MyShake

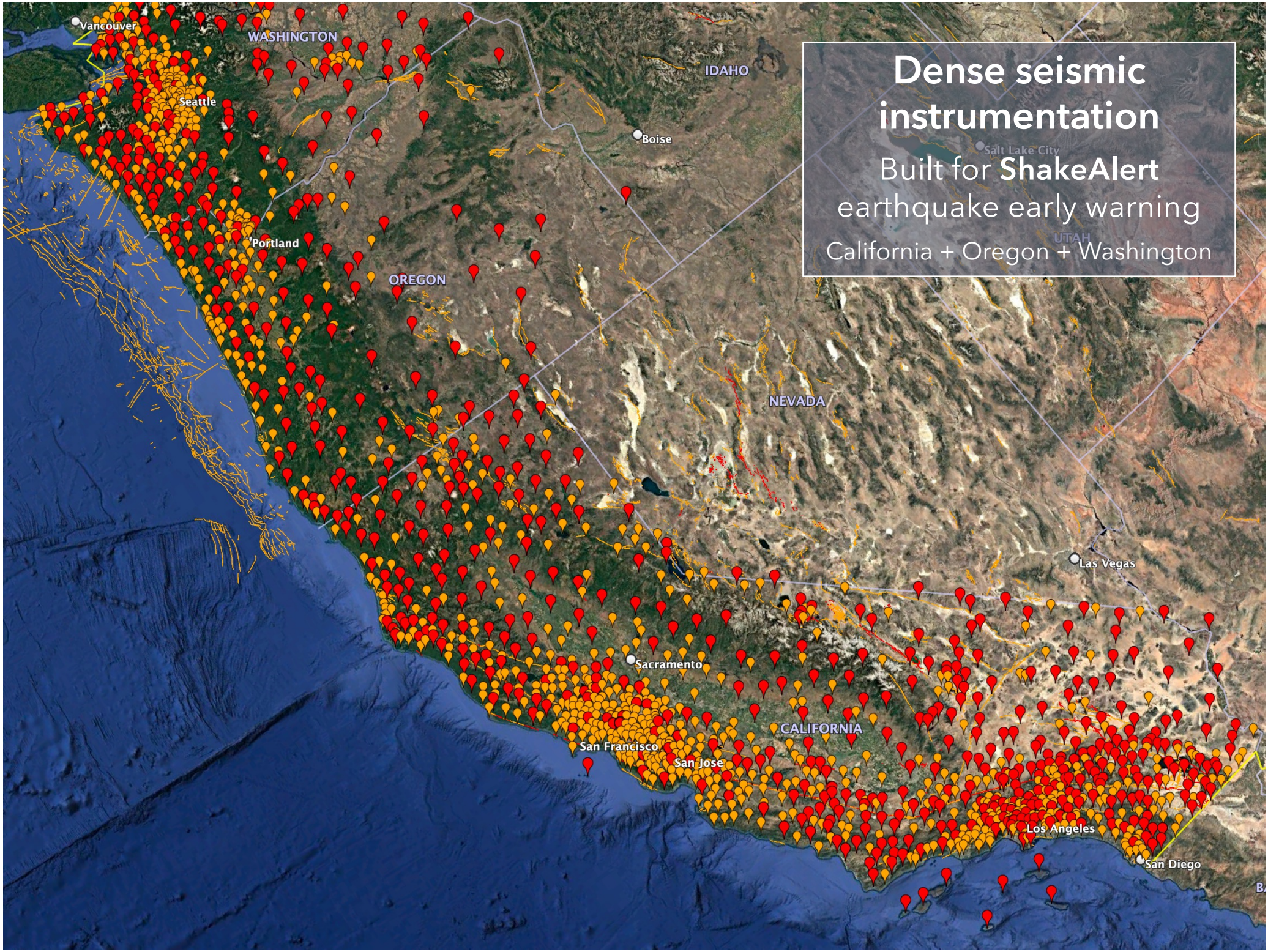
Capturing city-wide shaking

with a smartphone app

Richard Allen

Berkeley Seismology Lab

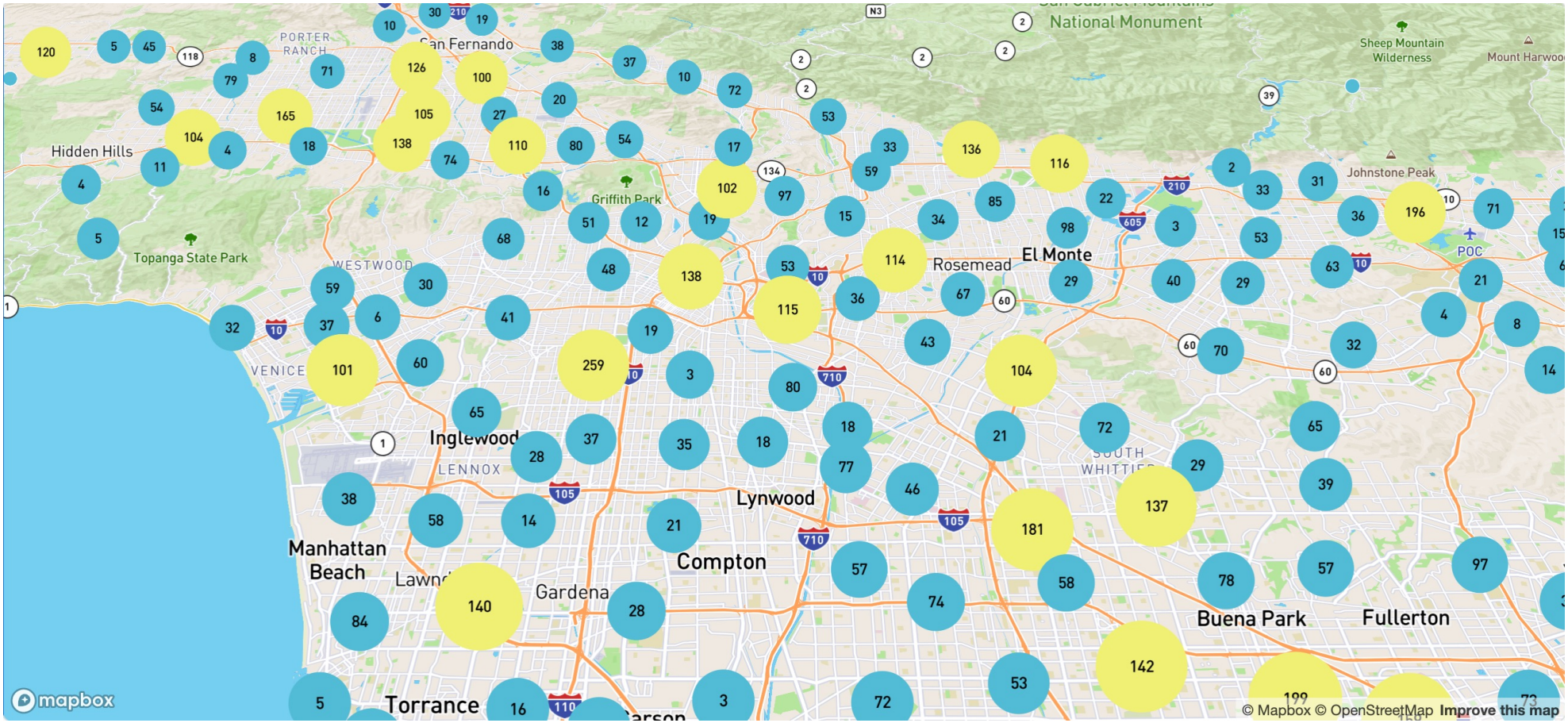
Google


Dense seismic instrumentation
Built for ShakeAlert earthquake early warning
California + Oregon + Washington
Vancouver
WASHINGTON
Seattle
IDAHO
Boise
Salt Lake City
UTAH
Portland
OREGON
NEVADA
Las Vegas
Sacramento
CALIFORNIA
San Francisco
San Jose
Los Angeles
San Diego

"Dense" seismic instrumentation
Built for ShakeAlert earthquake early warning
California + Oregon + Washington
Only course sampling of cities (5-10 km)
Need much denser observations to understand ground shaking across the urban environment
Santa Clarita
Kagel Canyon
San Fernando
Burbank
Altadena
Glendale
Pasadena
Arcadia
Azusa
Topanga
Beverly Hills
Alhambra
Covina
Los Angeles
El Monte
West Covina
Santa Monica
Culver City
Montebello
Marina Del Rey
Inglewood
Whittier
Downey
Manhattan Beach
Gardena
Compton
Norwalk
Brea
Torrance
Lakewood
Cerritos
Fullerton
Anaheim
Long Beach
Rancho Palos Verdes
Terminal Island
Garden Grove
Santa Ana
Fountain Valley
Irvine
Huntington Beach
Newport Beach
Lake Forest
Mission Viejo
Aliso Viejo
Laguna Beach
San Juan Capistrano
Trabuco Canyon
Temescal Valley
Corona
Yorba Linda
Norco
Eastvale
Riverside
Jurupa Valley
Chino Hills
Chino
Ontario
Pomona
Fontana
Colton
Woodcrest
Claremont
Rancho Cucamonga
Crestline
Victorville
Adelanto
Apple Valley

MyShake smartphone waveforms

collected across Los Angeles ***in 7 days***



MyShake smartphone waveforms

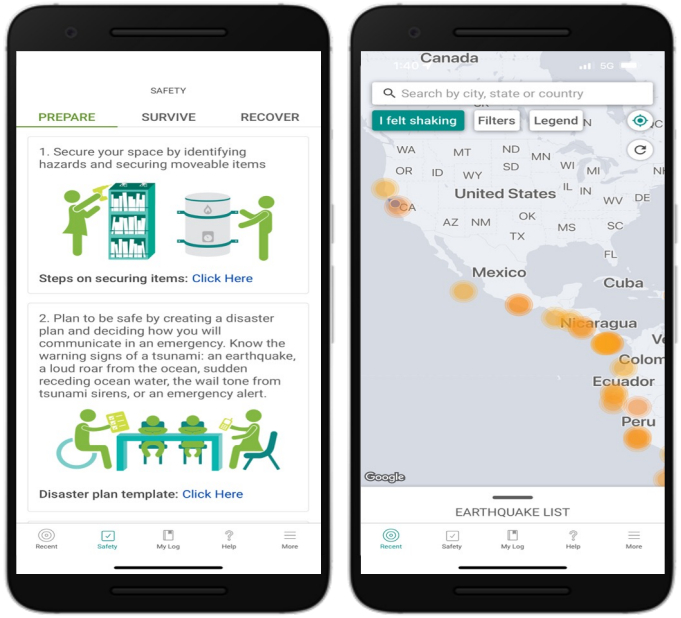
downtown Los Angeles in the ***last 5 years***

What is MyShake?

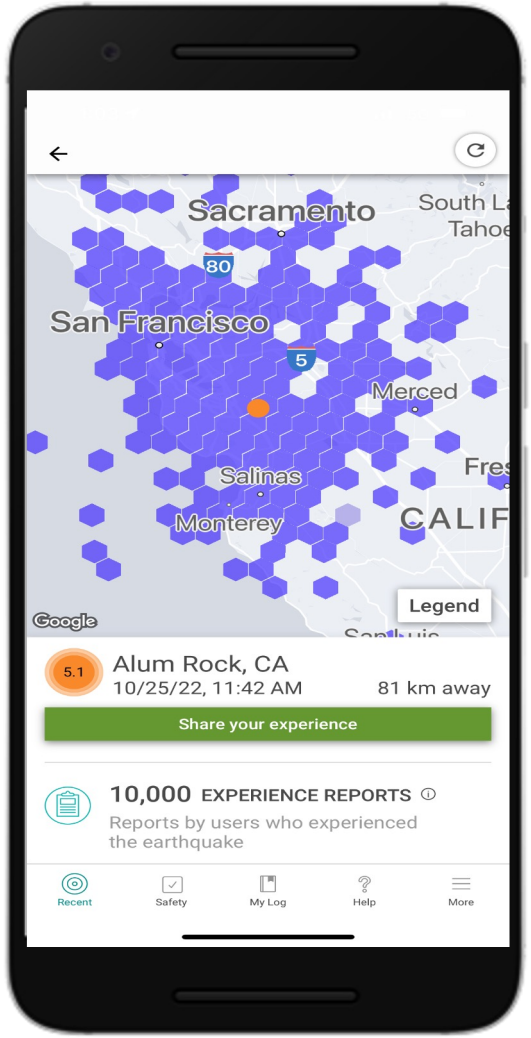
EARTHQUAKE WARNING CALIFORNIA

Available on the App Store

Available on Google Play



Safety information and global earthquakes



Detailed damage information reported by users

Early warning delivery

ShakeAlert: CA+OR+WA

MyShake Launched by California Governor Gavin Newson

The New York Times

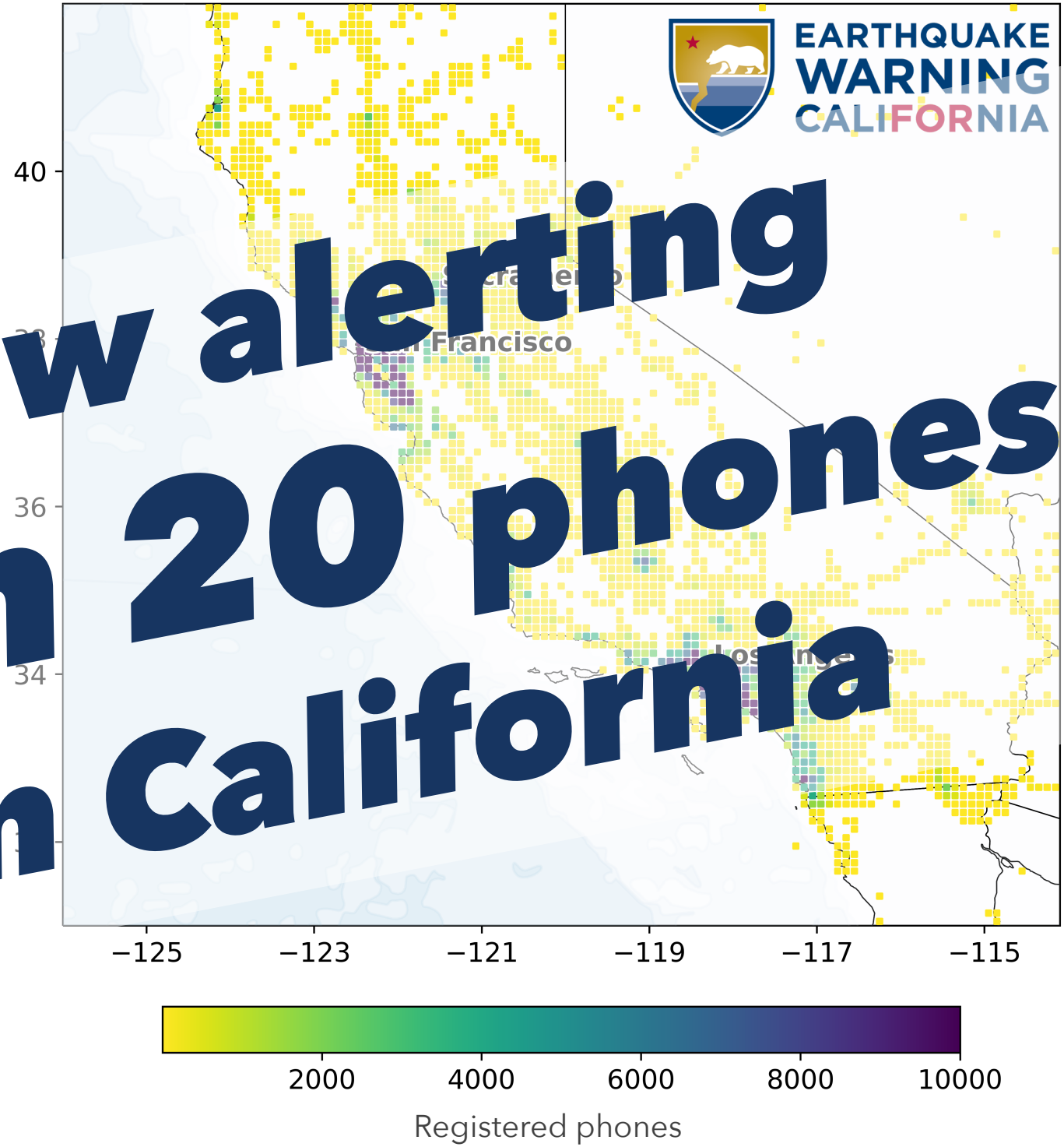
California Launches Earthquake Early Warning System It Calls Best in World

October 17, 2019

MyShake downloads

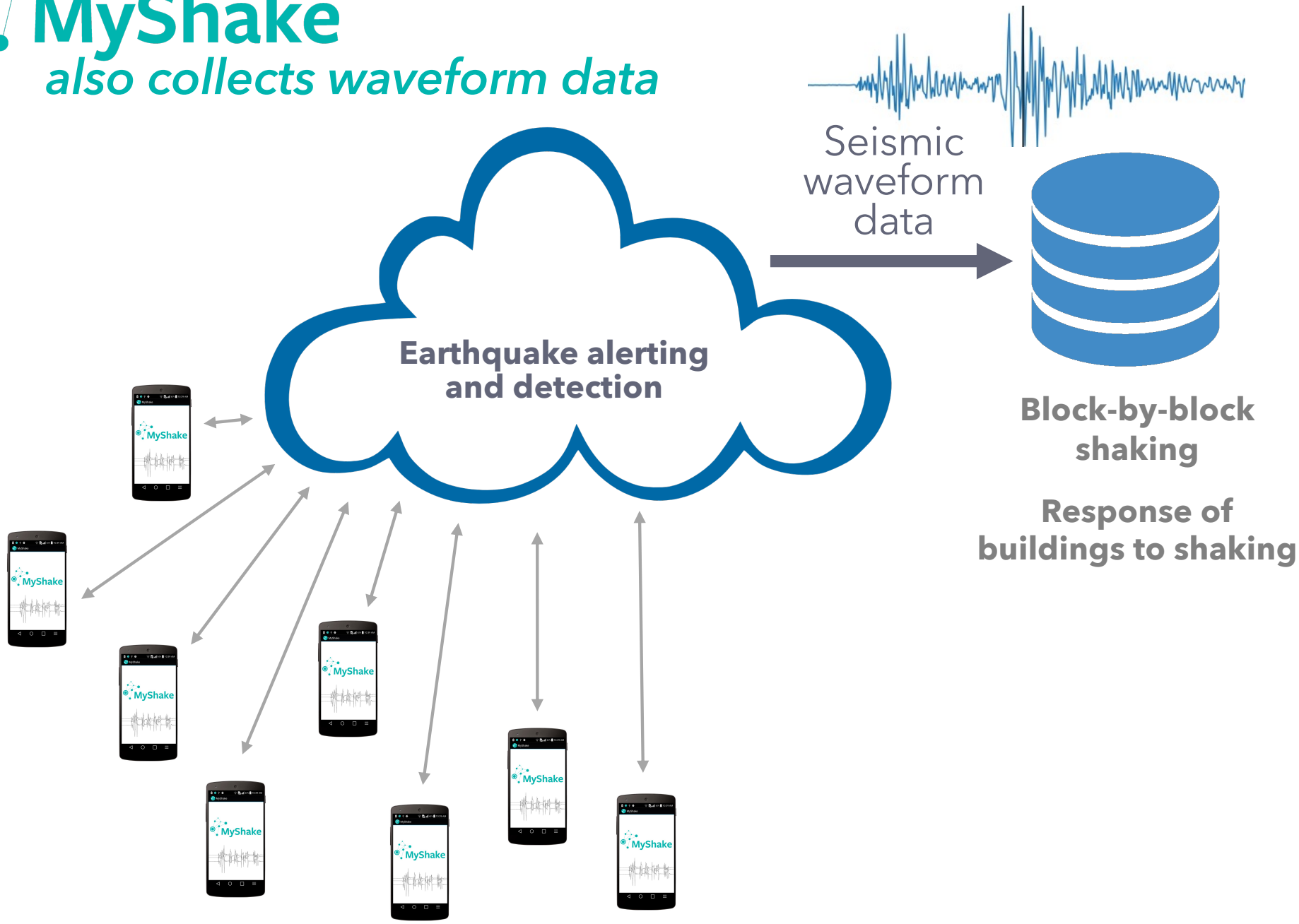
EARTHQUAKE WARNING CALIFORNIA

now alerting 1 in 20 phones in California



MyShake

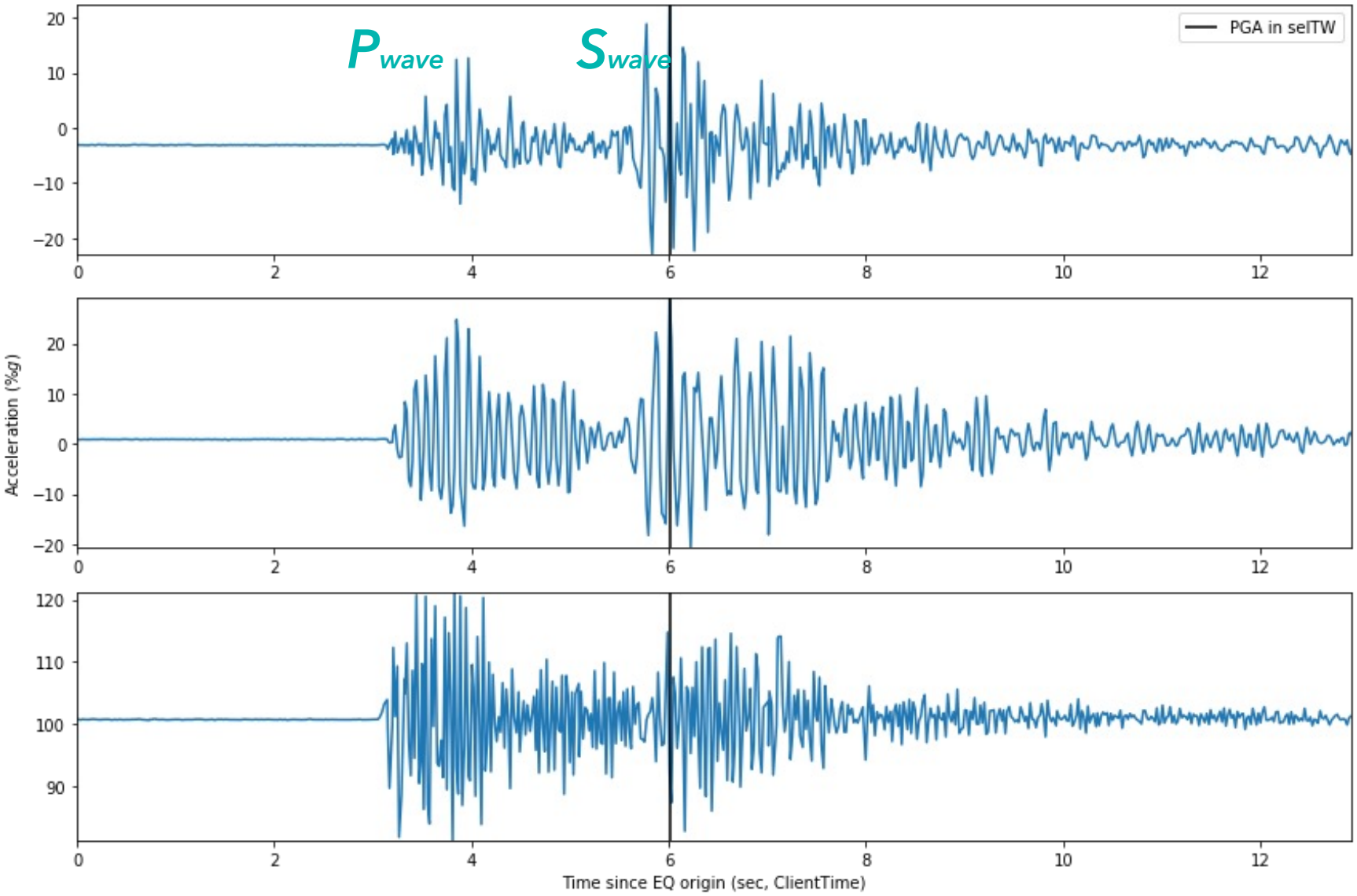
also collects waveform data



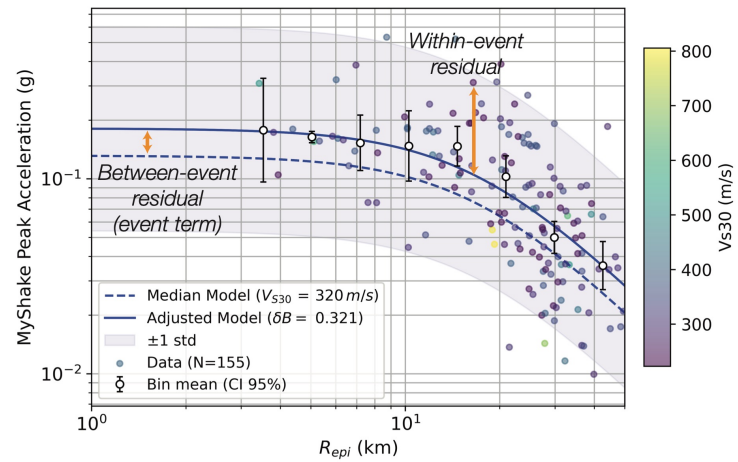
MyShake
also collects waveforms

M4.5 Los Angeles

3.4 km *epicentral distance*



Two opportunities



Shaking prediction

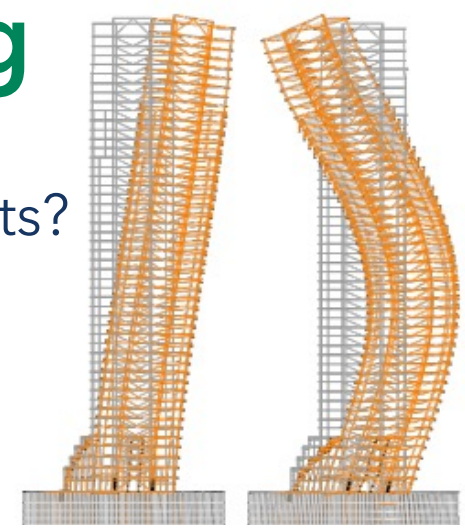
Ground motion prediction equations have a large uncertainty: ***factor of two in PGA***

➔ Can we reduce this with our new datasets?

Structural Health Monitoring

To ensure performance of building in earthquakes

➔ Can we monitor buildings with our new datasets?

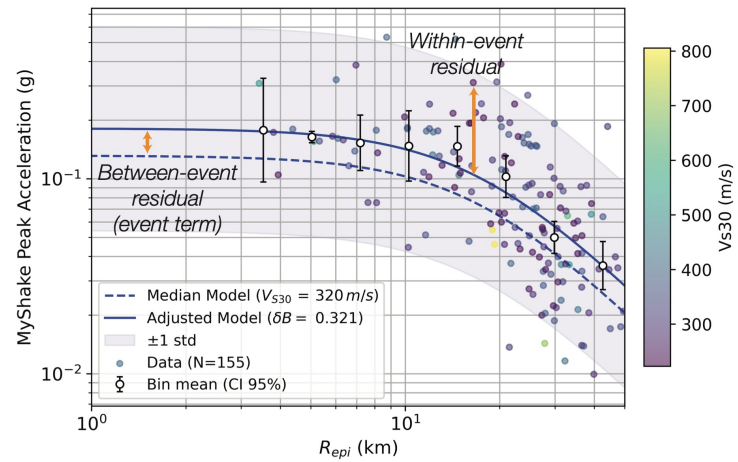


Two opportunities

Shaking prediction

Ground motion prediction equations have a large uncertainty: ***factor of two in PGA***

➔ Can we reduce this with our new datasets?



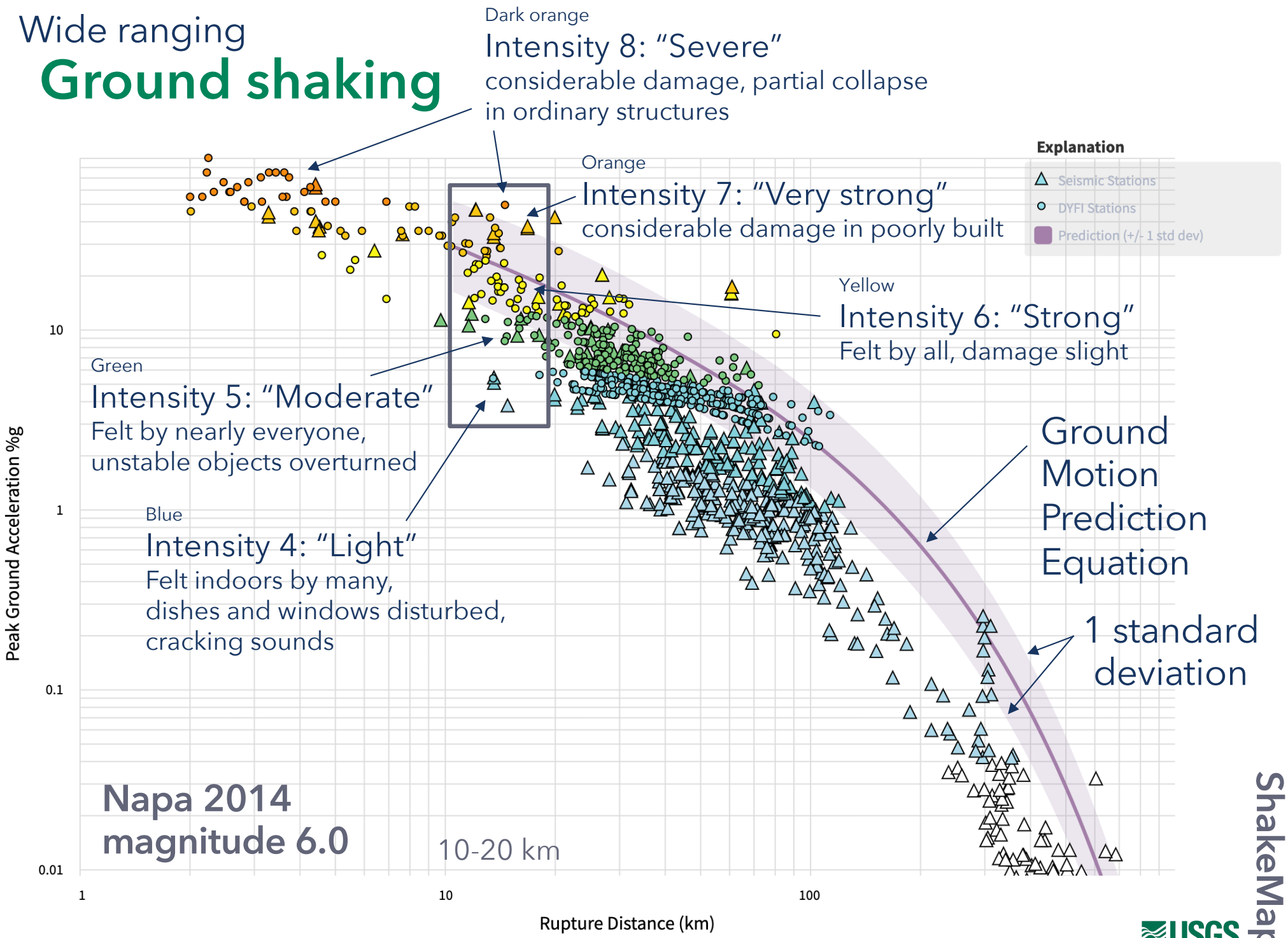
Structural Health Monitoring

To ensure performance of building in earthquakes

➔ Can we monitor buildings with our new datasets?

Wide ranging

Ground shaking



Ground Motion Prediction Equations
are important

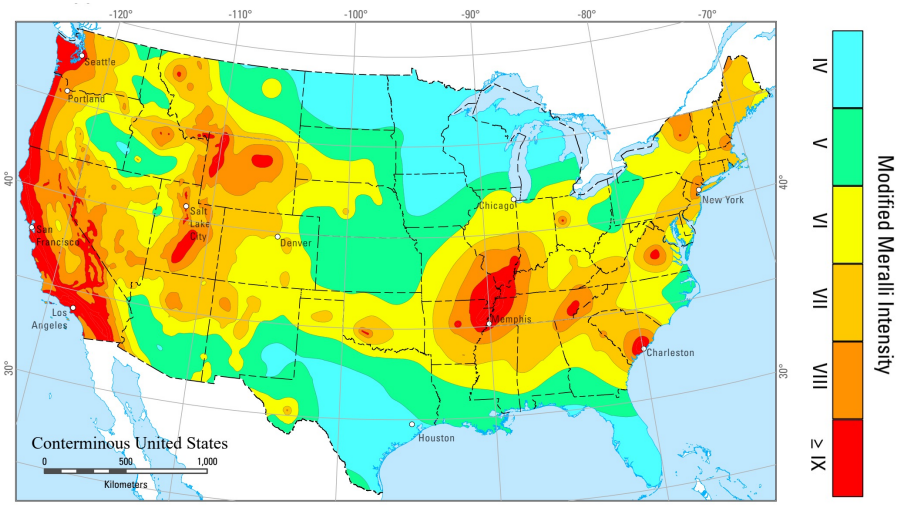
used to predict probabilistic ground motion for building standards and to determine alert area for earthquake early warning

Catalog of expected earthquake sources

+

Ground motion prediction equation

=



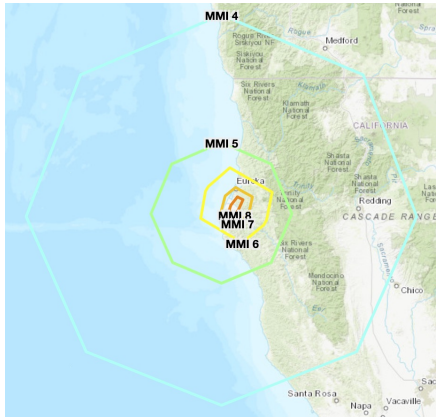
2% probability of exceedance in 50 years
NEHRP site class B/C (VS30 = 760 m/s)

magnitude and location

+

Ground motion prediction equation

=

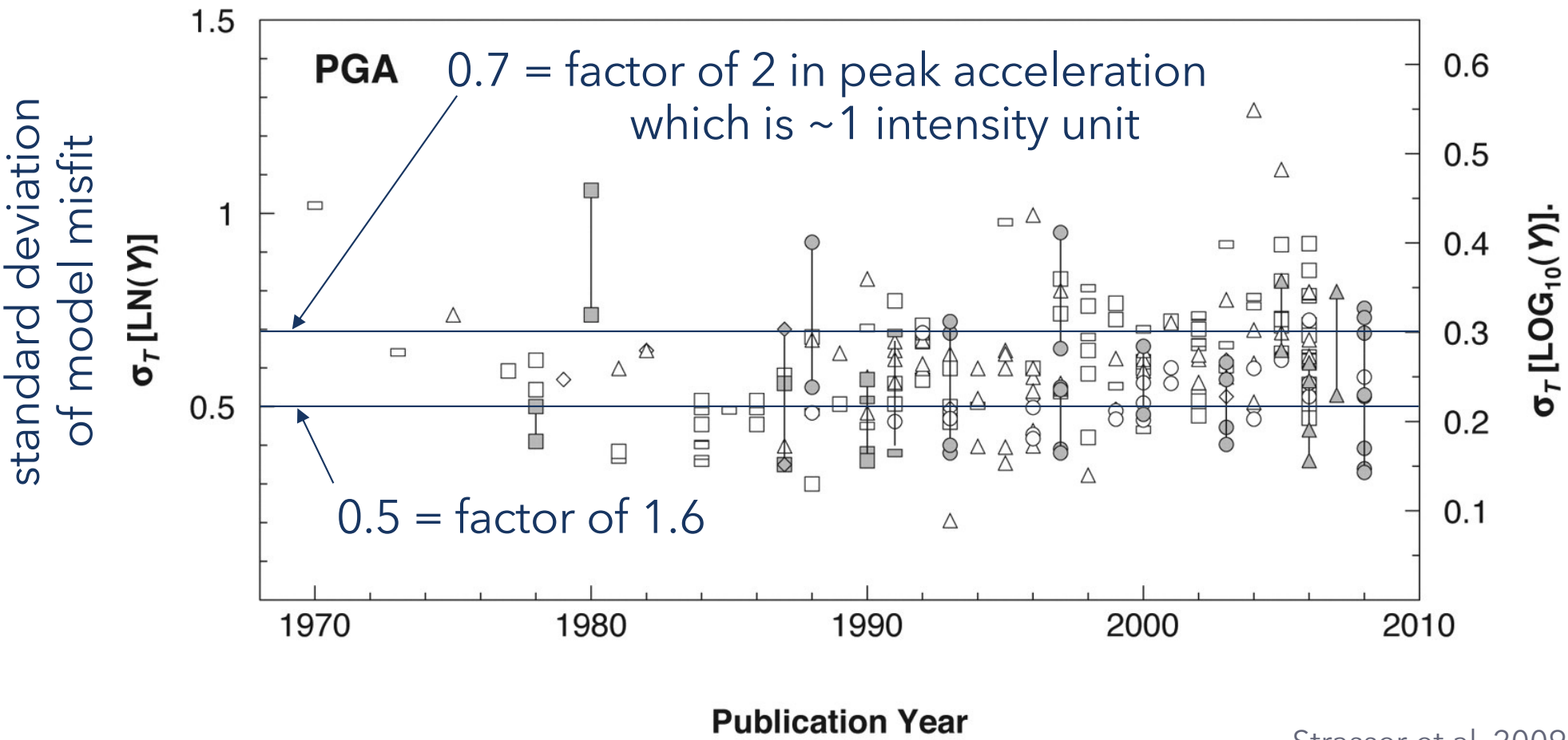


Alert region at various intensities

Ground Motion Prediction Equations
are important

used to predict probabilistic ground motion for building standards and to determine alert area for earthquake early warning

but they are not getting better!



Strasser et al, 2009

Ground Motion Prediction Equations

…despite their complexity

$$\ln Y = \begin{cases} \ln PGA; \\ f_{mag} + f_{dis} + f_{flt} + f_{hng} + f_{site} + f_{sed} + f_{hyp} + f_{dip} + f_{atn}; \end{cases}$$

Magnitude Term

$$f_{mag} = \begin{cases} c_0 + c_1\mathbf{M}; & \mathbf{M} \le 4.5 \\ c_0 + c_1\mathbf{M} + c_2(\mathbf{M} - 4.5); & 4.5 < \mathbf{M} \le 5.5 \\ c_0 + c_1\mathbf{M} + c_2(\mathbf{M} - 4.5) + c_3(\mathbf{M} - 5.5); & 5.5 < \mathbf{M} \le 6.5 \\ c_0 + c_1\mathbf{M} + c_2(\mathbf{M} - 4.5) + c_3(\mathbf{M} - 5.5) + c_4(\mathbf{M} - 6.5); & \mathbf{M} > 6.5 \end{cases}$$

Geometric Attenuation Term

$$f_{dis} = (c_5 + c_6\mathbf{M}) \ln\left(\sqrt{R_{RUP}^2 + c_7^2}\right)$$

Style of Faulting Term

$$f_{flt} = f_{flt,F} f_{flt,M}$$

$$f_{flt,F} = c_8 F_{RV} + c_9 F_{NM}$$

$$f_{flt,M} = \begin{cases} 0; & \mathbf{M} \le 4.5 \\ \mathbf{M} - 4.5; & 4.5 < \mathbf{M} \le 5.5 \\ 1; & \mathbf{M} > 5.5 \end{cases}$$

Hanging Wall Term

$$f_{hng} = c_{10} f_{hng,R_X} f_{hng,R_{RUP}} f_{hng,M} f_{hng,Z} f_{hng,\delta}$$

$$f_{hng,R_X} = \begin{cases} 0; & R_X < 0 \\ f_1(R_X); & 0 \le R_X < R_1 \\ \max\left[f_2(R_X), 0\right]; & R_X \ge R_1 \end{cases}$$

$$f_1(R_X) = h_1 + h_2(R_X/R_1) + h_3(R_X/R_1)^2$$

$$f_2(R_X) = h_4 + h_5\left(\frac{R_X - R_1}{R_2 - R_1}\right) + h_6\left(\frac{R_X - R_1}{R_2 - R_1}\right)^2$$

$$R_1 = W\cos(\delta)$$

$$R_2 = 62\mathbf{M} - 350$$

$$f_{hng,R_{RUP}} = \begin{cases} 1; & R_{RUP} = 0 \\ (R_{RUP} - R_{JB})/R_{RUP}; & R_{RUP} > 0 \end{cases}$$

$$f_{hng,M} = \begin{cases} 0; & \mathbf{M} \le 5.5 \\ (\mathbf{M} - 5.5)[1 + a_2(\mathbf{M} - 6.5)]; & 5.5 < \mathbf{M} \le 6.5 \\ 1 + a_2(\mathbf{M} - 6.5); & \mathbf{M} > 6.5 \end{cases}$$

$$f_{hng,Z} = \begin{cases} 1 - 0.06Z_{TOR}; & Z_{TOR} \le 16.66 \\ 0; & Z_{TOR} > 16.66 \end{cases}$$

$$f_{hng,\delta} = (90 - \delta)/45$$

Site Response Term

$$f_{site} = f_{site,G} + S_J f_{site,J}$$

$$f_{site,G} = \begin{cases} c_{11}\ln\left(\frac{V_{S30}}{k_1}\right) + k_2\left\{\ln\left[A_{1100} + c\left(\frac{V_{S30}}{k_1}\right)^n\right] - \ln[A_{1100} + c]\right\}; & V_{S30} \le k_1 \\ (c_{11} + k_2 n)\ln\left(\frac{V_{S30}}{k_1}\right); & V_{S30} > k_1 \end{cases}$$

$$f_{site,J} = \begin{cases} (c_{12} + k_2 n)\left[\ln\left(\frac{V_{S30}}{k_1}\right) - \ln\left(\frac{200}{k_1}\right)\right]; & V_{S30} \le 200 \\ (c_{13} + k_2 n)\ln\left(\frac{V_{S30}}{k_1}\right); & \text{All } V_{S30} \end{cases}$$

Basin Response Term

$$f_{sed} = \begin{cases} (c_{14} + c_{15}S_J)(Z_{2.5} - 1); & Z_{2.5} \le 1 \\ 0; & 1 < Z_{2.5} \le 3 \\ c_{16}k_3 e^{-0.75}[1 - \exp(-0.25(Z_{2.5} - 3)]; & Z_{2.5} > 3 \end{cases}$$

Hypocentral Depth Term

$$f_{hyp} = f_{hyp,H} f_{hyp,M}$$

$$f_{hyp,H} = \begin{cases} 0; & Z_{HYP} \le 7 \\ Z_{HYP} - 7; & 7 < Z_{HYP} \le 20 \\ 13; & Z_{HYP} > 20 \end{cases}$$

$$f_{hyp,M} = \begin{cases} c_{17}; & \mathbf{M} \le 5.5 \\ [c_{17} + (c_{18} - c_{17})(\mathbf{M} - 5.5)]; & 5.5 < \mathbf{M} \le 6.5 \\ c_{18}; & \mathbf{M} > 6.5 \end{cases}$$

Fault Dip Term

$$f_{dip} = \begin{cases} c_{19}\delta; & \mathbf{M} \le 4.5 \\ c_{19}(5.5 - \mathbf{M})\delta; & 4.5 < \mathbf{M} \le 5.5 \\ 0; & \mathbf{M} > 5.5 \end{cases}$$

Anelastic Attenuation Term

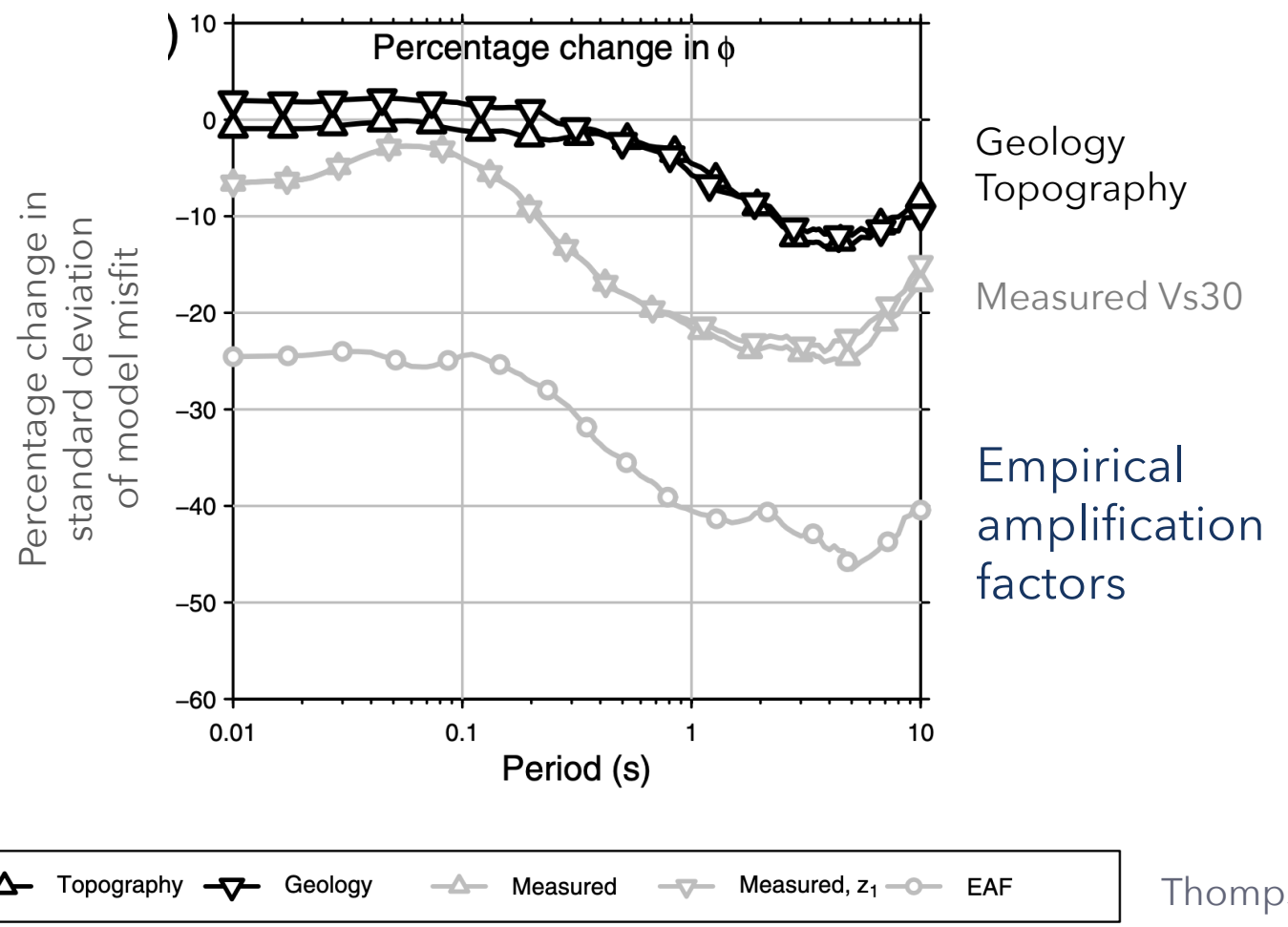
$$f_{atn} = \begin{cases} (c_{20} + \Delta c_{20})(R_{RUP} - 80); & R_{RUP} > 80 \\ 0; & R_{RUP} \le 80 \end{cases}$$

Campbell & Bozorgnia 2013

Ground Motion Prediction Equations
are important

used to predict probabilistic ground motion for building standards and to determine alert area for earthquake early warning

➔ site observations are needed (non-ergodic models)



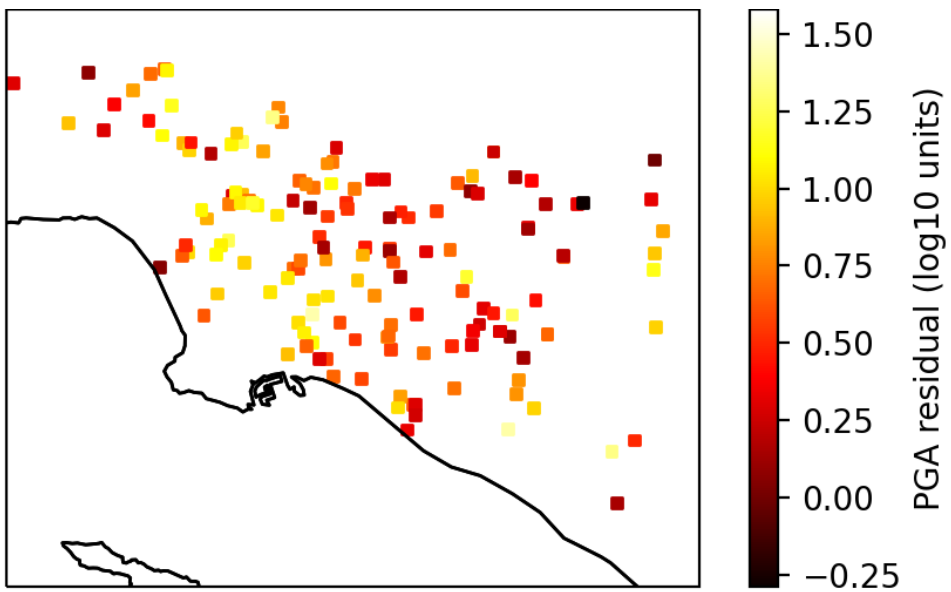
Thompson & Wald, 2016

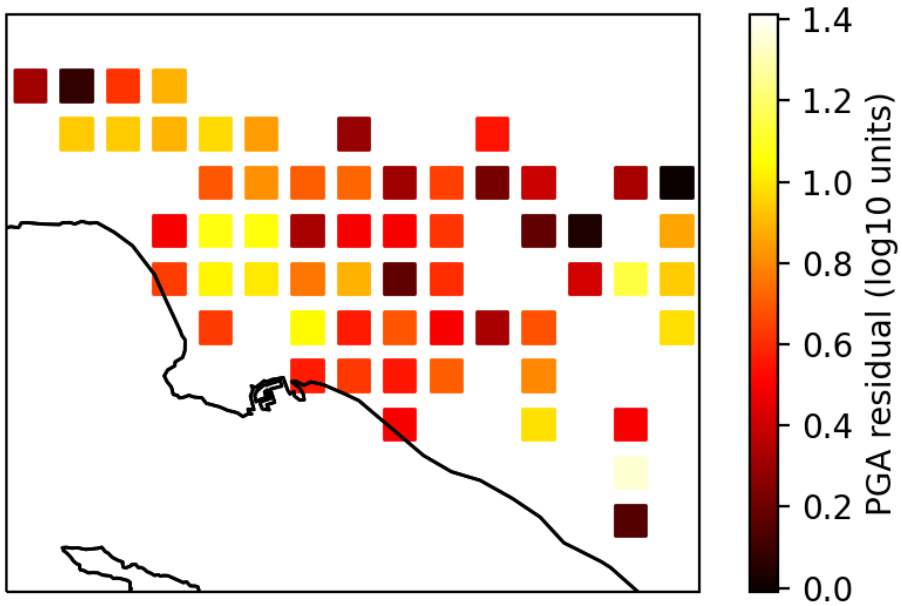
MyShake

empirical site amplification

For every earthquake, at every phone, calculate the difference between the expected PGA and the observed

Correct alerts for site conditions

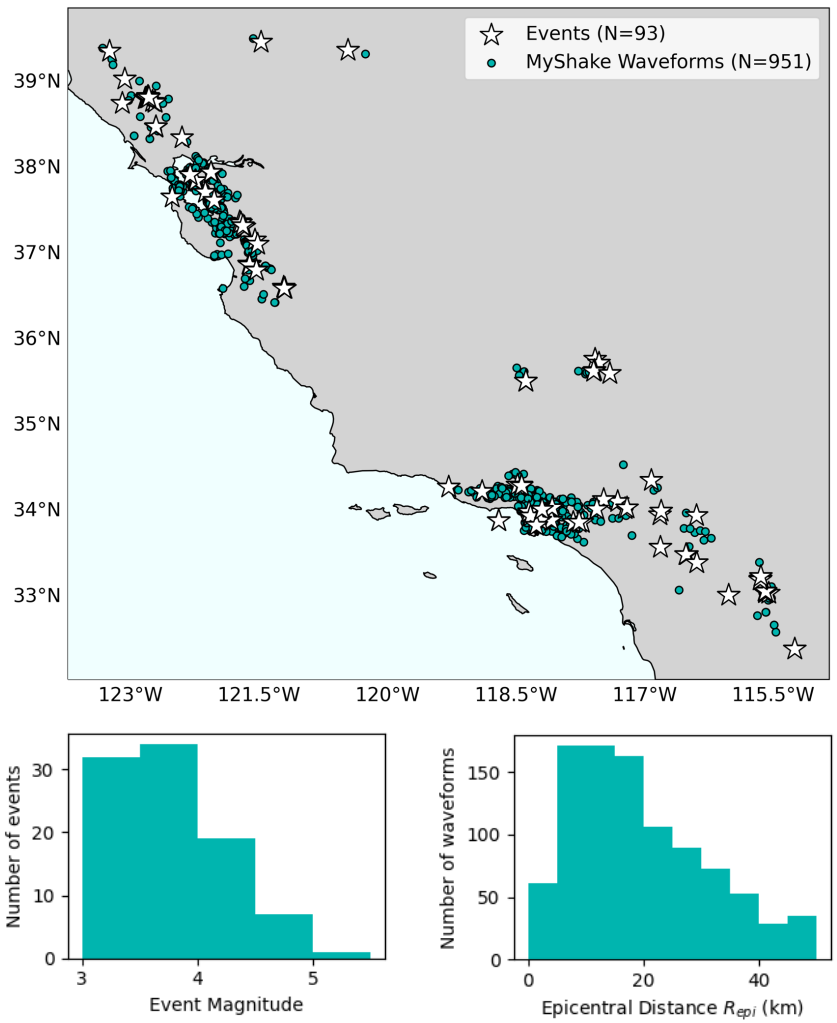


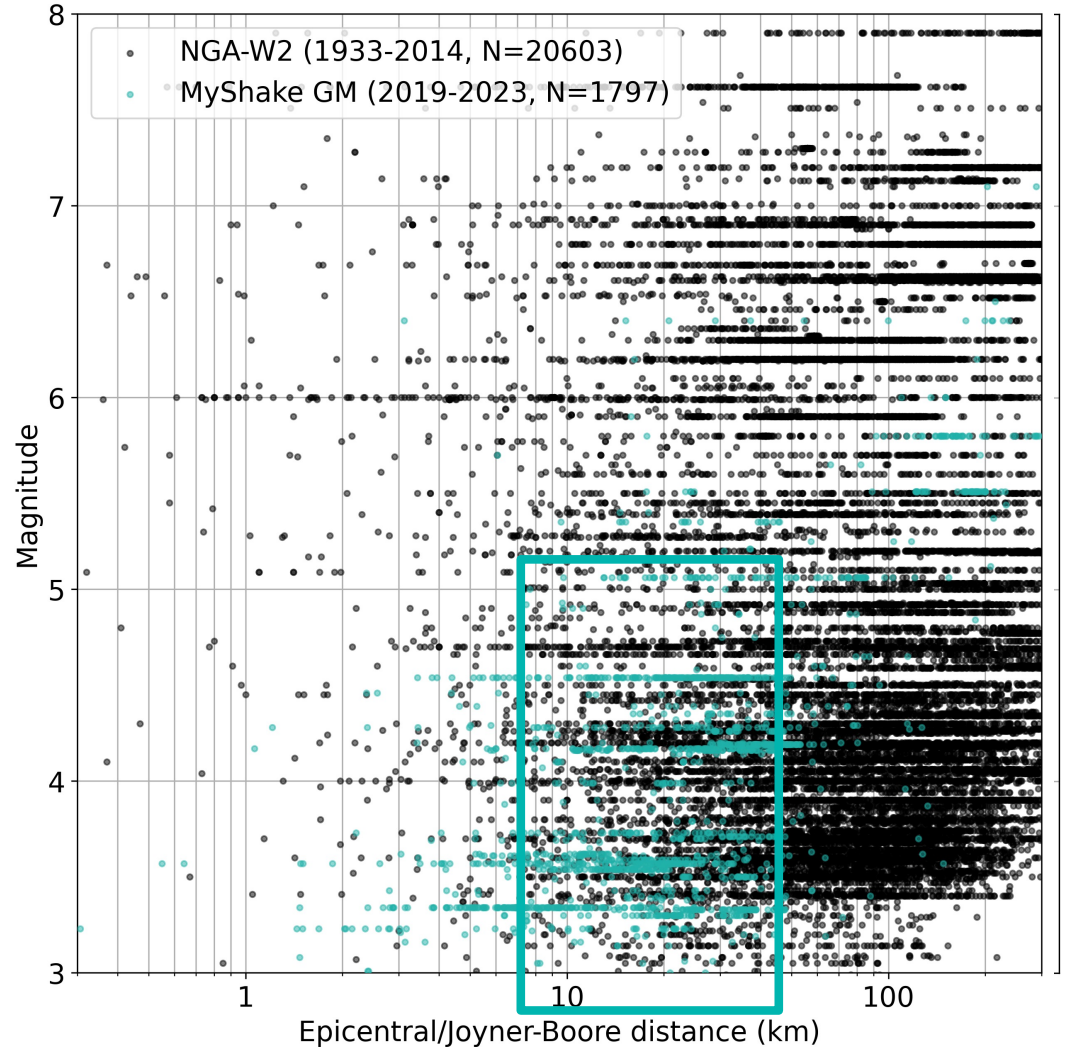


MyShake
Ground motion dataset

still small
but growing quickly

Savvas Marcou





Marcou et al., BSSA 2024

MyShake
Ground motion model

Savvas Marcou

Linear Mixed Effects Regression (Abrahamson & Youngs, 1992)

Magnitude scaling

Distance scaling

$$lnY_{ij} = c_0 + c'_{0,i} + c_1 M_i + c_2 M_i^2 + c_3 Z_{hyp,i} + c_4 lnR_{hyp,j} + \epsilon_{ij}$$

Peak MyShake acceleration

Fixed intercept

Random per-event intercept

Depth scaling

Residual

$Y = MyShakePeakAcc$

$$lnY = -7.692 + 3.037M - 0.234M^2 + 0.077Z_{hyp} - 1.627lnR_{hyp}$$

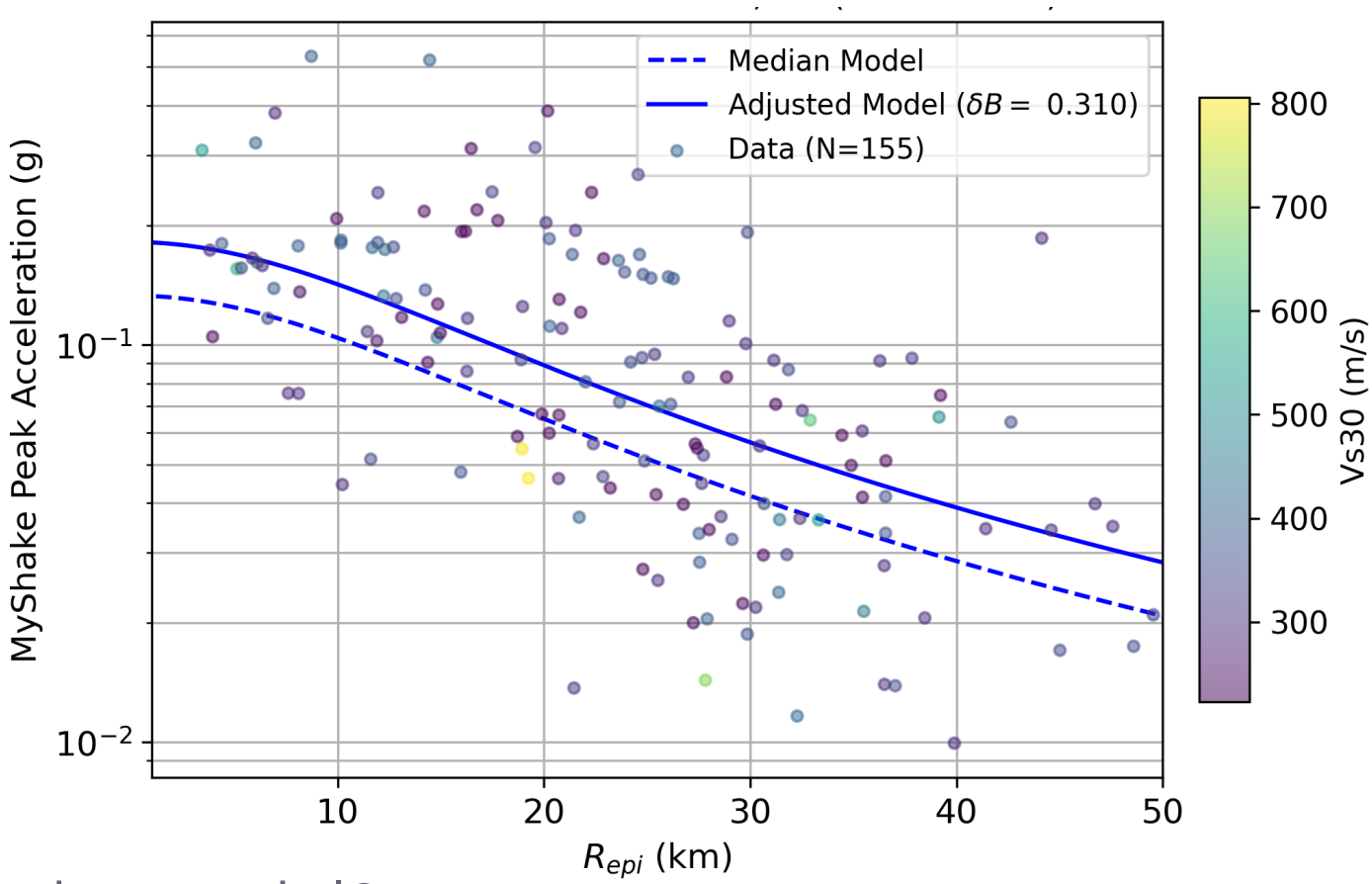
Marcou et al., BSSA 2024

MyShake
Ground motion model

Savvas Marcou

El Monte

Magnitude 4.5
Sep 19, 2020



How good is the model?

Residual standard deviation = 0.76

Similar to other models, but we have fewer parameters and no site corrections (yet)

Marcou et al., BSSA 2024

MyShake
Ground motion model

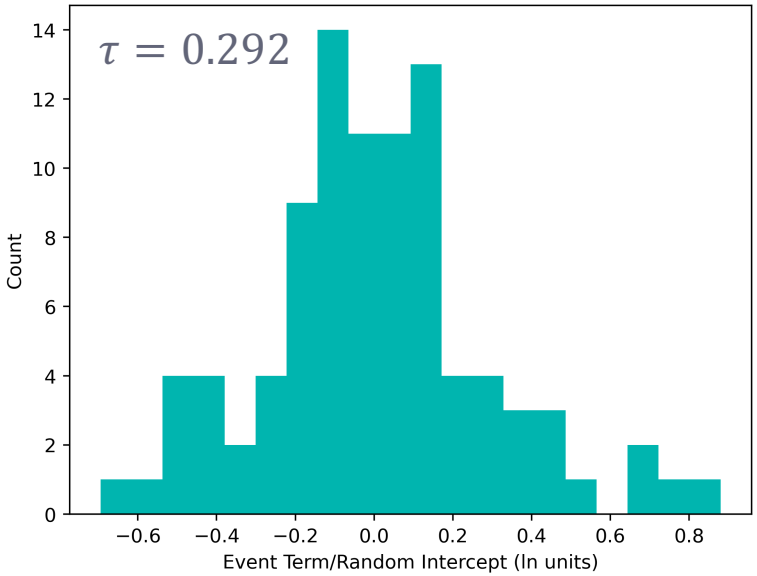
Savvas Marcou

Linear Mixed Effects Regression (Abrahamson & Youngs, 1992)

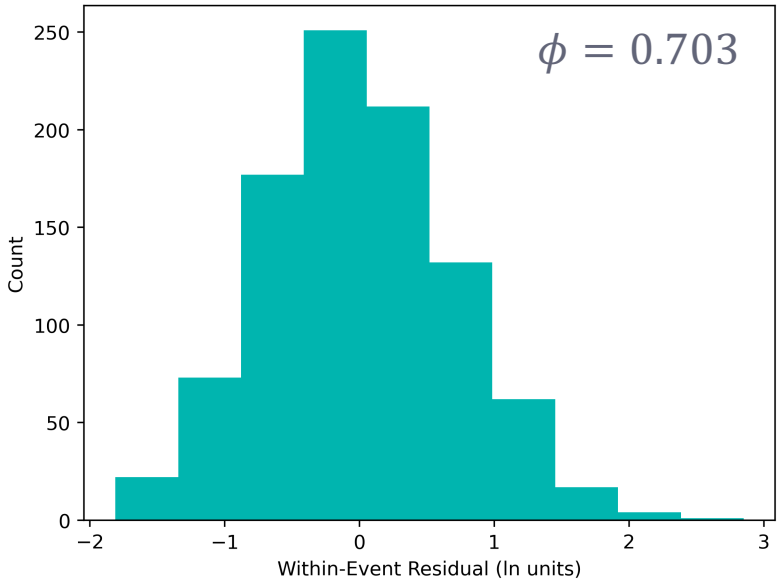
Standard deviation $\sigma_{tot} = \sqrt{\tau^2 + \phi^2} = 0.761$

NGA-W2 models have σ_{tot} 0.75-0.90 for M3-4 events

Between-event residuals



Within-event residuals



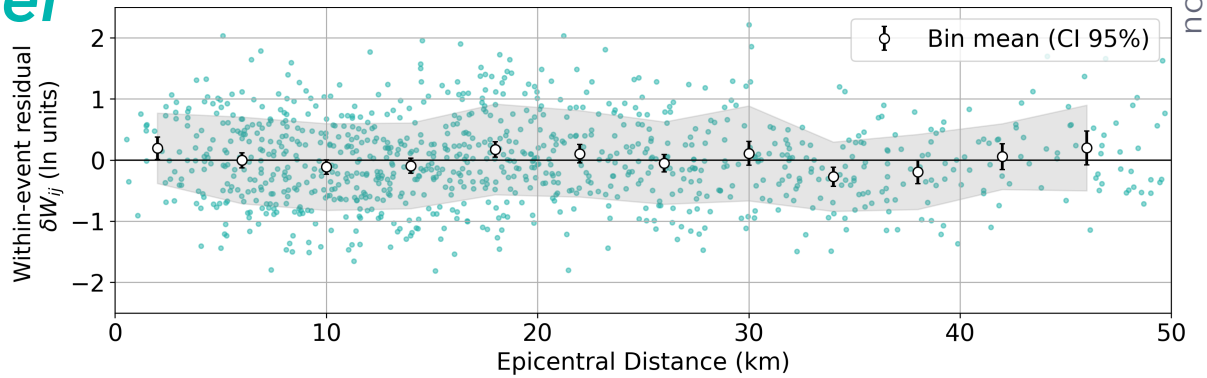
Marcou et al., BSSA 2024

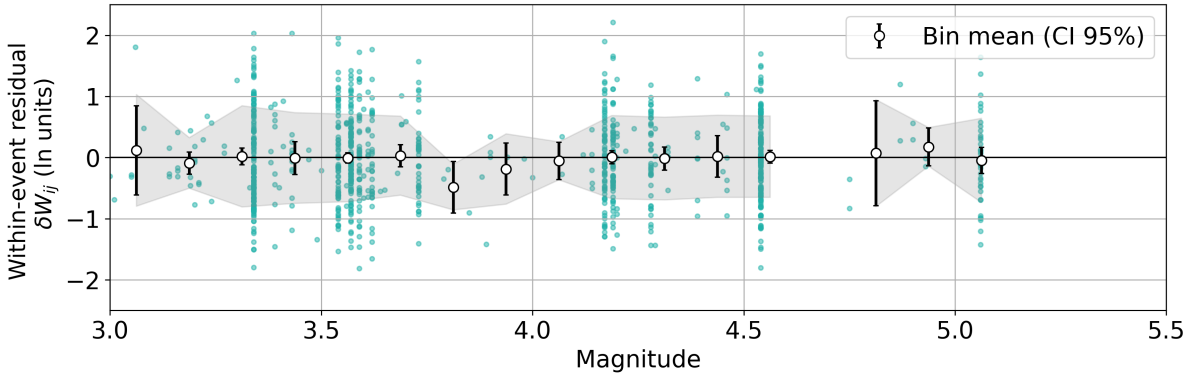
MyShake
Ground motion model

Savvas Marcou

Residual analysis

Good performance across range of predictive variables

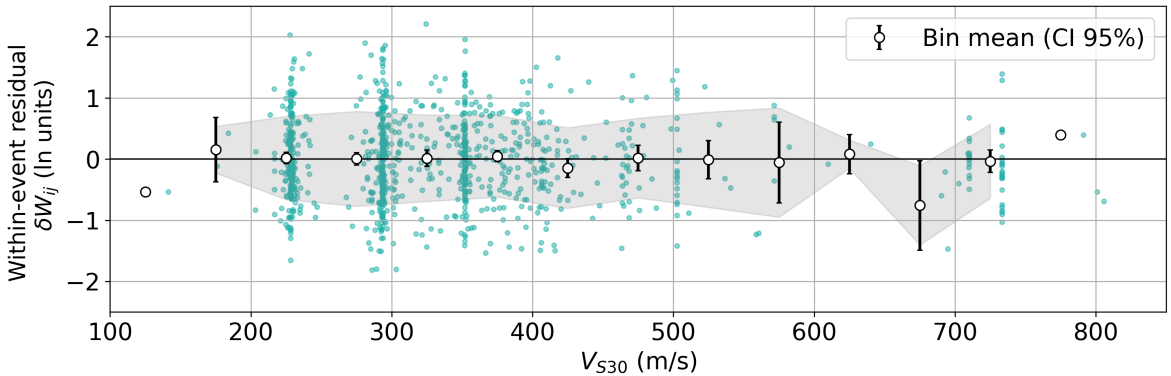




Lack of trend with site condition (Vs30)

Unexpected, but not unseen for short-period metrics

e.g., Kohler et al., 2020



$$lnY = -7.692 + 3.037M - 0.234M^2 + 0.077Z_{hyp} - 1.627lnR_{hyp}$$

Marcou et al., BSSA 2024

Two opportunities

Shaking prediction

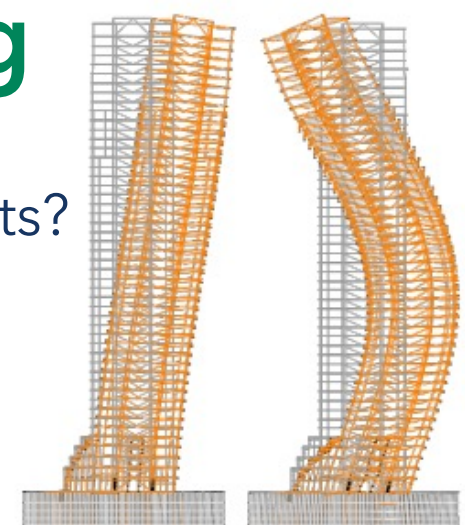
Ground motion prediction equations have a large uncertainty: ***factor of two in PGA***

➔ Can we reduce this with our new datasets?

Structural Health Monitoring

To ensure performance of building in earthquakes

➔ Can we monitor buildings with our new datasets?

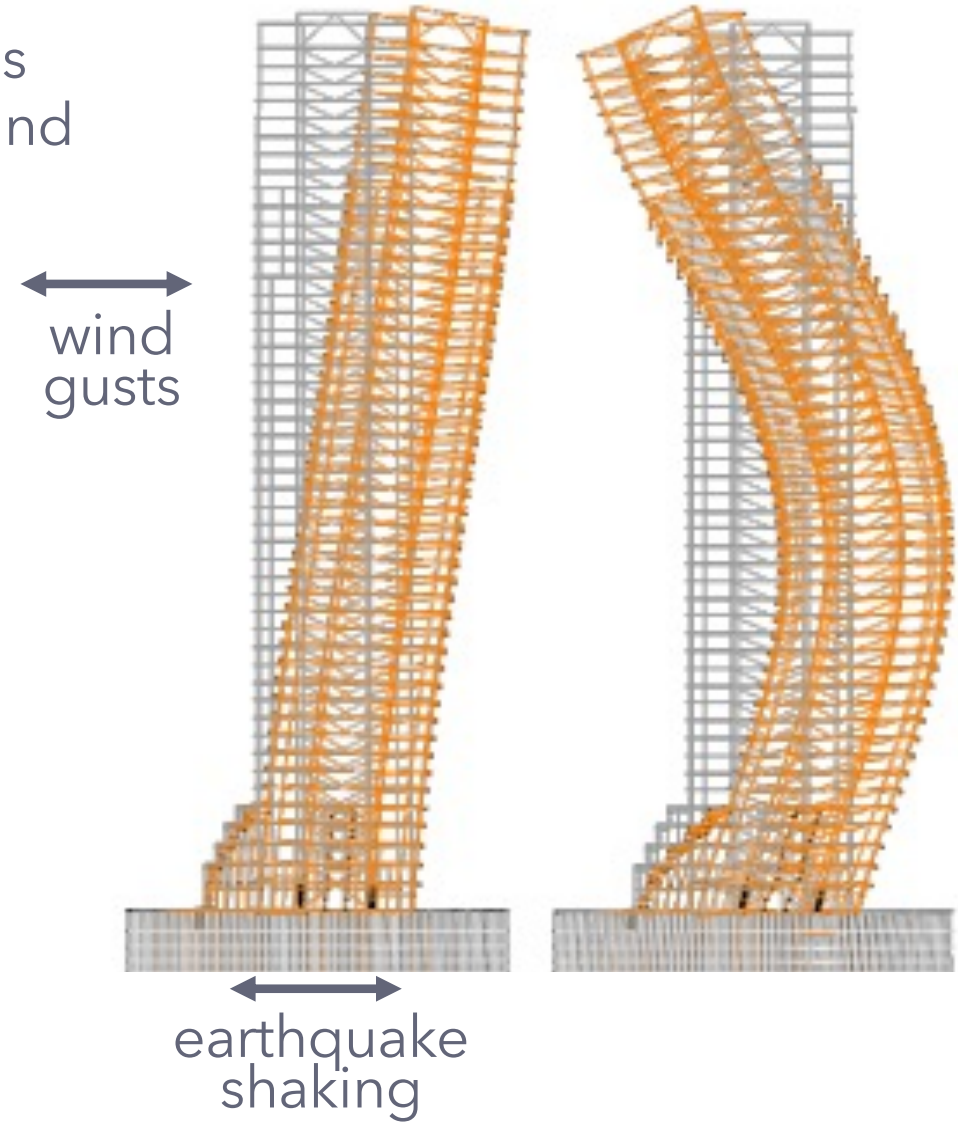


Structural Health Monitoring

To ensure **safe** performance of building in earthquakes

Building vibrate in earthquakes
…and all the time due to wind

Modes of vibration are a function of the structure's **mass**, **stiffness** and **damping**



Structural Health Monitoring

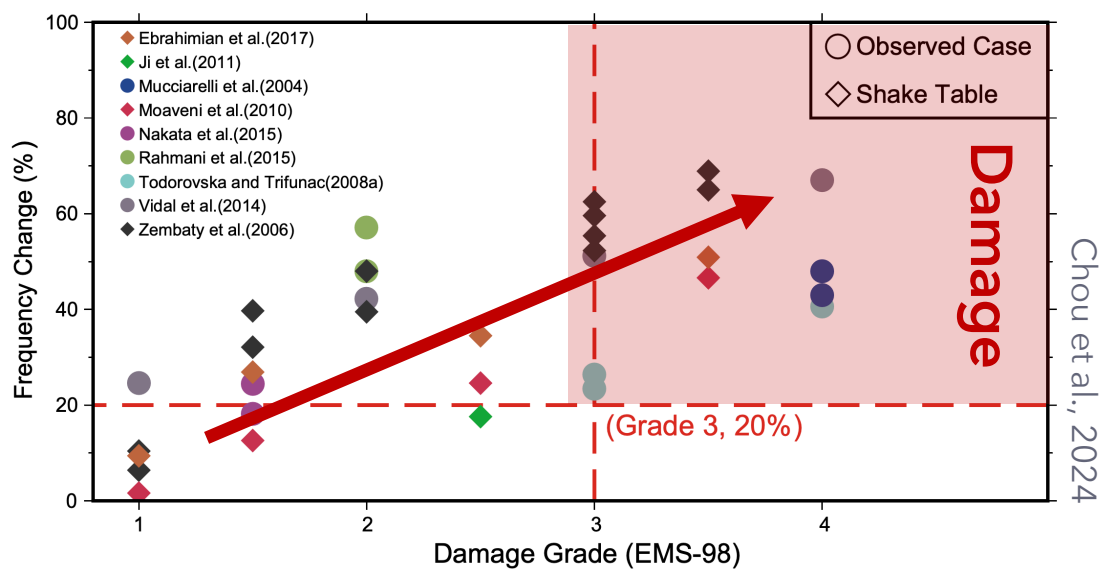
To ensure **safe** performance of building in earthquakes

Building vibrate in earthquakes
…and all the time due to wind

Modes of vibration are a function of the structure's **mass**, **stiffness** and **damping**

➔ Design-stage fragility analysis and
➔ **post-earthquake damage assessment**

Can **MyShake** monitor the structural health of buildings?
…all buildings?



Chou et al., 2024

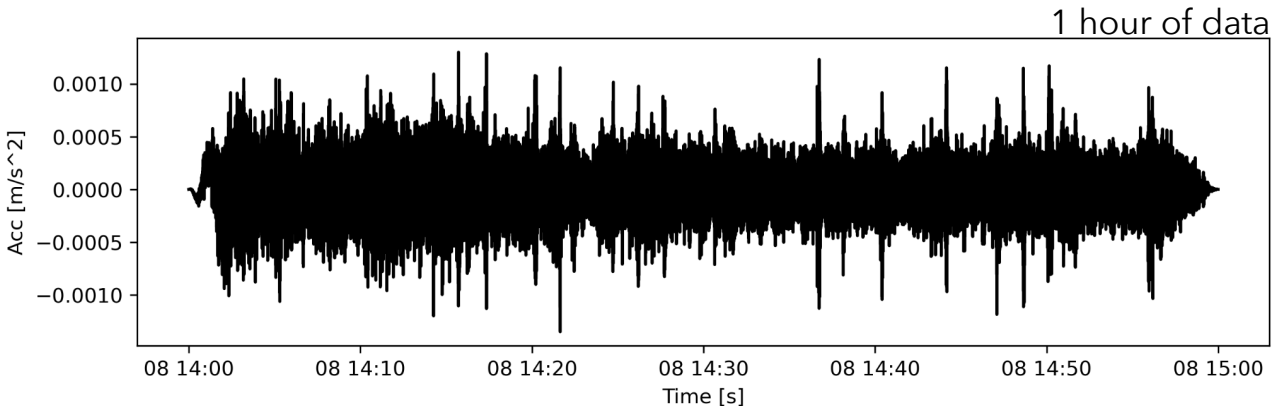
Damage level:	Slight	Moderate	Substantial to heavy	Very heavy	Destruction

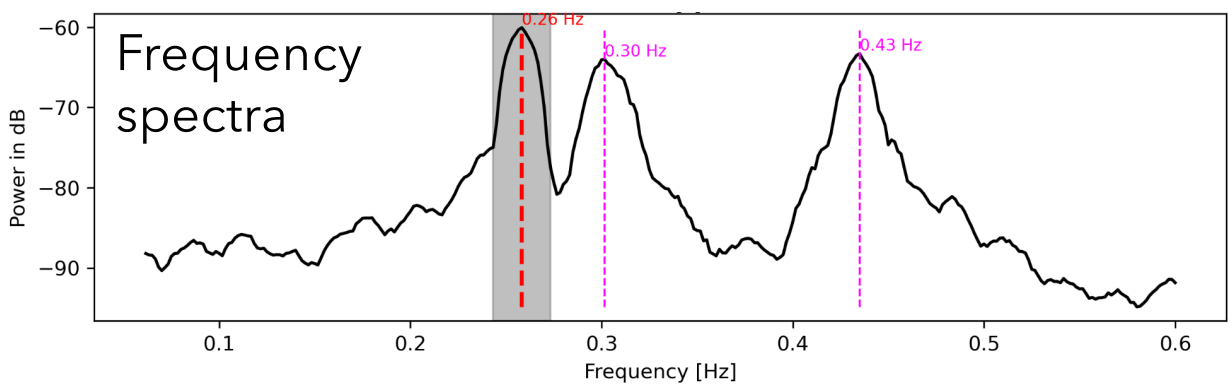
Ambient vibrations of buildings

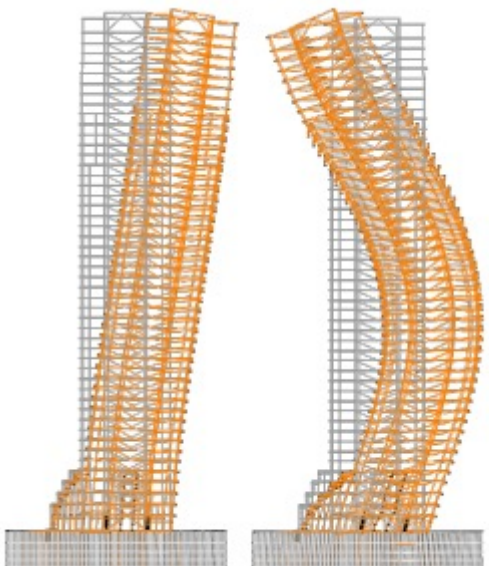
Utpal Kumar

Traditional seismometers can measure modal frequencies all the time

San Francisco high-rise: 60 floors







From traditional seismometer

Fundamental mode

in 2 horizontal directions

0.26 Hz = 3.8 sec

0.30 Hz = 3.3 sec

1st overtone

0.43 Hz = 2.3 sec

Kumar et al. in review

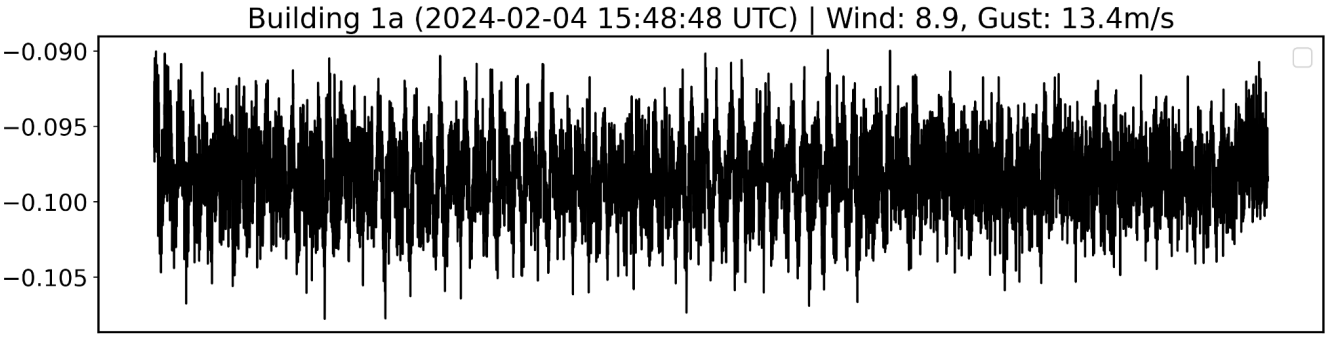
MyShake
Structural Health Monitoring

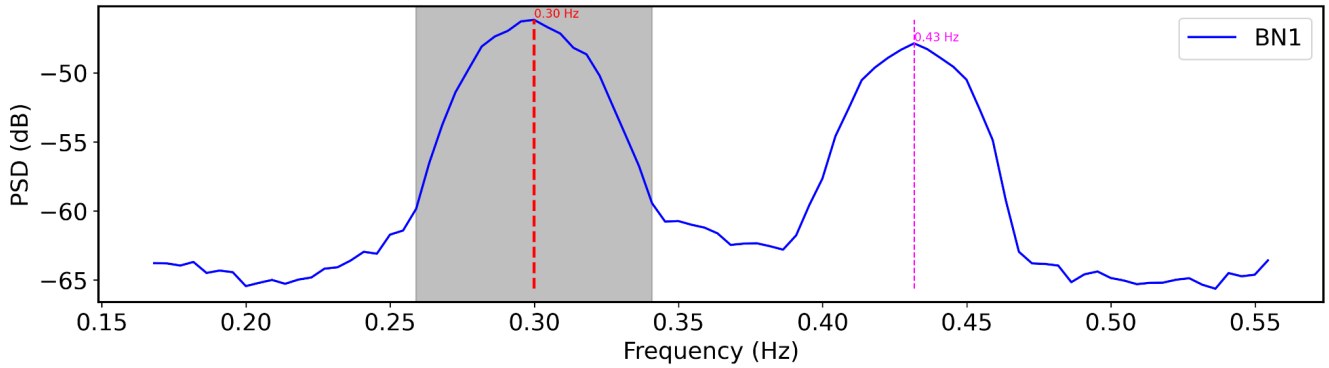
Utpal Kumar

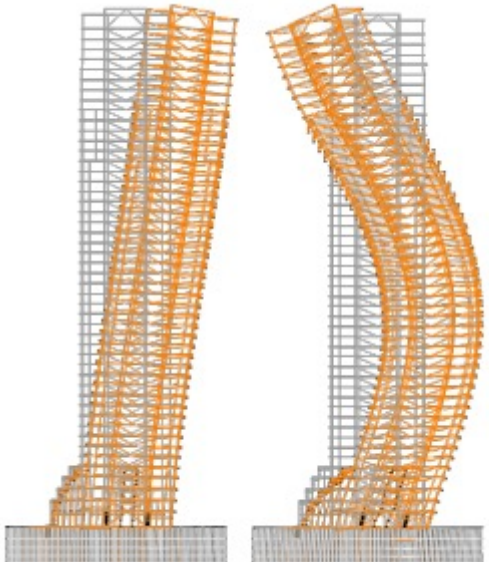
Ambient vibrations of buildings

San Francisco high-rise: 60 floors

5 minutes of data – X component







From traditional seismometer

Fundamental mode

in 2 horizontal directions

0.26 Hz = 3.8 sec

0.30 Hz = 3.3 sec

1st overtone

0.43 Hz = 2.3 sec

Kumar et al. in review

MyShake *in the wild*

Structural Health Monitoring

Downtown Los Angeles in the ***last 5 years***

MyShake *in the wild*

Structural Health Monitoring

Utpal Kumar

Metropolis
197m, 56 floors

35th floor

Los Angeles

Ritz Carlton
203m, 54 floors

44th floor

3rd floor

MyShake *in the wild*

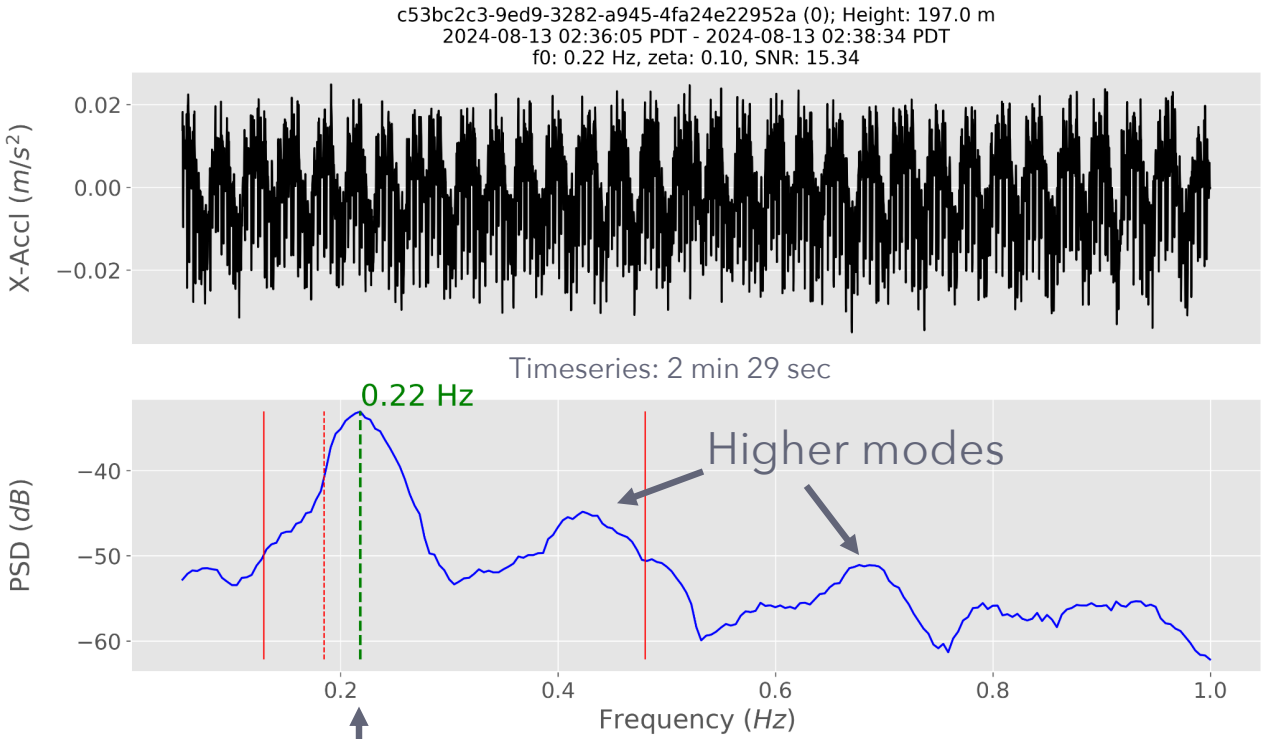
Structural Health Monitoring

Utpal Kumar

Metropolis

197m, 56 floors

35th floor



Observed modal freq: 0.22 Hz

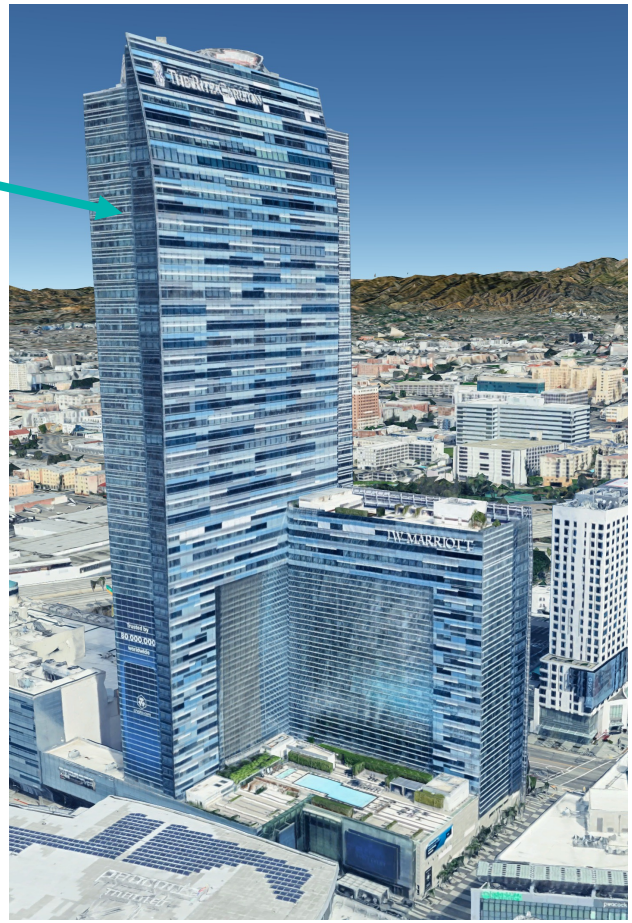
expected ASCE modal freq: 0.18 Hz

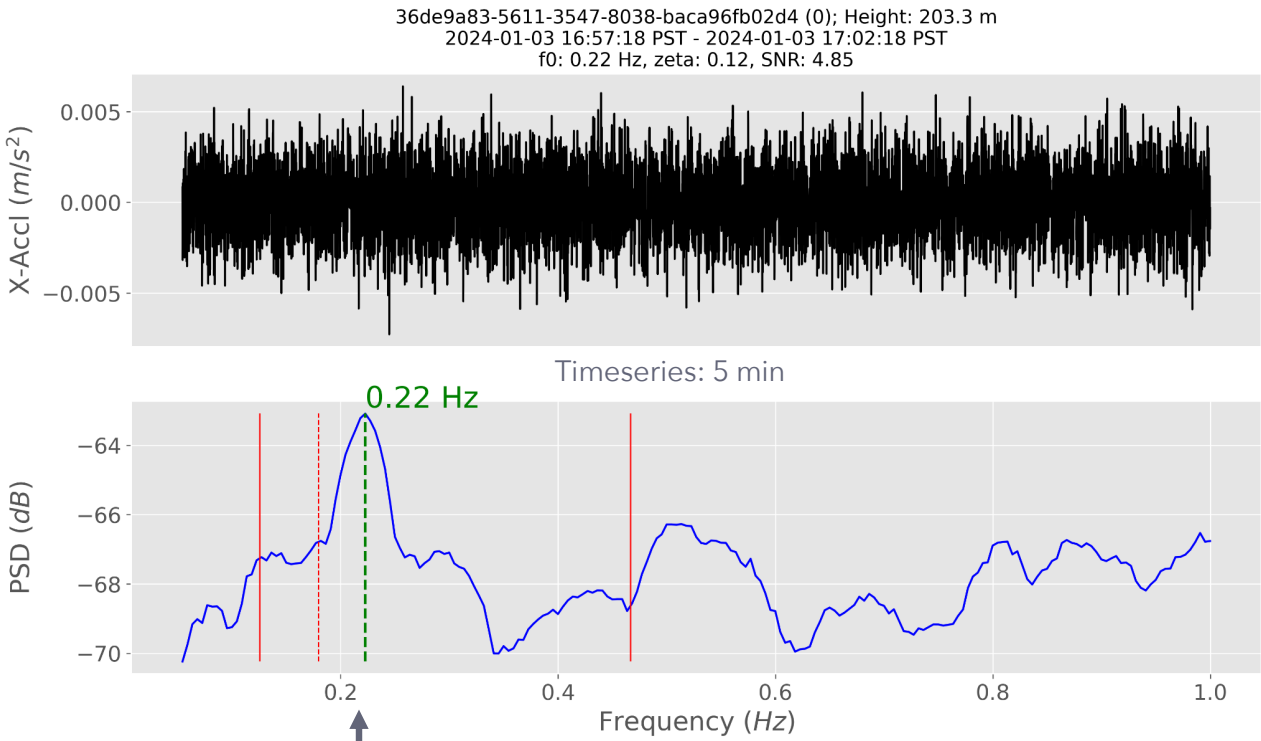
MyShake in the wild
Structural Health Monitoring

Utpal Kumar

Ritz Carlton
203m, 54 floors

44th floor





Observed modal freq: 0.22 Hz

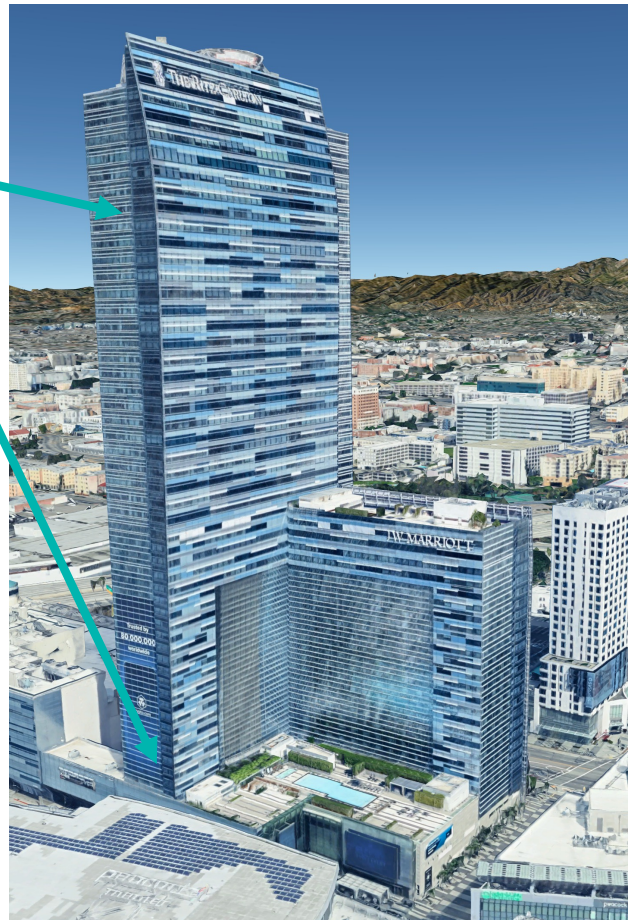
expected ASCE modal freq: 0.18 Hz

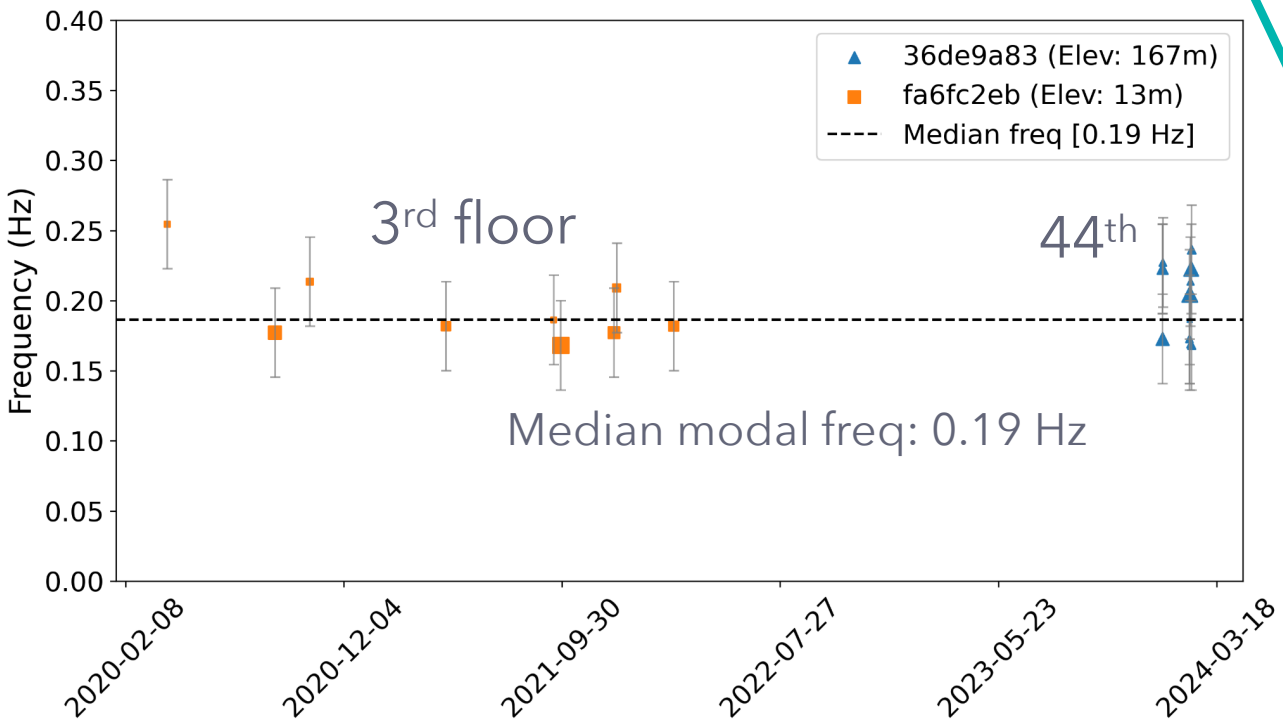
MyShake in the wild
Structural Health Monitoring

Utpal Kumar

Ritz Carlton
203m, 54 floors

44th floor
3rd floor





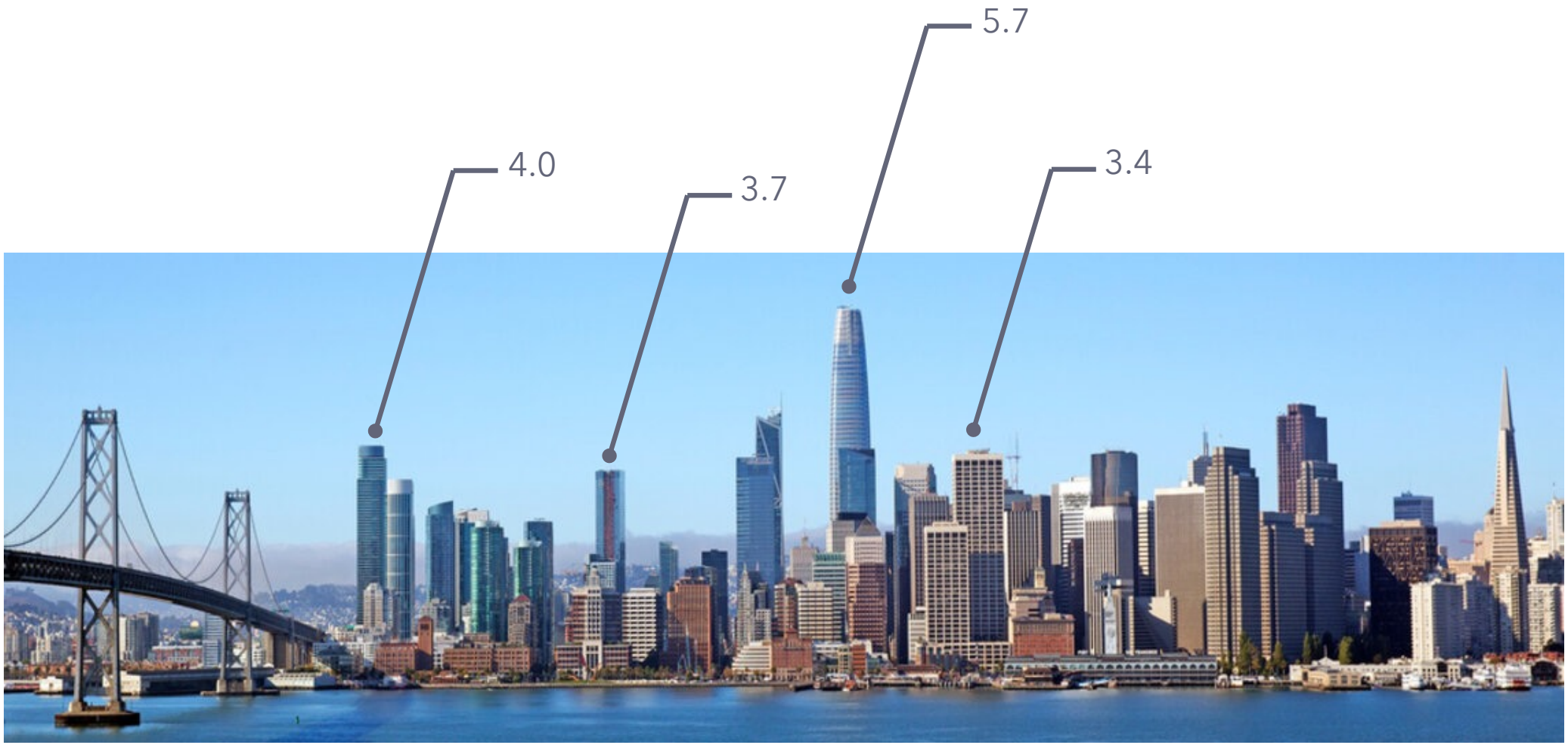
4 years years of observations

expected ASCE modal freq: 0.18 Hz

Our vision

Ubiquitous state-wide building health monitoring using *MyShake*

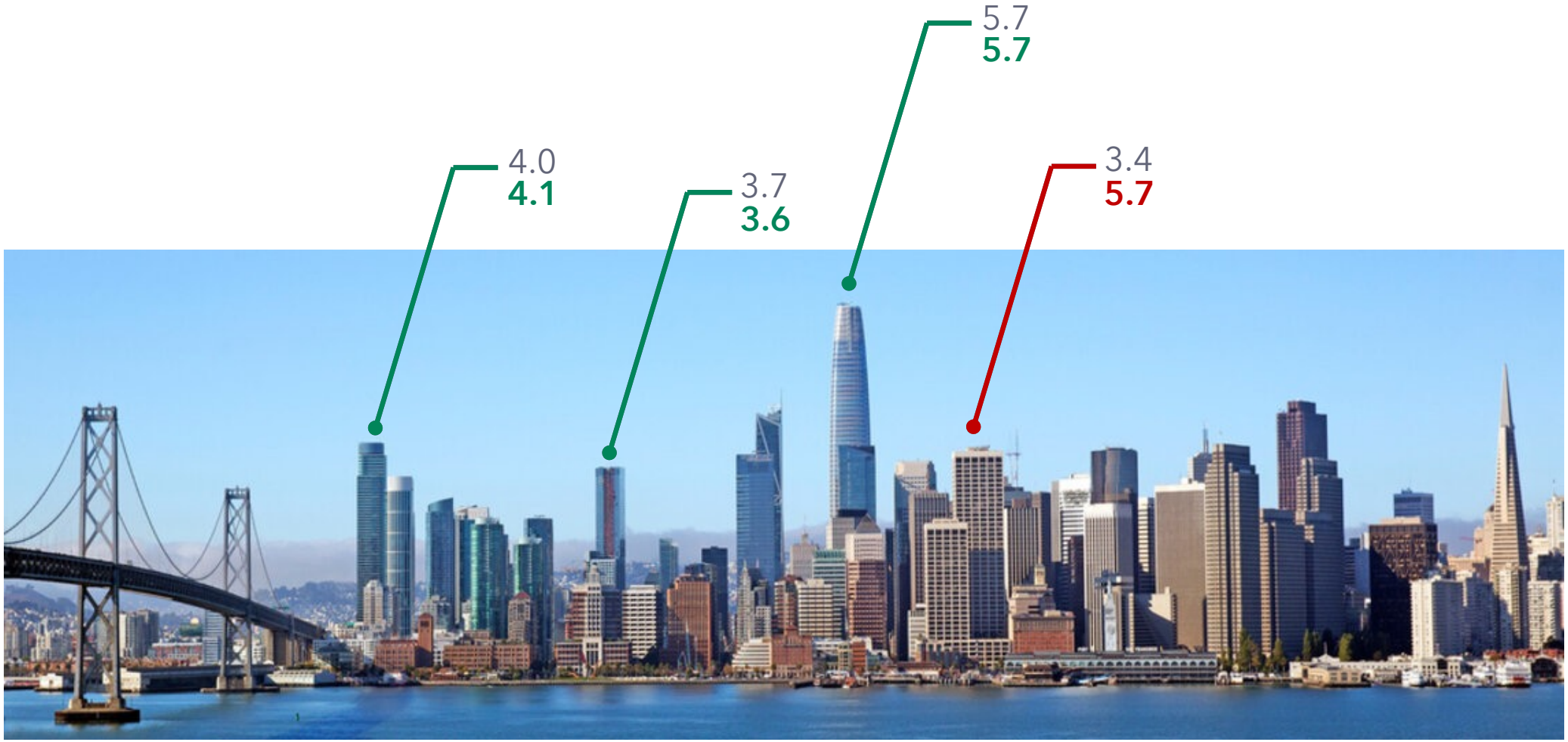
1. Baseline: Map structural characteristics across cities



Our vision

Ubiquitous state-wide building health monitoring using *MyShake*

1. Baseline: Map structural characteristics across cities
2. Post quake: Which buildings have structural damage



MyShake

opportunities

Smartphones can

- Record earthquake and ambient building vibrations
- Provide dense building-by-building observations
- Deliver user-satisfying alerts justifying seismology use

Smartphones could

- Provide empirical ground motion amplification factors to improve hazard models and refine building codes
- Provide building health monitoring and help identify damaged buildings after natural hazard events

challenges

- Privacy: data sharing is difficult
- Five-minute waveforms; Roving locations
- Maintaining the network = keeping users interested