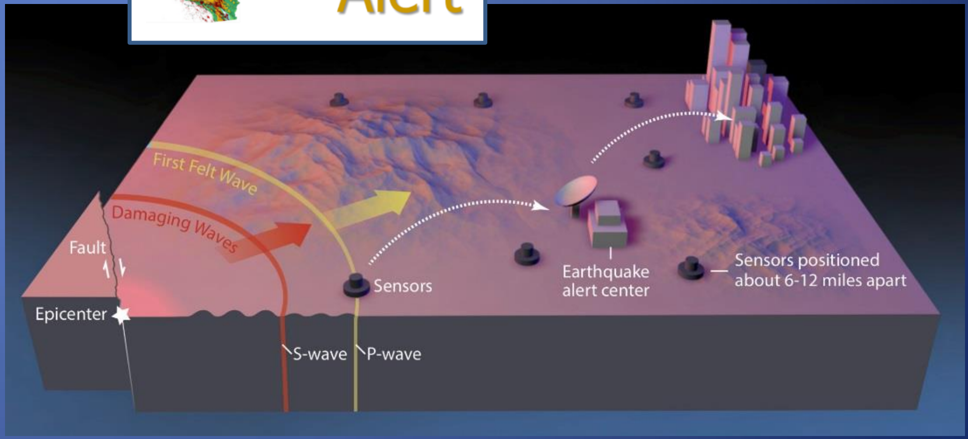
Earthquake Fault Deformation Monitoring Program with Focus on Use of GNSS

Larry Hothem
USGS

Surveying, Mapping and Geosciences Subcommittee, CGSIC
ION GNSS+, Portland, OR
25 September 2017

CISN California Integrated Seismic Network
ShakeAlert



USGS
science for a changing world
Earthquake Hazards Program

Overview

- USGS Natural Hazards Mission
- Shake Alert – Earthquake Early Warning Systems (EEWS)
  - EEWS – network based alerts
  - Major system components
- USGS Use Case for GPS/GNSS

USGS Natural Hazards Mission

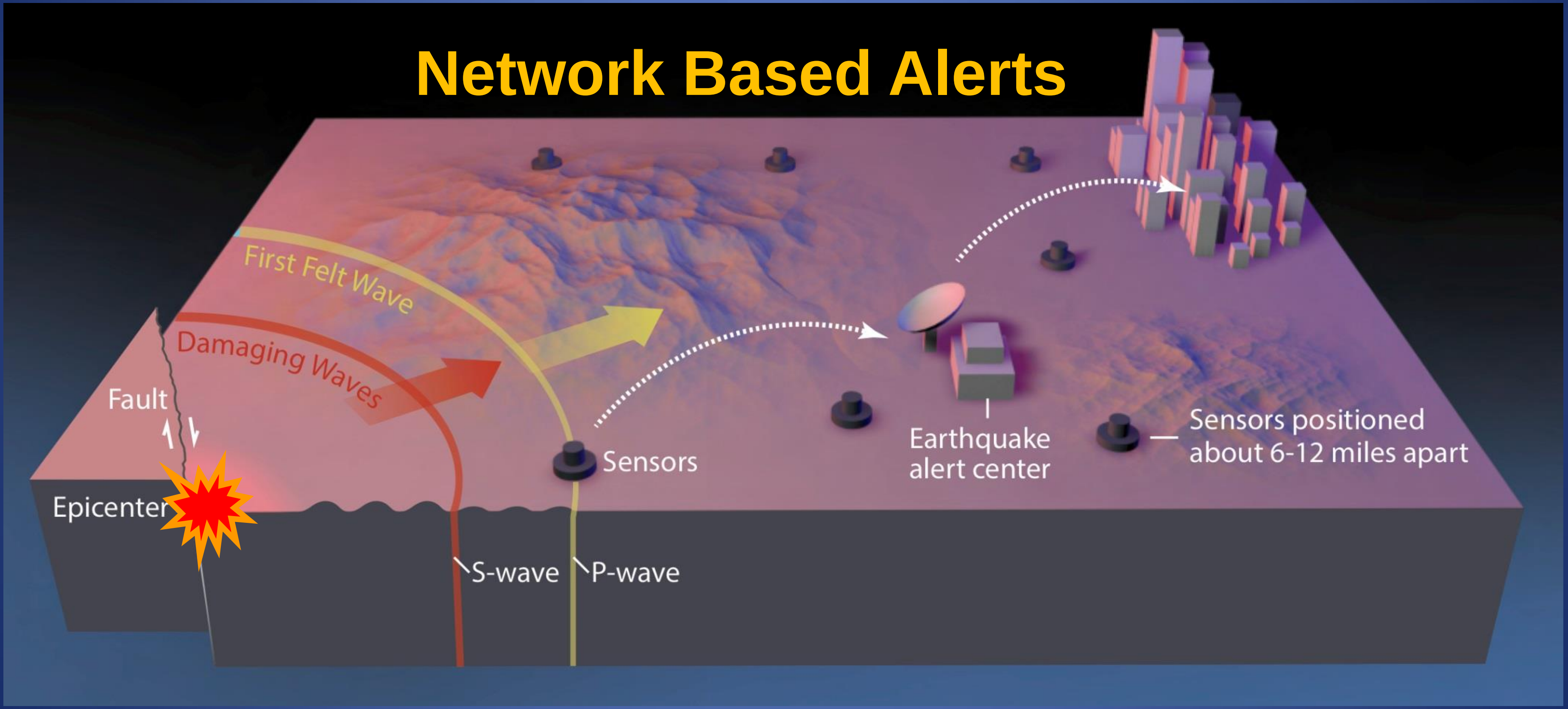
- Every year in the US, natural hazards threaten lives and livelihoods and result in billions of dollars in damage.

- The USGS works with many partners to monitor, assess, and conduct targeted research on a wide range of natural hazards.

- Major natural hazards include:
  - Earthquakes
  - Volcanoes
  - Landslides

ShakeAlert

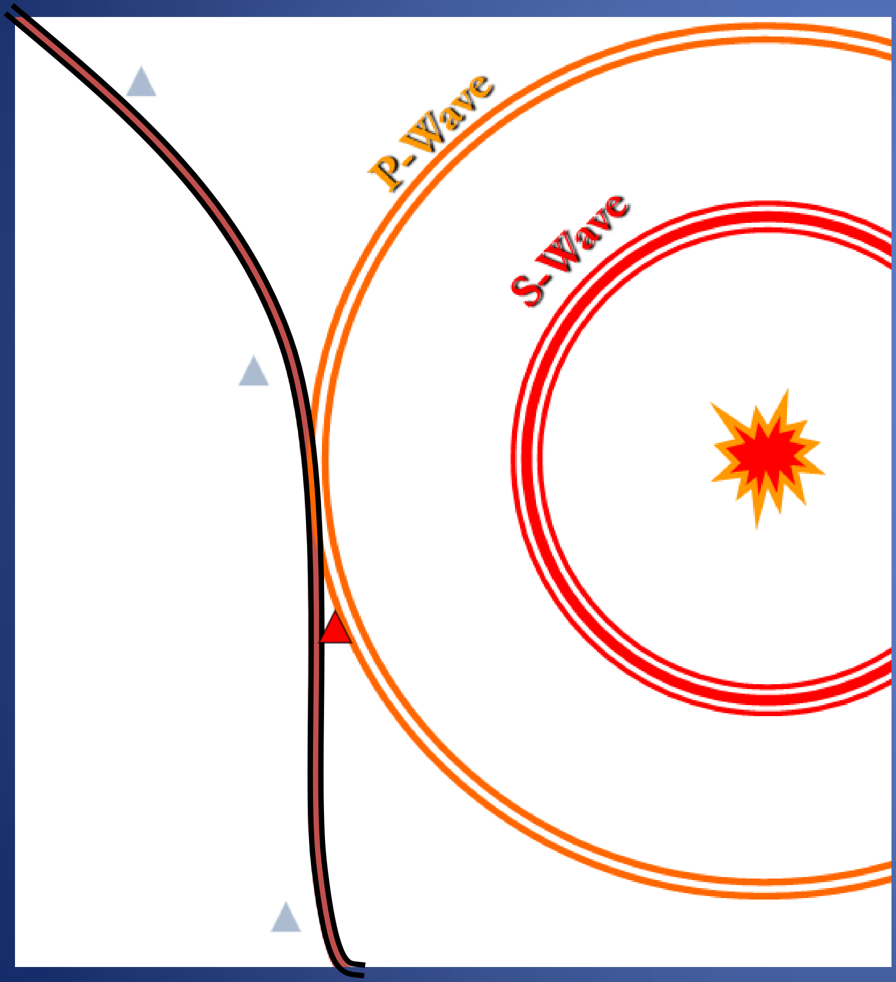
Earthquake Early Warning System



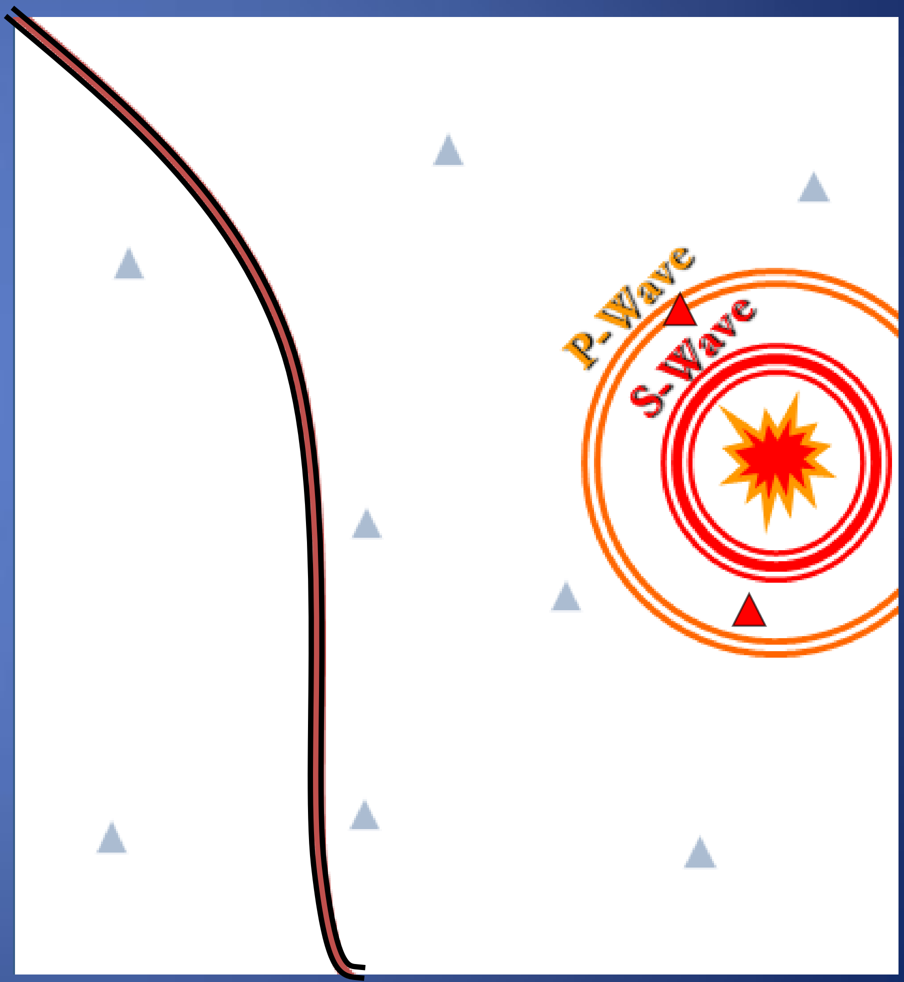
P-wave ~ 3.5 mi/sec (felt waves)
S-wave ~ 2.0 mi/sec (damaging waves)
Alert ~ 186,000 mi/sec

Regional Network Alerts

Maximize reliability for warning time



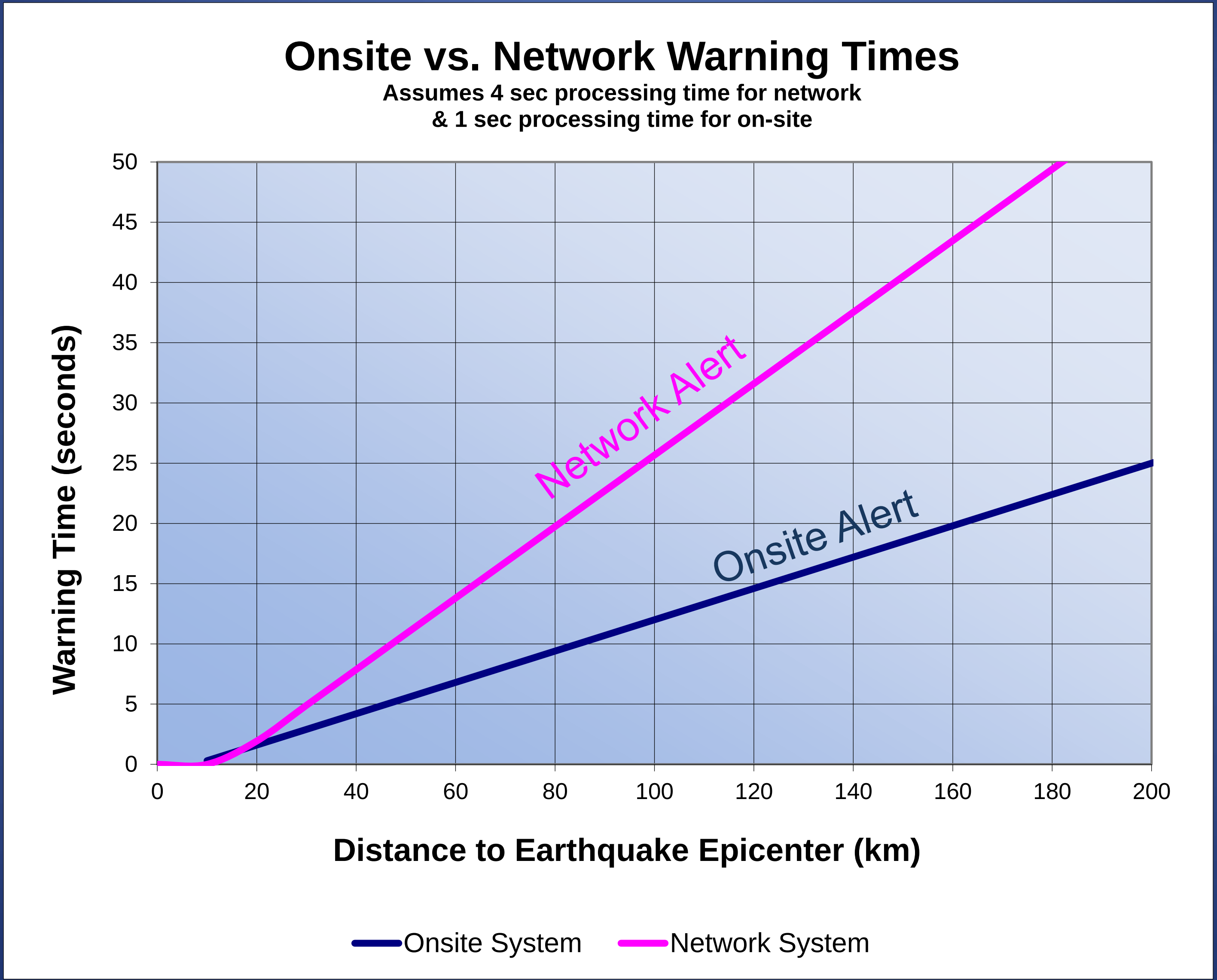
Onsite Alert



Network Alert

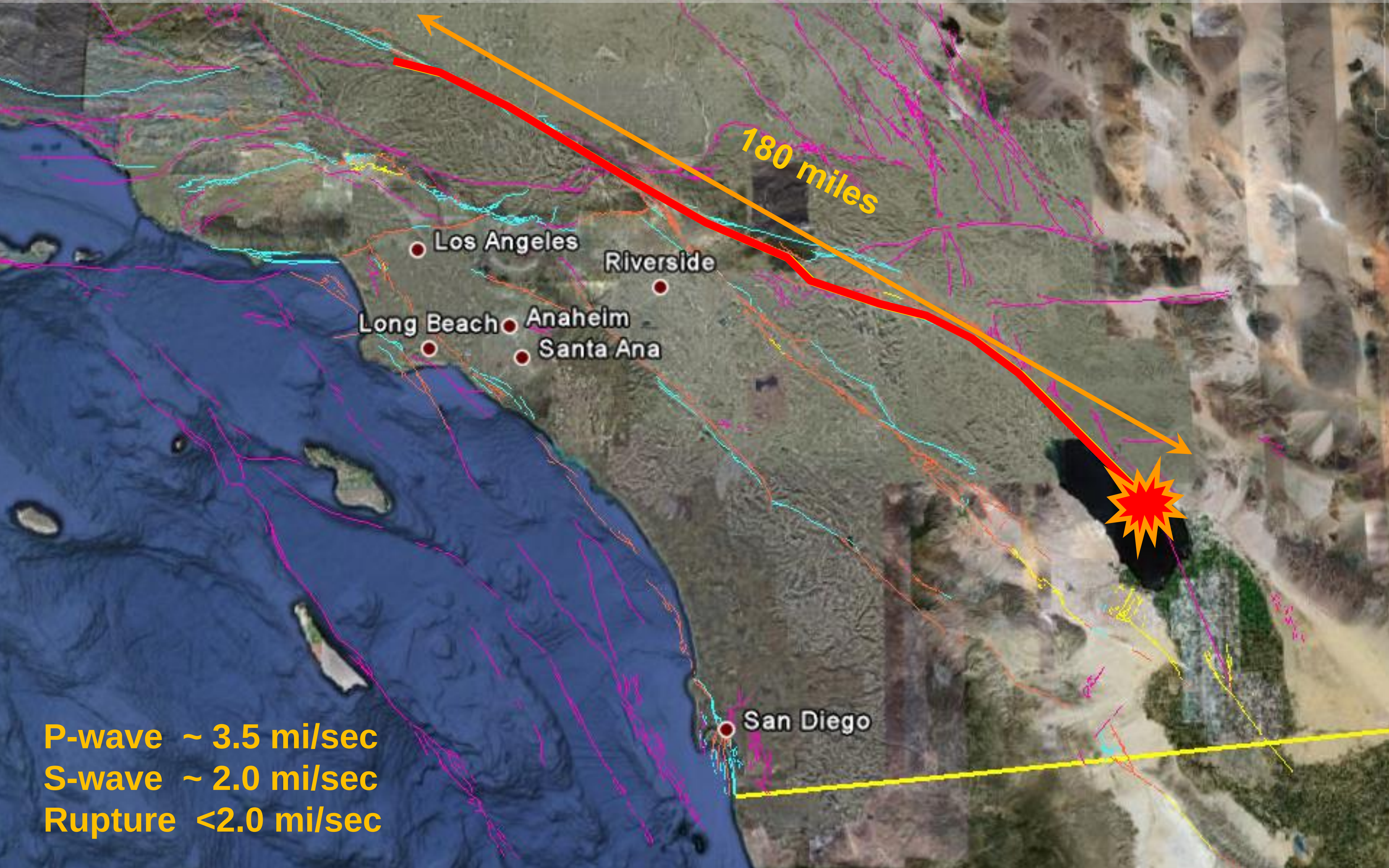
Warning Time

Network alerts give most users more time

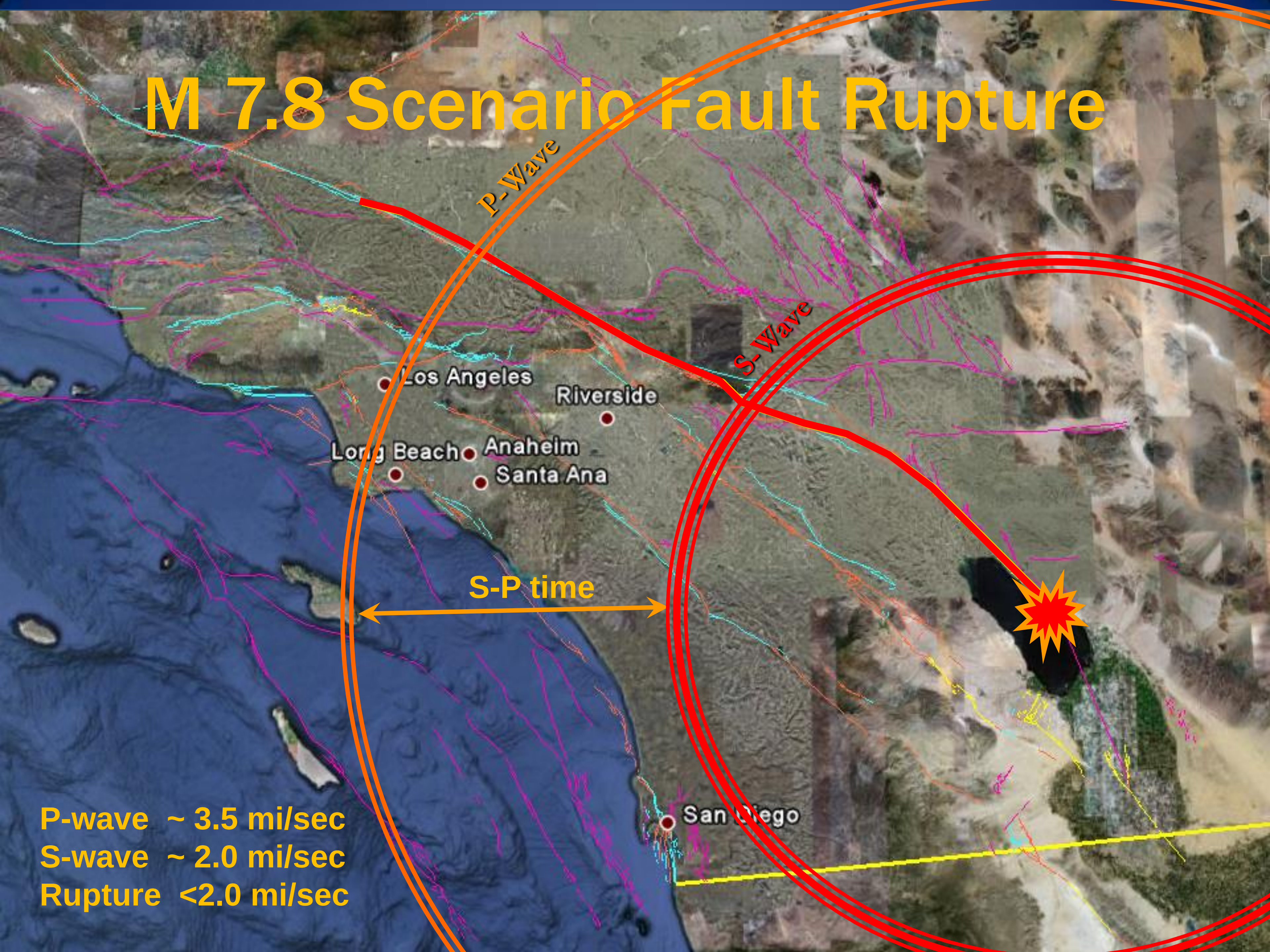


Big Earthquakes are on Long Faults

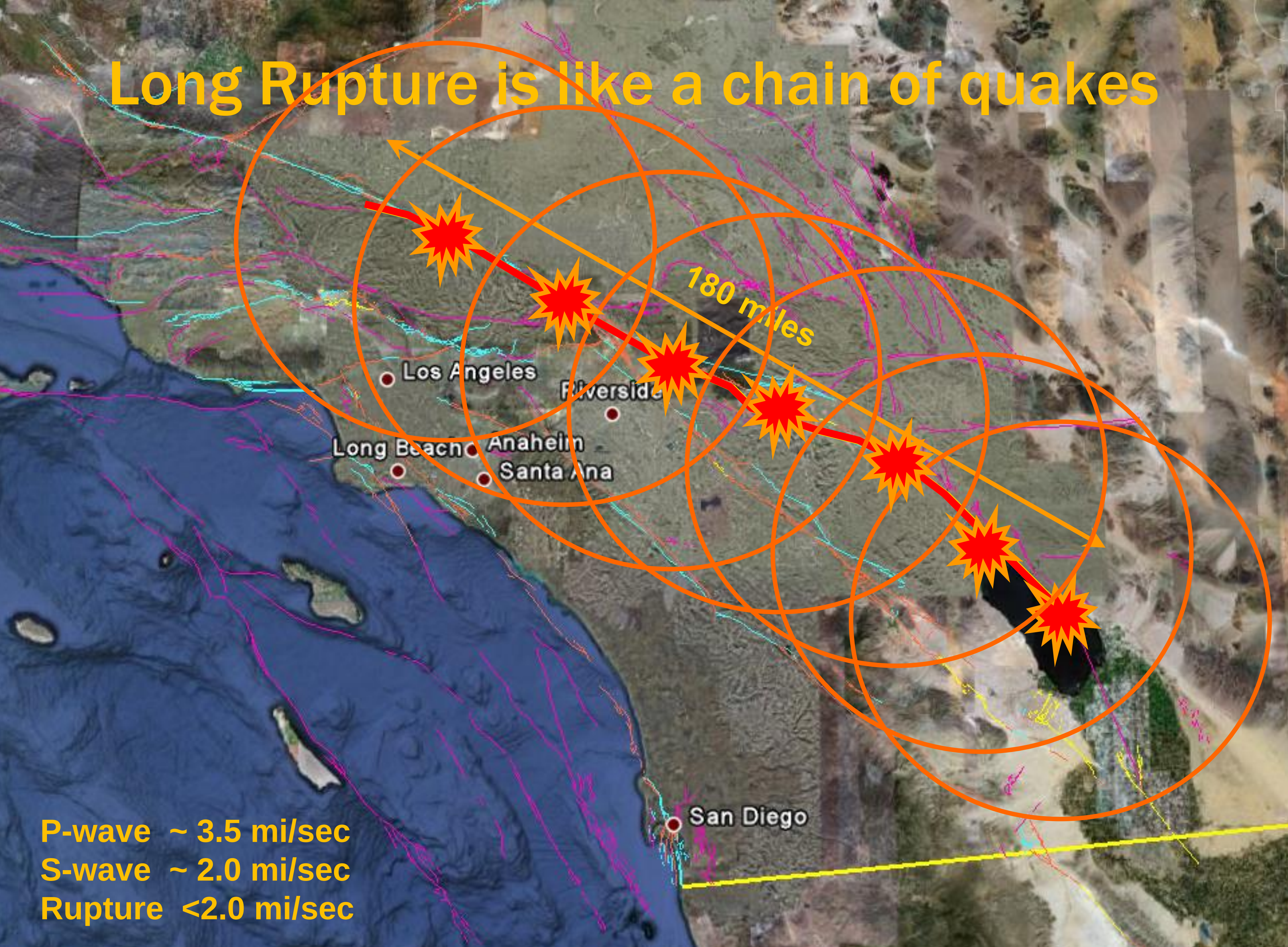
M 7.8 Scenario Fault Rupture



M 7.8 Scenario Fault Rupture



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

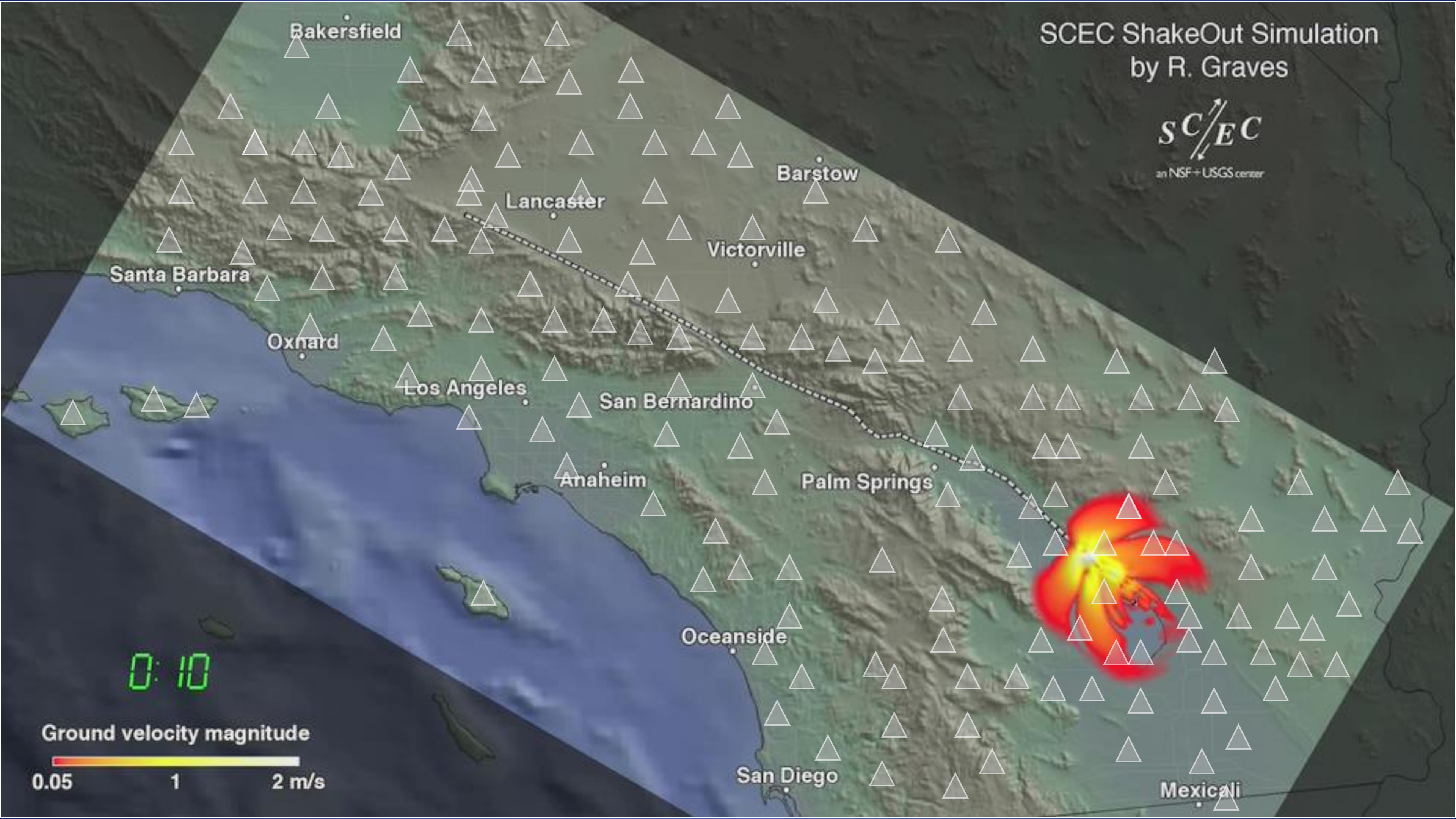
M7.8 SoSAFZ Scenario

Stations Sense Shaking

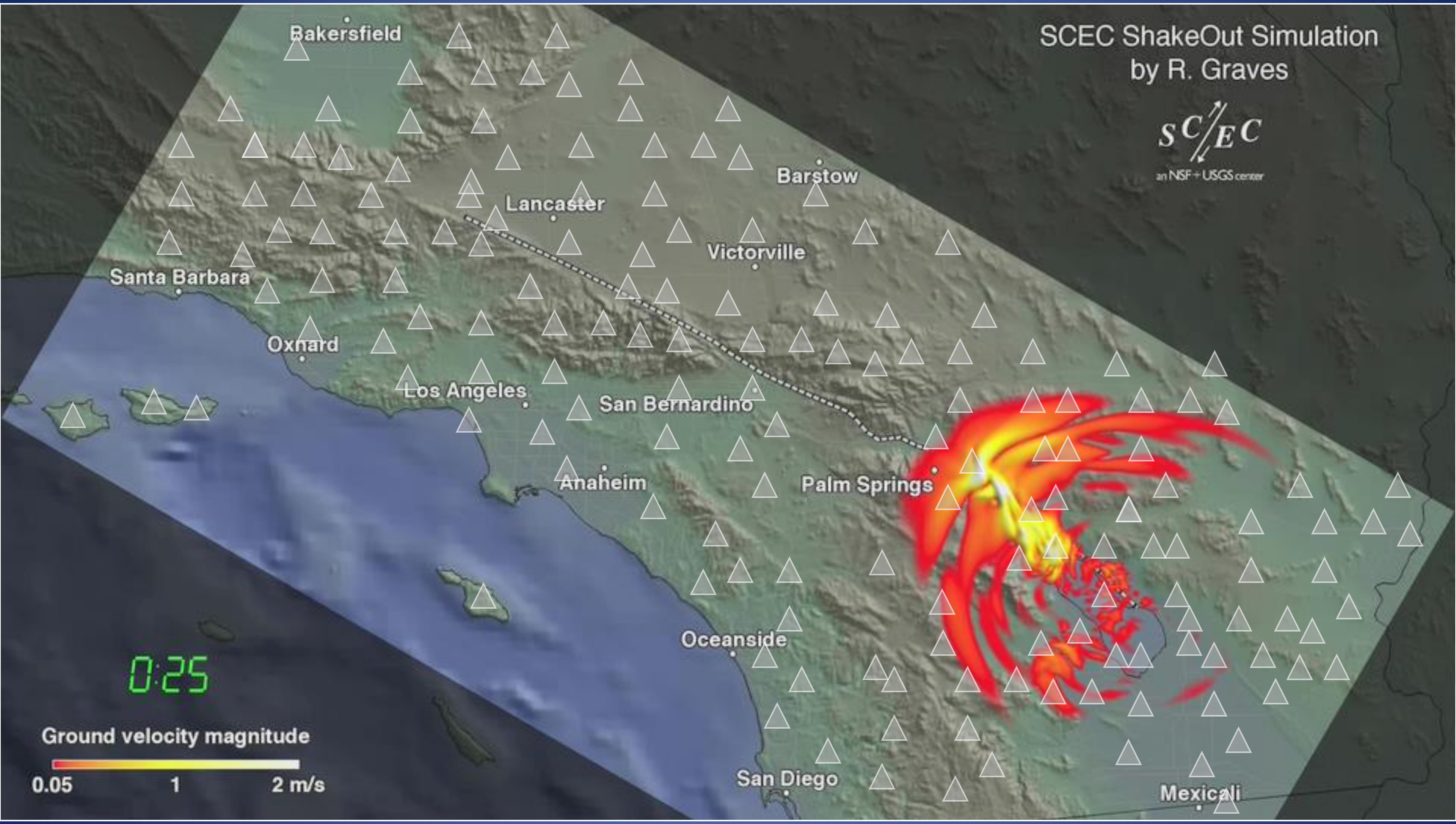
ShakeAlert Detects Event – Issues Alert

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

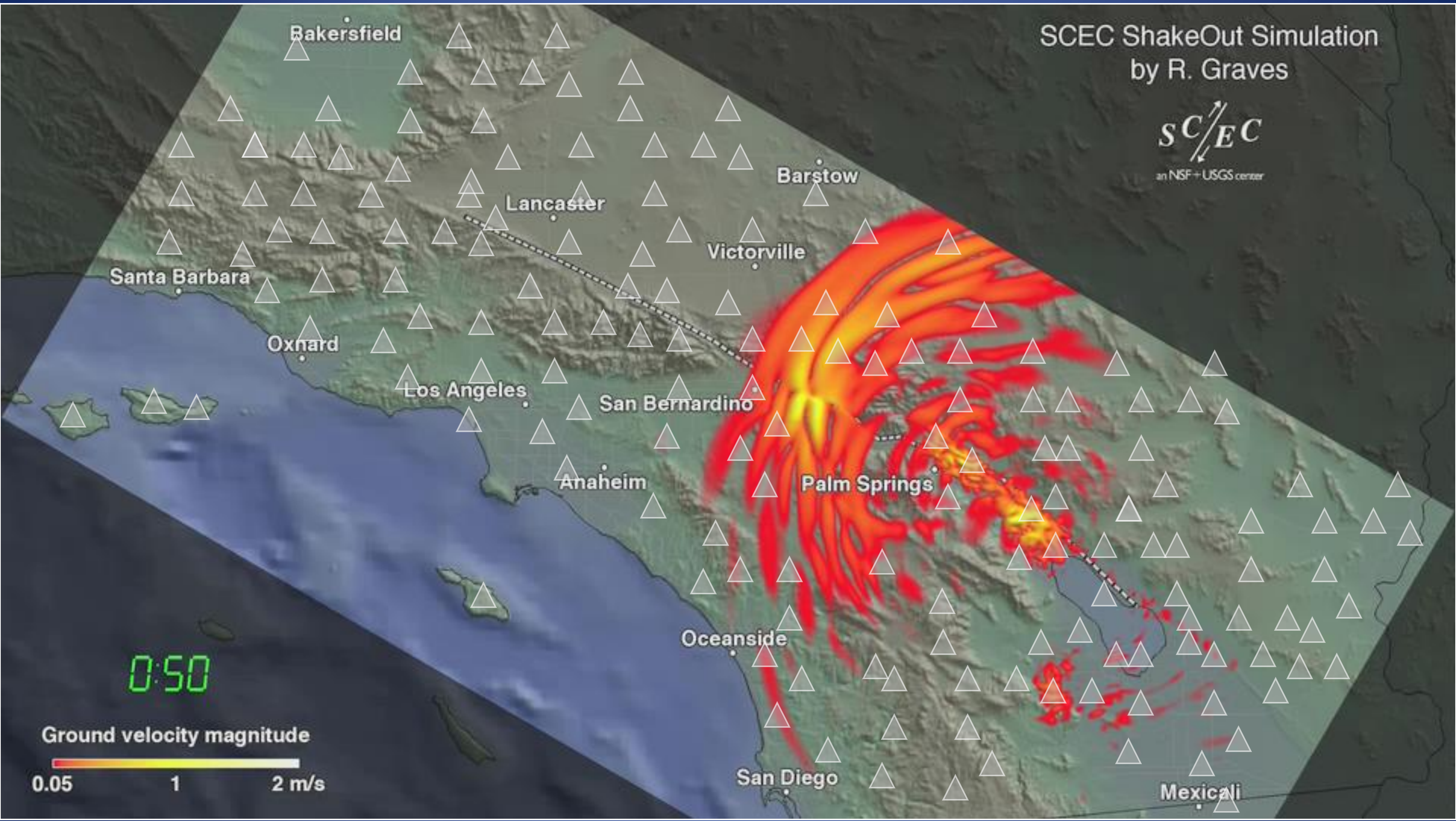
Rupture Moves Up Fault



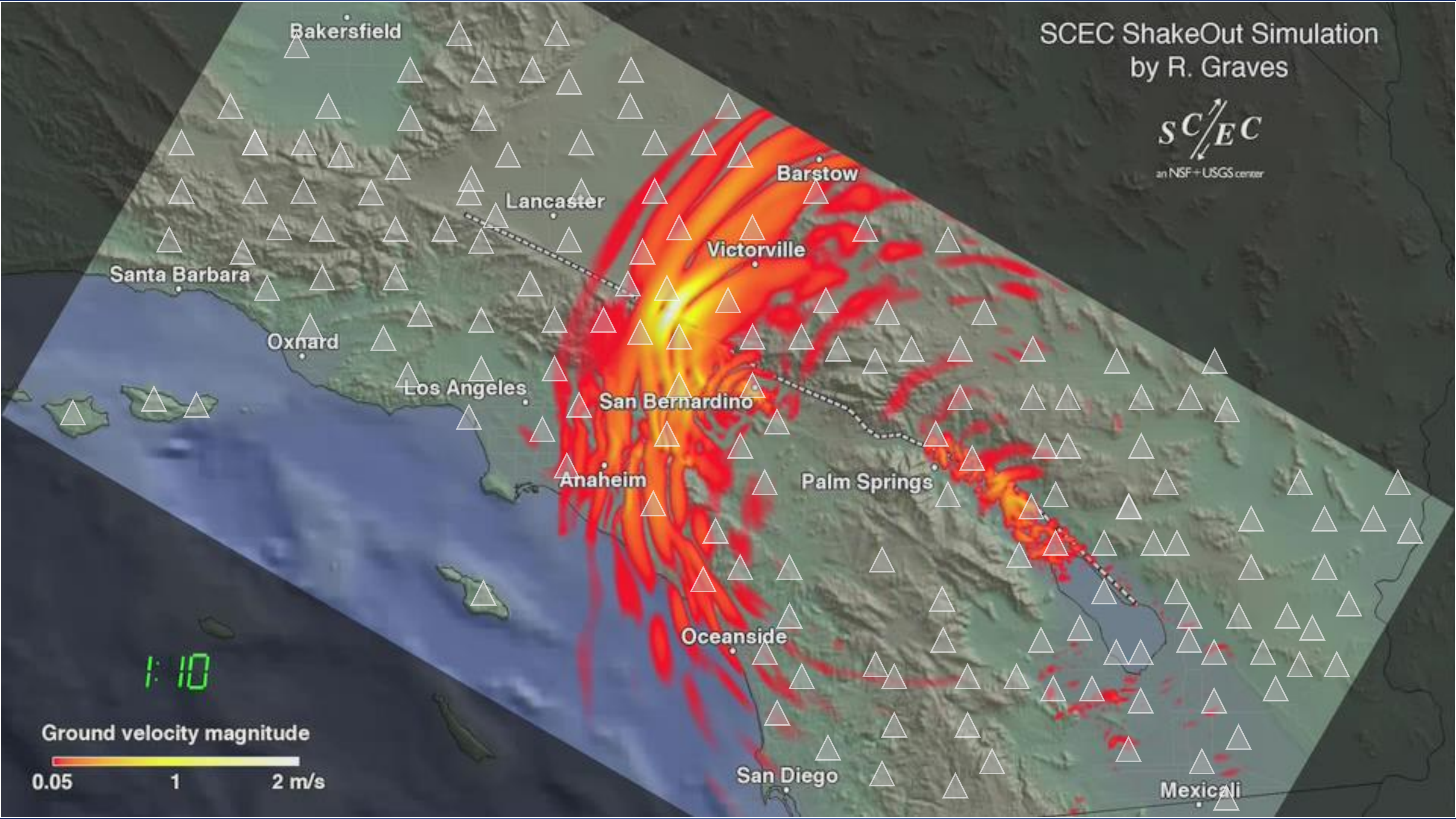
Strong Shaking Arrives – Palm Springs



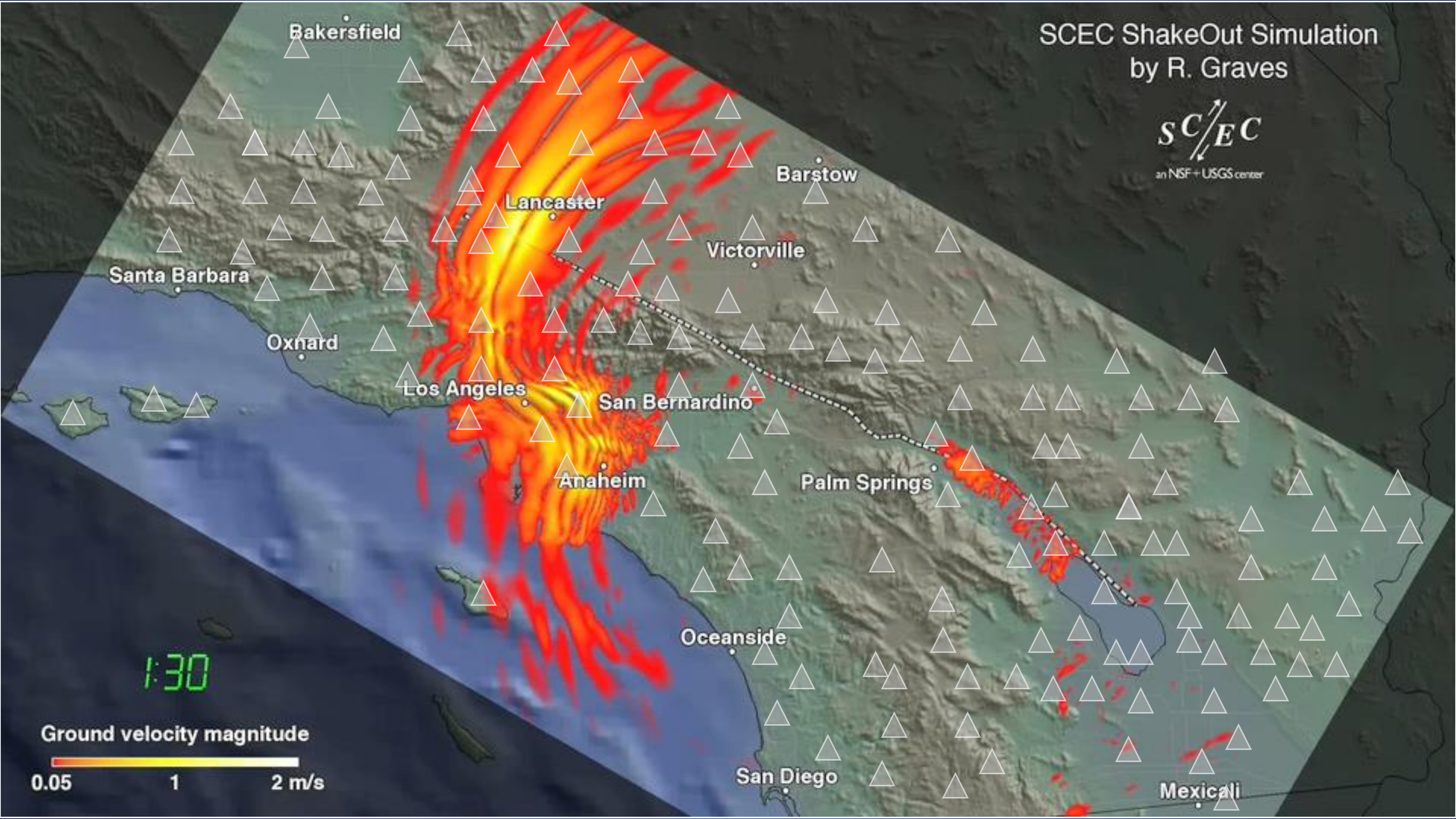
Strong Shaking Arrives – San Bernardino



Strong Shaking Arrives – Orange Co.



Strong Shaking Arrives – Los Angeles



ShakeAlert Performance

Speed and Accuracy

La Habra quake:

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

<u>ShakeAlert Timeline</u>

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

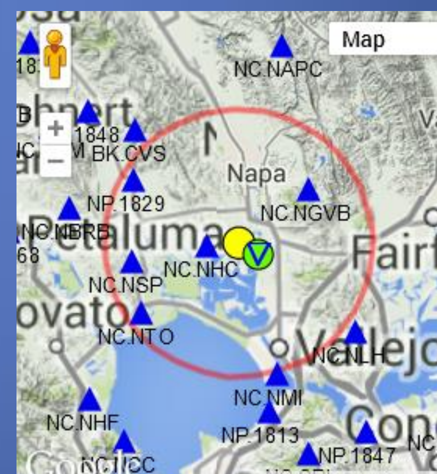
- Upgraded stations would be faster
- 4 stations required for alert
- Size of “zone of no warning” depends on # stations required to alert

South Napa quake:

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

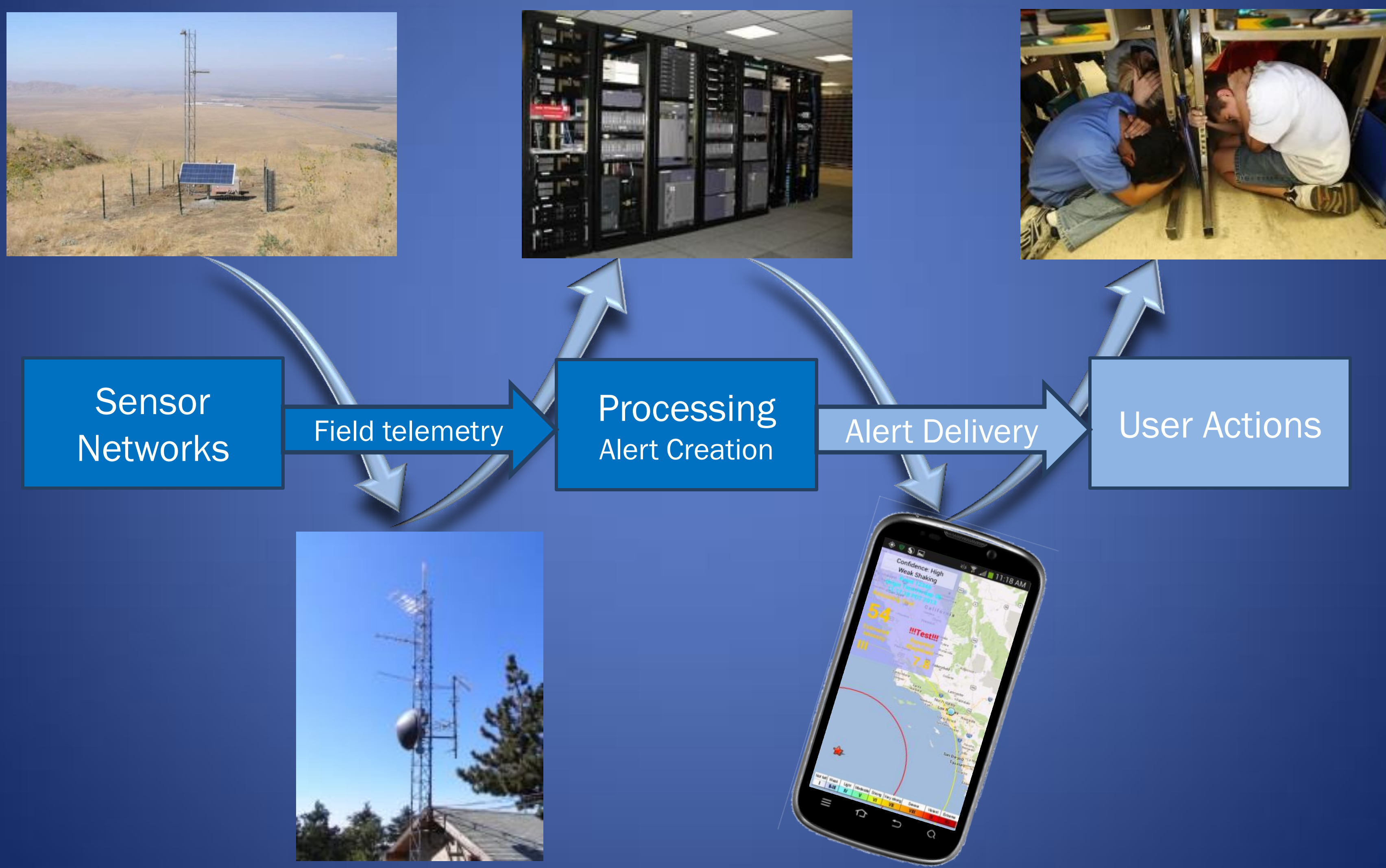
<u>ShakeAlert Timeline</u>

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

ShakeAlert: Major System Components

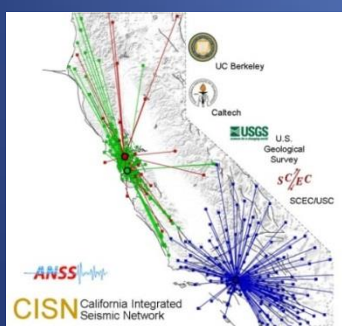


Network Telecommunications

Diverse Telecomm Strategy

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

- Data telecomm from field sensors

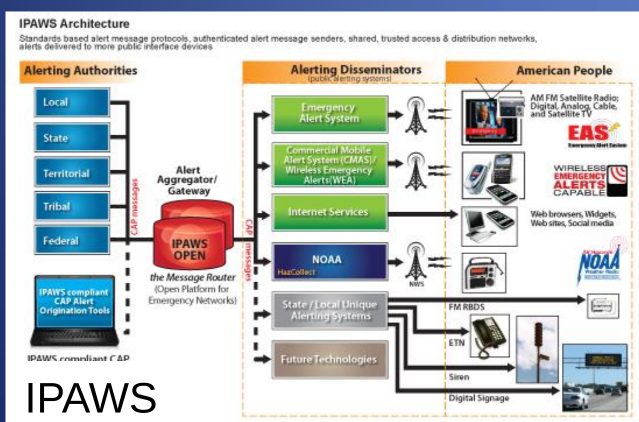


Sensor Networks → Field telemetry → Processing Alert Creation → Alert Delivery → User Actions

Alert Delivery

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

- 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

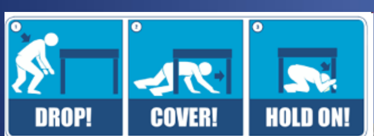
Two User Categories

People (the public)

- Social Science R&D
- Alert content, sounds
- Ongoing education
- Messaging, "branding"

Things (automated)

- Automated actions
- Situational decision-making capabilities
- User-specific applications



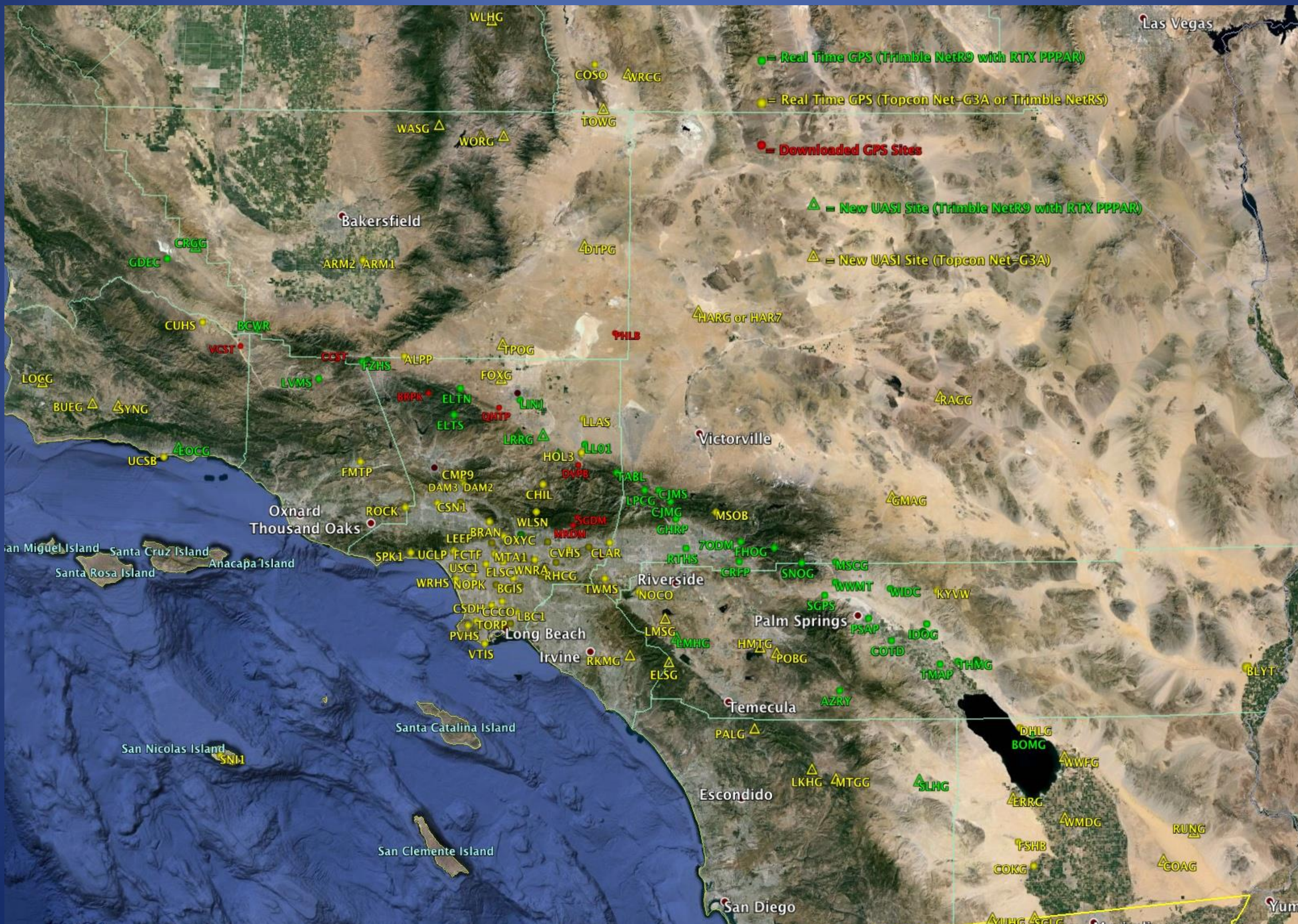
Sensor Networks → Field telemetry → Processing Alert Creation → Alert Delivery → User Actions

USGS GPS/GNSS ‘use case’ (1)

- *USGS Earthquake Program operates over 100 real-time GNSS stations to monitor the San Andreas and other faults in Southern California.*
- *Real-time GNSS station position data at cm level accuracy are streamed into the earthquake early warning system (EEW), Shake Alert, that issues alert messages for public safety in case of a major earthquake.*
- *The GNSS component of the Shake Alert system augments the inertial and seismic sensors - especially important for the largest earthquakes.*
- *Real-time, **uninterrupted GNSS signals are required, without interference, at all times***
  - *temporary black-out of data at from stations could thwart effectiveness of the EWS*
  - *Critical impact if one or more stations are close to the epicenter of a major earthquake.*
  - *Loss of data due to RFI could increase the “blind zone” and delay delivering or degrade the accuracy of the Shake Alert message to the public.*

GPS/GNSS Network

Southern California



USGS GPS/GNSS ‘use case’ (2)

- 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 achieving the highest station position accuracy possible in real-time.

- The 100+ 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

USGS GPS/GNSS ‘use case’ (3)

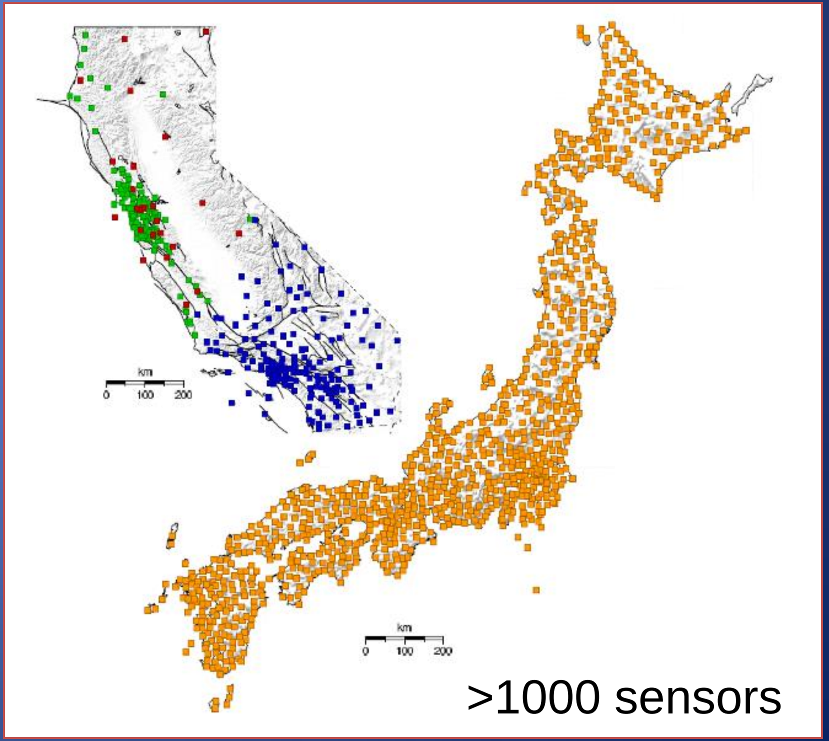
- PBO GNSS station data are streamed in real-time and soon will be included into the EEW system.

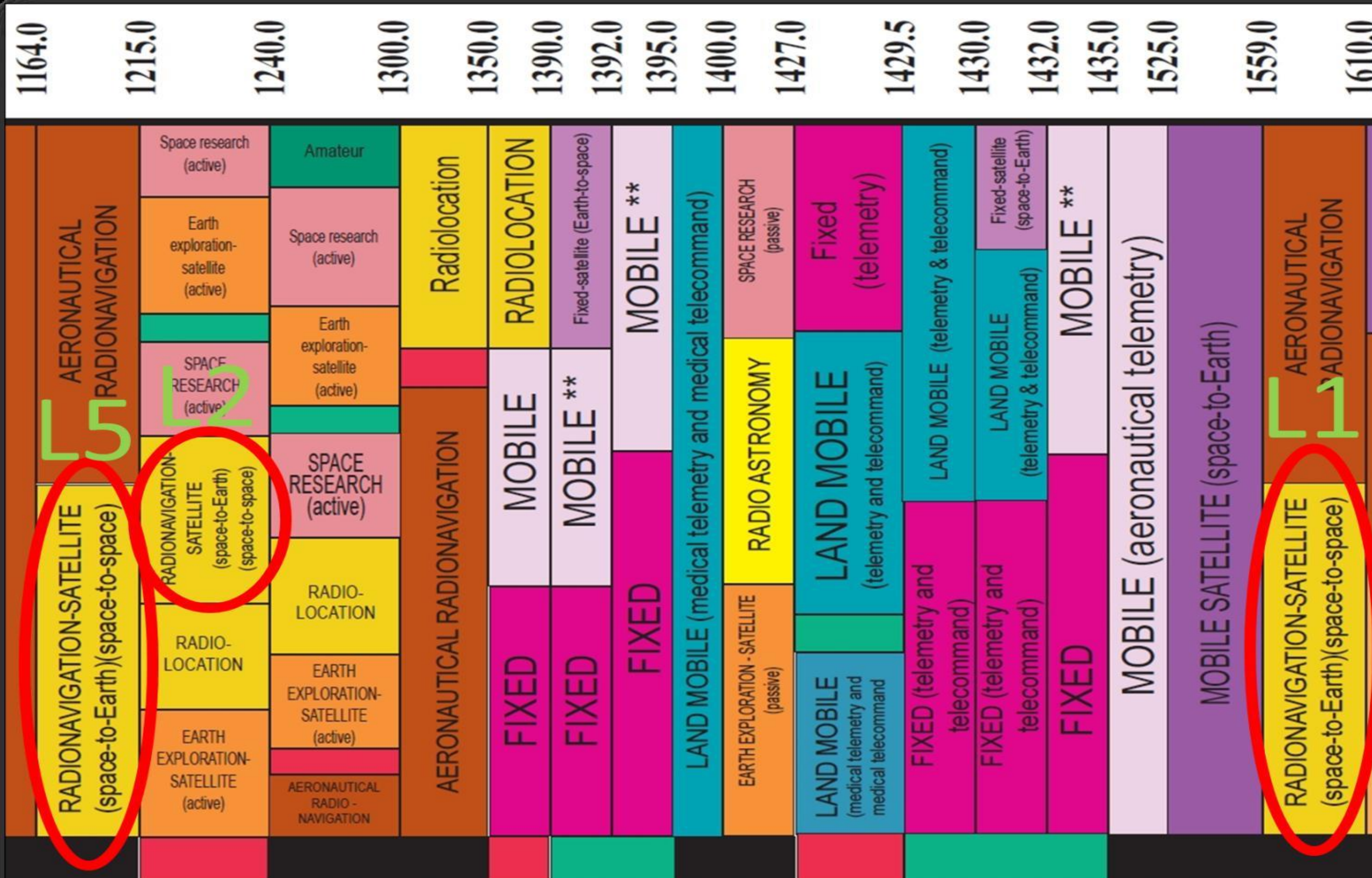
- Added benefit is plan for inclusion of real-time GNSS data from PBO into the NOAA tsunami alert system and USGS volcano alert system.

- Working with JPL/NASA, the EEW will benefit from the IGS global array of GNSS stations for Precise Point Positioning with Ambiguity Resolution PPP(AR) processing using highly accurate GNSS orbit and clock corrections.

Japanese EEW system

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





L5 1176.45 1152-1200

Band

L2 1227.6 1212-1243

GPS Signals (MHz)

L1 1575.42 Band 1559-1591

Acknowledgements

Ken Hudnut, Ph.D.	hudnut@usgs.gov (626)583-7232	Geophysicist; West Coast Earthquake Early Warning System; Chair, GNSS Working Group
Dan Determan	ddeterman@usgs.gov (626)583-6729	Geodesist; Southern California GPS Network Coordinator

Thank you

USGS
science for a changing world
Earthquake Hazards Program