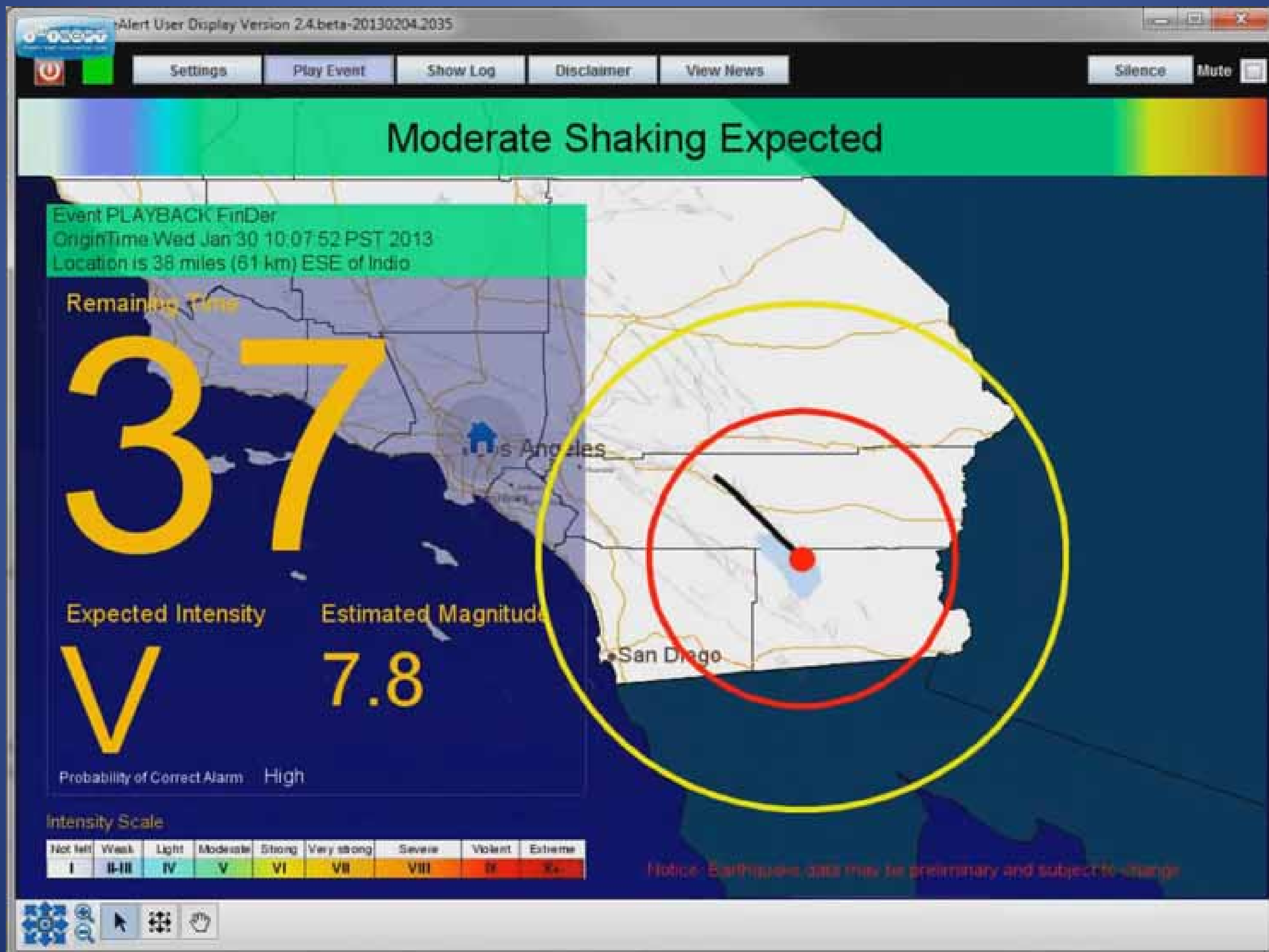
P-wave ~ 3.5 mi/sec
S-wave ~ 2.0 mi/sec
Rupture <2.0 mi/sec

UserDisplay – ShakeOut M7.8
Real-time Finite Fault Solution



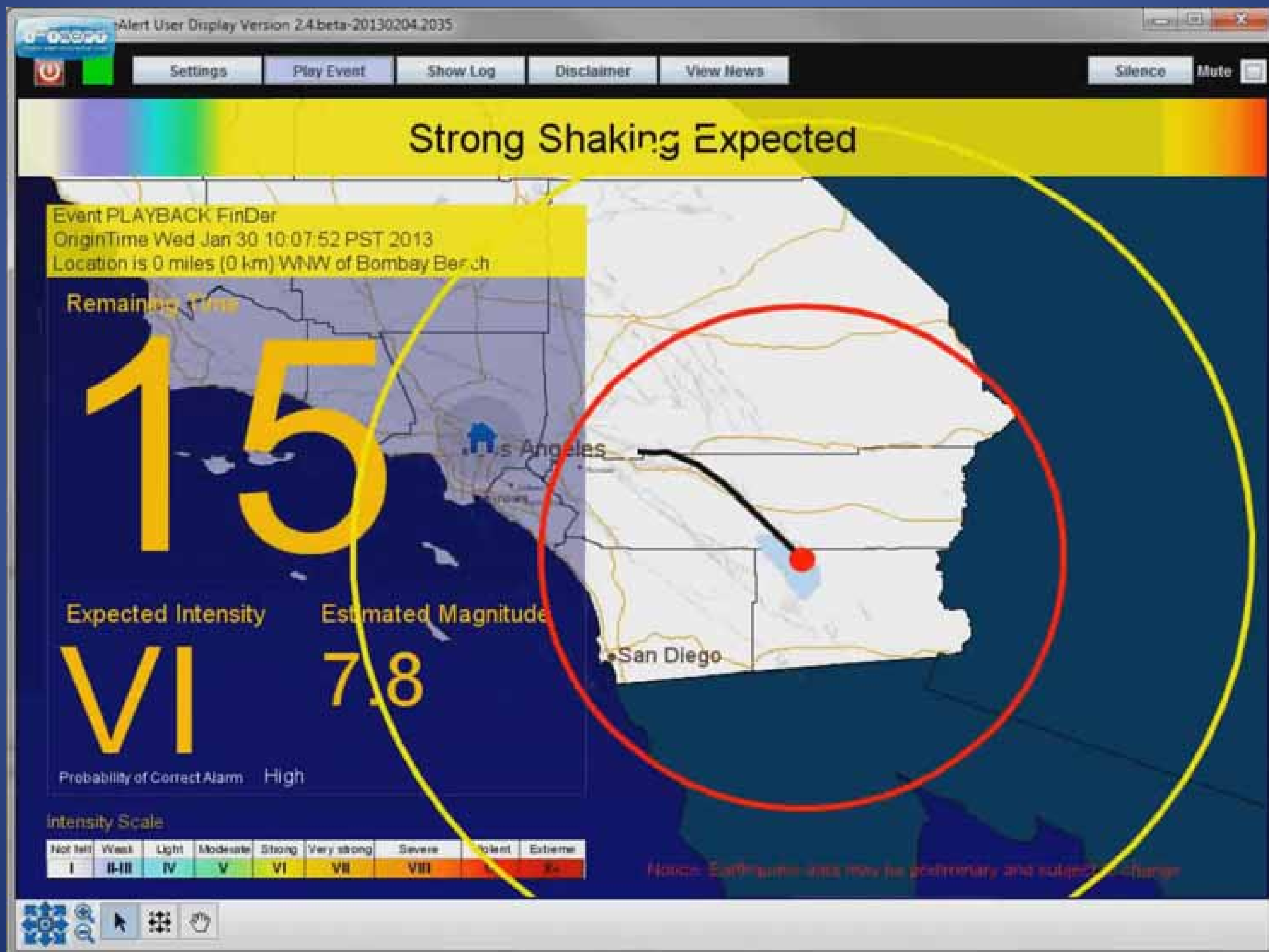
UserDisplay – ShakeOut M7.8

Real-time Finite Fault Solution



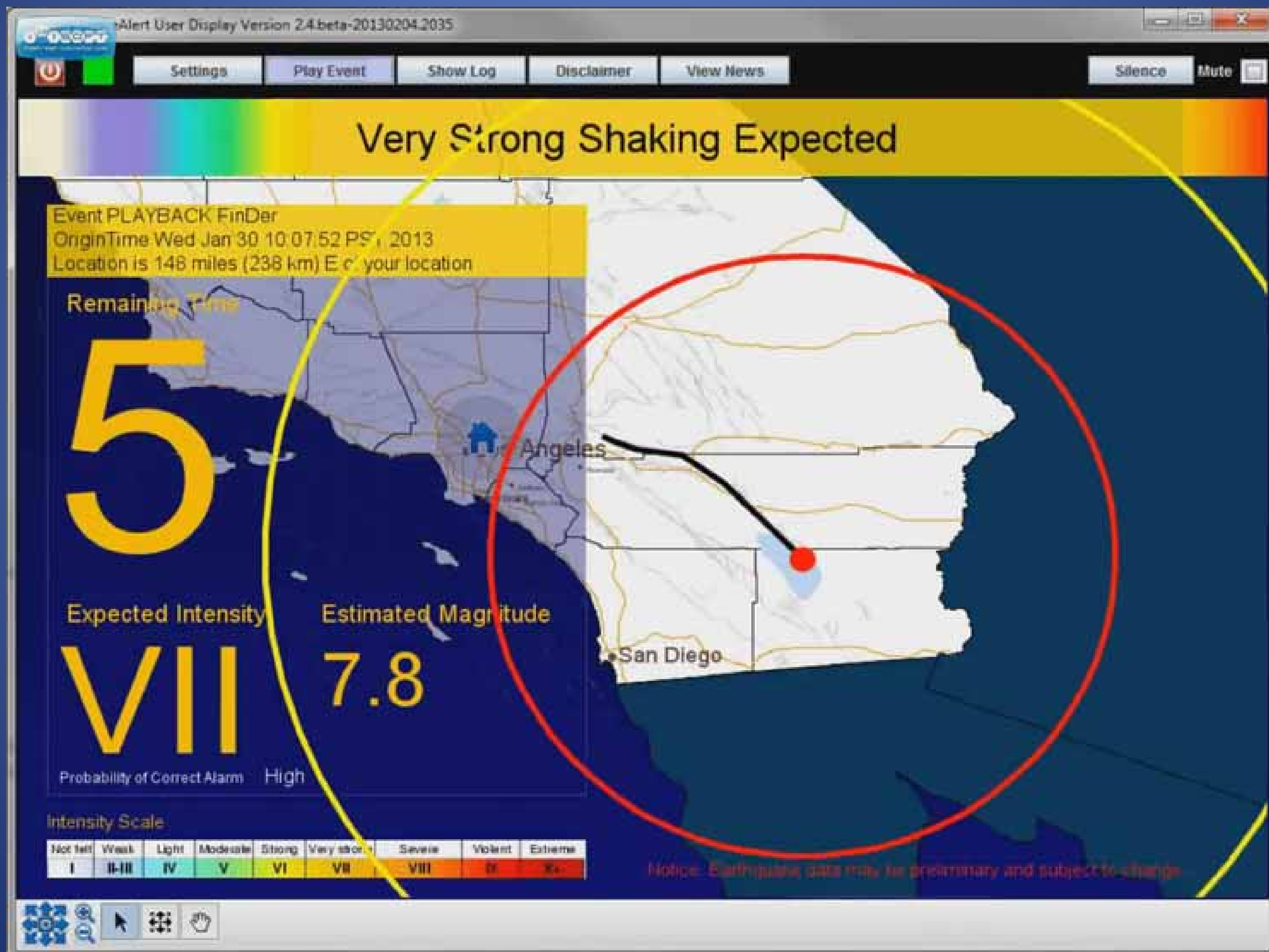
UserDisplay – ShakeOut M7.8

Real-time Finite Fault Solution



UserDisplay – ShakeOut M7.8

Real-time Finite Fault Solution



First proposed earthquake early warning system
– San Francisco, 1868

J.D. Cooper, MD, proposed:

- Detectors outside the city
- Telegraph wires to send warning
- Earthquake bell in tower
- Automated ("self-acting")
- Will work for distant shocks

Earthquake Indicator.

EDITOR BULLETIN—Since the Japanese magnet indicator has proved a failure, we are now obliged to look for some other means of prognosticating these fearful convulsions, and I wish to suggest the following mode by which we may make electricity the means, perhaps, of saving thousands of lives in case of the occurrence of more severe shocks than we have yet experienced. It is well known that these shocks are produced by a wave-motion of the surface of the earth, the waves radiating from a centre just as they do in water when a stone is thrown in. If this centre happens to be far enough from this city, we may be easily notified of the coming wave in time for all to escape from dangerous buildings before it reaches us. The rate of velocity, as observed and recorded in Dr. J. B. Trask's work on *Earthquakes in California from 1800 to 1864*, is 6 1-5 (six and one-fifth) miles per minute, or a little less per hour (40 miles) than the tidal wave is reported to have travelled across the ocean to this port from the Sandwich Islands or Japan.

A very simple mechanical contrivance can be arranged at various points from 10 to 100 miles from San Francisco, by which a wave of the earth high enough to do damage, will start an electric current over the wires now radiating from this city, and almost instantaneously ring an alarm bell, which should be hung in a high tower near the center of the city. This bell should be very large, of peculiar sound, and known to everybody as the *earthquake bell*. Of course nothing but the distant undulation of the surface of the earth should ring it. This machinery would be self-acting, and not dependent on the telegraph operators, who might not always retain presence of mind enough to telegraph at the moment, or might sound the alarm too often. As some shocks appear to come from the west, a cable might be laid to the Farallone Islands, 25 miles distant, and warnings thus given of any danger from that direction.

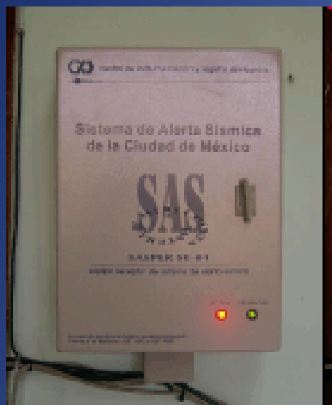
Of course there might be shocks the central force of which was too near this city to be thus predicted, but that is not likely to occur once in a hundred times.

J. D. COOPER, M.D.

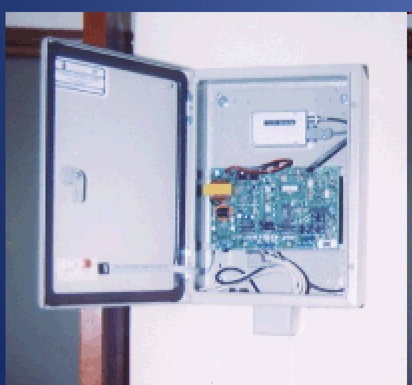
Brief History of EEW

- 1868 Hayward, M6.8 (30 killed)
  - Dr. J.D. Cooper suggests EEW system
- 1964 Japan Railroad builds Shinkansen
  - EEW for the system
- 1985 Mexico City M8.0 (~10,000 killed)
  - 1991 Mexico's EEW system goes live
- 1989 Loma Prieta M6.9 (57 killed)
  - USGS rapid-prototype EEW system
- 1995 Kobe M6.9 (6,400 killed)
  - 2007 JMA system (~$500M) goes live
- 2006 ShakeAlert development begins
  - 2012 Demonstration system live

Mexico City Early Warning System (SASMEX)



SAS Radio Receiver



centro de instrumentación y registro sísmico a.c.

Imprimir Inicio Cerrar

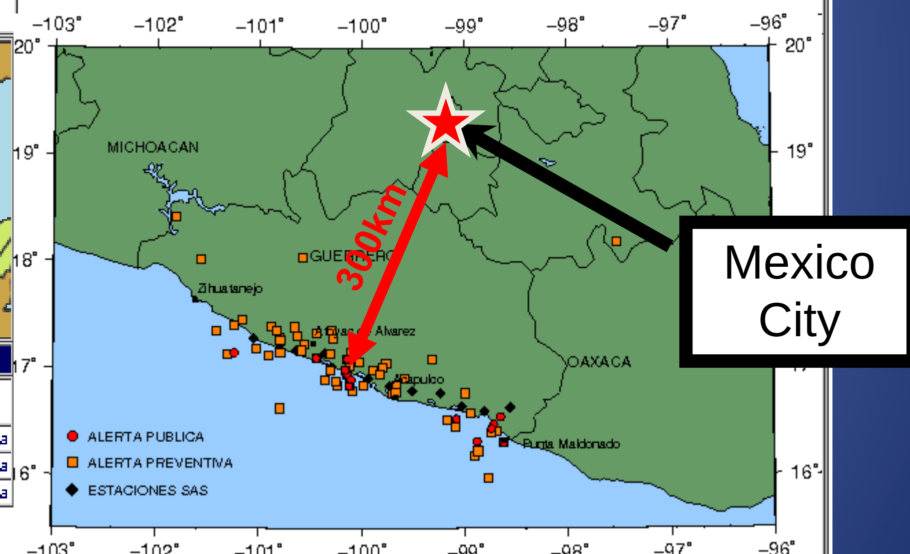
BOLETÍN DEL SISTEMA DE ALERTA SÍSMICA (SAS)

Avisos Recientes

No.	Fecha	Hora Local	Tipo de Aviso
1	2009-10-29	22:10:29	Sin Alerta
2	2009-10-28	19:24:02	Sin Alerta
3	2009-10-24	16:04:51	Sin Alerta

Buscar Avisos Recientes

El 29 DE OCTUBRE DE 2009 a las 22:10:29 hrs. (hora local) el SAS detectó un sismo en 2 de sus 12 estaciones en Guerrero. El SAS NO GENERÓ señal de alerta porque la energía del sismo en desarrollo no superó los niveles de disparo preestablecidos. El epicentro del sismo detectado por el SAS (Fuente SSN), se indica en el mapa de abajo.



Alertas Recientes

No.	Fecha	Hora Local	Tipo de Alerta
1	2009-04-27	11:46:45	Preventiva
2	2009-03-27	02:48:32	Preventiva
3	2008-11-11	05:02:28	Preventiva

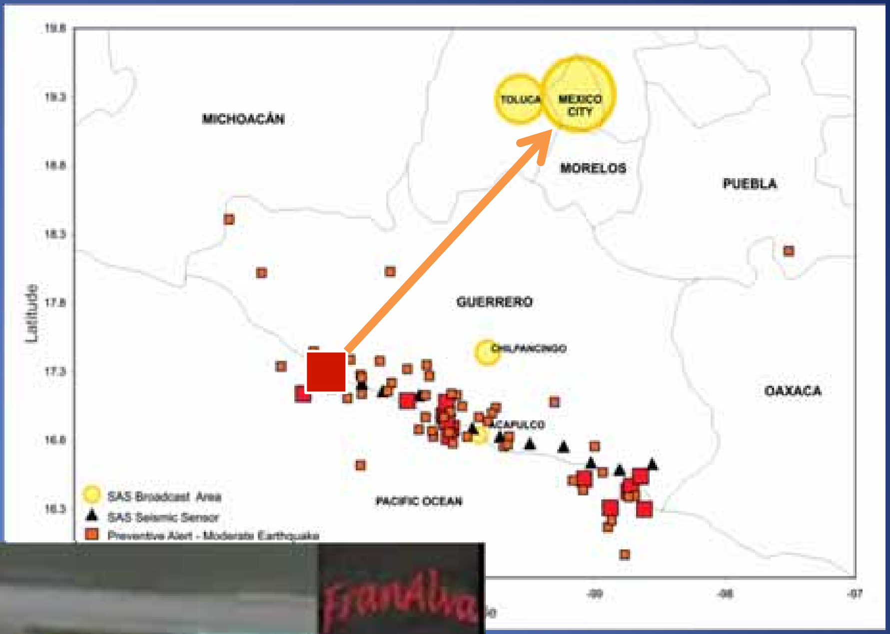
Buscar Alertas Recientes

Estado de las Estaciones del SAS, Fecha: 2009-10-29 Hora: 22:10:29

No.	Estación	Boletín	No.	Estación	Boletín	No.	Estación	Boletín
1	Papanoa	No Detectó	5	Pénjamo	No Detectó	9	Las Vigas	Detectó
2	El Veinte	No Detectó	6	El Jardín	No Detectó	10	El Carrizo	Detectó
3	Tetitlán	No Detectó	7	San Pedro	No Detectó	11	Marquelia	No Detectó
4	Cacalutla	No Detectó	8	El Cortés	No Detectó	12	Huehuetán	No Detectó

http://www.cires.org.mx/

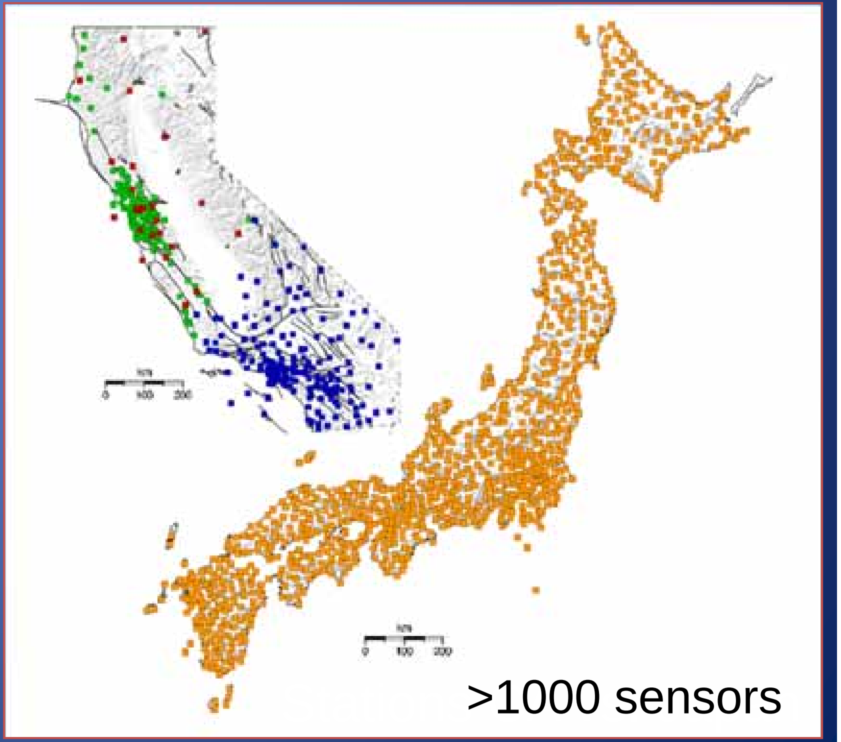
Mexico City
April 18, 2014
M7.2



- Built following the 1985 earthquake killed 10,000
- Operational since 1992
- ~70 sec warning in Mexico City

Japanese EEW system

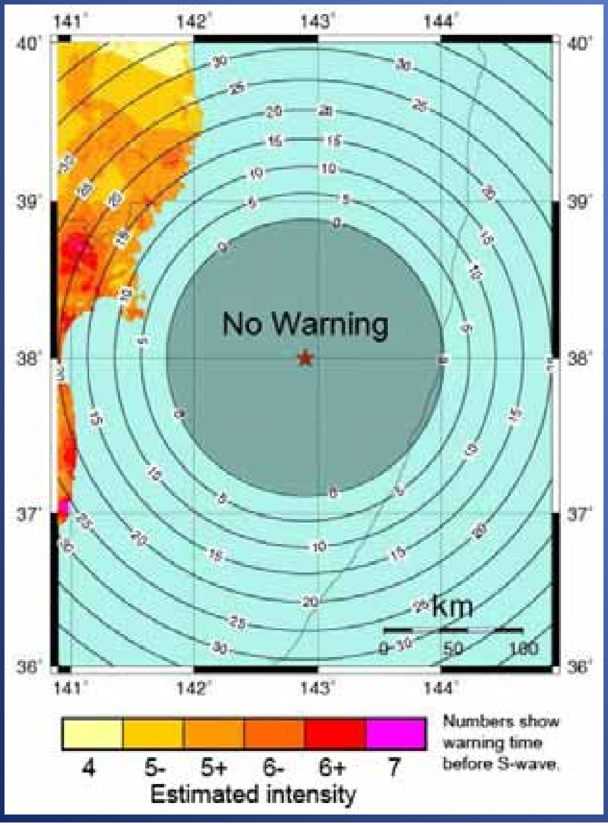
- Spent ~$600M on EEW after the M7.2 1995 Kobe earthquake killed 6,400
- Public warnings since Nov. 2007



Tohoku M9.0 – JMA EEW Alert

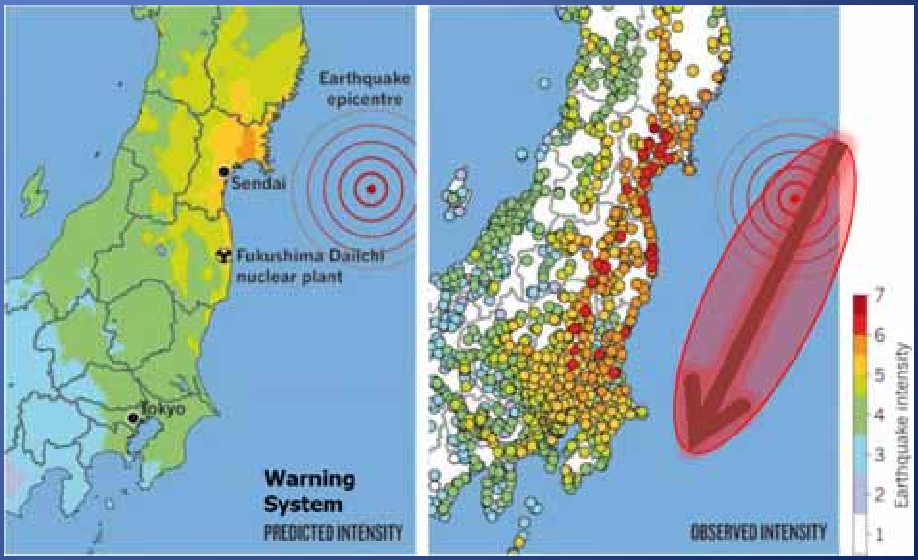
The good:

- **Alert was sent in ~9 sec**
- **Millions of people got 5 – 40 sec warning**



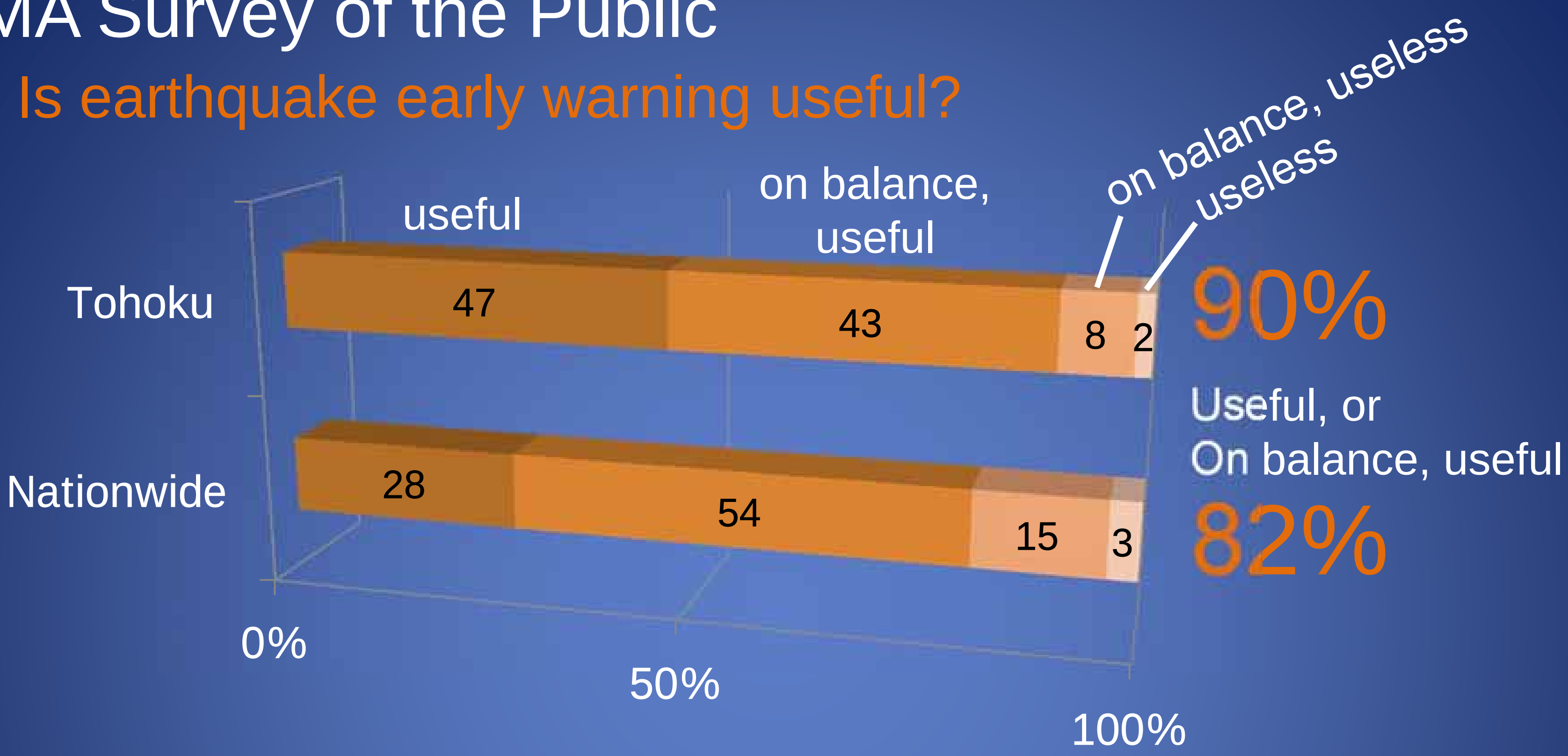
The not-so-good:

- **Underestimated magnitude (8.1)**
- **No finite fault solution**
- **Miscalculated intensity of area affected**
- **Missed aftershocks**

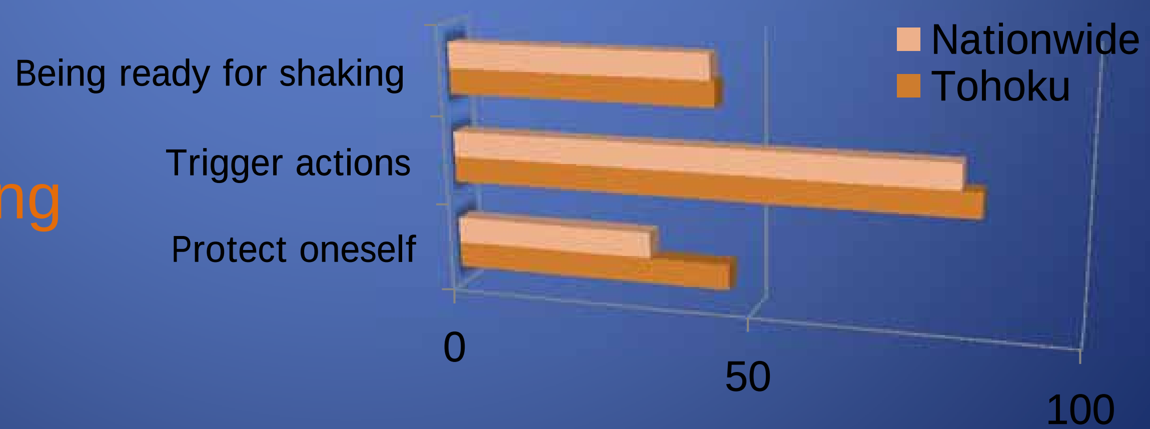


JMA Survey of the Public

Is earthquake early warning useful?



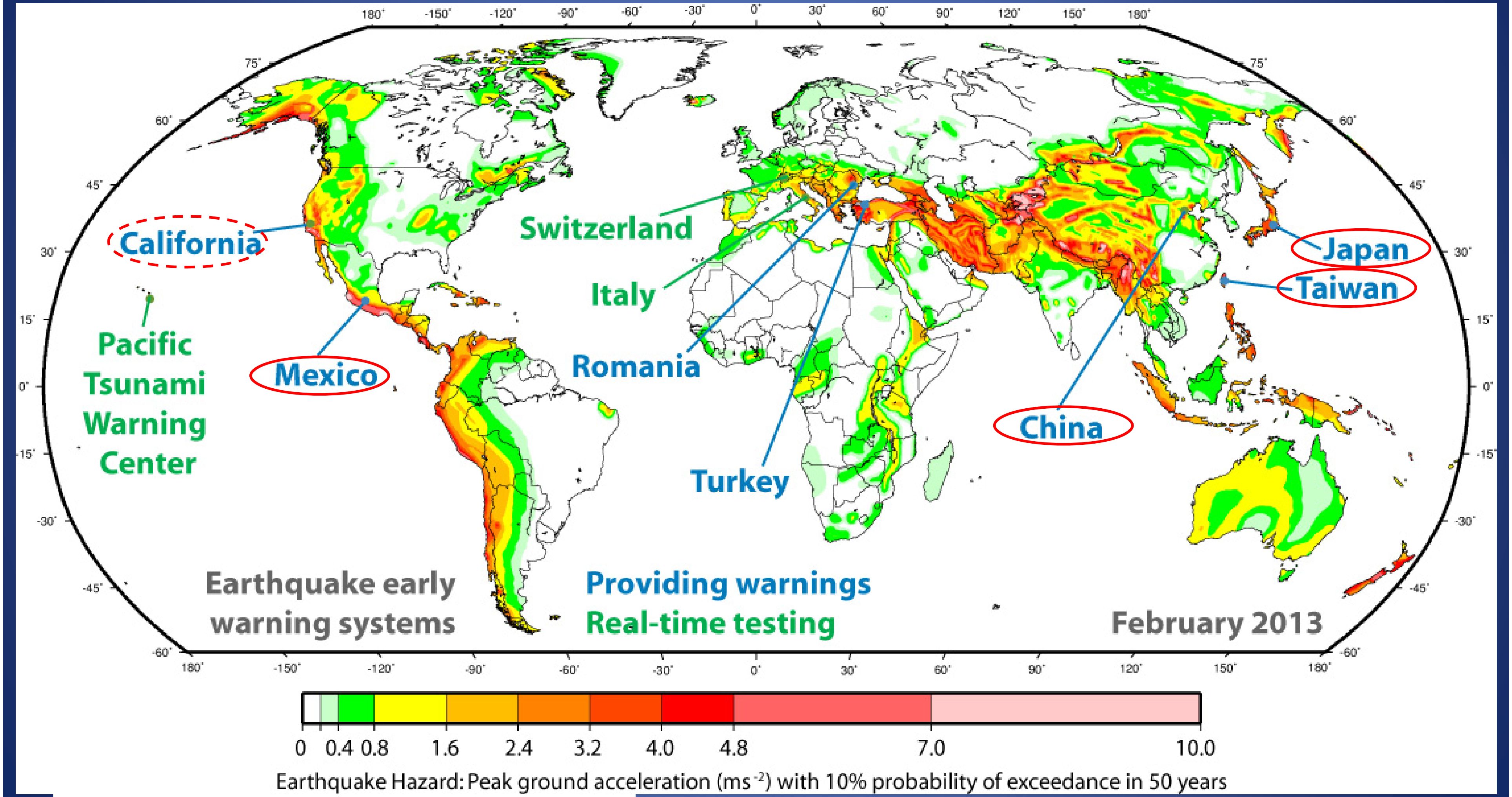
Why is early warning useful?



Data provided by Hoshiba

http://www.jma.go.jp/jma/press/1203/22c/manzokudo201203.html

Who in the World is Doing EEW?



Public notifications

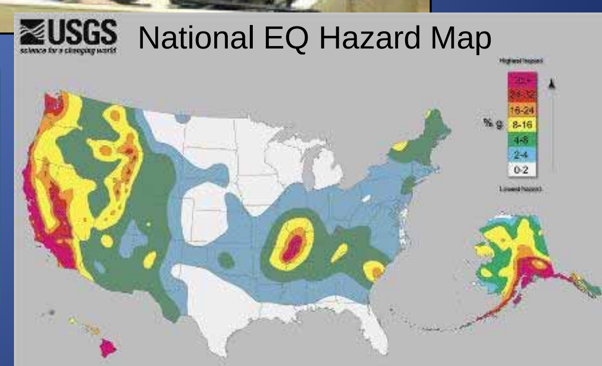
Richard Allan, UCB

USGS - Earthquake Hazard Program

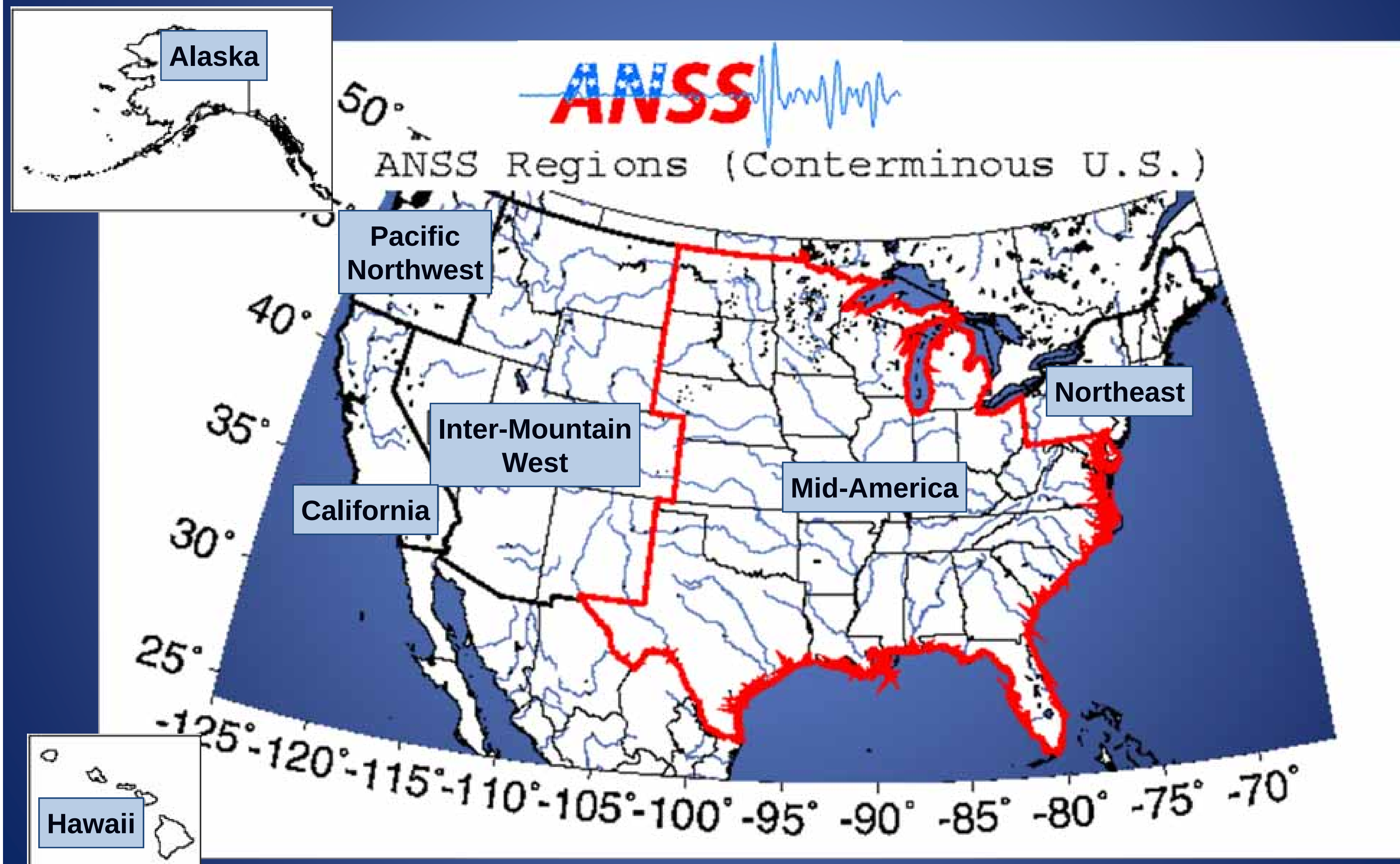
- USGS/EHP Mission: reduce deaths, injuries, and property damage from earthquakes
- USGS uniquely qualified to characterize hazard and warn for earthquake, volcano, and landslide
- *Earthquake Hazards Reduction Act of 1977, 42 U.S.C. §§ 7701 (NEHRP)*

NEHRP Agencies	NEHRP Activities: Research	NEHRP Activities: Development	NEHRP Activities: Implementation
NSF			
NIST			
USGS			
FEMA			

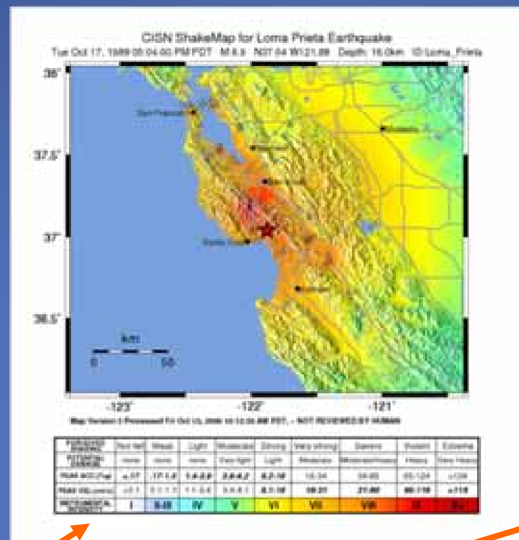
National Earthquake Hazards Reduction Program

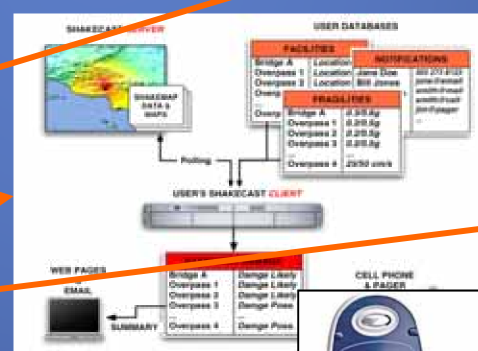


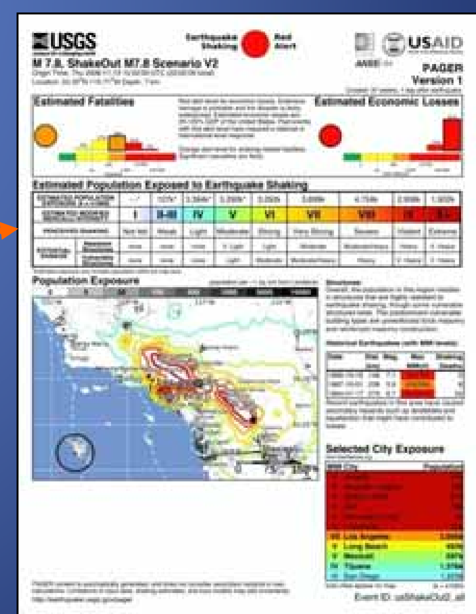
ANSS – Advanced National Seismic System



CISN Post-earthquake Products







- ShakeMap
- CISN Display
- ShakeCast
- Pager
- ENS
- *ShakeAlert…*

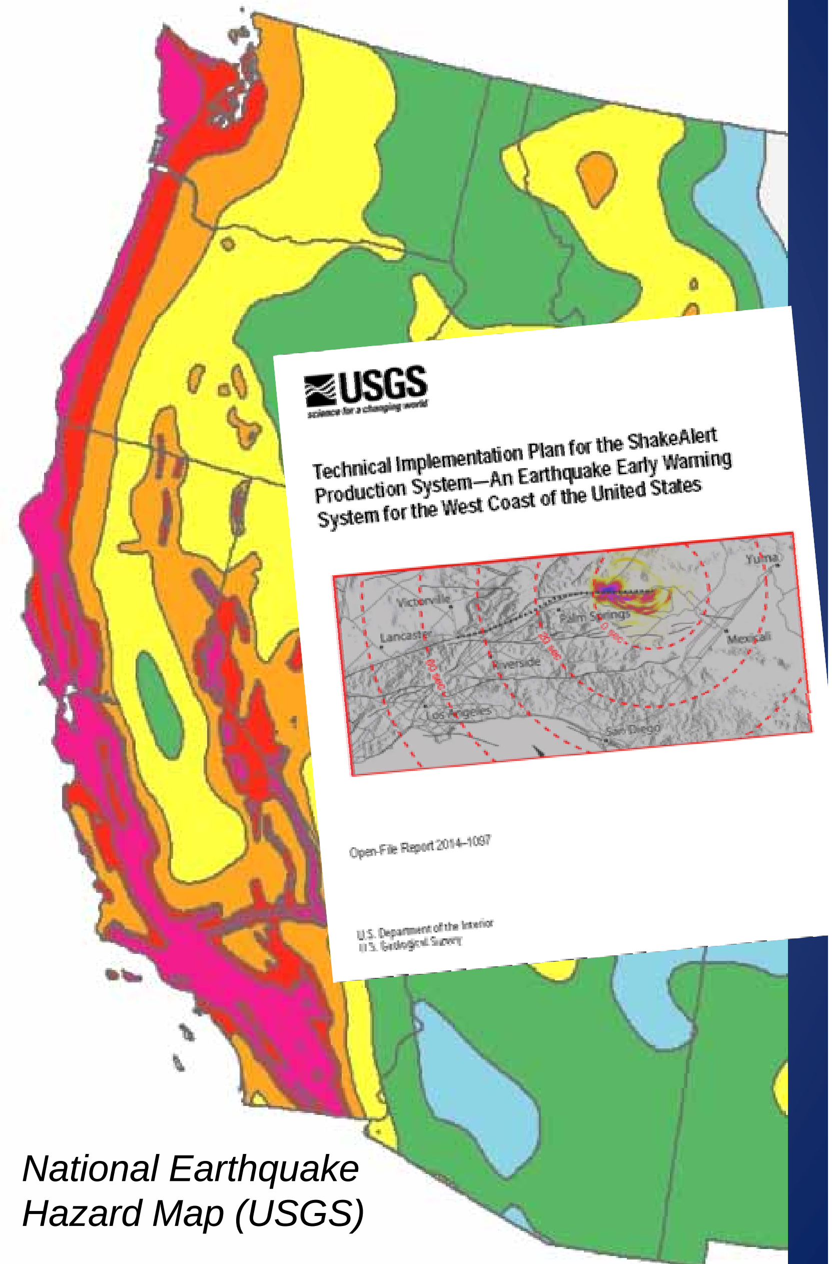
http://cisn.org   http://earthquake.usgs.gov

ShakeAlert Technical Implementation Plan

Goal: build & operate a West Coast EEW system to…

- *Issue <u>public warnings</u> for large earthquakes and…*
- *Send <u>warning parameters</u> to government and private sector users…*
- *…as soon as ShakeAlert meets <u>quality and reliability standards</u> on a region by region basis*

USGS Open-File Report 2014-1097

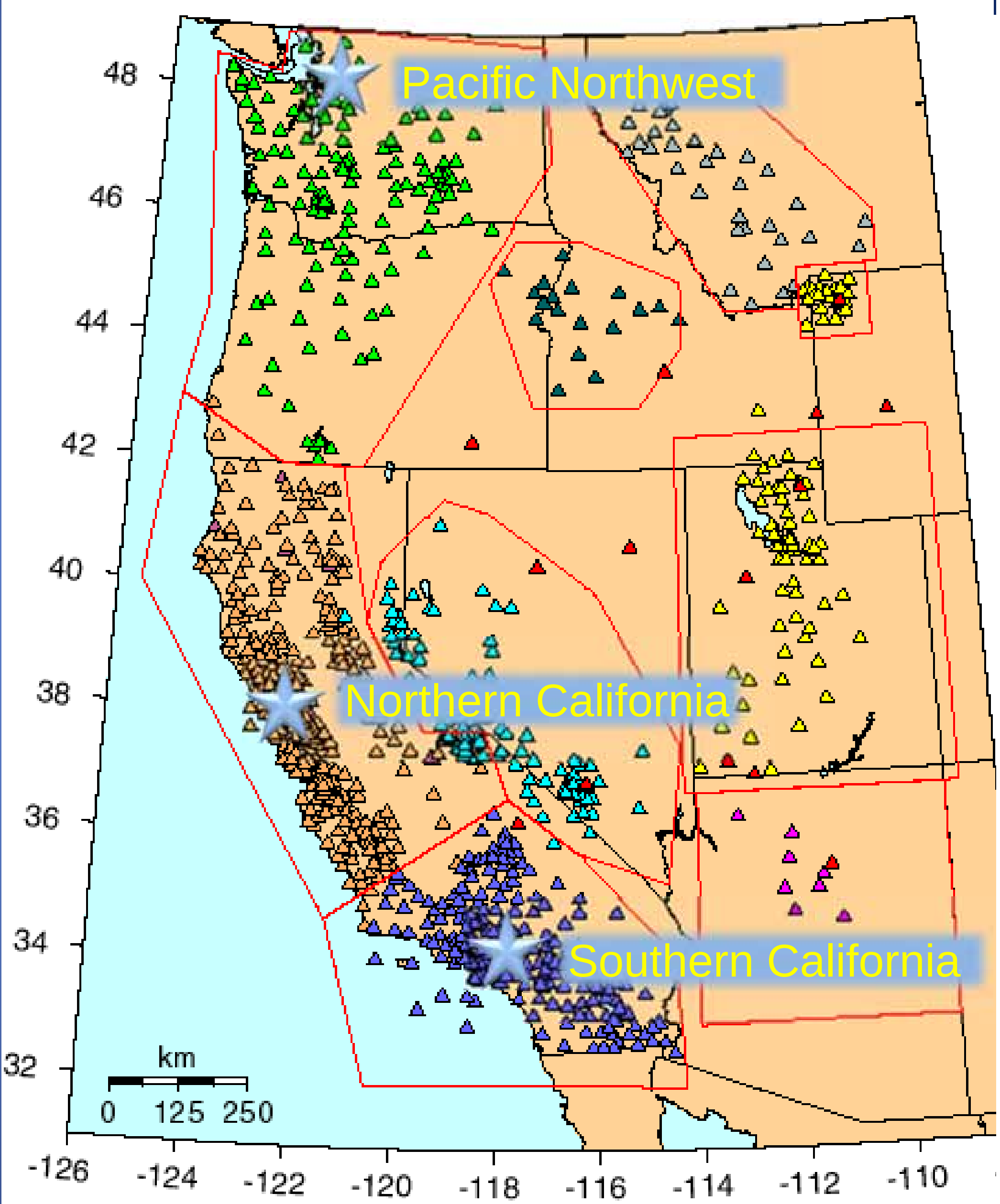


National Earthquake Hazard Map (USGS)

Large Scale System Architecture

- ShakeAlert is built on ANSS regional networks
- Leverages ANSS
  - Stations
  - Telecomm
  - Hardened centers
  - Software (EW, AQMS)
  - Expertise
  - Management structures
- Extension of ANSS Tier 1 center operations (AQMS)
  "A new ANSS product"

ANSS West Coast Centers



Progress Toward a Public EEW System

CISN California Integrated Seismic Network

ShakeAlert

Evolutionary Approach

→2006-now – R & D phase

→Jan. 2012 – Demonstration System Live

→2014 – Production Prototype

→?* – Limited Regional Rollout

→?* – Full Operation

*Rollout schedule depends on funding levels

Receiving alerts today:

- >50 scientists
- BART
- CalEMA
- Google.org
- LA Metro
- Metrolink
- Amgen
- So Cal Edison
- SF DEM
- L.A. City
- L.A. County
- UC Berkeley OEP

more…

ShakeAlert

Performance – *Speed and Accuracy*

- First hazard estimate 0.1 sec after P-wave detection
- Network approach: Requires 2 or 4 station triggers for alert
- Speed of alert is a choice based on alert thresholds

La Habra quake: Friday March 28th, 2014. 9:09 pm PDT, M5.1

09:09:42.3	Origin time
09:09:43.3 (+1.0s)	1st P-wave CI.OLI
09:09:46.3 (+4.0s)	1st Alert

Similar performance for M4.4 March 17th, 2014 in Encino, CA:
1st alert 4.3 sec after origin time

Investments in EEW Development

(Through FY14)

USGS

(2002-2015)

- External coop agreements for R&D for EEW
  - Phase I & II (2002-2012) $2,093,851
  - Phase III (2012-2015) $1,575,000
- ARRA California (2009-2011) $4,426,110
  - Network equipment upgrades
- MultiHazards Project (2008-2014) $2,342,150
  - San Andreas sensors, station upgrades, production computers, personnel

TOTAL $10,437,111

Moore Foundation

(2012-2014, no renewal)

- Caltech $1,996,888
- UC Berkeley $2,040,889
- Univ. of Washington $1,848,351
- USGS $ 594,406

TOTAL $6,480,534

FY14 – Federal Omnibus Budget Bill

- $850,000 for EEW
- "The Committees support efforts to continue developing an earthquake early warning prototype system on the West Coast."

City of Los Angeles – UASI funding

- To Caltech **$5,600,000**
  - 125 new & upgraded stations
  - 40 RT-GPS stations
  - System infrastructure upgrades

Est. Cost to Complete & Operate ShakeAlert

	California	Pacific Northwest	*West Coast Total*
Construction	**$23.1M**	$15.2M	*$38.3M*
Annual M&O	**$11.4M**	$4.7M	*$16.1M*

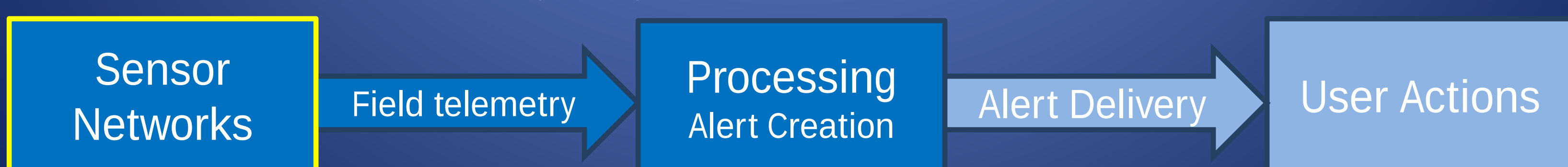
- New and upgrades seismic stations & GPS stations
- Significant field telemetry upgrades
- Support personnel
  - to bring ANSS (CISN) network staffing up to robust levels
  - EEW implementation and testing
  - EEW operation and user outreach
- Support for continued R & D

Ground Motion Sensors

- ANSS seismic networks (CISN + partners)
  - Optimum density ~20km
  - Add & upgrade stations
  - High quality
  - Low latency
- Geodetic Networks (CISN + partners)
  - Real-time, high precision
  - Collocate with seismic
  - Continued work on RT data processing

Instrument Type	California (CISN)	Pacific Northwest	Total: West Coast U.S.
Seismic: Type A[1]	125	66	191
Seismic: Type B[2]	314	210	524
Total Seismic	439	276	715
GPS	150	156	306

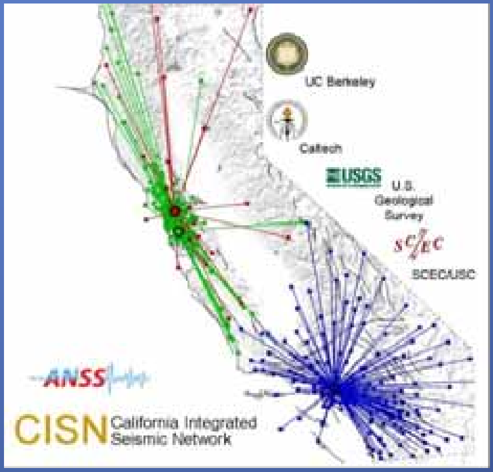
[1] ANSS station; broadband plus strong motion instrumentation
[2] Only strong motion accelerometer



Network Telemetry

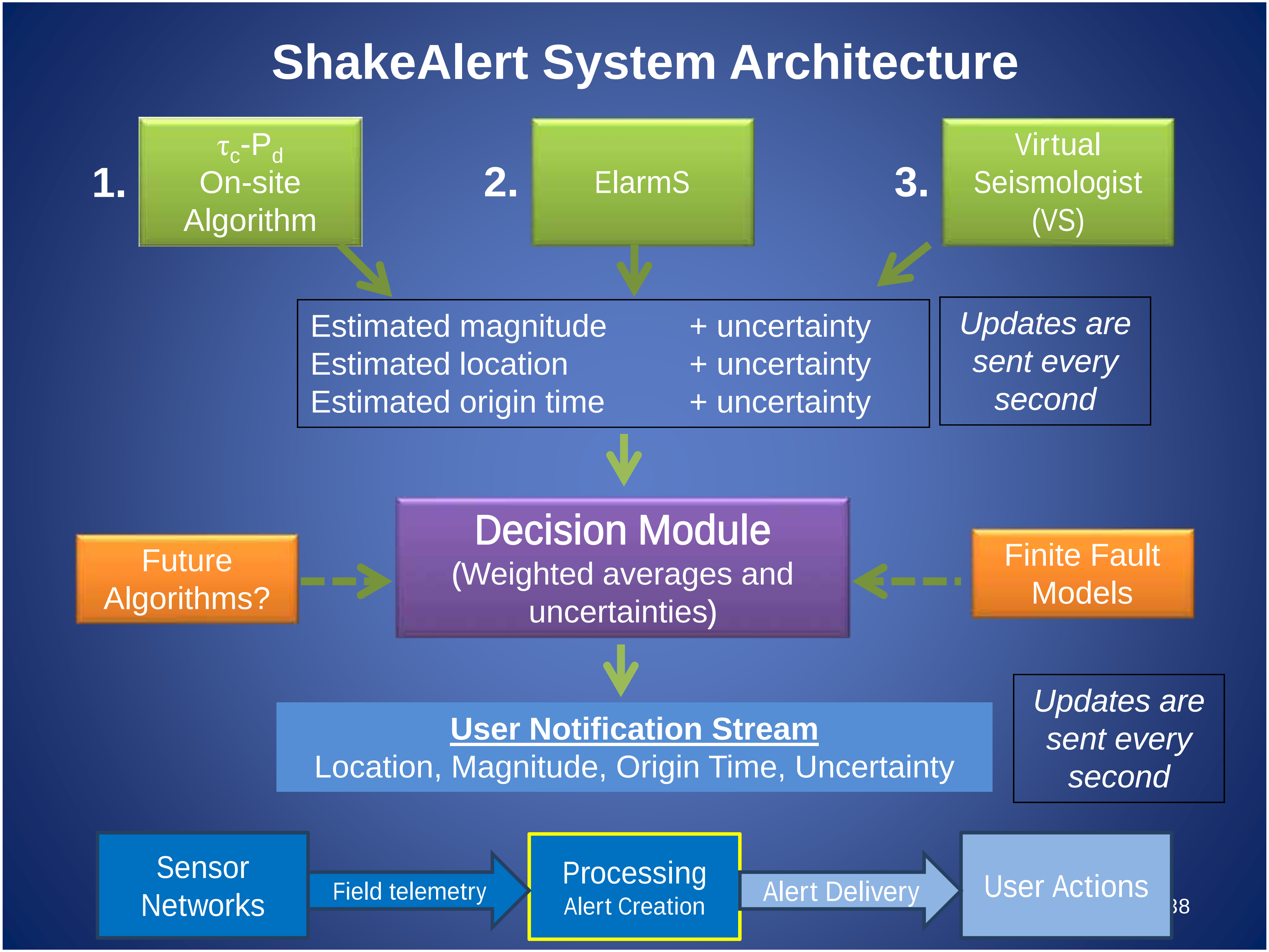
Path Diversity

- Commercial Telecomm
  - Cellular (Verizon & Sprint)
  - Leased circuits
  - DSL, cable
- IP Radio
- Digital microwave
  (Freq. sale upgrade)
- Satellite
- Public Internet
- Private Intranets
- Partner systems



Strawberry Pk. Microwave

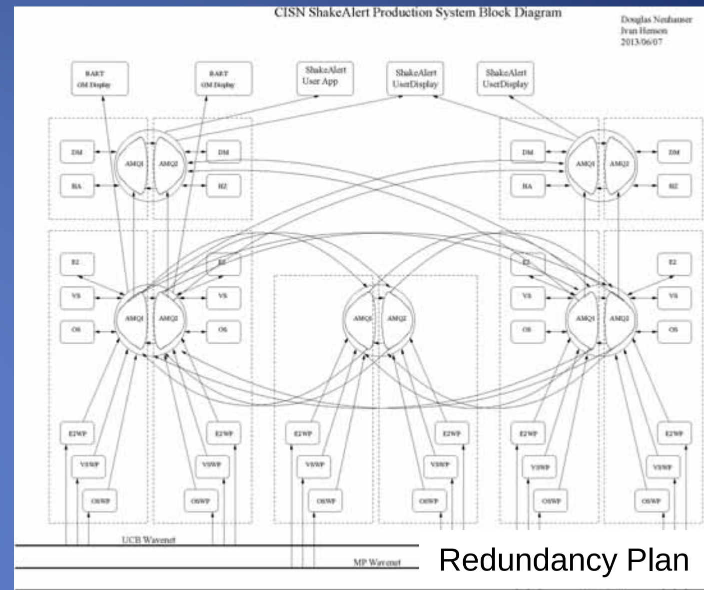
Sensor Networks → Field telemetry → Processing Alert Creation → Alert Delivery → User Actions



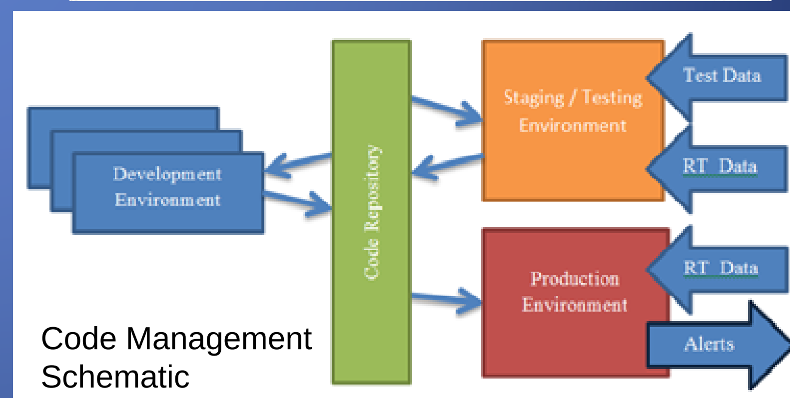
ShakeAlert System Architecture
1.
τc-Pd
On-site
Algorithm
2.
ElarmS
3.
Virtual
Seismologist
(VS)
Estimated magnitude + uncertainty
Estimated location + uncertainty
Estimated origin time + uncertainty
Updates are sent every second
Future Algorithms?
Decision Module
(Weighted averages and uncertainties)
Finite Fault Models
User Notification Stream
Location, Magnitude, Origin Time, Uncertainty
Updates are sent every second
Sensor Networks
Field telemetry
Processing
Alert Creation
Alert Delivery
User Actions

Processing & Alert Creation

- Building Engineered Production Prototype
  - Standardized, robust, sustainable computer environment
  - Best practices software engineering & code management
  - Design for redundancy
  - Rigorous testing with playback of archived and synthetic data sets
- Continuing tuning & testing
- Continuing R & D
- Integrating GPS methods
- System performance monitoring



Redundancy Plan



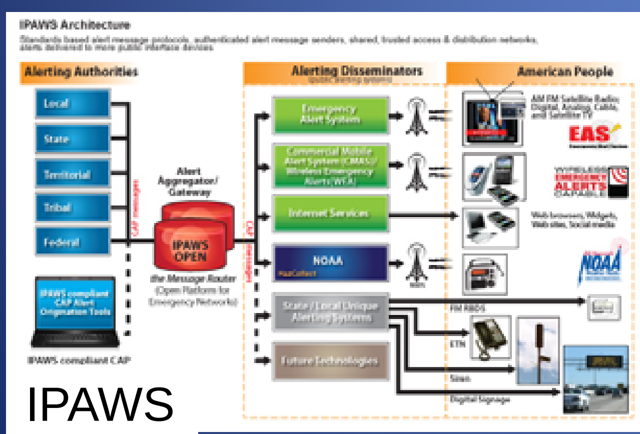
Code Management Schematic

System Standards

- System infrastructure
  - Station density
  - Telemetry latency
  - Security (FISMA)
- System performance goals and metrics
  - Latency
  - Missed events
  - False events
  - Mislocations
- Incoming data
  - Sensor/logger hardware
  - Algorithms, parameters
  - Data formats
- Outgoing notifications
  - Latency, reliability
  - Data formats (CAP, XML)
- Computer & code management practices
- Testing & certification

Reliable Notification

- Internet
- Direct radio, VSAT, etc.
- Private partner systems
- FEMA-IPAWS (TV, radio, cell) "alert authority"
- RBDS - FM radio project
- Mass notification companies
- Partner redistribution
- Cloud services, phone app
- Google, Twitter?

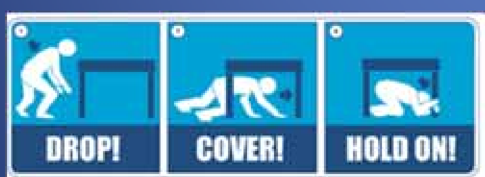


Sensor Networks → Field telemetry → Processing Alert Creation → Alert Delivery → User Actions

Education = User Actions

The Public

- Drop, cover, hold on
- Integrate hazards education
- Social science on:
  - Effective messaging
  - Alert content, sounds



Institutions (automated)

- Complex data stream
- Private partners to develop user-specific applications
- Japanese created a non-profit (REIC)

Sensor Networks → Field telemetry → Processing Alert Creation → Alert Delivery → User Actions

EEW System Limitations

- Always a trade off between speed and accuracy
  - Event information improves with time
- False alarms
  - Alarm, no quake (noise, glitch, equipment failure)
- Bad alarm
  - Miscalculated location or magnitude
- Missed events
  - Damaging quake, no alarm
- “Blind zone” – near the epicenter
- “So what” zone – far from epicenter

Summary

- USGS is dedicated to implementing a public EEW system for the West Coast
- The State of California is also committed to a system
- ShakeAlert demo system is running in California now
- Completing public EEW will require further investment & partner participation

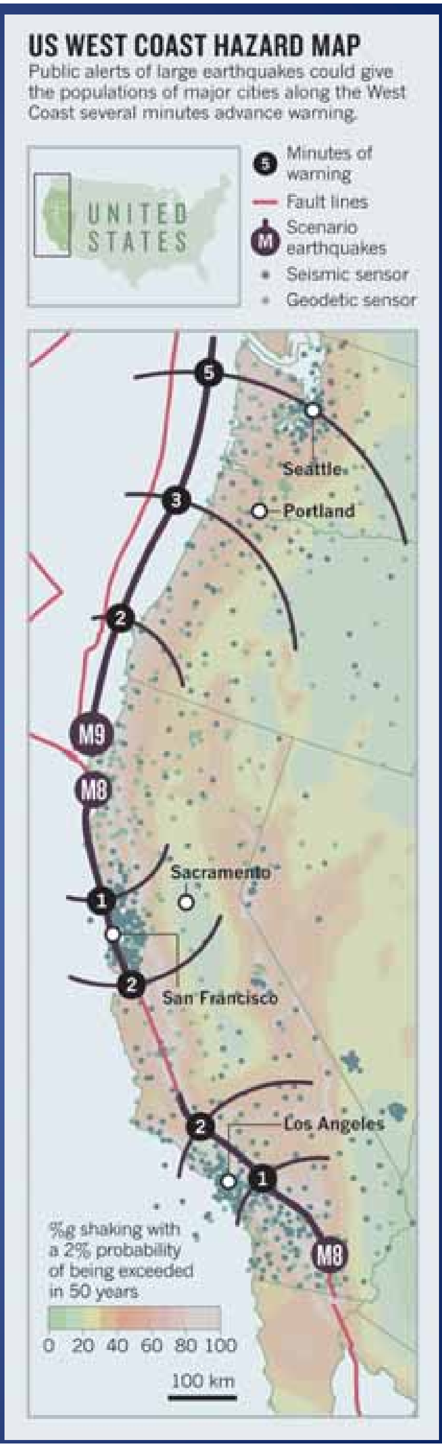
CISN California Integrated Seismic Network

ShakeAlert

http://shakealert.org

- Why not use Japan's system?
  – Do use same/improved algorithms
  – Expensive field deployment
  – Japanese are guarded
  – Had issues in Tohoku

- Why not use Mexico's system?
  – Simple algorithms
  – City/source topology



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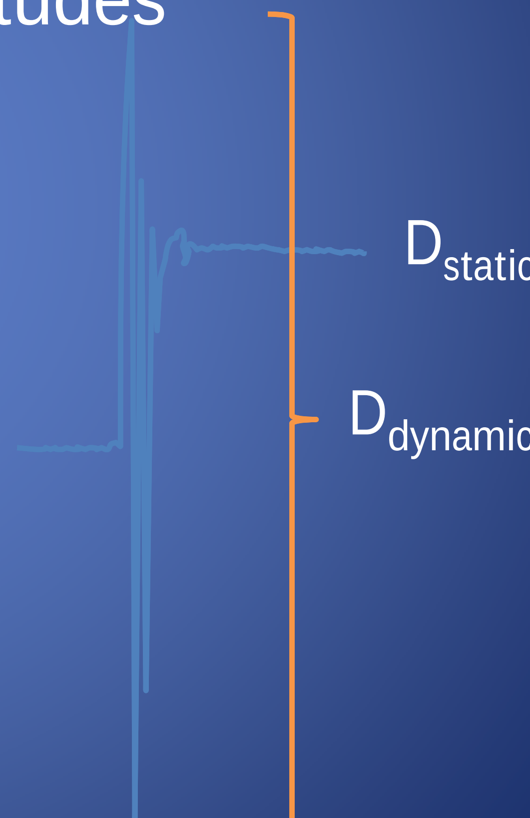
USGS “zipper array” along San Andreas for early warning

The Value of GPS Data

- Earthquake Early Warning
  - Determination of large magnitudes
  - Fault modeling
  - Slip detection



Issues: Magnitude estimation

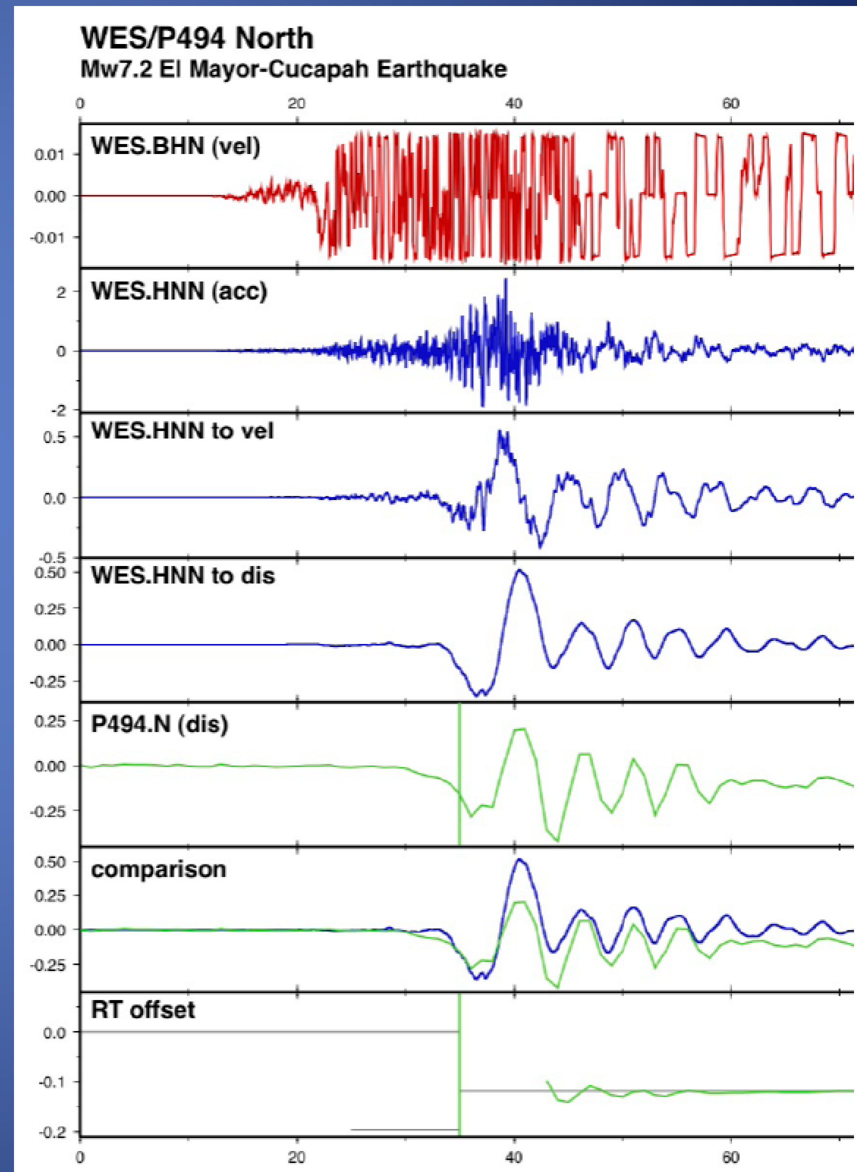
- Real-time, high precision GPS can help get large magnitudes right

Seismic →

GPS →

Seismic + GPS →

Static displacement



Collocated Seismic/GPS Sites

24 in SCSN (41 soon)

Summary

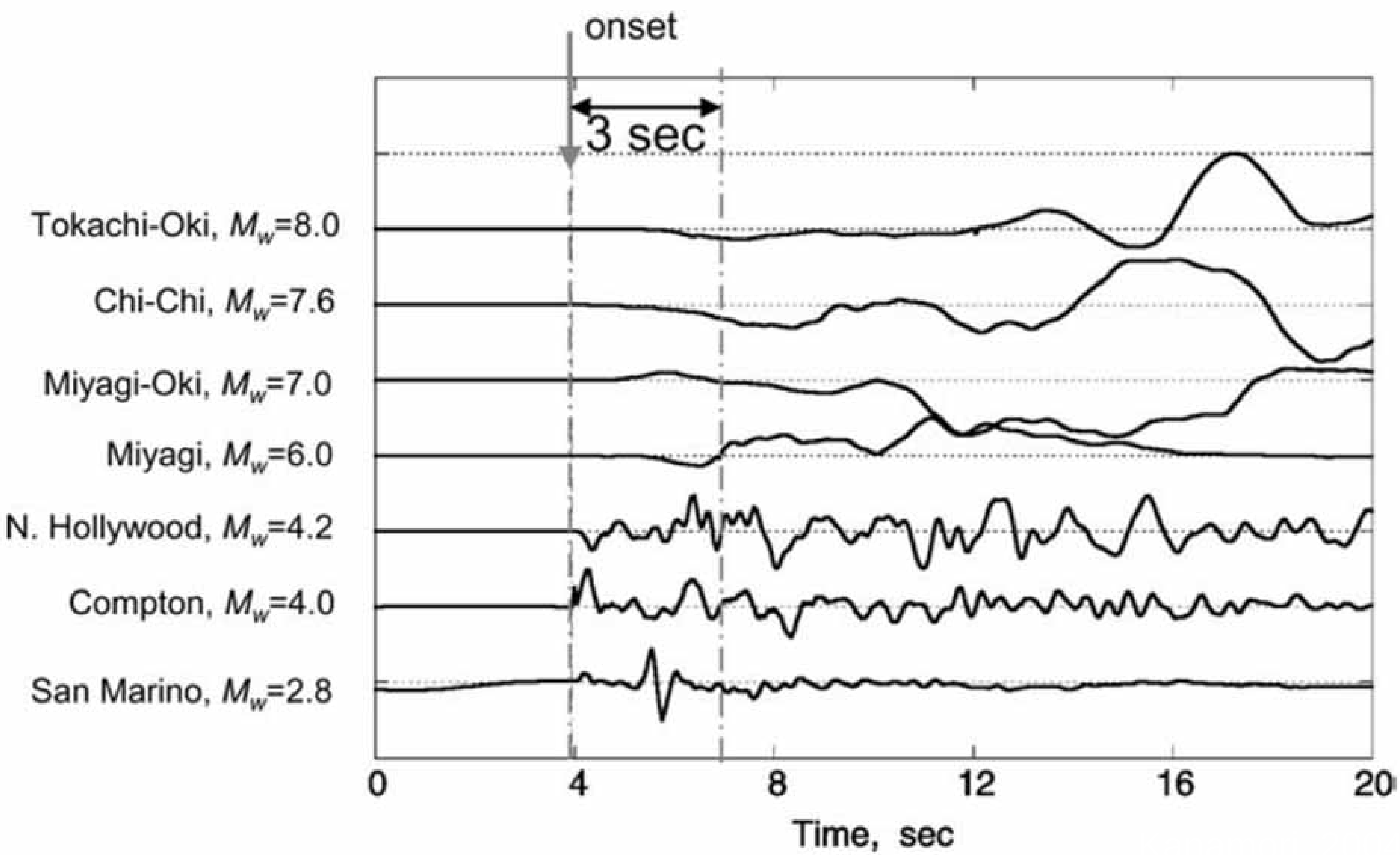
- USGS is dedicated to implementing a public EEW system for the West Coast
- ShakeAlert demo system is running in California now
- This complements Cal OES mandate for EEW
- Completing public EEW will require further investment & partner participation

CISN California Integrated Seismic Network

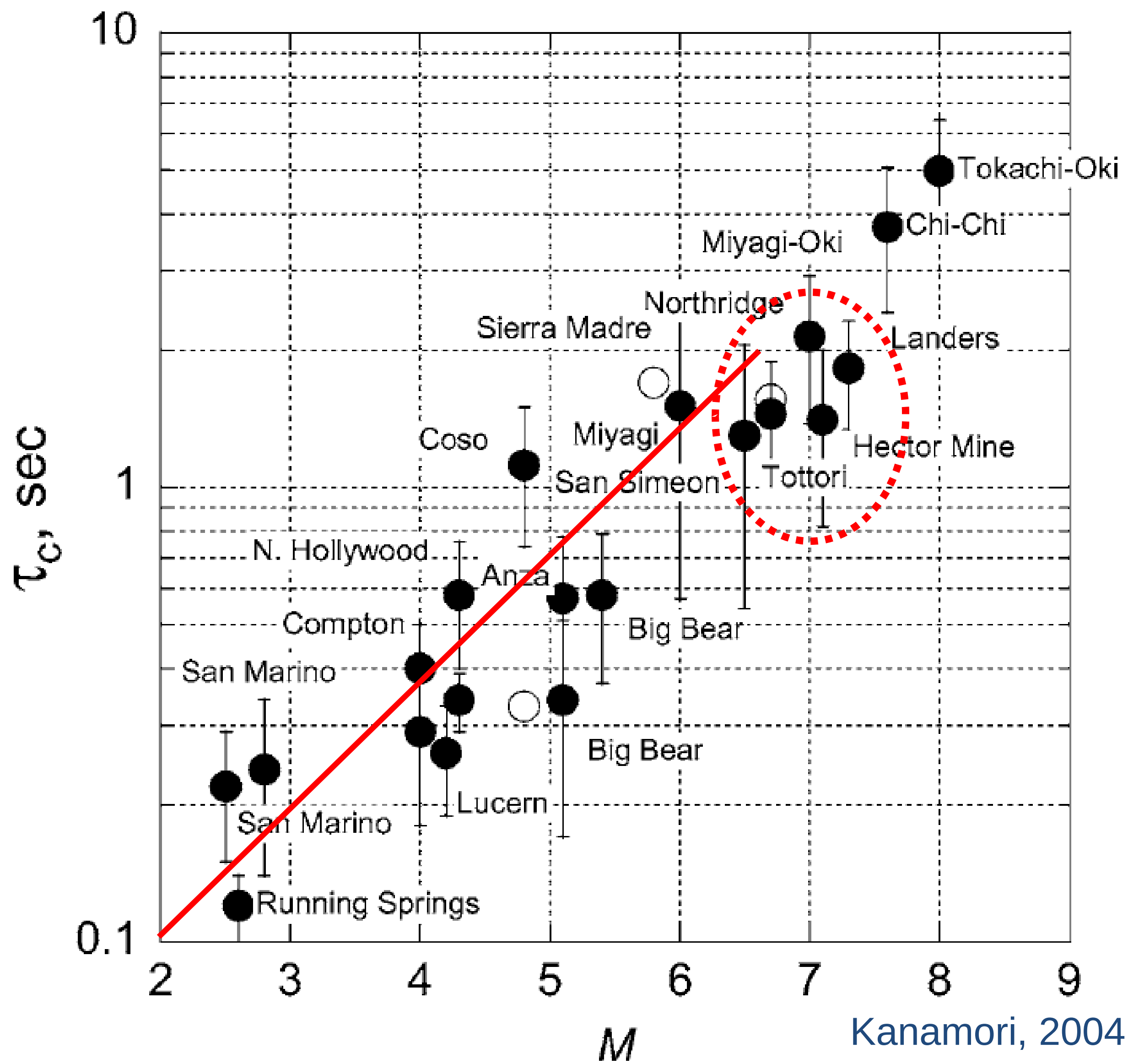
ShakeAlert

http://shakealert.org

Do Big Events Start Big? Yes!



τ_c Scales with Magnitude



Kanamori, 2004