A Puzzle About Intensity IX (Modified Mercalli) Ground Motions

PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.1	0.5	2.4	6.7	13	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	11	22	43	83	>160
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

Scale based upon Wald, et al.; 1999

John G. Anderson
University of Nevada, Reno

Outline

- What is Intensity IX
  - How often does it occur?
- Seismic Hazard Curve
  - Properties
  - Model to estimate the seismic hazard curve
- Problematic Seismic Hazard Estimates
- Ideas for Improving the Seismic Hazard Estimates
  - Ergodic assumption
  - Indicators for the solution
  - Indications using synthetic seismograms

What is Modified Mercalli Intensity IX ?

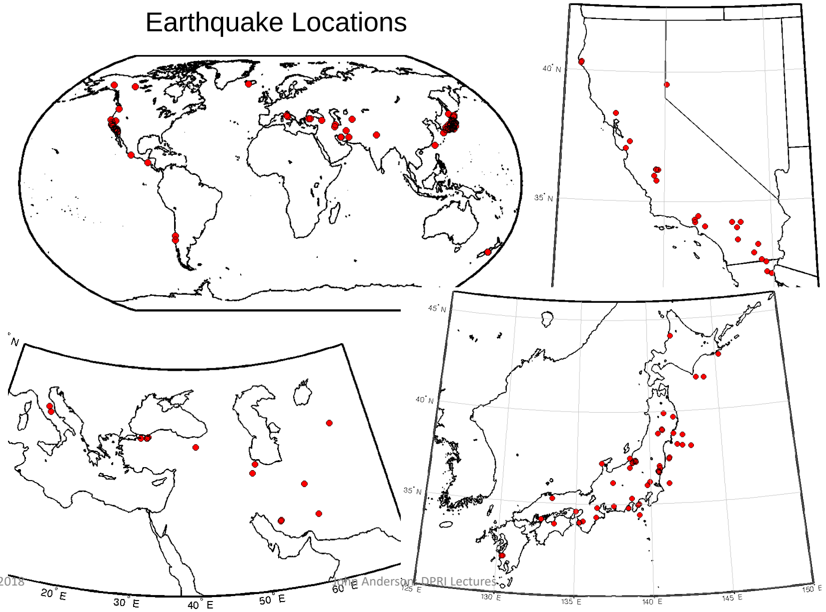
- Dewey et al. (1997): IX. Worst effects include multiple cases of structural damage to reinforced concrete buildings and parking structures built when a seismic code was in effect, with some cases of partial or complete collapse; collapse of elevated freeway sections; widespread damage to unreinforced masonry buildings (e.g., old brick buildings), with total collapse; widespread incidence of wood-frame houses shifted off foundations where not securely anchored and braced; widespread destruction of wood-frame apartment buildings having large open areas in their first stories; widespread collapse of masonry (brick, block or stone) chimneys, whether reinforced or not, on single-family homes; furniture and building contents generally overturned and thrown across room.

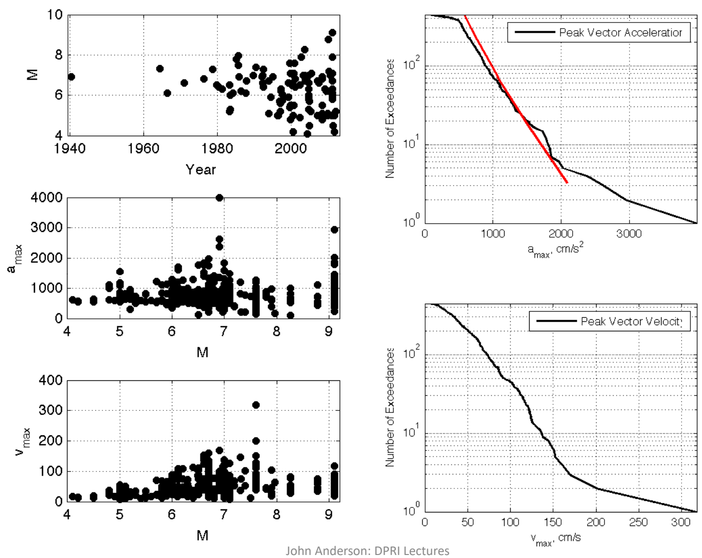
PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<0.1	0.5	2.4	6.7	13	24	44	83	>156
PEAK VEL.(cm/s)	<0.07	0.4	1.9	5.8	11	22	43	83	>160
INSTRUMENTAL INTENSITY	I	II–III	IV	V	VI	VII	VIII	IX	X+

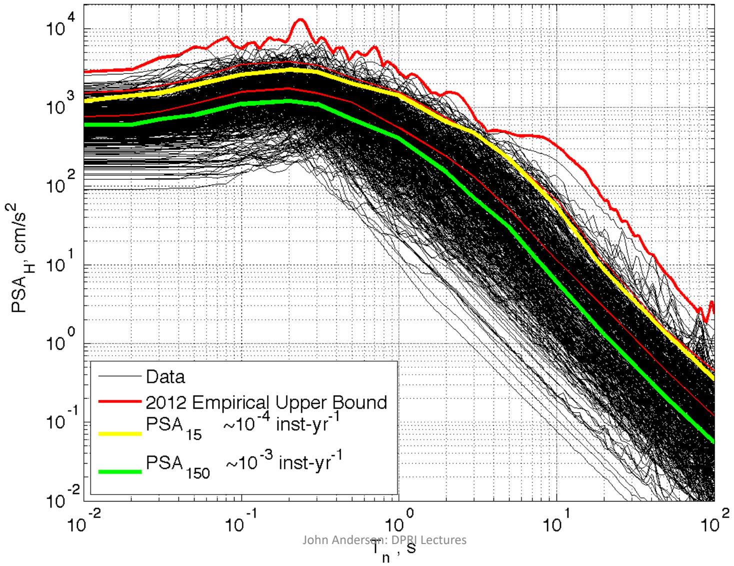
Scale based upon Wald, et al.; 1999

The puzzle: Intensity IX has not happened as often as seismic hazard analysis predicts.

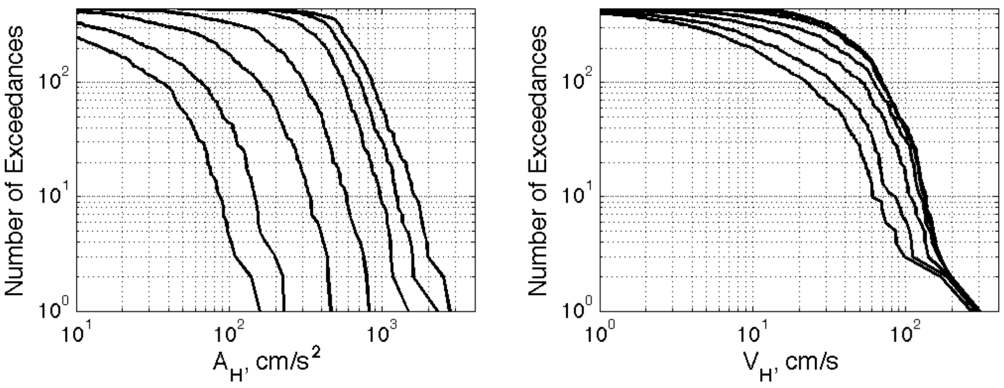
How often does Intensity IX occur?





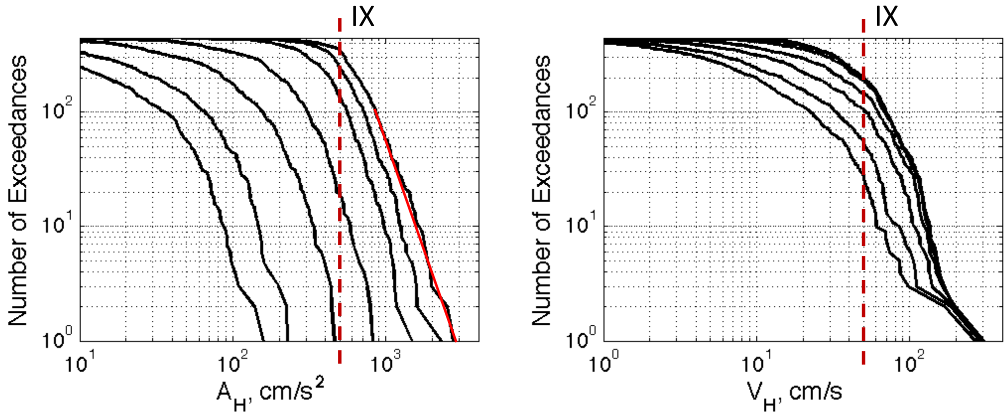


Peak horizontal acceleration and velocity, filtered



Low-pass filters: f_C=0.33, 0.5, 1, 2, 5, 10, 25 Hz

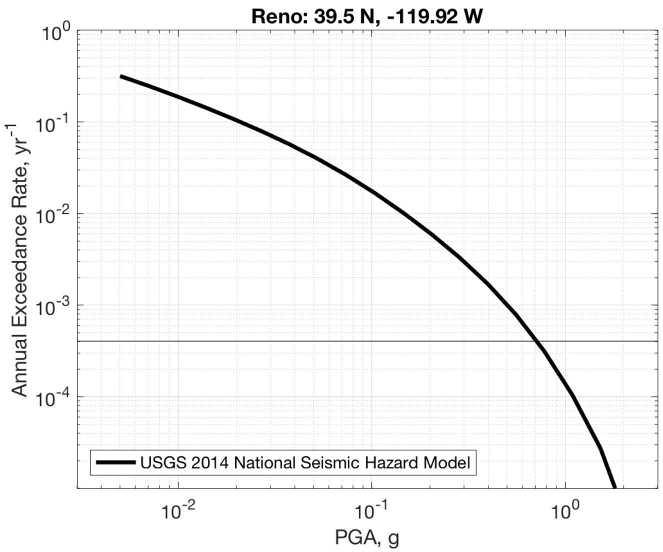
Peak horizontal acceleration and velocity, filtered



Low-pass filters: f_C=0.33, 0.5, 1, 2, 5, 10, 25 Hz

Seismic Hazard Curve

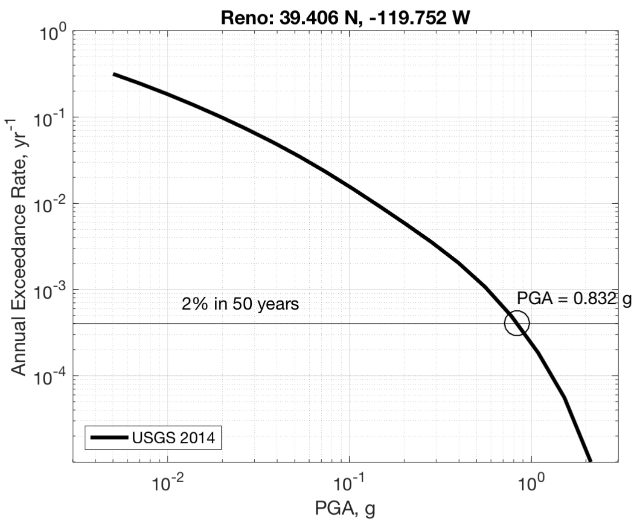
Basic Assumption:
a hazard curve exists for each point on the planet.



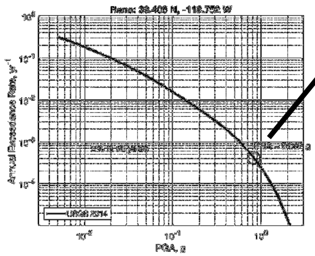
Use of hazard curve?
building design

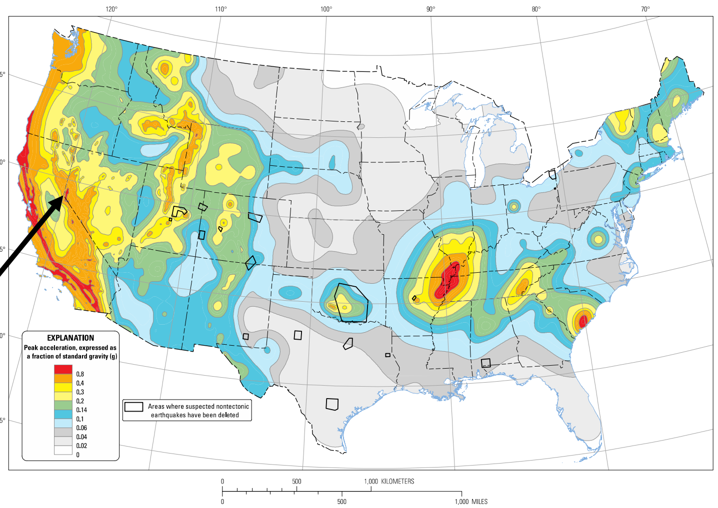
United States Code:
Motion with probability of 2% in 50 years.

Poisson assumption:
Exceedance rate = 4.04×10^{-4} yr^{-1}



Use of the hazard curve



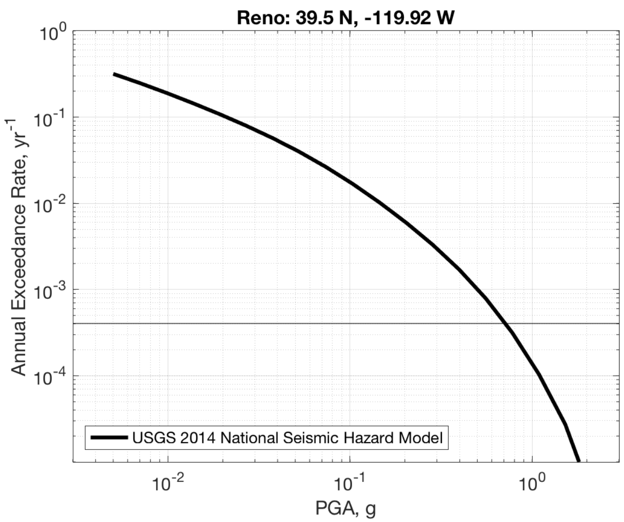


Two-percent probability of exceedance in 50 years map of peak ground acceleration

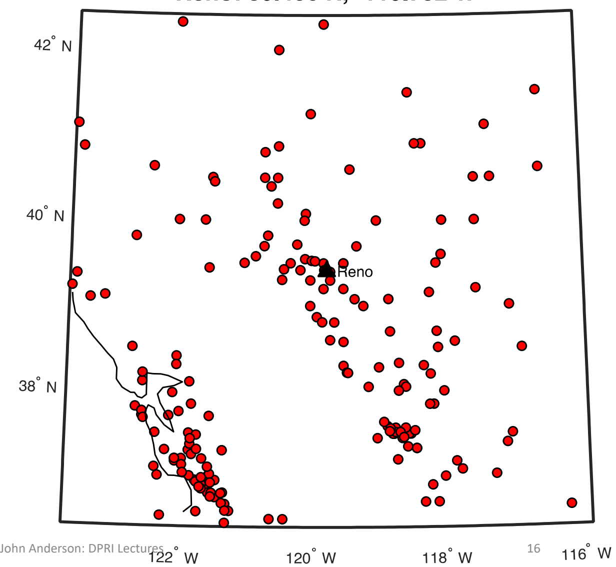
Model to estimate the hazard curve

Assumptions:

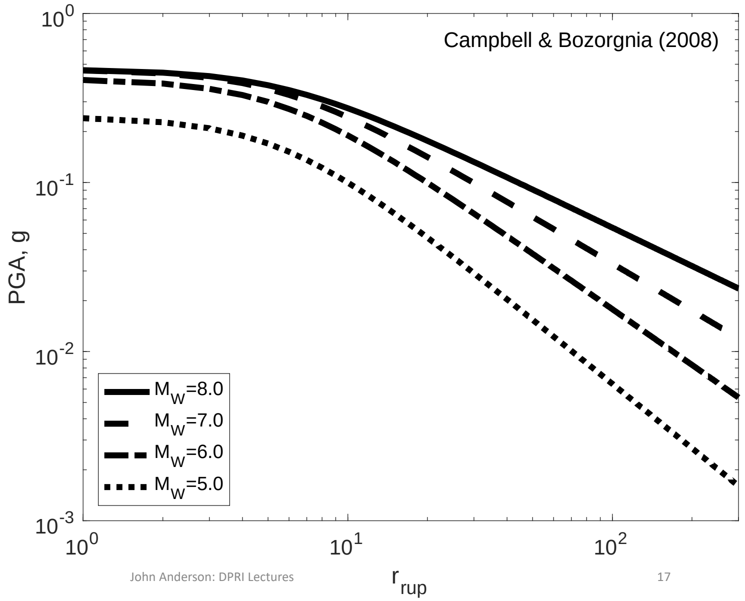
1. A true hazard curve exists for every point on the planet.
2. If we could get $>10^4$ years of seismograms at the site, we could know the “correct” answer.



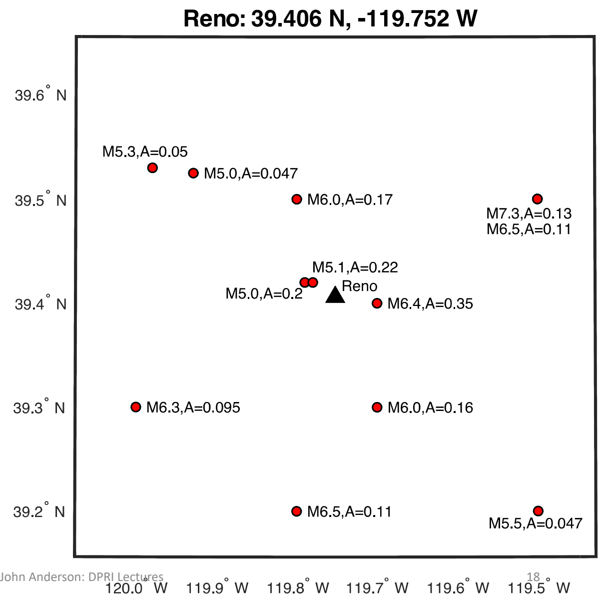
Historical earthquakes



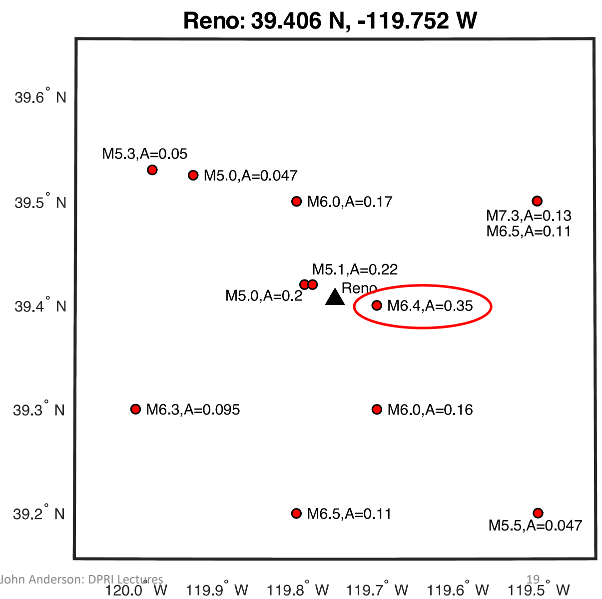
Ground Motion Prediction Equation (GMPE)



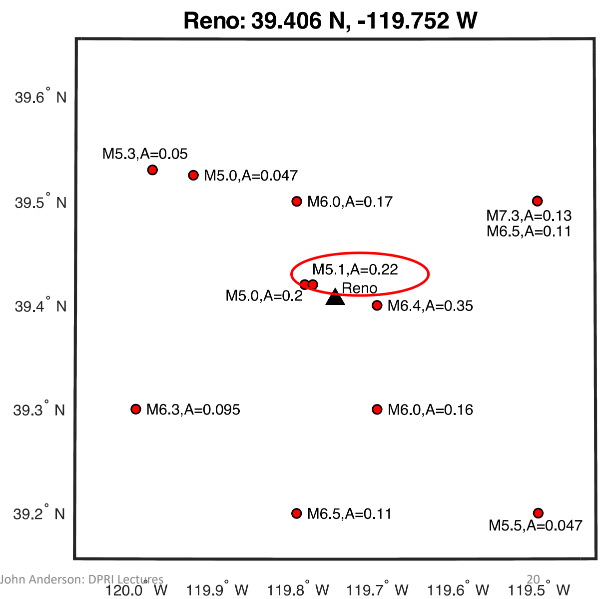
Estimate peak acceleration from each earthquake.



0.35 g was equaled or exceeded one time

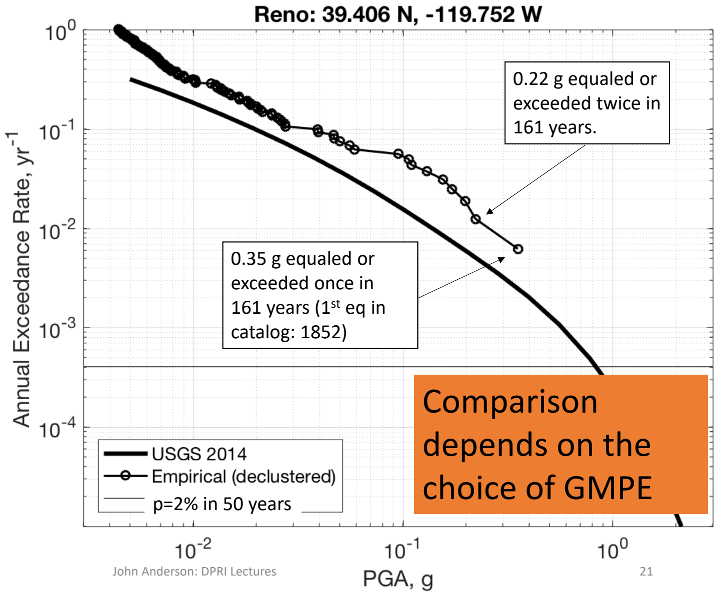


0.22 g was equaled or exceeded two times.



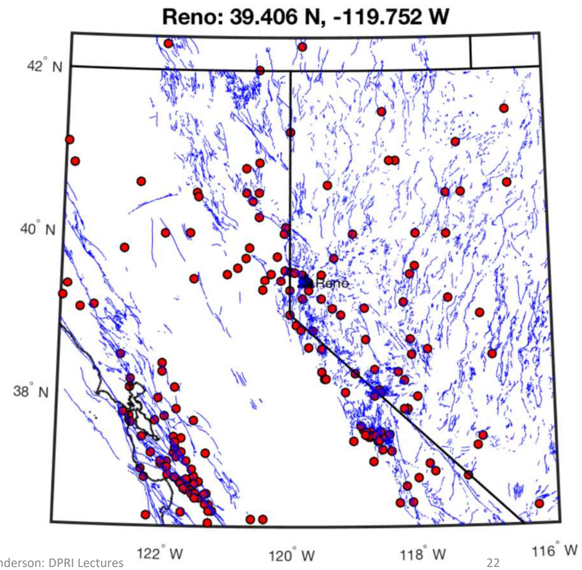
USGS curve:

- Includes faults
- Uncertainties in ground motion estimates
- Smooths the locations of historical earthquakes
- Result: curve extended to low enough rates.



Lower exceedance rates

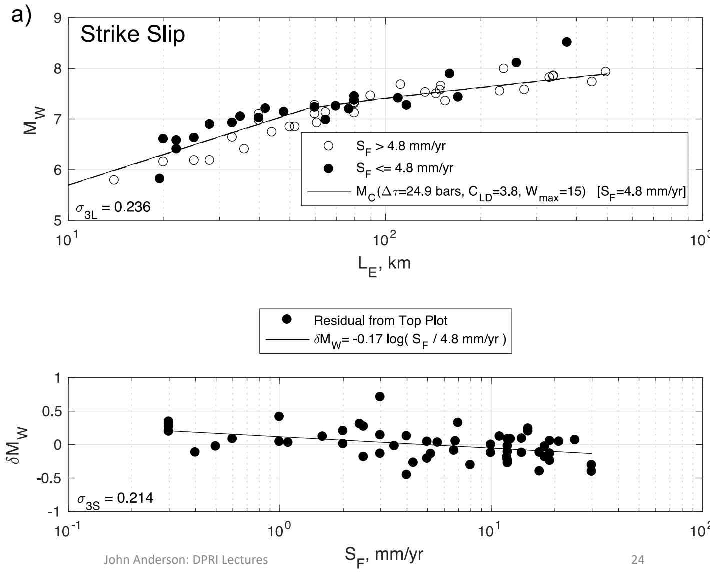
- Add hazard from active faults.



Moment Balance

- Rupture length → Magnitude / Moment
- Moment → Slip per event
- Slip rate on fault, recurrence interval, slip per event need to be consistent.
- More techniques if the fault has a range of sizes.

Model: fault length to magnitude

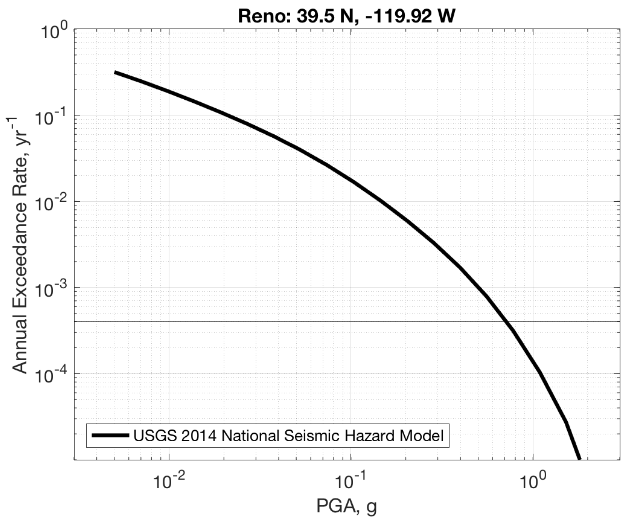


From Anderson et al., 2017, BSSA (December)

Model to Estimate the Hazard Curve

Assumptions:

1. A true hazard curve exists for every point on the planet.
2. If we could get >10^4 years of seismograms at the site, we could know the “correct” answer.
3. We can trust the basic mathematical method to estimate the curve.



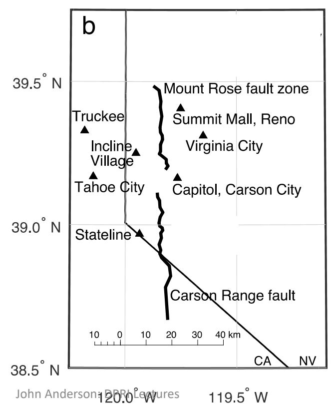
Symbolic equations to build a hazard curve

$$\gamma_C(Y) = \iint n[M,\mathbf{x}]\,\Phi\left\{y \geq Y|\hat{Y},\sigma_T\right\} dM\,d\mathbf{x}$$

γ = rate of exceedance of ground motion *Y*
n = rate of earthquake occurrence, magnitude *M*, at location **x**
Φ = probability of the earthquake exceeding *Y*.

In summary, this is just the expected value of a distribution.

$$\gamma_C(Y) = \iint n[M,\mathbf{x}]\,\Phi\left\{y \geq Y|\hat{Y},\sigma_T\right\} dM\,d\mathbf{x}$$



Seismicity Model

Earthquake catalog
Fault studies
Geodesy

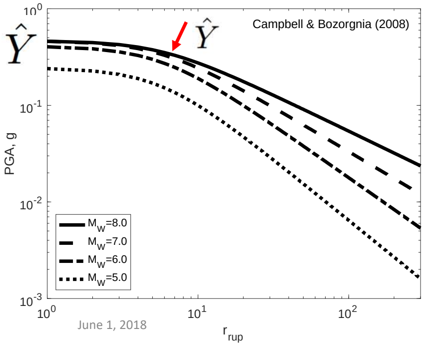
→

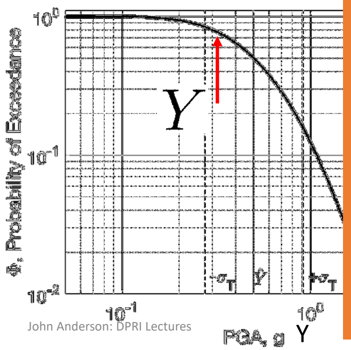
Complete model of where earthquakes occur, how often, and how large.

$$\gamma_C(Y) = \iint n[M,\mathbf{x}]\,\Phi\left\{y \ge Y|\hat{Y},\sigma_T\right\} dM\,d\mathbf{x}$$

Functions of M, x

GMPE $[M,\mathbf{x}] \rightarrow \left[\hat{Y},\sigma_T\right]$



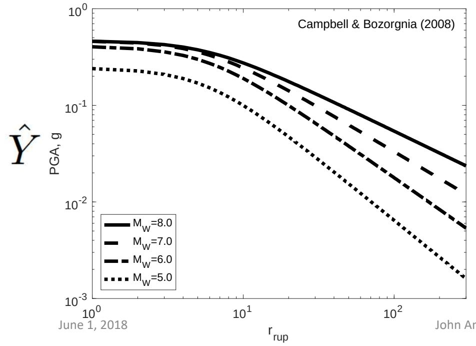


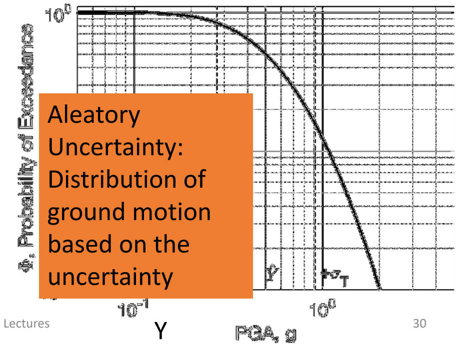
Ground Motion Prediction Equation

- Strong motion data
- V_{S30} and basin velocity models
- Future: site response, waveform models

$$\gamma_C(Y) = \iint n[M,\mathbf{x}]\,\Phi\left\{y \ge Y|\hat{Y},\sigma_T\right\} dM\,d\mathbf{x}$$

Functions of M, x

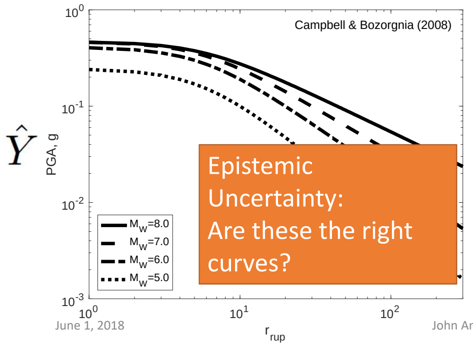




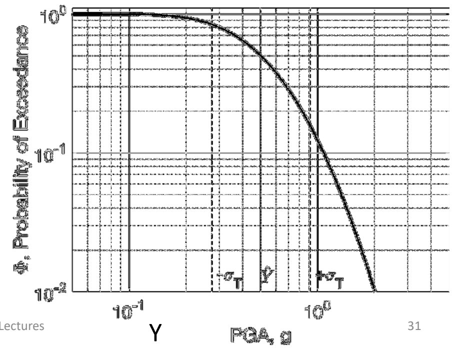
Aleatory Uncertainty: Distribution of ground motion based on the uncertainty

$$\gamma_C(Y) = \iint n[M,\mathbf{x}]\,\Phi\left\{y \ge Y|\hat{Y},\sigma_T\right\} dM\,d\mathbf{x}$$

Functions of M, x



Epistemic Uncertainty: Are these the right curves?



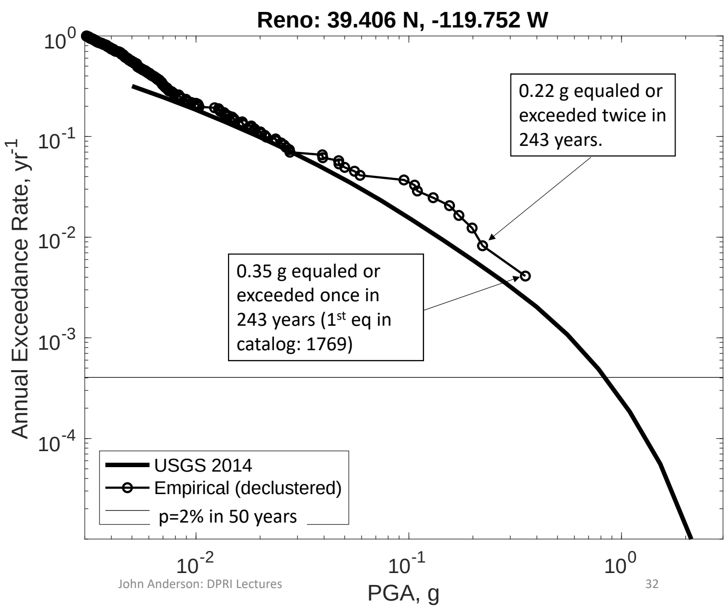
USGS curve includes:

Faults

Uncertainties in ground motion estimates

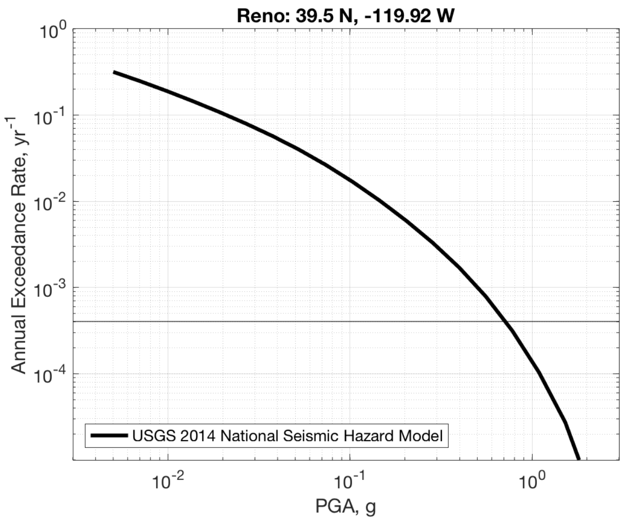
Smooth the historical earthquakes

Result: curve extended to low enough rates.



Assumptions:

1. A true hazard curve exists for every point on the planet.
2. If we could get >10^4 years of seismograms at the site, we could know the "correct" answer.
3. We can trust the basic mathematical method to estimate the curve.
4. The hazard curve and the input is testable in limited cases, and can be improved by with data.

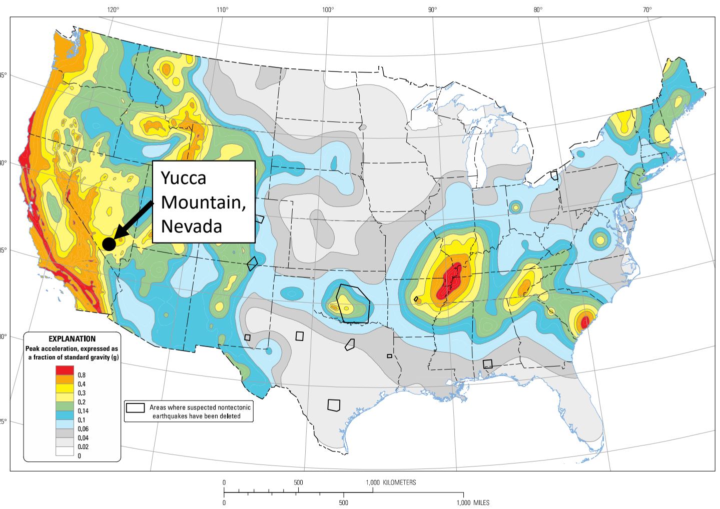


Problematic Seismic Hazard Estimates

- Yucca Mountain.
- Southern California Precariously Balanced Rock Sites

Seismic Hazard: Yucca Mountain, Nevada

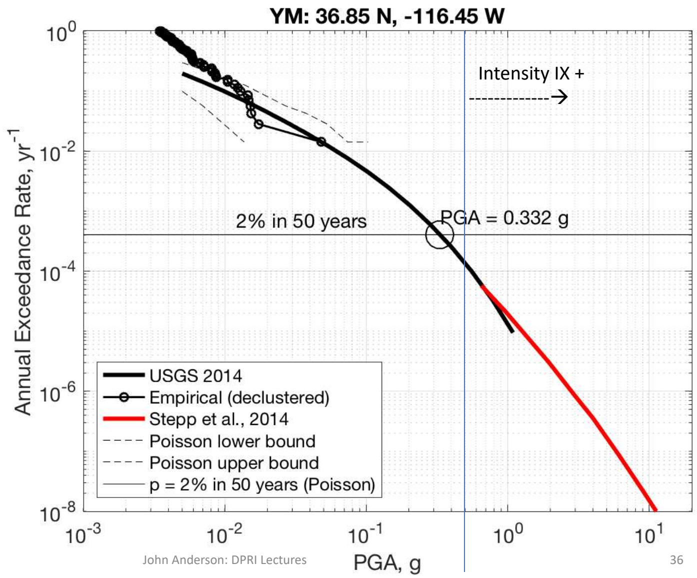
- Proposed geological repository for nuclear waste from US nuclear power plants.

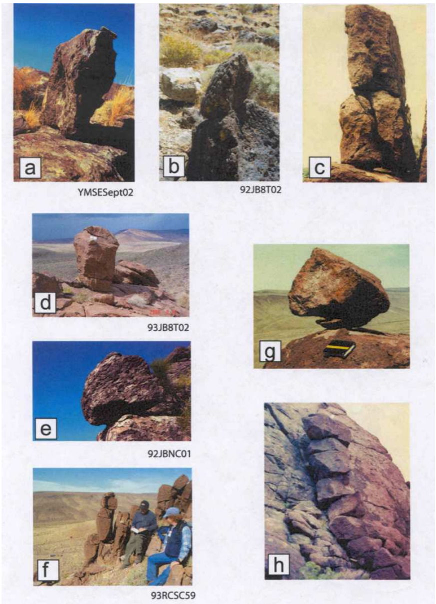


Two-percent probability of exceedance in 50 years map of peak ground acceleration

The hazard curve finds violent ground motions at low probabilities.

At 10^{-8} per year:
- 11.2 g
- 13.0 m/s





Site/Rock ID	Site/Rock Nickname	WGS 84 Locations Lat	Lon	Quasi-Static Toppling Accel. (g)	Measured Alpha (rad)	Dynamic Toppling Accel. (g)	Azimuth (deg)
	PSHA	36.8444	-116.4622				
92JBNC01	Doozy	36.85278	-116.46678	0.07*		0.09*	225
93JB8T02	Fluffy	36.80524	-116.47682	0.19	0.30	0.25, 0.39	98
92JB8T02	Red Eye	36.81464	-116.48969	0.19		0.25	0
YMSESept02	WALW	36.79925	-116.45851	0.14, 0.38		0.18, 0.49	115, 29[illegible]
93RCSC59	Tripod	36.83018	-116.47085		0.21, 0.32	0.27, 0.42	65, 245

Precarious Rock Name	Chlorine-36 exposure age of rock surface, ka
Whitney 1	242
Whitney 2	56
Whitney 3	88
Len 4	81
Len 5	79
Len 6	74
CBD 7	174
CBD 8	154
ACRS 9	32

Unstable Cliffs

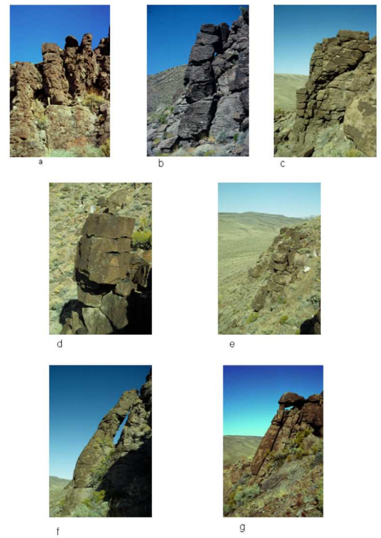


Figure 3
Precipitous Cliffs

Shattered Cliffs and Mega-Breccias

Shattered by underground nuclear explosions.

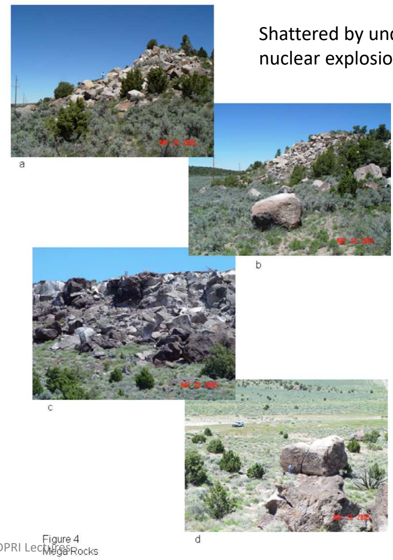
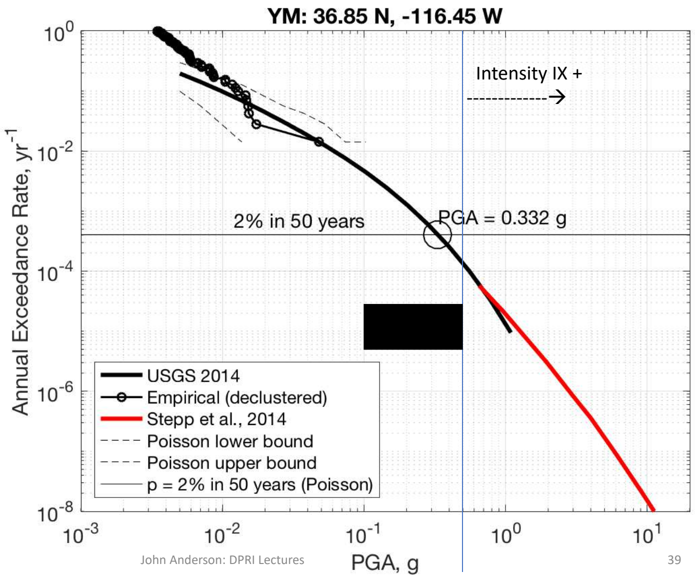


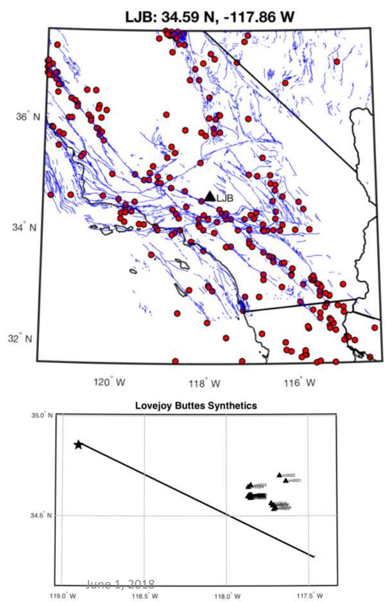
Figure 4
Mega Rocks

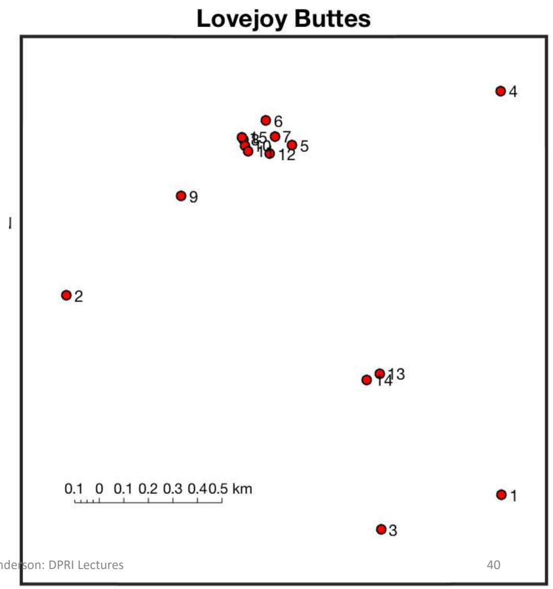
The hazard curve finds violent ground motions at low probabilities.

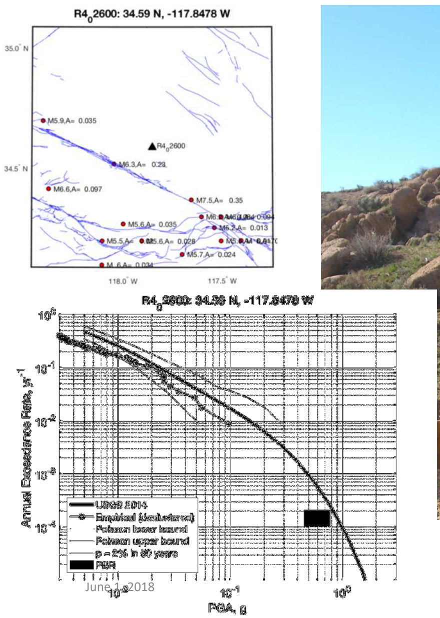
At 10^{-8} per year:

- 11.2 g
- 13.0 m/s

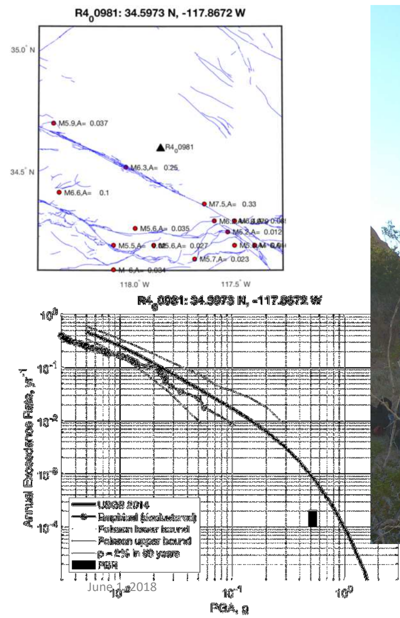




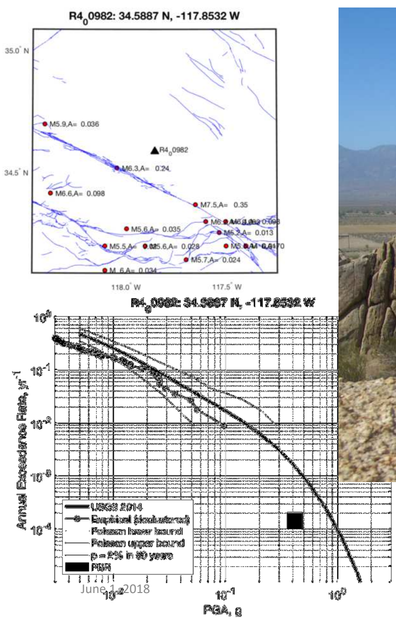




1

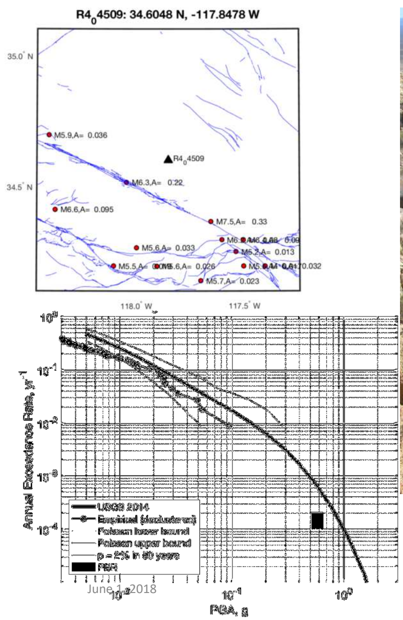


2

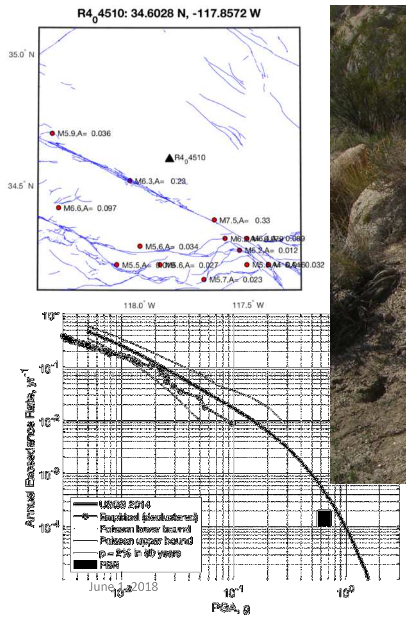


14.5 km from the San Andreas fault.
Fault is at the base of the mountains in the background.

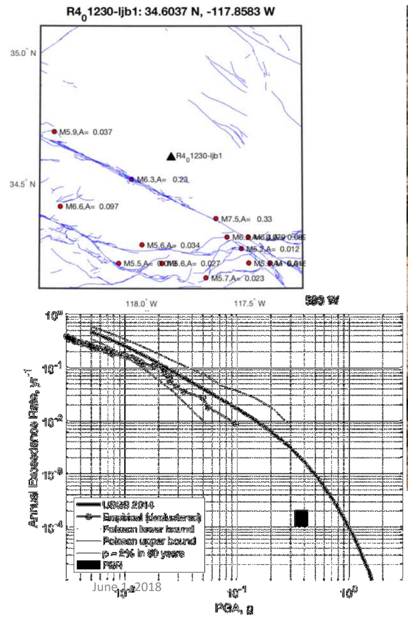
3

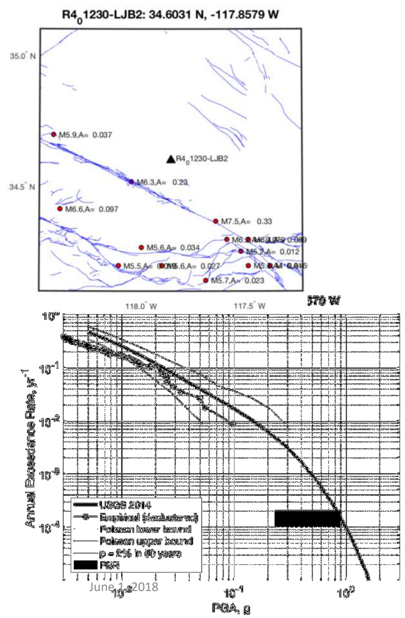


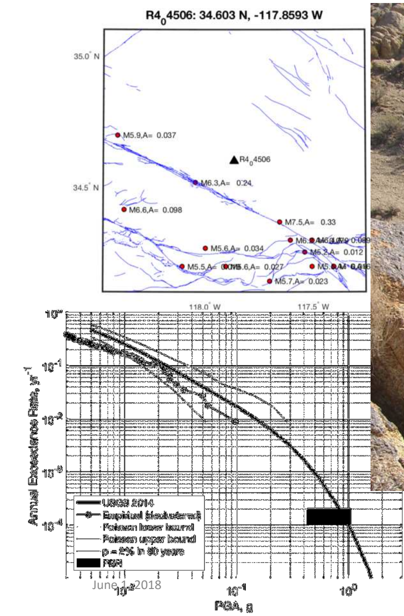
4

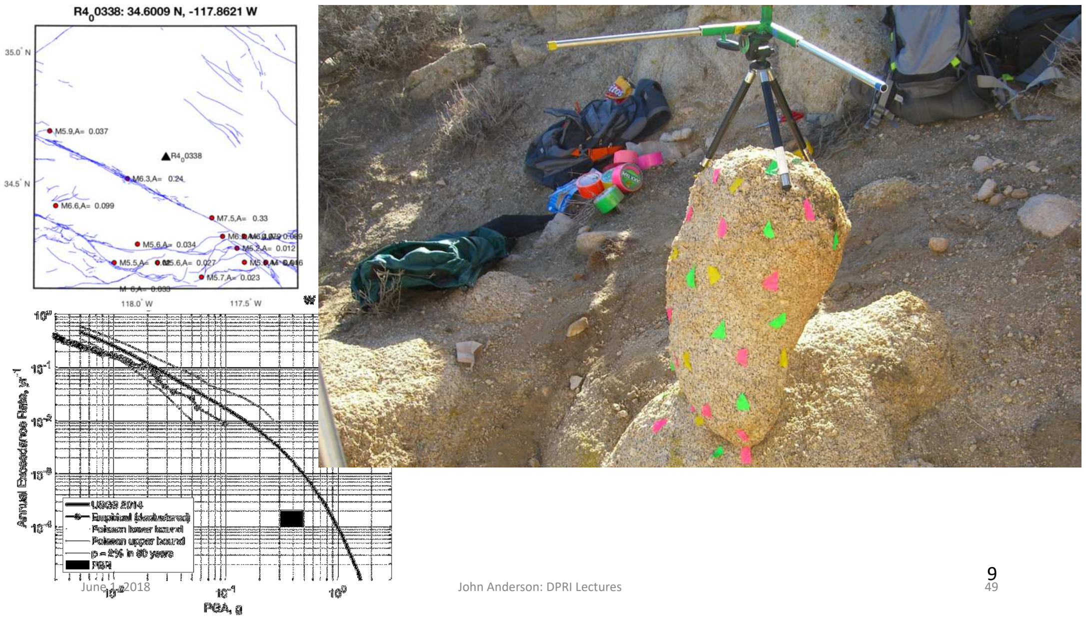

R4₀4510: 34.6028 N, -117.8572 W
Annual Exceedance Rate, yr⁻¹
PGA, g
USGS 2014
Empirical (declustered)
Poisson lower bound
Poisson upper bound
p = 2% in 50 years
PBR

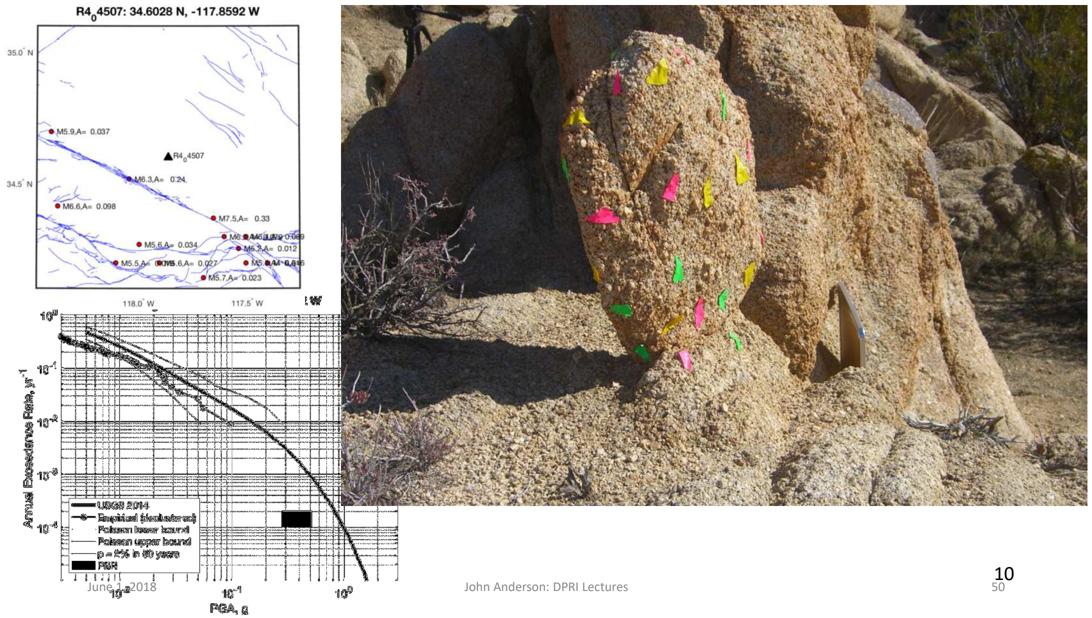

2-24-16
34.6028
-117.85716

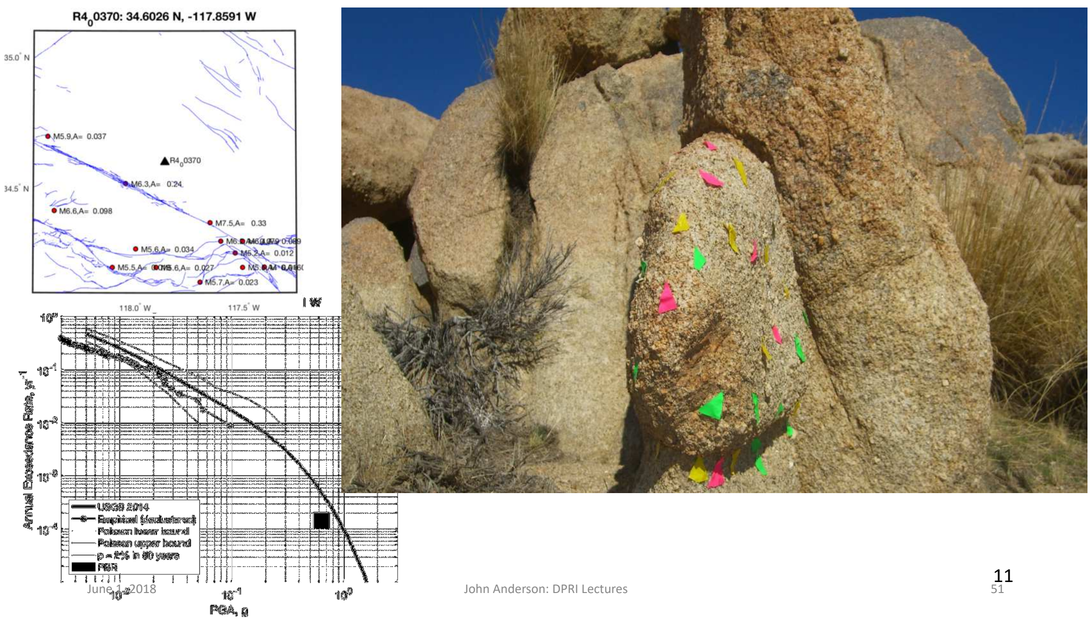

R4₀1230-ljb1: 34.6037 N, -117.8583 W
Annual Exceedance Rate, yr⁻¹
PGA, g
USGS 2014
Empirical (declustered)
Poisson lower bound
Poisson upper bound
p = 2% in 50 years
PBR

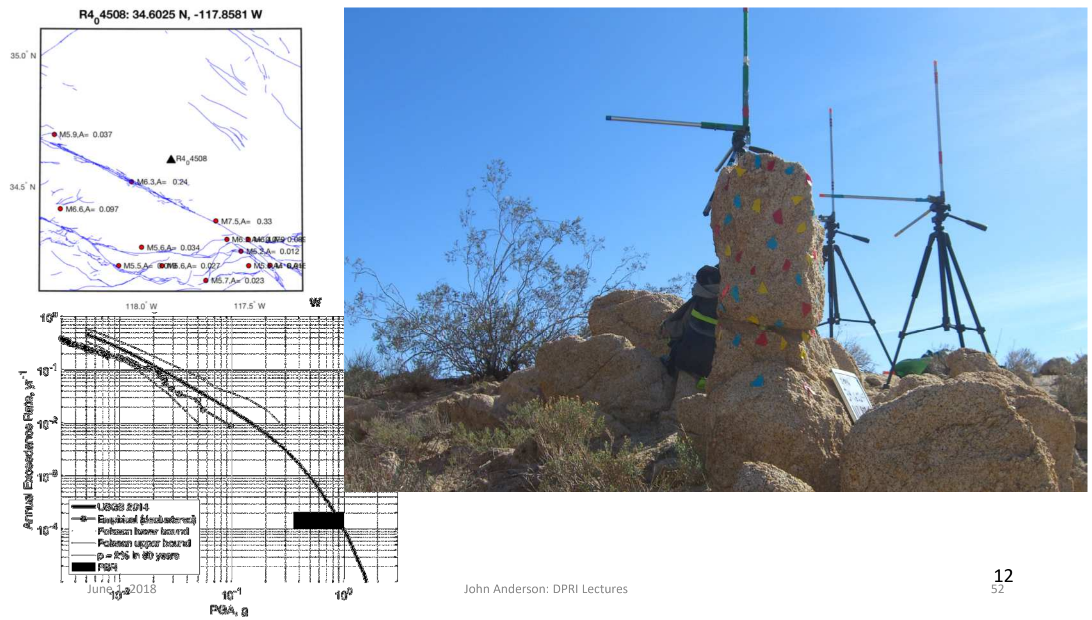

R4₀1230-LJB2: 34.6031 N, -117.8579 W
Annual Exceedance Rate, yr⁻¹
PGA, g
USGS 2014
Empirical (declustered)
Poisson lower bound
Poisson upper bound
p = 2% in 50 years
PBR

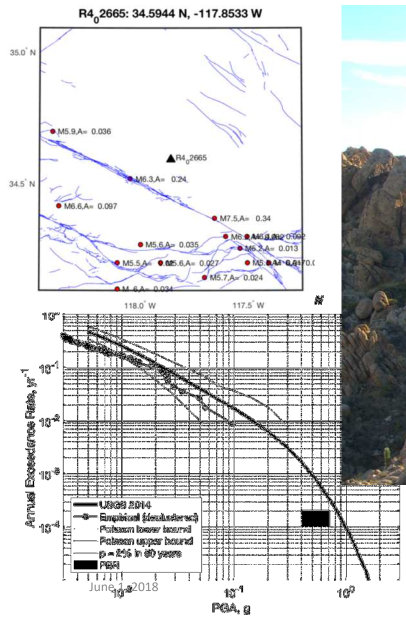

R4₀4506: 34.603 N, -117.8593 W
Annual Exceedance Rate, yr⁻¹
PGA, g
USGS 2014
Empirical (declustered)
Poisson lower bound
Poisson upper bound
p = 2% in 50 years
PBR


R4$_0$0338: 34.6009 N, -117.8621 W
35.0° N
34.5° N
118.0° W
117.5° W
M5.9,A= 0.037
M6.3,A= 0.24
M6.6,A= 0.099
M7.5,A= 0.33
M5.6,A= 0.034
M5.5,A=
M5.7,A= 0.023
Annual Exceedance Rate, yr^{-1}
PGA, g
USGS 2014
Empirical (declustered)
Poisson lower bound
Poisson upper bound
p = 2% in 50 years
PBR

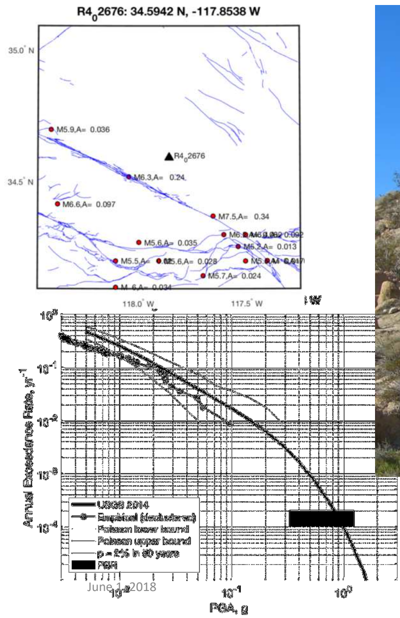

R4$_0$4507: 34.6028 N, -117.8592 W
35.0° N
34.5° N
118.0° W
117.5° W
M5.9,A= 0.037
M6.3,A= 0.24
M6.6,A= 0.098
M7.5,A= 0.33
M5.6,A= 0.034
M5.3,A= 0.012
M5.7,A= 0.023
Annual Exceedance Rate, yr^{-1}
PGA, g
USGS 2014
Empirical (declustered)
Poisson lower bound
Poisson upper bound
p = 2% in 50 years
PBR


R4$_0$0370: 34.6026 N, -117.8591 W
35.0° N
34.5° N
118.0° W
117.5° W
M5.9,A= 0.037
M6.3,A= 0.24
M6.6,A= 0.098
M7.5,A= 0.33
M5.6,A= 0.034
M5.3,A= 0.012
M5.7,A= 0.023
Annual Exceedance Rate, yr^{-1}
PGA, g
USGS 2014
Empirical (declustered)
Poisson lower bound
Poisson upper bound
p = 2% in 50 years
PBR

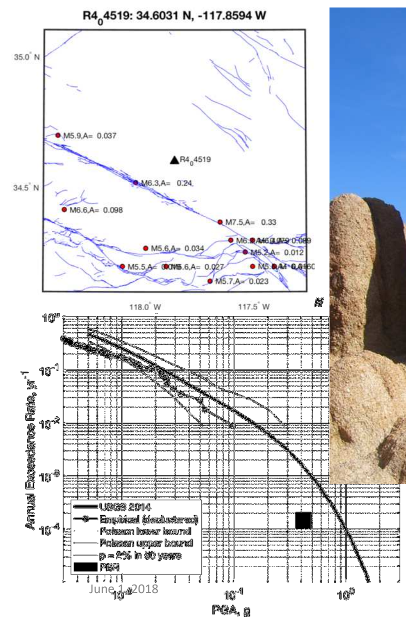

R4$_0$4508: 34.6025 N, -117.8581 W
35.0° N
34.5° N
118.0° W
117.5° W
M5.9,A= 0.037
M6.3,A= 0.24
M6.6,A= 0.097
M7.5,A= 0.33
M5.6,A= 0.034
M5.3,A= 0.012
M5.7,A= 0.023
Annual Exceedance Rate, yr^{-1}
PGA, g
USGS 2014
Empirical (declustered)
Poisson lower bound
Poisson upper bound
p = 2% in 50 years
PBR

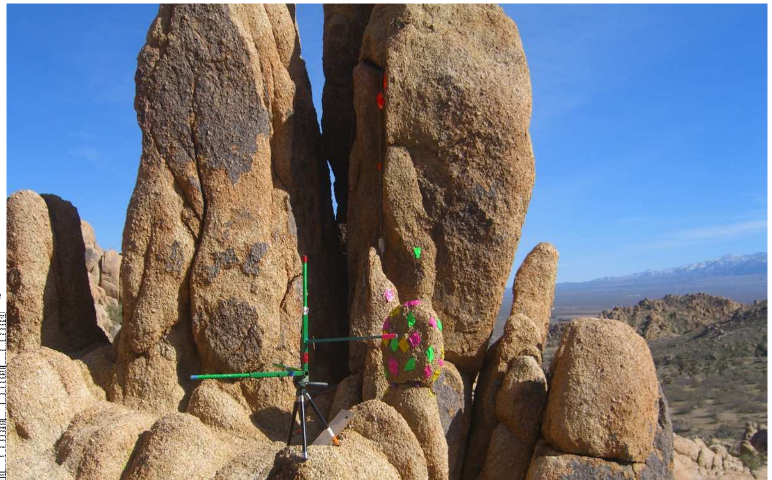

R4$_0$2665: 34.5944 N, -117.8533 W
M5.9,A= 0.036
M6.3,A= 0.24
M6.6,A= 0.097
M7.5,A= 0.34
M5.6,A= 0.035
M5.7,A= 0.024
118.0° W
117.5° W
Annual Exceedance Rate, yr^{-1}
PGA, g
USGS 2014
Empirical (declustered)
Poisson lower bound
Poisson upper bound
p = 2% in 50 years
PBR

13

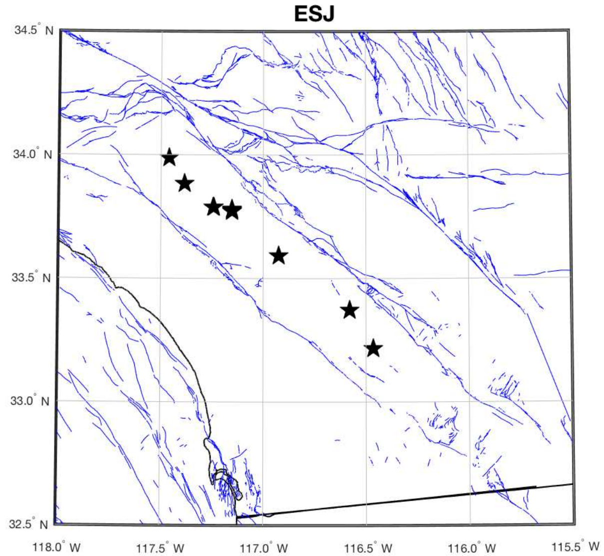

R4$_0$2676: 34.5942 N, -117.8538 W
M5.9,A= 0.036
M6.3,A= 0.24
M6.6,A= 0.097
M7.5,A= 0.34
M5.6,A= 0.035
M5.7,A= 0.024
118.0° W
117.5° W
Annual Exceedance Rate, yr^{-1}
PGA, g
USGS 2014
Empirical (declustered)
Poisson lower bound
Poisson upper bound
p = 2% in 50 years
PBR

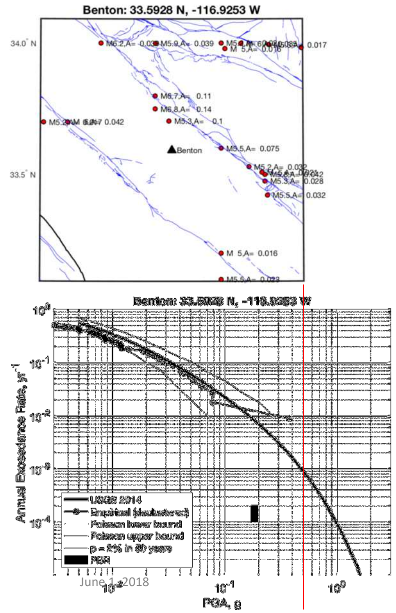
14

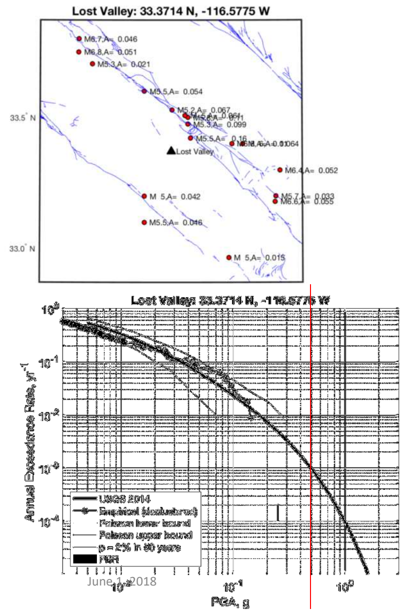

R4$_0$4519: 34.6031 N, -117.8594 W
M5.9,A= 0.037
M6.3,A= 0.24
M6.6,A= 0.098
M7.5,A= 0.33
M5.6,A= 0.034
M5.7,A= 0.023
118.0° W
117.5° W
Annual Exceedance Rate, yr^{-1}
PGA, g
USGS 2014
Empirical (declustered)
Poisson lower bound
Poisson upper bound
p = 2% in 50 years
PBR

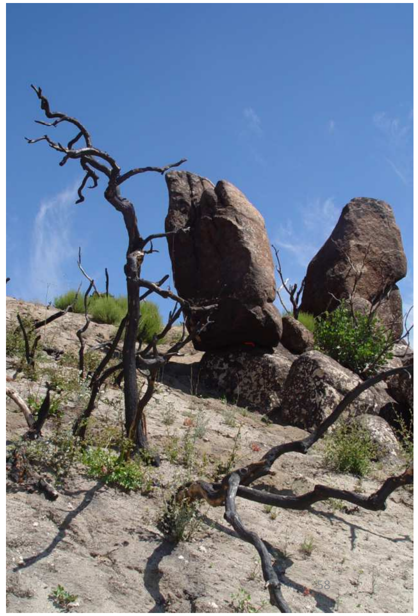


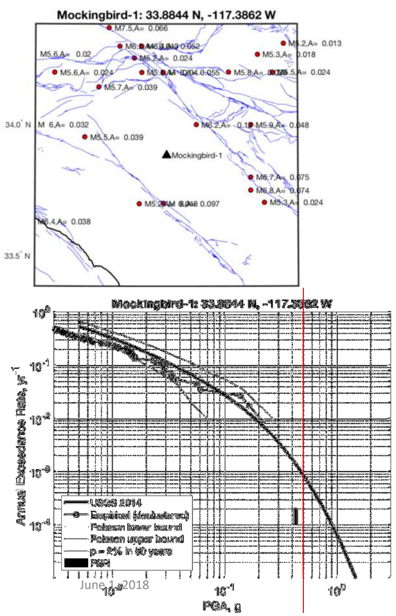
15

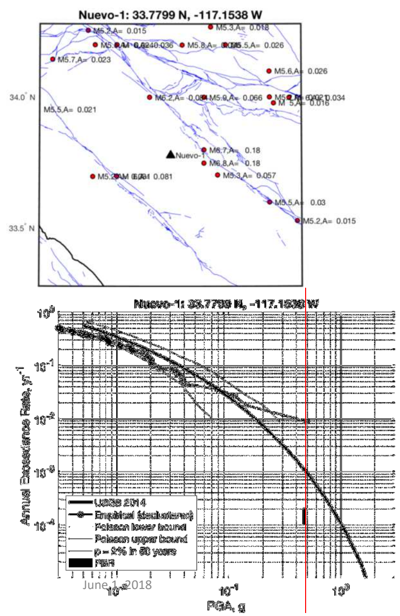

ESJ
34.5° N
34.0° N
33.5° N
33.0° N
32.5° N
118.0° W
117.5° W
117.0° W
116.5° W
116.0° W
115.5° W

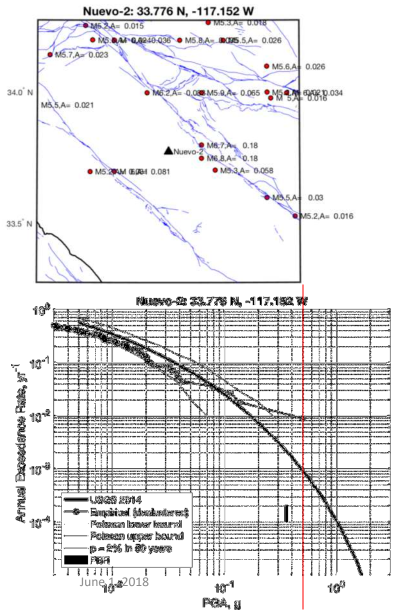

Benton: 33.5928 N, -116.9253 W
Annual Exceedance Rate, yr^-1
PGA, g
USGS 2014
Empirical (declustered)
Poisson lower bound
Poisson upper bound
p = 2% in 50 years
PBR


Lost Valley: 33.3714 N, -116.5775 W
Annual Exceedance Rate, yr^-1
PGA, g
USGS 2014
Empirical (declustered)
Poisson lower bound
Poisson upper bound
p = 2% in 50 years
PBR

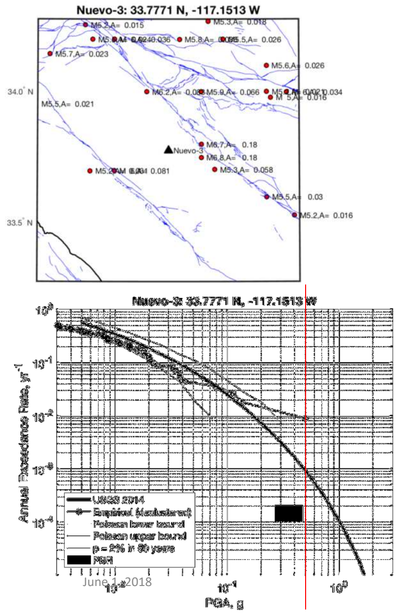



Mockingbird-1: 33.8844 N, -117.3862 W
Annual Exceedance Rate, yr^-1
PGA, g
USGS 2014
Empirical (declustered)
Poisson lower bound
Poisson upper bound
p = 2% in 50 years
PBR

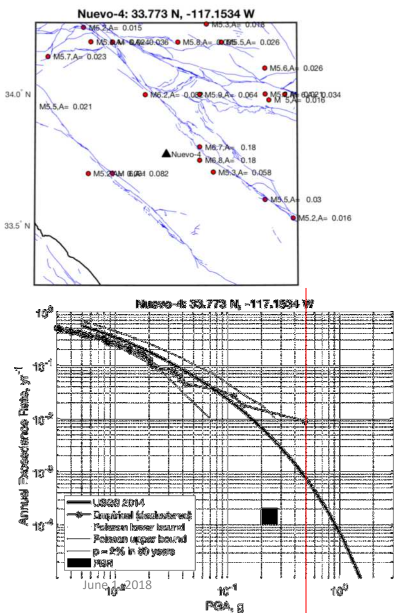

Nuevo-1: 33.7799 N, -117.1538 W
Annual Exceedance Rate, yr^-1
PGA, g
USGS 2014
Empirical (declustered)
Poisson lower bound
Poisson upper bound
p = 2% in 50 years
PBR



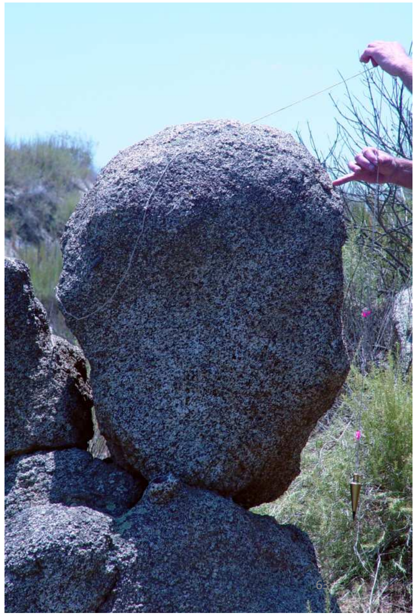
Nuevo-2: 33.776 N, -117.152 W
34.0° N
33.5° N
Nuevo-2
Nuevo-2: 33.776 N, -117.152 W
Annual Exceedance Rate, yr^-1
PGA, g
USGS 2014
Empirical (declustered)
Poisson lower bound
Poisson upper bound
p = 2% in 50 years
PBR

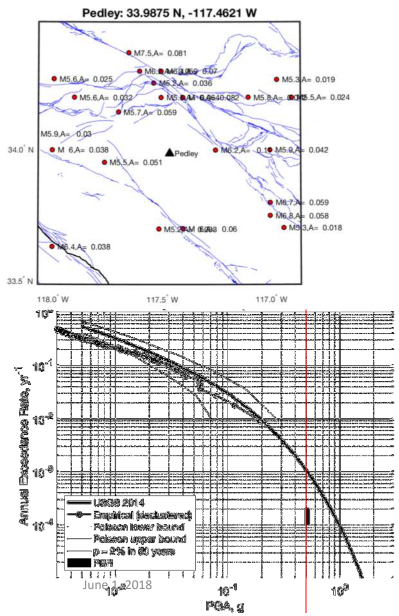


Nuevo-3: 33.7771 N, -117.1513 W
34.0° N
33.5° N
Nuevo-3
Nuevo-3: 33.7771 N, -117.1513 W
Annual Exceedance Rate, yr^-1
PGA, g
USGS 2014
Empirical (declustered)
Poisson lower bound
Poisson upper bound
p = 2% in 50 years
PBR

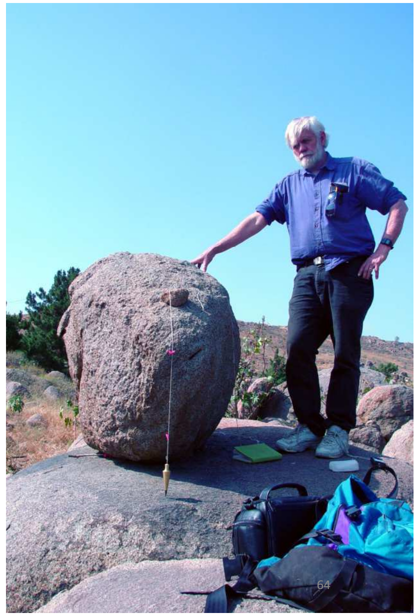


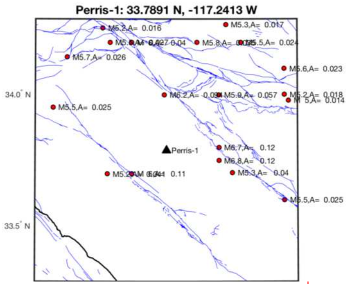
Nuevo-4: 33.773 N, -117.1534 W
34.0° N
33.5° N
Nuevo-4
Nuevo-4: 33.773 N, -117.1534 W
Annual Exceedance Rate, yr^-1
PGA, g
USGS 2014
Empirical (declustered)
Poisson lower bound
Poisson upper bound
p = 2% in 50 years
PBR

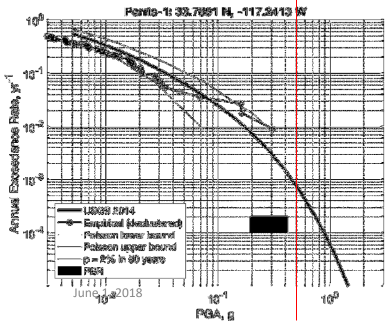


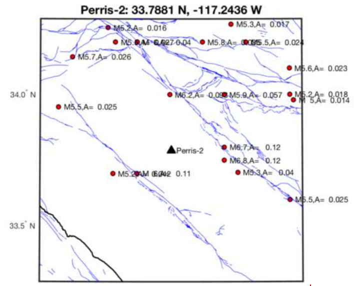


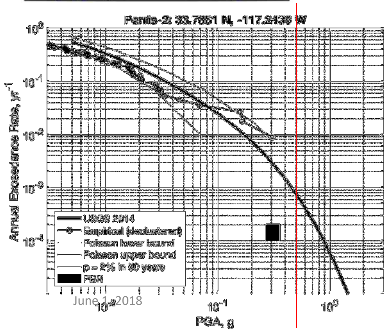
Pedley: 33.9875 N, -117.4621 W
34.0° N
33.5° N
Pedley
118.0° W
117.5° W
117.0° W
Annual Exceedance Rate, yr^-1
PGA, g
USGS 2014
Empirical (declustered)
Poisson lower bound
Poisson upper bound
p = 2% in 50 years
PBR

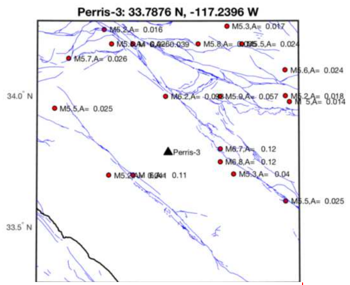


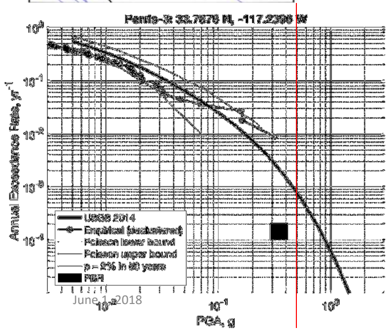

Perris-1: 33.7891 N, -117.2413 W


Perris-1: 33.7891 N, -117.2413 W
Annual Exceedance Rate, yr^-1
PGA, g
USGS 2014
Empirical (declustered)
Poisson lower bound
Poisson upper bound
p = 2% in 50 years
PBR

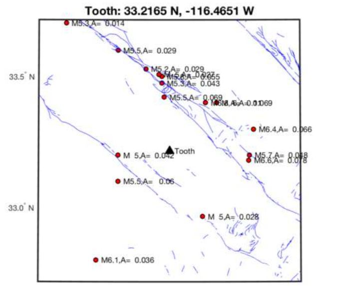

Perris-2: 33.7881 N, -117.2436 W

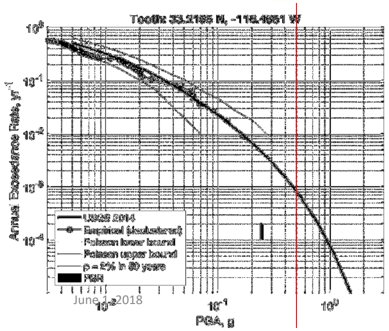

Perris-2: 33.7881 N, -117.2436 W
Annual Exceedance Rate, yr^-1
PGA, g
USGS 2014
Empirical (declustered)
Poisson lower bound
Poisson upper bound
p = 2% in 50 years
PBR

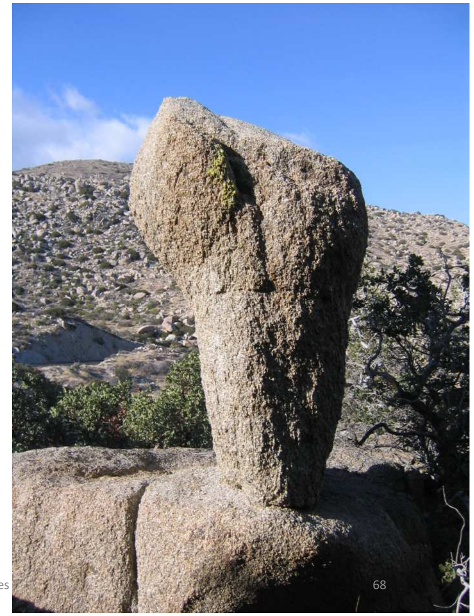

Perris-3: 33.7876 N, -117.2396 W


Perris-3: 33.7876 N, -117.2396 W
Annual Exceedance Rate, yr^-1
PGA, g
USGS 2014
Empirical (declustered)
Poisson lower bound
Poisson upper bound
p = 2% in 50 years
PBR


MAR 25 2004


Tooth: 33.2165 N, -116.4651 W


Tooth: 33.2165 N, -116.4651 W
Annual Exceedance Rate, yr^-1
PGA, g
USGS 2014
Empirical (declustered)
Poisson lower bound
Poisson upper bound
p = 2% in 50 years
PBR



Discussion, if our analysis of the PBRs is correct

- Hazard curves predict collapse of these precarious rocks.
- So these hazard curves are likely not correct.
- The correct hazard curve exists.
- Something must be wrong with the input to synthesize the hazard curves.
- How can we correct the input to the model?
- Expect that the correction will have a more general impact beyond the desert of southwestern USA.

Ideas for Improving the Seismic Hazard Estimates

- Ergodic Assumption

Probabilistic Seismic Hazard Analysis without the Ergodic Assumption

John G. Anderson and James N. Brune
University of Nevada at Reno

INTRODUCTION

An *ergodic process* is a random process in which the distribution of a random variable in space is the same as the distribution of that same random variable at a single point when sampled as a function of time. An ergodic assumption is commonly made in probabilistic seismic hazard analysis (PSHA). A regression analysis is used to obtain a mean curve to predict ground motion as a function of magnitude and distance (and sometimes other parameters). The standard deviation of this ground-motion regression is determined mainly by the misfit between observations and the corresponding predicted ground motions at multiple stations for a small number of well recorded earthquakes. Thus, the standard deviation of the ground-motion regression is dominantly related to the statistics of the spatial variability of the ground motions. An ergodic assumption is made when PSHA treats that spatial uncertainty of ground motions as an uncertainty over time at a single point (Anderson and Brune, 1998b).

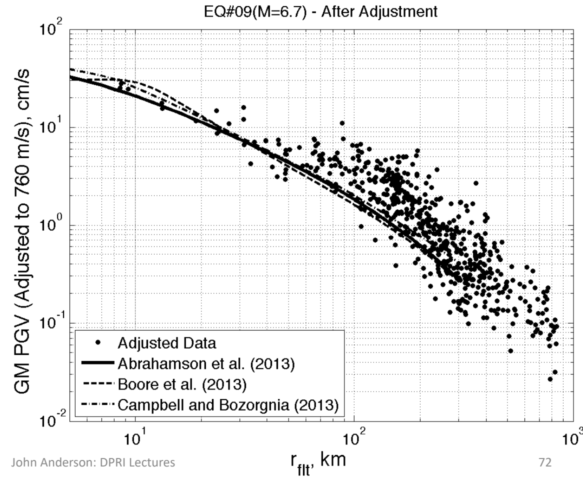
Characteristic ground motion earthquake:

Slip function and dynamics of rupture are identical every time the fault ruptures.
Expect that ground motion will be identical every time.
"Single-station sigma" will be zero.

Seismological Research Letters, 1999

Ergodic Assumption

- The Ground Motion Prediction Equations measure the variability of ground motion in space
- In seismic hazard analysis, this spatial variability is treated as the variability at a single location.



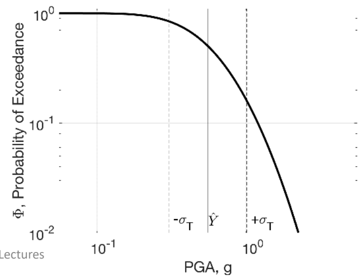
Equation: hazard is a probabilistic mean value

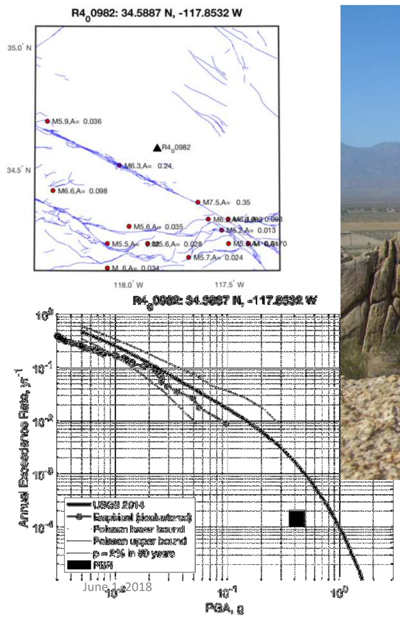
$$\gamma_C(Y) = \iint n[M,\mathbf{x}]\,\Phi\left\{y \geq Y|\underline{\hat{Y},\sigma_T}\right\} dM\,d\mathbf{x}$$

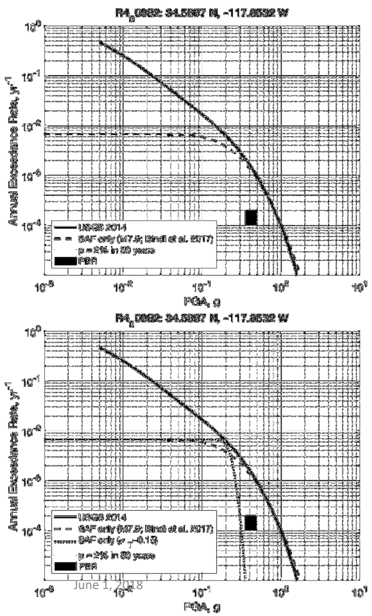
Functions of M, x

Y = ground motion
n = number of earthquakes, magnitude M, at location x
Φ = probability of the earthquake exceeding Y.

- To change the hazard curve we have to change the integrands.
- There is very little room to change n.
- Primarily suspect the ground motion prediction equation, represented by Φ.

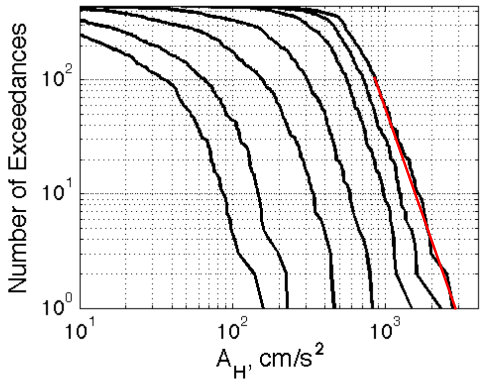


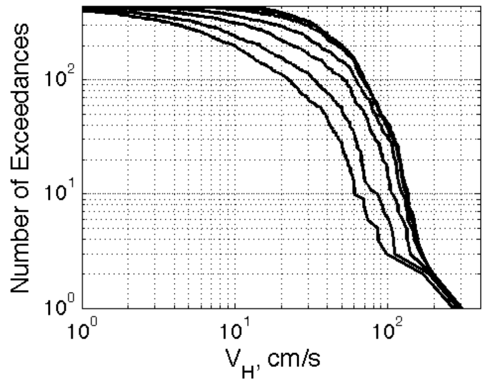




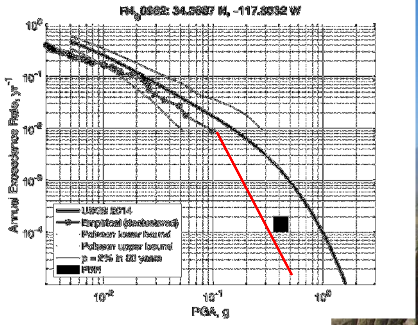
The hazard here is dominated by the San Andreas fault.
If the uncertainty in the GMPE is smaller (0.15), the inconsistency goes away.
What is the right value for sigma?

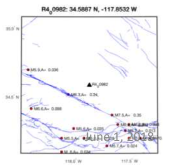
Peak horizontal acceleration and velocity, filtered





Low-pass filters: f_C=0.33, 0.5, 1, 2, 5, 10, 25 Hz





Extend empirical curve at the same slope as the slope of extreme PGAs?
This would be consistent with existence of the PBR.
This approach mixes time & space – no control over site conditions, magnitude, distance. It is an ergodic assumption.

3

Indicators for the solution

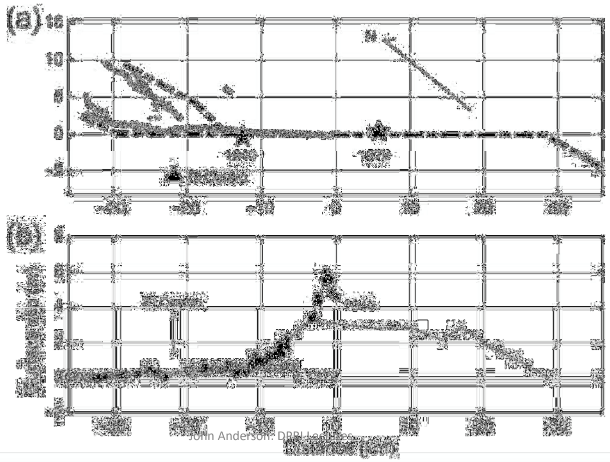
- Statistics of the largest observed motions.
- Statistics of foamquakes.

Bulletin of the Seismological Society of America, Vol. 105, No. 4, pp. –, August 2015, doi: 10.1785/0120140196

Between-Event Variance for Large Repeating Earthquakes

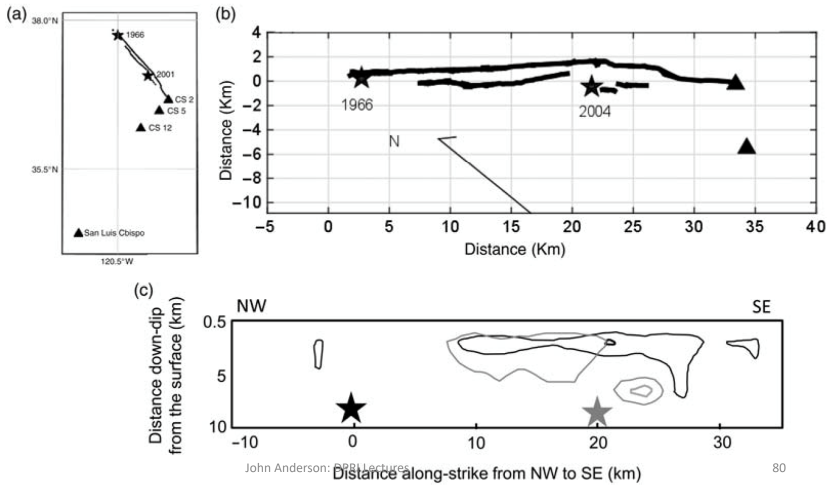
by Gony Yagoda-Biran,* John G. Anderson, Hiroe Miyake, and Kazuki Koketsu

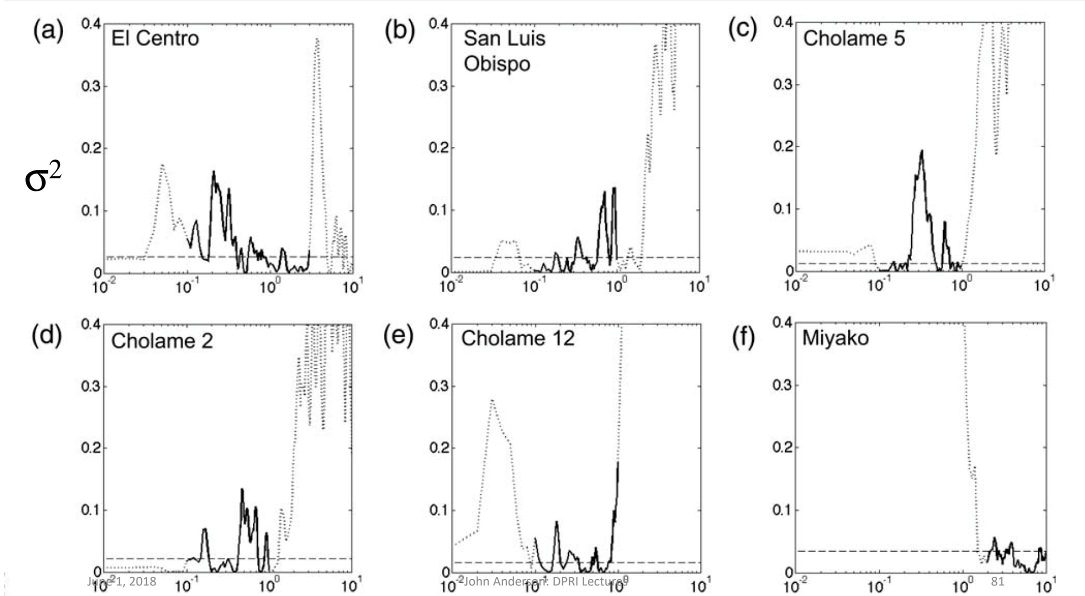
Imperial Valley
1940 and 1979

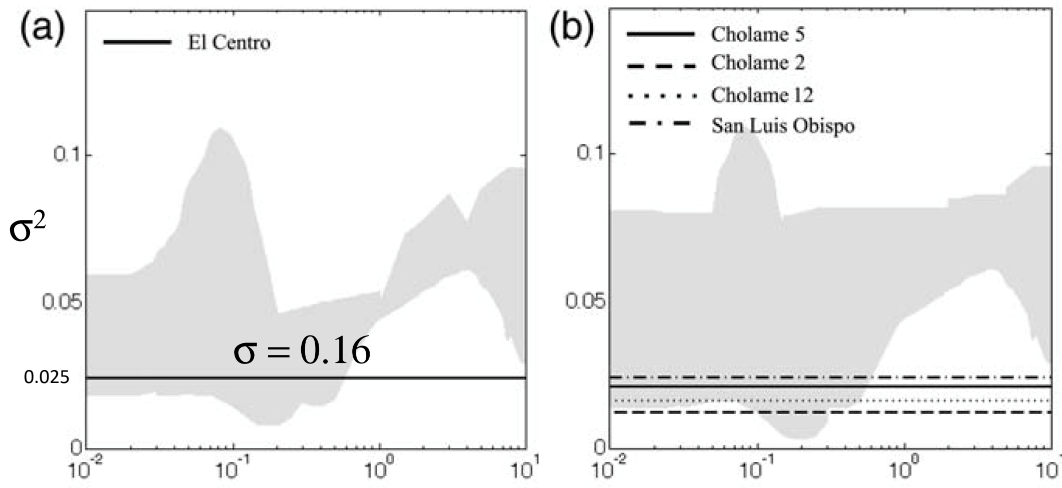


Map

Parkfield
1966 and 2004







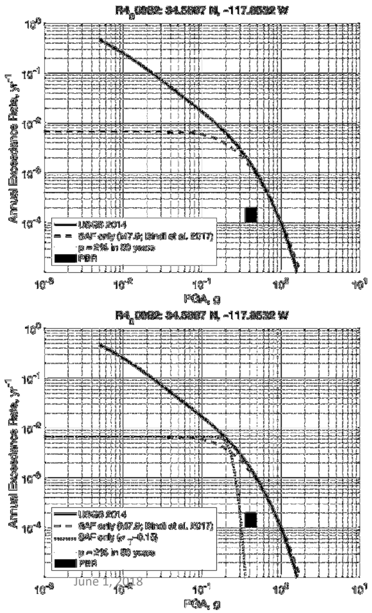
What did Kevin find?

- We have constructed a method to generate synthetic seismograms that

1. Gives sigma of about this size
2. Can be calibrated in part by the precarious rocks.
3. Gives realistic broadband seismograms.

Indicators for the solution

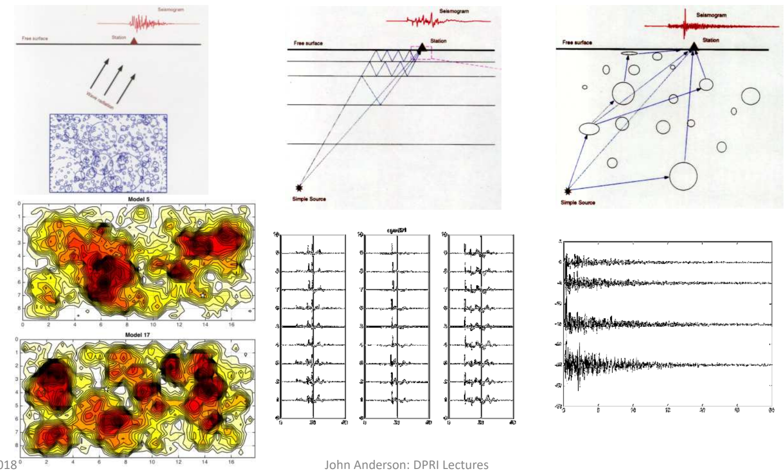
- Synthetics
  - Calibration
  - Sigma from CSM



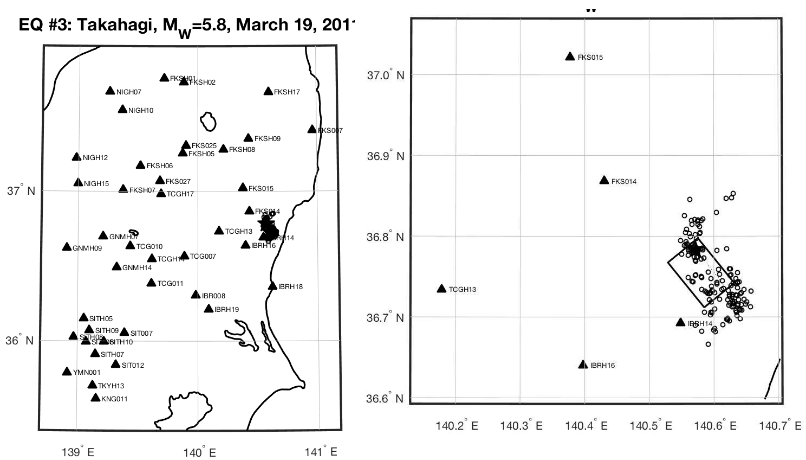
The hazard affecting the rock is dominated by the San Andreas fault. If the uncertainty in the GMPE were smaller (0.15), the inconsistency would go away.

Synthetic Seismograms using a Composite Source Model

$$u_n(\vec{x},t)=\int_{-\infty}^{\infty} d\tau \iint_{\Sigma} \left[u_i(\vec{\xi},\tau)\right] c_{ijpq}\nu_j \frac{\partial G_{np}\left(\vec{x},t-\tau;\vec{\xi},0\right)}{\partial \xi_q} d\Sigma$$



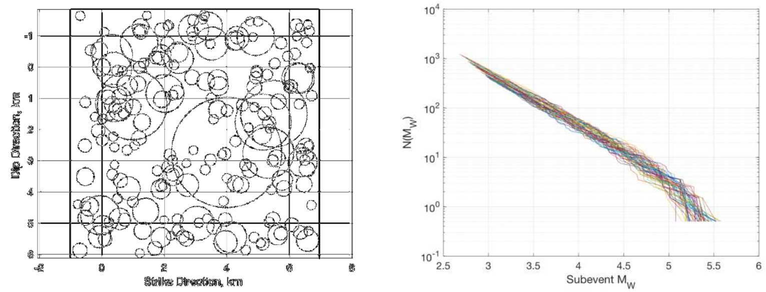
Example – modeling an M5.8 Iwaki earthquake

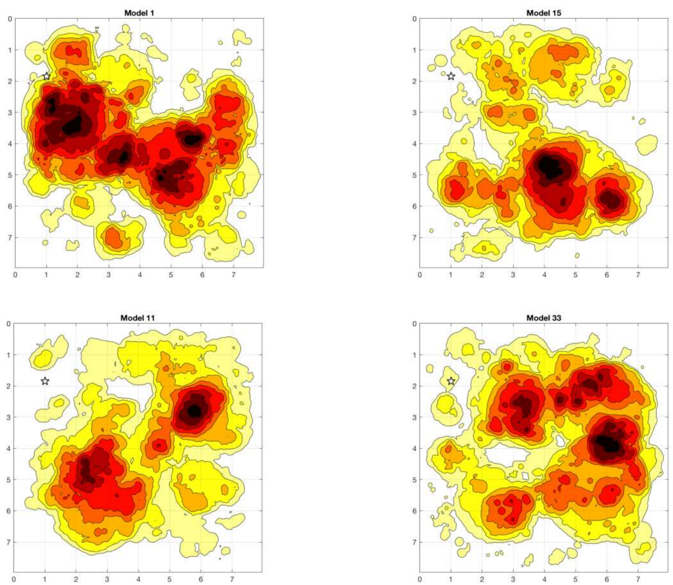


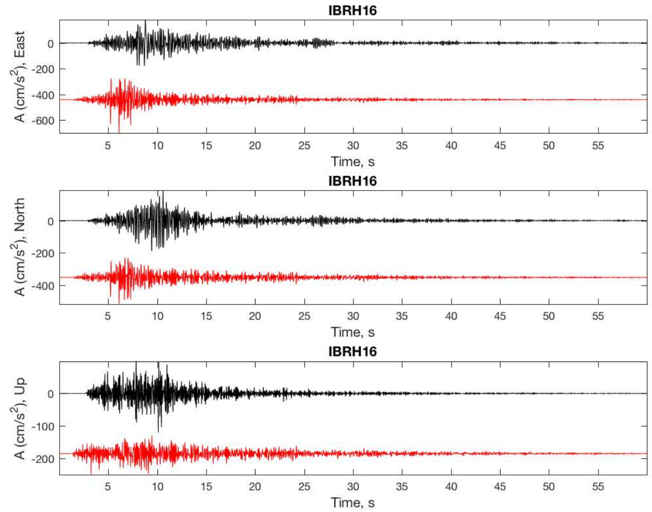
Generate subevents

$$M_0 = \frac{16}{7}\Delta\tau_S r_E^3$$

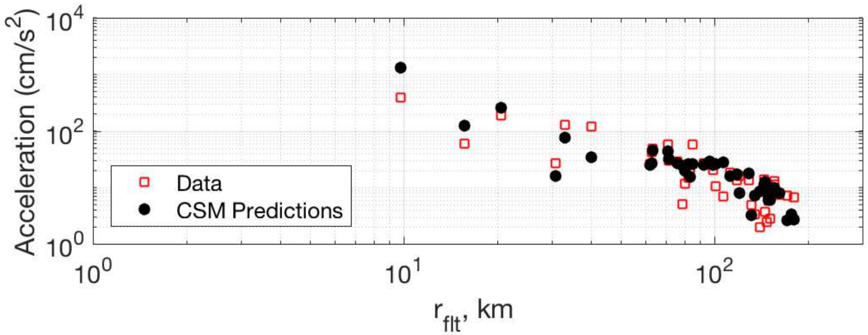
- Subevent stress drop does not need to be 3 MPa.
- Sum of moments of all subevents must equal earthquake moment
- Stochastic realization – gives b=1 for distribution of subevents on the fault.
- Locations are random

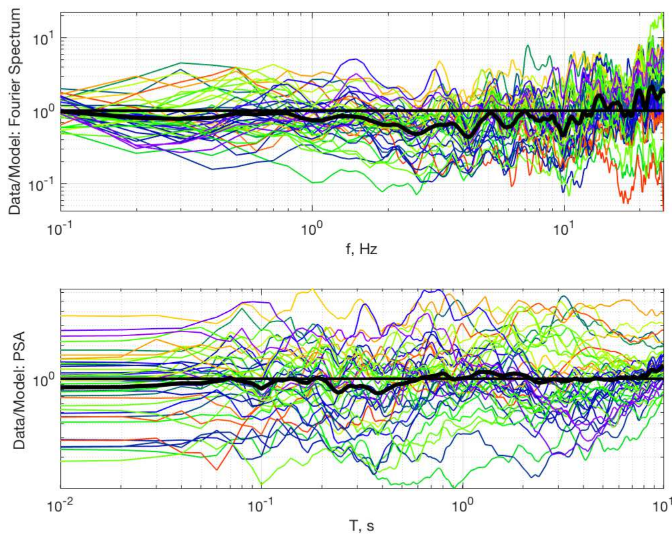




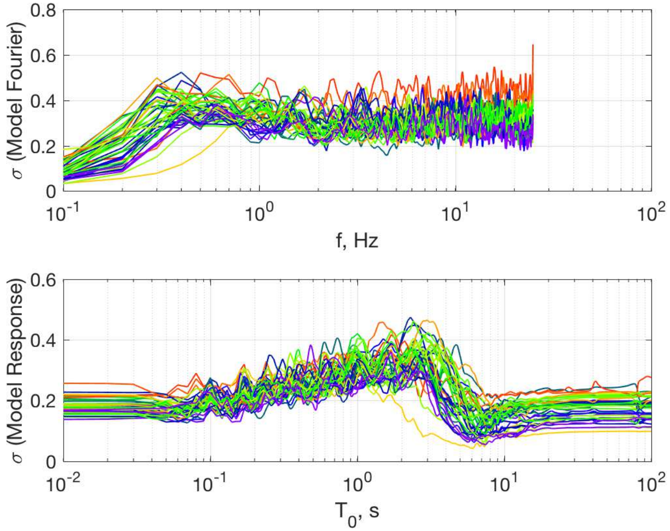


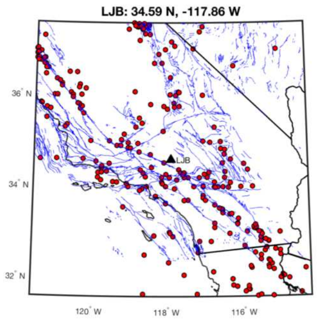
Peak acceleration vs. distance

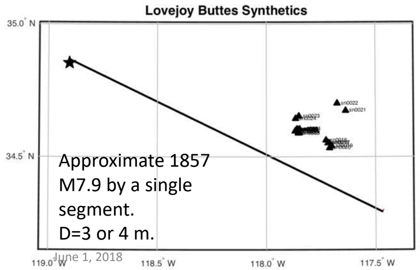


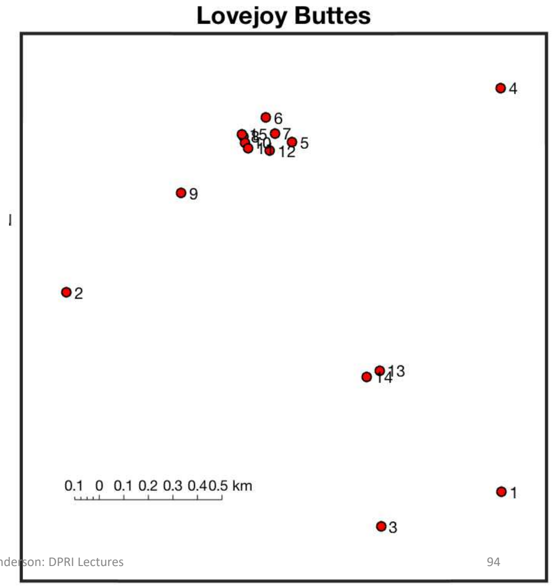


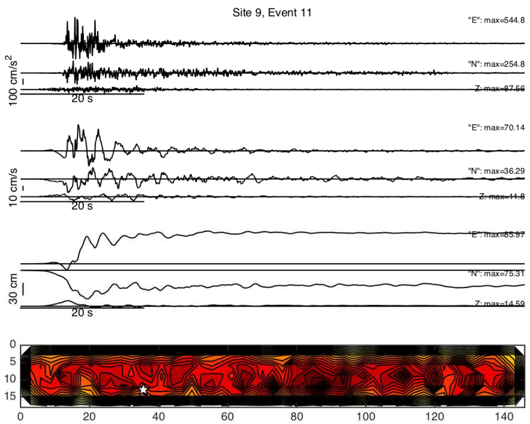
Sigma

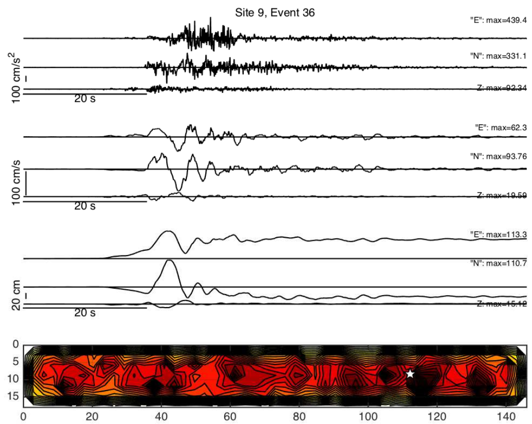

σ (Model Fourier)
f, Hz
σ (Model Response)
T0, s

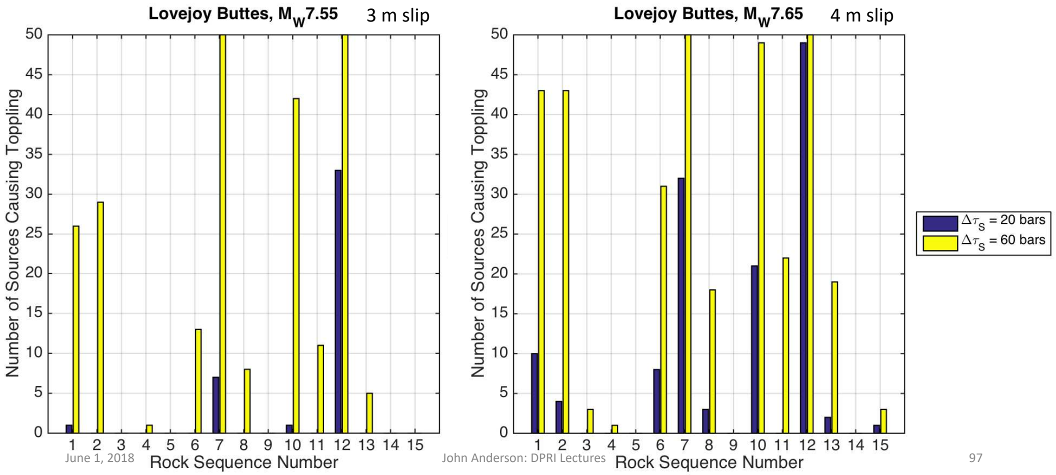

LJB: 34.59 N, -117.86 W

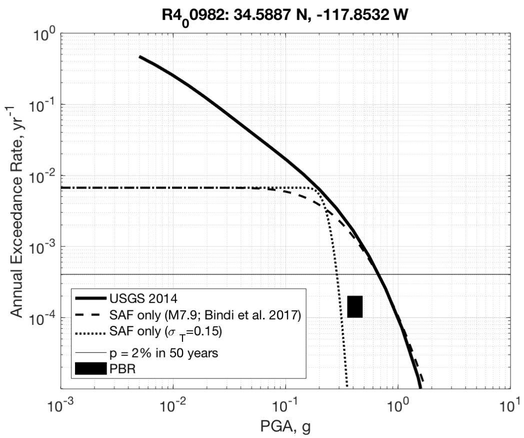

Lovejoy Buttes Synthetics
Approximate 1857
M7.9 by a single
segment.
D=3 or 4 m.


Lovejoy Buttes
0.1 0 0.1 0.2 0.3 0.4 0.5 km


Site 9, Event 11
100 cm/s²
10 cm/s
30 cm
20 s


Site 9, Event 36
100 cm/s²
100 cm/s
20 cm
20 s





The hazard affecting the rock is dominated by the San Andreas fault.
Very little opportunity to change the source term in the integral for the hazard at this site.
The only way to estimate a hazard curve consistent with these observations is to adjust the ground motion.

Have at least one technique to generate synthetics, where sigma from multiple ruptures is low enough.

Is the USGS National Hazard Map Wrong?

- No.
- For general design guidance, one has to make the ergodic assumption.
- There is a cost for lack of knowledge.
- Site-specific studies can remove the ergodic assumption or reduce it’s effects for important structures.

Summary

- Intensity IX happens.
- PSHA predicts that it will happen more than it should.
- We might know why
- Future may involve use of a combination of synthetic seismograms and ground motion prediction equations, especially for site-specific hazard studies.