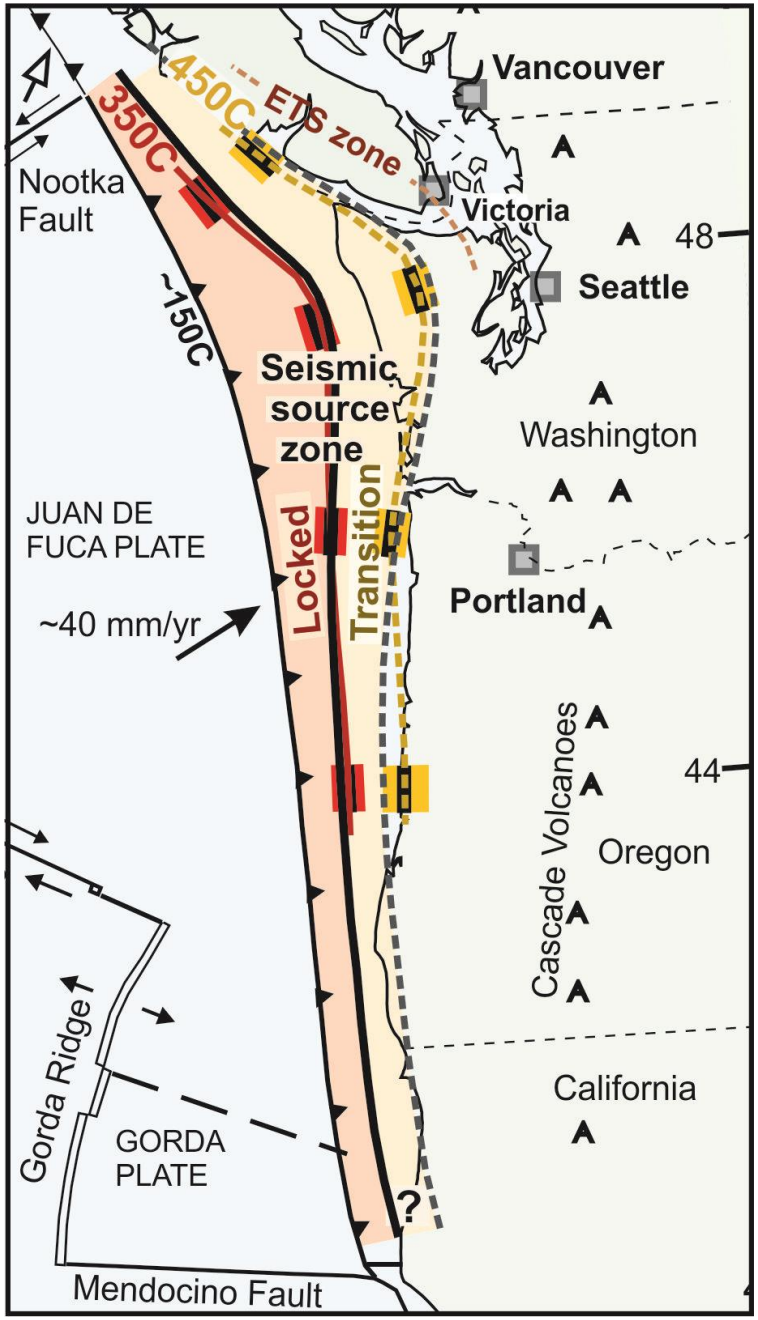
PNW Earthquakes: Hazards, Monitoring & Early Warning

Doug Toomey
University of Oregon

May 17, 2016 NW Hydro Forum

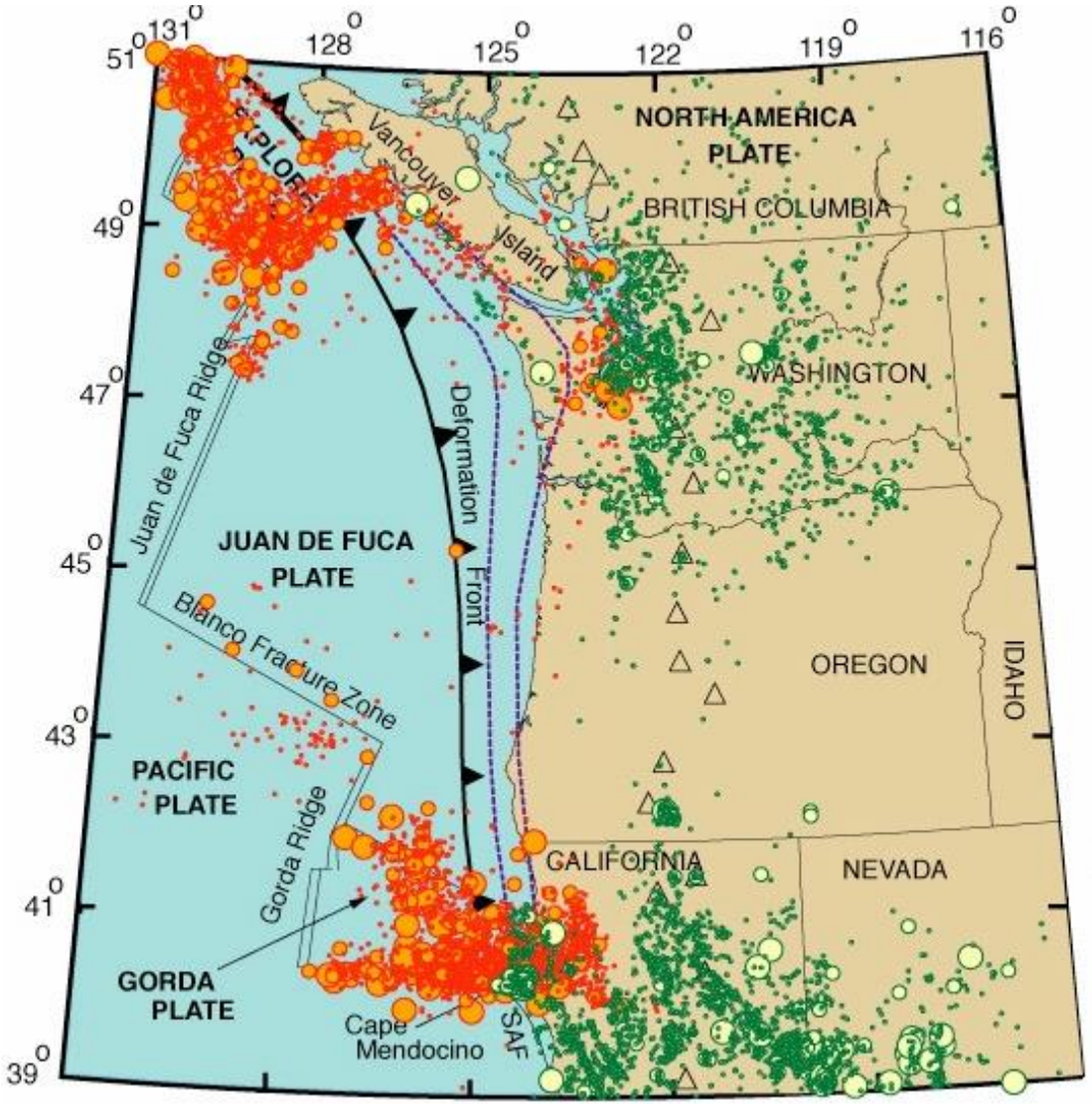
Outline

1. Earthquake Hazards in the Pacific Northwest
   - 3 earthquake threats
   - Intensity of shaking
2. The Pacific Northwest Seismic Network
   - Operated by UW and UO
   - Monitors earthquakes and volcanoes
3. West Coast earthquake warning
   - Public warning system being developed by USGS, Caltech, UC Berkeley, UW and UO



Earthquake hazards

- Cascadia subduction zone and regional threats not recognized until a few decades ago



Today: Apparently we're toast.

The Really Big One

The New Yorker

An earthquake will destroy a sizable portion of the coastal Northwest. The question is when.

BY KATHRYN SCHULZ

SHARE TWEET

The truth lies between these two extremes, and science is required to find out where.

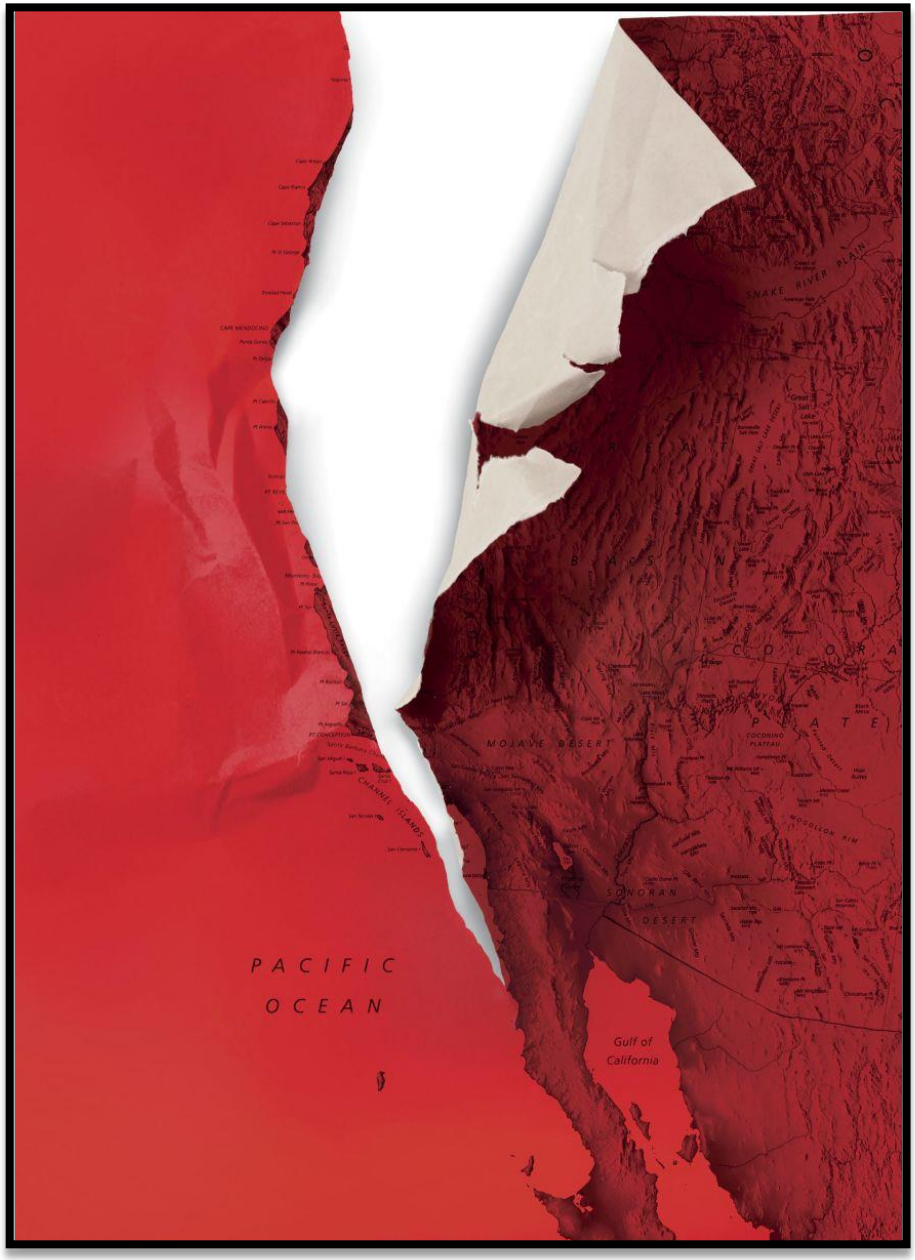
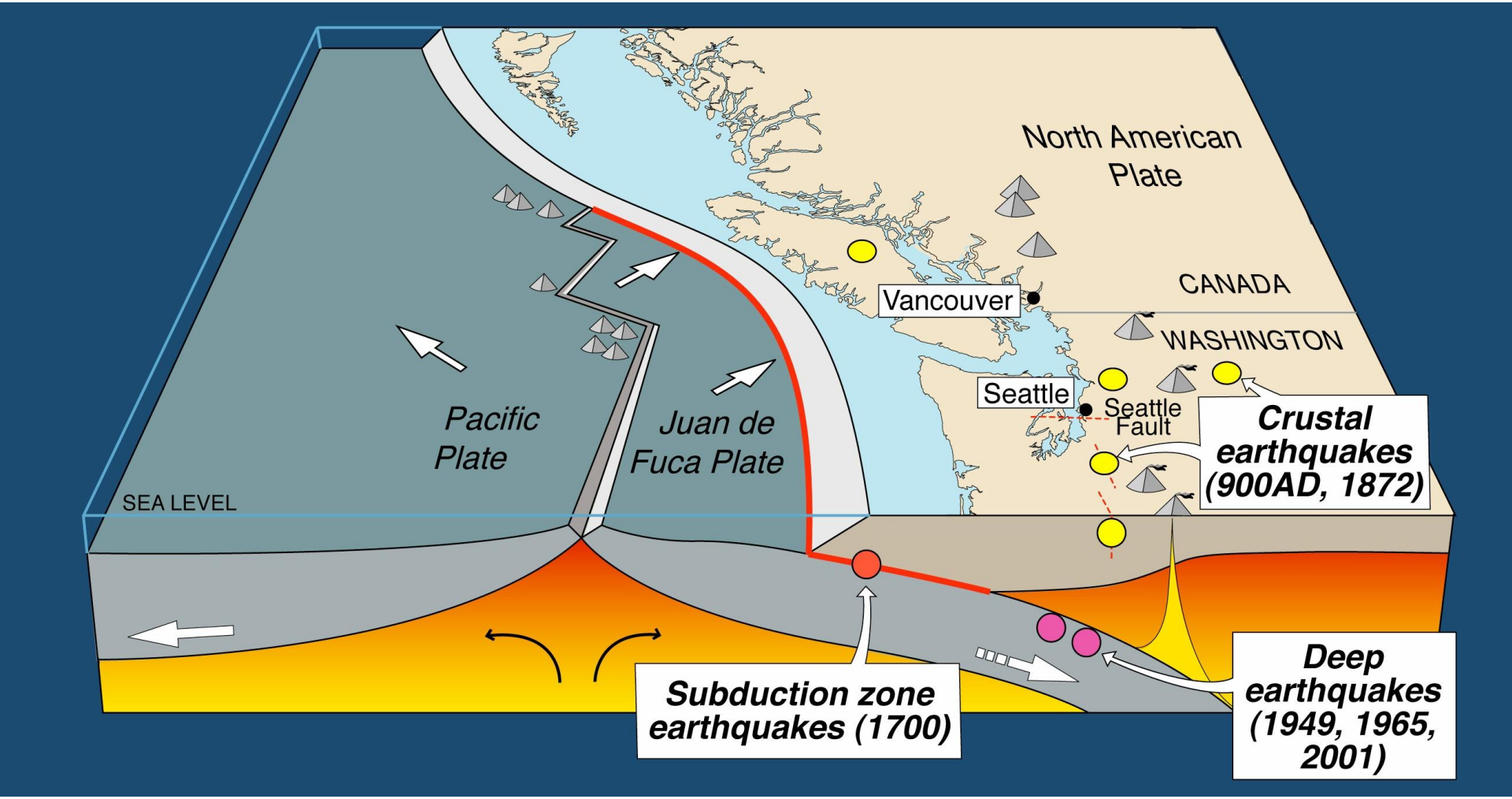


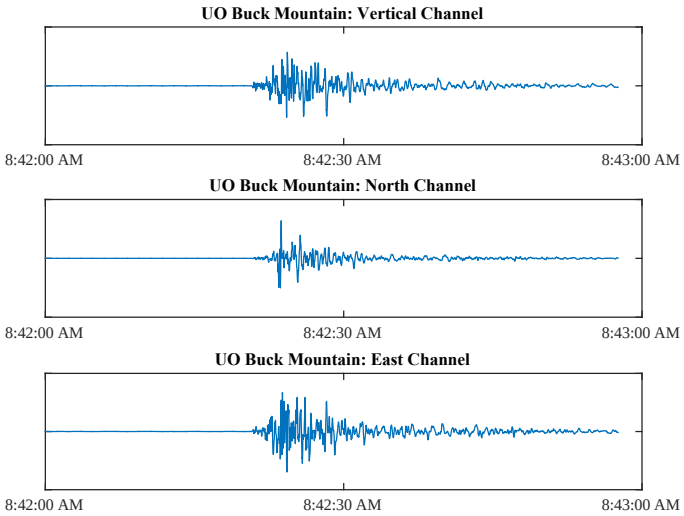
Plate tectonic setting



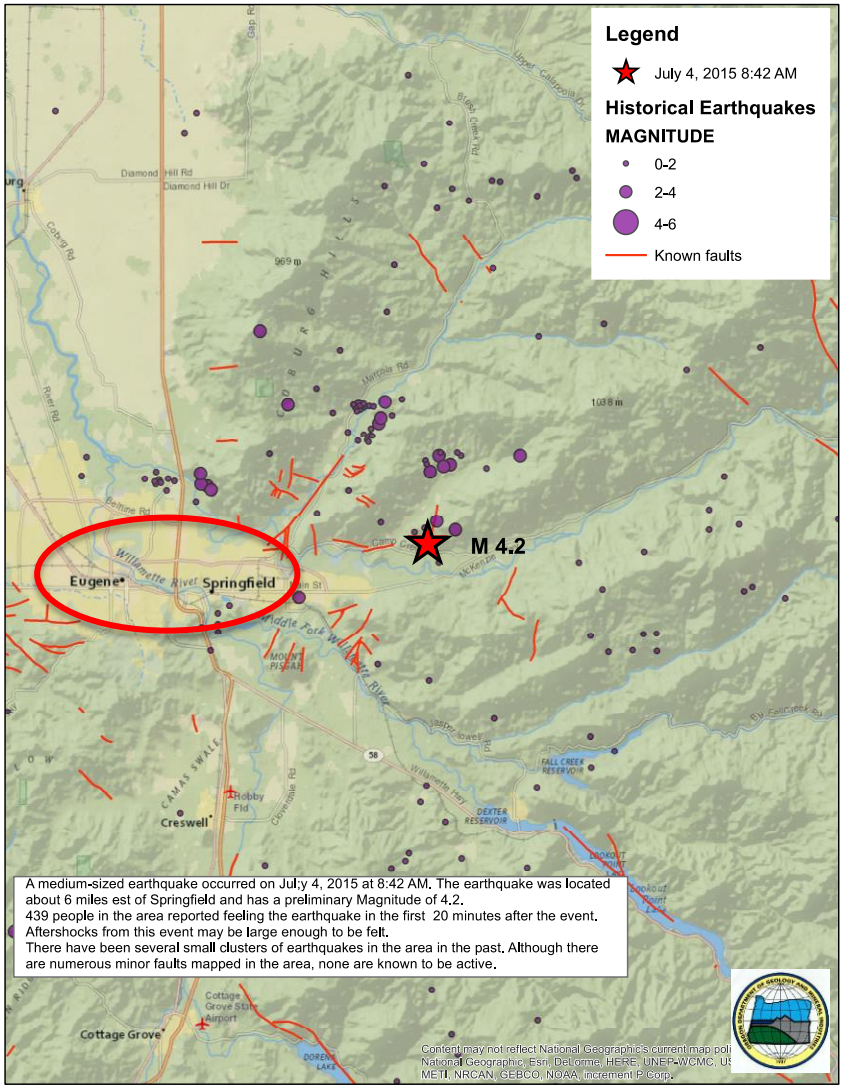
Three earthquake threats – yellow, magenta, and red

Crustal earthquakes

- Depth generally <20 km
  - Occur throughout PNW
  - **Duration of shaking** can be seconds to tens of seconds
  - If large enough, local damage
  - Scott's Mills (**M5.2**) and Klamath Falls (**M6.0**) earthquakes (1993)

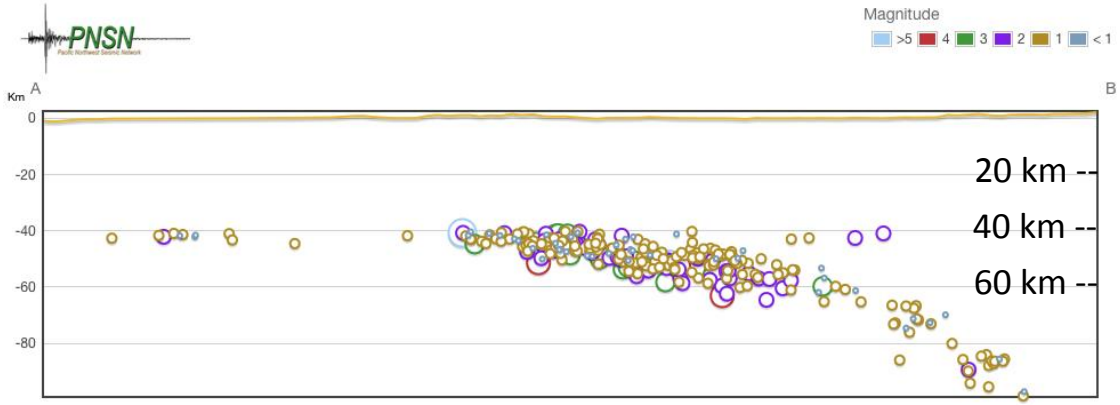


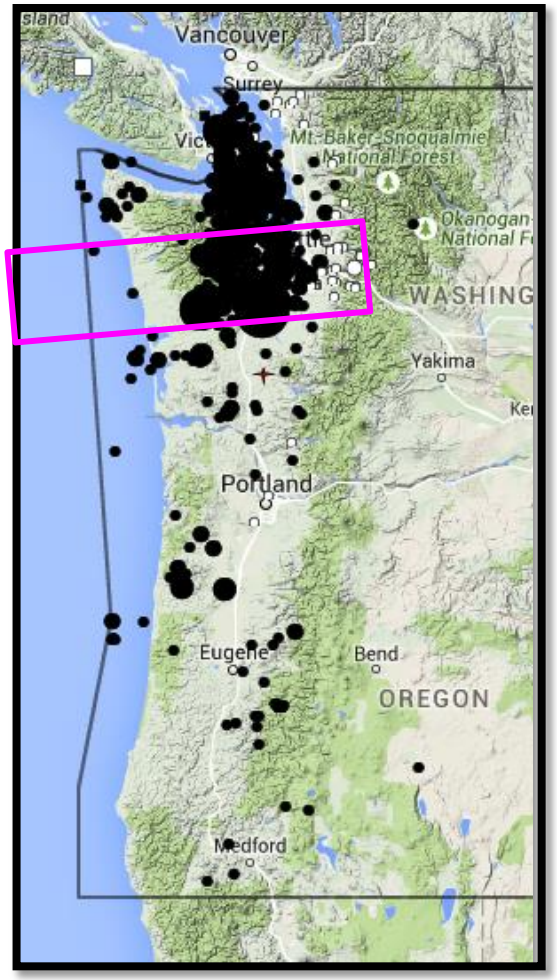
July 4, 2015 Walterville earthquake (**M4.2**)



Deep earthquakes

- Depth > 40 km
  - Mainly under Puget Sound
  - **M7 events** in 1949 & 1965, plus 2001 Nisqually event
  - **Duration of shaking** can be tens of seconds
  - Can be large, local damage can be severe

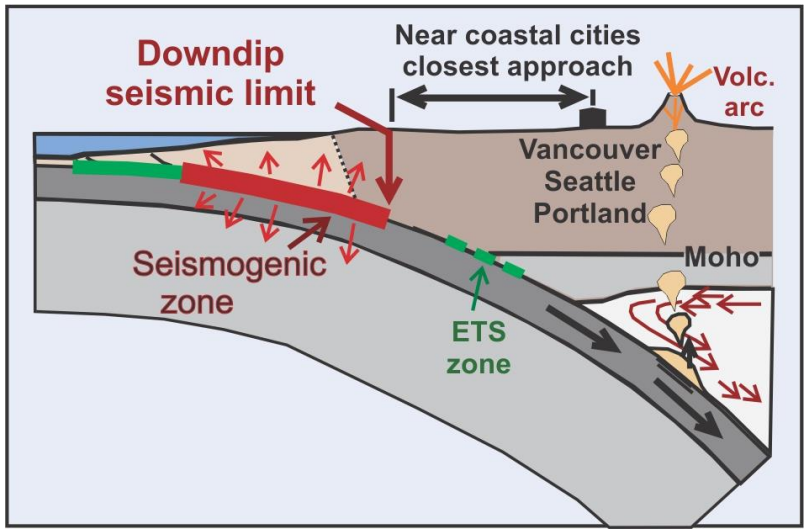


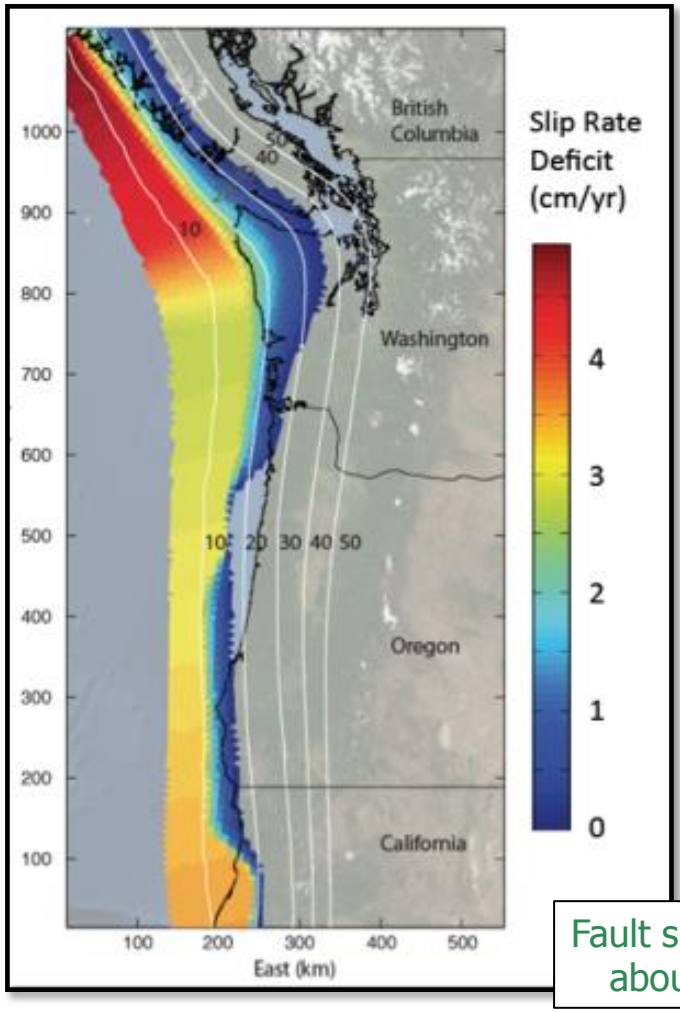


Since 2000

Subduction zone earthquakes

- Locked portion of fault:
  - **M9** event in 1700
  - Lies primarily offshore
  - Extends from N. California to Vancouver Island
  - **Duration of shaking** can be up 4 to 5 minutes





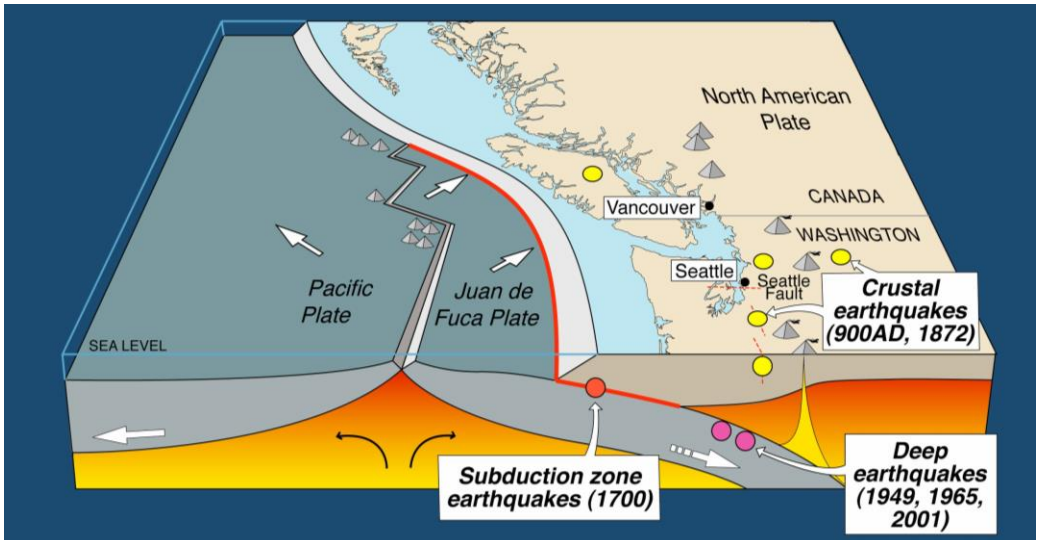
M9 fault rupture (UO model)

50-year probabilities

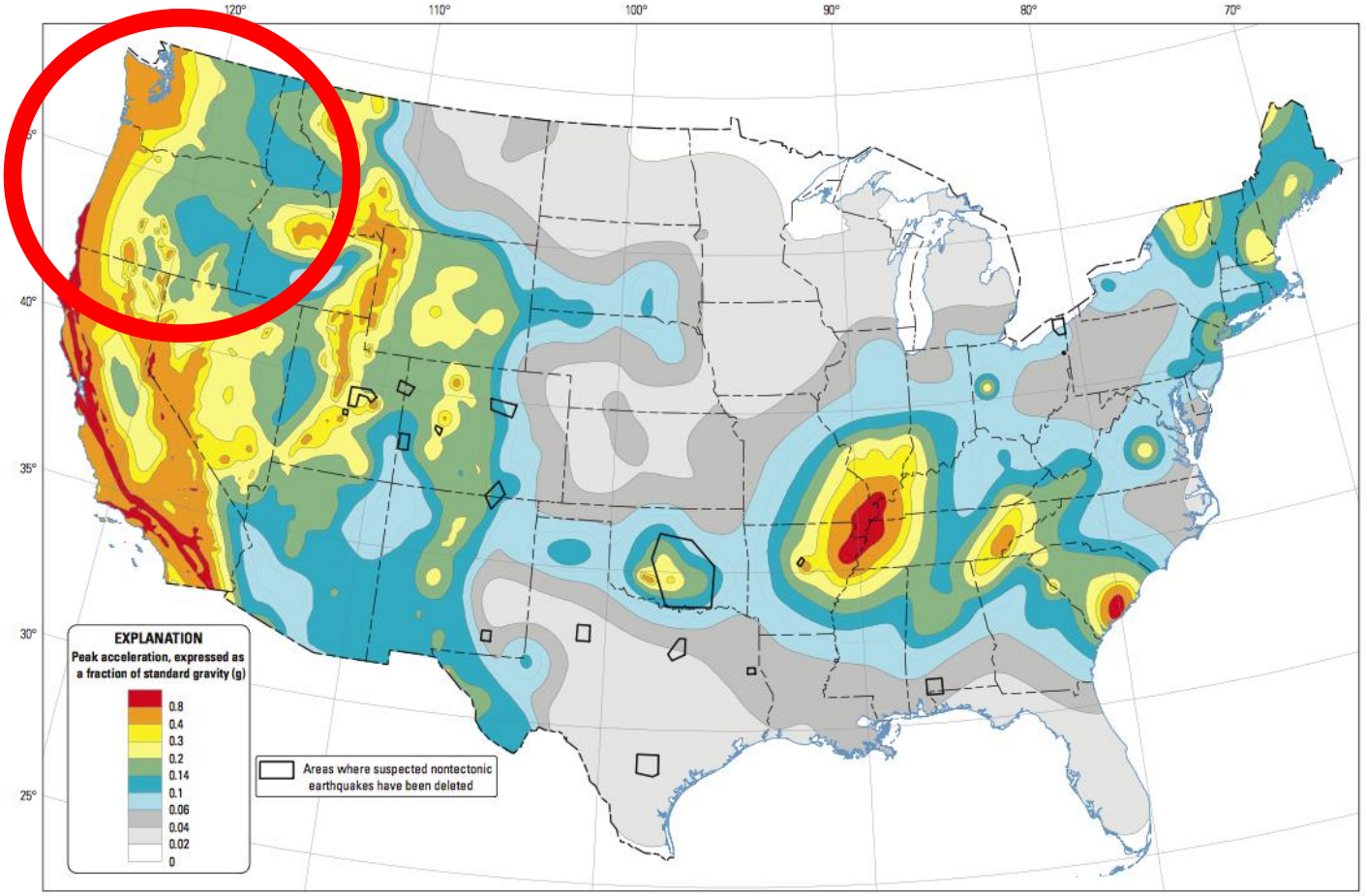
- Cascadia M9: 10-20%
- Southern Cascadia M8-9: 25-40%

- Deep M ≥ 6.5: 84%
  - –(similar to 1949, 1965, 2001)

- Shallow Puget Sound and I-5 corridor M ≥ 6.5
  - –Shallow in entire area: 15%



2014 National Seismic Hazard Maps



Peak acceleration, 2% probability of exceedance in 50 years

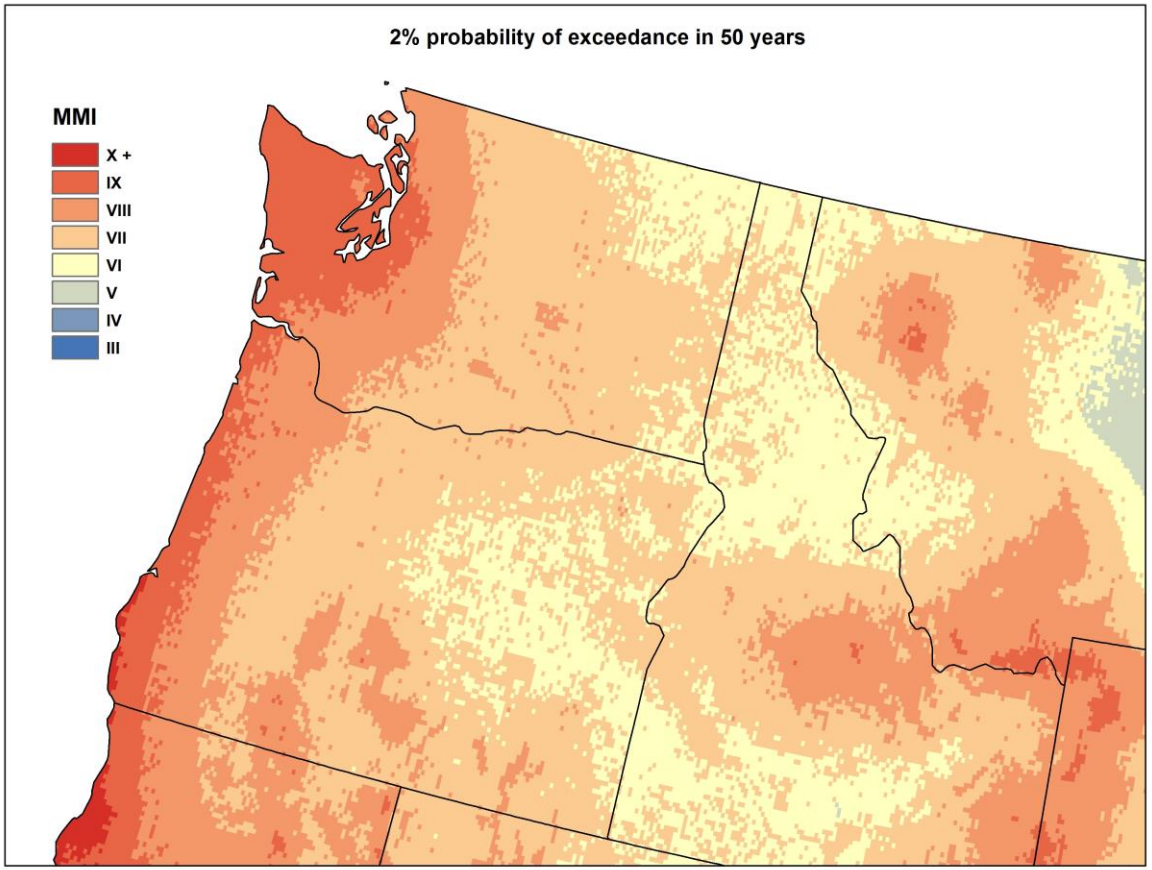
http://earthquake.usgs.gov/hazards

At 2% probability of exceedence in 50 years

Portland-to-Eugene region is in the Modified Mercalli Intensity (MMI) of VIII

- **VII (very strong):** Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken

- **VIII (severe):** Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls.



The Oregon Resilience Plan

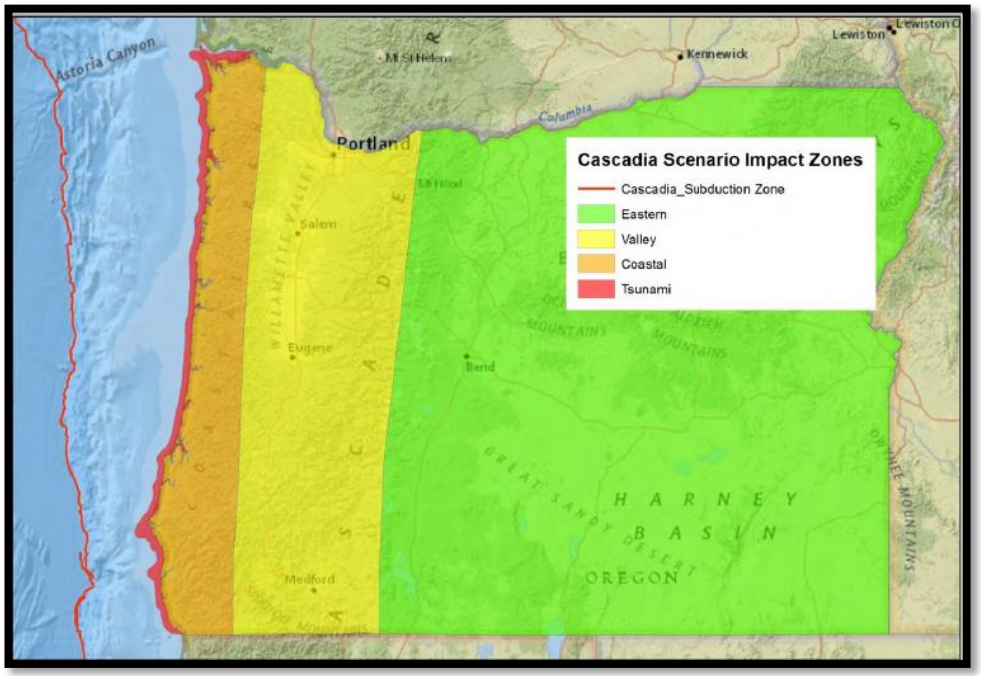
Oregon Seismic Safety Policy Advisory Commissioin (OSSPAC)

The Tsunami Zone, where severe shaking and tsunami inundation would cause near total damage, and threaten the lives of thousands of residents

The Coastal Zone, where severe shaking and damage to transportation systems would severely disrupt and isolate communities and where the major challenge after the earthquake would be to keep the population sheltered, fed and healthy.

The Valley Zone, where widespread moderate damage would severely disrupt daily life and commerce and where restoring services to business and residents would be the main priority.

Earthquake Scenario



Impact zones for the magnitude 9.0 Cascadia **earthquake scenario**

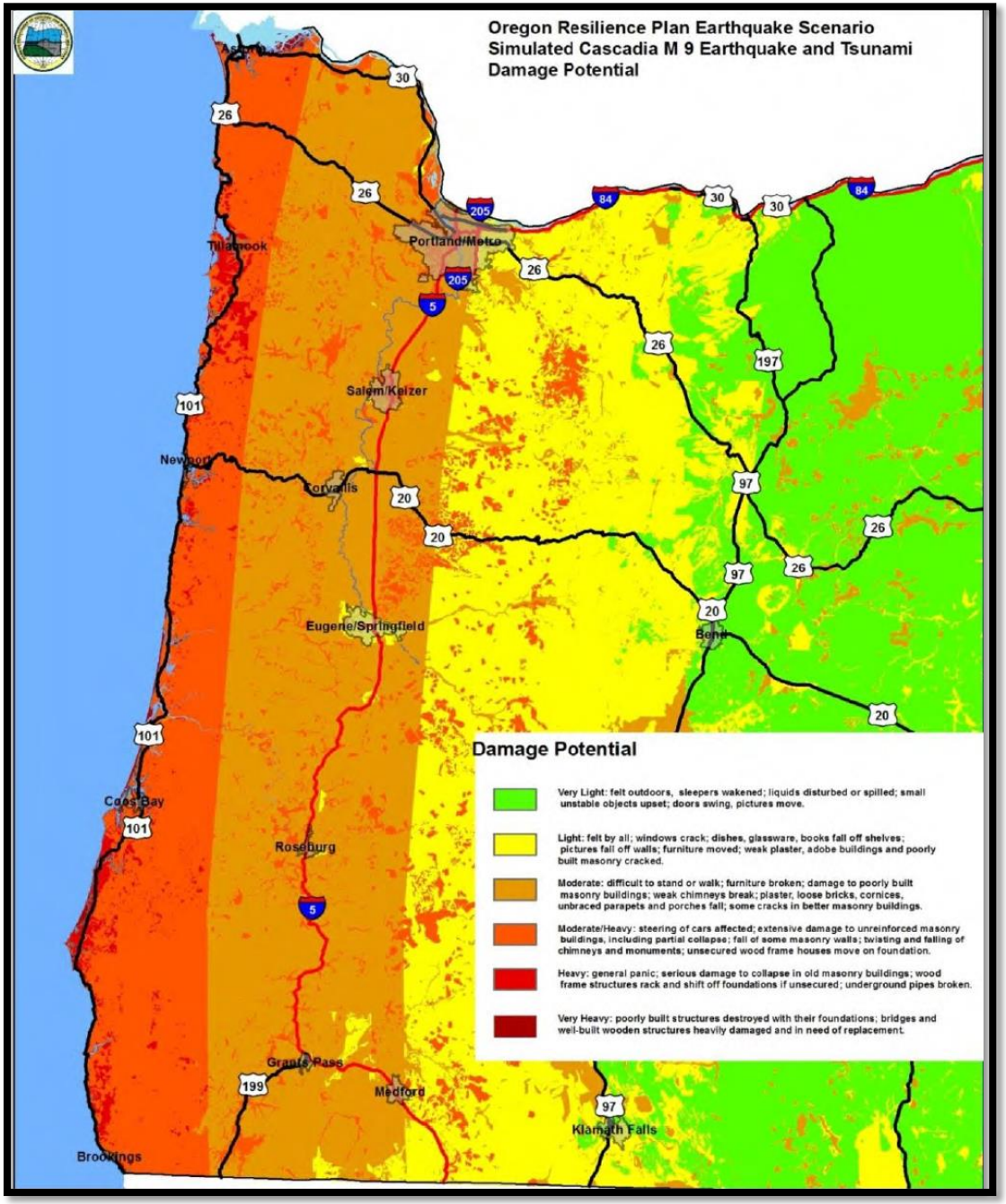
Damage Potential

Site response is important

Light: felt by all; windows crack; dishes, glassware, books fall off shelves; pictures fall off walls; furniture moved; weak plaster, adobe building and poorly built masonry cracked.

Moderate: difficult to stand or walk; furniture broken; damage to poorly built masonry buildings; weak chimneys break; plaster, loose bricks, cornices, unbraced parapets and porches fall; some cracks in better masonry buildings:

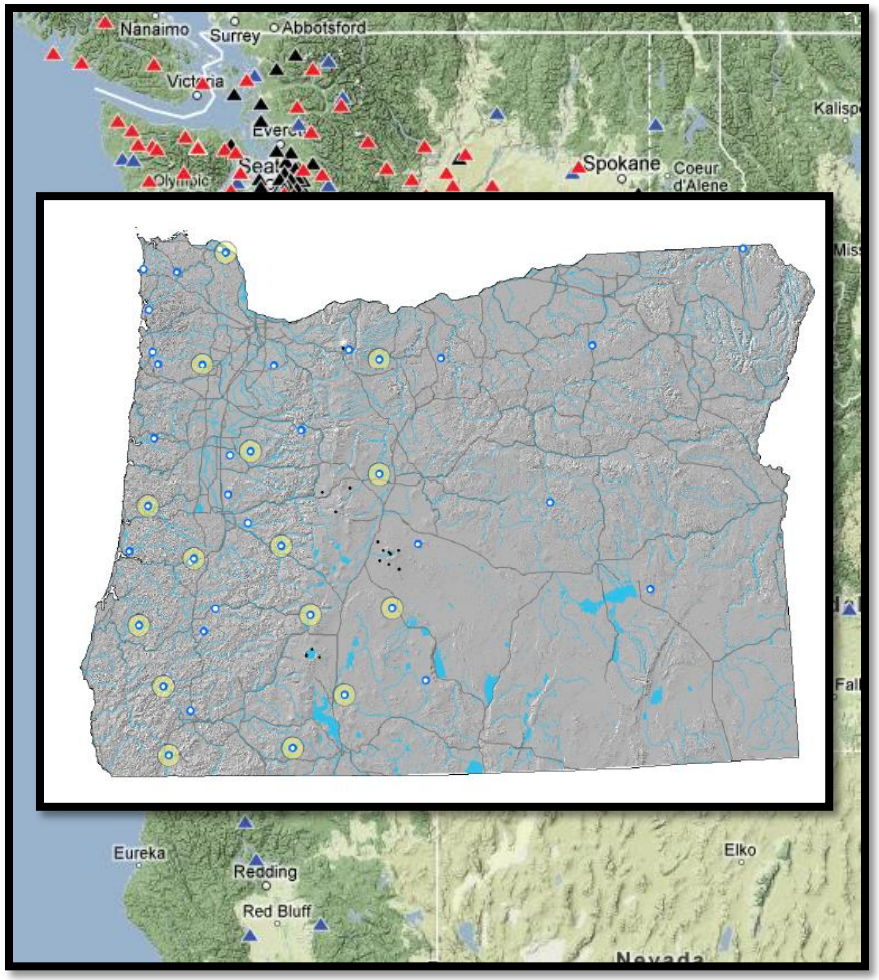
Moderate/Heavy: steering of cars affected; extensive damage to unreinforced masonry buildings, including partial collapse; fall of some masonry walls; twisting and falling of chimneys and monuments; unseecured wood frame house move on foundation.



PNSN: Pacific Northwest Seismic Network

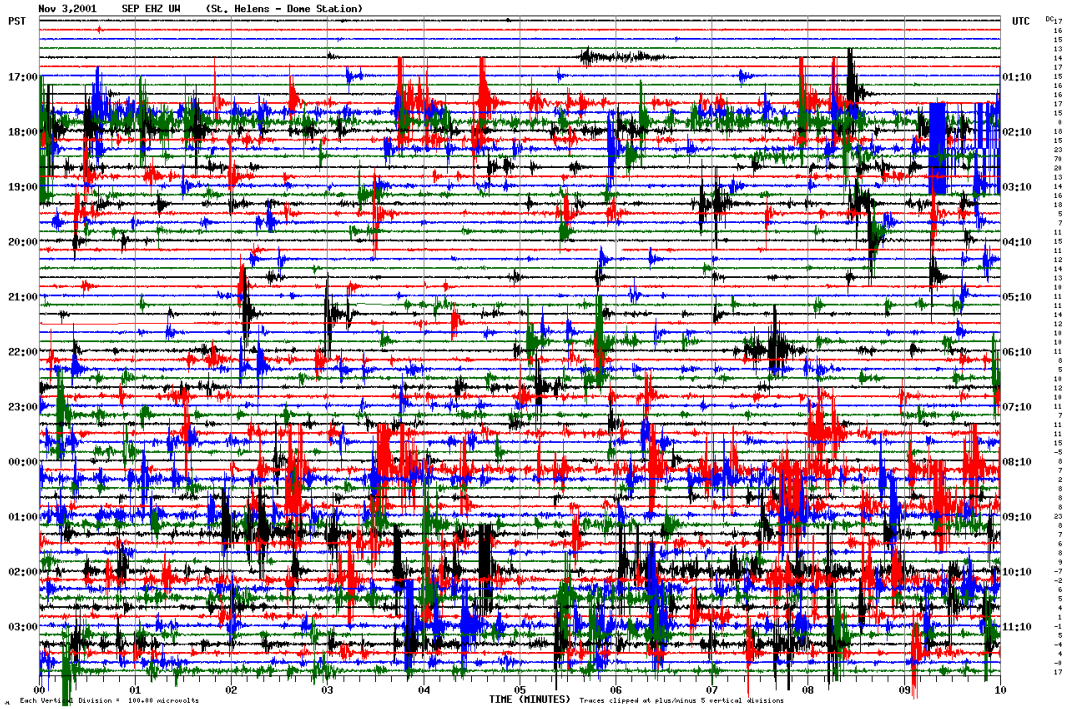
(http://pnsn.org)

- The University of Washington and the University of Oregon cooperatively operate the PNSN
- Monitors earthquakes and volcanoes
- ~400 seismometers of varying types and vintages
  - State of Oregon recently purchased 15 high quality sites from NSF ($670K)
- Communicates earthquake information to the public



Near-realtime information products

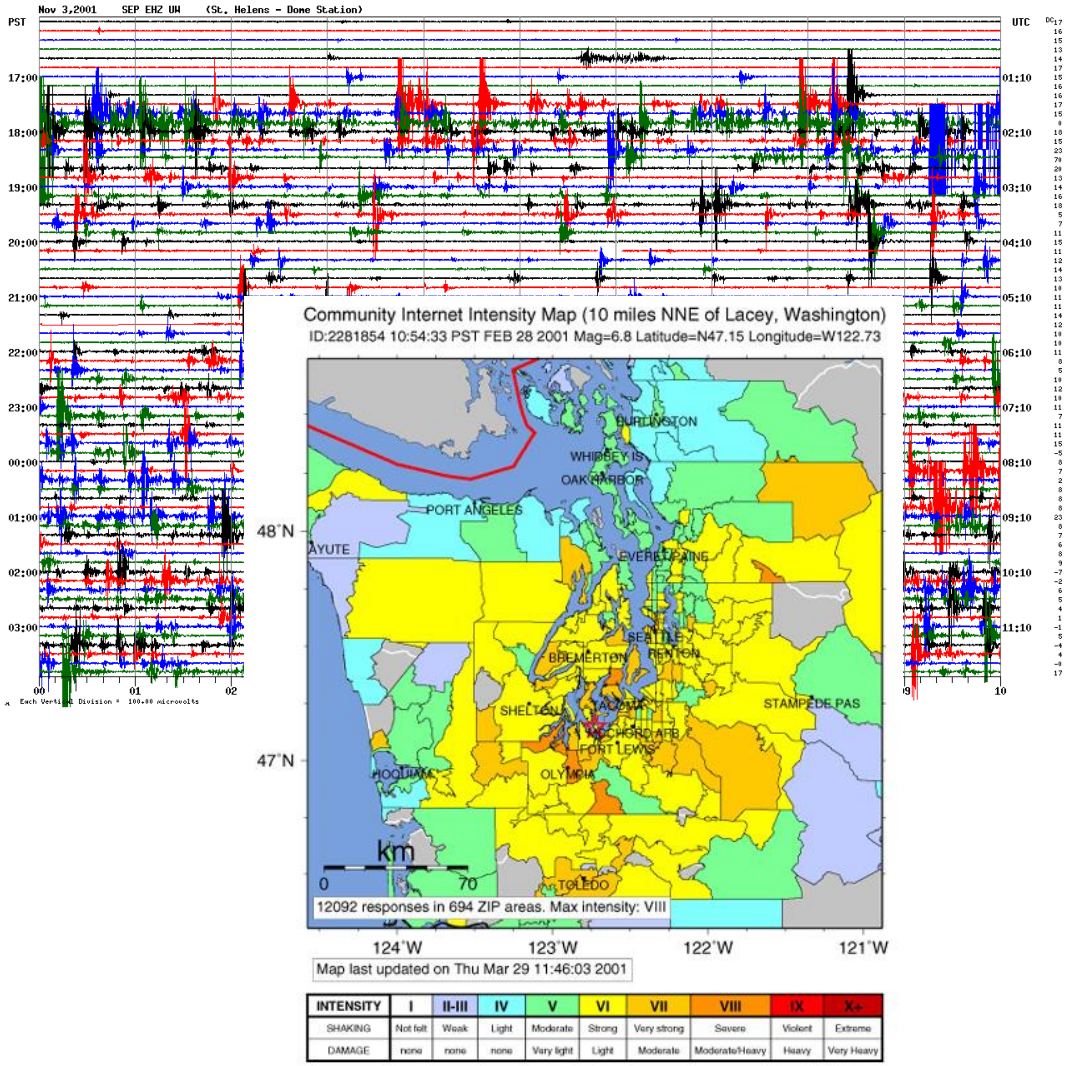
Seismograms



Near-realtime information products

Seismograms

Did You Feel It (DYFI) Maps

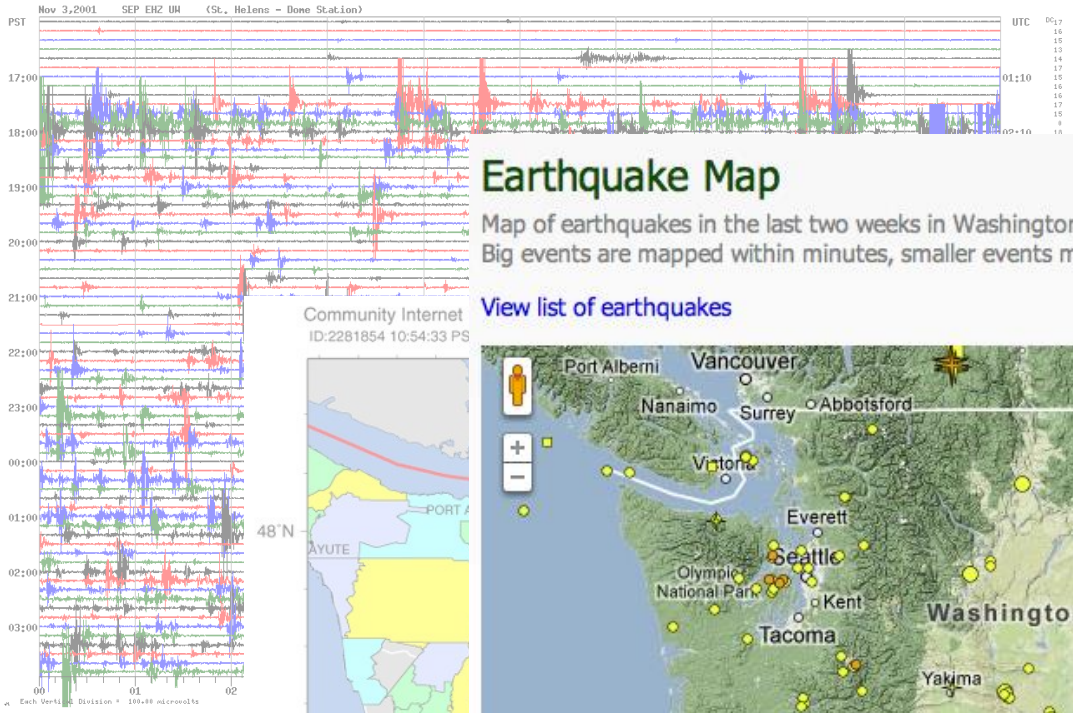


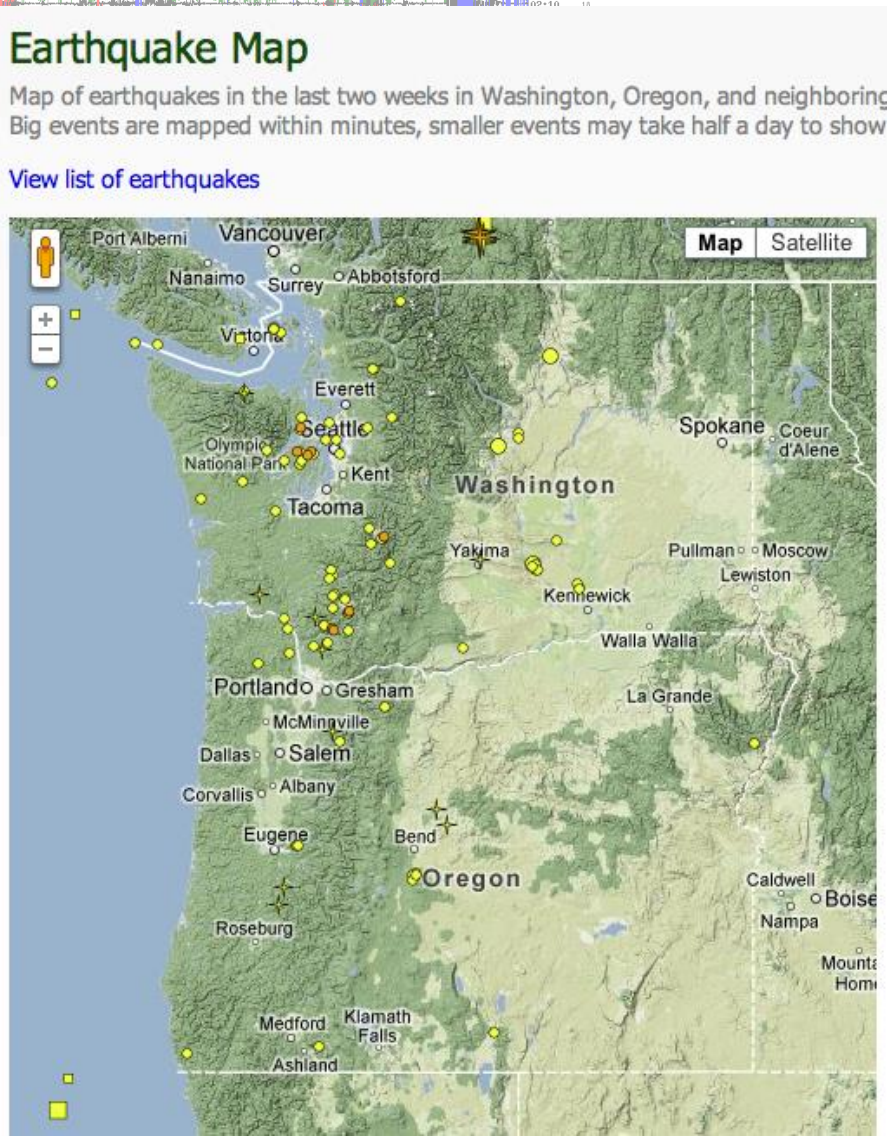
Near-realtime information products

Seismograms

Did You Feel It (DYFI) Maps

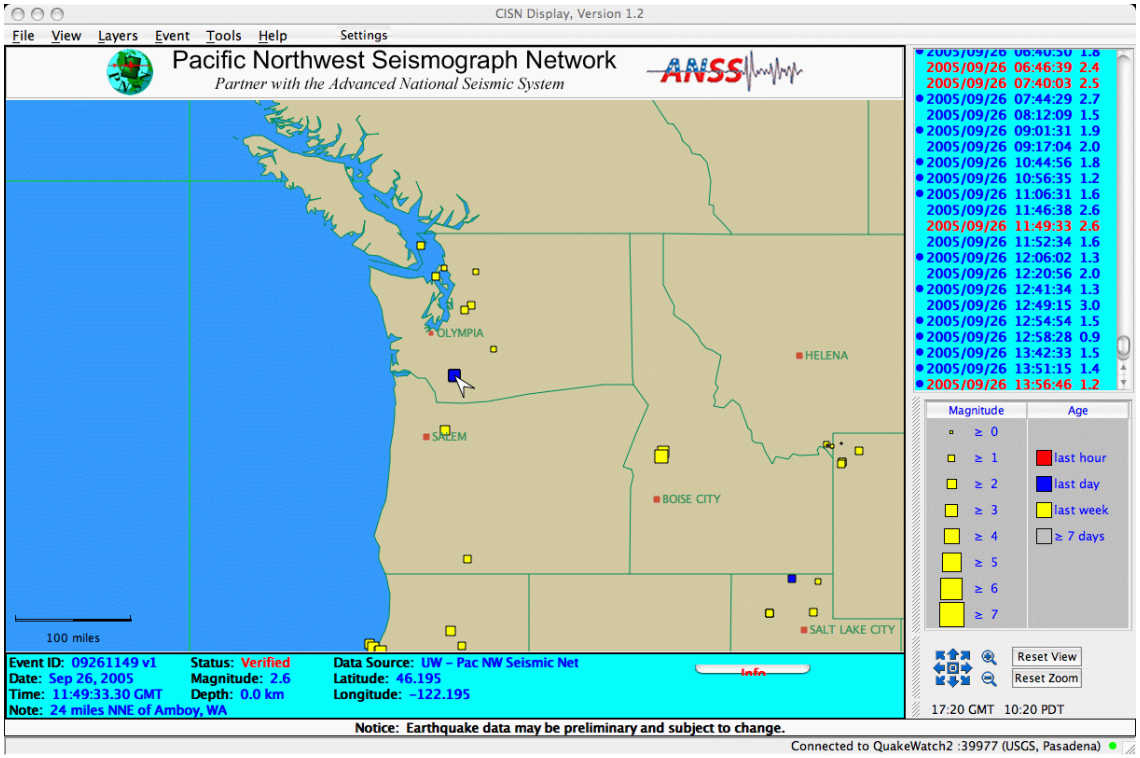
Recent Earthquakes





Near-realtime information products

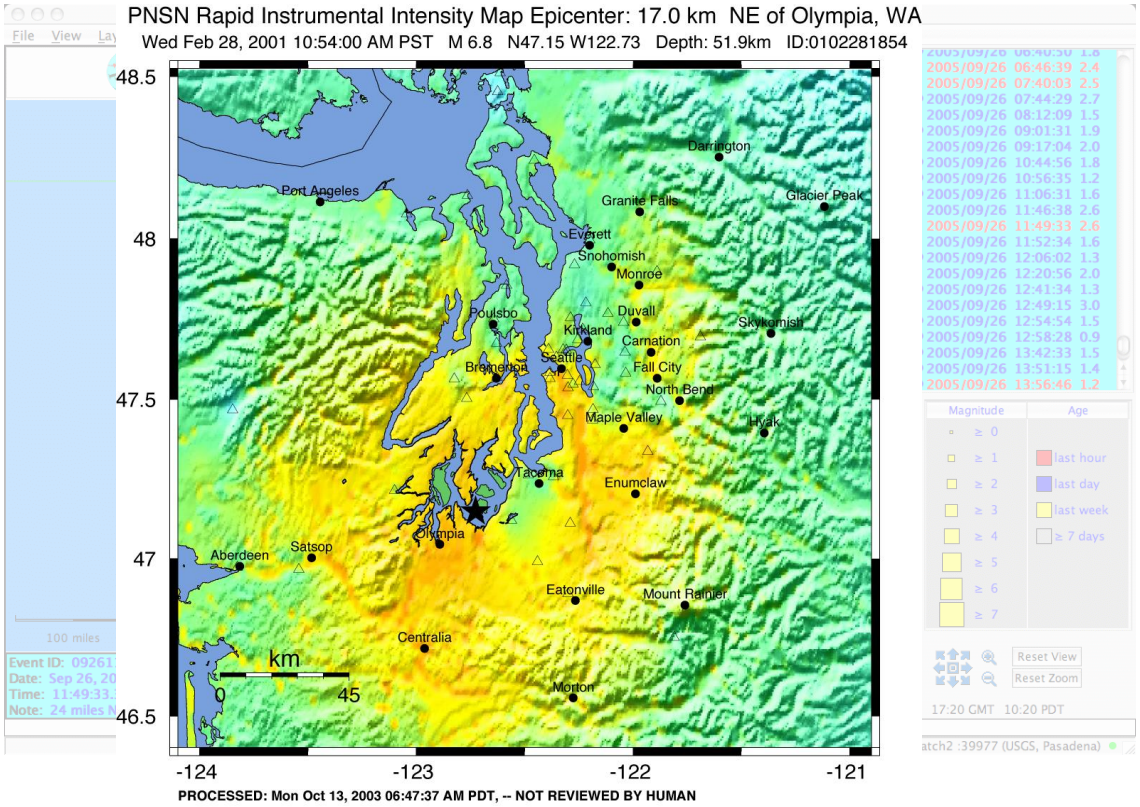
Broadcast notification of earthquakes



Near-realtime information products

Broadcast notification of earthquakes

ShakeMaps



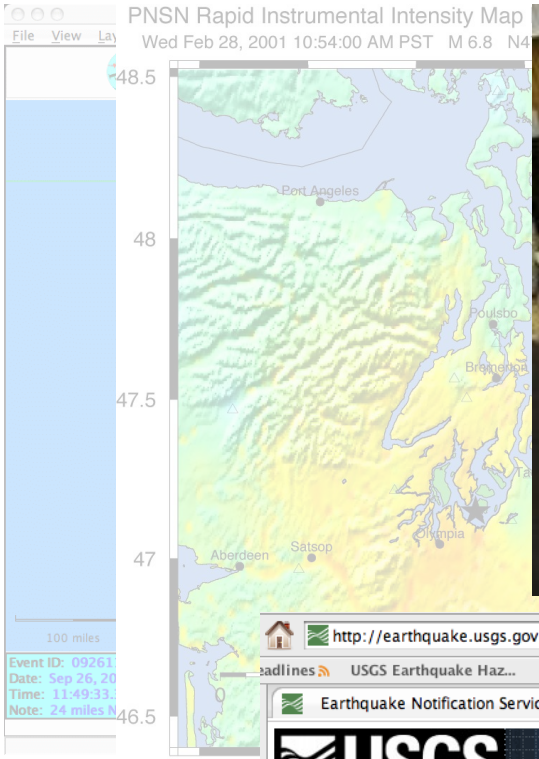
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

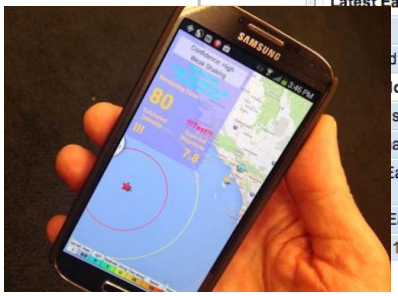
Near-realtime information products

Broadcast notification of earthquakes

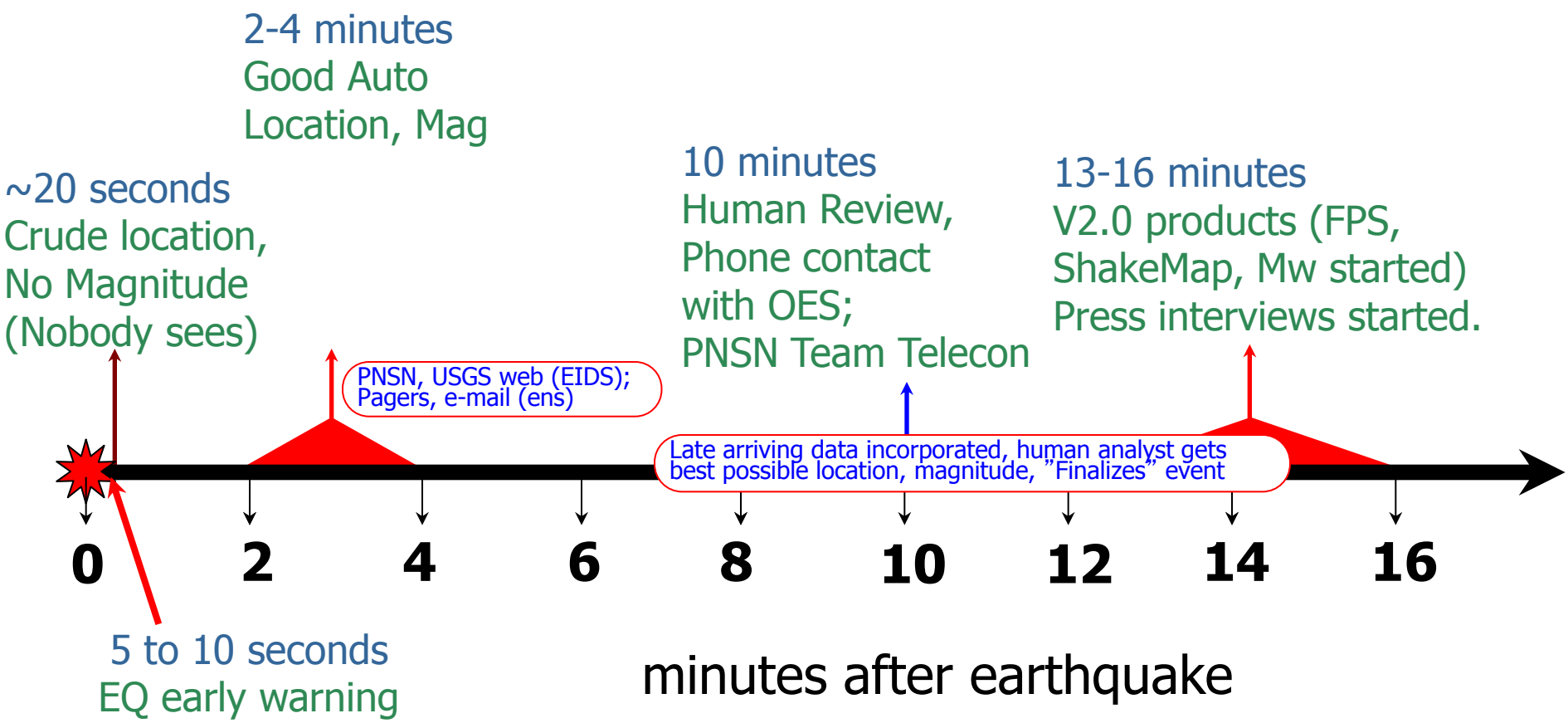
ShakeMaps

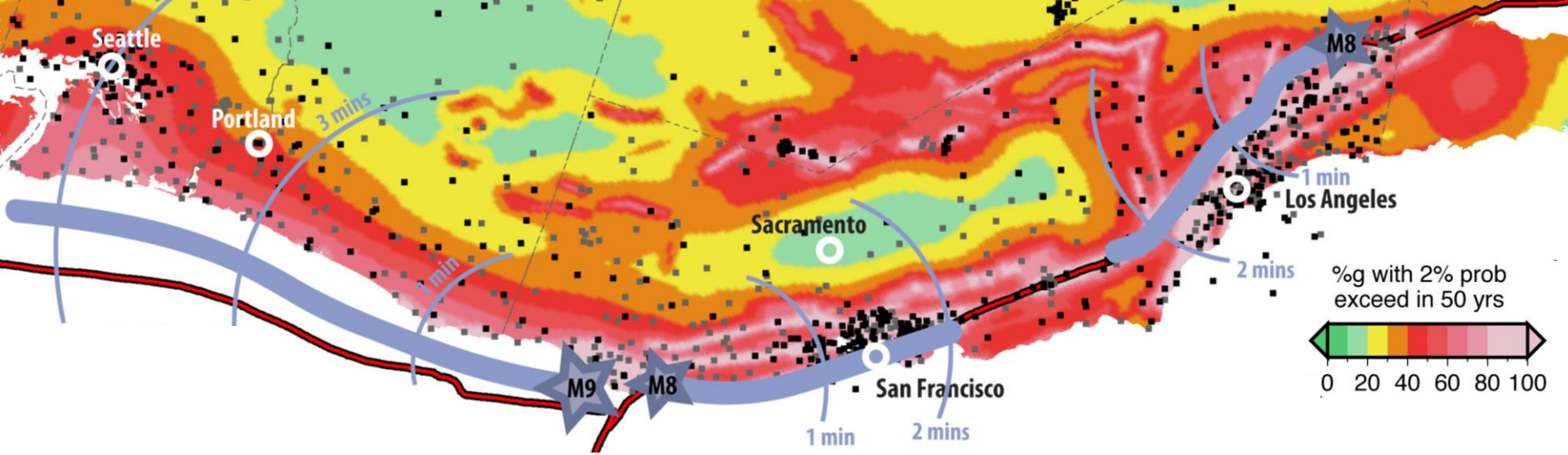
Earthquake Notification Service





Earthquake timeline





ShakeAlert:

Societal application of scientific data

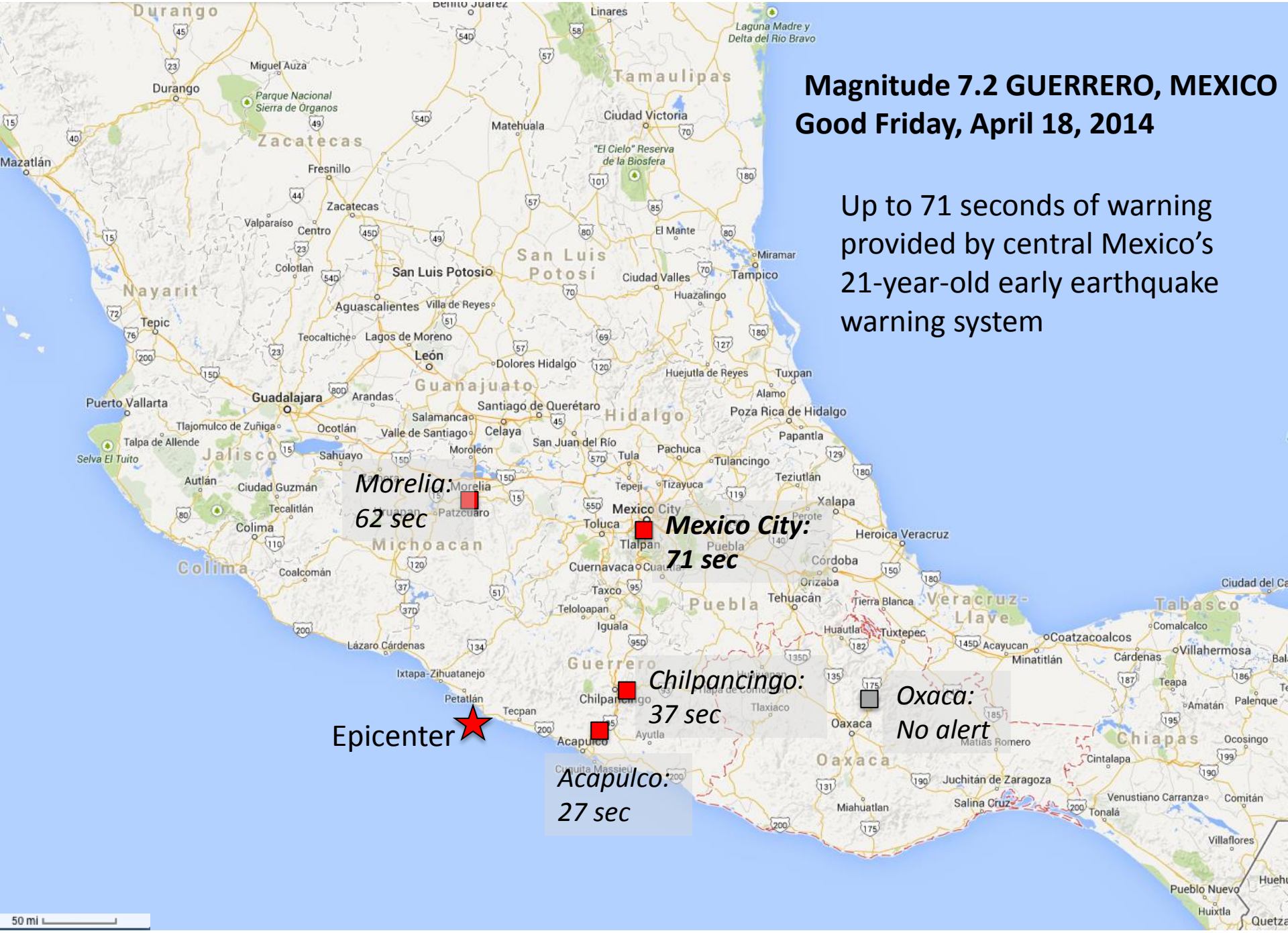
USGS science for a changing world · Caltech · Berkeley University of California · University of Washington · University of Oregon

Cal OES · ETH · SCEC an NSF+USGS center · Gordon and Betty Moore Foundation

ShakeAlert Major System Components

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

Good Friday, April 18, 2014
Mexico established an EEW system over 20 years ago


Magnitude 7.2 GUERRERO, MEXICO
Good Friday, April 18, 2014
Up to 71 seconds of warning provided by central Mexico's 21-year-old early earthquake warning system
Morelia:
62 sec
Mexico City:
71 sec
Chilpancingo:
37 sec
Oxaca:
No alert
Epicenter
Acapulco:
27 sec
Durango
Zacatecas
Tamaulipas
Nayarit
Jalisco
Michoacán
Guerrero
Oaxaca
Chiapas
Puebla
Hidalgo
Guanajuato
San Luis Potosí
Colima
Veracruz-Llave
Tabasco
Guadalajara
Mexico City
Morelia
Chilpancingo
Acapulco
Oaxaca
50 mi

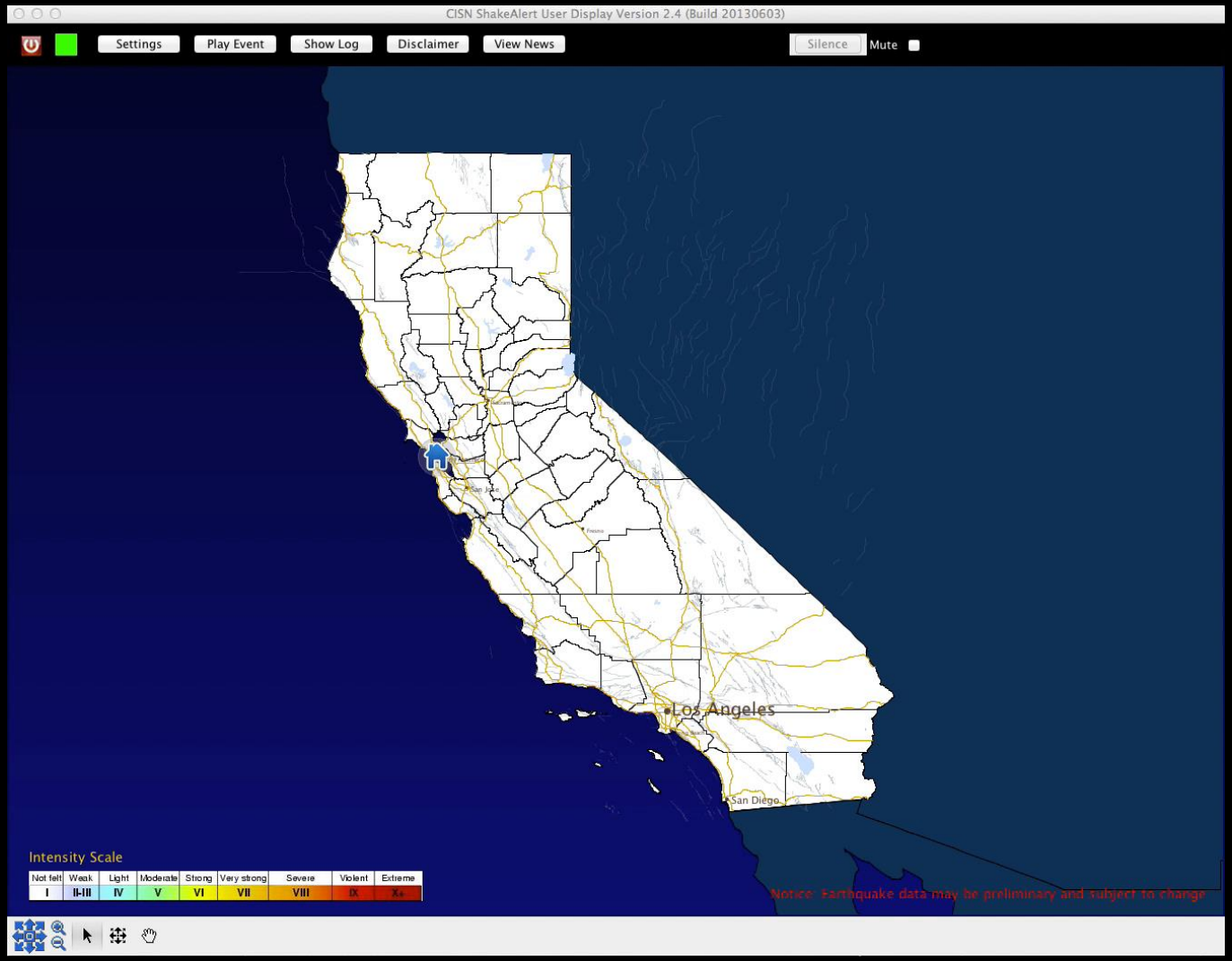
ShakeAlert

August 24, 2014, early in the morning…

Napa Performance

Sunday August 24th, 2014. 3:20 am PDT, **M6.0**

Alert at San Francisco 911 center on Turk St



BART trains

Automatically slow and stop trains – takes 24 sec

why?

Rush-hour:

- 10 car train: 1000 passengers
- 64 trains operating
- 40-45 traveling at 70 mph
- **How many might derail?**
- **Automatic deceleration reduces risk**

One 10-car train = $33 million

Post-earthquake recovery:

- $2.1B retrofit so BART remains operational
- Evacuate people + Bring in supplies
- **Only if derailed trains are not blocking the tracks**

Reducing
Falling hazards

Loma Prieta >50% injuries were linked to falls

Northridge >50% injuries were non-structural (falling) hazards

if everyone received a few seconds warning

if everyone dropped, took cover, and held on

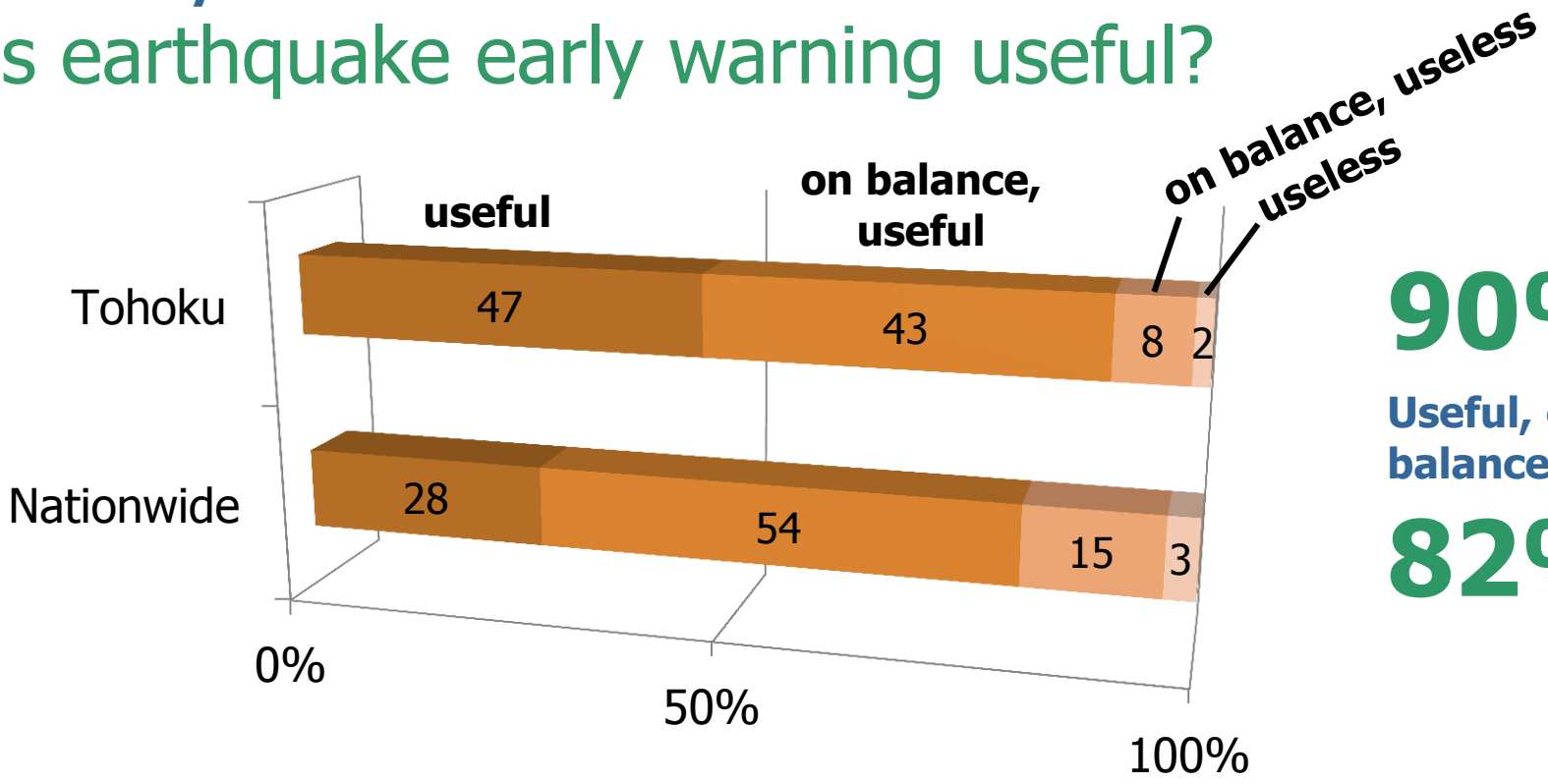
then early warning could reduce injuries by 50%

Cost of injuries in Northridge: $2-3 billion

Shoaf et al, 1998; Porter et al, 2006

JMA Survey of the Public

Is earthquake early warning useful?

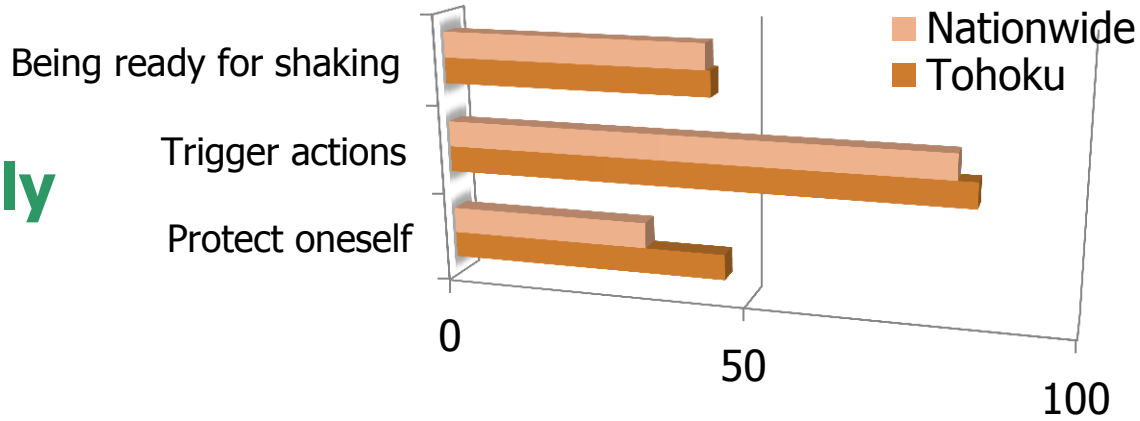


90%

Useful, or, On balance, useful

82%

Why is early warning useful?

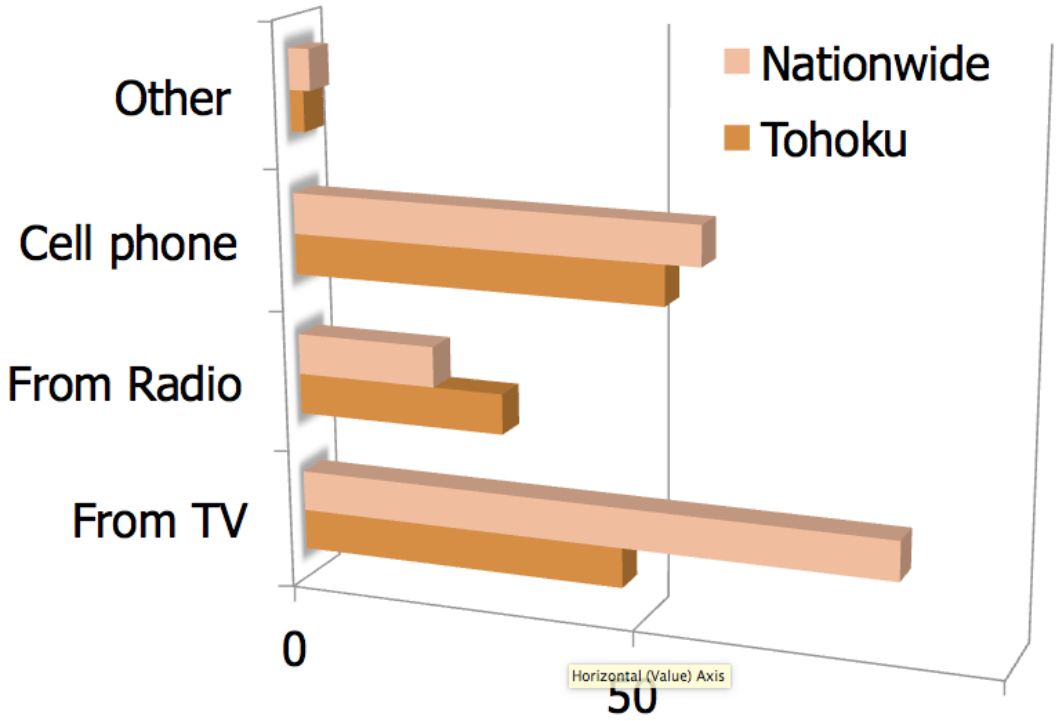


Data provided by Hoshiba

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

JMA Survey of the Public

How have you received warnings?



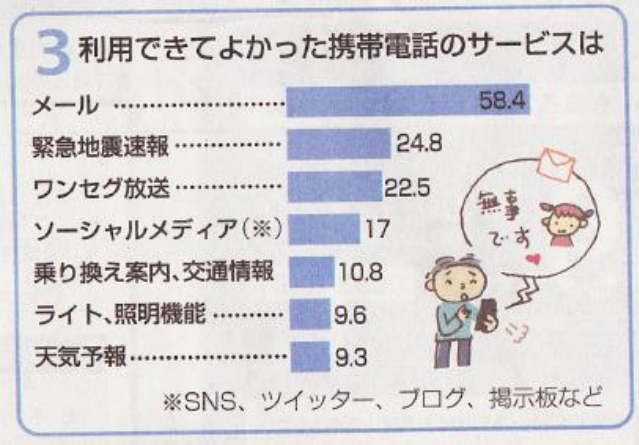
One third were sleeping
when their strongest
earthquake occurred

Of those sleeping
62% in the Tohoku region, and
75% nationwide were
woken by cell phone warning

Most useful cell phone app

1. Email 58%
2. **Earthquake alerts 25%**
3. TV 23%
4. Twitter, Blog 17%
5. Transportation info 11%

Asahi Shinbun Newspaper – June 2011



Data provided by Hoshiba

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

What facilities are needed?

Dense seismic and geodetic networks

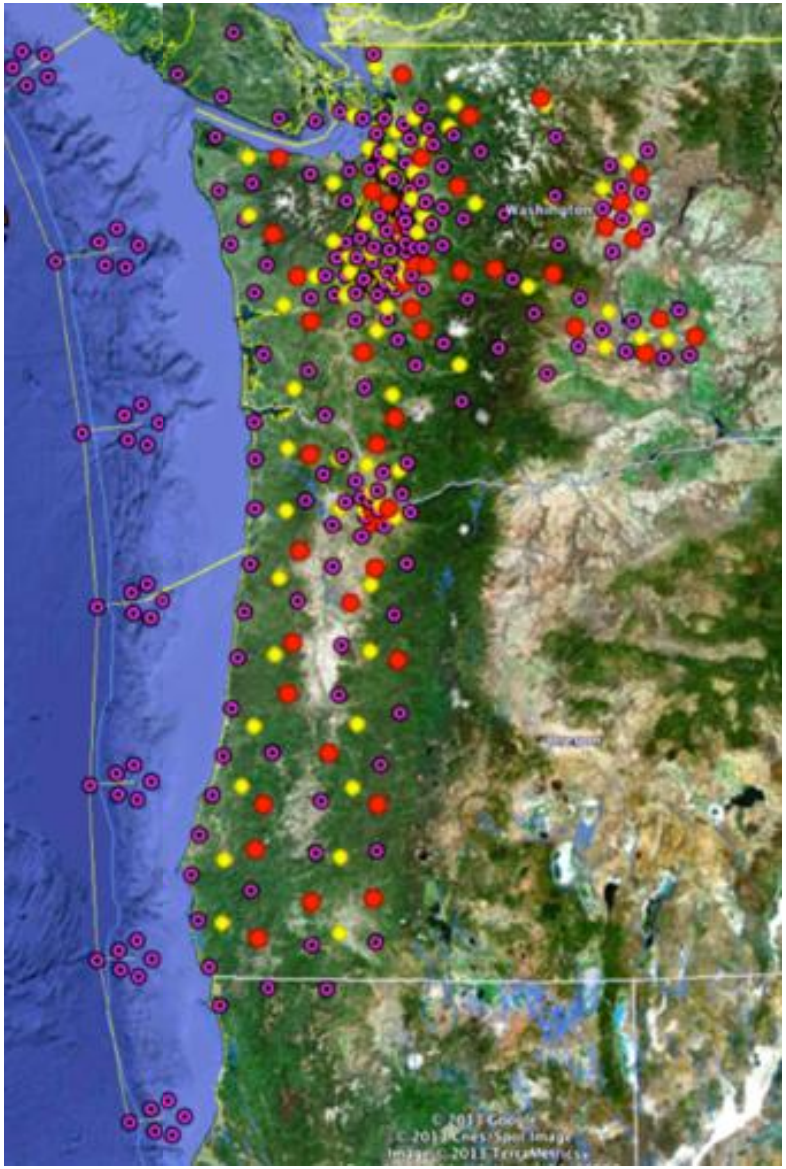
Seismic Risk

Deeper quakes (30-50km)

➔ **want ~30km spacing**

Shallow quakes (8km)

➔ **want 10-20km spacing**



Current goal: Onshore

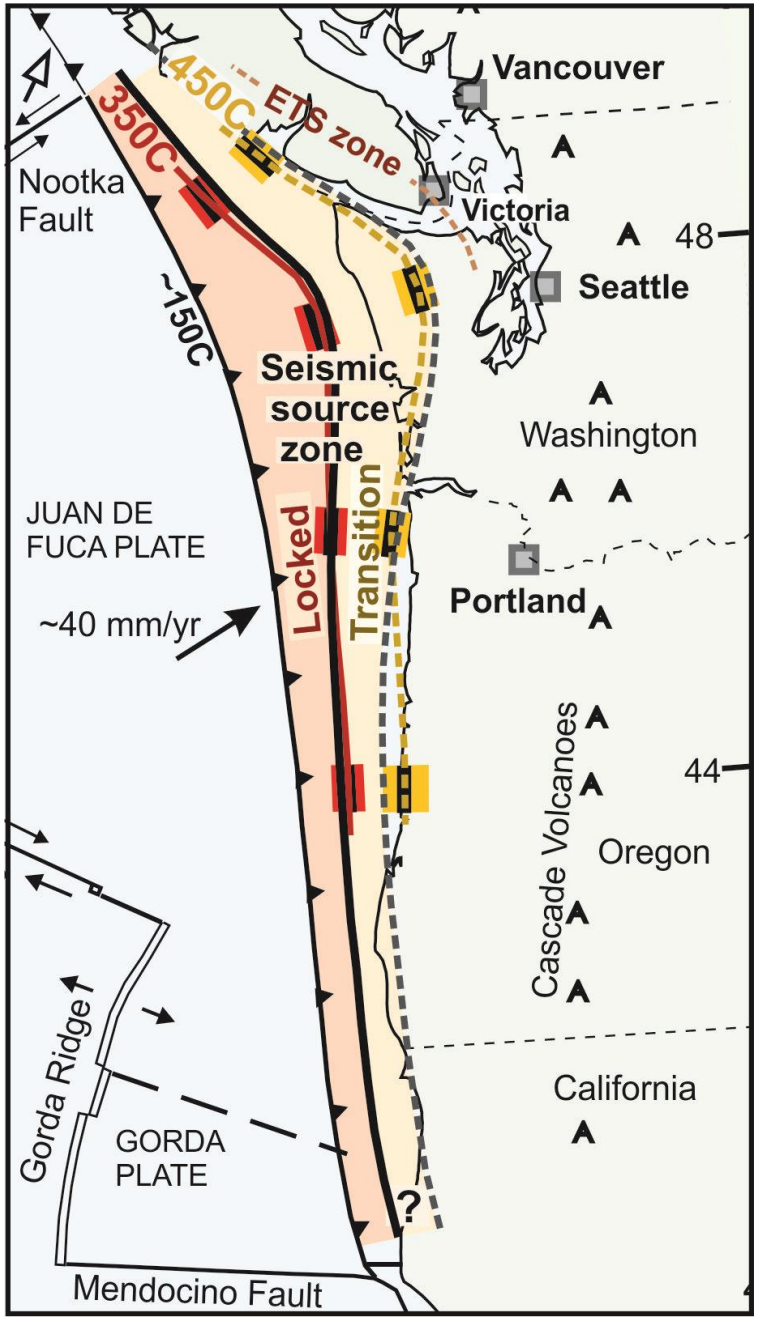
Ultimate goal: Offshore also

Opportunities for Partnership

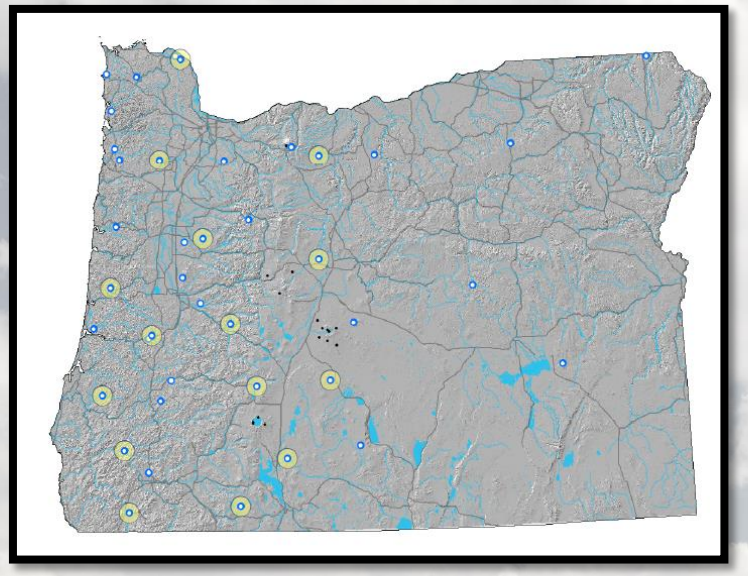
- Sensors & data
  - Buy & install sensors
  - Host ANSS sensors
  - Make EEW compliant devices
- Telemetry
  - Provide bandwidth
  - Host ANSS equipment
- Alert delivery
  - Integrate with mass notification systems
  - Integrate with apps
- Implementation
  - Make, install, service receivers & actuators
  - Develop user-specific decision logic
  - Integrate EEW with current hazard education

Summary

1. Earthquake Hazards in the Pacific Northwest
   - 3 earthquake threats
2. The Pacific Northwest Seismic Network
   - Operated by UW and UO
   - Monitors earthquakes and volcanoes
3. West Coast earthquake warning provides
   - Alert of event
   - Earthquake location and magnitude
   - Time to shaking
   - Intensity of shaking



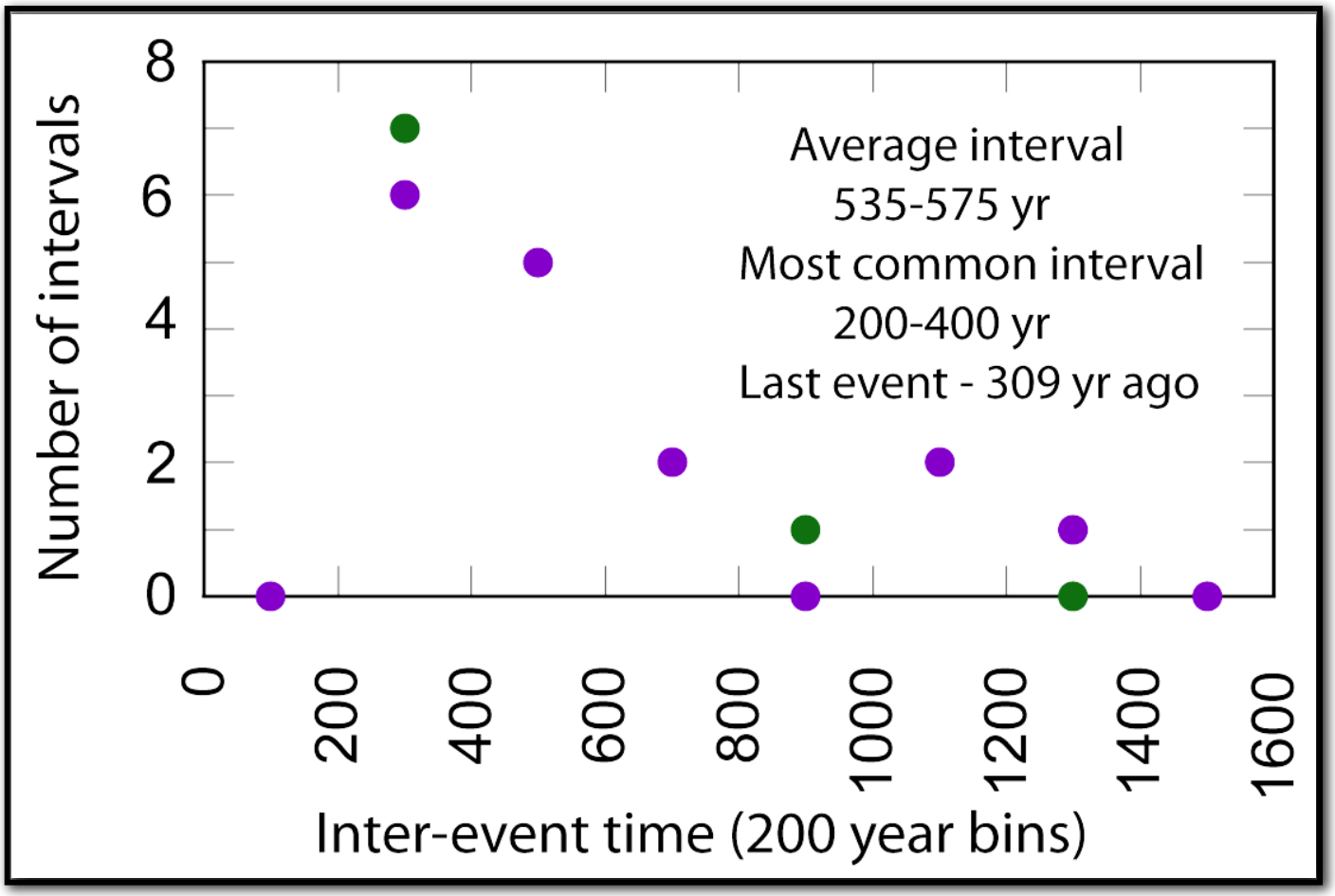
Thank you



What is earthquake early warning?

msnbc

August 25, 2014


Number of intervals
0
2
4
6
8
0
200
400
600
800
1000
1200
1400
1600
Inter-event time (200 year bins)
Average interval
535-575 yr
Most common interval
200-400 yr
Last event - 309 yr ago

Toward public warning

2012: Started running demonstration system
– delivered alerts for Napa, La Habra, etc.

2013: California's Earthquake Early Warning Law
– we should have a public system, *but no funding*

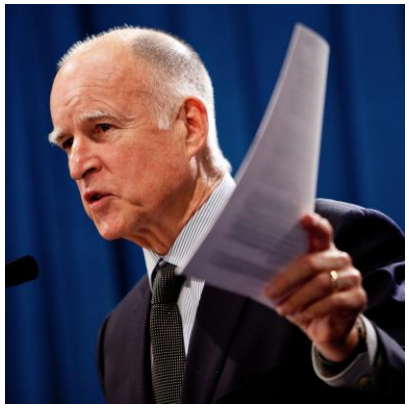
2014: US Congress appropriates $5 million (FY15)
– moving toward a public rollout
– infrastructure upgrades and more users

2015: President requests $5 million (FY16)

Total cost for a west coast system (CA+OR+WA)

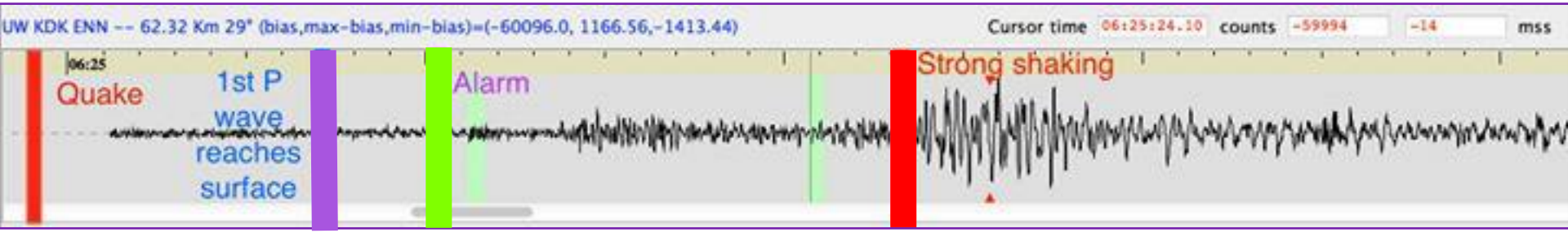
+ $16 million *per year* operation

+ $38 million infrastructure (one time)

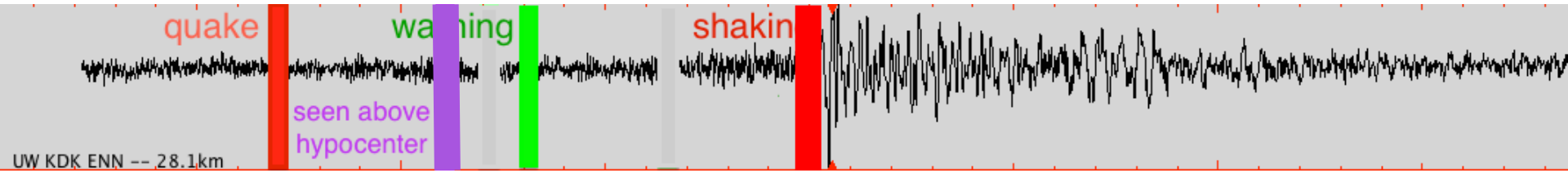


Recent tests of EEW system

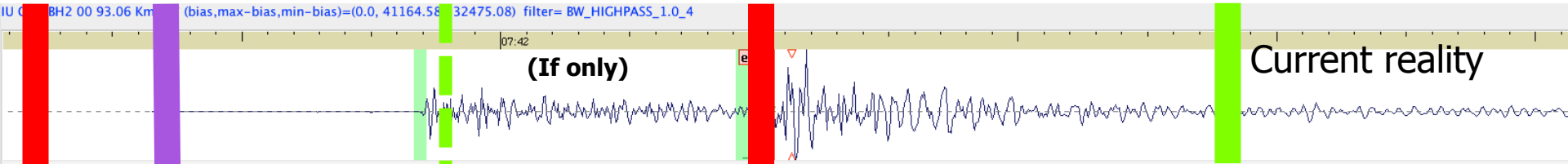
M3.5 event near Nisqually location, 13 s warning, right magnitude



M2.6 event 8km east of Redmond, 7s warning



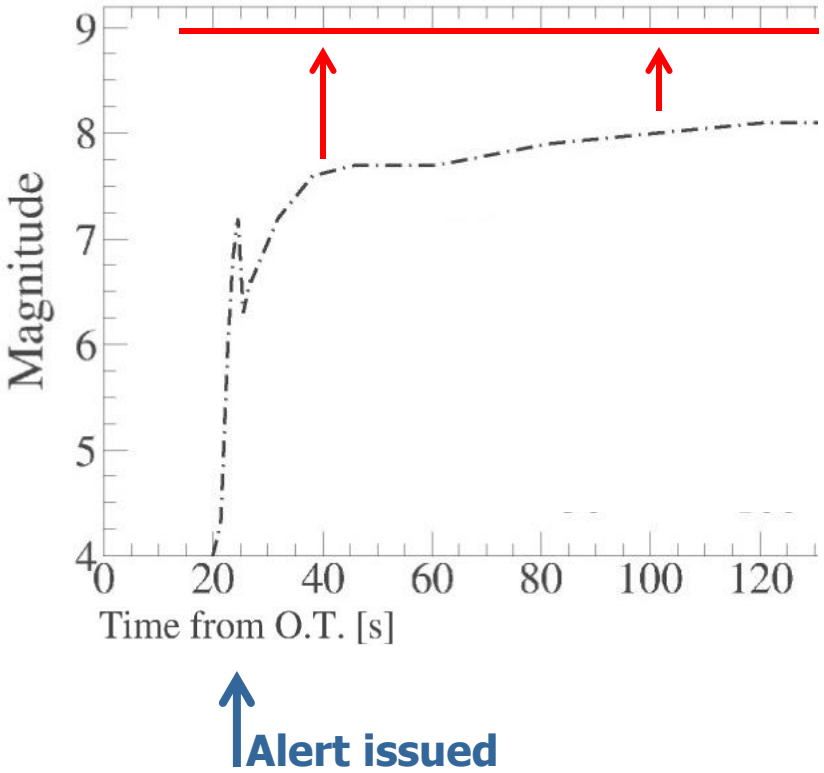
M3 off Salem, killed by latency



Japan

M_w9.0, Tohoku-oki

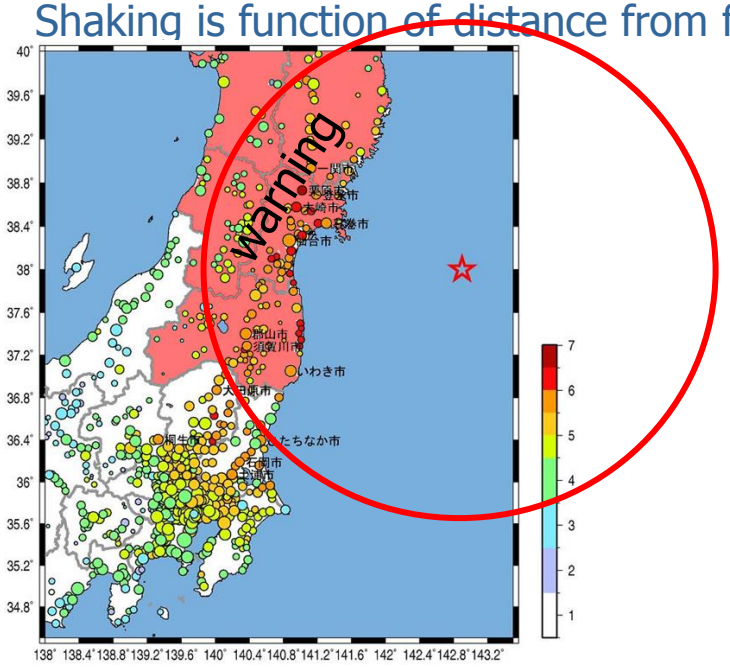
Success: warning issued



But, **two limitations** with point-source, seismology-based approach

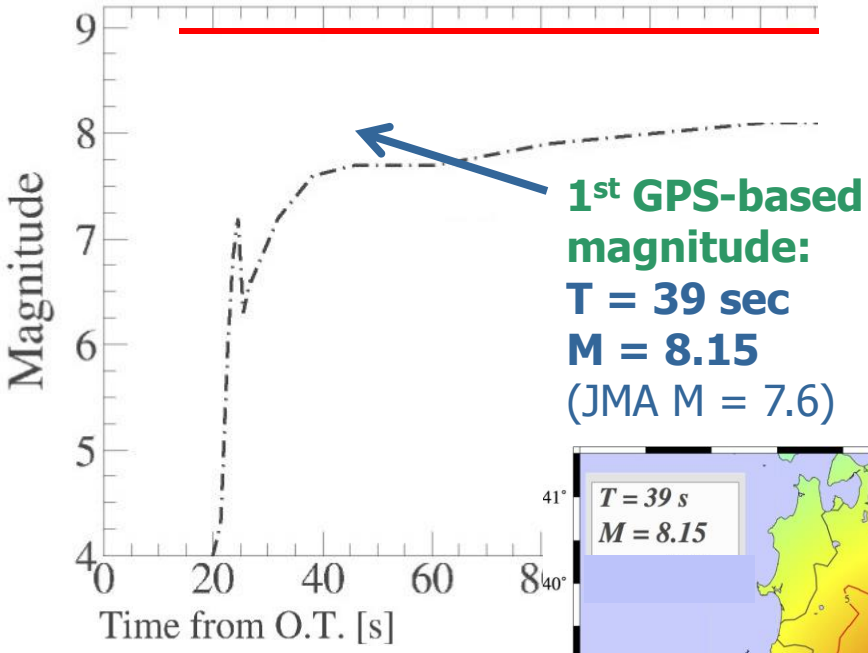
1. **Underestimates magnitude**
   - Estimated: M7.1 to 8.0
   - Actual: M9.0

2. **Point source approximation**
   - Estimates shaking by distance from epicenter
   - Shaking is function of distance from fault



Japan

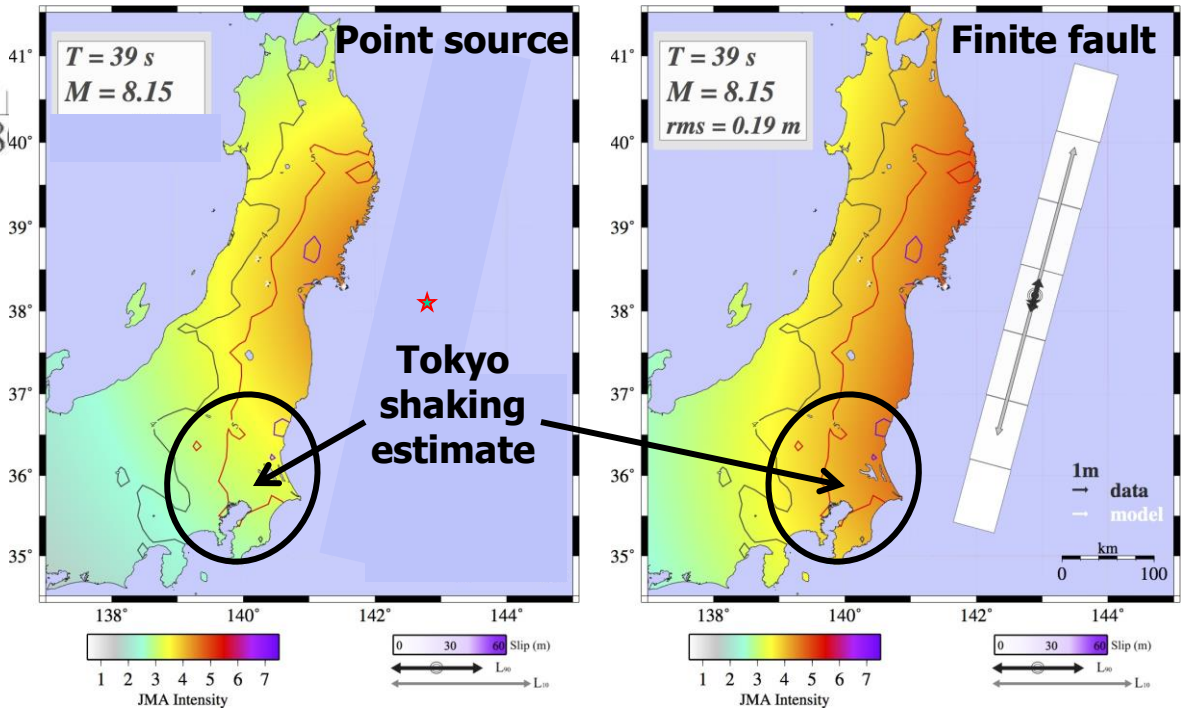
M_w9.0, Tohoku-oki



1st GPS-based magnitude:
T = 39 sec
M = 8.15
(JMA M = 7.6)

One solution:
Real-time GPS slip detection

1. **GPS-based magnitude**
   Better (higher) magnitude estimation from the first estimate
2. **GPS-based fault mapping**
   Estimate length if fault ruptured
   Shaking is function of distance from fault

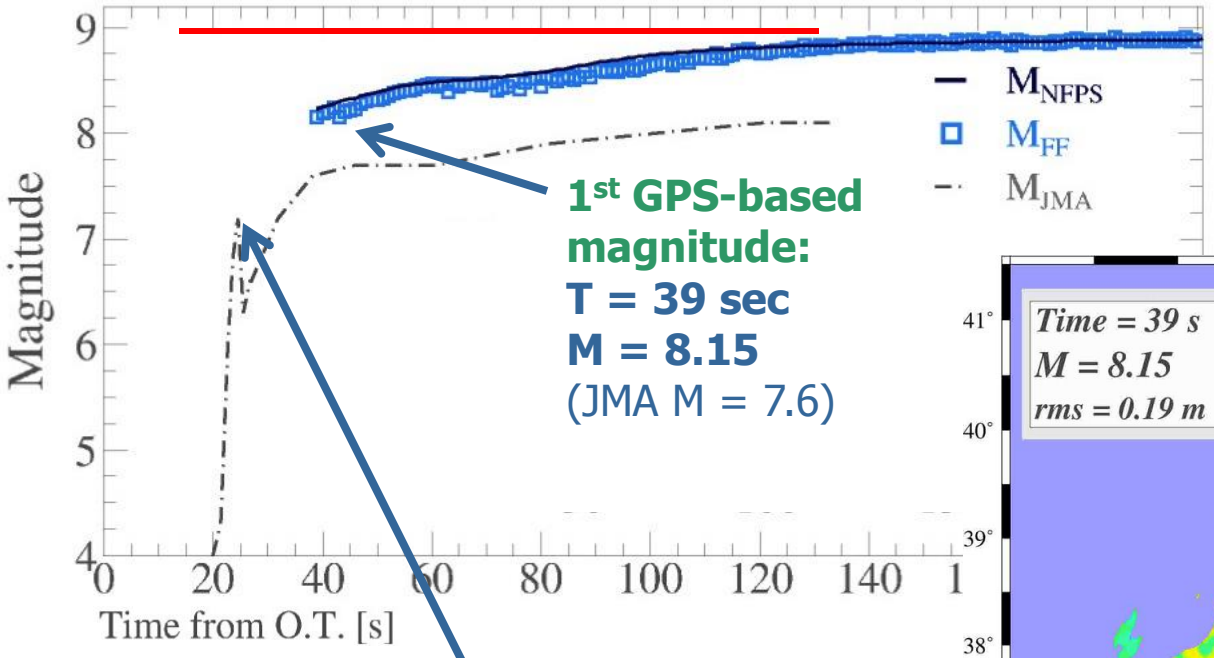


Colombelli *et al.* 2013

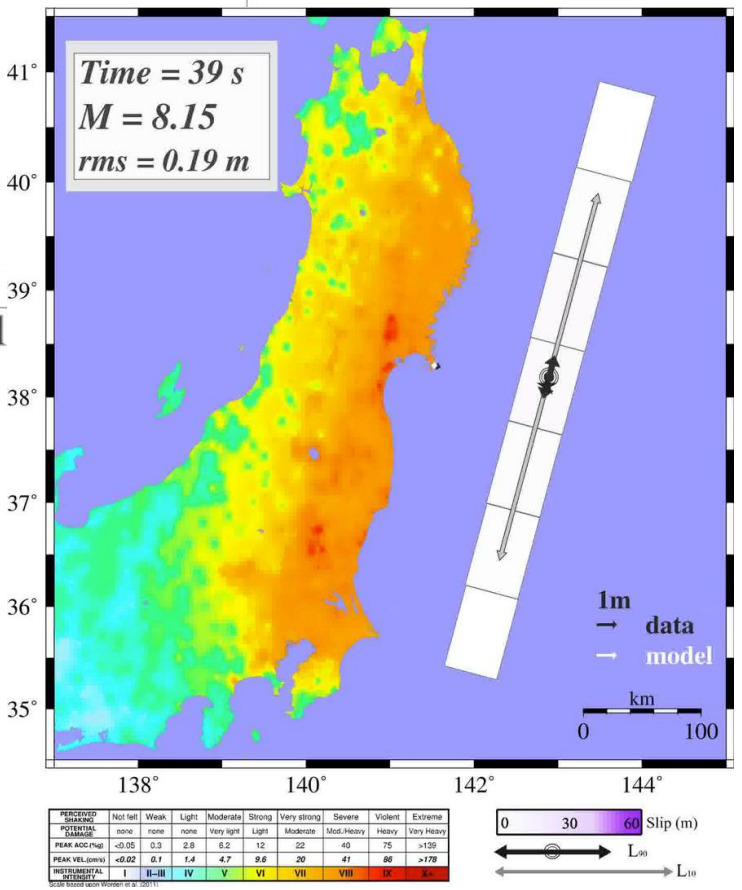
Japan

M_w9.0, Tohoku-oki

One solution:
Real-time GPS slip detection
improves with time

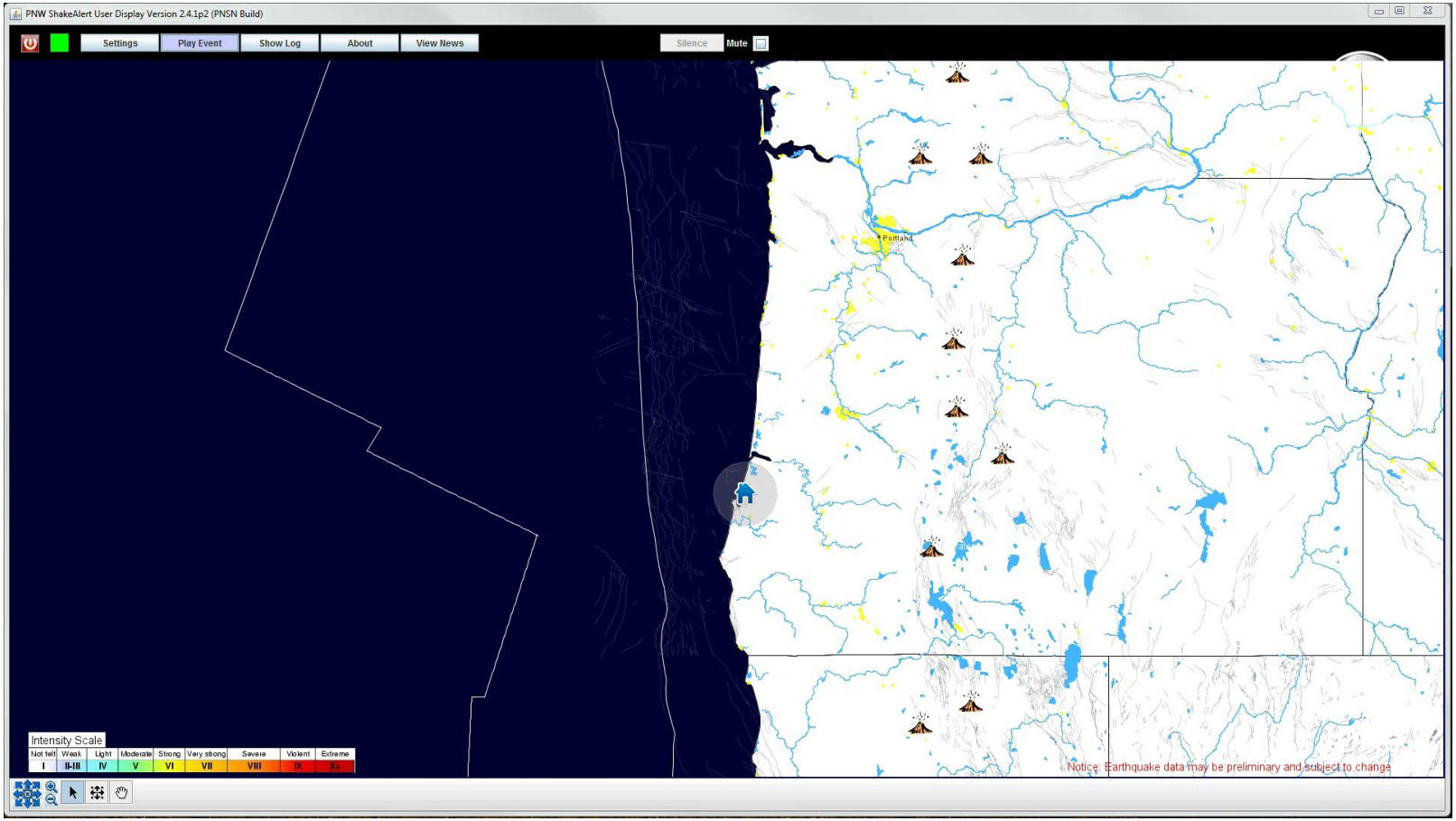


But…
P-wave based detections will always be first



Colombelli *et al.* 2013

Example: Cape Mendocino event



Example: Newport Event