USGS
science for a changing world

Some New Directions in Probabilistic Seismic Hazard Analysis

Robert L. Wesson

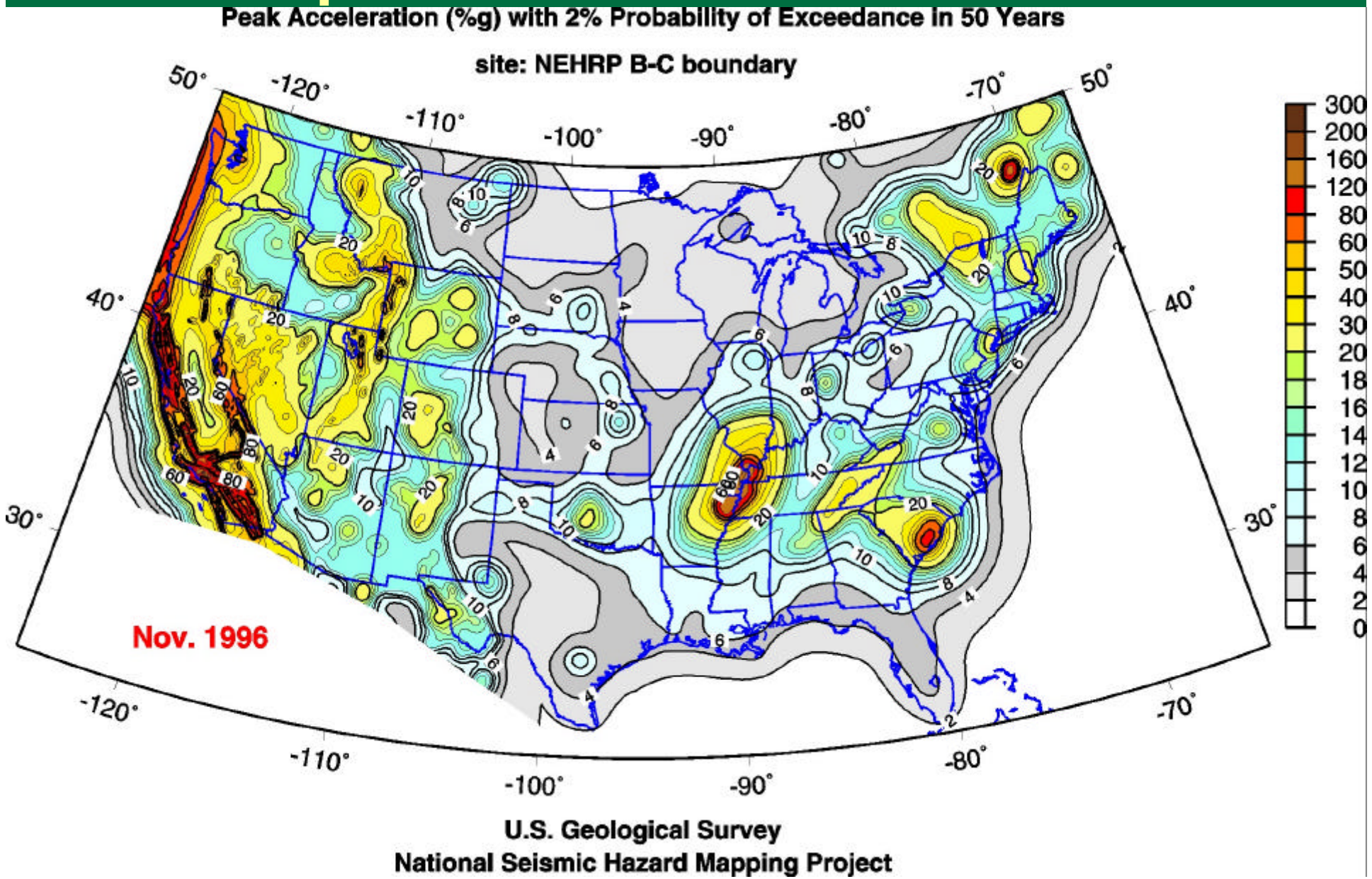
UJNR, Panel on Earthquake Research

Morioka, Japan

November 6, 2002

U.S. Department of the Interior
U.S. Geological Survey

1996 Map


Peak Acceleration (%g) with 2% Probability of Exceedance in 50 Years
site: NEHRP B-C boundary
Nov. 1996
U.S. Geological Survey
National Seismic Hazard Mapping Project

Uses of U.S. National Seismic Hazard Map

- Current
  - Building Codes
- Emerging
  - Financial Loss Estimation

USGS

Potential Uses of Map for Loss Estimation

- How can we use the results of probabilistic seismic hazard mapping to estimate financial losses from earthquakes directly?

USGS

Loss Estimation in U.S.

- Private Sector
  - Proprietary models
  - Insurance Industry
- Public Sector
  - HAZUS

USGS

Our Aim–Provide Means for Loss Estimation

- Publicly available
- Based on quantitative measures of ground motion
- Compatible with National Seismic Hazard Map

USGS

General Idea

- From probabilistic seismic hazard analysis we obtain the “hazard curve,” which is closely related to the probability density function (pdf) for ground motion.
- If we can develop a conditional pdf for loss, given the ground motion, we can estimate the pdf for loss.

USGS

General Idea II

- The mean losses from different locations may be summed to determine the mean loss to a portfolio.
- Additional information about the shape of the pdf for loss to the portfolio requires knowledge about the spatial correlation of probabilistic ground motion.

USGS

Steps Toward Loss Estimation from Hazard Map

- Find the conditional pdf for loss to single family homes from insurance claims from the Northridge earthquake
- Develop a direct method for calculating the spatial correlation of probabilistic ground motion and loss (see Wesson and Perkins, Bulletin of the Seismological Society, December, 2001.)

USGS

Conditional PDF for Loss: The Data Set

- 1994 Northridge, California, Earthquake (Magnitude 6.7)
- Insurance data for single family homes
  - Dollar losses for 80,727 claims in 316 zip codes paid for structural damage on 413,854 insurance policies within 784 zip codes.
- Ground motion
  - Ground motion recordings interpolated using ShakeMap.

USGS

Typical Structures

USGS

Known For Each Loss

- Dollar value of structure as determined from “fire structural value.”
- Dollar loss paid above 10% deductible.
- Geographic location by zip code (U.S. postal code).

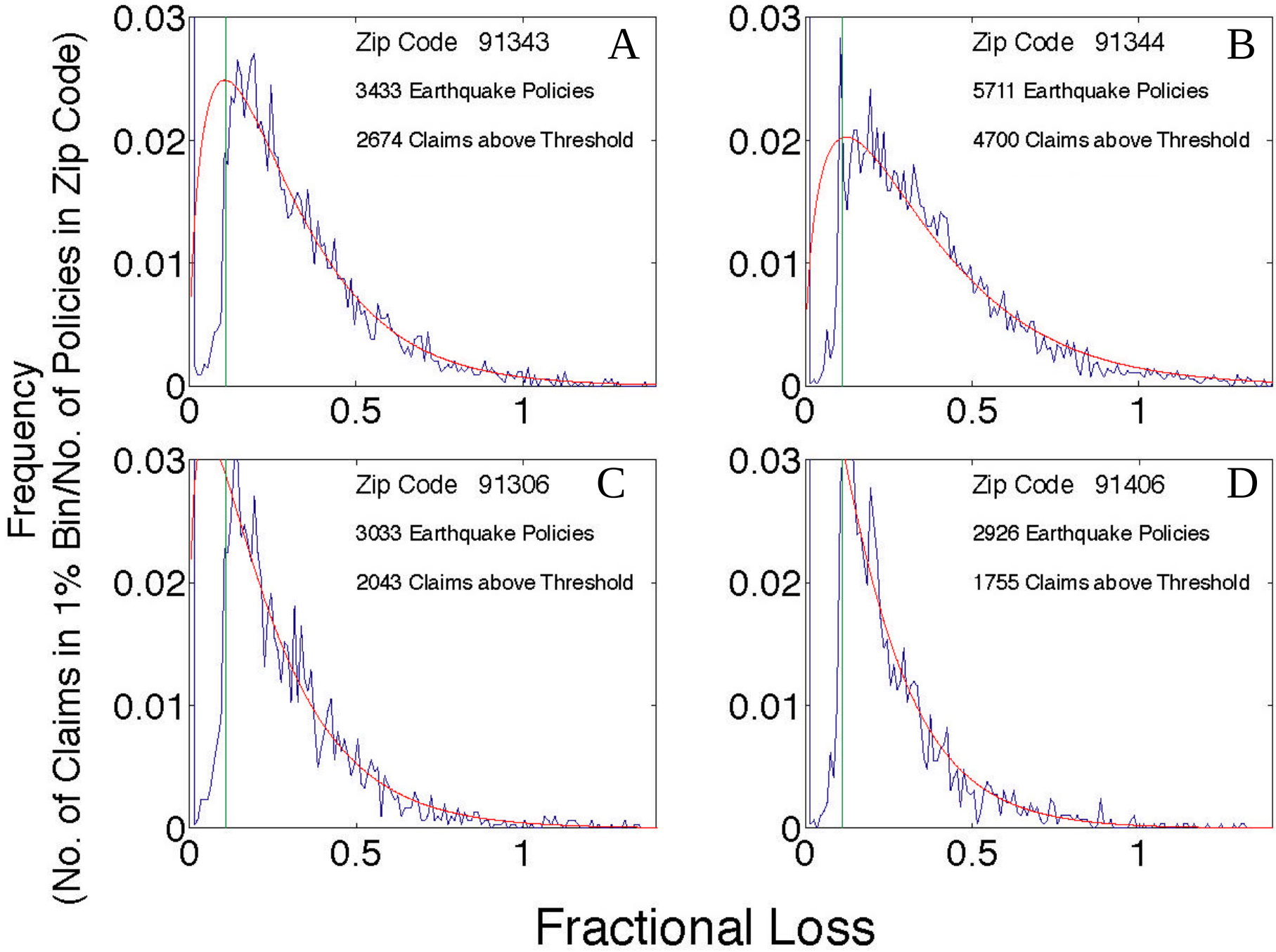
- Also know total number of policies in each zip code.

USGS

Distribution of Loss

- For each claim, calculate “fractional loss”
  - Fract. Loss = Structural Claim/Fire Str. Value
- Then for each zip code, make histogram of fractional losses
- Consider only losses greater than deductible of 10% because sample is incomplete at lower values

USGS

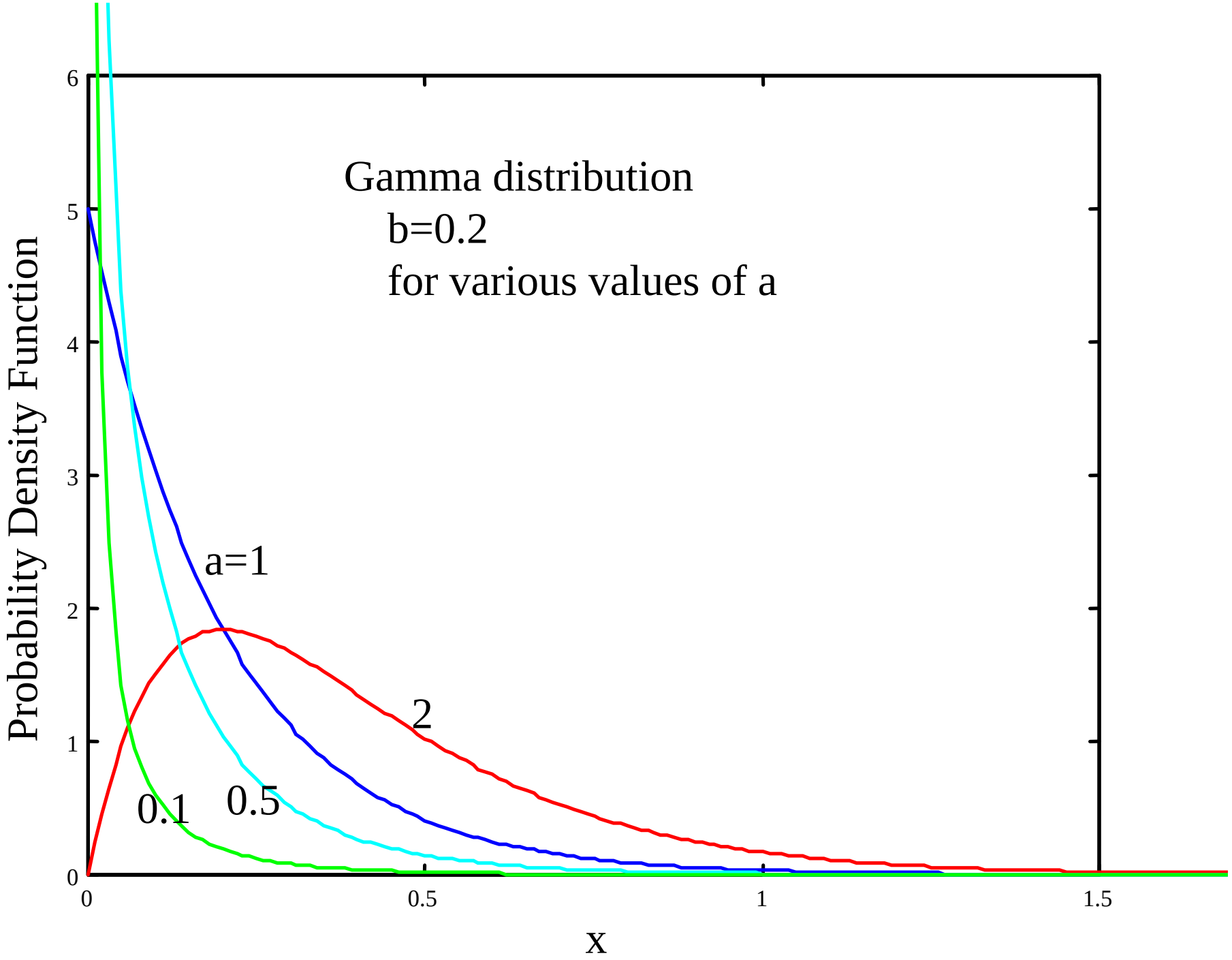

Frequency
(No. of Claims in 1% Bin/No. of Policies in Zip Code)
Zip Code 91343
A
3433 Earthquake Policies
2674 Claims above Threshold
Zip Code 91344
B
5711 Earthquake Policies
4700 Claims above Threshold
Zip Code 91306
C
3033 Earthquake Policies
2043 Claims above Threshold
Zip Code 91406
D
2926 Earthquake Policies
1755 Claims above Threshold
0.03
0.02
0.01
0
0.5
1
Fractional Loss

Probability density function for gamma distribution

$$f(x \mid a,b) = \frac{1}{b^a \Gamma(a)} x^{a-1} e^{-\frac{x}{b}}$$

a, shape parameter
b, scale parameter

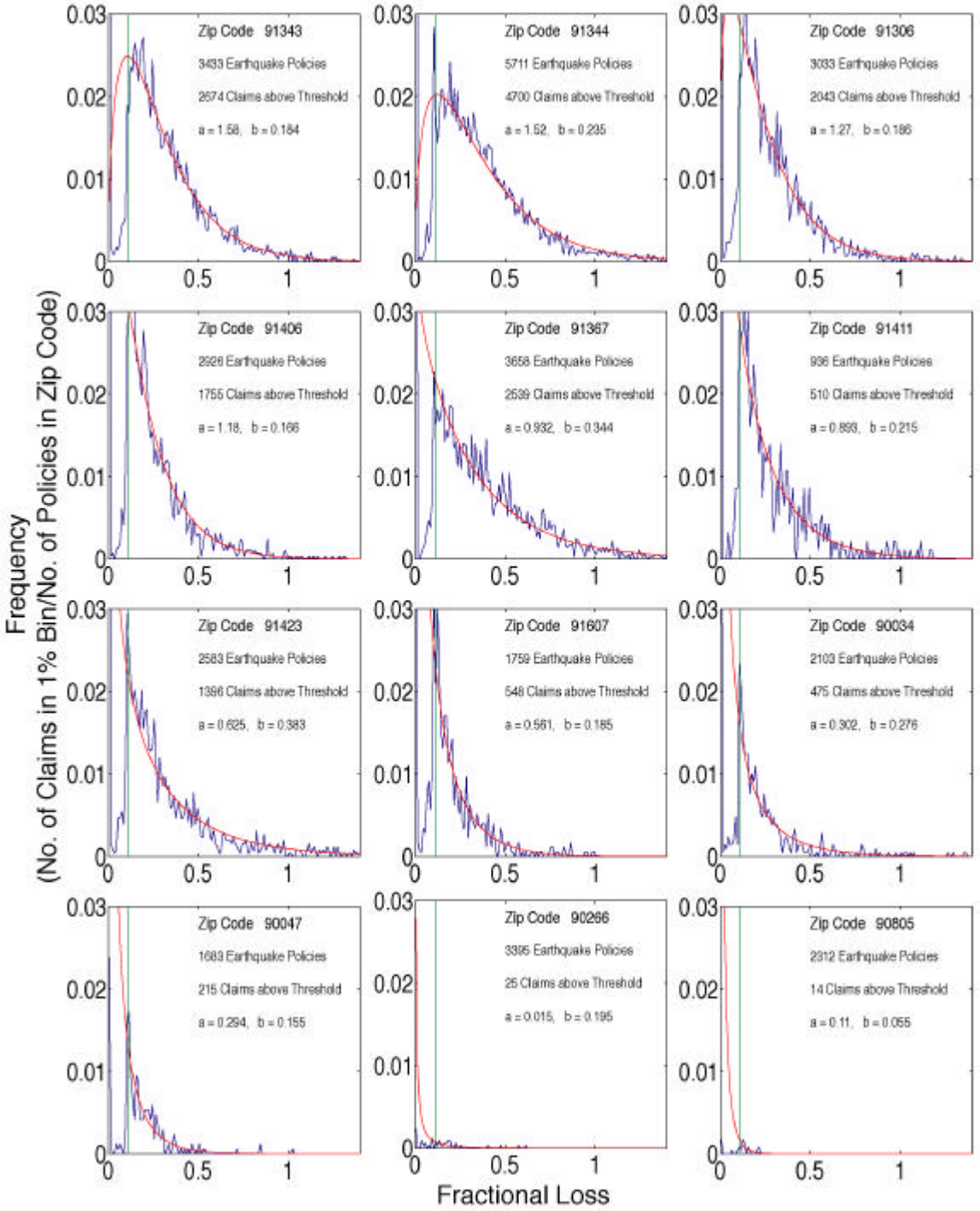
USGS

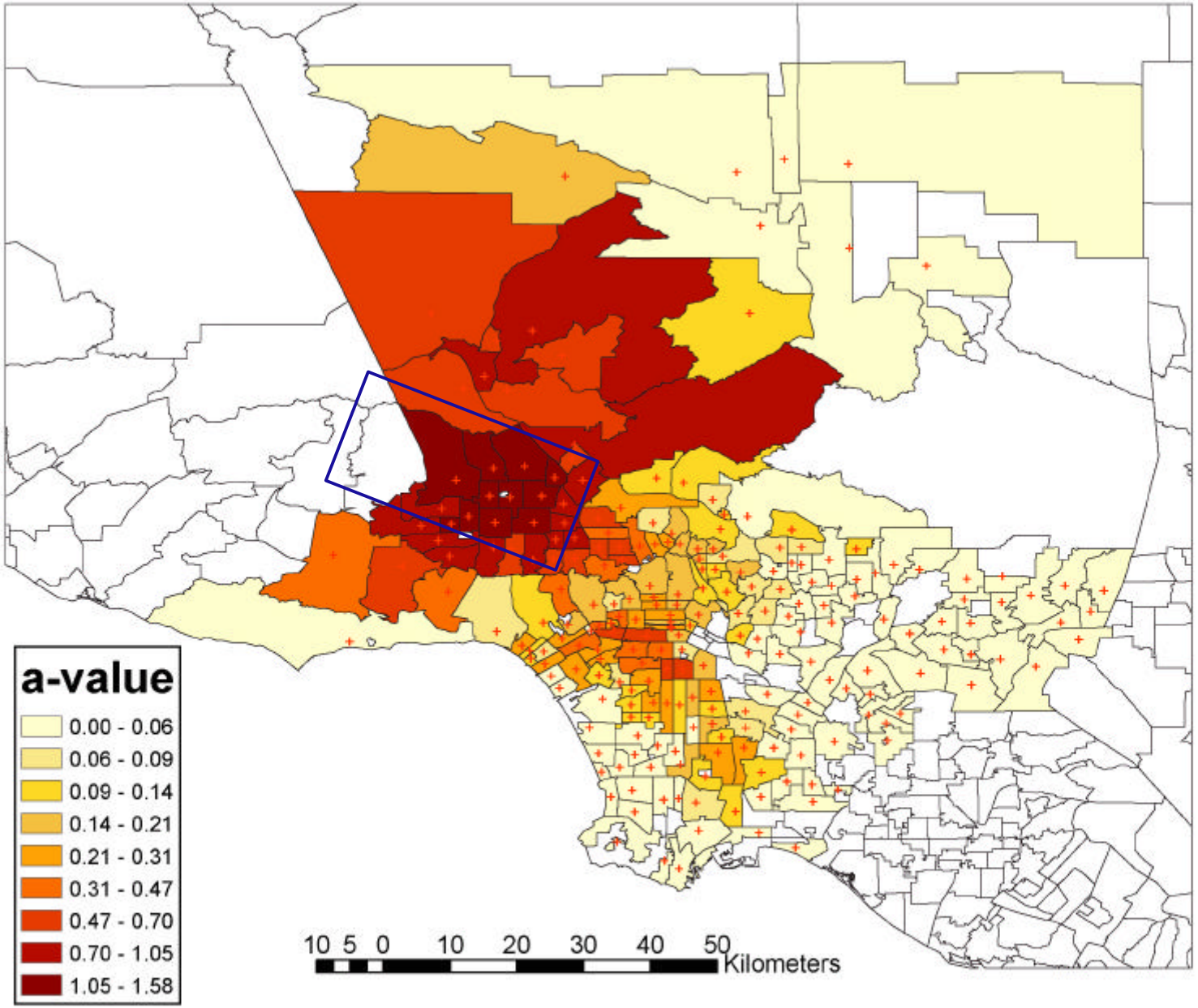

Gamma distribution
b=0.2
for various values of a
Probability Density Function
x
a=1
2
0.5
0.1
0
1
2
3
4
5
6
0
0.5
1
1.5

Data Analysis

- Determine fractional loss for each structure.
  - Many fractional losses greater than one.
- Determine fraction of total policies in zip code with losses less than the deductible.
- For each zip code, determine the gamma distribution that best fits the distribution of fractional losses above the deductible using a maximum likelihood technique.

USGS


Zip Code 91343
3433 Earthquake Policies
2574 Claims above Threshold
a = 1.58, b = 0.184
Zip Code 91344
5711 Earthquake Policies
4700 Claims above Threshold
a = 1.52, b = 0.235
Zip Code 91306
3033 Earthquake Policies
2043 Claims above Threshold
a = 1.27, b = 0.186
Zip Code 91406
2926 Earthquake Policies
1755 Claims above Threshold
a = 1.18, b = 0.166
Zip Code 91367
3658 Earthquake Policies
2539 Claims above Threshold
a = 0.932, b = 0.344
Zip Code 91411
936 Earthquake Policies
510 Claims above Threshold
a = 0.893, b = 0.215
Zip Code 91423
2583 Earthquake Policies
1396 Claims above Threshold
a = 0.625, b = 0.383
Zip Code 91607
1759 Earthquake Policies
548 Claims above Threshold
a = 0.561, b = 0.185
Zip Code 90034
2109 Earthquake Policies
475 Claims above Threshold
a = 0.302, b = 0.276
Zip Code 90047
1683 Earthquake Policies
215 Claims above Threshold
a = 0.294, b = 0.155
Zip Code 90266
3395 Earthquake Policies
25 Claims above Threshold
a = 0.015, b = 0.195
Zip Code 90805
2312 Earthquake Policies
14 Claims above Threshold
a = 0.11, b = 0.055
Frequency
(No. of Claims in 1% Bin/No. of Policies in Zip Code)
Fractional Loss
0.03
0.02
0.01
0
0.5
1


a-value
0.00 - 0.06
0.06 - 0.09
0.09 - 0.14
0.14 - 0.21
0.21 - 0.31
0.31 - 0.47
0.47 - 0.70
0.70 - 1.05
1.05 - 1.58
10 5 0 10 20 30 40 50
Kilometers

Question

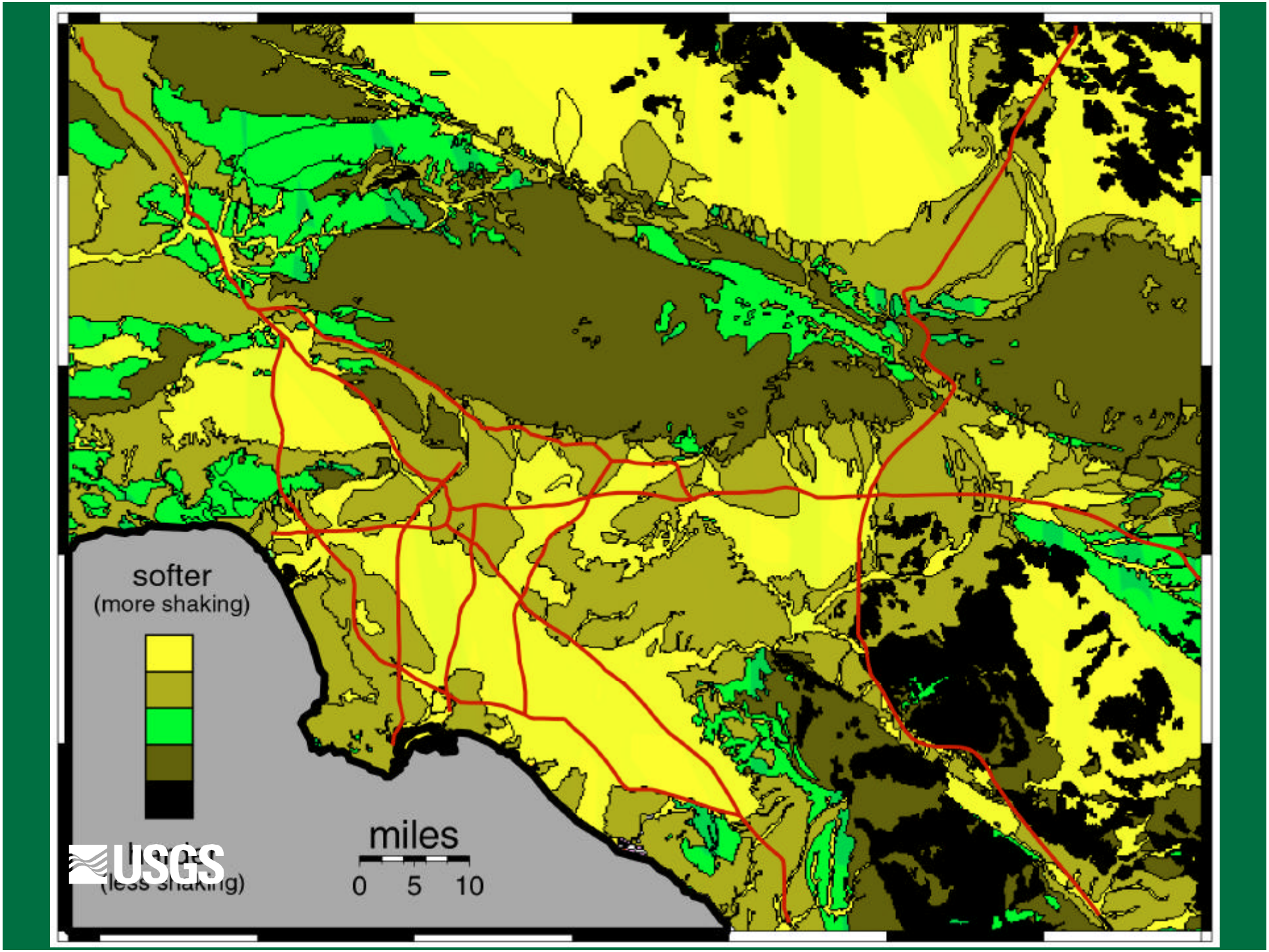
- Can we correlate the parameters in the statistical distributions with ground motion?

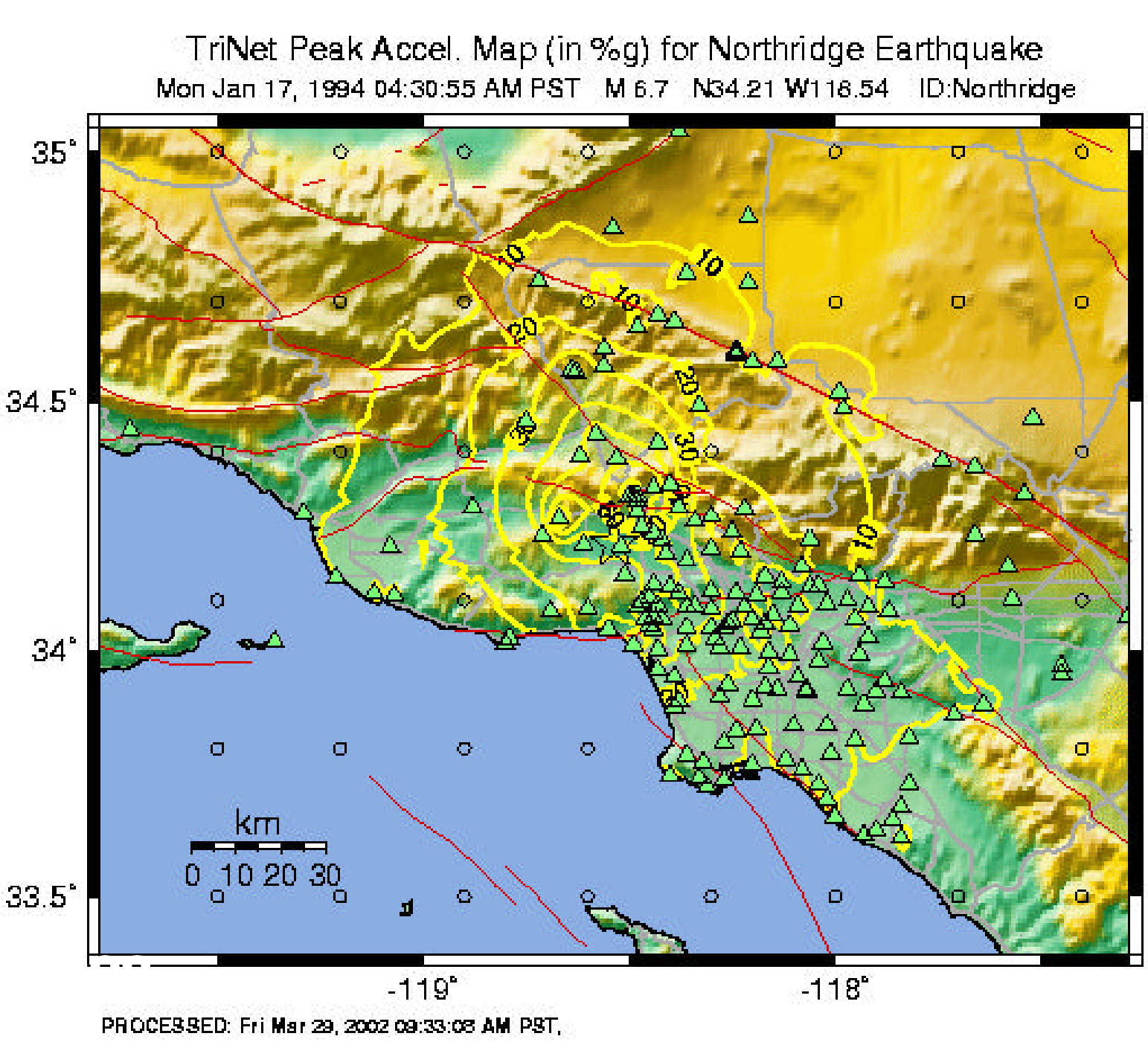
USGS

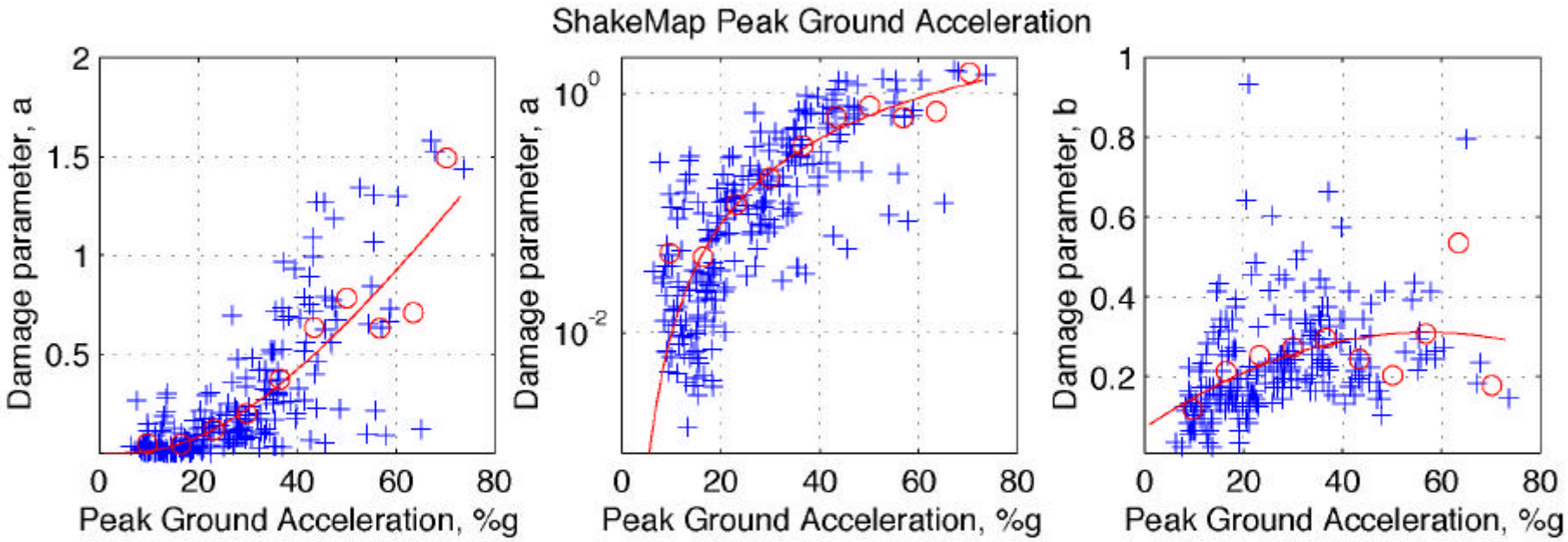
ShakeMap Estimates

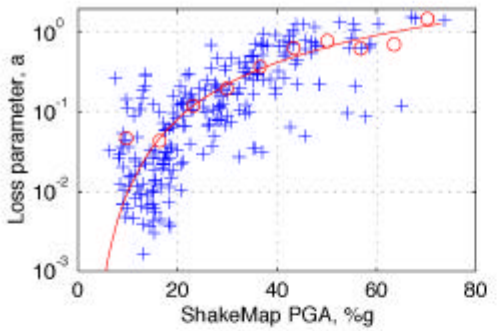
- Start with observed strong motion observations
- Correct for site response
- Estimate ground motions throughout region for appropriate site response
- Interpolate at population centroid of zip code
- Estimates PGA, PGV, IIM, 3 Hz, 1Hz, 3 sec

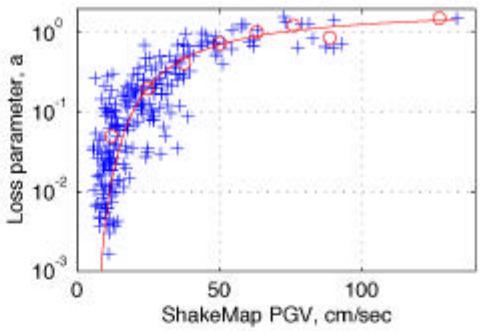
USGS

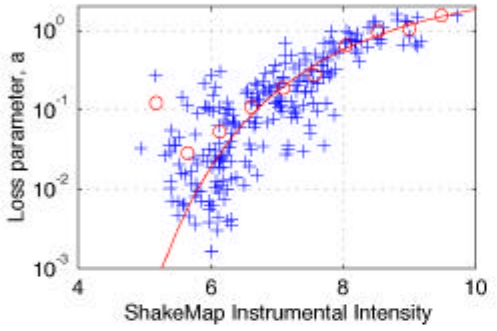

softer
(more shaking)
(less shaking)
miles
0 5 10
USGS

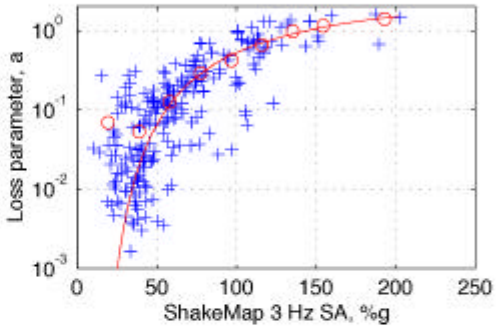

TriNet Peak Accel. Map (in %g) for Northridge Earthquake
Mon Jan 17, 1994 04:30:55 AM PST M 6.7 N34.21 W118.54 ID:Northridge
35°
34.5°
34°
33.5°
-119°
-118°
10
10
10
20
20
30
30
km
0 10 20 30
PROCESSED: Fri Mar 29, 2002 09:33:03 AM PST,

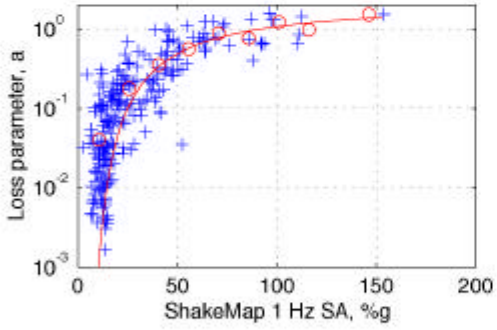

ShakeMap Peak Ground Acceleration
Damage parameter, a
2
1.5
1
0.5
0
20
40
60
80
Peak Ground Acceleration, %g
Damage parameter, a
10^{0}
10^{-2}
0
20
40
60
80
Peak Ground Acceleration, %g
Damage parameter, b
1
0.8
0.6
0.4
0.2
0
20
40
60
80
Peak Ground Acceleration, %g

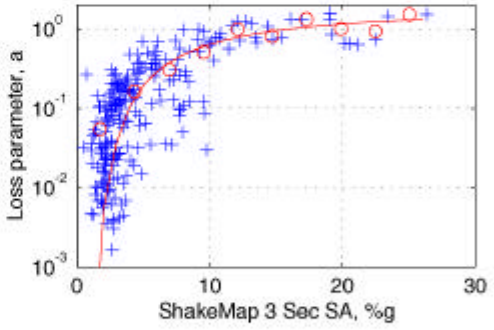

Loss parameter, a
ShakeMap PGA, %g

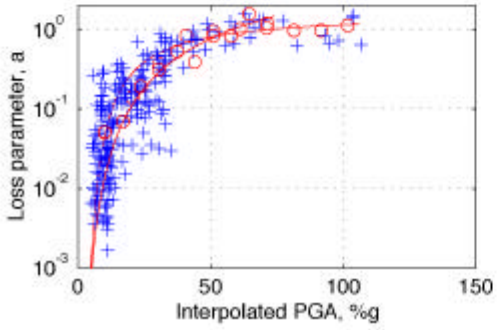

Loss parameter, a
ShakeMap PGV, cm/sec

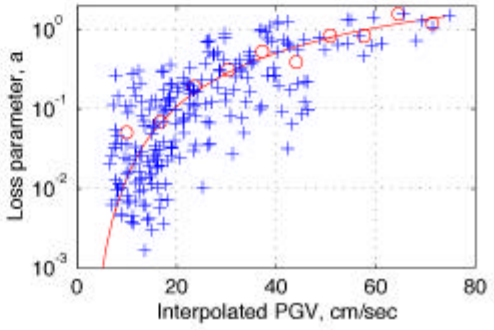

Loss parameter, a
ShakeMap Instrumental Intensity

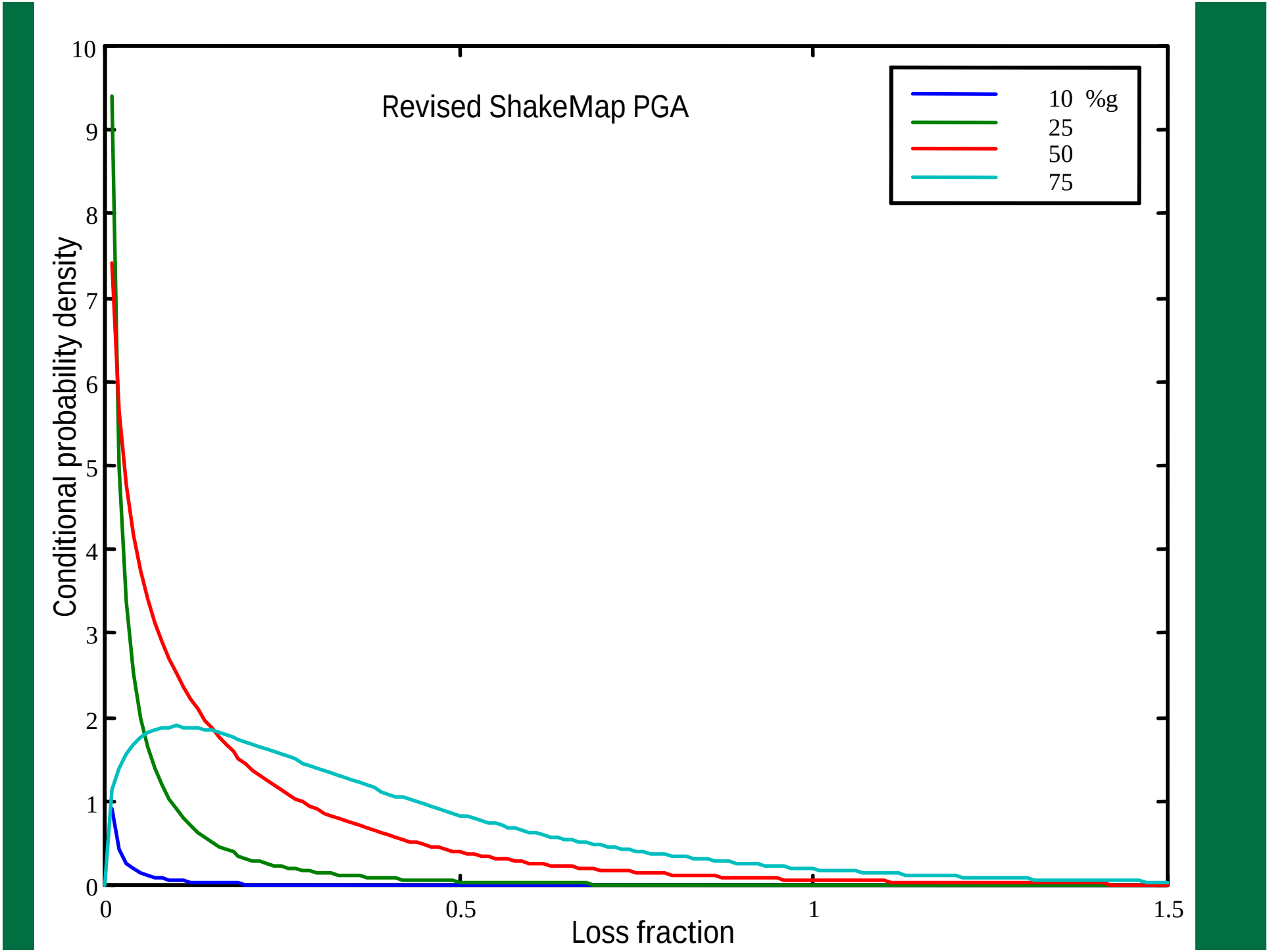

Loss parameter, a
ShakeMap 3 Hz SA, %g


Loss parameter, a
ShakeMap 1 Hz SA, %g


Loss parameter, a
ShakeMap 3 Sec SA, %g


Loss parameter, a
Interpolated PGA, %g

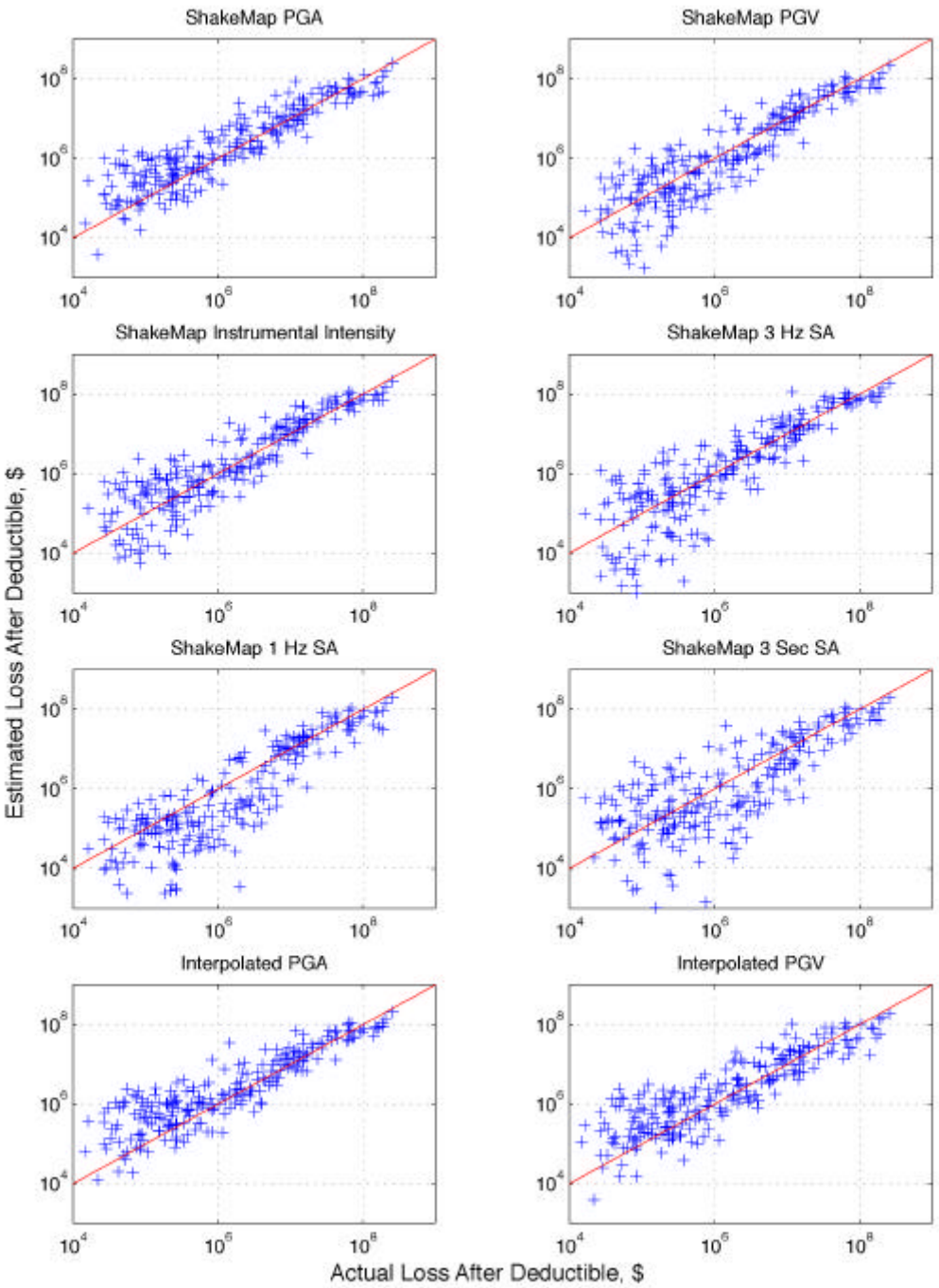

Loss parameter, a
Interpolated PGV, cm/sec


Revised ShakeMap PGA
10 %g
25
50
75
Conditional probability density
Loss fraction
0
1
2
3
4
5
6
7
8
9
10
0
0.5
1
1.5

Compare Estimated and Actual Losses

- From ShakeMap ground motions, estimate pdf for loss in zip code.
- From pdf, calculate mean fractional loss above deductible.
- Multiple by total fire structural value to obtain estimate of dollar loss for zip code.
- Compare with actual dollar loss for zip code.

USGS


ShakeMap PGA
ShakeMap PGV
ShakeMap Instrumental Intensity
ShakeMap 3 Hz SA
ShakeMap 1 Hz SA
ShakeMap 3 Sec SA
Interpolated PGA
Interpolated PGV
Estimated Loss After Deductible, $
Actual Loss After Deductible, $

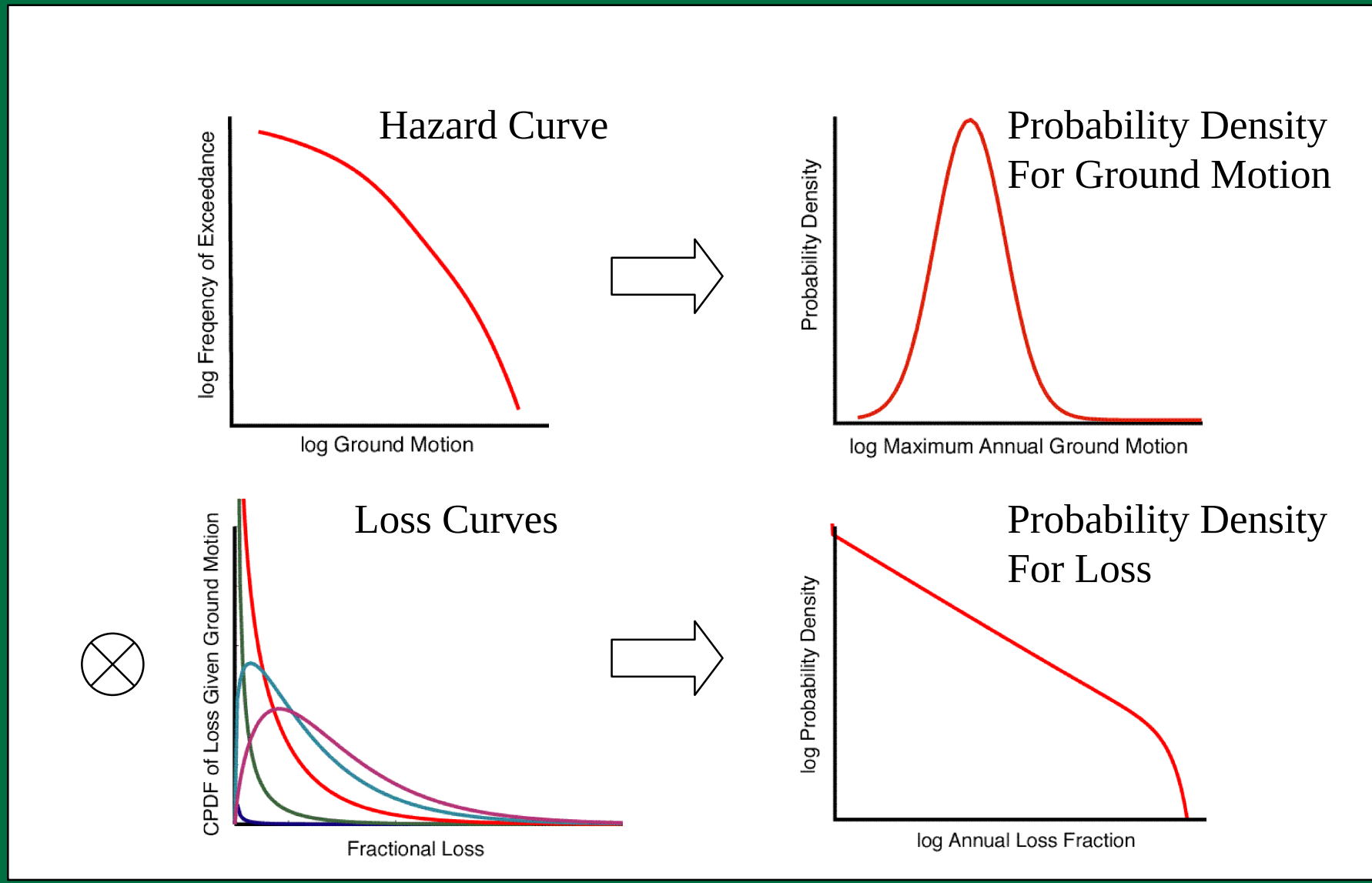
Actual and Estimated Loss

	($B)	234 Zip Codes
Actual Loss	**3.4**	
Est. PGA	**3.0**	
Est. PGV	**2.9**	
Est. IMM	**3.2**	
Est. 3 Hz	**3.2***	
Est. 1 Hz	**2.5***	
Est. 3 sec.	**2.1***	
Int. PGA	**3.2***	
Int. PGV	**3.0**	

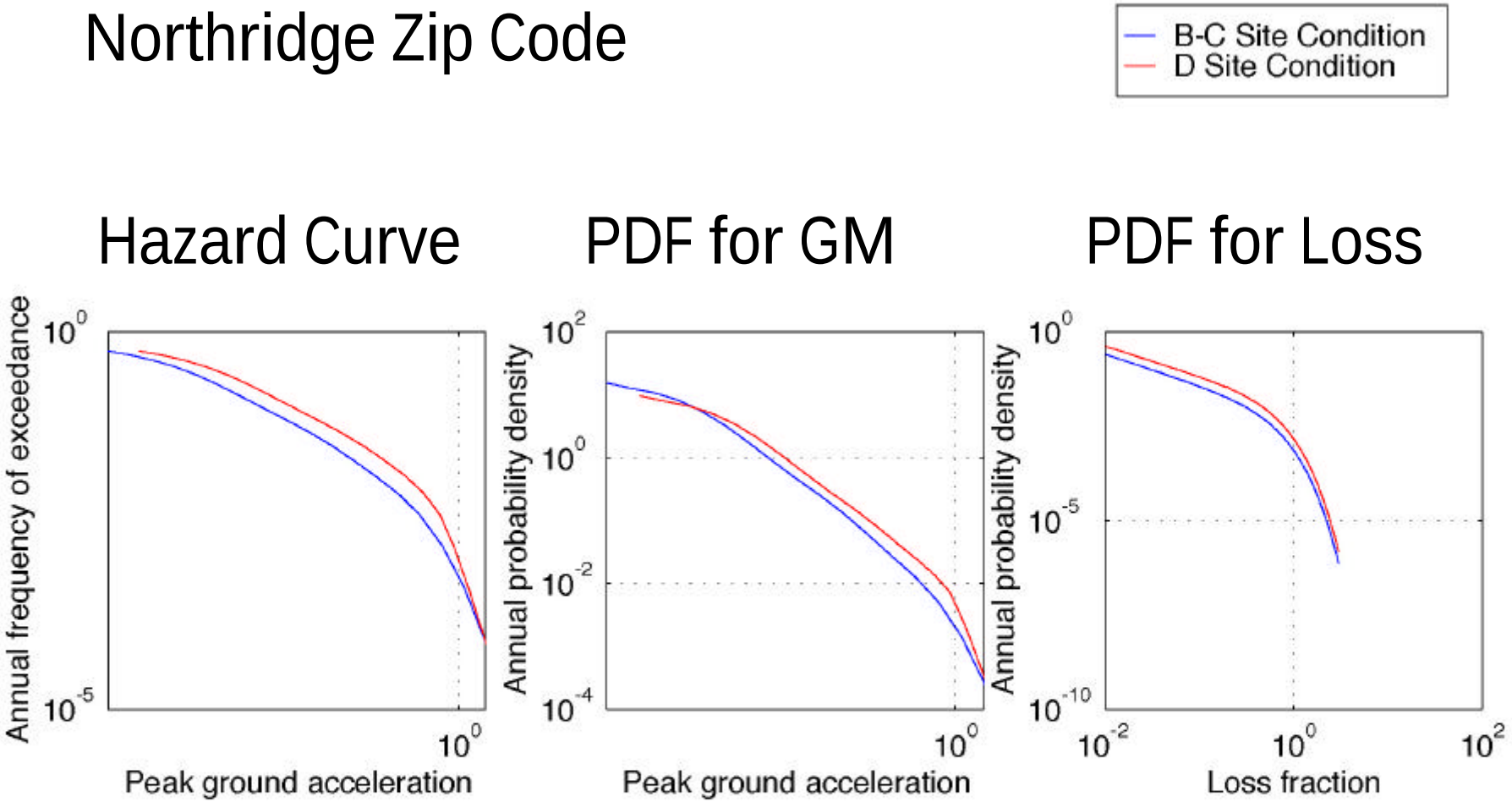
USGS

*n constrained to 1

Loss from Hazard Curve



Northridge Zip Code



Conclusions

- Losses to single family houses aggregated by zip code are well fit by gamma distributions.
- Shape parameter of gamma distribution correlates with ground motion, providing basis for loss relations.
- Can estimate total losses to within about 15%.

USGS