USGS GPS ABC Workshop 'Use Case'

- Real-Time GPS for Earthquake Early Warning (EEW): CRITICAL EFFECT

  *USGS is the federal agency with hazard alert responsibilities for earthquakes, volcanoes and landslides nationwide.

  – High Accuracy, High Precision User/Application

  – The EEW (Shake Alert) system has a critical requirement for continuous, uninterrupted carrier phase measurements.

    - Any interference/interruption of the GPS carrier phase measurements, at any real-time GPS station at or near the epicenter of an event, could adversely affect the Shake Alert system, degrading and possibly thwarting our ability to accurately characterize the event and to send the appropriate earthquake early warning alerts through Shake Alert with minimal delay.
    - Any carrier phase measurement interruption, even of a couple of seconds or so, can cause a phase break in the GPS receiver that, even with the current best available processing methods, can then require 15 minutes for "re-convergence" of a PPP solution at that site.
      – If one or several sites in a given area near the epicenter of an event are interfered with and are "re-converging" when an event occurs, it will have a significant negative impact on the EEW (Shake Alert) system.
      – If the nearest GPS station was interfered with and "re-converging" during that event, that station would not be used by the Shake Alert system and will not only delay the alert (it would miss the first site impacted), but it could also cause the system to inaccurately characterize the event (instantaneous slip would be missed closest to the epicenter).

USGS Earthquake Hazards Program (EHP) GPS Use Case: *Earthquake Early Warning (EEW) and Shake Alert*

Dan Determan; Slides by Ken Hudnut
USGS Earthquake Hazards Program

GPS Adjacent Band Workshop VI
RTCA Inc., Washington D.C.
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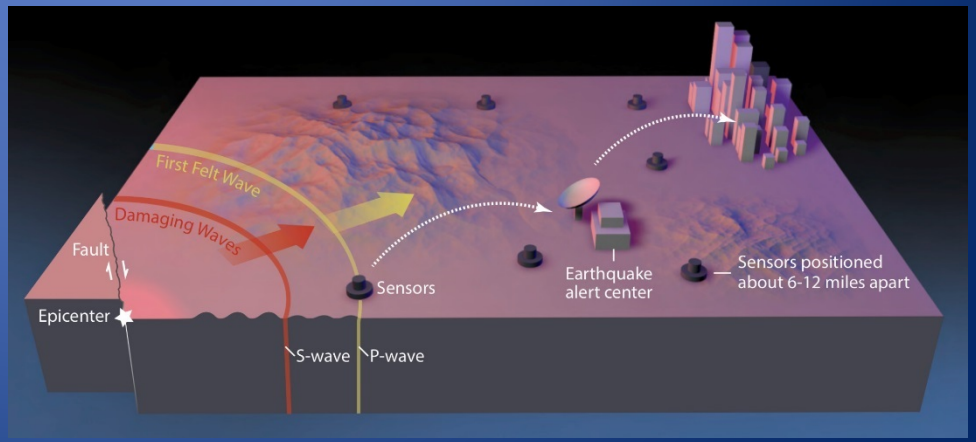


USGS science for a changing world
Earthquake Hazards Program

USGS GPS receiver ‘use case’

- Real-Time GPS for EEW - Continued: CRITICAL EFFECT
  - 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 delay or thwart our early warning system (particularly if site is close to the epicenter of a major earthquake).
  - Radio Frequency Interference (RFI) could increase our “blind zone” and delay delivering or degrade the accuracy of our Shake Alert message to the public.
  - EEW (as well as Volcano, Landslide, and Tsunami early warning applications to come) requires the broadest spectrum so as to fully utilize the GNSS signals, including side bands, for getting the highest station position accuracy and precision possible in real-time.
  - The proposed RFI can potentially cause multiple critical sites to be useless for EEW during an event, especially if the RFI affected an entire region or sub-region of the real-time GPS network.
  - Depending on the stations affected by the interference/interruption, how many, how badly they are affected, their location relative to the events epicenter, and the magnitude of the event, GPS data could completely fail to contribute to the EEW Shake Alert system.
  - Any interference/interruption of the carrier phase measurements at a real-time GPS station has significant potential to degrade our ability to issue the most accurate and timely EEW alert, particularly concerning the largest earthquake events when the GPS data becomes most critical.

Additional Information Pertaining to the GPS Network and the Earthquake Early Warning (EEW) Application:

The USGS Earthquake Hazards Program currently operates 140+ real-time GNSS stations to monitor the San Andreas and other faults in 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. Our 140 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.

USGS GPS Network Status

Receivers Model/Make/Series:

Make	Model	Series	Approximate Number of Units Deployed
Trimble	NetR9 (w RTX and GLONASS)		41
Topcon	Net-G3A	Sigma	90
Trimble	NetRS		09

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

ShakeAlert

Earthquake Early Warning System

Doug Given

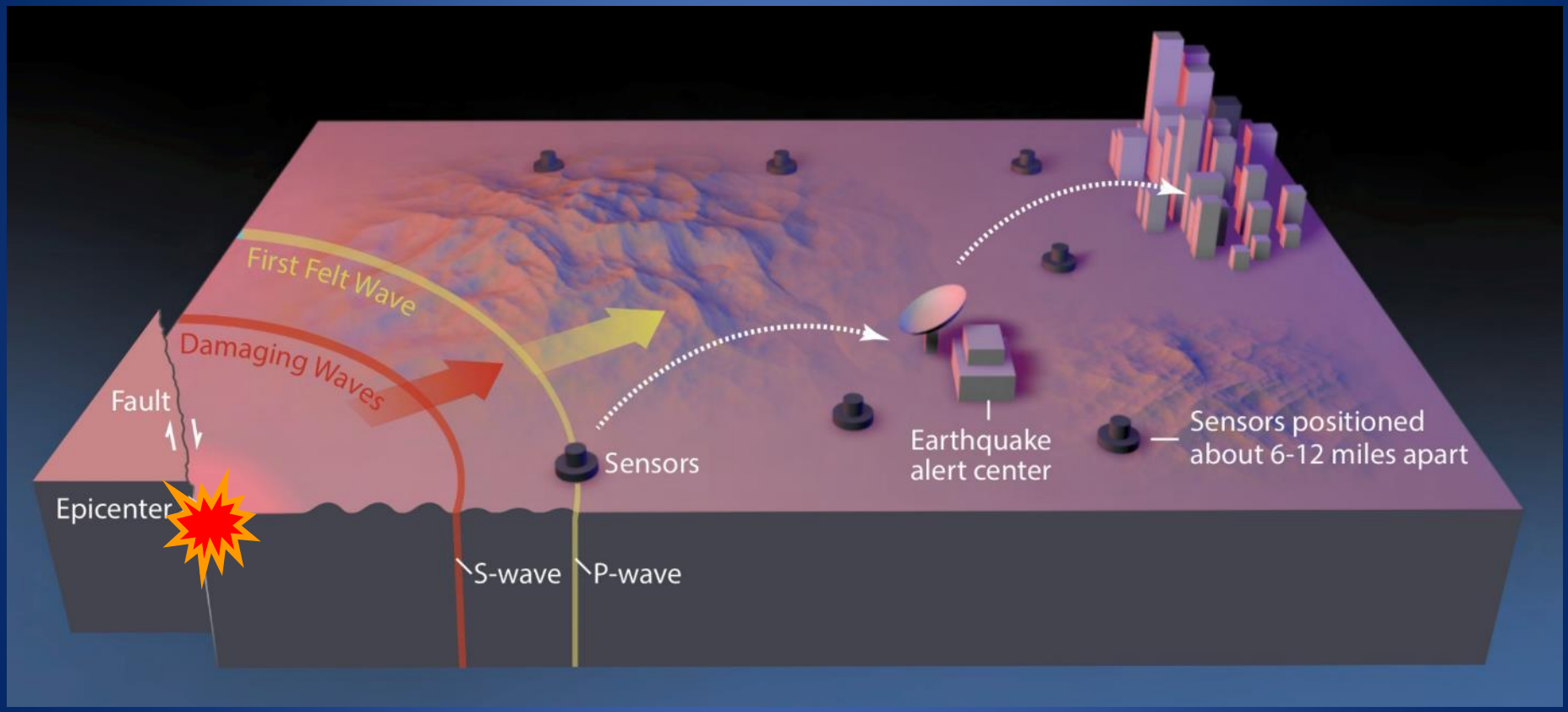
USGS

Earthquake Early Warning Coordinator

Primary Collaborators

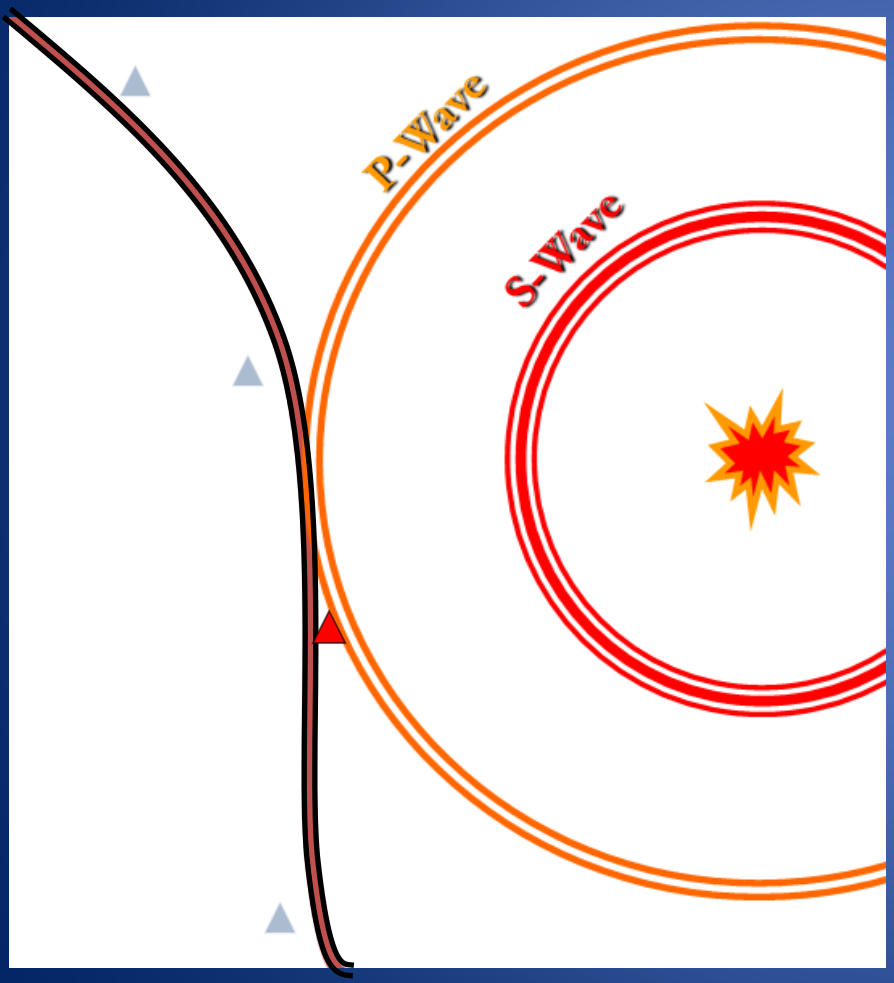
- **USGS**
  - Given, D., Cochran, E., Oppenheimer, D.
- **State of California (Cal OES, CGS)**
  - Johnson, M., Parrish, J.
- **Caltech**
  - Heaton, T., Hauksson, E.
- **UC Berkeley**
  - Allen, R., Hellweg, P., Strauss, J.
- **U. of Washington**
  - Vidale, J., Bodin, P.
- **Swiss Seismological Service,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

EEW Concept
Network Based Alerts

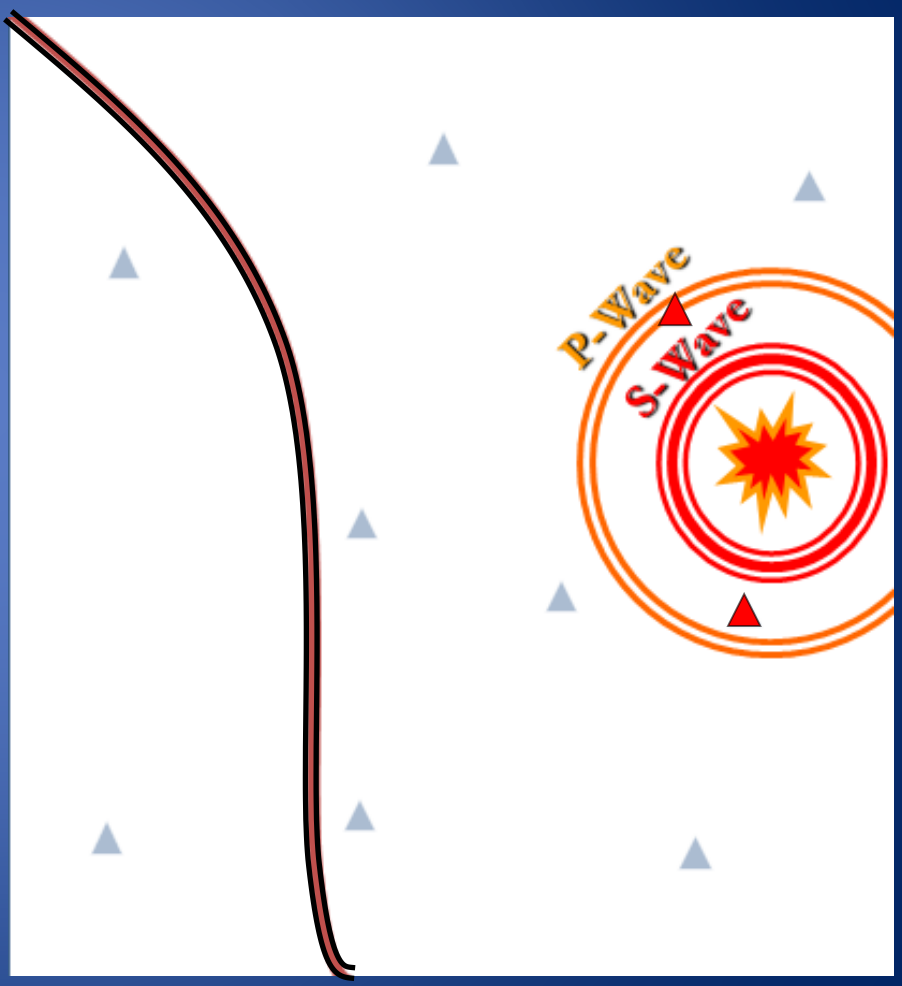


P-wave ~ 3.5 mi/sec (felt waves)
S-wave ~ 2.0 mi/sec (damaging waves)
Alert ~ 186,000 mi/sec

Regional Network Alerts
maximize warning time



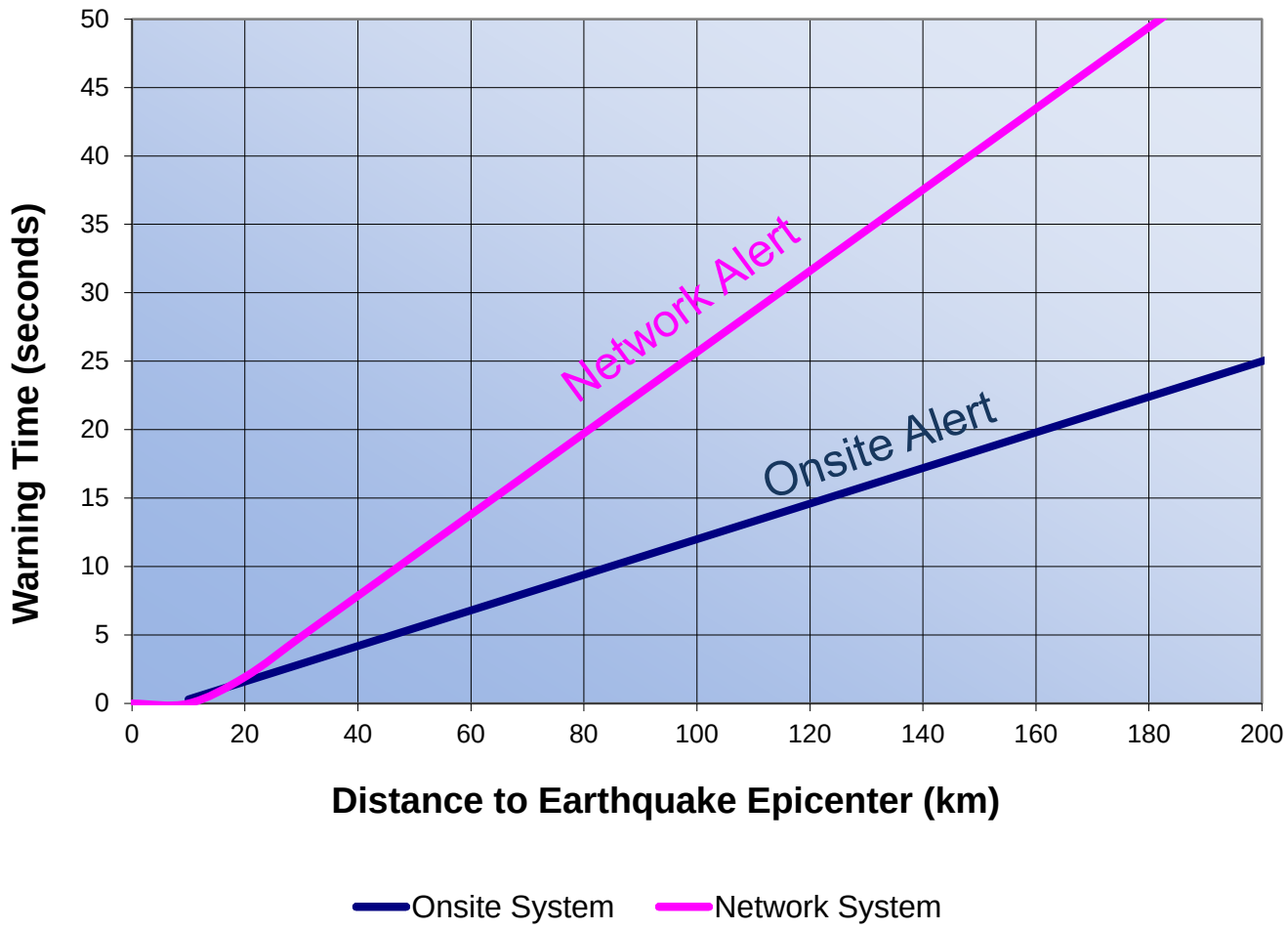
Onsite Alert



Network Alert

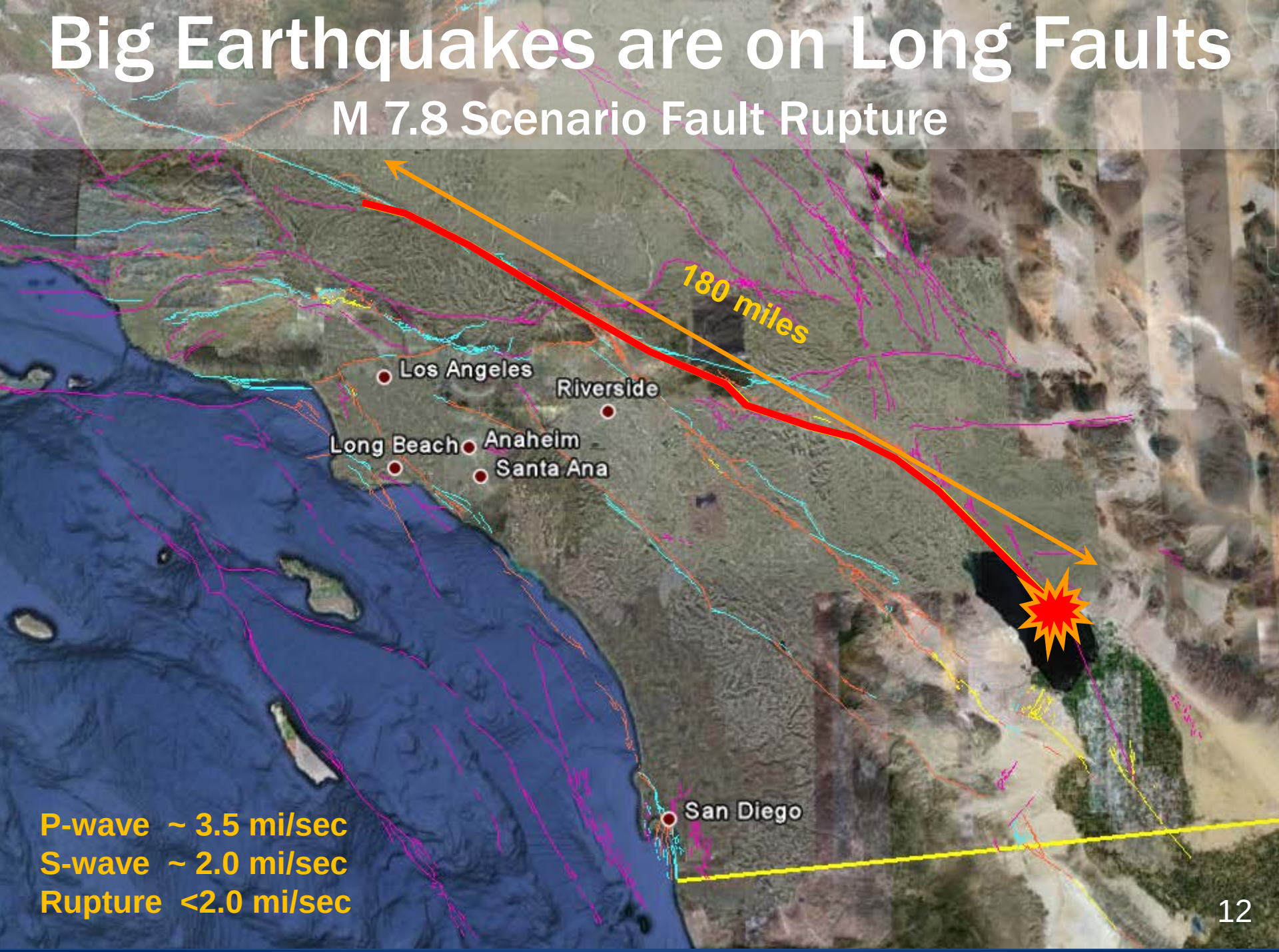
Warning Time

Network alerts give most users more time

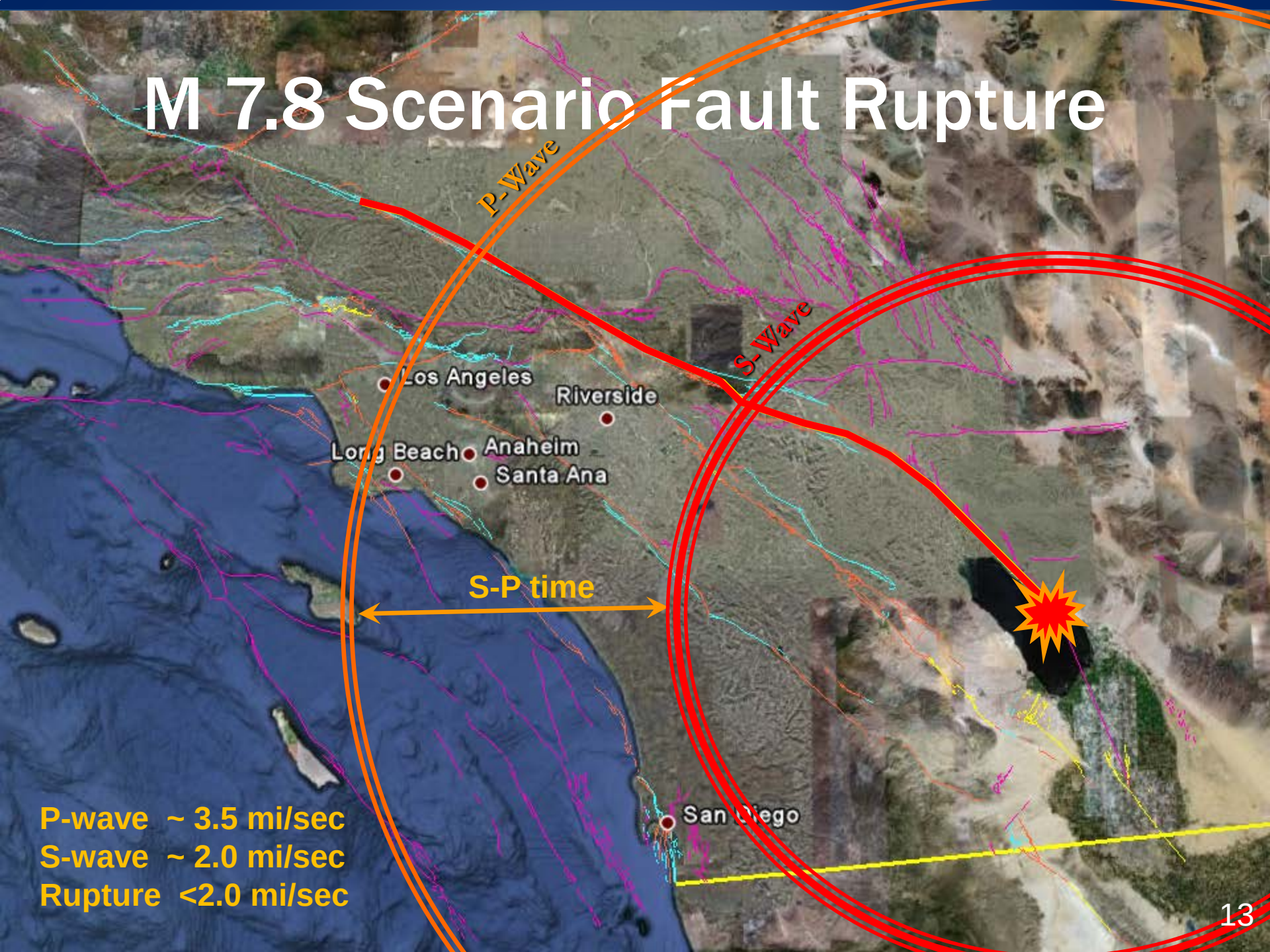


Big Earthquakes are on Long Faults

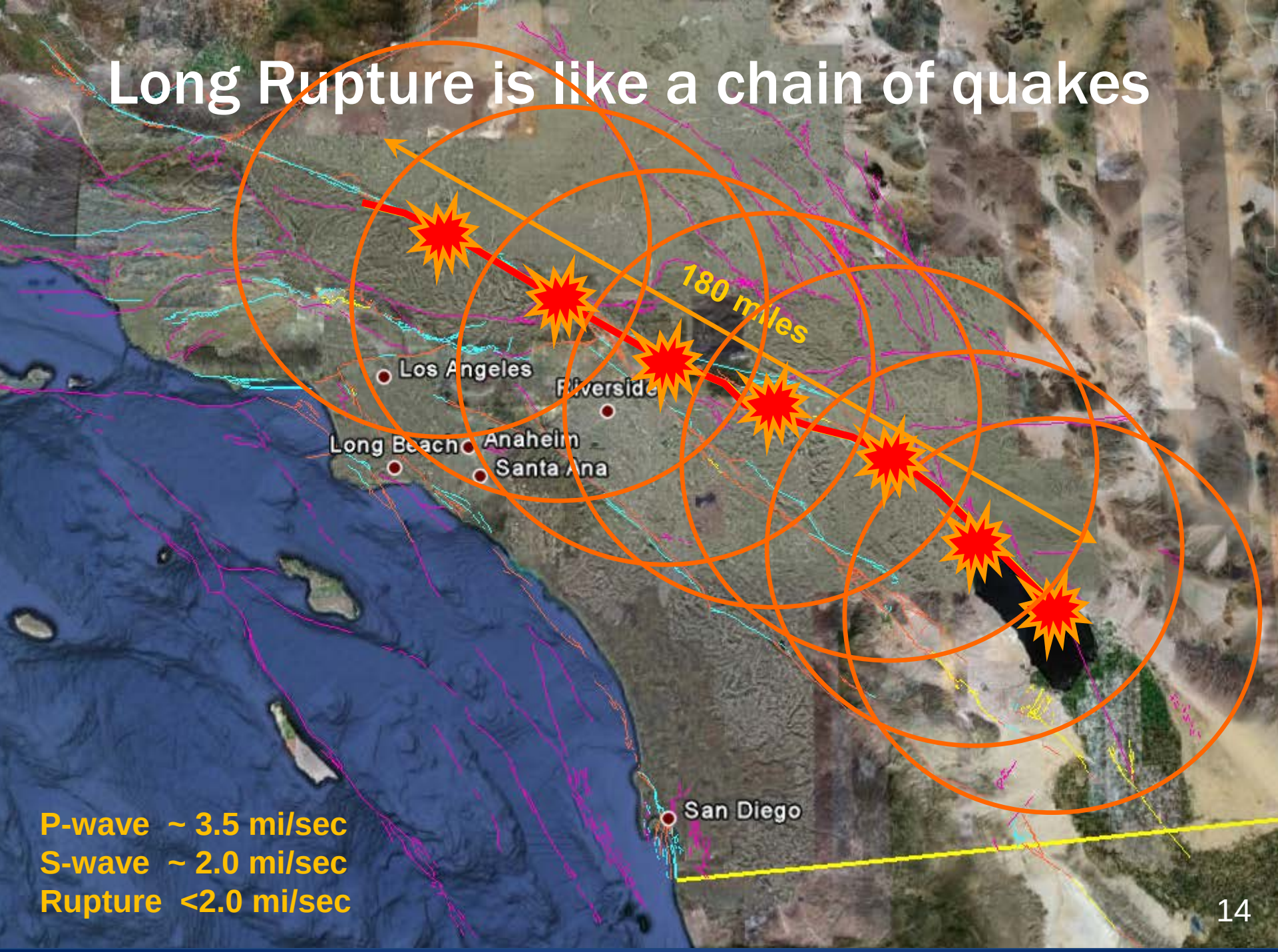
M 7.8 Scenario Fault Rupture



M 7.8 Scenario Fault Rupture

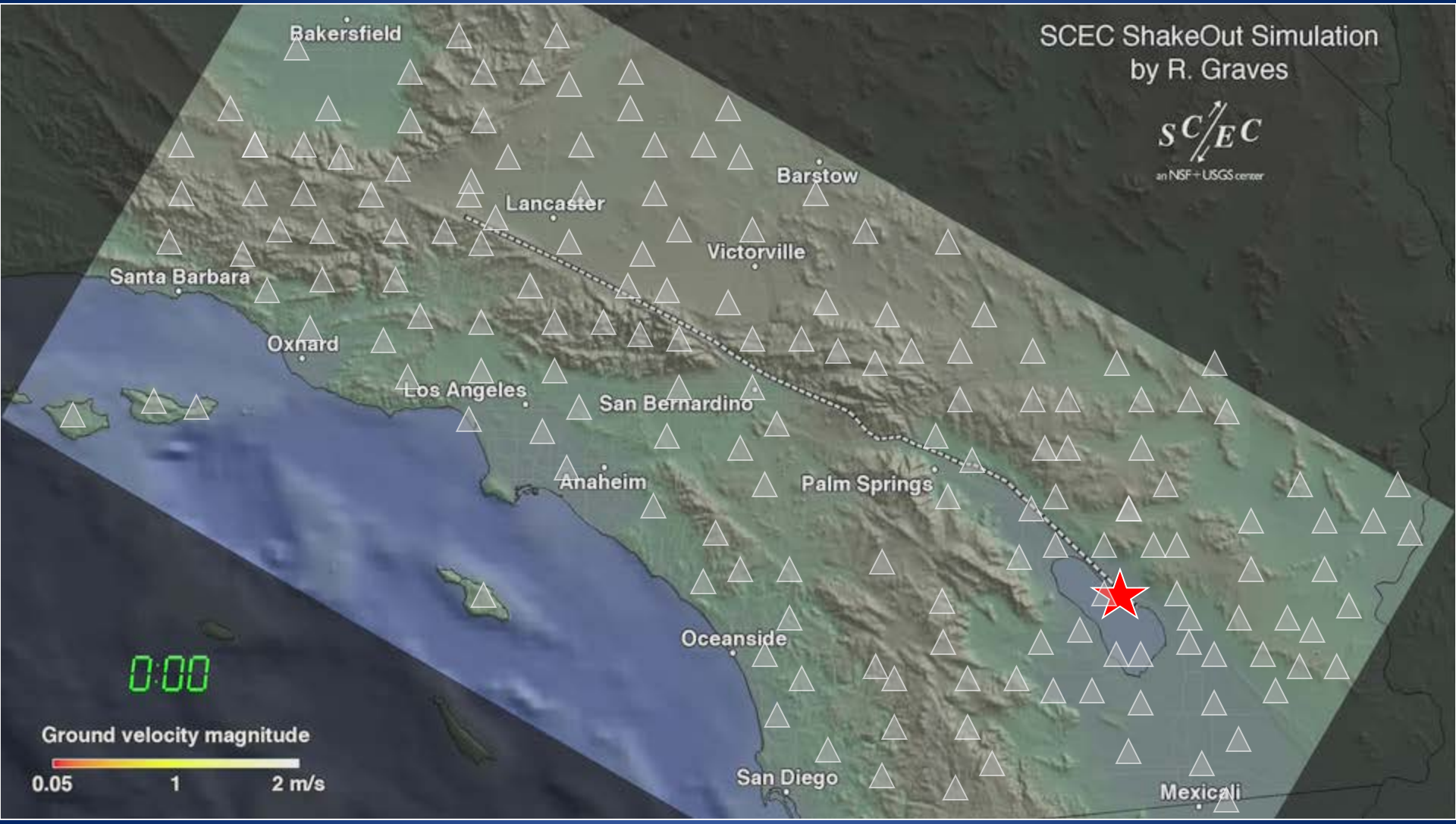


Long Rupture is like a chain of quakes



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

Earthquake Begins



M7.8 ShakeOut Scenario

Stations Sense Shaking

ShakeAlert Detects Event – Issues Alert

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

Rupture Moves Up Fault