Crash Course in Probabilistic Seismic Hazard Analysis (PSHA)

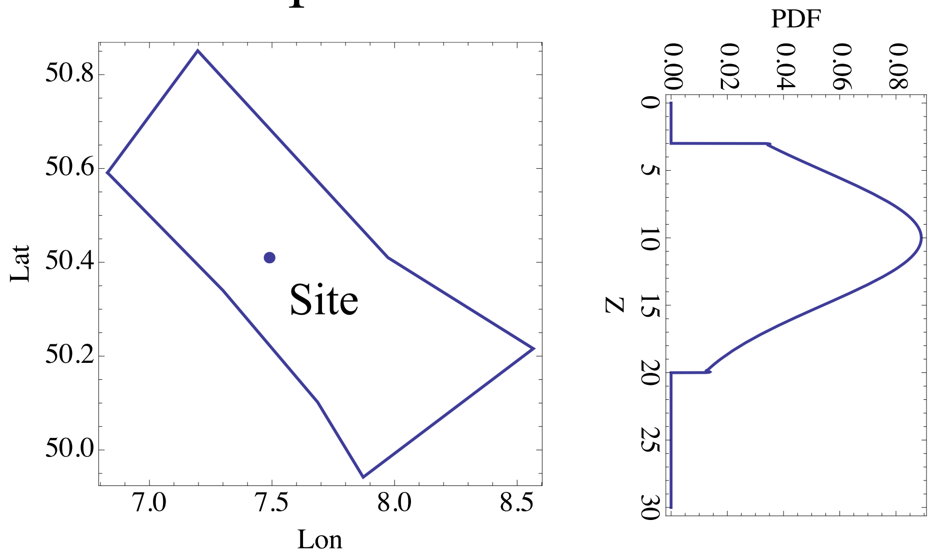
Part 3

Frank Scherbaum

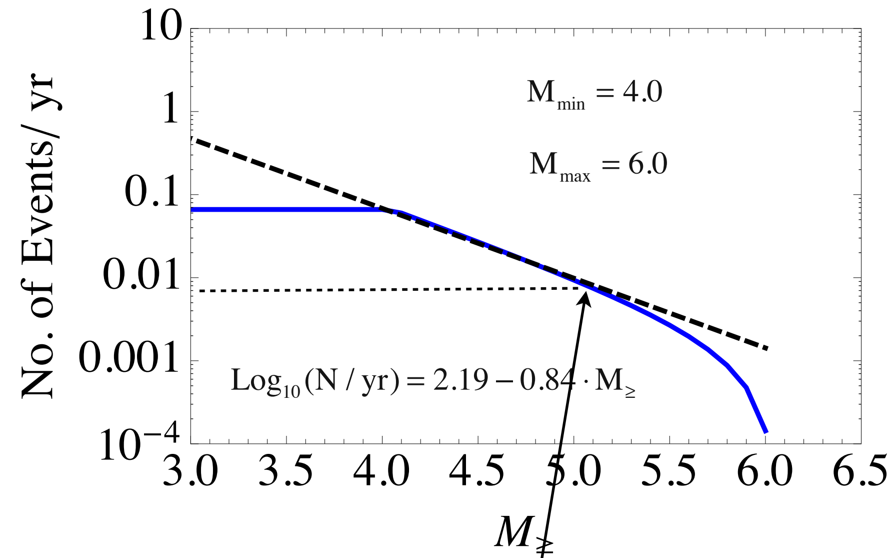
The hazard curve revisited again (Monte Carlo approach)

Areal seismic source

Spatial distribution



Magnitude-frequency distribution



Assumption: Only earthquakes with $M \geq 5$ cause damage (in our experiment)

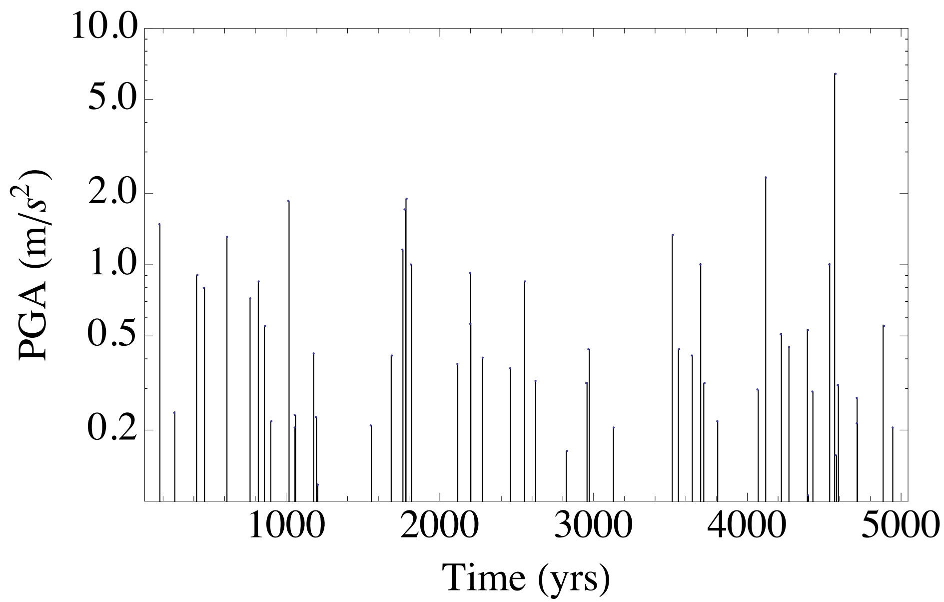
Expected annual rate of earthquakes with $M \geq 5$: $\lambda = 0.0085$

on **average** every $1/0.0085 \approx 118$ years 1 event $M \geq 5$

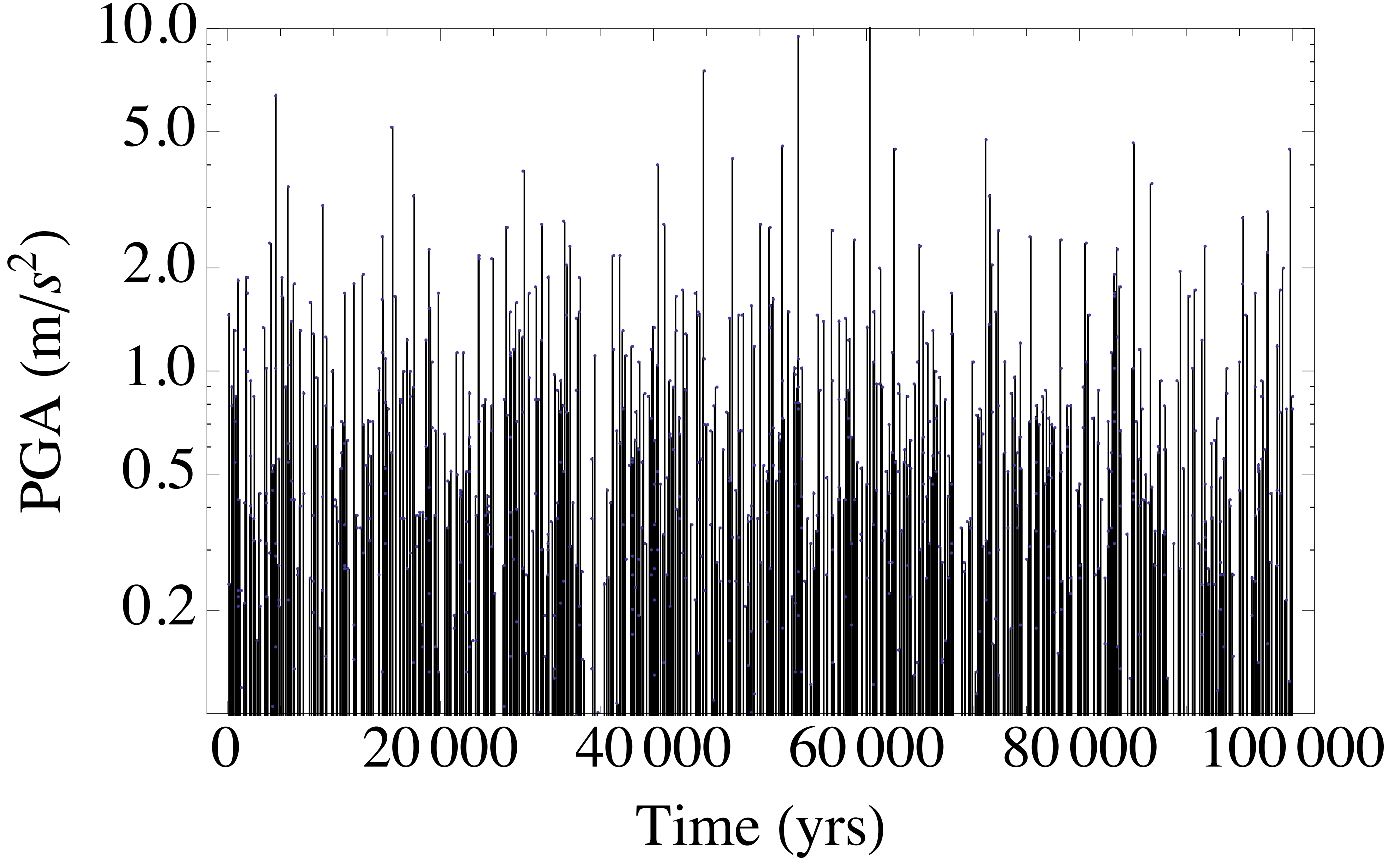
Frank Scherbaum

Let´s count (sample)

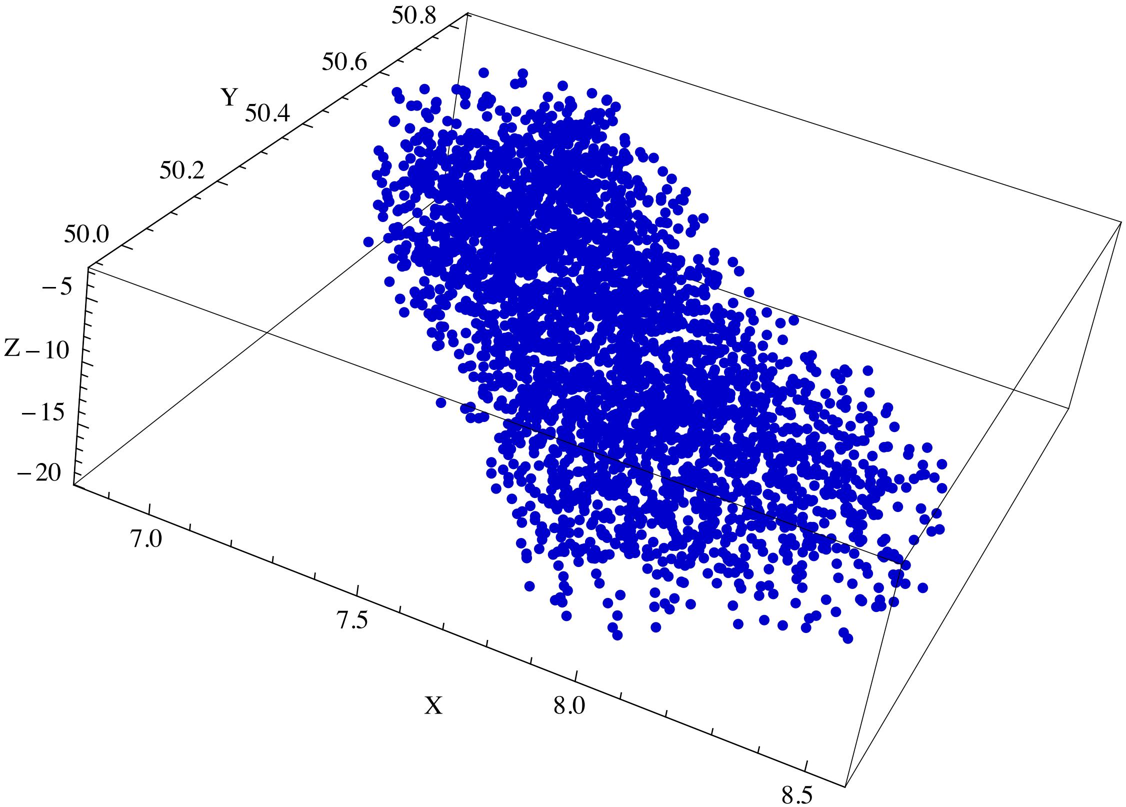
Time (yrs)	Mw	R (km)	PGA (m/s^2)	ϵ
179.204	5.1	21.3	1.47	1.32
276.154	5.8	41.8	0.24	-1.02
417.84	5.3	24.6	0.90	0.65
469.318	5.0	59.2	0.80	2.14
615.378	5.2	14.6	1.32	0.49
765.78	5.2	15.9	0.72	-0.36
819.33	5.4	33.2	0.85	0.89
858.895	5.2	20.5	0.55	-0.35
900.66	5.3	34.6	0.22	-0.97
1019.39	5.3	15.2	1.85	0.91
		⋮		
4396.29	5.4	46.8	0.11	-1.71
4426.52	5.2	41.1	0.29	-0.18
4535.81	5.2	37.5	1.01	1.52
4568.1	6.0	21.4	6.43	2.57
4580.34	5.2	39.5	0.16	-1.20
4592.19	5.4	38.3	0.31	-0.40
4714.07	5.5	38.8	0.27	-0.68
4717.11	5.3	28.7	0.21	-1.26
4883.27	5.2	62.3	0.56	1.53
4946.02	5.2	44.4	0.20	-0.53

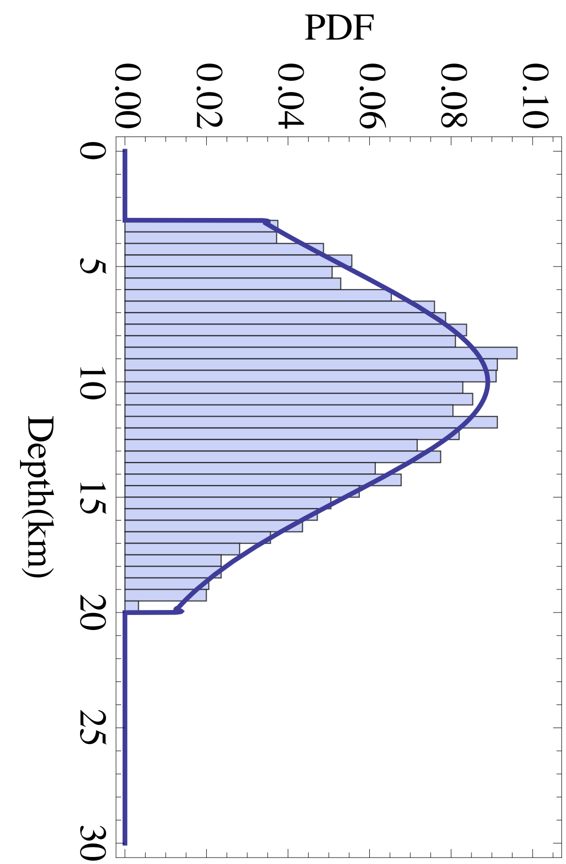


200000 years
Temporal distribution

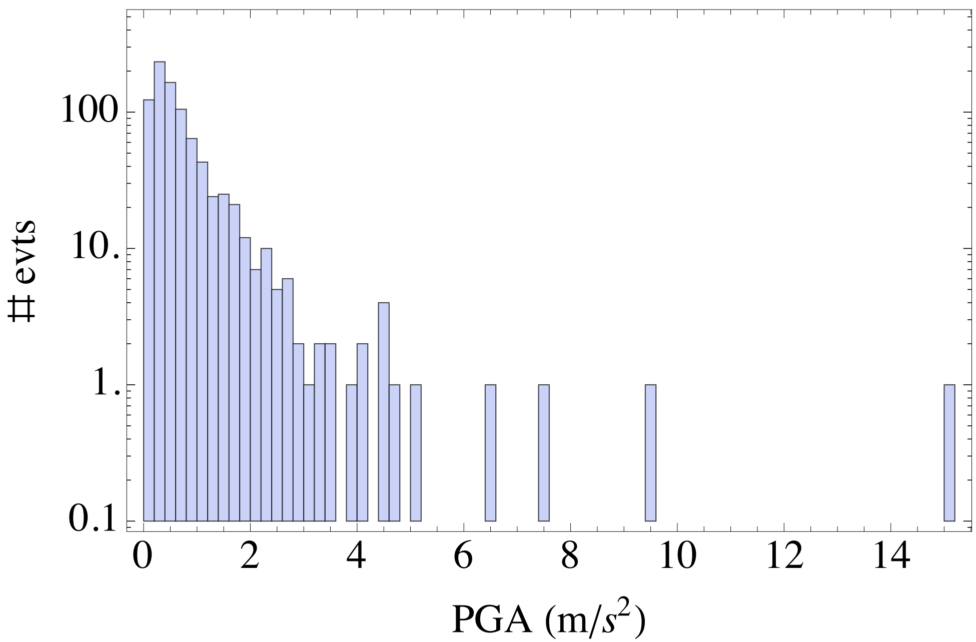


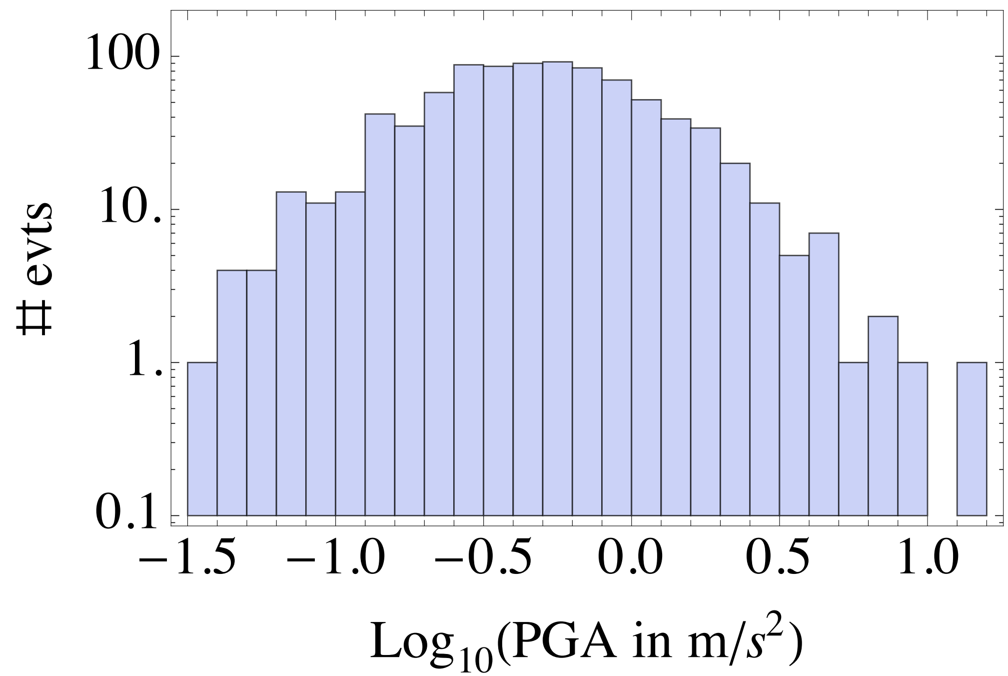
200000 years
Spatial distribution





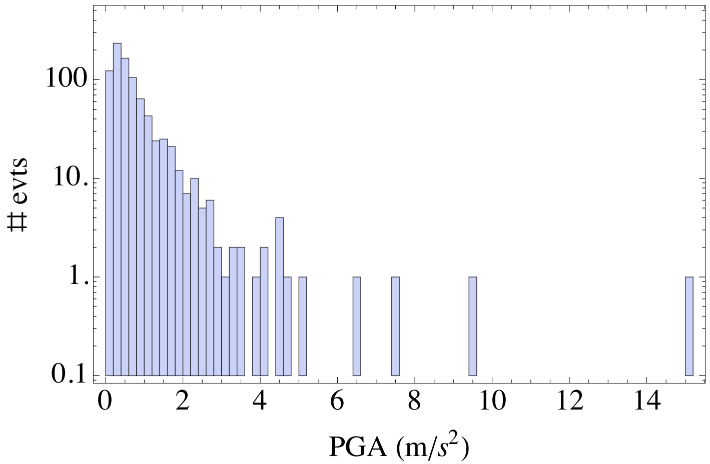
Observed PGA values in 200000 years





Mostly small values, but once in a while a big one

Determining the hazard values



$$P(PGA > a_{test}) = \frac{\#(PGA > a_{test})}{Total\#}$$

Exceedance probability:

$$P(PGA > 1.5 m/s^2) = \frac{\#(PGA > a_{test})}{Total\#} = \frac{43}{432} = 0.09953$$

Expected annual exceedance rate:

$$\nu(PGA > 1.5 m/s^2) = \lambda \cdot P(PGA > 1.5 m/s^2)$$

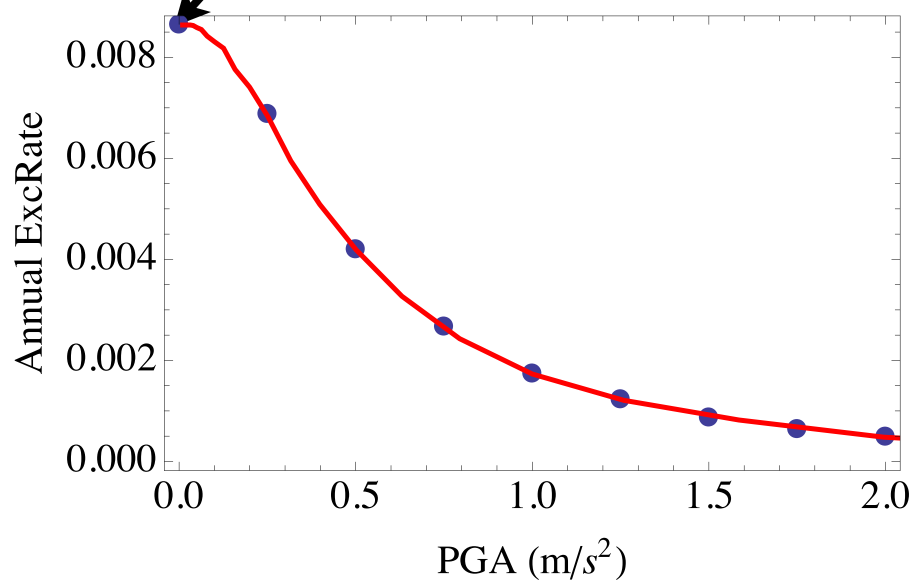
$$= 0.00864 \cdot 0.09953 = 0.00086$$

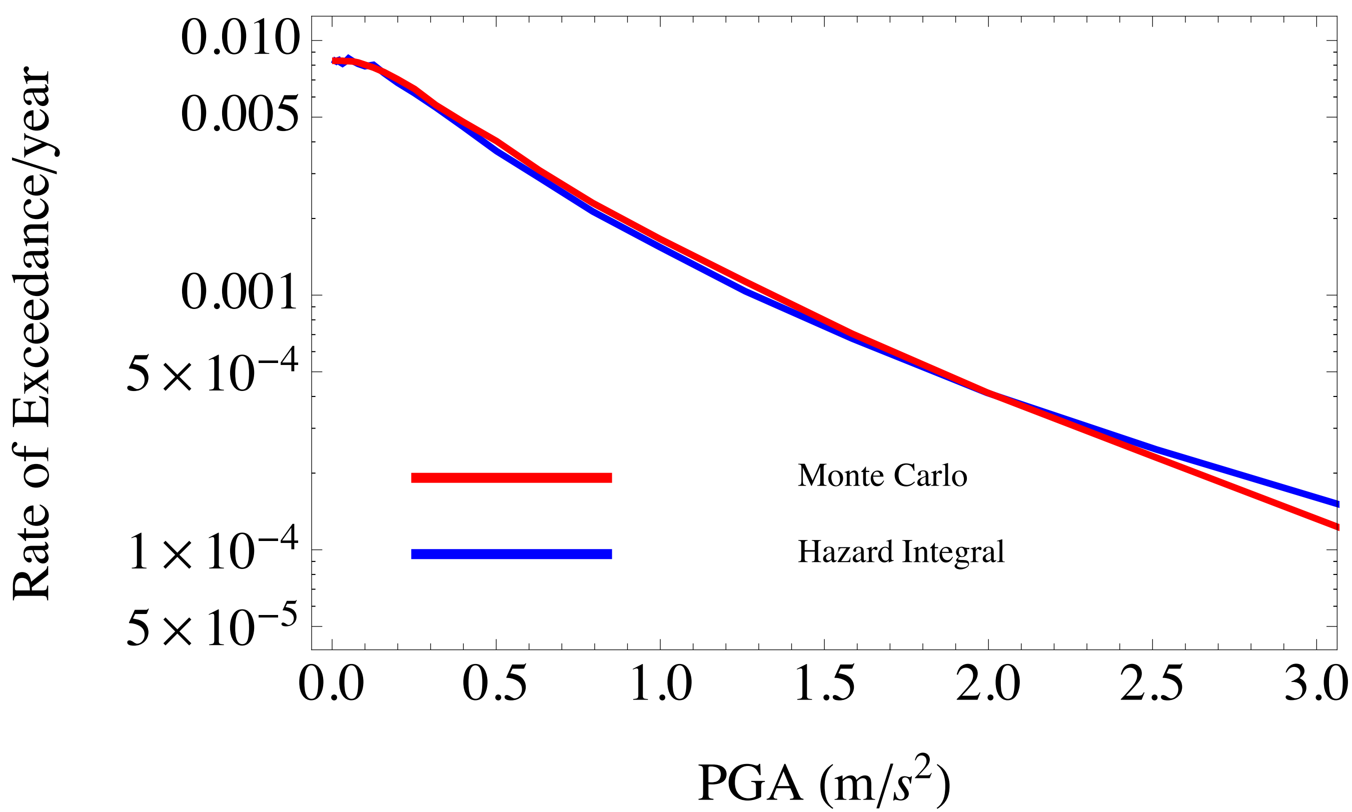
expected # of earthquakes with M≥5 per year

Hazard curve

Hazard curve must converge to the expected # of earthquakes with M≥5 per year for a_{test}= 0 since P(PGA>0)=1.

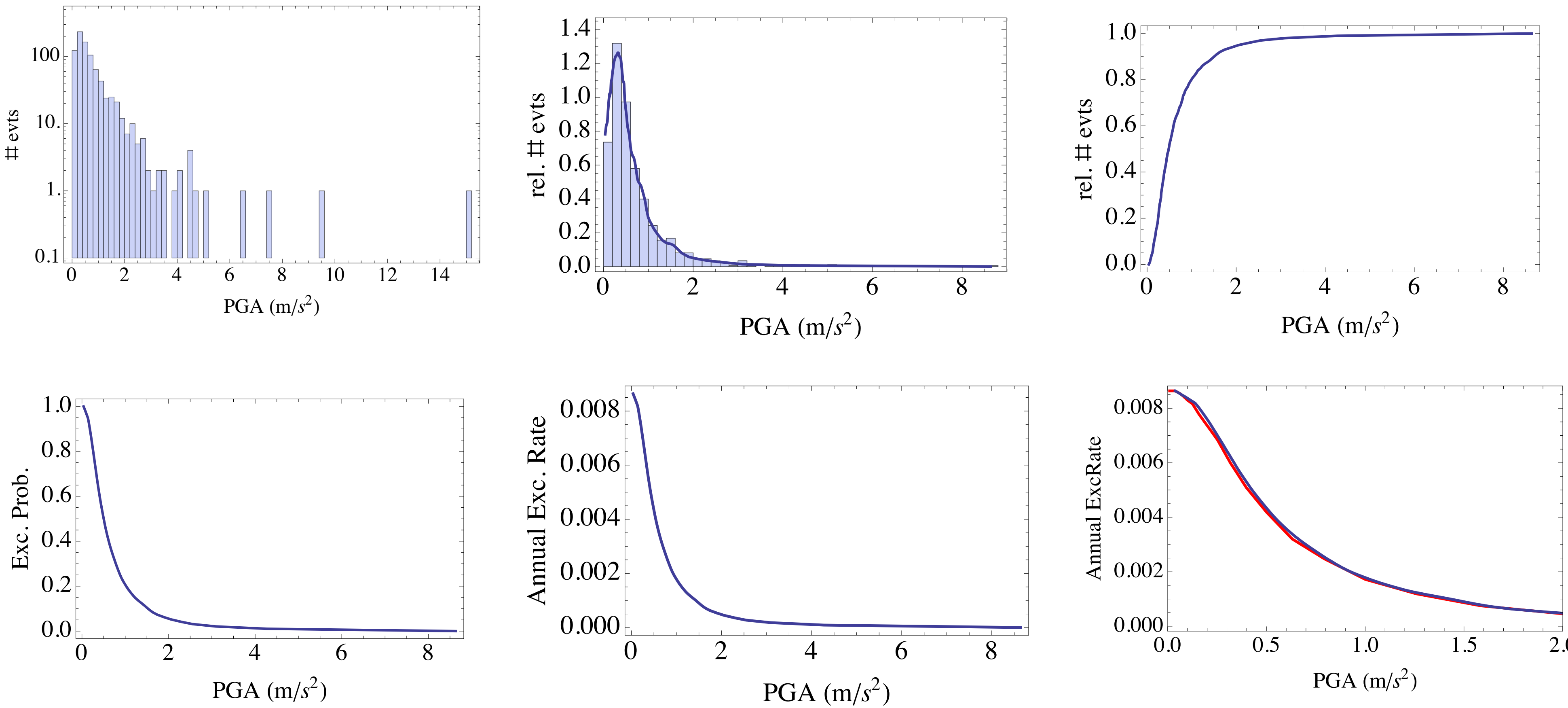
a_{test}	#(a>a_{test})	total-#	rel.-#(a>a_{test})	λ	ν
0.	864	864	1.	0.00864	0.00864
0.25	686	864	0.793981	0.00864	0.00686
0.5	420	864	0.486111	0.00864	0.0042
0.75	270	864	0.3125	0.00864	0.0027
1.	172	864	0.199074	0.00864	0.00172
1.25	119	864	0.137731	0.00864	0.00119
1.5	89	864	0.103009	0.00864	0.00089
1.75	60	864	0.0694444	0.00864	0.0006
2.	46	864	0.0532407	0.00864	0.00046





Rate of Exceedance/year
0.010
0.005
0.001
5 × 10−4
1 × 10−4
5 × 10−5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
PGA (m/s2)
Monte Carlo
Hazard Integral

Histogram, PDF, CDF, Hazard curve

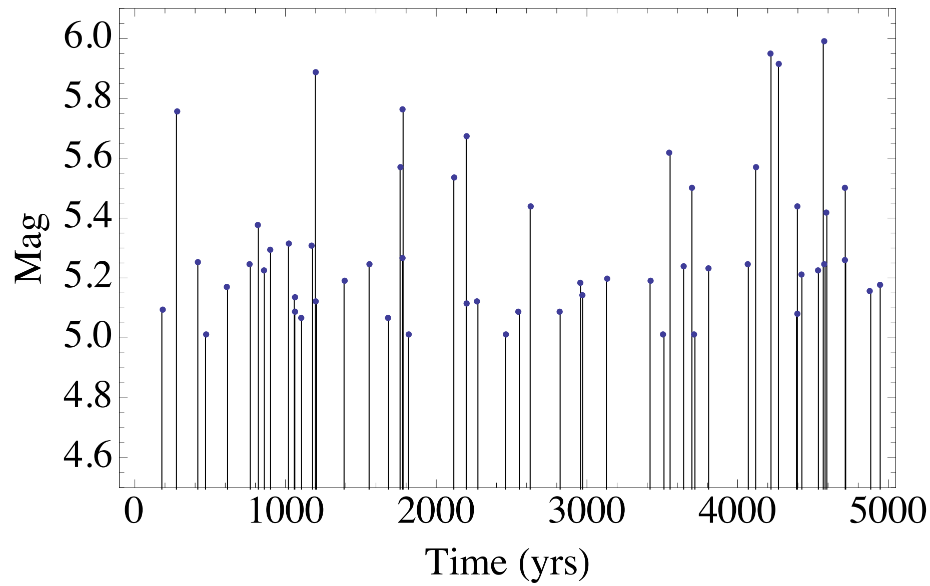


Red: from relative numbers

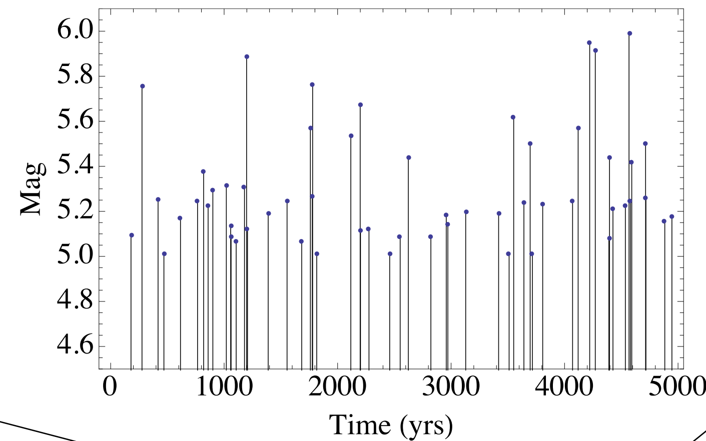
The hazard curve revisited again (Real time PSHA)

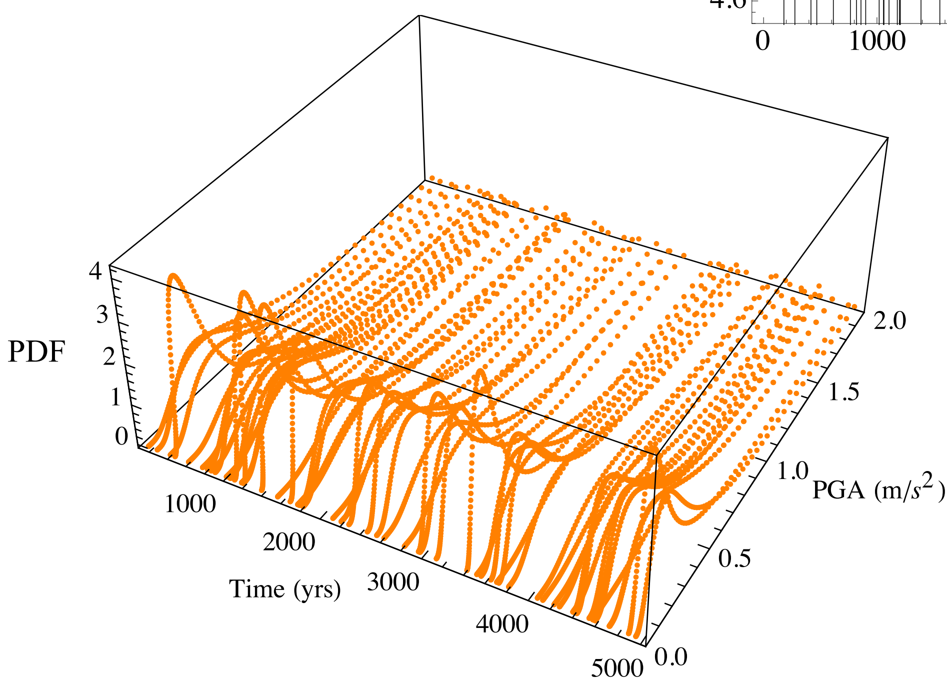
A different catalog

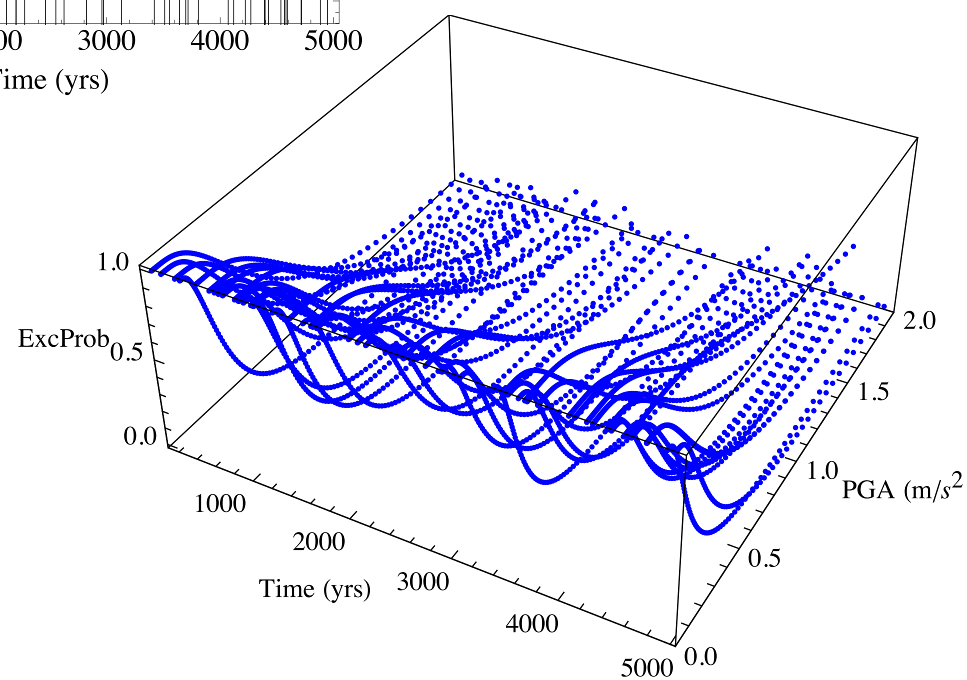
Time (yrs)	Mw	R (km)	μ_{PGA} (m/s^2)	σ
179.204	5.1	22.2	0.58	0.67
276.154	5.8	43.4	0.45	0.67
417.84	5.3	27.4	0.52	0.67
469.318	5.0	59.2	0.19	0.67
615.378	5.2	18.7	0.73	0.67
765.78	5.2	20.4	0.71	0.67
819.33	5.4	33.1	0.46	0.67
858.895	5.2	20.0	0.71	0.67
900.66	5.3	37.9	0.38	0.67
1019.39	5.3	19.1	0.79	0.67
		.		
		.		
		.		
4396.29	5.4	46.5	0.34	0.67
4426.52	5.2	42.1	0.32	0.67
4535.81	5.2	36.6	0.37	0.67
4568.1	6.0	17.3	1.43	0.67
4580.34	5.2	40.0	0.35	0.67
4592.19	5.4	39.4	0.40	0.67
4714.07	5.5	36.0	0.46	0.67
4717.11	5.3	30.2	0.47	0.67
4883.27	5.2	62.3	0.20	0.67
4946.02	5.2	44.7	0.29	0.67



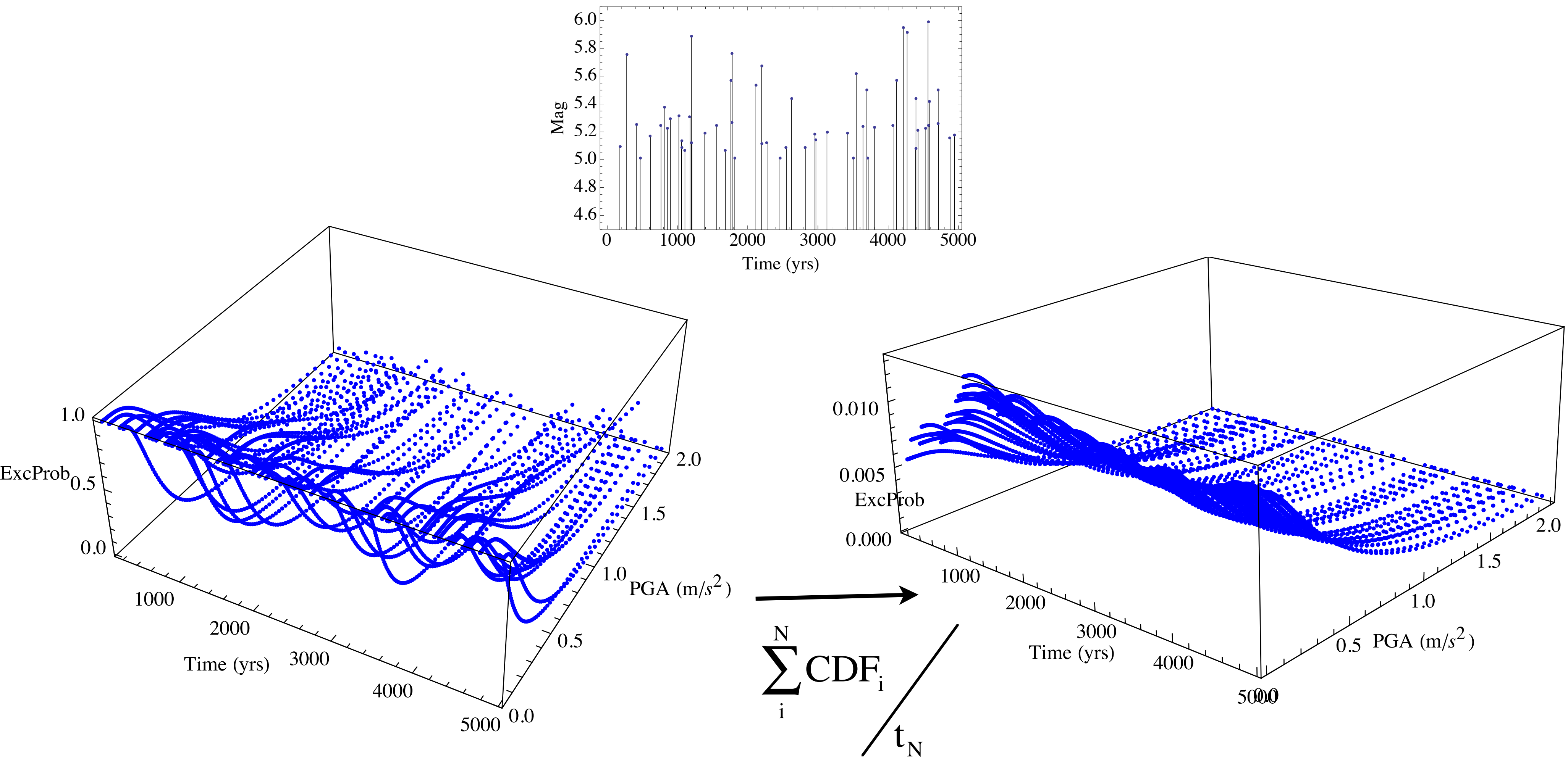
Individual PDFs and CDFs







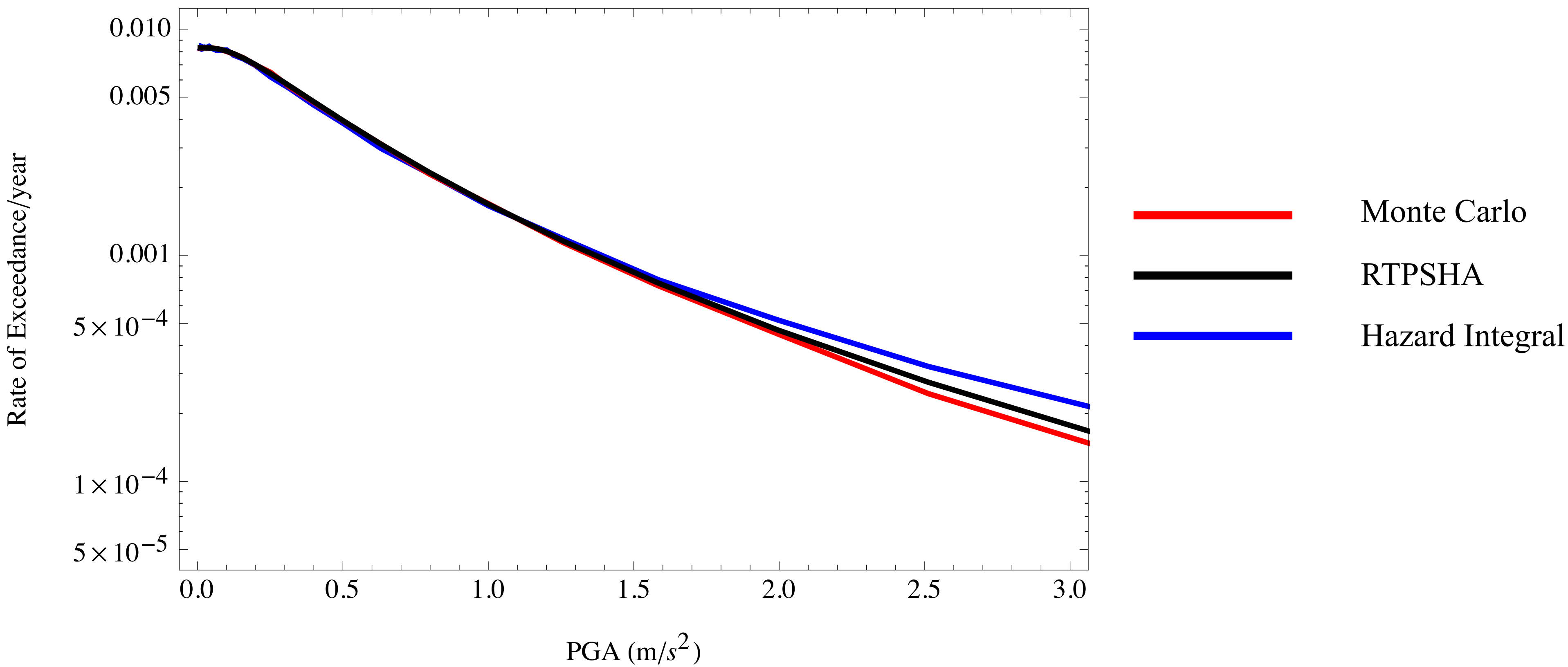
Cumulating CDFs



$$\sum_{i}^{N} CDF_i \Big/ t_N$$

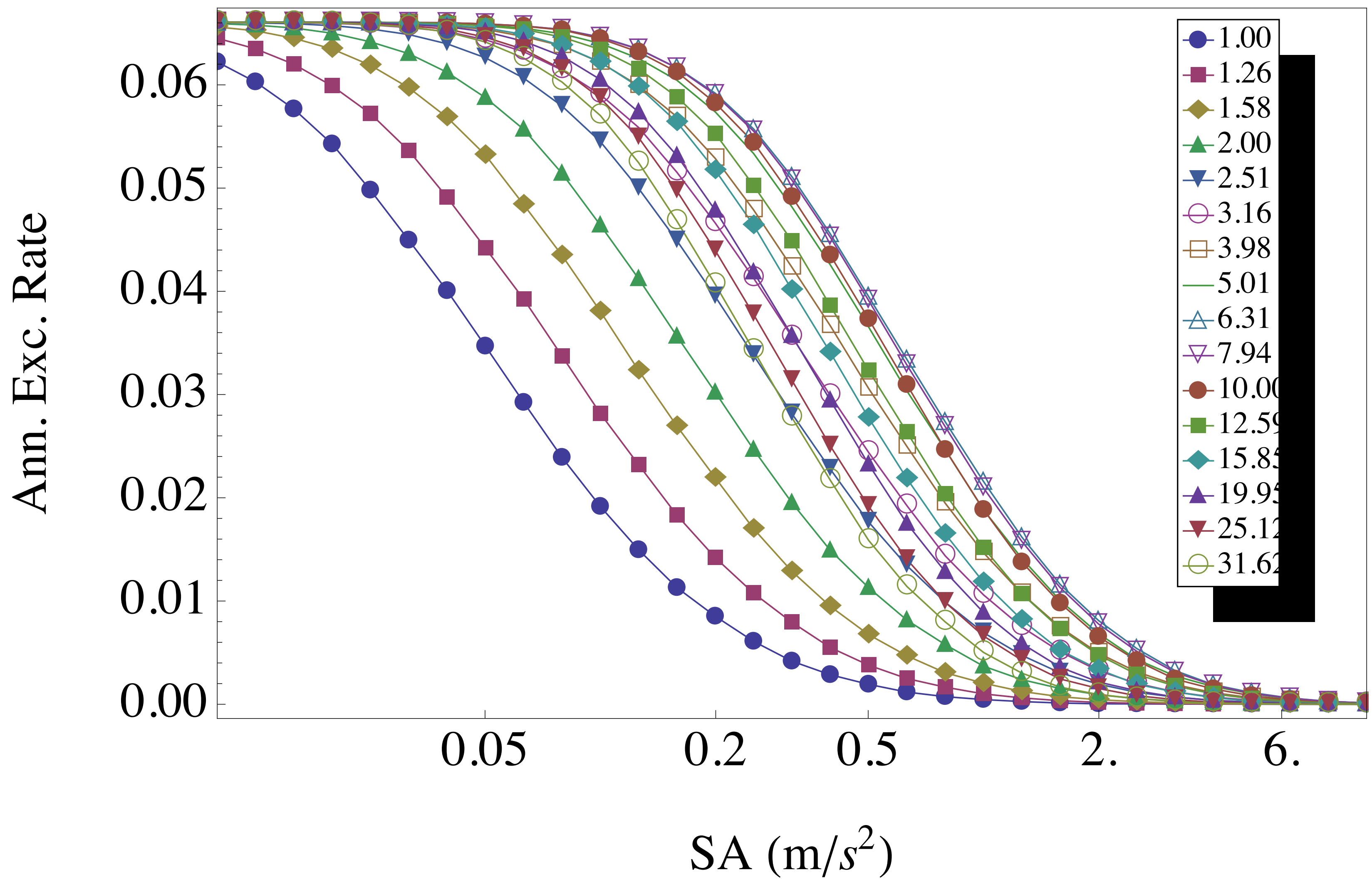
Frank Scherbaum

Comparizon of approaches

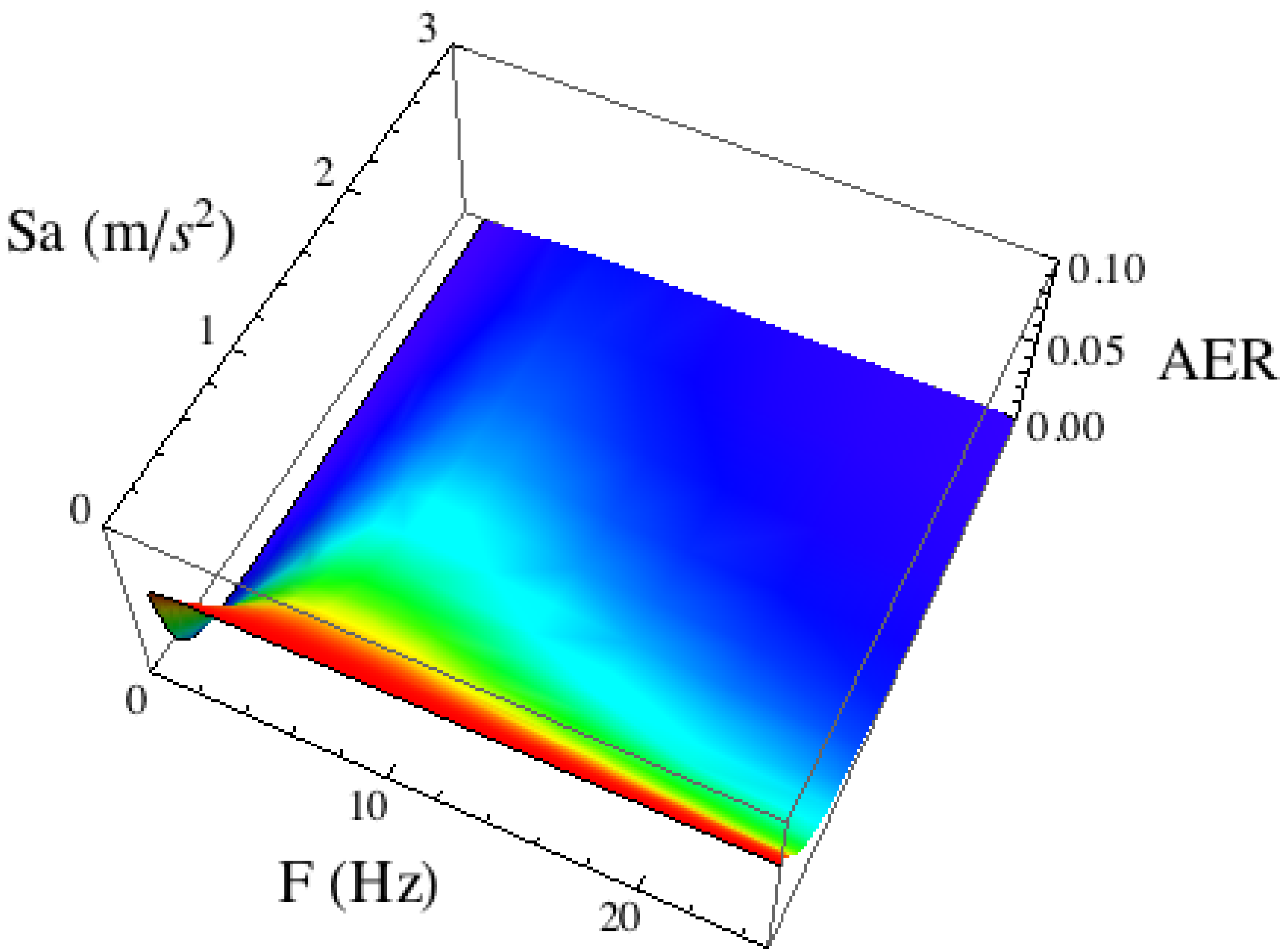


From single frequency hazard curves to uniform hazard spectra

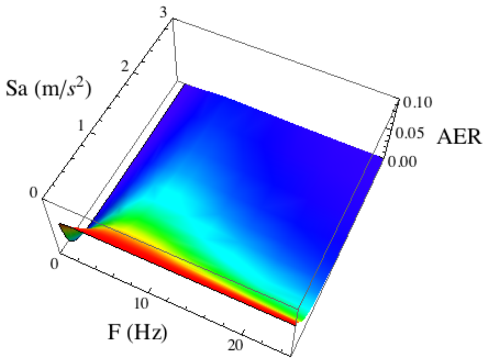
Several oscillator frequencies

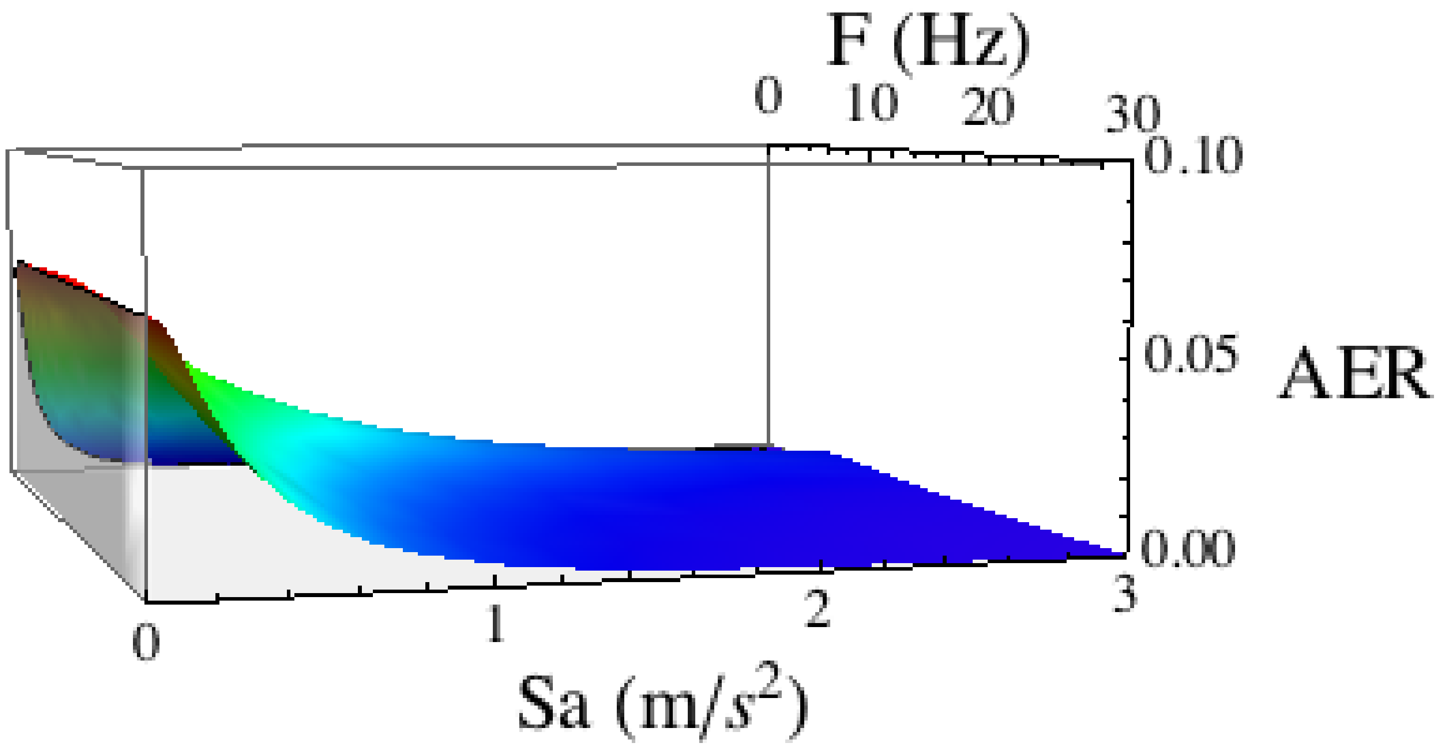


Different display

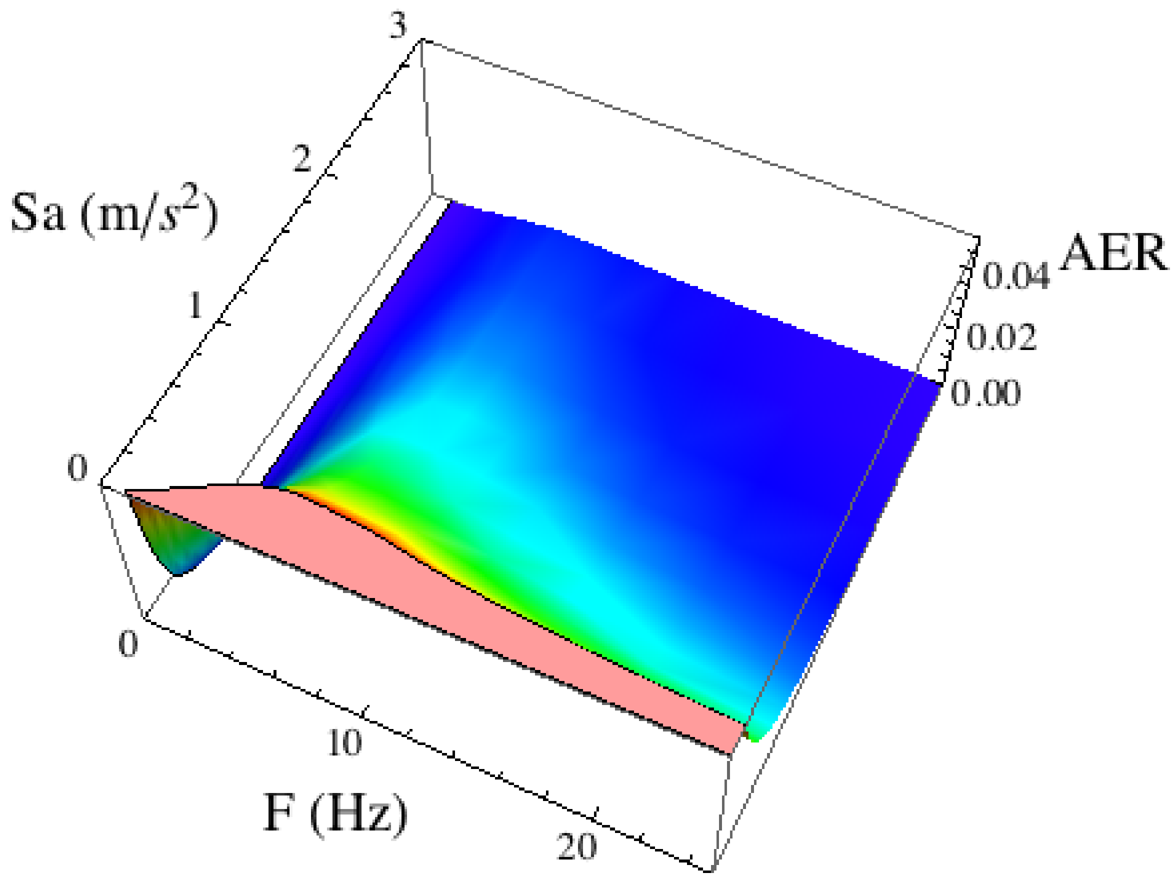


Different viewpoint

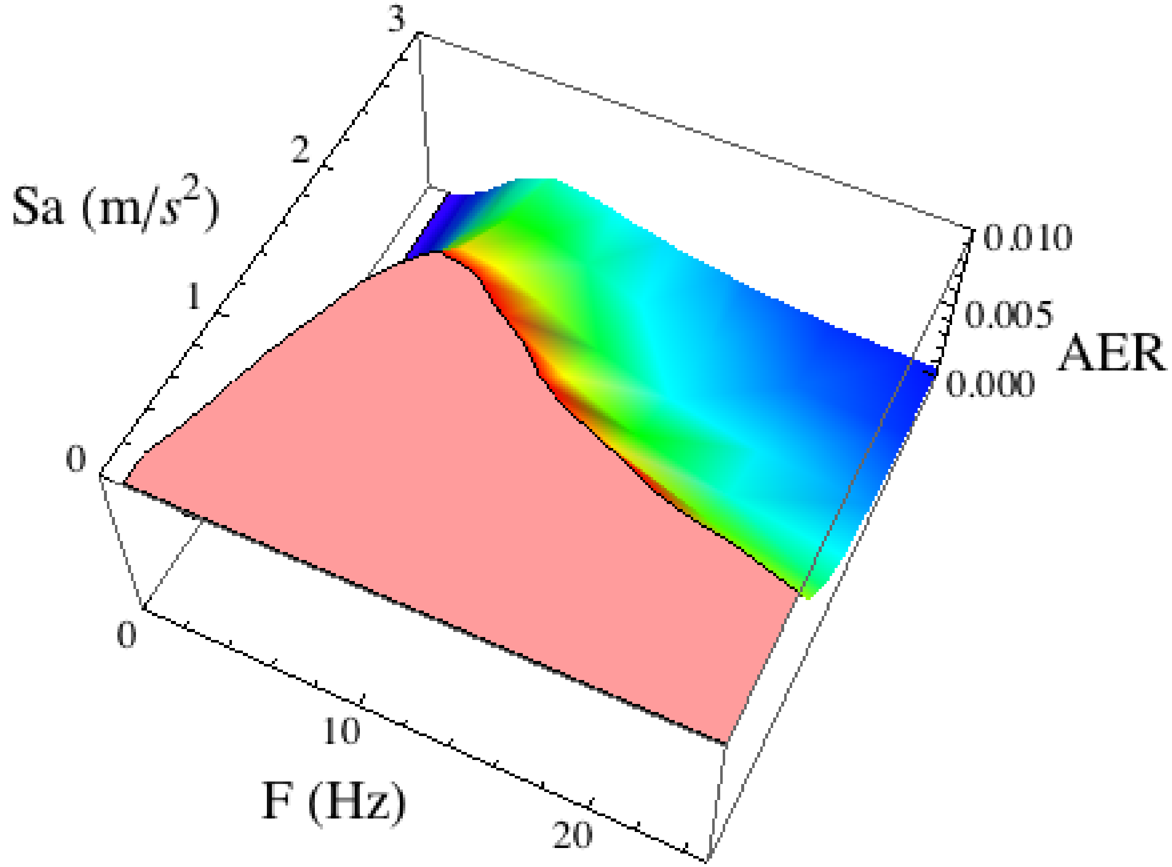




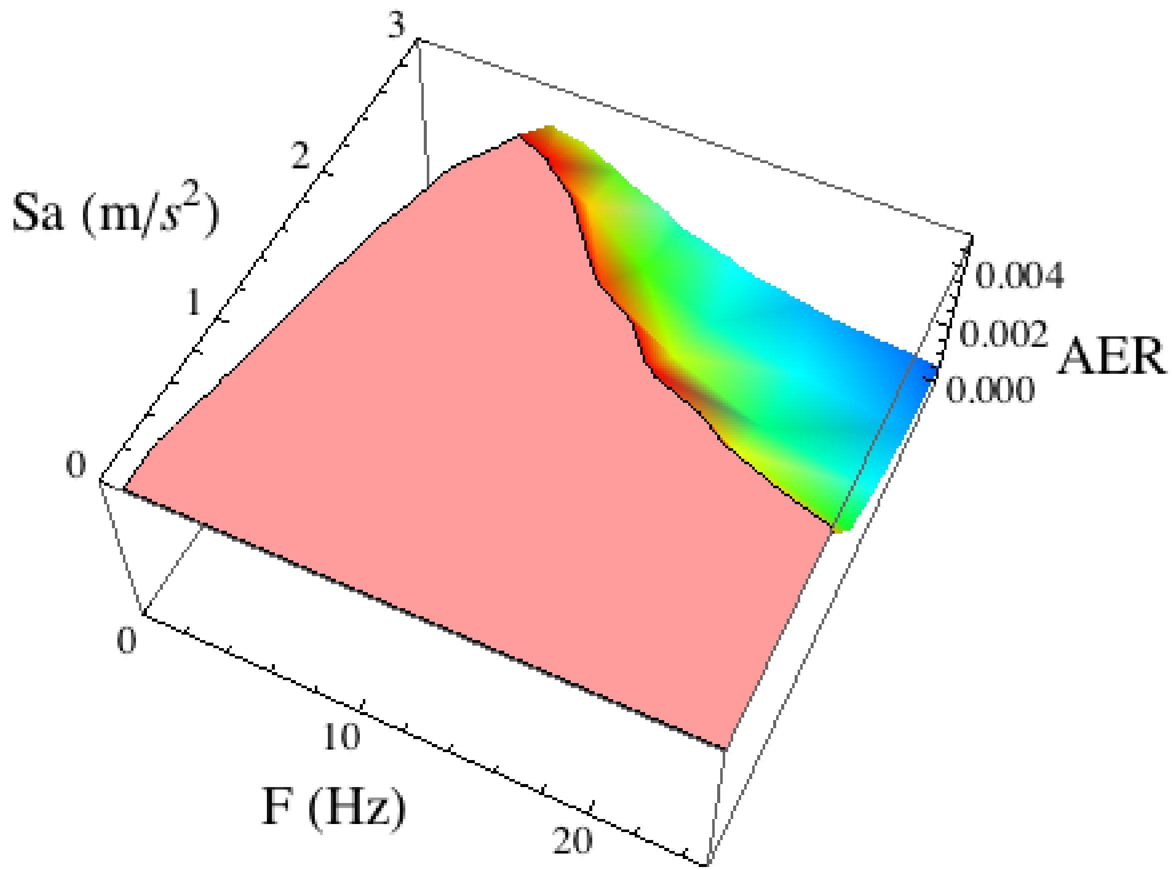
Uniform Hazard Spectra



Uniform Hazard Spectra

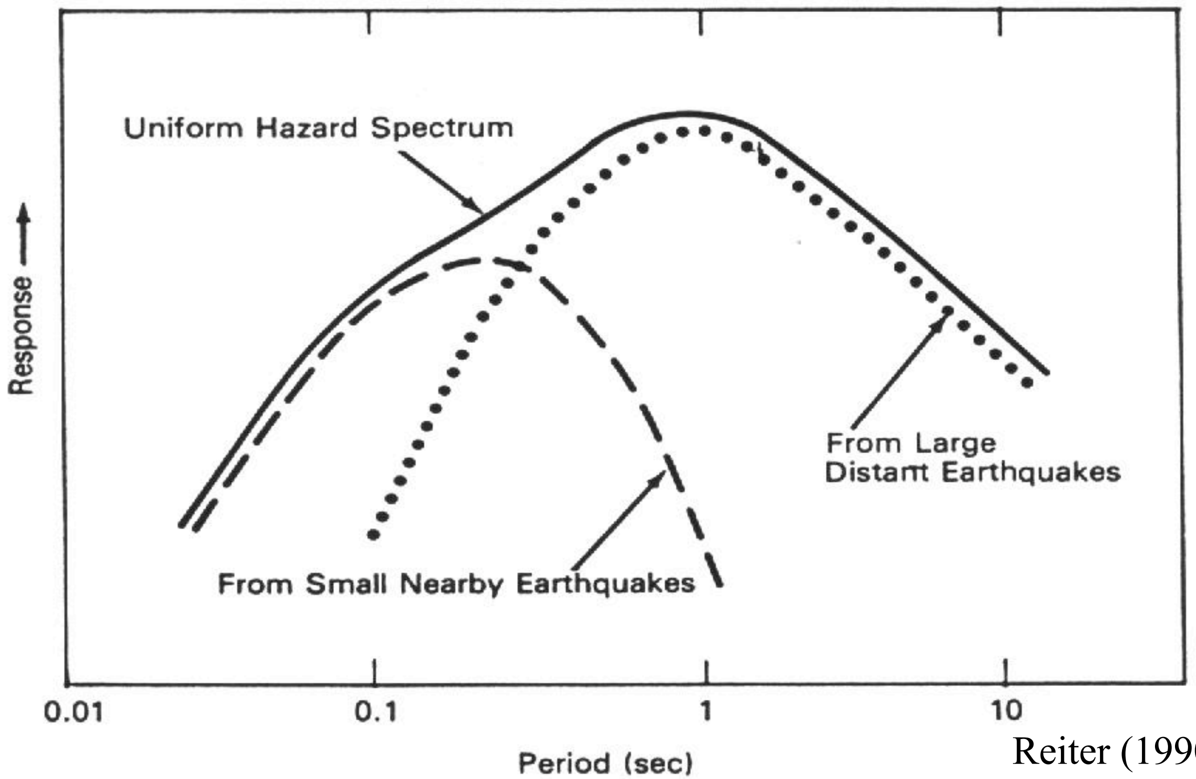


Uniform Hazard Spectra

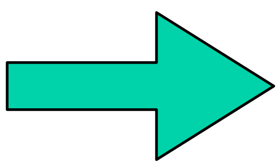


Closing the loop
Back to scenarios

Uniform Hazard Spectra Interpretation



Reiter (1990)



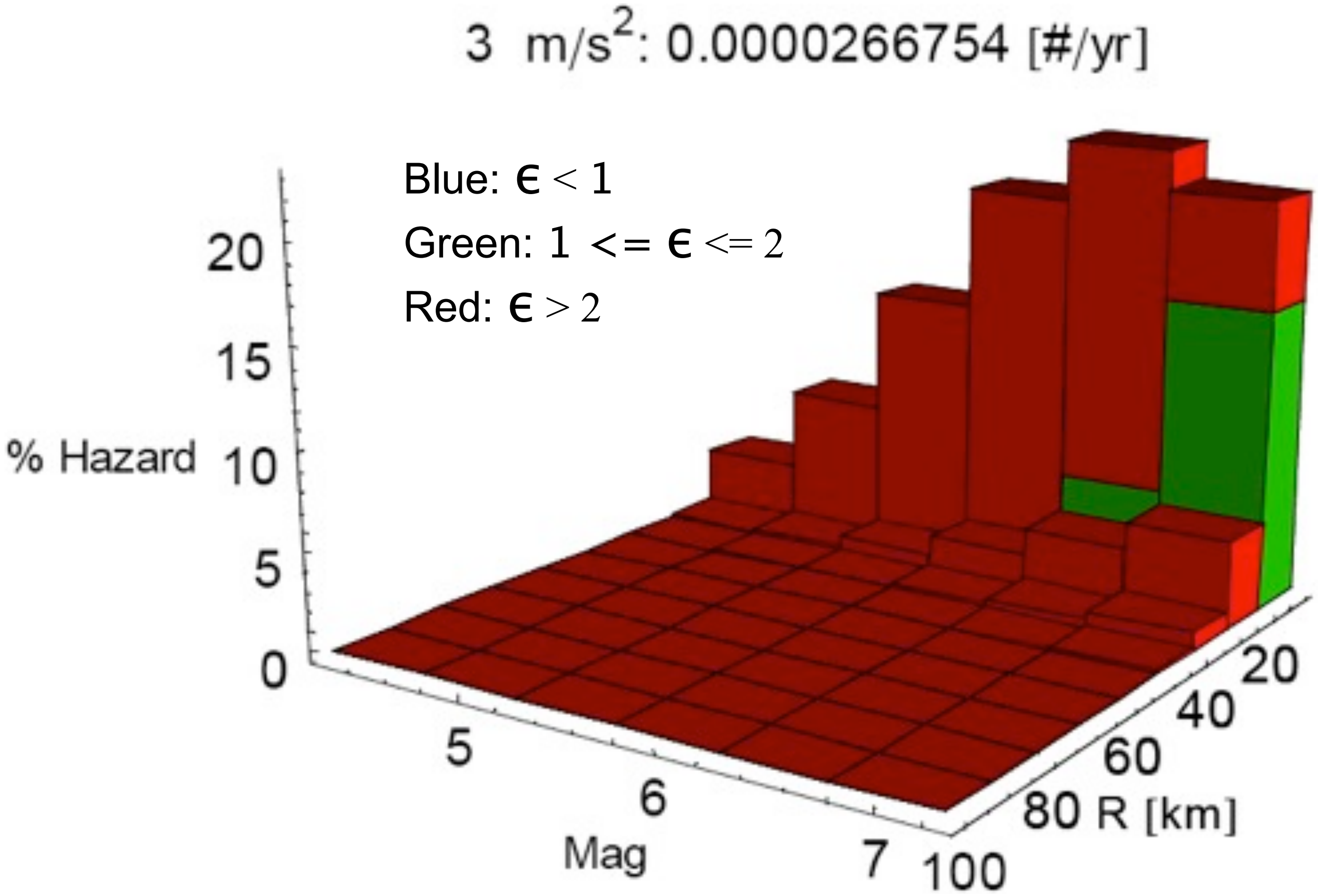
Disaggregation

Dissagregating hazard

Disaggregation: The hazard at a certain ground-motion level is separated into the contributions from different model parameter ranges.

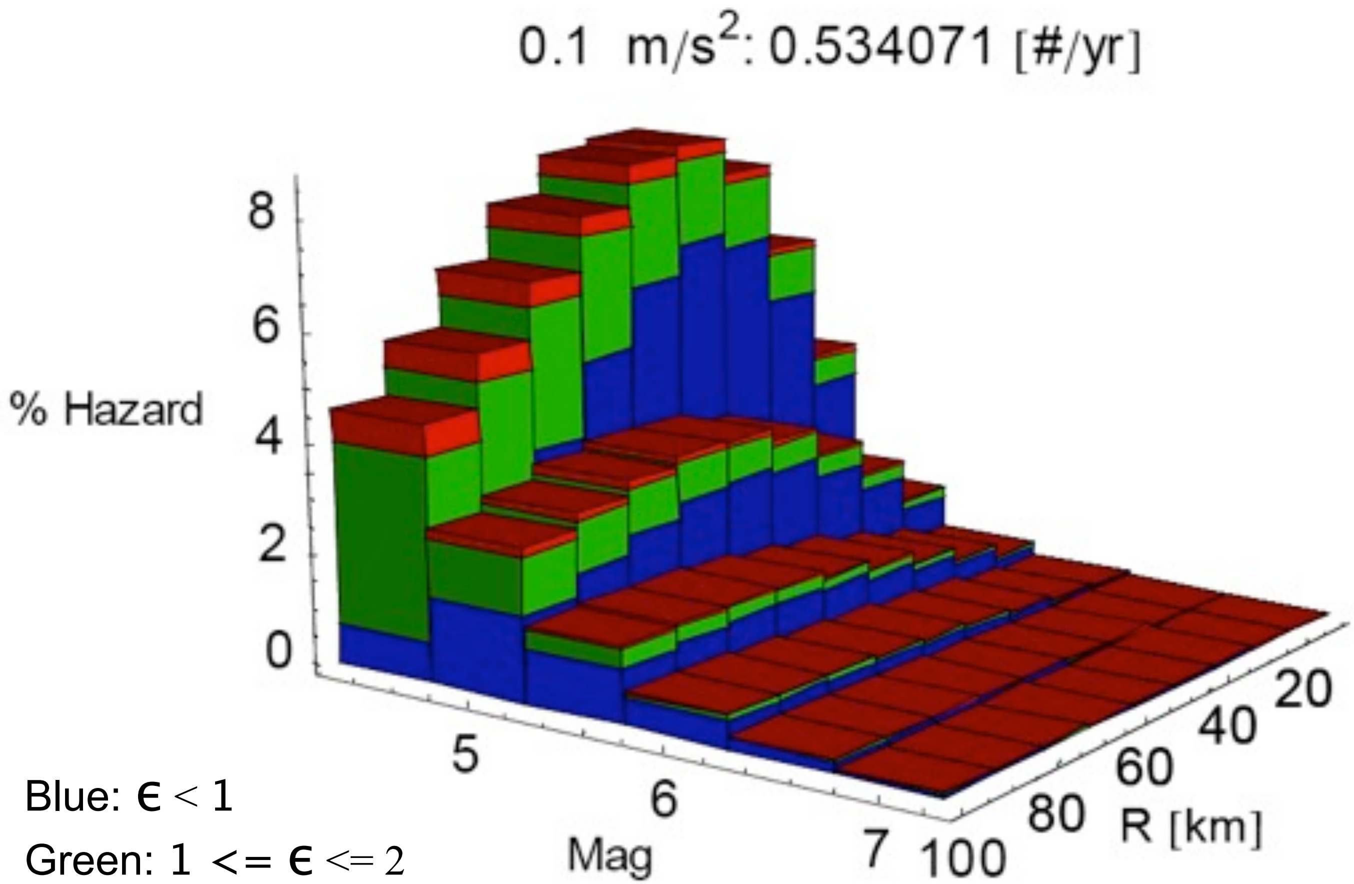
e. g. in magnitudes, distances, and ε (distance of a ground-motion level from the median of the distribution, expressed in multiples of σ).

Example 1
(high ground motion level)



- Hazard mostly from nearby sources
- Strongest contributions from magnitudes between 6 and 6.5.
- Majority of the ϵ-values is above 2.
- Only for the highest magnitude some contribution lower ϵ-values.

Example 2
(low ground motion level)



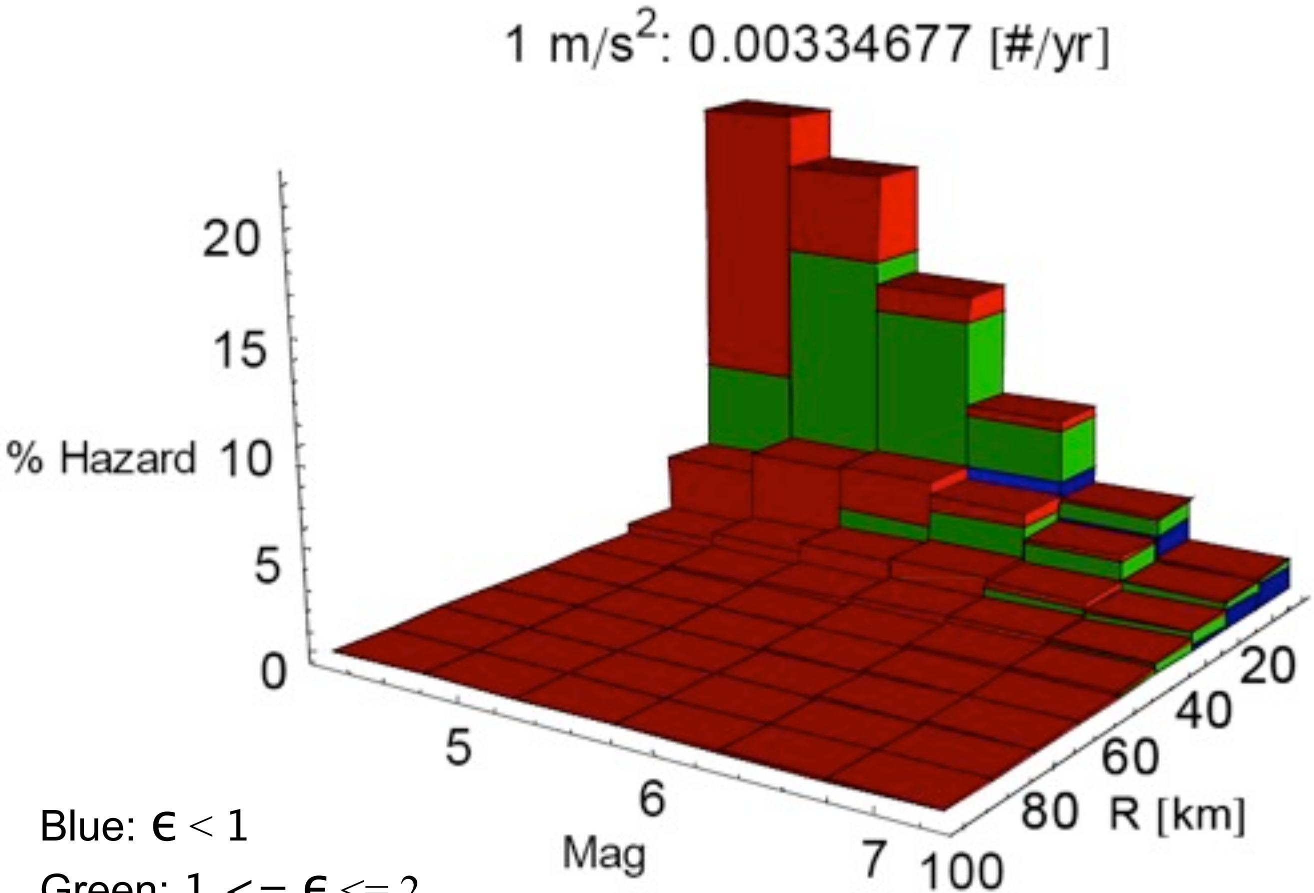
Blue: $\epsilon < 1$

Green: $1 <= \epsilon <= 2$

Red: $\epsilon > 2$

- Mainly contributions from earthquakes with low magnitudes, but at rather large distances
- Most of the contributions come from the central parts of the ground-motion distributions (blue color) or the range between 1 and 2 σ. Values above this level are rather rare.

Example 3
(intermediate ground motion level)



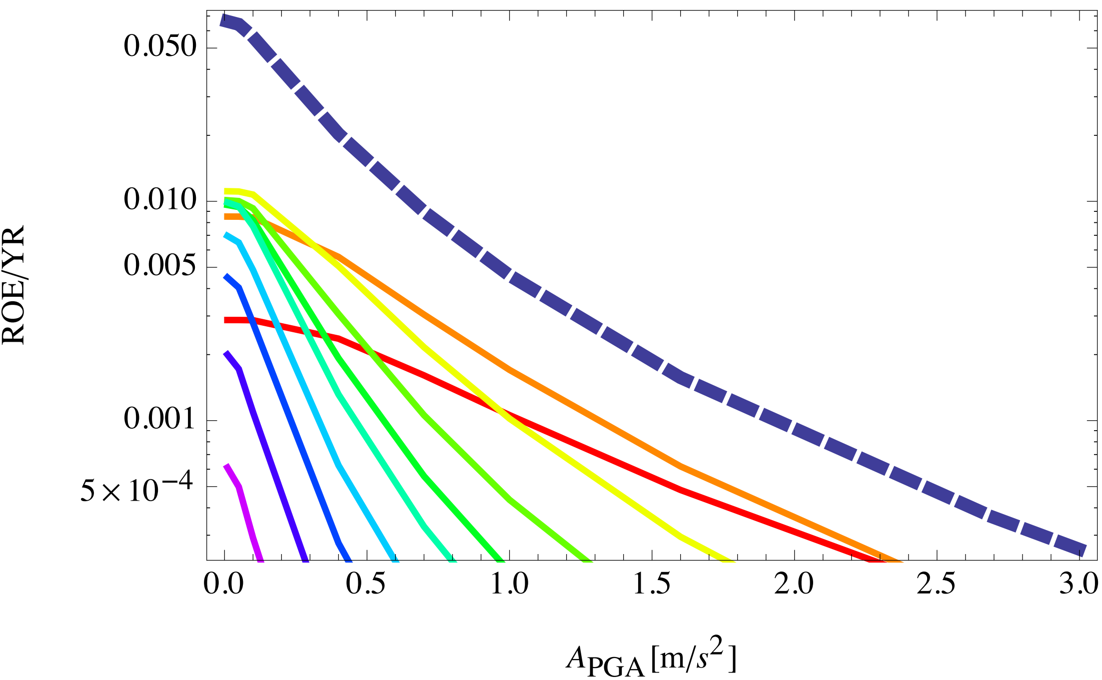
Blue: ϵ < 1

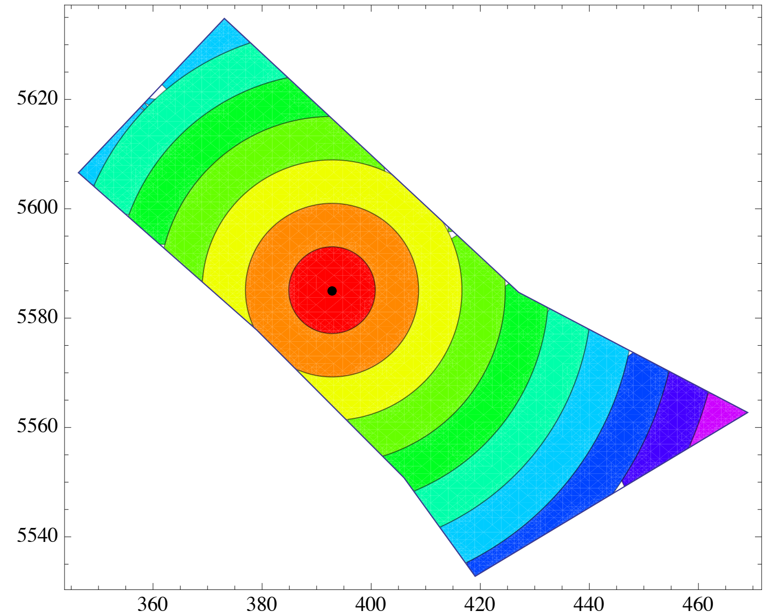
Green: 1 <= ϵ <= 2

Red: ϵ > 2

- Only sources at short distances contribute.
- Majority of contributions comes from the tail of the distribution (red color).
- Only for the larger, nearby sources, the ϵ-values do fall below 1.

A different perspective on disaggregation





Contribution from different distances

Yet another aspect

Would you buy a Japanese camera?

William Edwards Deming (1900-1993)

Don´t try to produce a perfect product, produce a reliable product!

Quality control according to Deming:

“Each activitiy in a production line has its own variability due to environmental causes. Instead of waiting for the final product to exceed arbitrary limits of variability, the managers should be looking at the variability of each of these activities. ***The most variable of the activities is the one that should be addressed. Once that variability is reduced, there will be another activity that is “most variable”, and it should then be addressed.***

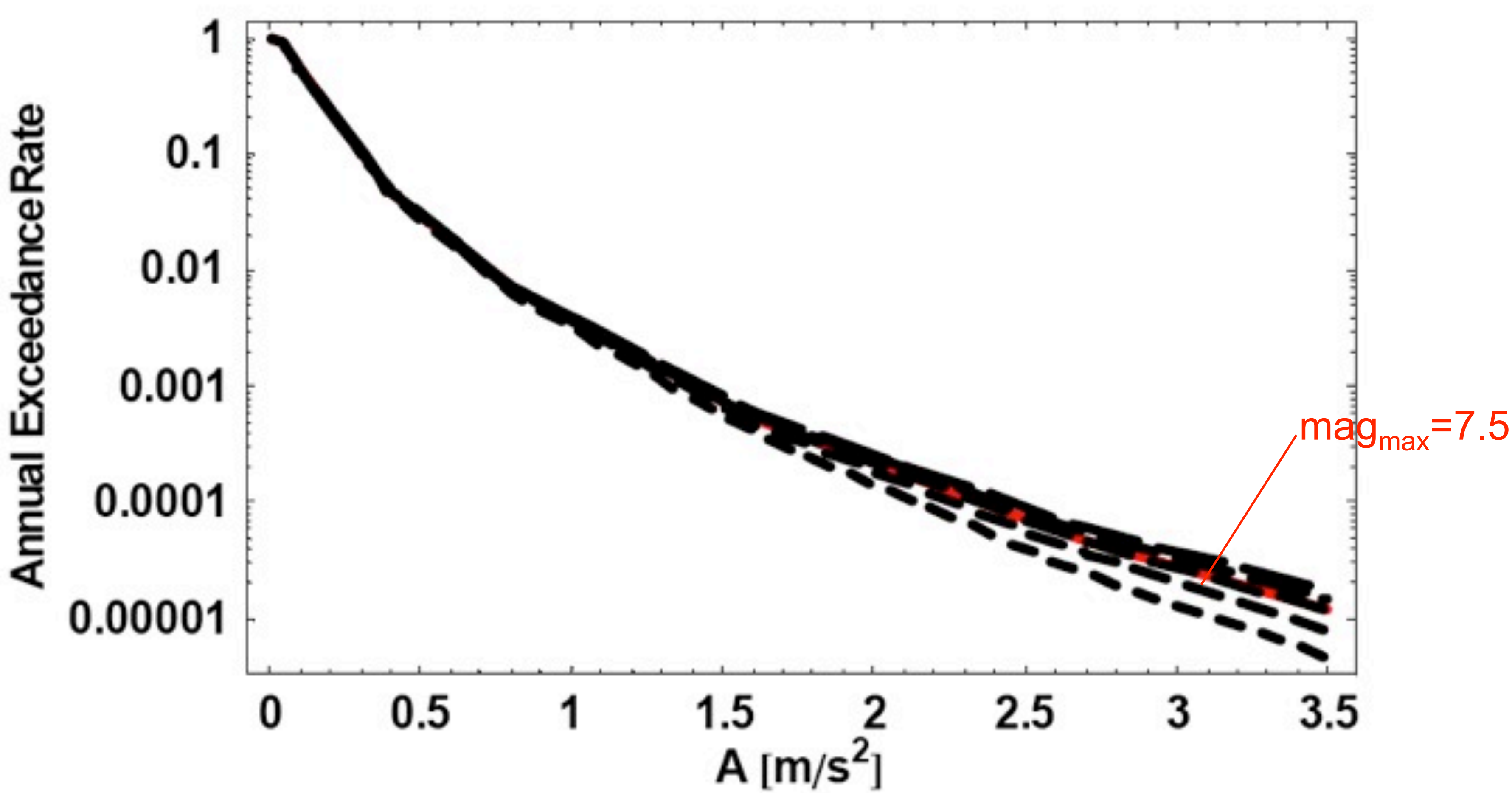
Deming´s strategy and PSHA

- Each PSHA should be accompanied by a sensitivity study to identify those uncertainties that can be reduced

SensitivityMagAndSigma

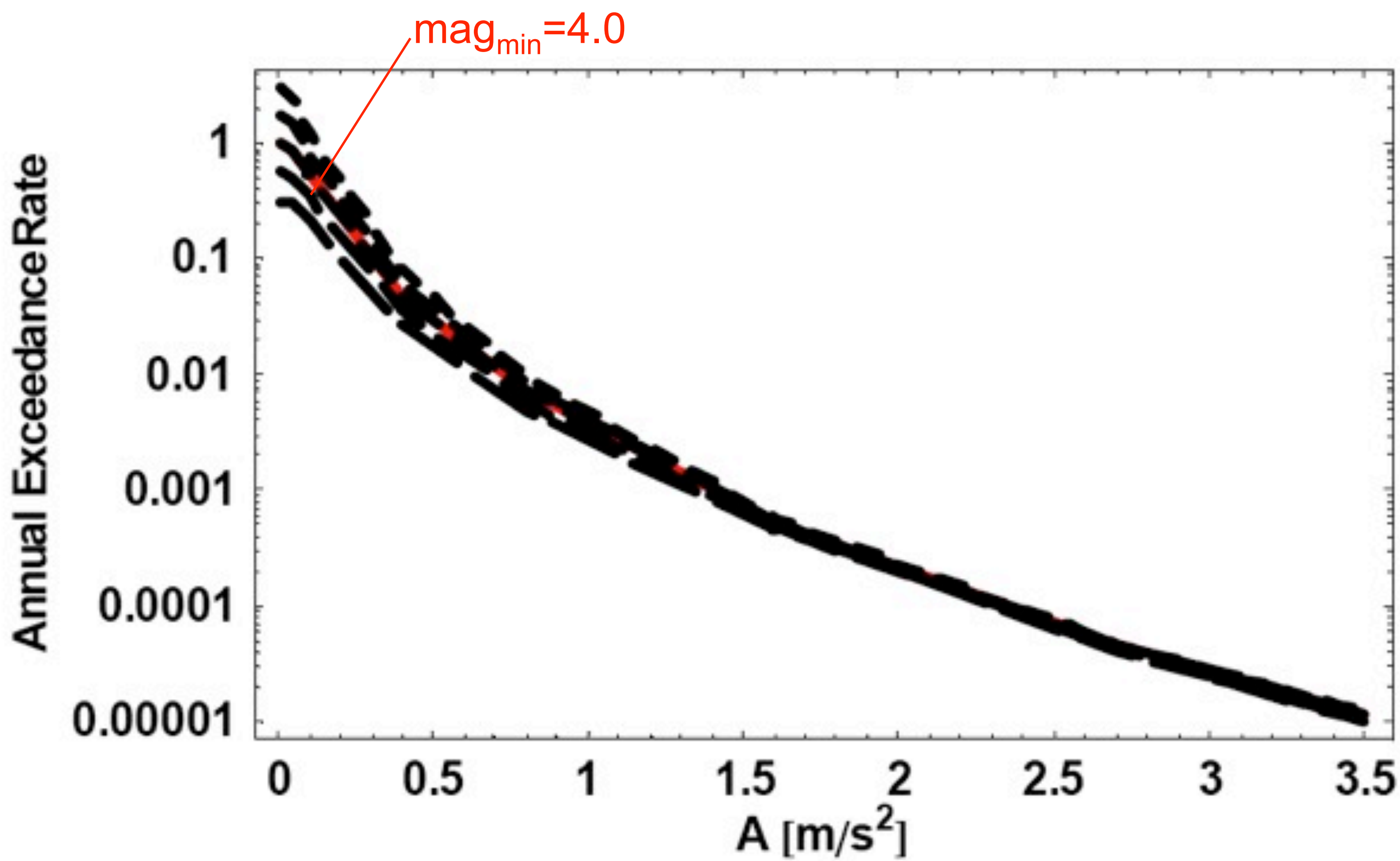
SensitivityMagAndTruncation

The influence of mag_{max}



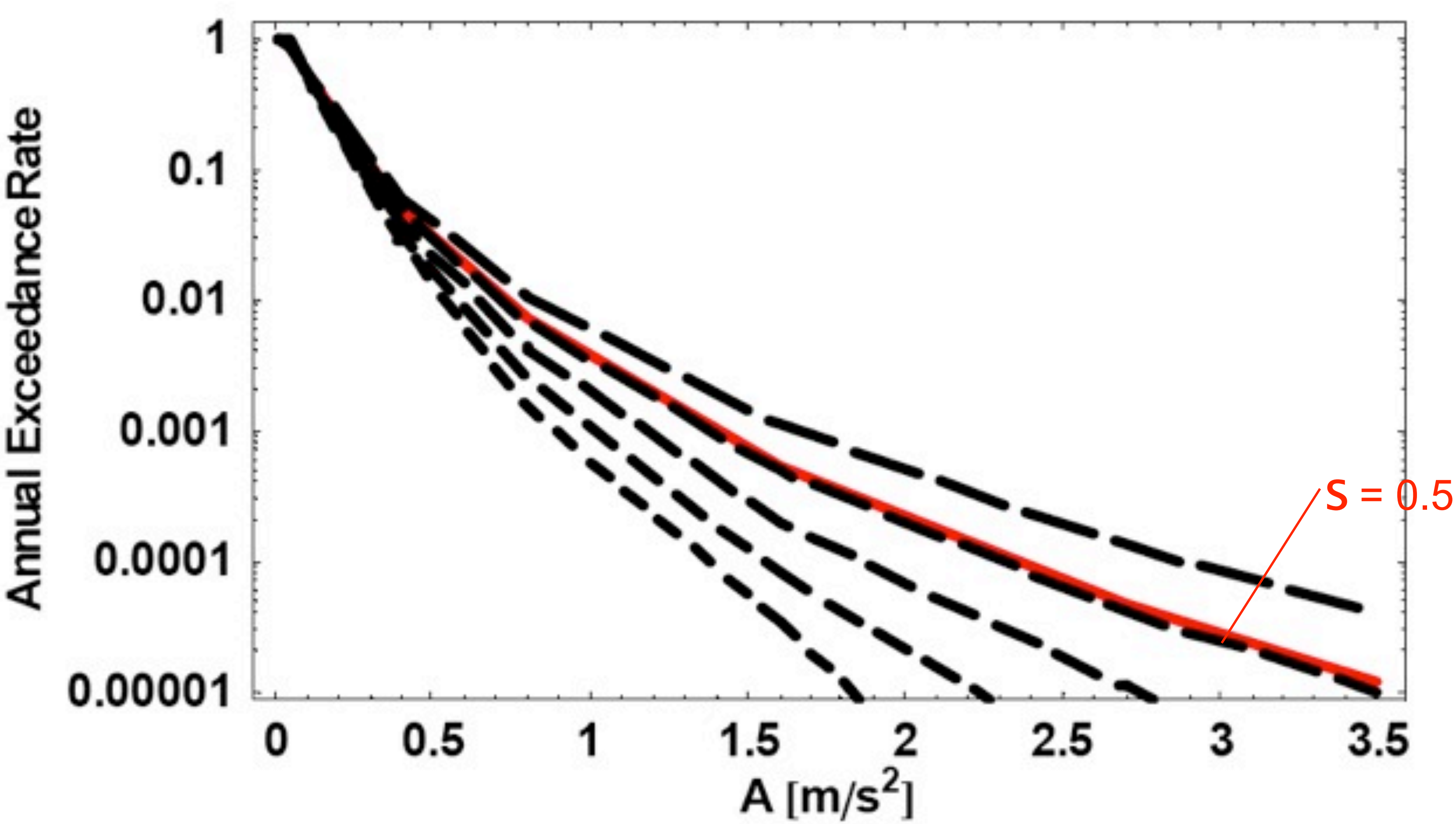
mag_{max} varies from 6.5 to 8.5 in steps of 0.5 magnitude units

The influence of mag_{min}



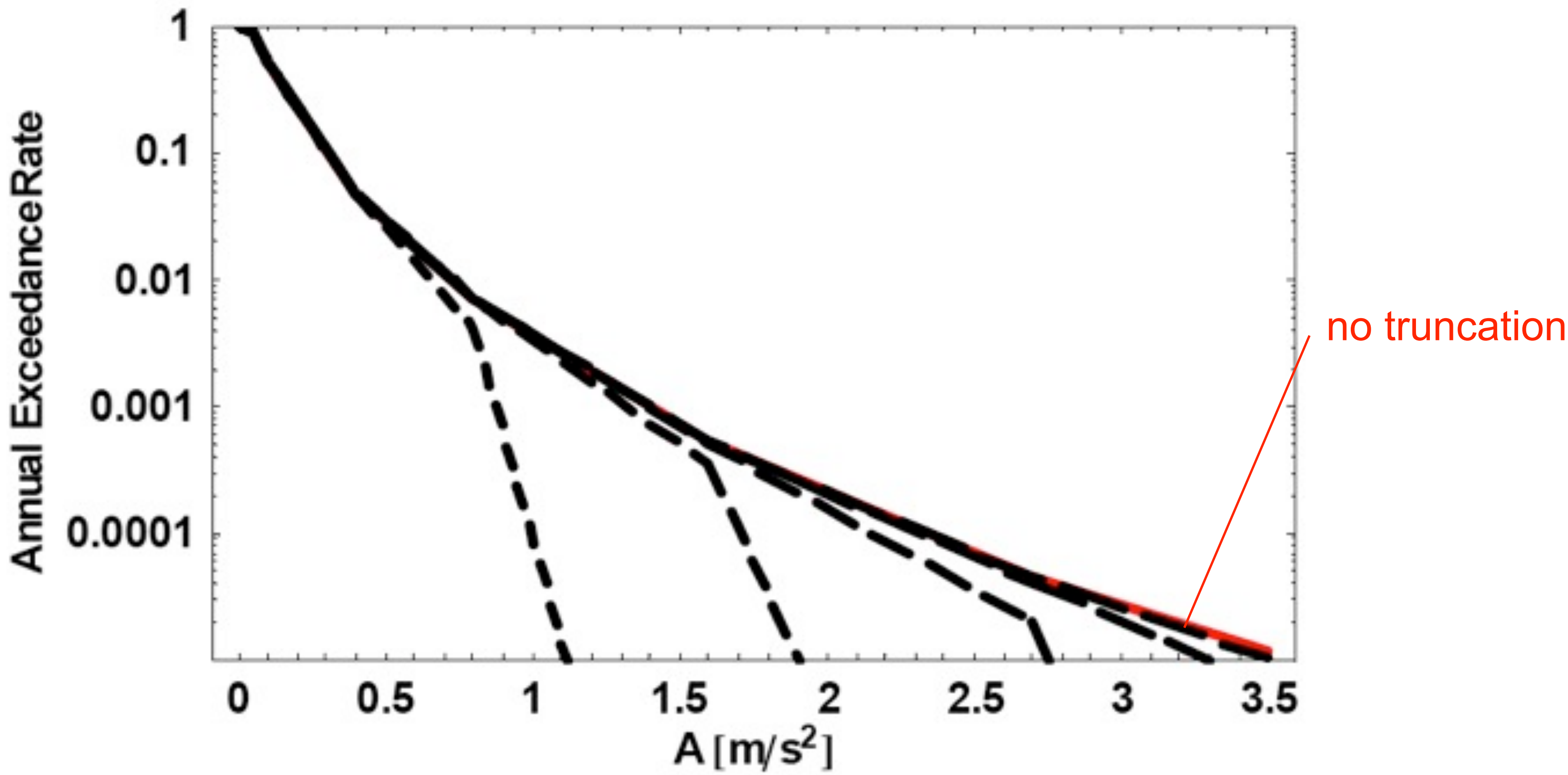
mag_{min} varies from 3.5 to 4.5 in steps of 0.25 magnitude units

The influence of s



s varies from 0.2 to 0.6 in steps of 0.1

The influence of truncating the ground motion distribution



Truncation at 1 to 5 s from the median in steps of 1 s.

Concluding remarks

The shape and the ground-motion level of a hazard curve are influenced by a number of factors the significance of which are not always immediately obvious.

Sensitivity studies can help to understand what matters and what not