USGS Earthquake Program GPS Use Case: *Earthquake Early Warning*

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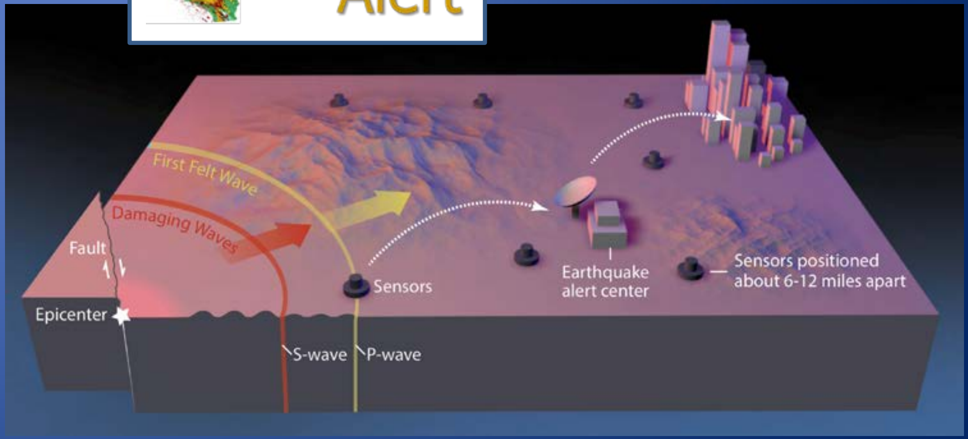
USGS Earthquake Program

GPS Adjacent Band Workshop III
Aerospace Corp, El Segundo, CA
12 March 2015

CISN California Integrated Seismic Network
ShakeAlert



USGS
science for a changing world
Earthquake Hazards Program

USGS GPS receiver ‘use case’

- Item 1 – High Precision User (federal agency with Stafford Act hazard alert responsibilities for earthquakes, volcanoes and landslides nationwide)
- Item 2 - Description of Associated GPS Application(s):

The USGS Earthquake Program currently operates 108+ real-time GNSS stations to monitor the San Andreas and other faults Southern California. Real-time GNSS station position data at centimeter level accuracy are streamed into the earthquake early warning system, called Shake Alert (USGS OFR # 2014-1097) that issues alert messages for public safety in case of a major earthquake. The GNSS component of the Shake Alert system augments the inertial sensors and is especially important for the largest earthquakes. The sensitive inertial sensors may go off scale, whereas GNSS data is expected to provide reliable ground motion recordings of displacement even in the largest events. Real-time, uninterrupted GNSS signals are required, without interference, at all times because even a temporary black-out of data from one site could thwart our early warning system (if that station is close to the epicenter of a major earthquake). That is, the RFI could increase our “blind zone” and delay delivering or degrade the accuracy of our Shake Alert message to the public.

Receivers Model/Make/Series:

Make	Model	Series	Approximate Number of Units Deployed
Trimble	NetR9 (w RTX and GLONASS)		41
Topcon	Net-G3A	Sigma	66
Trimble	NetRS		11

Antenna Models:

Make	Model	Series
Trimble	Zeohyr Geodetic II (ZGII)	TRM57971.00
Topcon	CR-G3	TPSCR.G3
Ashtech	Choke Ring	ASH701945B_M ASH701945D_M

Range of Operational Speeds (min/max velocities)

- From 0 MPH up to 7200 MPH (miles per hour)
- Rupture speed at crack front ~ 3 kilometer per second ground motions occur in an earthquake), and at any station, up to ~3 g and 2 meters per second station velocity
- Platform dynamics include high ‘jerk’ (rate of acceleration); TCXO and other tracking challenges

Any Additional Information Pertaining to the GPS Application You Would Like to Provide:

USGS high precision application for Earthquake Early Warning (EEW) requires the broadest spectrum so as to fully utilize the GNSS signals, including side bands, for getting the highest station position accuracy possible in real-time. Our 108 stations operated by USGS in real-time are only part of a much larger collaborative inter-agency partnership. In all, over 1000 high precision GNSS stations called the Plate Boundary Observatory (PBO) are operated by UNAVCO for the National Science Foundation, many of which also stream data in real-time and are expected to soon be included into the earthquake early warning system as well. Eventual inclusion of real-time GNSS data from PBO into the NOAA tsunami alert system and USGS volcano alert system is also expected, all based on the real-time development led by the USGS Shake Alert earthquake early warning system. NASA has also invested in the technological development surrounding continuous GNSS over many years, and they support the IGS global array of GNSS stations that we also require to do Precise Point Positioning with Ambiguity Resolution PPP(AR) processing using highly accurate GNSS orbit and clock corrections, required by our EEW application as well.

ShakeAlert

Earthquake Early Warning System

Doug Given

USGS

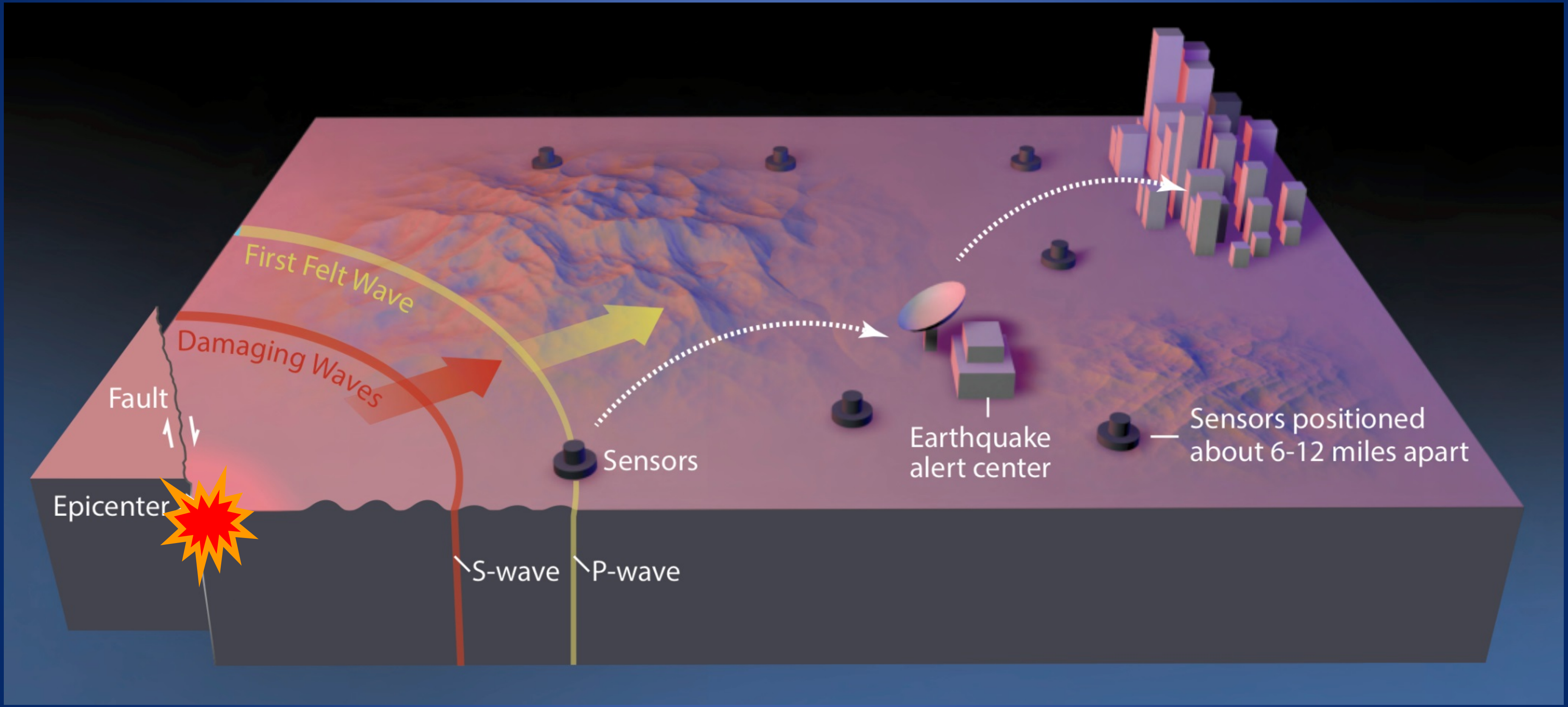
Earthquake Early Warning Coordinator

Primary Collaborators

- ***USGS***
  Given, D., Cochran, E., Oppenheimer, D.
- ***State of California (Cal OES, CGS)***
  Johnson, M., Parrish, J.
- ***Caltech***
  Heaton, T., Hauksson, E.
- ***UC Berkeley***
  Allen, R., Hellweg, P., Strauss, J.
- ***U. of Washington***
  Vidale, J., Bodin, P.
- ***Swiss Seismological Service, ETH***
  Clinton, J., Behr, Y.
- ***Moore Foundation***
  Chandler, V., Koch, N.

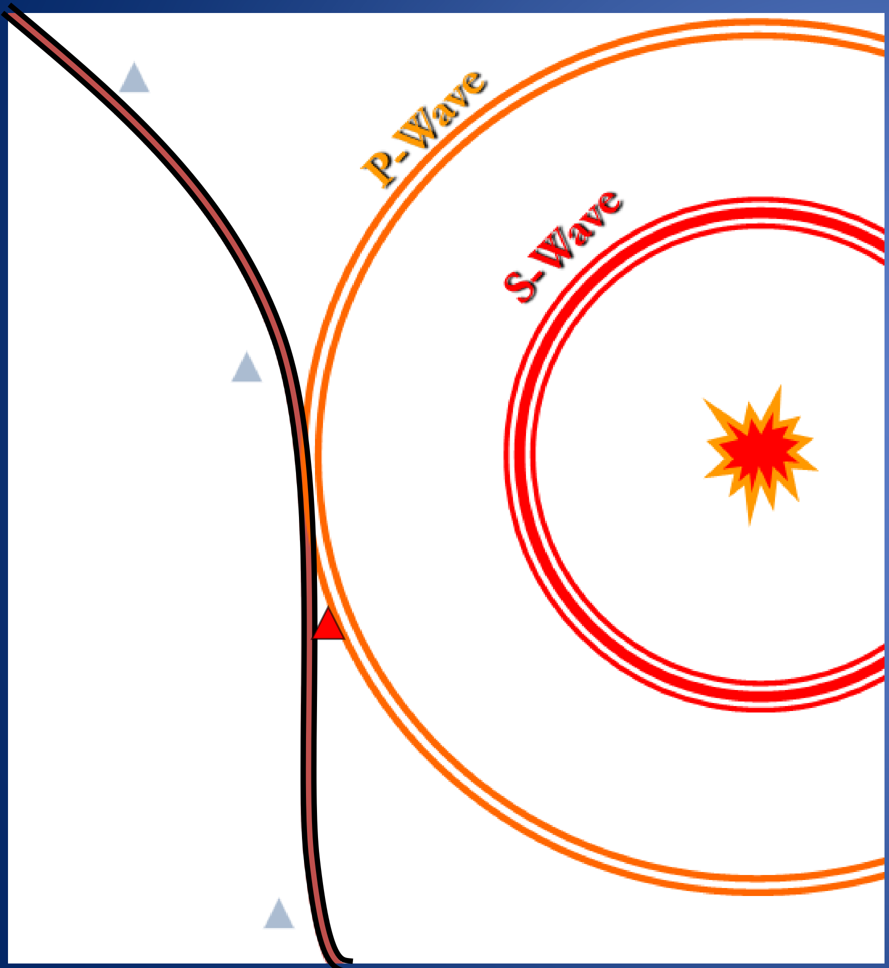
EEW Concept

Network Based Alerts

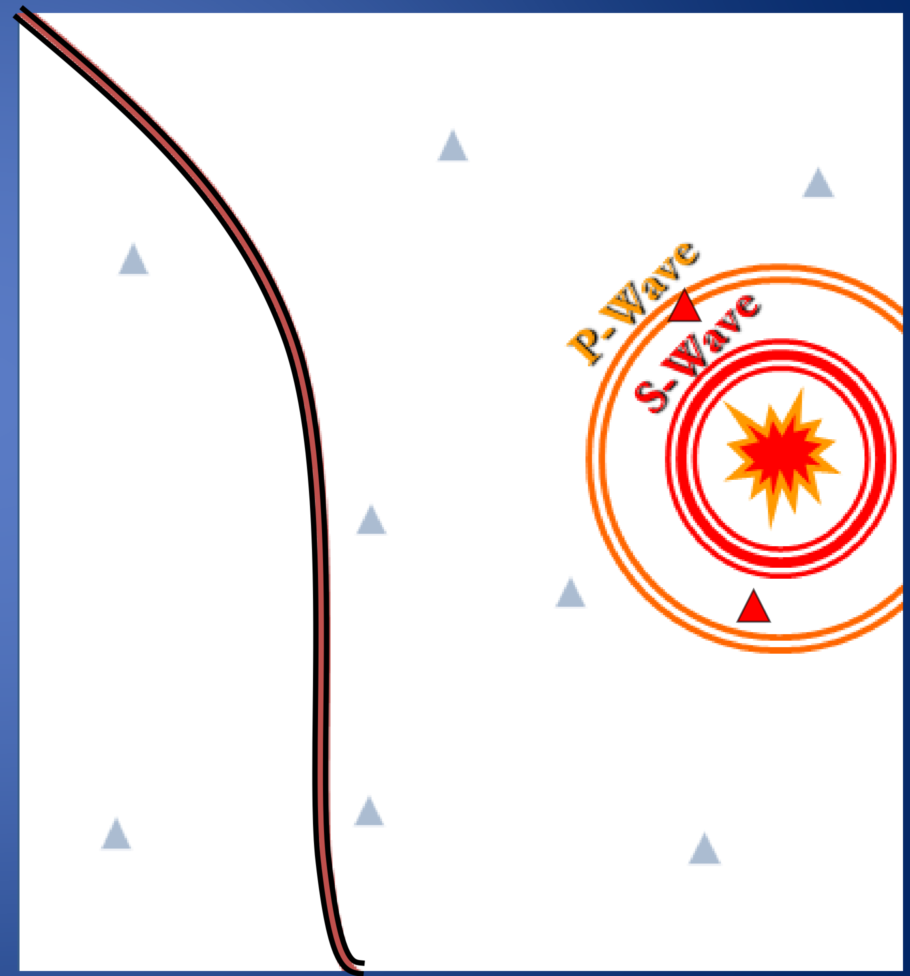


P-wave ~ 3.5 mi/sec (felt waves)
S-wave ~ 2.0 mi/sec (damaging waves)
Alert ~ 186,000 mi/sec

Regional Network Alerts
maximize warning time



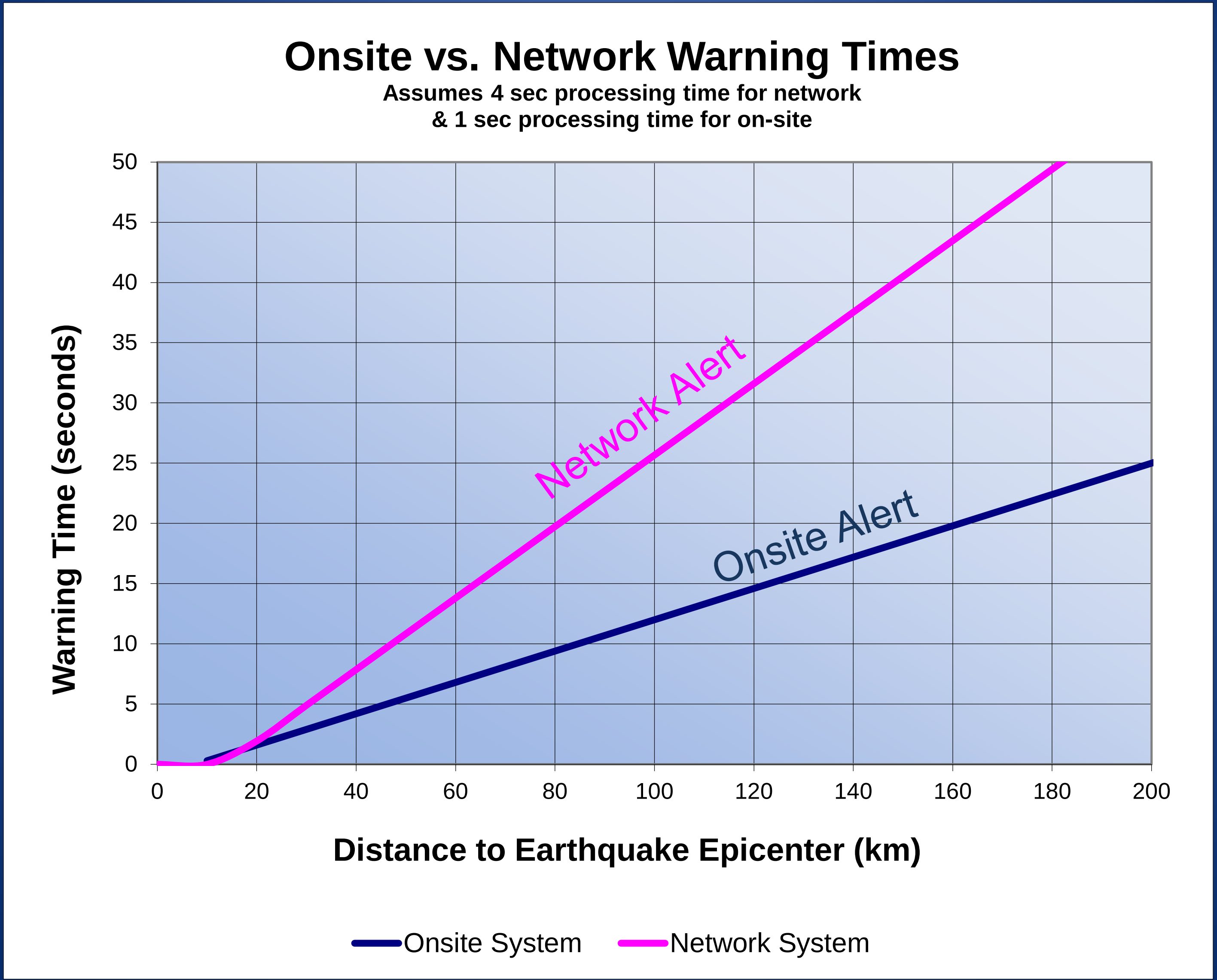
Onsite Alert



Network Alert

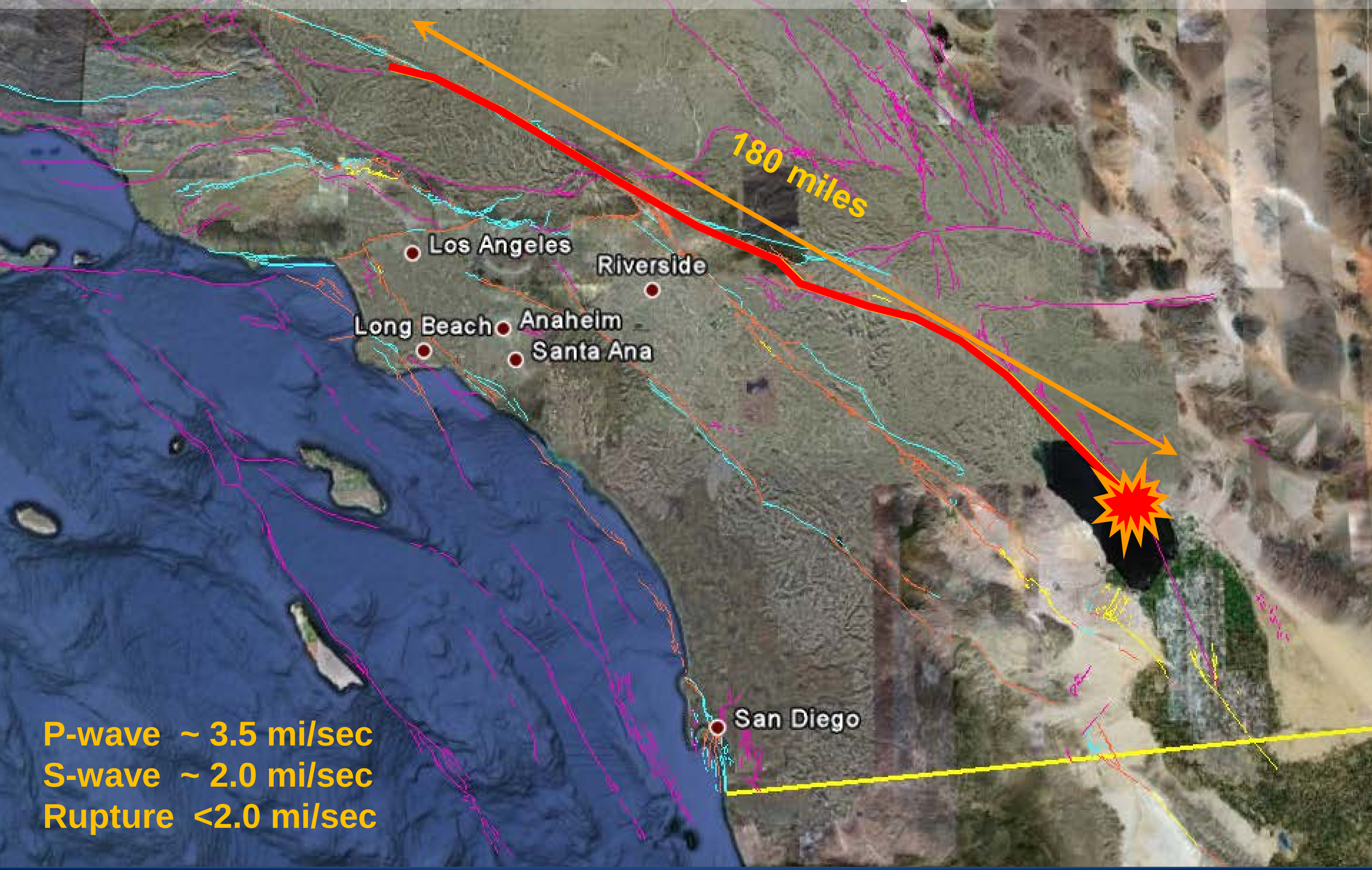
Warning Time

Network alerts give most users more time

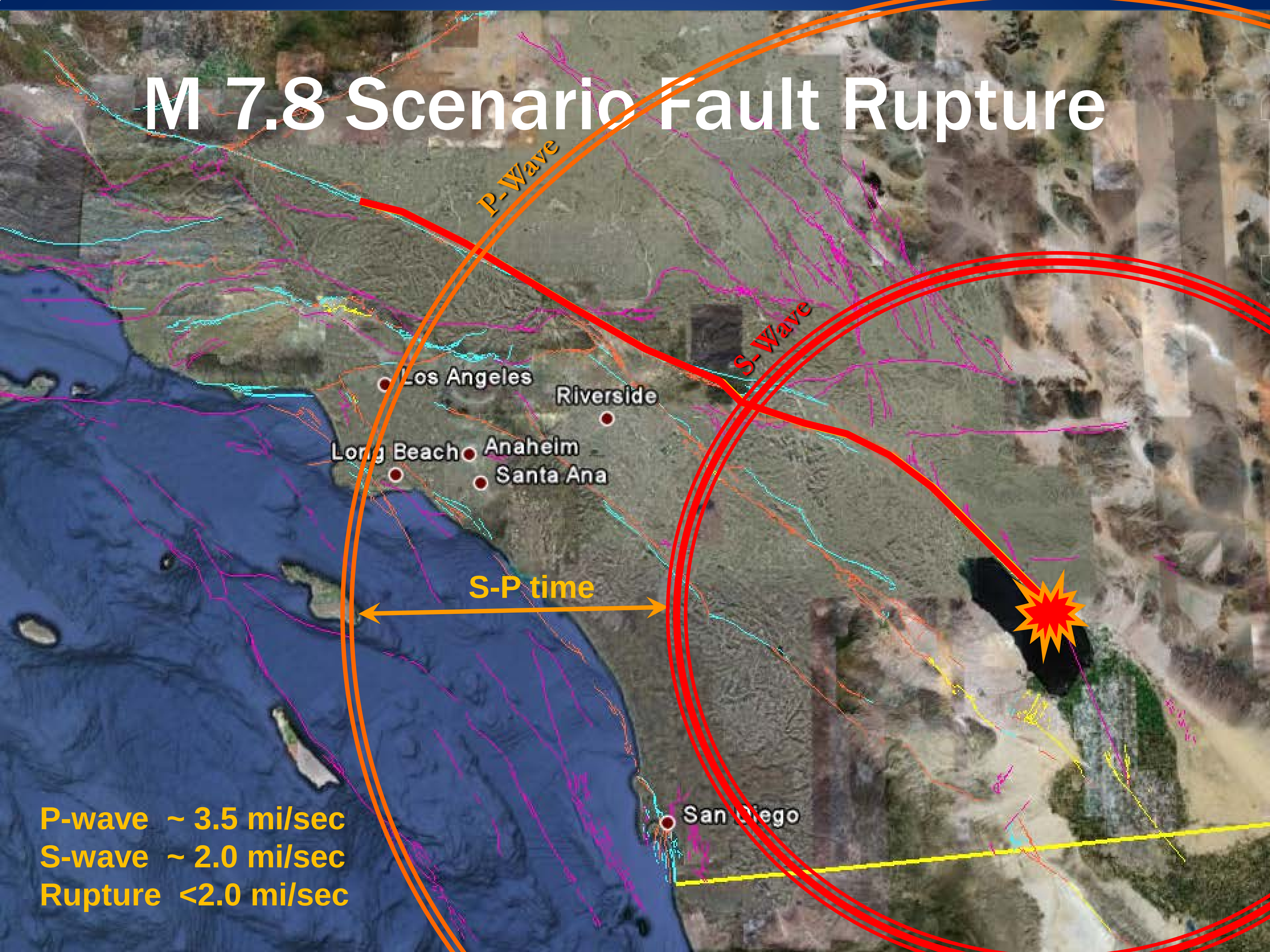


Big Earthquakes are on Long Faults

M 7.8 Scenario Fault Rupture

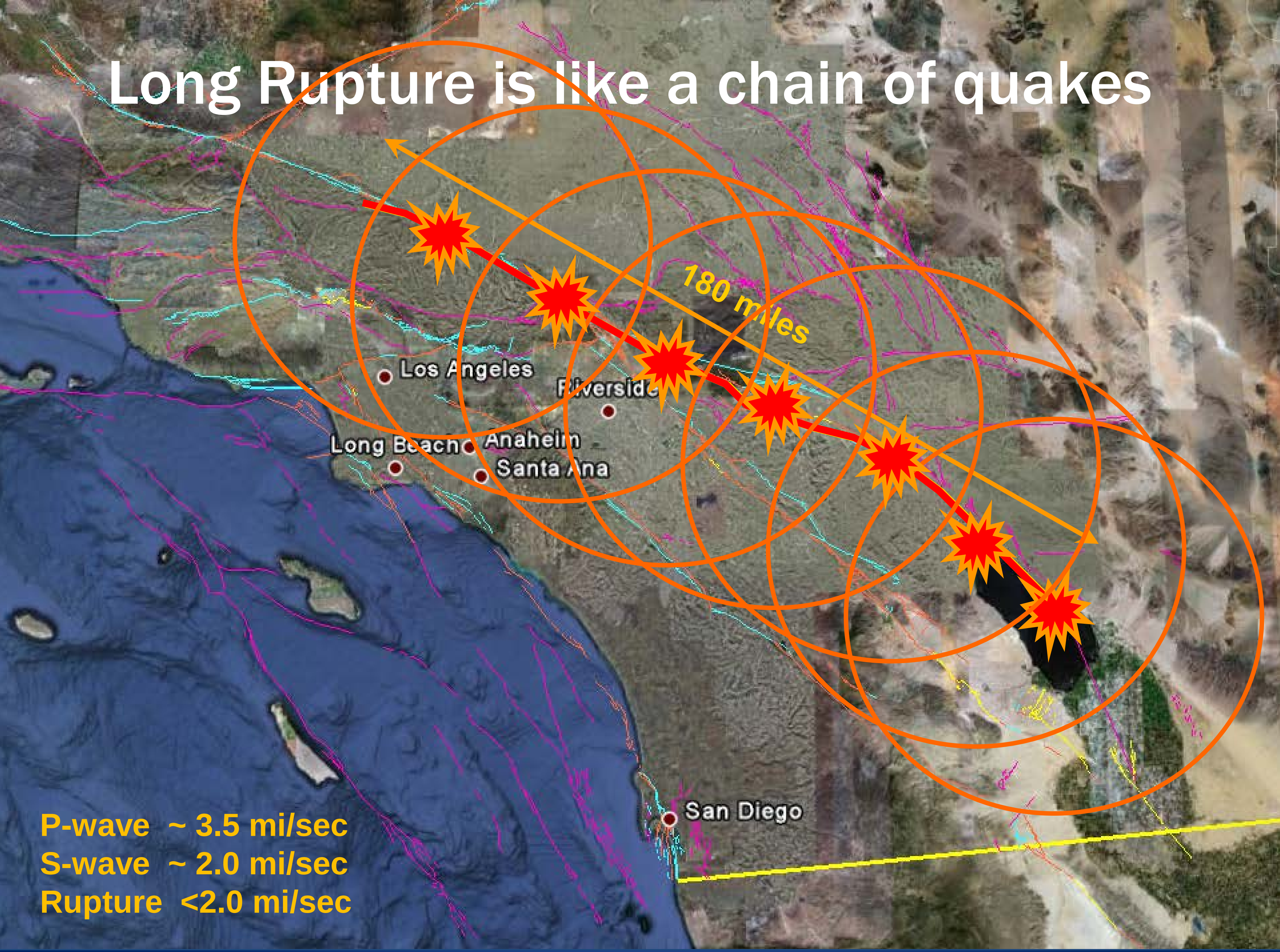


P-wave ~ 3.5 mi/sec
S-wave ~ 2.0 mi/sec
Rupture <2.0 mi/sec



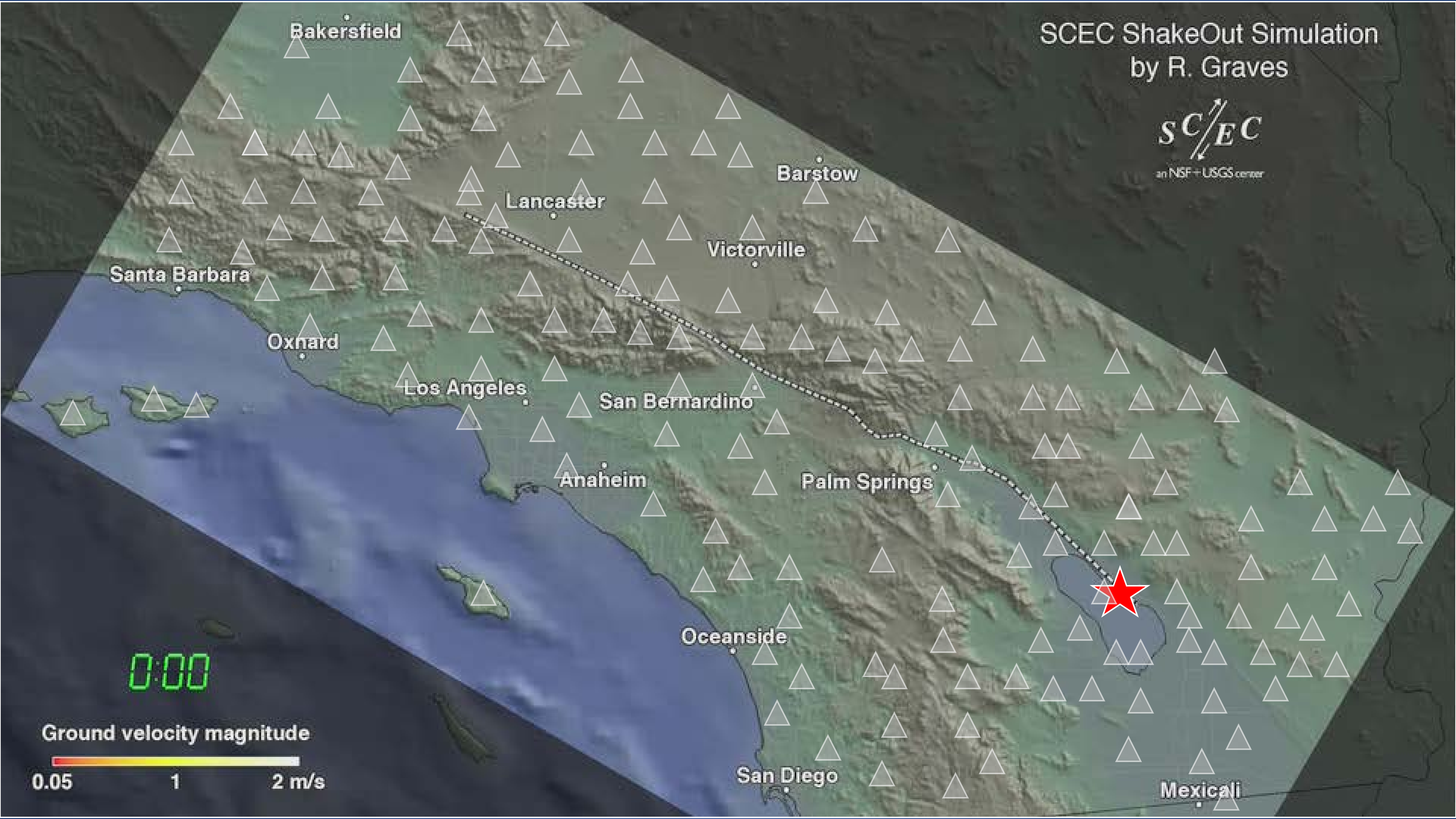
M 7.8 Scenario Fault Rupture
P-Wave
S-Wave
Los Angeles
Riverside
Long Beach
Anaheim
Santa Ana
S-P time
San Diego
P-wave ~ 3.5 mi/sec
S-wave ~ 2.0 mi/sec
Rupture <2.0 mi/sec

Long Rupture is like a chain of quakes



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

Earthquake Begins



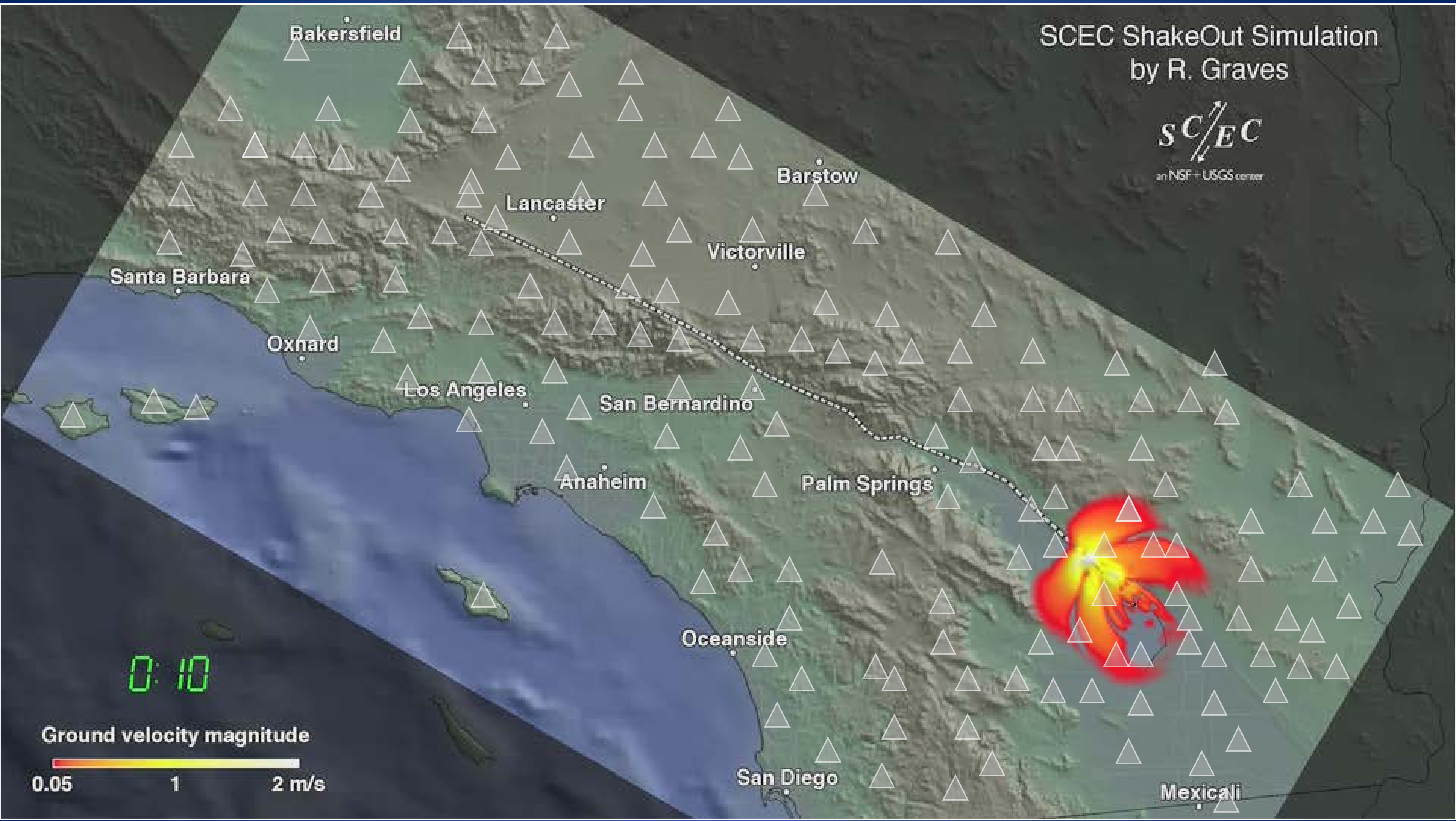
M7.8 SoSAFZ Scenario

Stations Sense Shaking

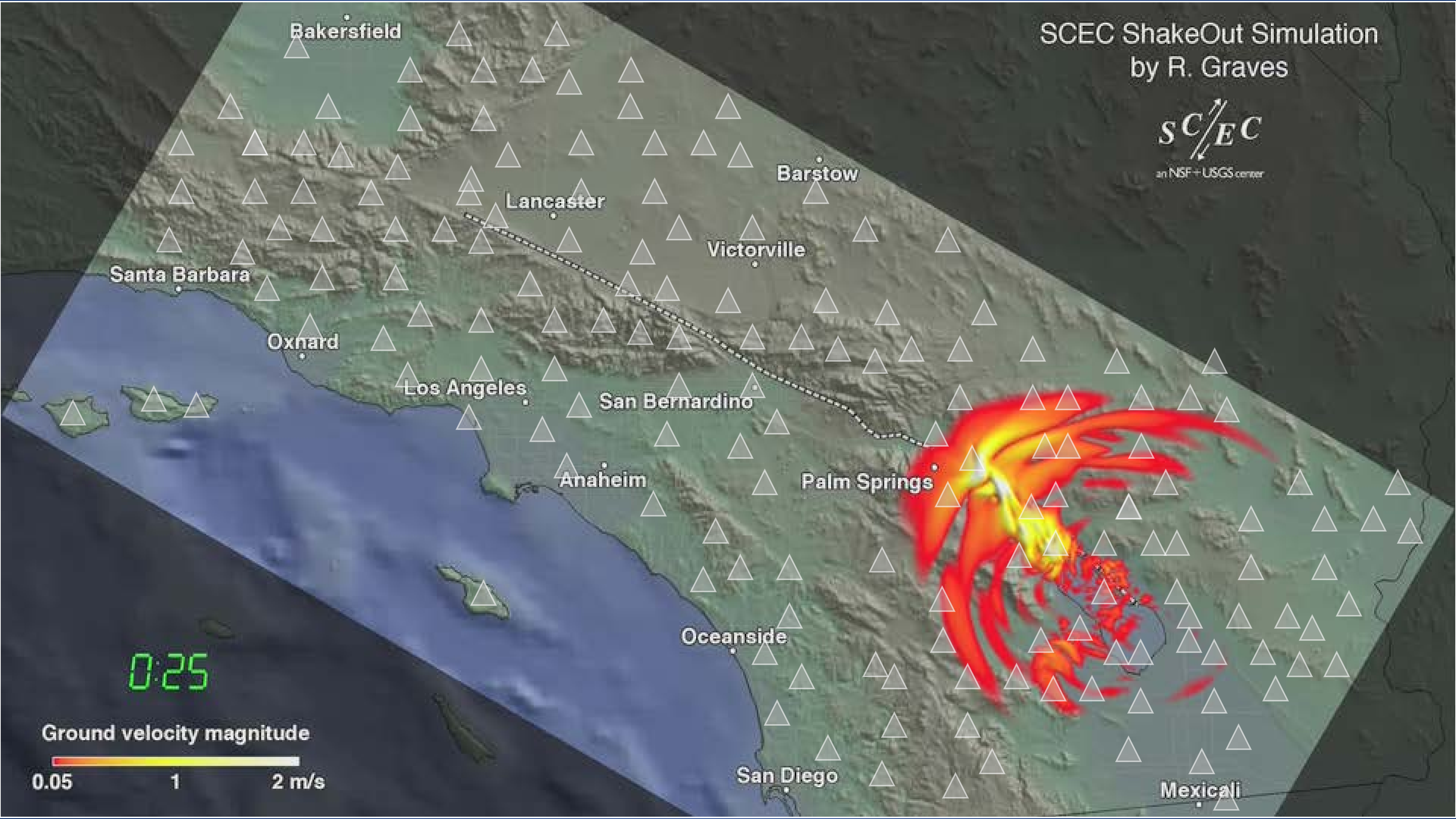
ShakeAlert Detects Event – Issues Alert

Size of "blind zone" depends on stations spacing and system speed.

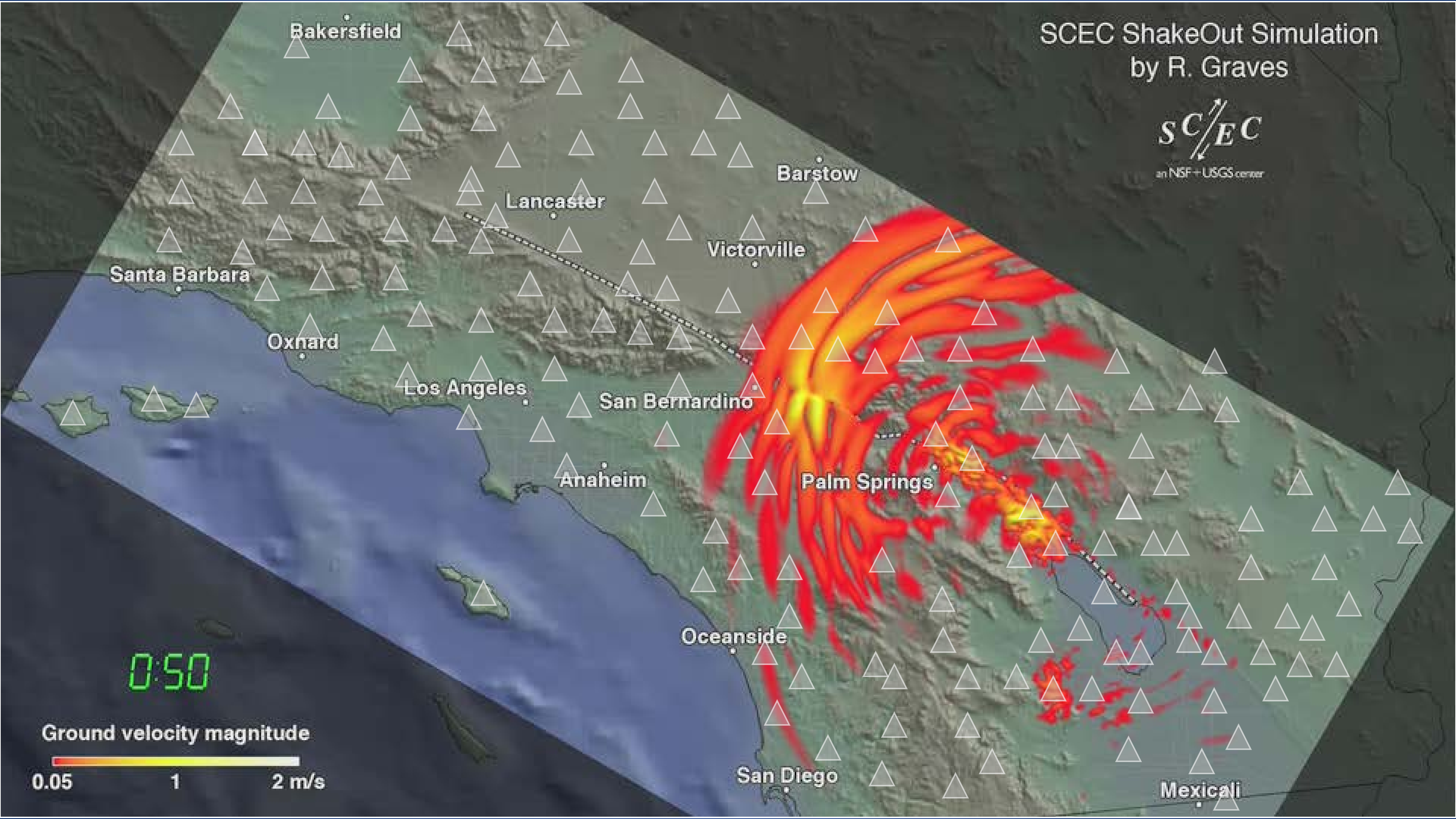
Rupture Moves Up Fault



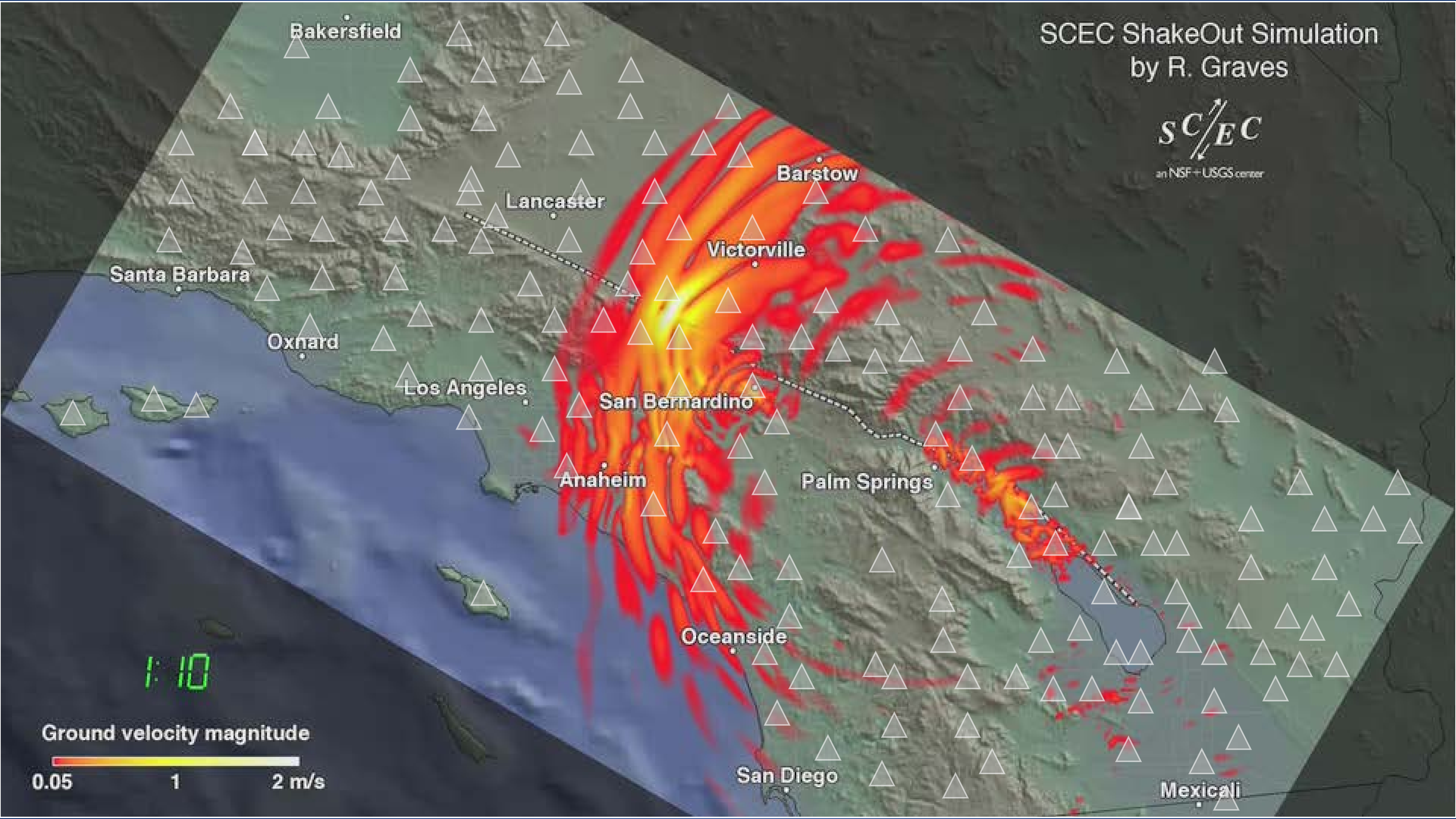
Strong Shaking Arrives – Palm Springs



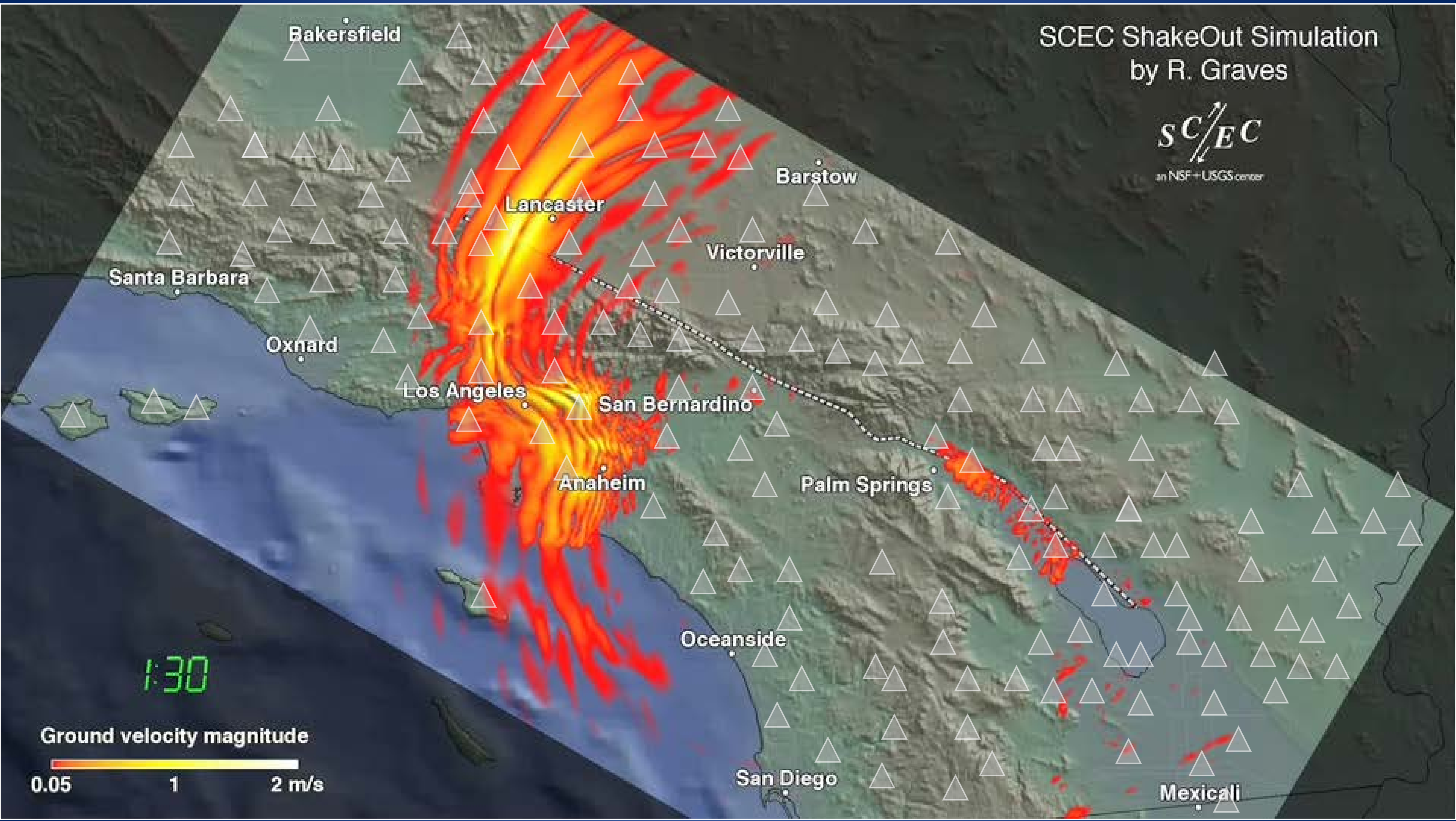
Strong Shaking Arrives – San Bernardino



Strong Shaking Arrives – Orange Co.

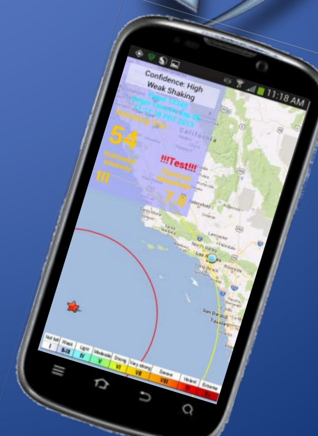


Strong Shaking Arrives – Los Angeles



ShakeAlert: Major System Components

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



ShakeAlert is built on CISN

(California Integrated Seismic Network)

- Leverages…
  - Stations
  - Telecommunications
  - Hardened centers
  - Software (EW, AQMS)
  - Expertise
  - Partnerships
  - Management structures

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

Ground Motion Sensors

CISN will:

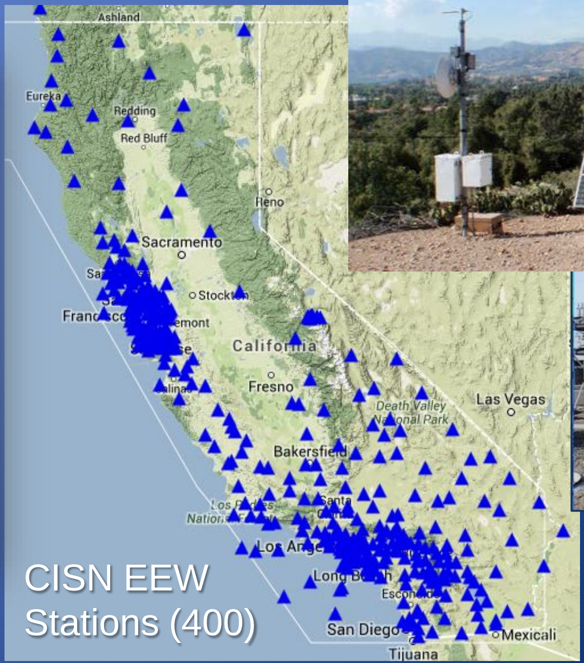
- Add & upgrade stations
- Both seismic & RT-GPS
- Optimum spacing ~20km

Partners can:

- Host CISN sensors
- Buy & install their sensors
- Provide data to ShakeAlert

CISN Stations needed for EEW in California

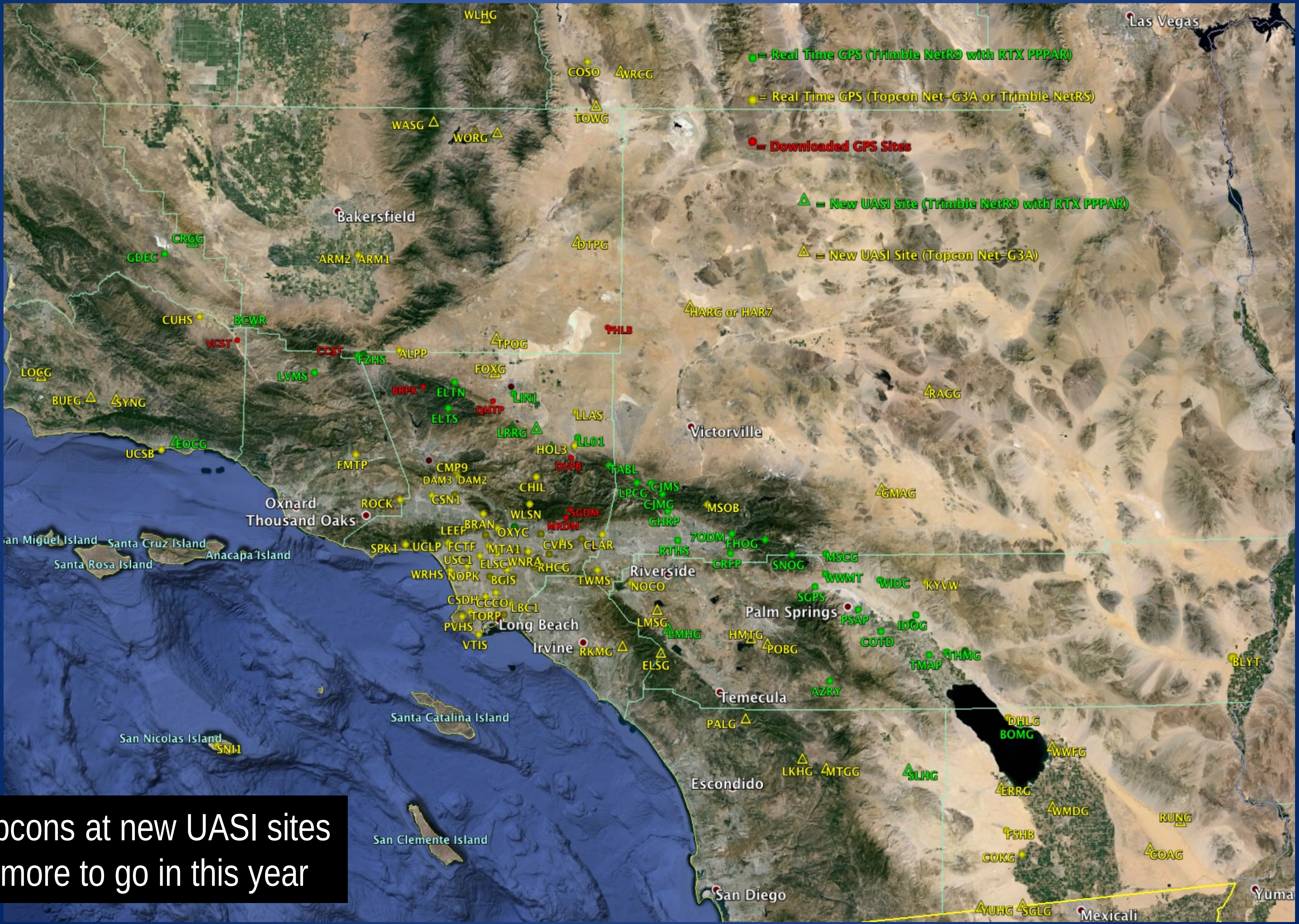
	No Cal	So Cal	Total
Stations currently contributing to EEW	**400**		**400**
Stations to be Upgraded or Installed			
Class A: Seismic equipment (ANSS station, BB+SM)	*100*	*25*	*125*
Class B: Seismic equipment (Strong motion only)	*239*	*75*	*314*
Total: New/upgraded	**339**	**100**	**439**
Station needing telemetry	**99**	**177**	**276**
Total: Stations to be added	**438**	**277**	**715**
Final station count: current + planned	**1,115**		**1,115**
*GPS equipment (NetR9 w/ RTX & ant.)**	*100*	*50*	***150***



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

USGS GPS Status – After UASI

(41 RTX's; of these 34 at SoSAFz 'zipper', 7 at new UASI sites)



6 Topcons at new UASI sites
26 more to go in this year

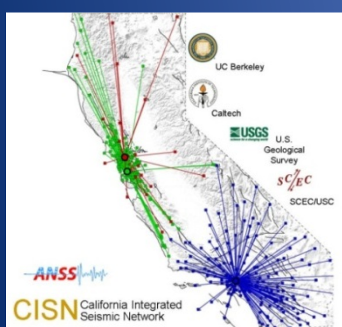
Network Telecommunications

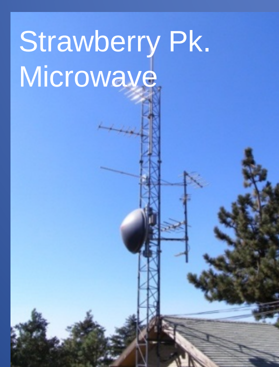
CISN

- Diverse Telecomm Strategy
  - Cellular (multiple carriers)
  - DSL, cable
  - IP Radio
  - Digital microwave
  - Satellite
  - Public Internet
  - Partner systems

Partners

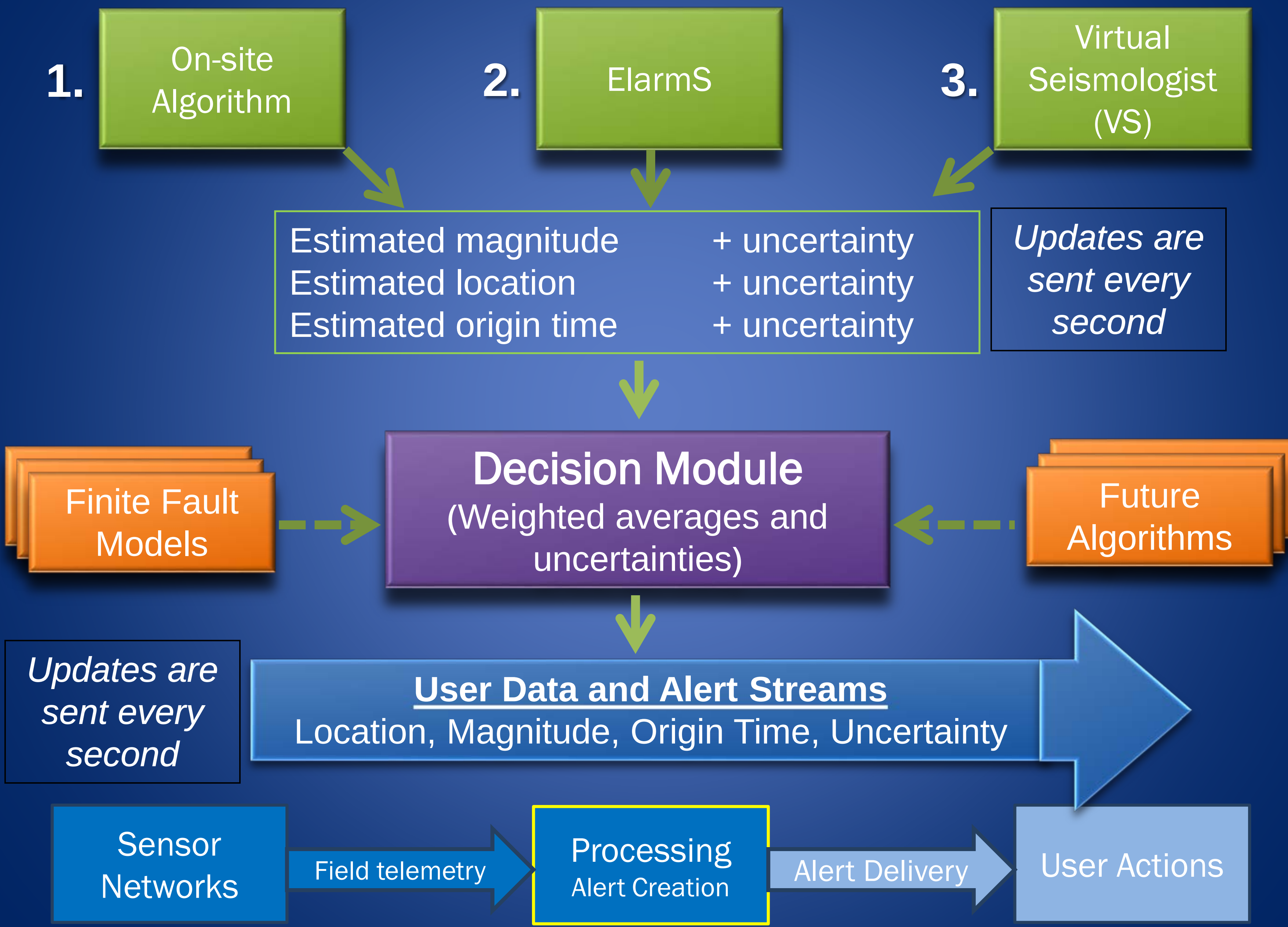
- Provide data telecomm from field sensors
- Provide locations for CISN telecomm





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

ShakeAlert System Data Architecture



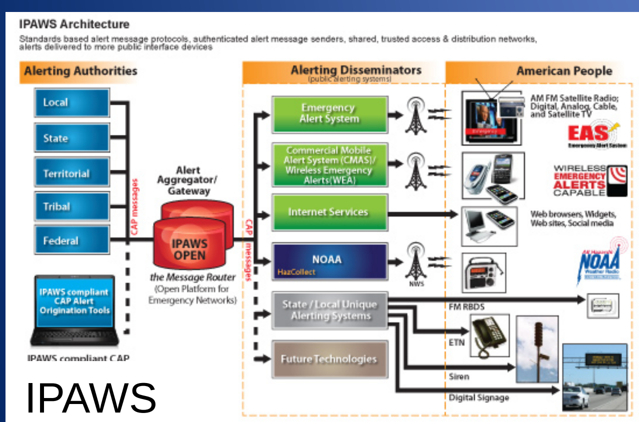
Alert Delivery

CISN

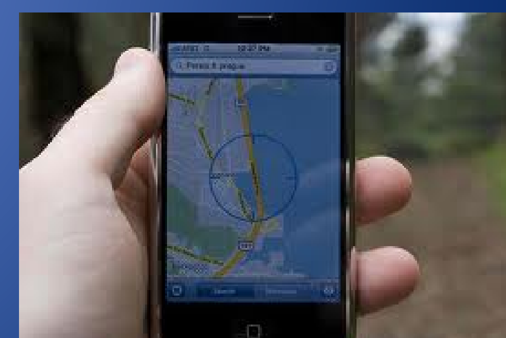
- Create and send alert and data streams
- Data services (servers, cloud)
- IPAWS alert authority
  - TV, radio, WEA, FIA, etc.

Partners

- Mass notification integration
- FM radio, VSAT, push, pubsub
- New EEW products
- Smartphone Apps
- Social media, etc.



IPAWS



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

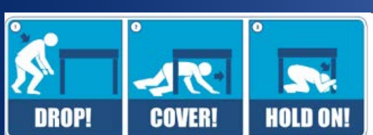
Two User Categories

<u>People</u> (the public)

- CISN will coordinate:
  - Social Science R&D
  - Alert content, sounds
  - Ongoing education
  - Messaging, “branding”

<u>Things</u> (automated)

- CISN will foster private:
  - Automated actions
  - Situational decision-making capabilities
  - User-specific applications



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

Current ShakeAlert Beta Users

- Amgen*
- Bay Area Rapid Transit (BART)
- Boyd Gaming , Las Vegas, NV*
- Cal OES, Warning Center
- Caltrans (8 traffic mgmt. centers)
- Caltech Safety/Security
- Disneyland*
- Google.org (crisis response)*
- Los Angeles City, EMD, Police, Fire
- Los Angeles Co. OEM, Sheriff, Fire
- Los Angeles Metro
- Los Angeles Unified School District
- Long Beach EOC, Fire, PD, Waste, Trans.
- Long Beach Airport

- Metrolink (dispatch)
- Metropolitan Water District
- Ontario City EOC
- Port of Long Beach
- Riverside County OEM/Fire
- San Bernardino OEC/Fire
- San Francisco DEM
- Southern California Edison*
- UC Berkeley OEP
- Universal Studios / NBC*
- US Digital Designs, Inc.*

- CRADA's with:
  - Global Security Systems*
  - Early Warning Labs*
  - More to come…

*** Private company**

ShakeAlert Performance

Speed and Accuracy

La Habra quake:

M 5.1, March 28, 2014. 9:09 pm PDT

ShakeAlert Timeline

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

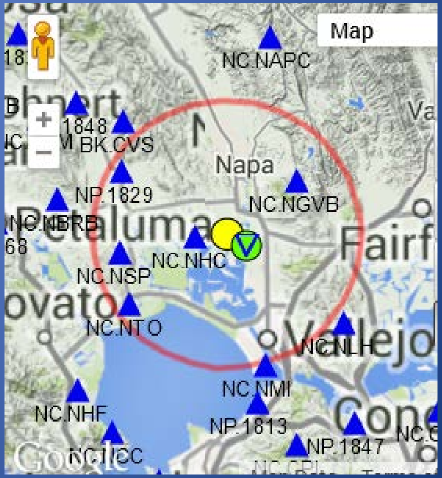
- Upgraded stations would be faster
- 4 stations required for alert
- Size of "zone of no warning" depends on # stations required to alert

South Napa quake:

M 6.0, Aug. 24th, 2014. 3:20am PDT

ShakeAlert Timeline

10:20:44.4		Origin time
10:20:49.5	**(+5.1s)**	1st Alert



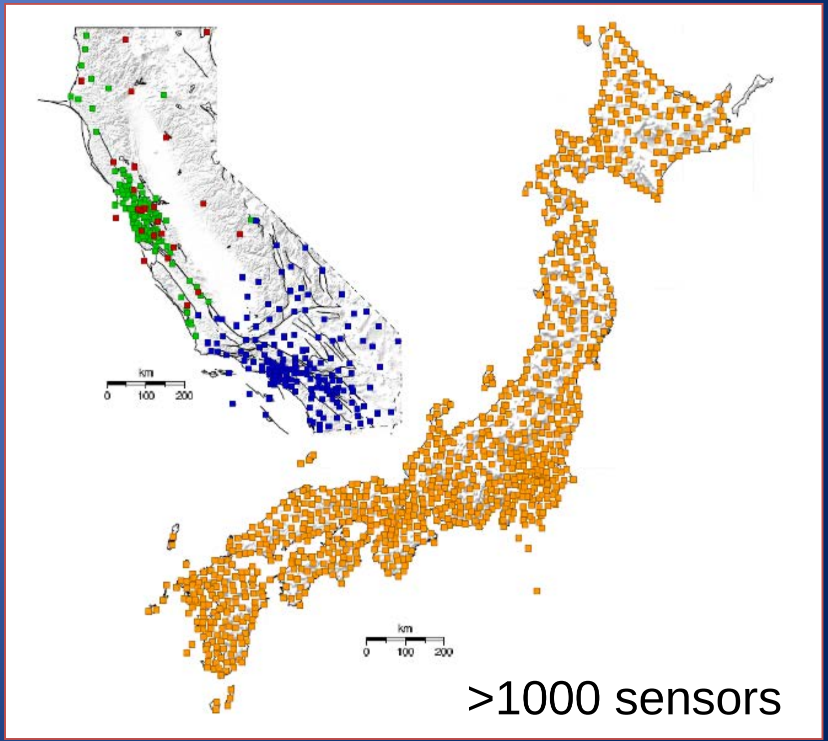
Similar performance for:

M4.4 Encino Event of March 17, 2014

M4.2 Westwood Event of June 2, 2014

Japanese EEW system

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



Thank you – any questions?

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