# Crash Course in Probabilistic Seismic Hazard Analysis (PSHA)

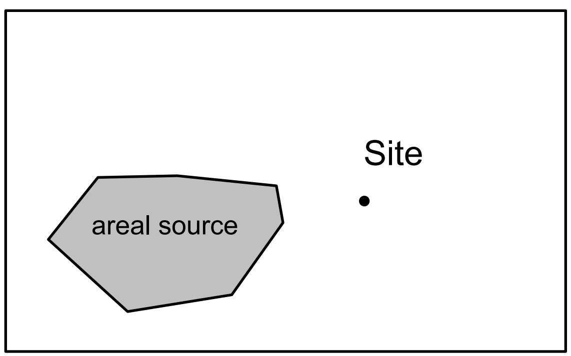
**Final**

# Outlook

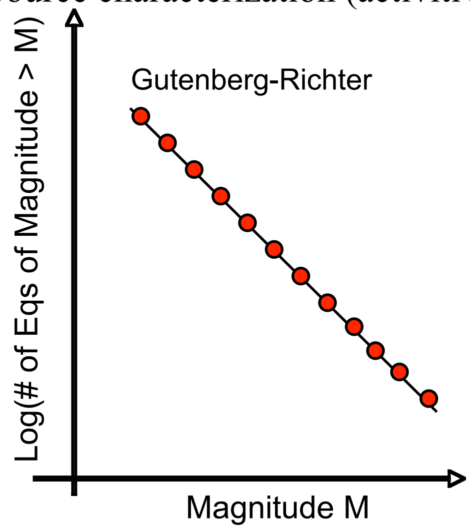
**From basic principles to practical problems**

# The elements of PSHA
# Sequential view

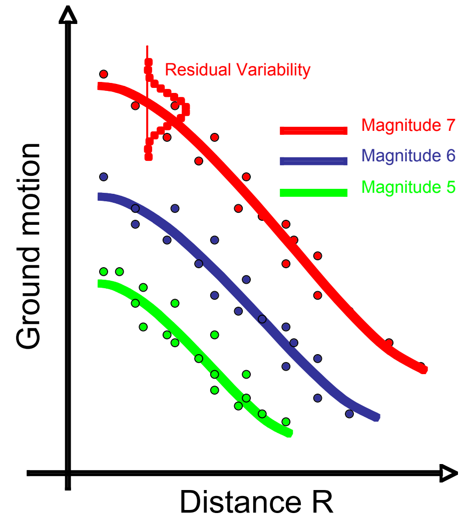
Source characterization (geometrically)




Source characterization (activitivity)

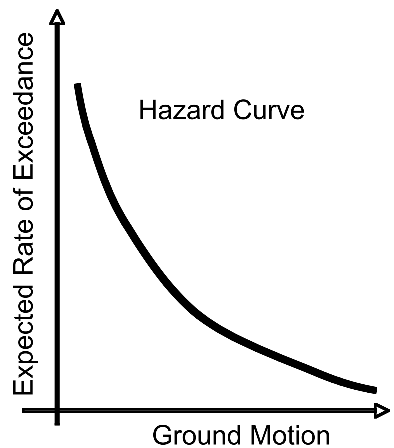



Ground Motion Modeling




after Reiter (1990)

**Result**



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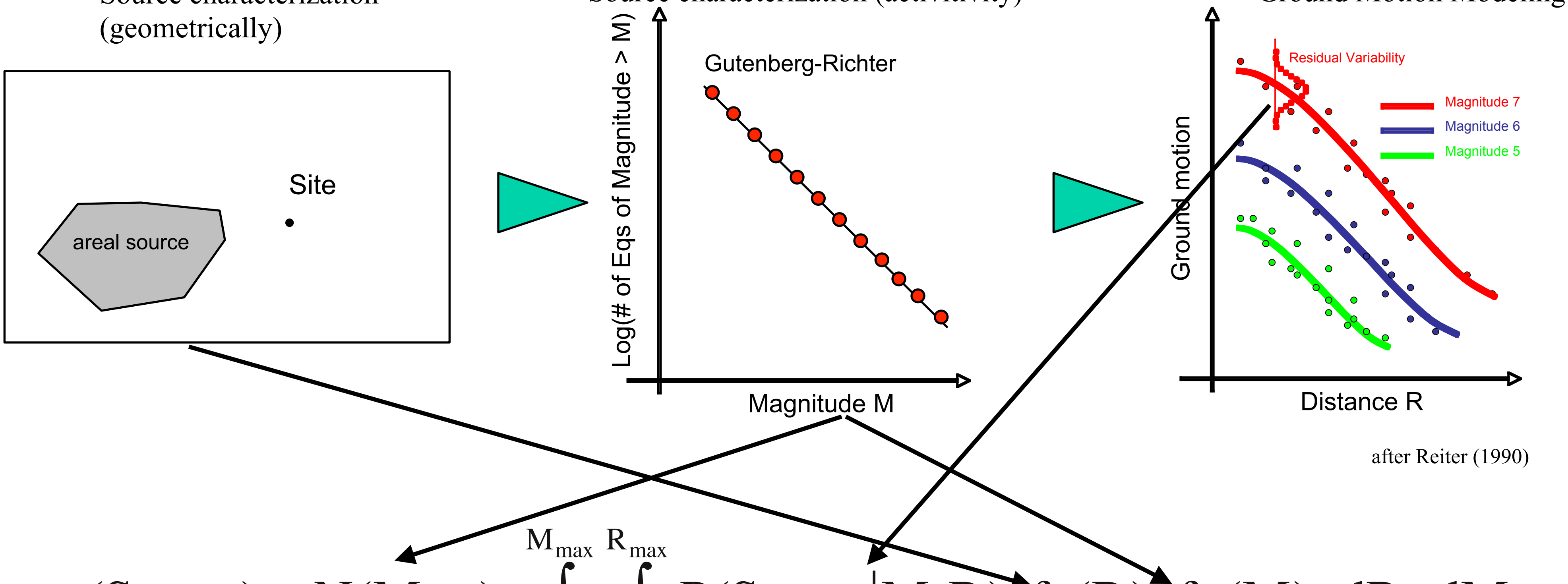
# The elements of PSHA
# Relation to the hazard integral




after Reiter (1990)

$$\nu(Sa > a) = N(M_{min}) \cdot \int_{M_{min}}^{M_{max}} \int_{R_{min}}^{R_{max}} P(Sa > a \mid M,R) \cdot f_R(R) \cdot f_m(M) \cdot dR \cdot dM$$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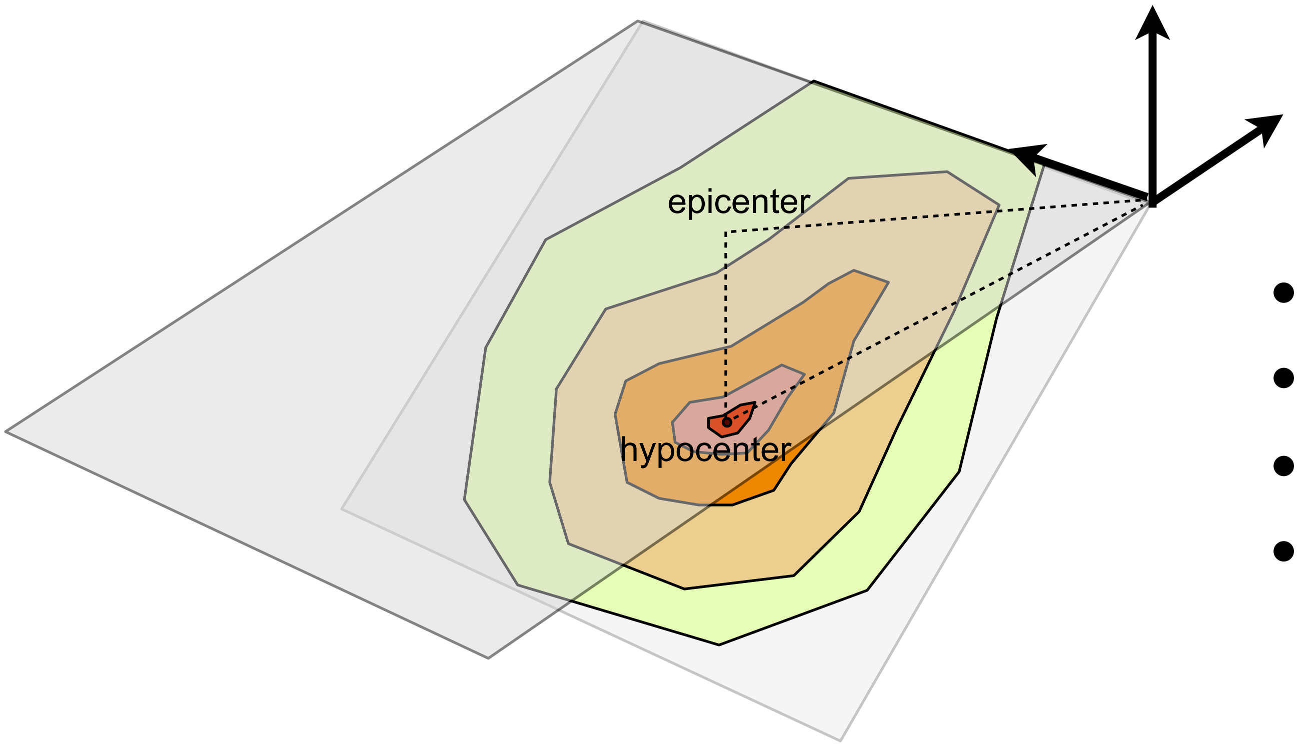
# From point sources to extended sources
# Rupture propagation




- mechanism
- directivity effects
- hanging wall effects
- buried source effects

# Influence of focal mechanism

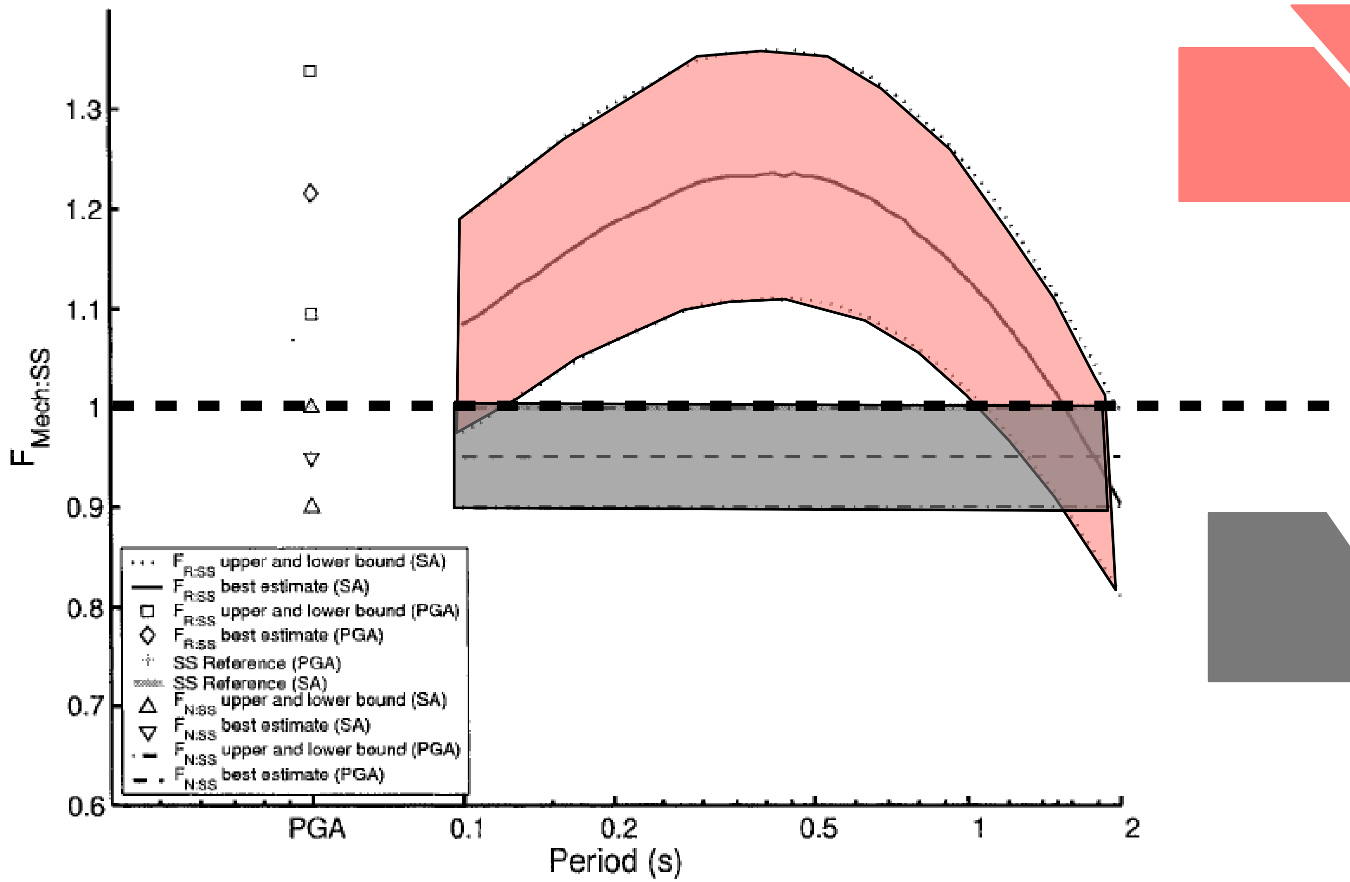



*Figure 4.* Simplified three-branch estimates for $F_{R:SS}$ and $F_{N:SS}$.

tendency to
larger
ground motion

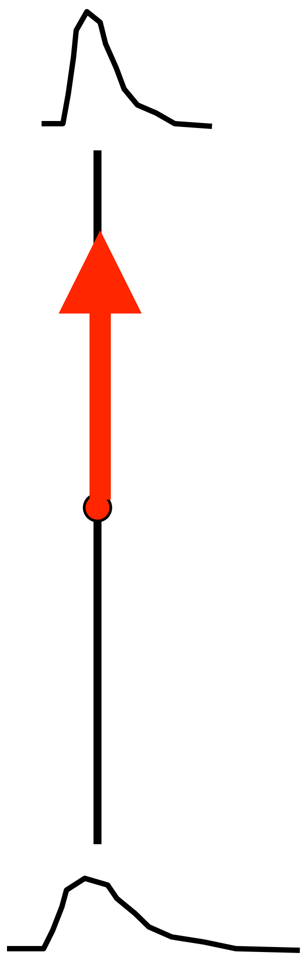
Strike slip

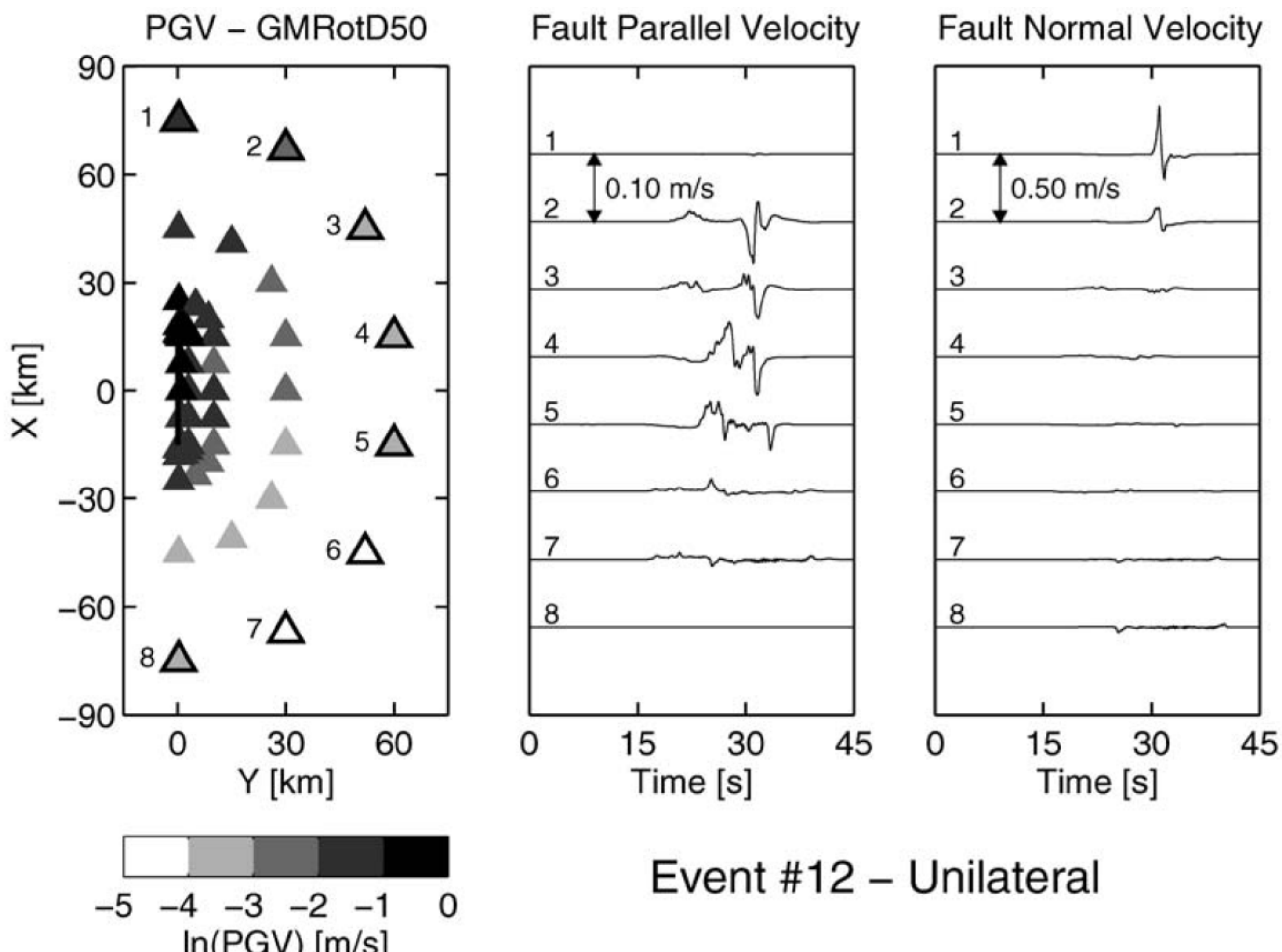
tendency to
smaller
motion

Bommer et al. (2003)

# Influence of rupture directivity
# Unilateral rupture

rupture
propagation

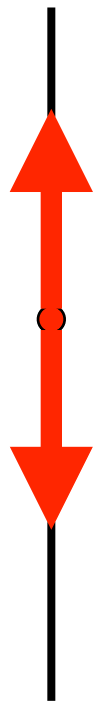


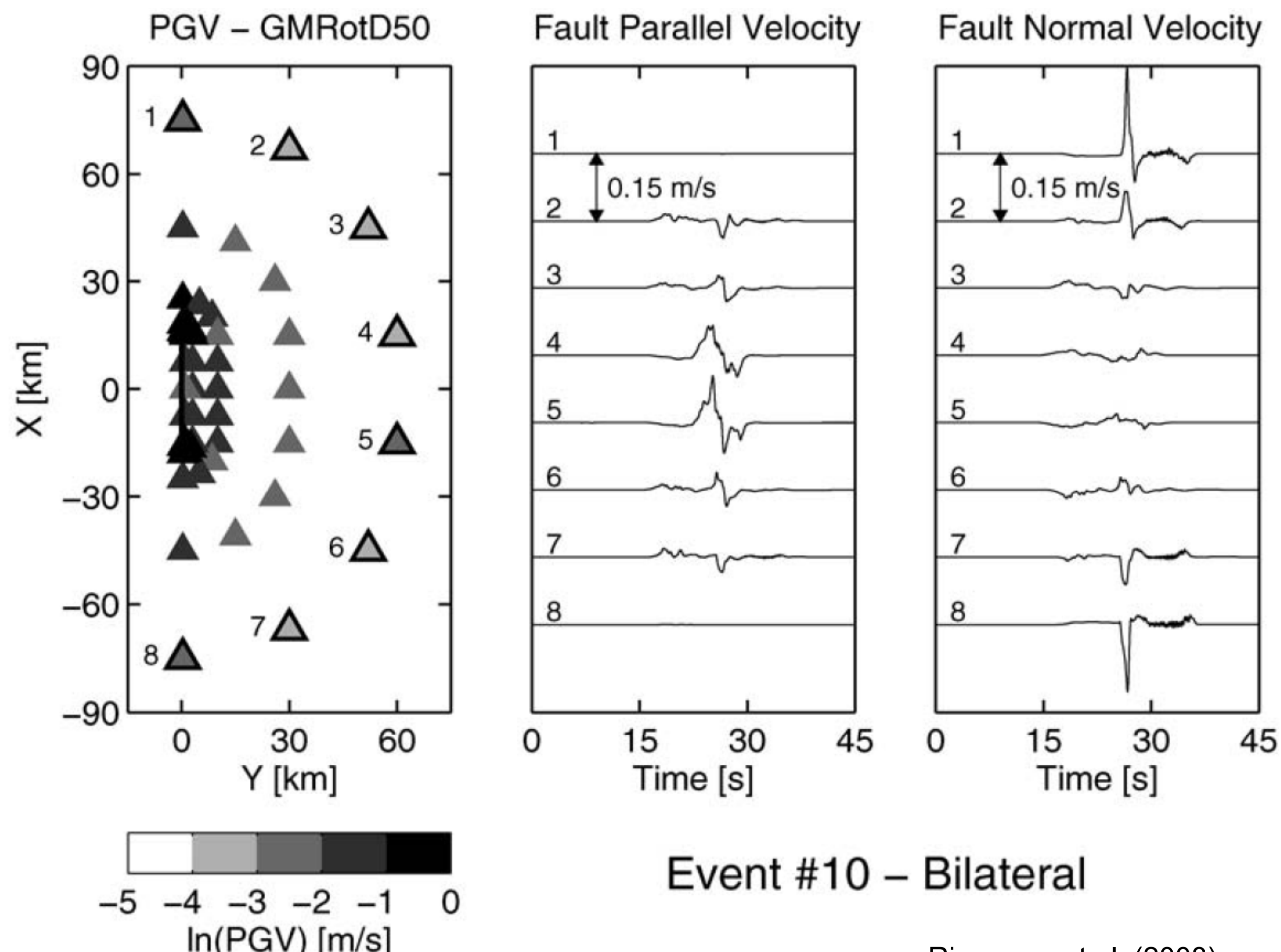



Ripperger et al. (2008)

# Influence of rupture directivity
# Bilateral rupture

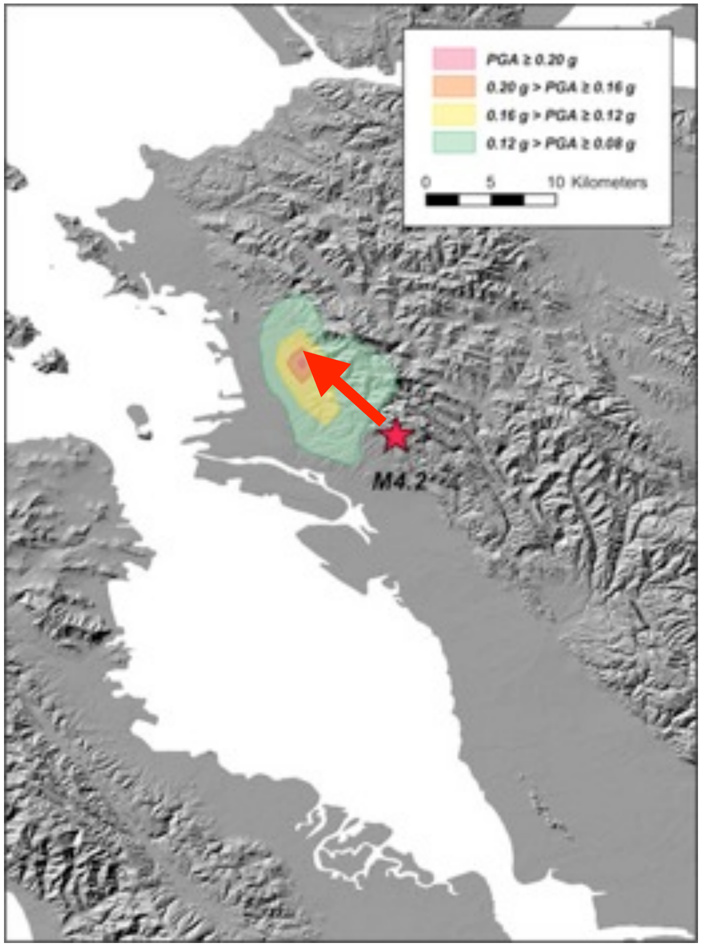
rupture
propagation

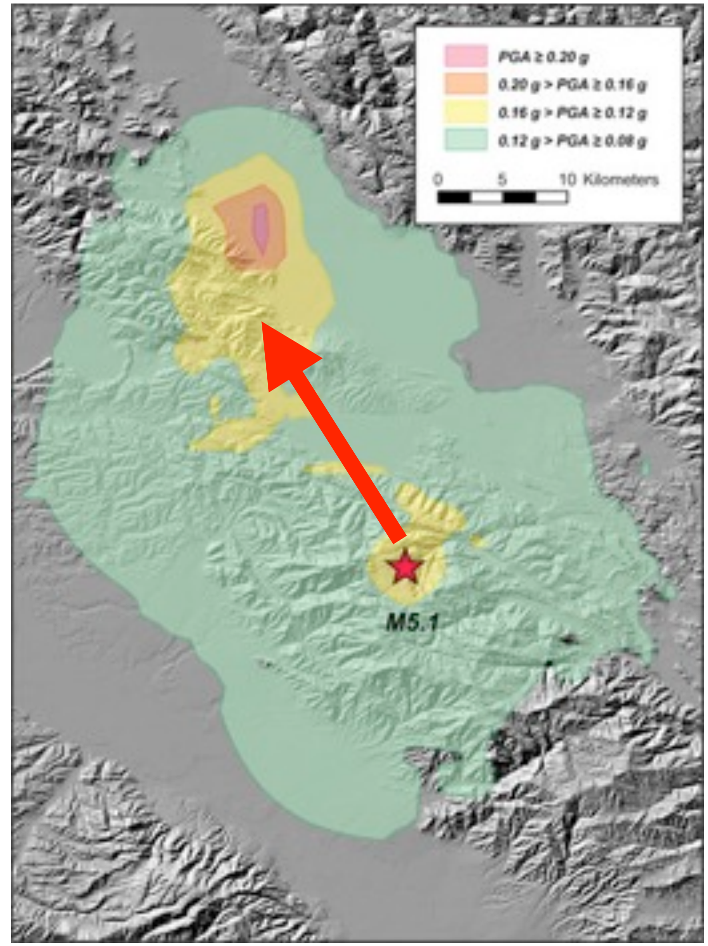





Ripperger et al. (2008)

# Influence of rupture directivity
# Examples



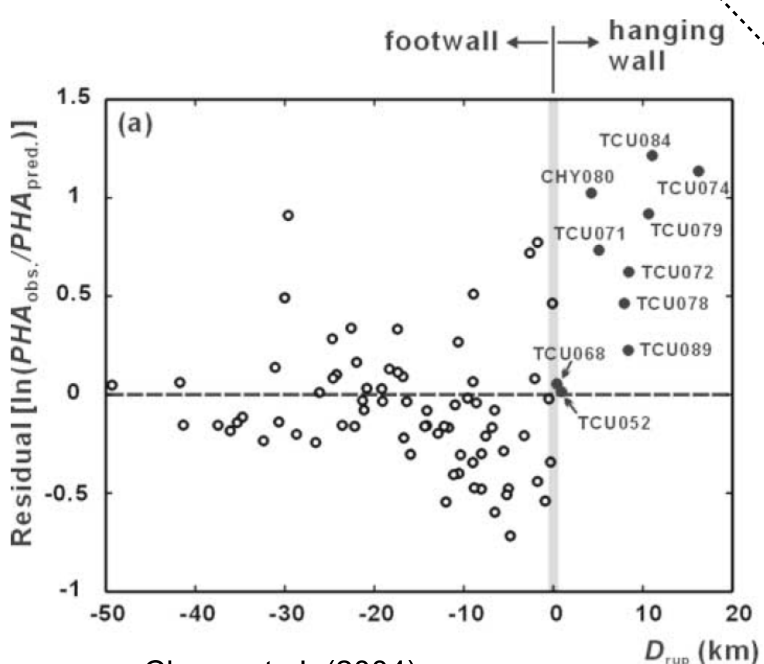

http://earthquake.usgs.gov/regional/nca/rupture/directivity/

# Hanging wall effect

**larger** ground motion

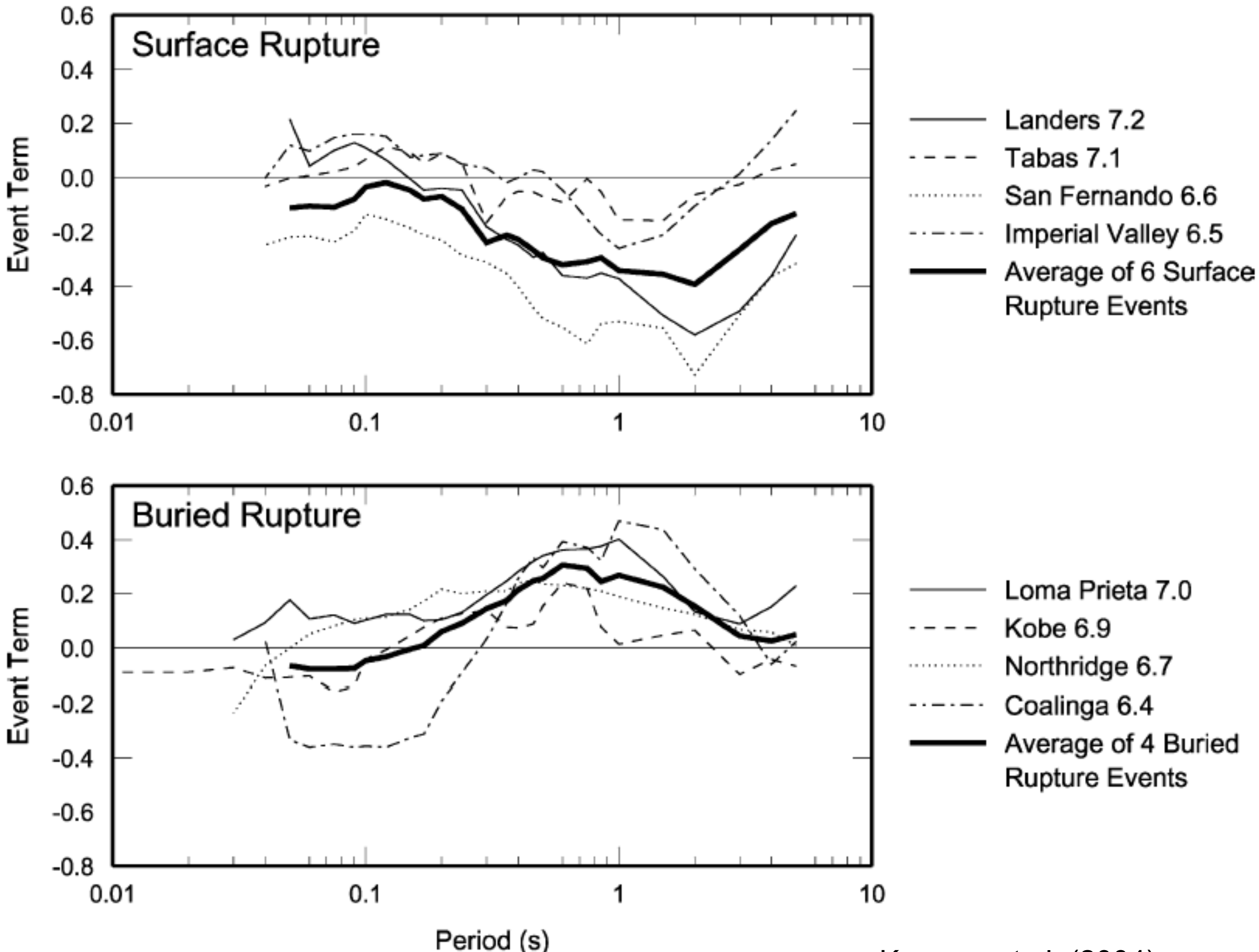
foot wall

hanging wall



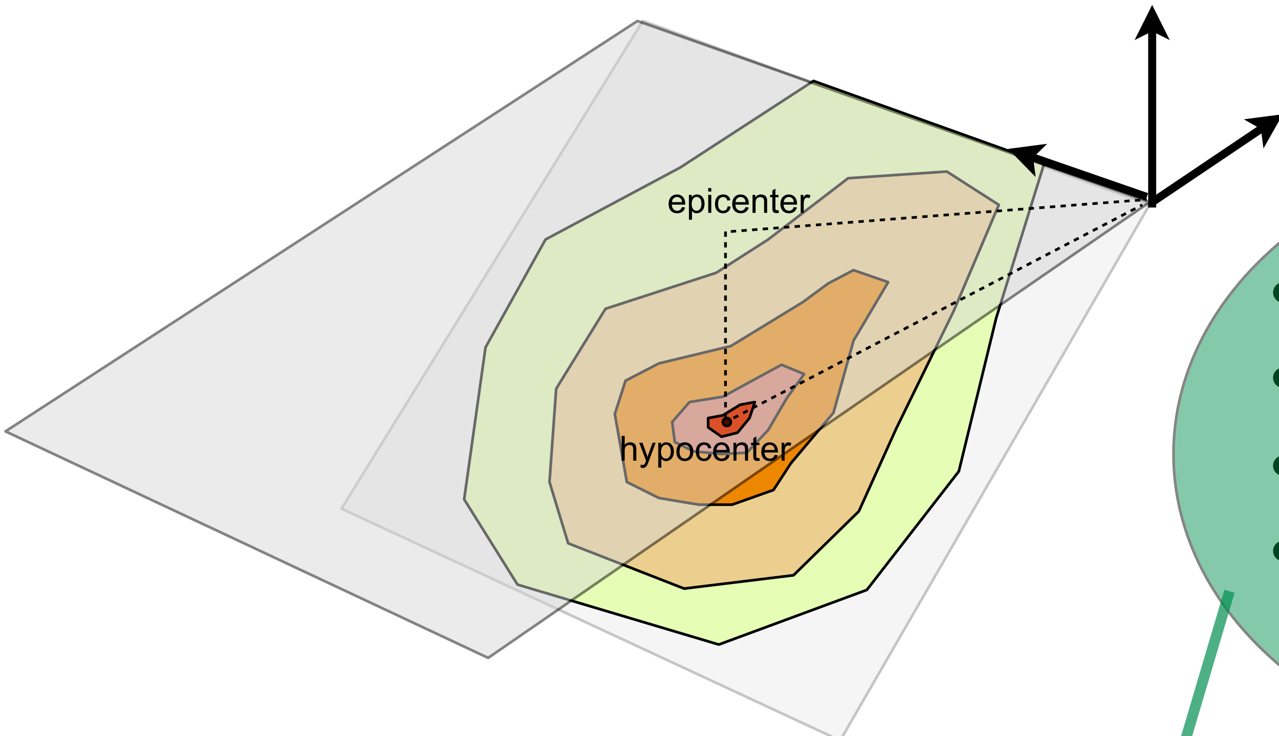

Chang et al. (2004)

# Buried source effect




Kagawa et al. (2004)

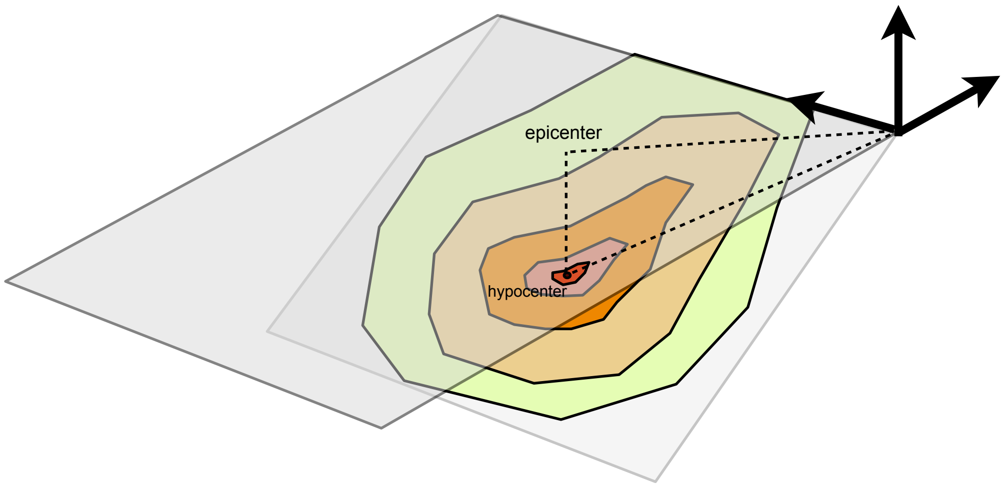
# From point sources to extended sources
# Effect on hazard integral kernel




- mechanism
- directivity effects
- hanging wall effects
- buried source effects

$$\nu(Sa > a) = N(M_{min}) \cdot \int_{M_{min}}^{M_{max}} \int_{R_{min}}^{R_{max}} P(Sa > a | M,R) \cdot f_R(R) \cdot f_m(M) \cdot dR \cdot dM$$

# From point sources to extended sources
# Extended source distance metric




**Which distance?**

$$\ln Y = c_1 + c_2 M - c_3 \ln R - c_4 r + c_5 F + c_6 S + \varepsilon \cdot \sigma$$

magnitude

composite distance term

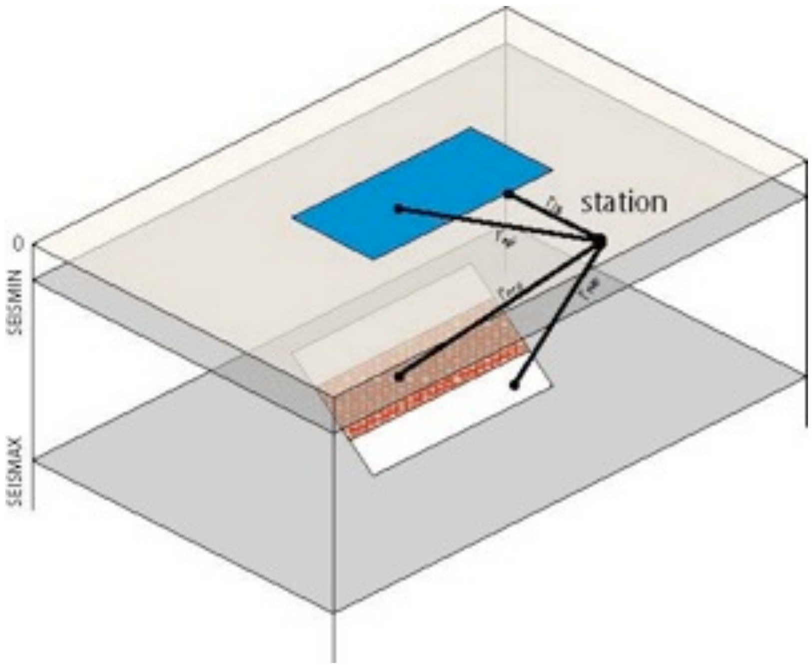
Source-to-site distance measure

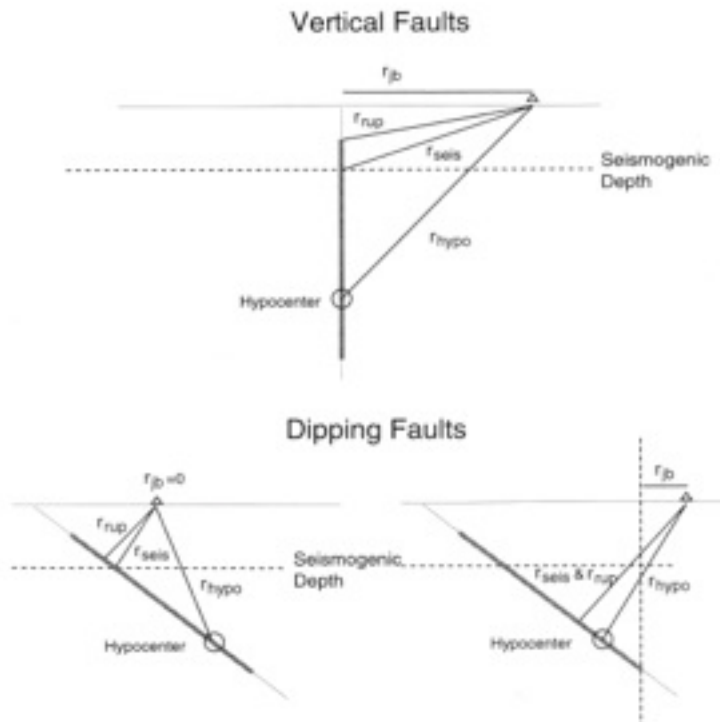
Site condition

Style of faulting

Residual in terms of σ

# From point sources to extended sources
# Extended source distance metric



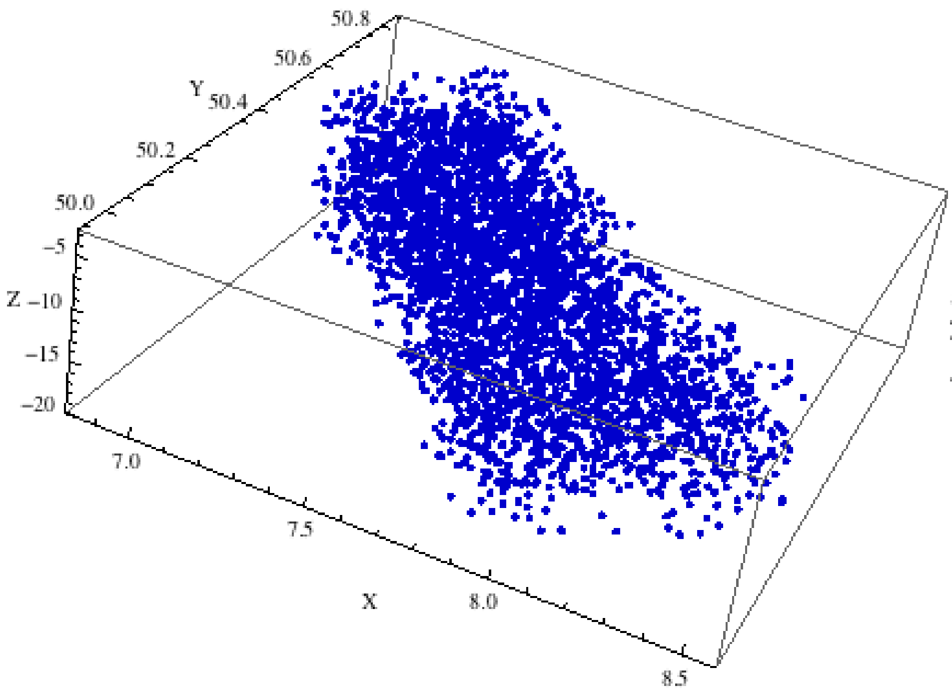



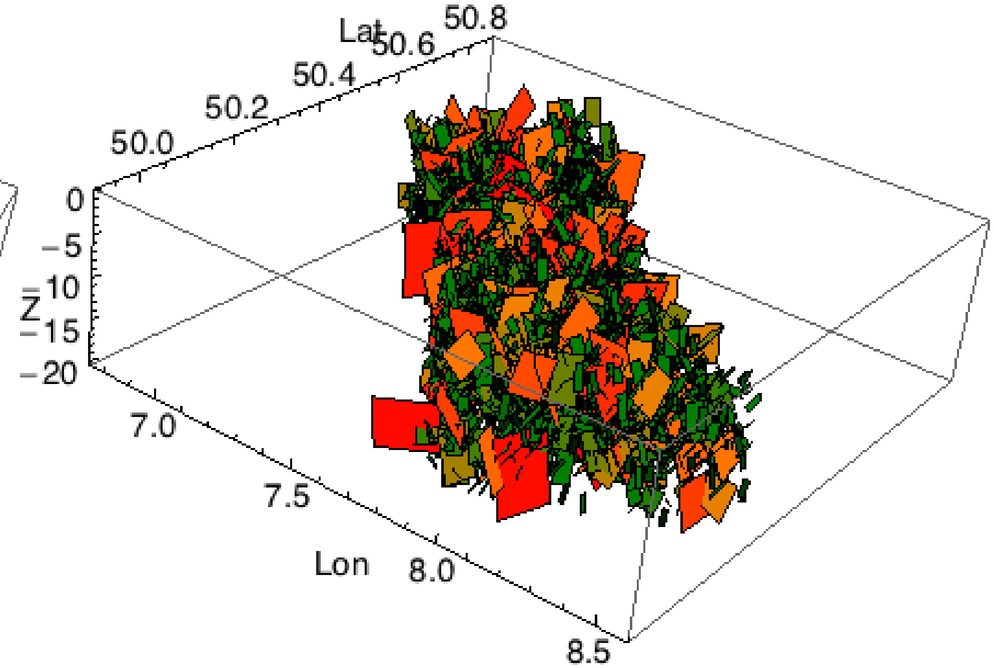

- RHYP
- REPI
- RRUP
- RSEIS
- RJB
- RRMS
- ……

Abrahamson & Shedlock (1997)

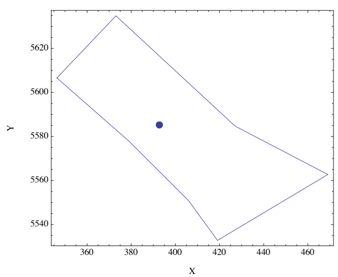
$$\nu(Sa > a) = N(M_{min}) \cdot \int_{M_{min}}^{M_{max}} \int_{R_{min}}^{R_{max}} P(Sa > a \mid M,R) \cdot f_R(R) \cdot f_m(M) \cdot dR \cdot dM$$

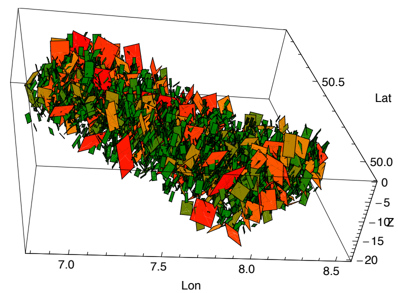
# From point sources to extended sources
# Each source becomes a plane



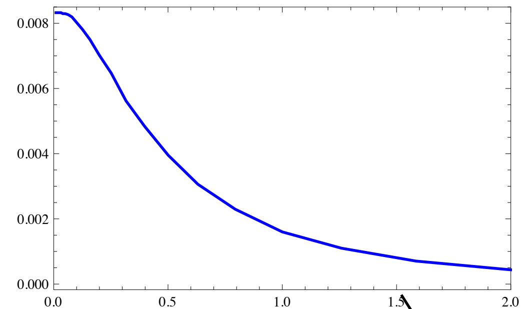



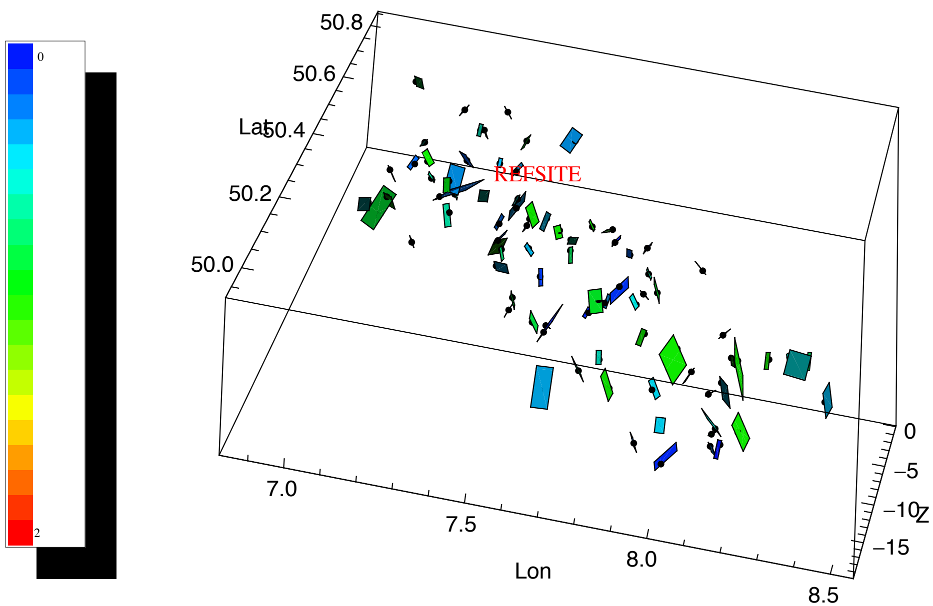
# From point sources to extended sources
# Disaggregation becomes more interesting




Hazard curve



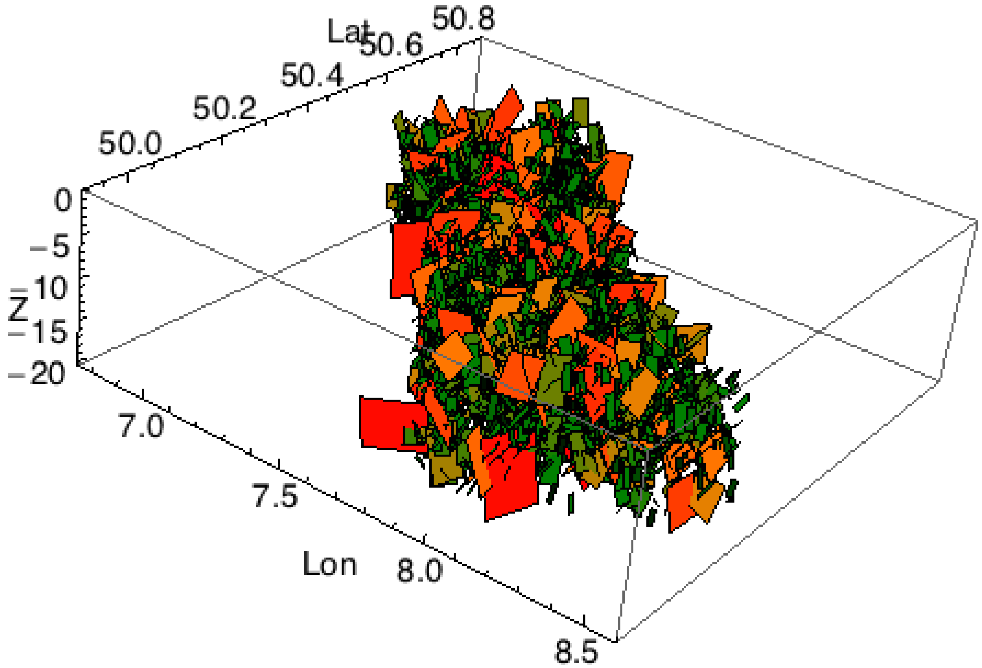




Earthquakes contributing to 1.5 m/s$^2$

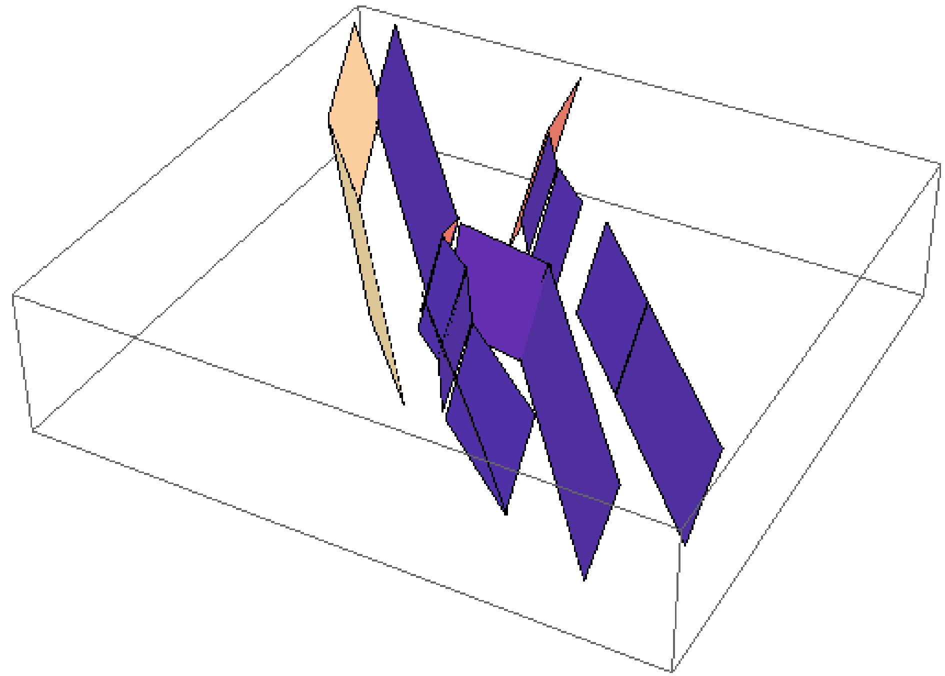
color coding according to ε

# From point sources to extended sources
# From areal sources to faults

Areal source with extended
individual rupture planes



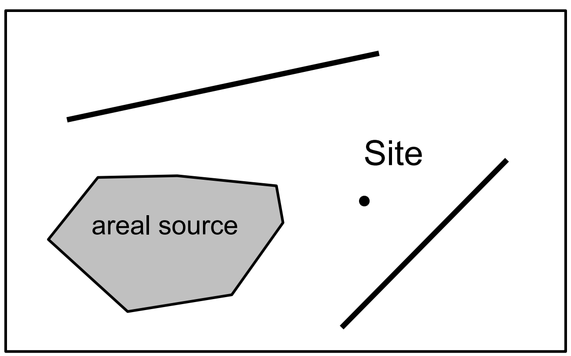

## How about big faults?



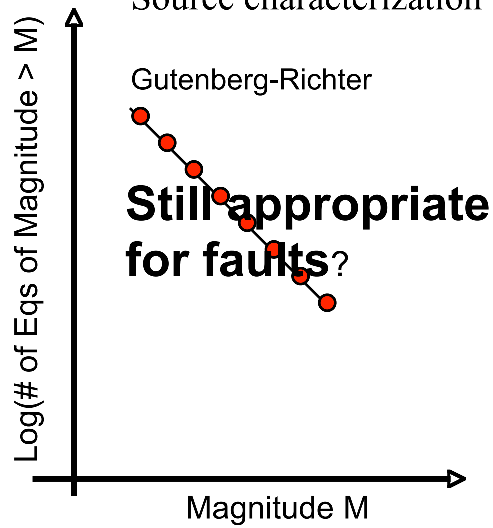
courtesy K. G. Hinzen

# The elements of PSHA
# Including faults

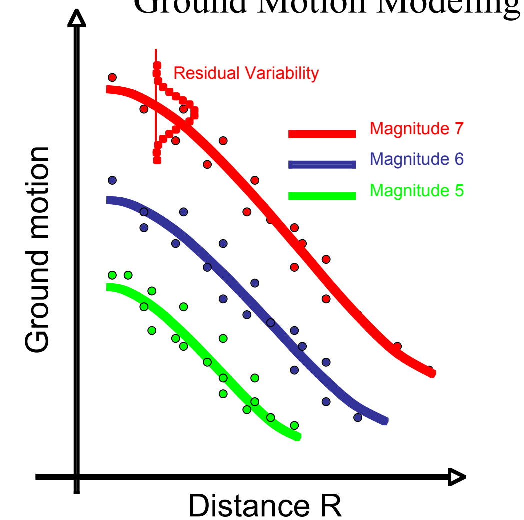
Source characterization (geometrically)



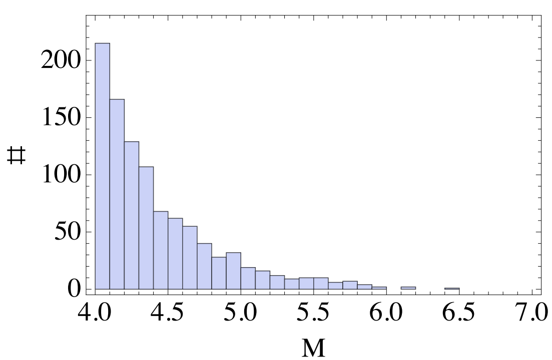

Source characterization



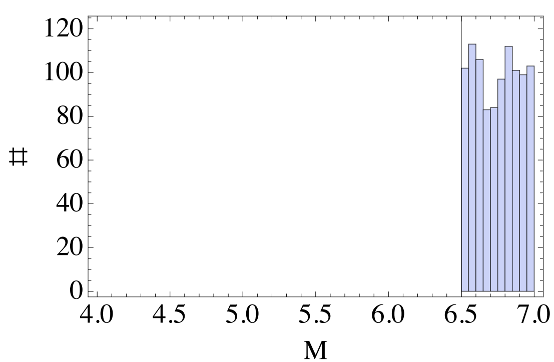

Ground Motion Modeling



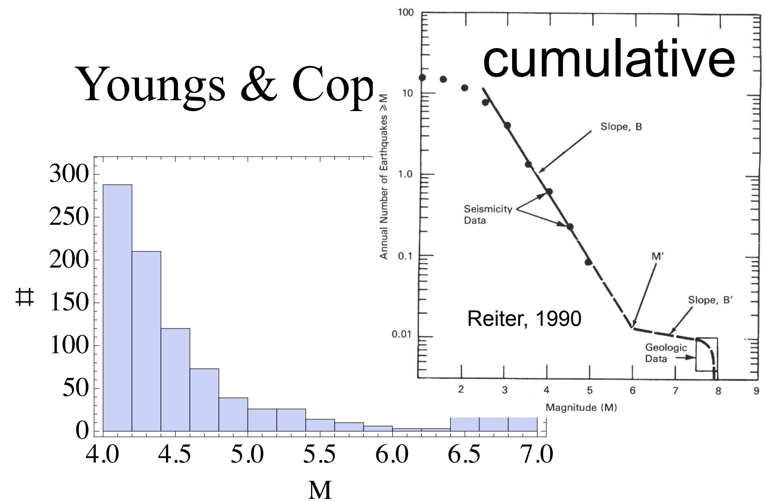

Gutenberg-Richter



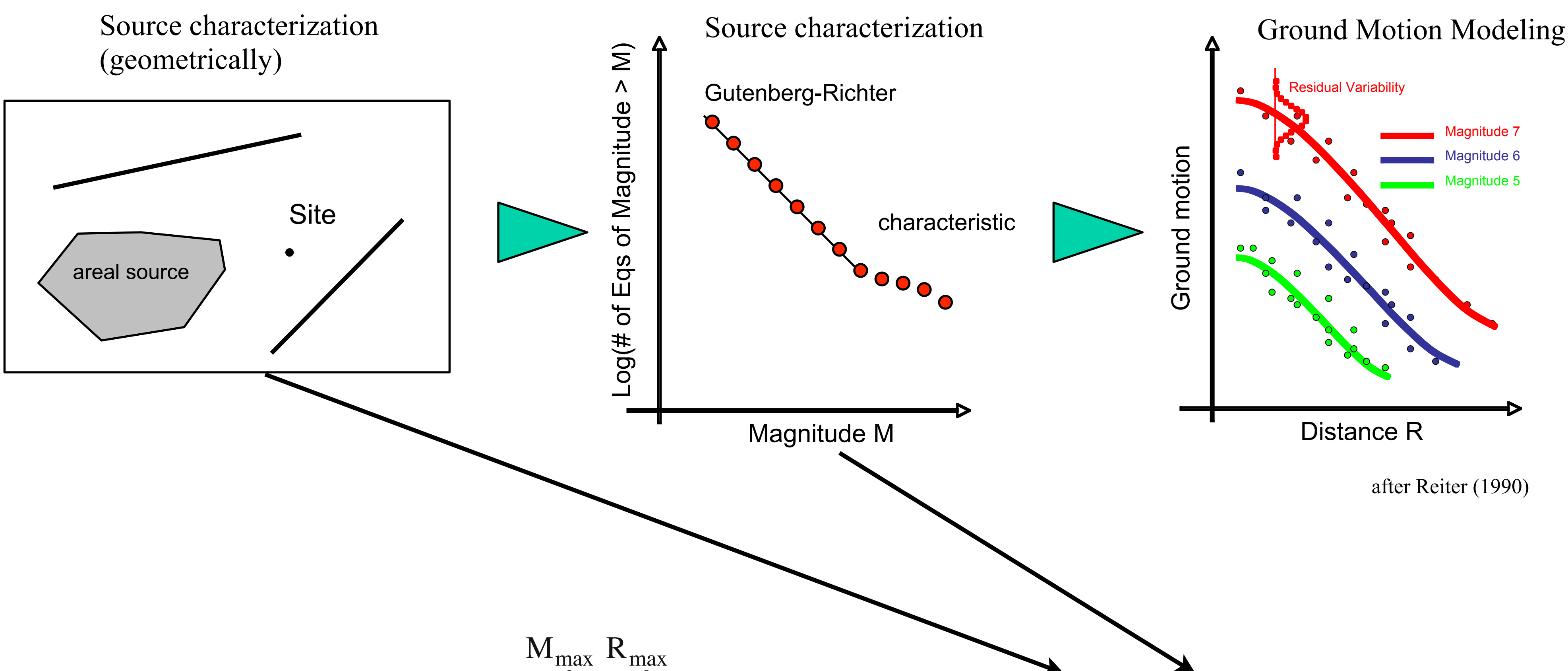

Characteristic




Youngs & Cop



# The elements of PSHA
# Including faults




after Reiter (1990)

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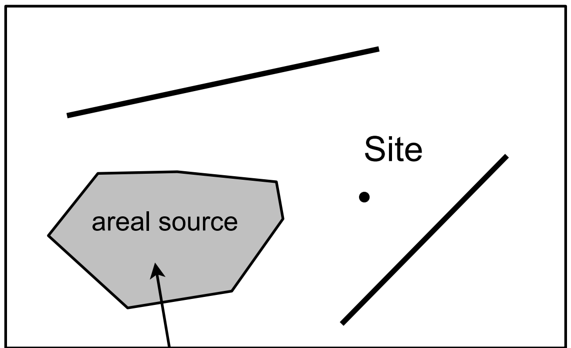
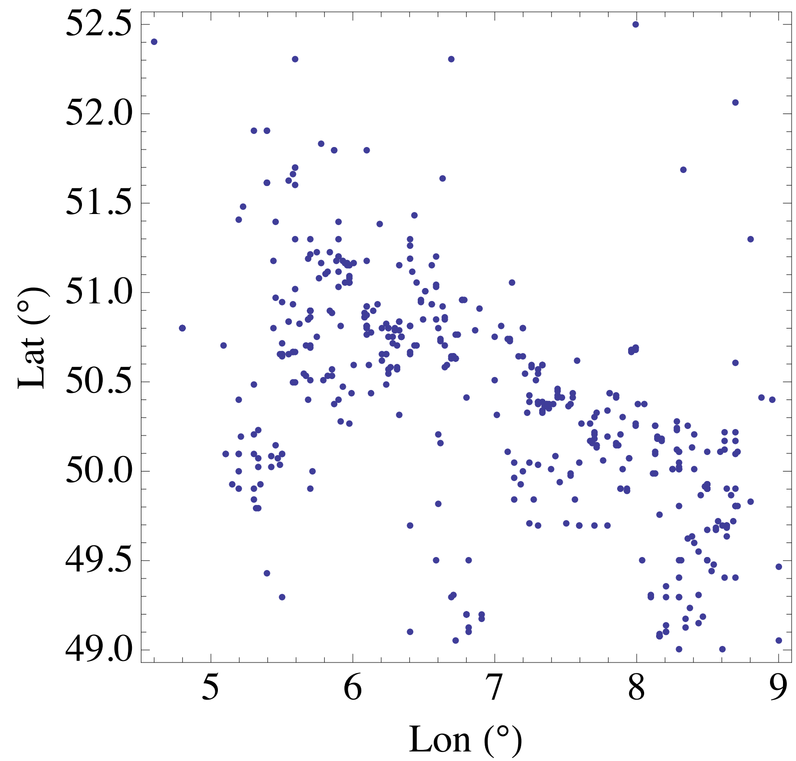
# Geometrical characterization of areal sources
# Spatial distribution of epicenters

Source characterization
(geometrically)



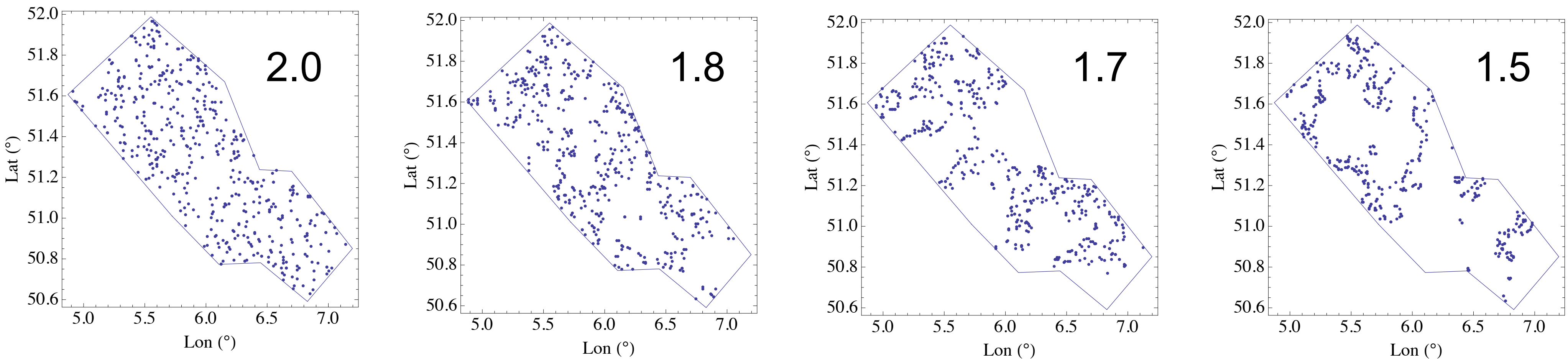

Usual assumption:
spatial uniformity of epicenters

Spatially uniform?



# Geometrical characterization of areal sources
# Spatial distribution of epicenters

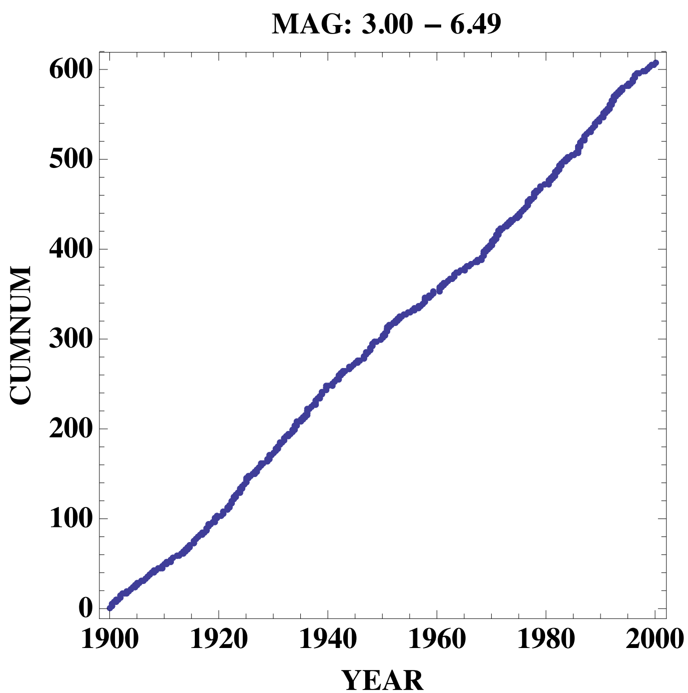
## Fractal distributions



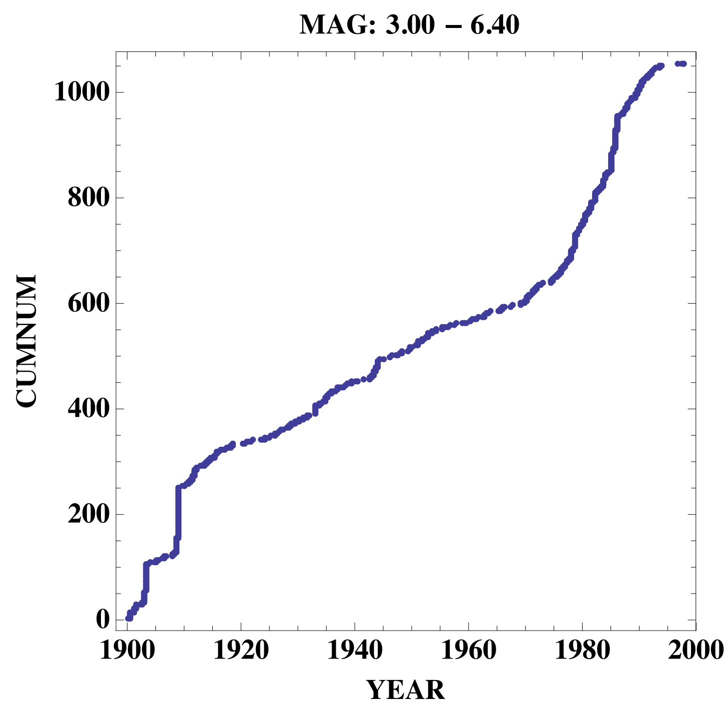

→ Hazard becomes dependent on actual location

# Temporal source models in PSHA

Poissonian

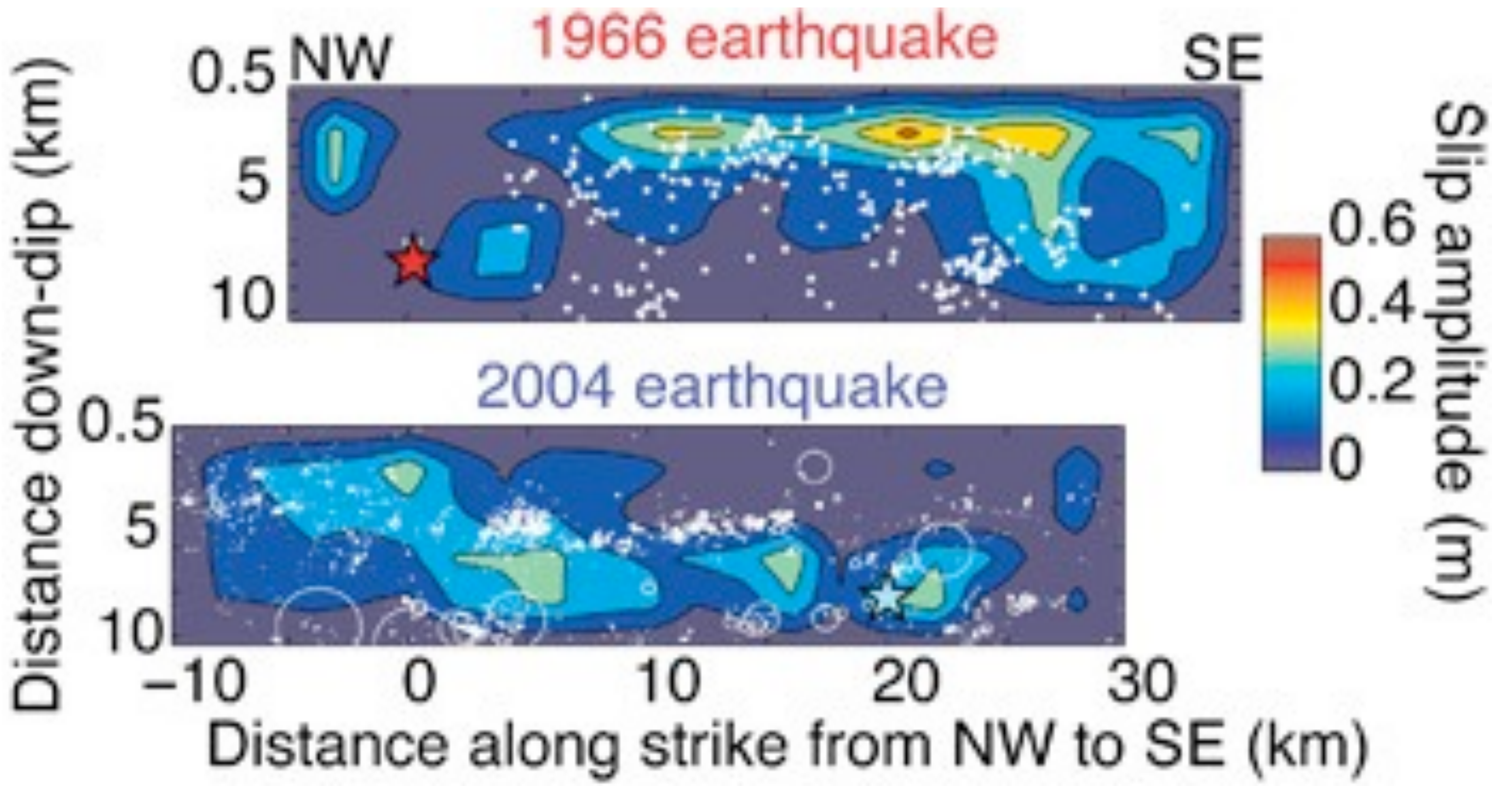



True catalog



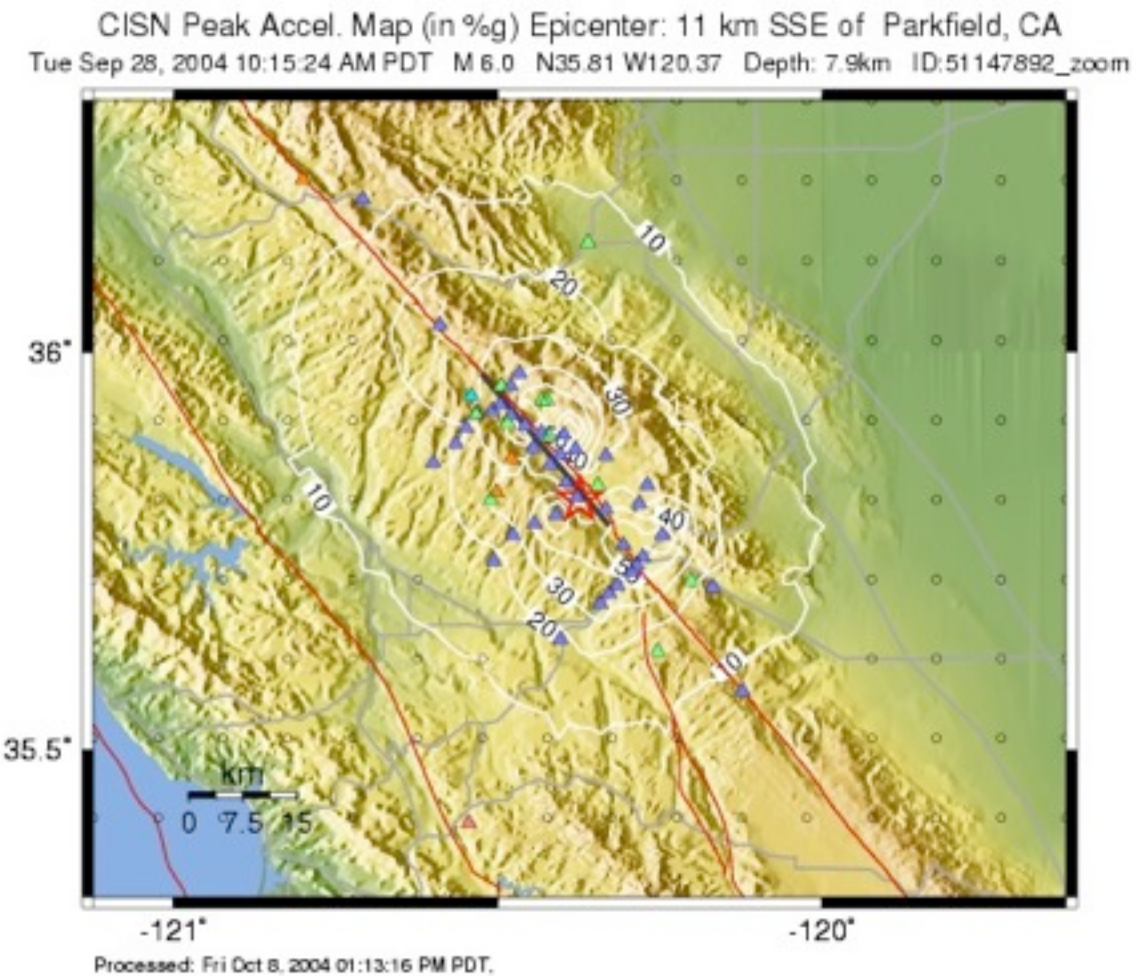

→ Actual hazard is time-dependent

# Earthquakes are complex sources




(Custodio and Archuleta, in press)

# Near source ground motion can be highly variable



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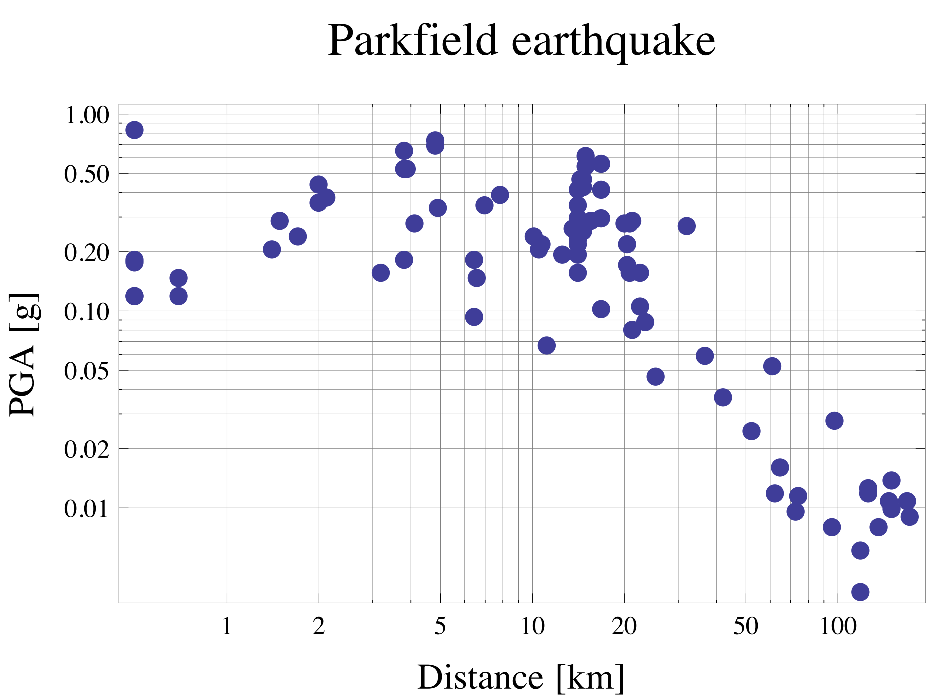
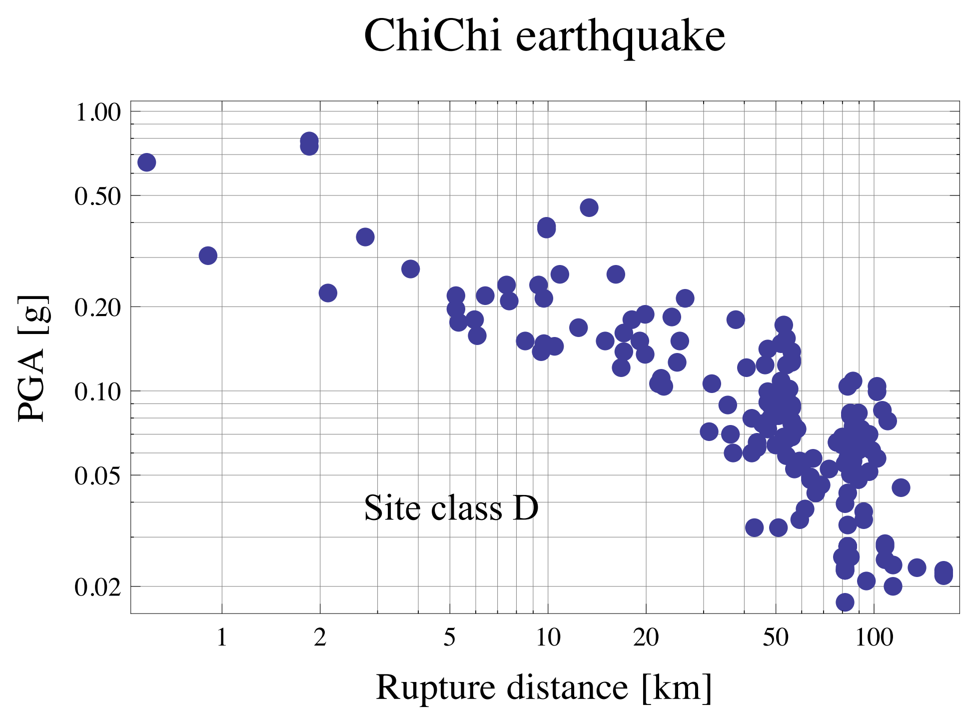
# Observed near source ground motion




**potential reasons:**

- stress drop heterogenities
- rupture propagation heterogenities
- focusing/defocusing
- site effects



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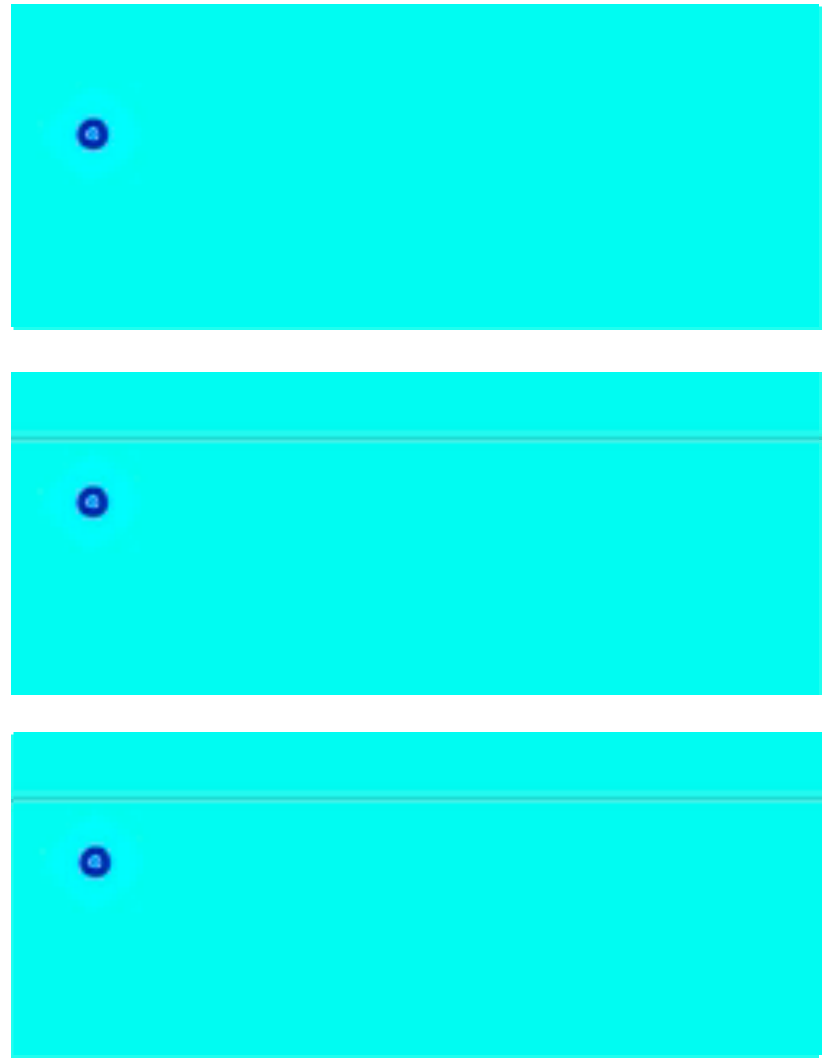
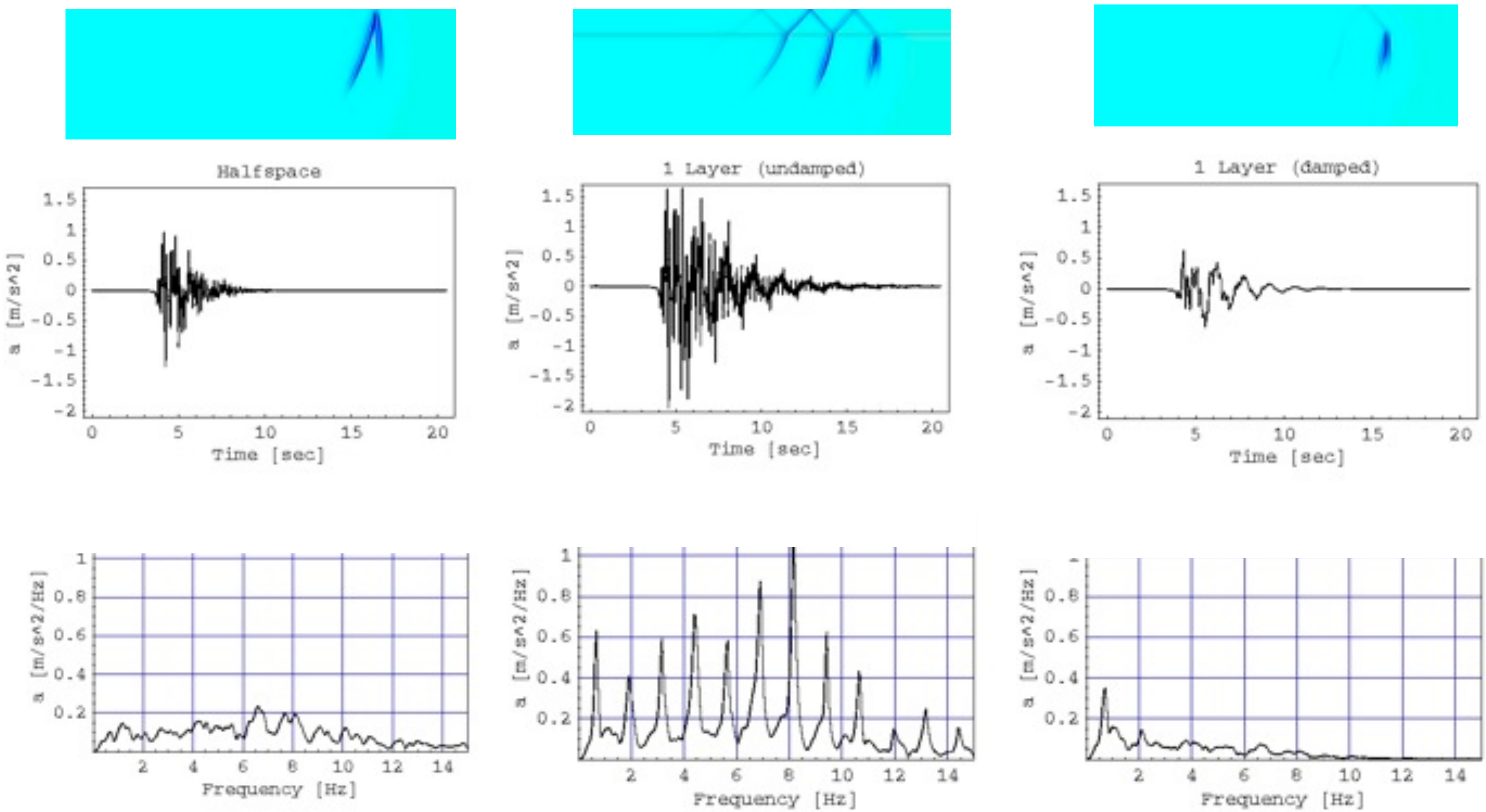
# Site effects

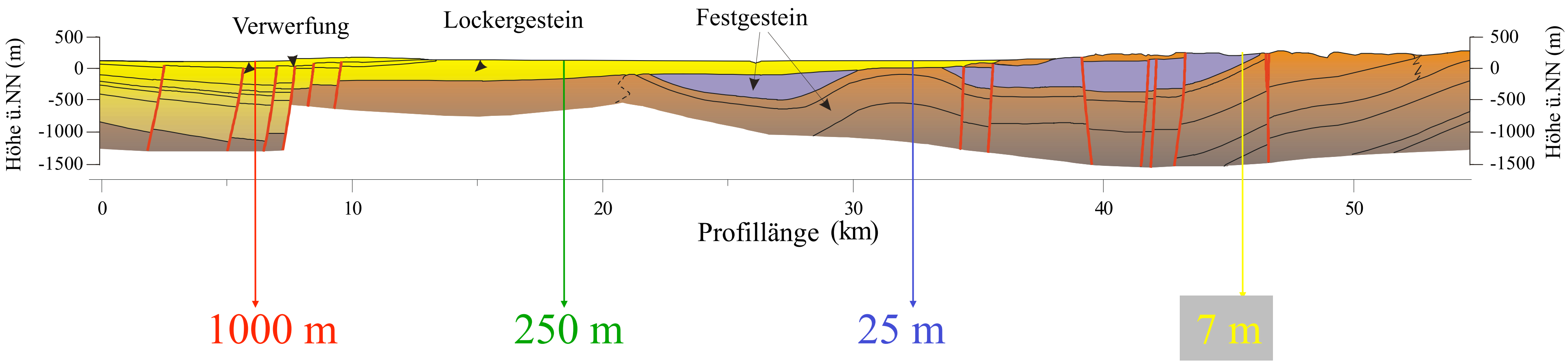
# Single layer over halfspace

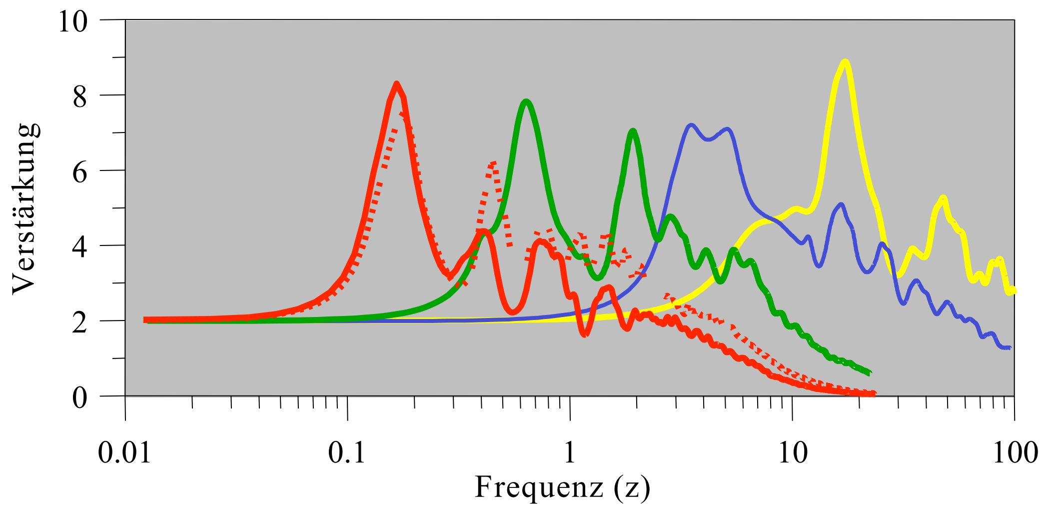


# The influence of sediments



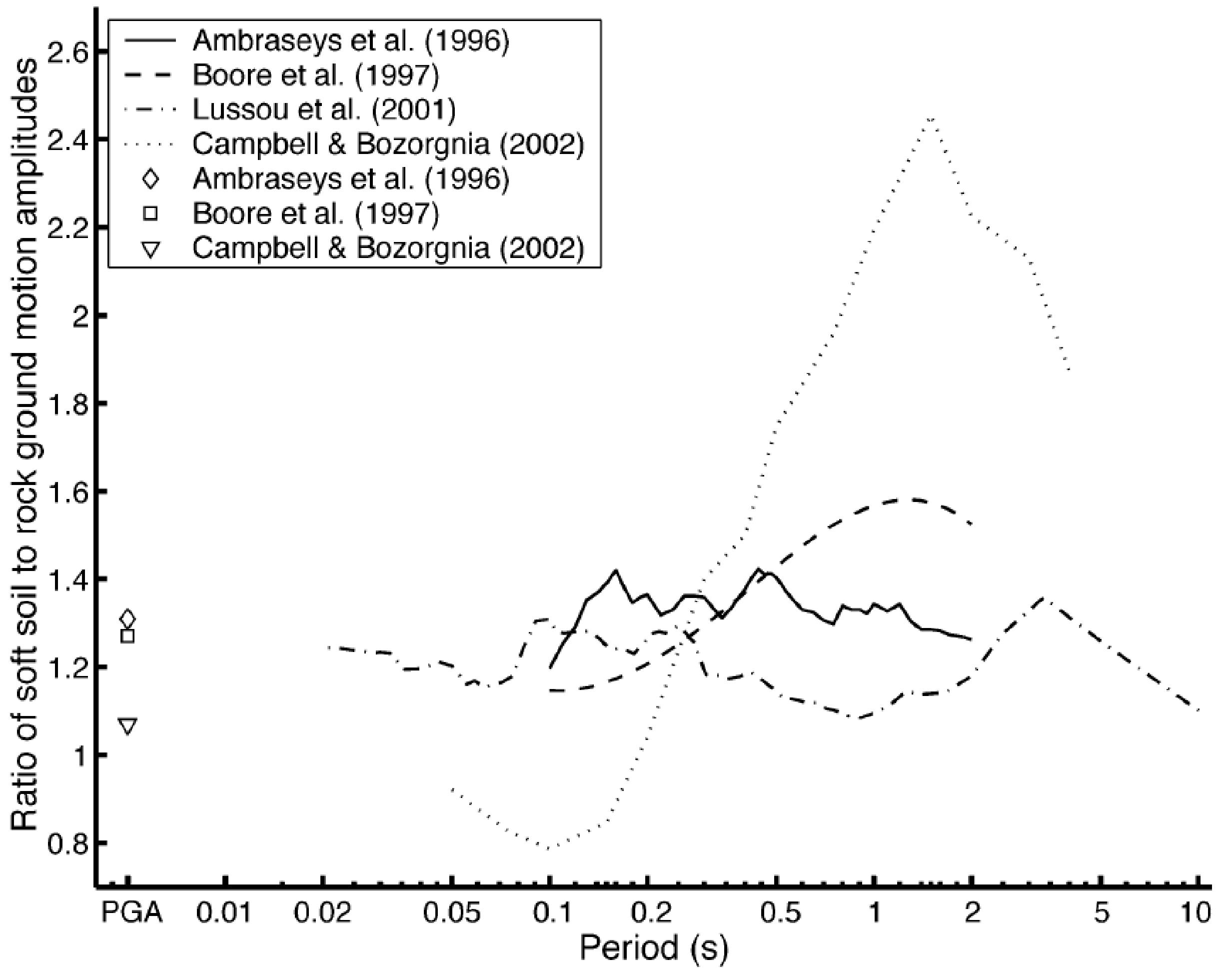
# Lower Rhine Embayment




(Hinzen pers. comm)

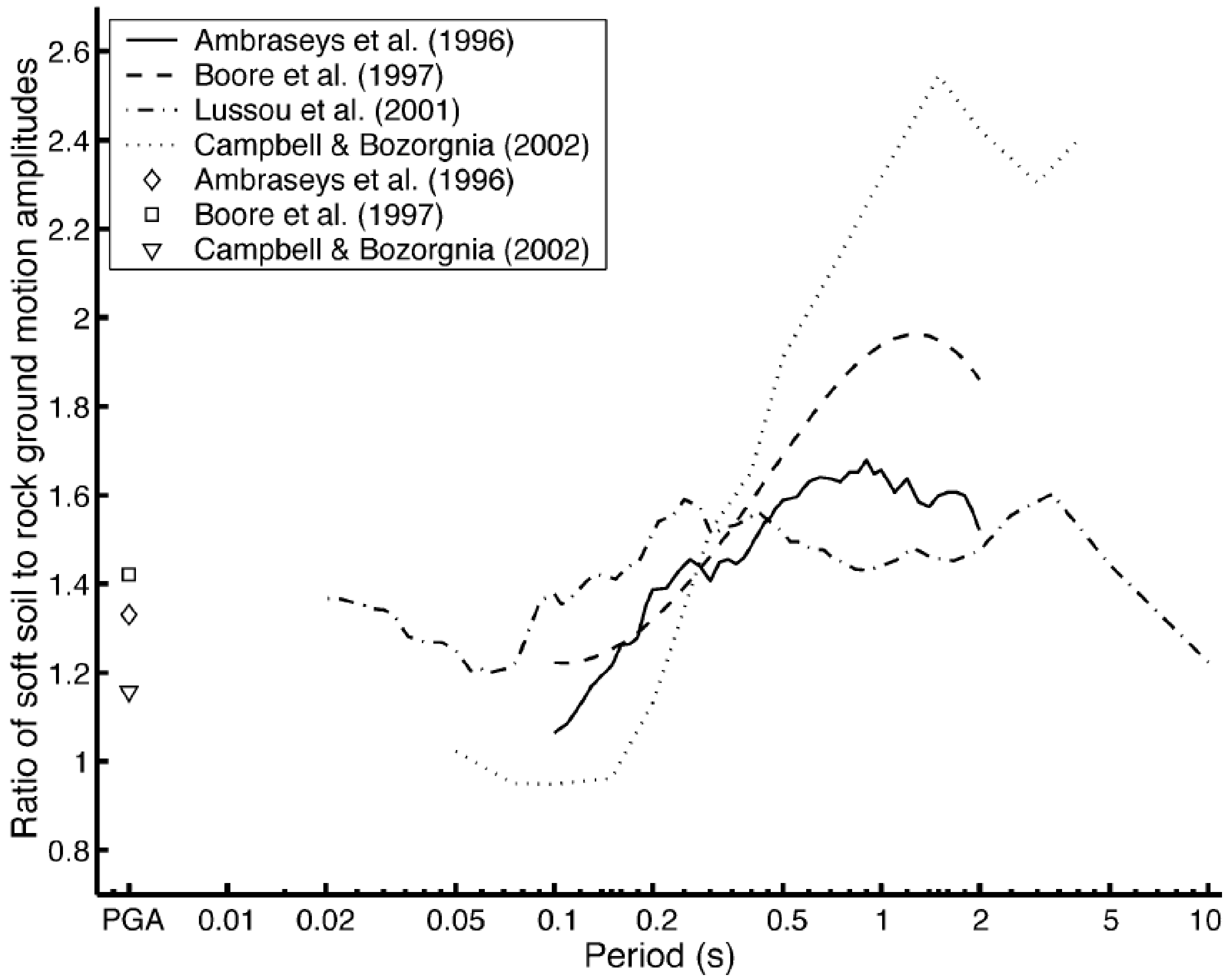
# Site effects in GMPEs
# Stiff soil versus rock




(b) Stiff soil.

Douglas (2003)

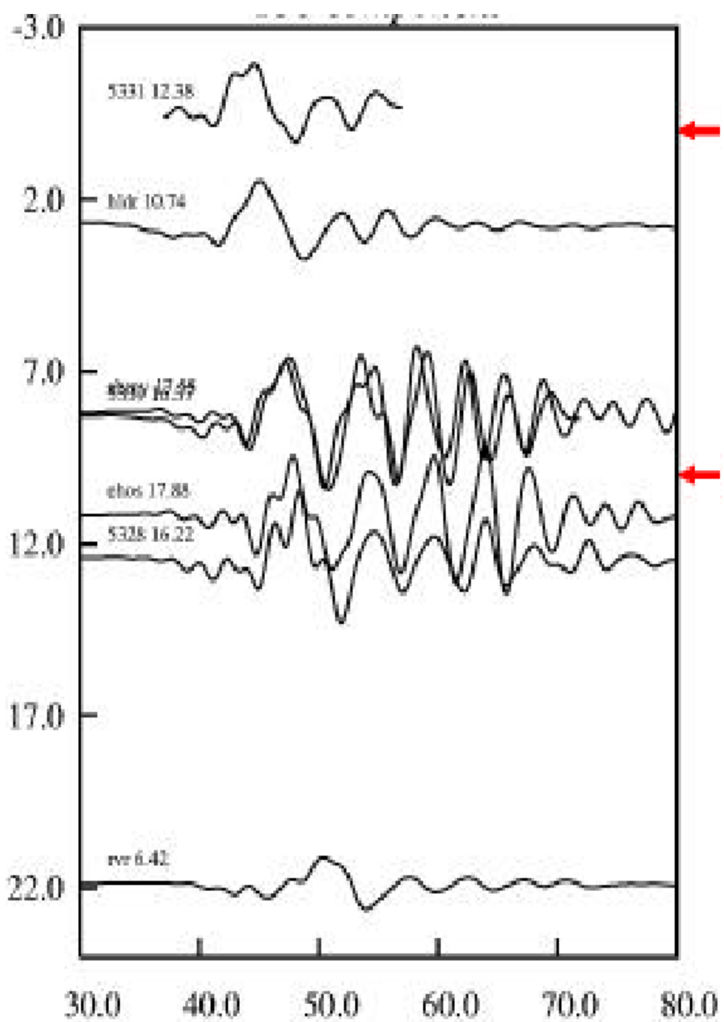
# Site effects in GMPEs
# Soft soil versus rock




(a) Soft soil.

Douglas (2003)

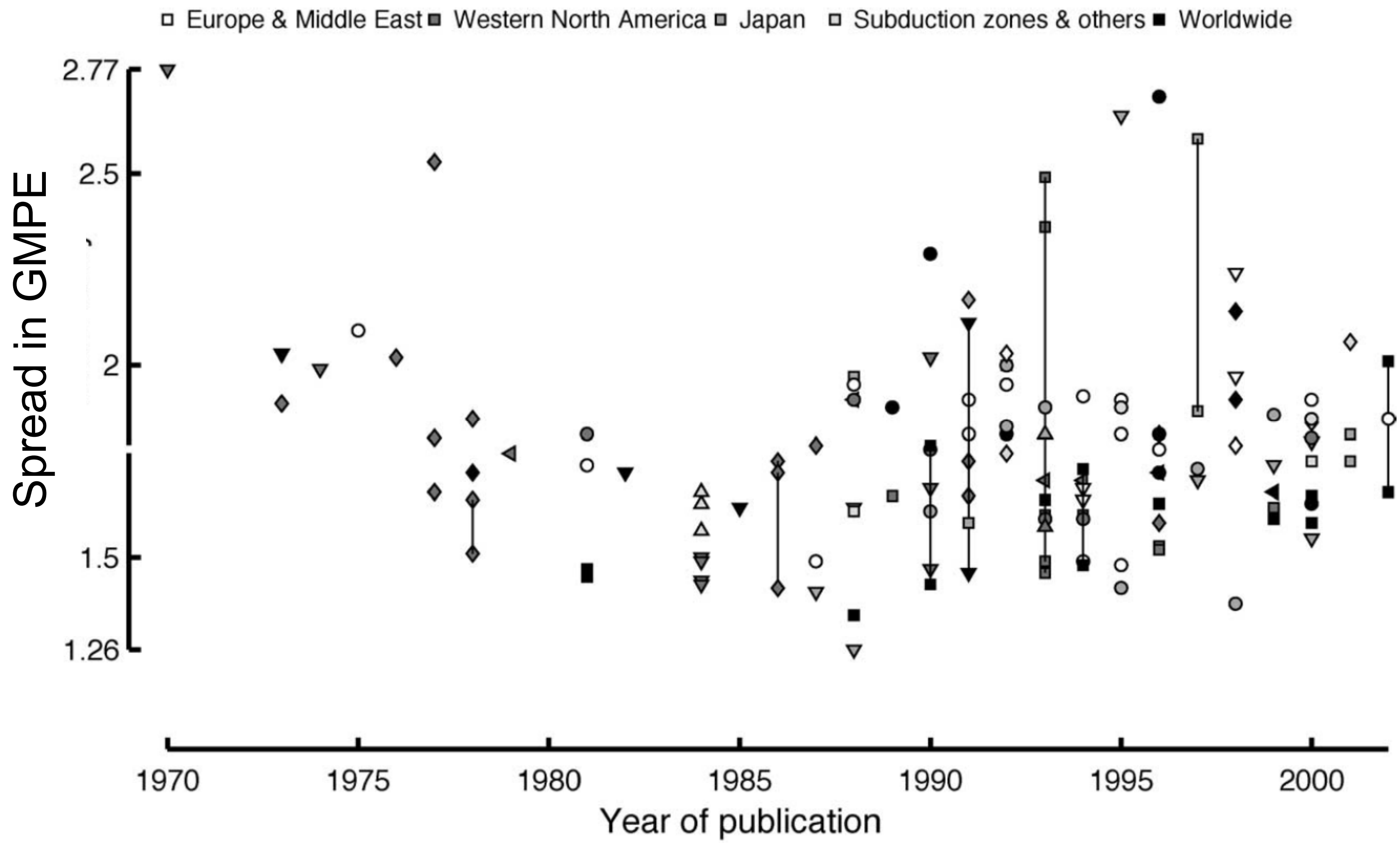
# Basin effects




Somerville et al. (2003)

# Some open problems

# What is represented by σ?



# Other issues

**Ground motion**

- Near source variability
- Upper bound
- Model generation (bias/variance tradeoff)
- Predictor variable uncertainties
- ....

**Source**

- Maximum magnitude
- Time dependence
- Spatial distribution
- ...

**Site effects**

- proxy (vs30)
- 2D/3D effects
- kappa
- ...

For the real world problems, the models become more complicated, but don´t require  change of concept

**But which models should we use?**

All models are wrong but some are useful

- G. E. P. Box

# Types of uncertainties

**Epistemic: lack of „*knowledge*"** ⟹ **Logic Tree**

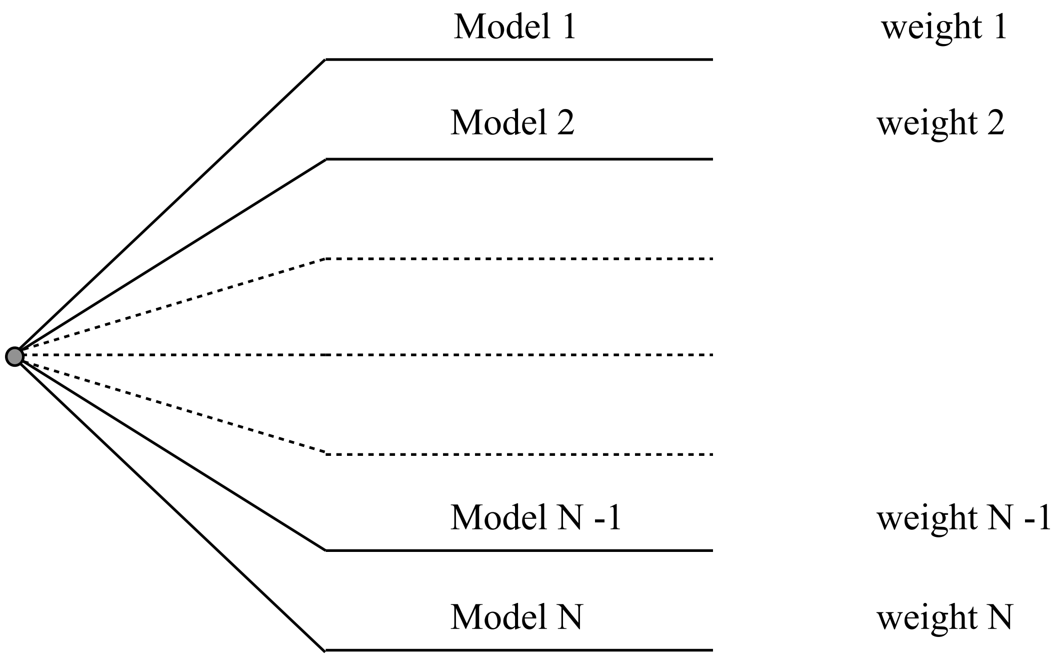
Can be reduced through increased „*knowledge*"

**Aleatory: intrinsic randomness** ⟹ **Hazard integral**

Cannot be reduced since it describes natural variability

$$\nu(\mathrm{Sa} > a) = \sum_{i=1}^{n_{sources}} N_i(M_{min}) \cdot \int_{M_{min}}^{M_{max}} \int_{R_{min}}^{R_{max}} \int_{\frac{\ln(a)-\ln(\mu)}{\sigma}}^{\infty} \mathrm{PDF}_{\ln(gm)}(\varepsilon \mid R, M) \cdot f_R(R) \cdot f_m(M) \cdot d\varepsilon \cdot dR \cdot dM$$

# The logic tree framework



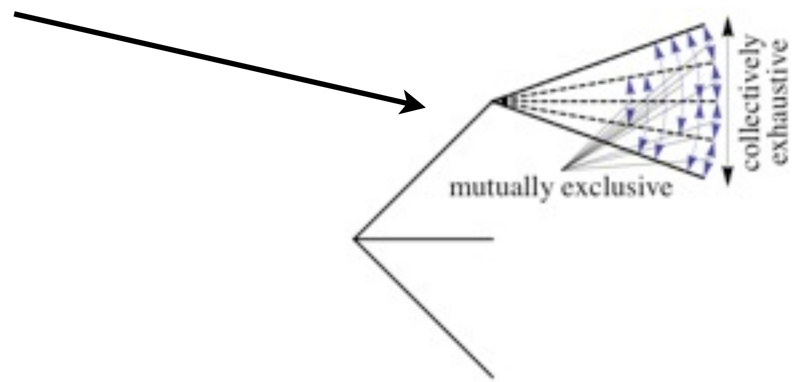

Each model is assigned a branch weight which expresses the degree-of-belief of the analyst in the particular model

# The role of branch weights

- In the logic tree  framework, epistemic uncertainty is represented by discrete probability distributions

- The  branch weights take the role of (conditional) subjective probabilities of models

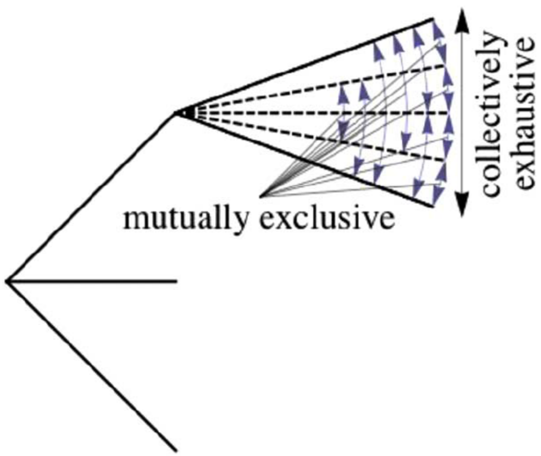
  - As a consequence, the models together with  the branch weights have to meet  the rules of probability calculus (Kolomogorov´s axioms)

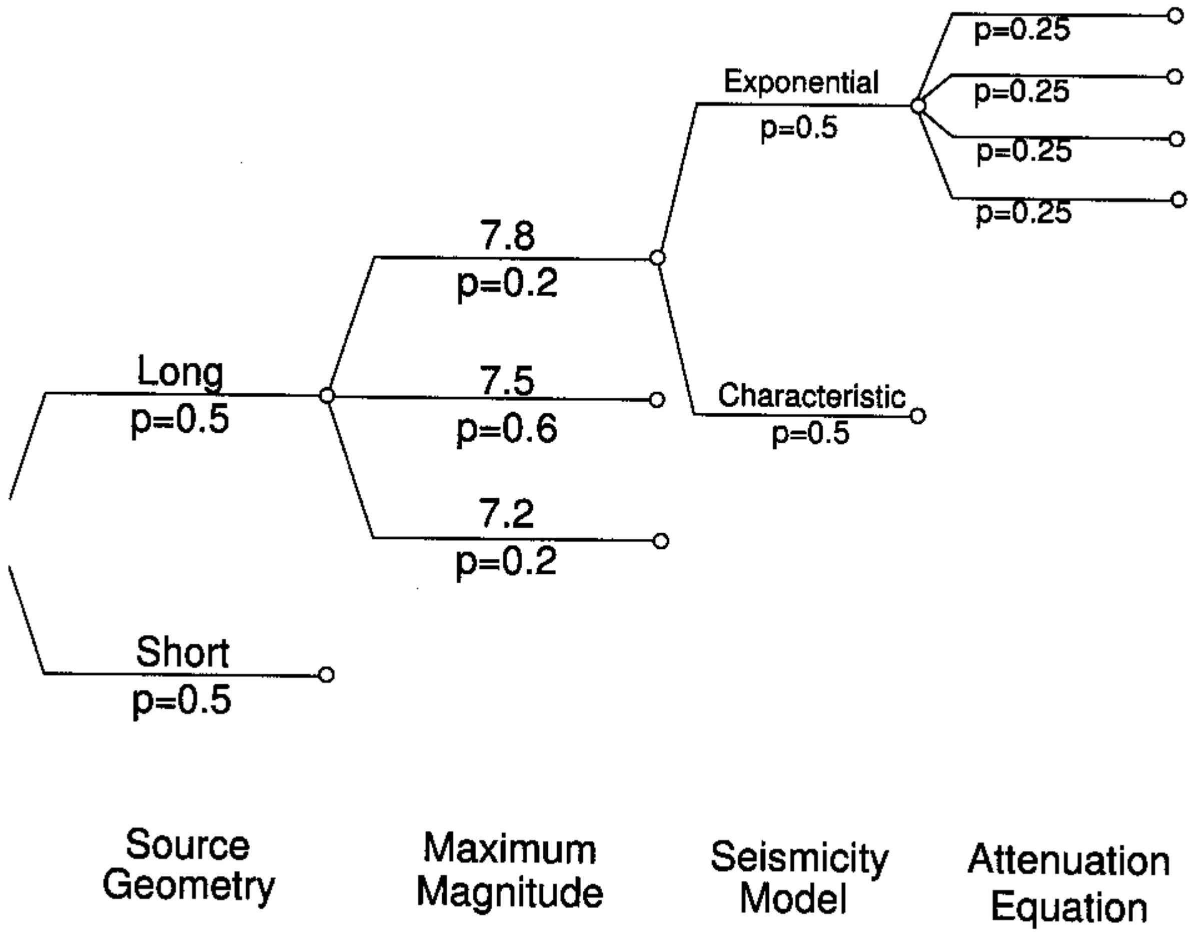



Details: Bommer, J. J. , and F. Scherbaum (2008). The use and misuse of logic-trees in PSHA, *Earthquake Spectra,* **24**(4),997-1009 .

# Epistemic uncertainties and logic trees

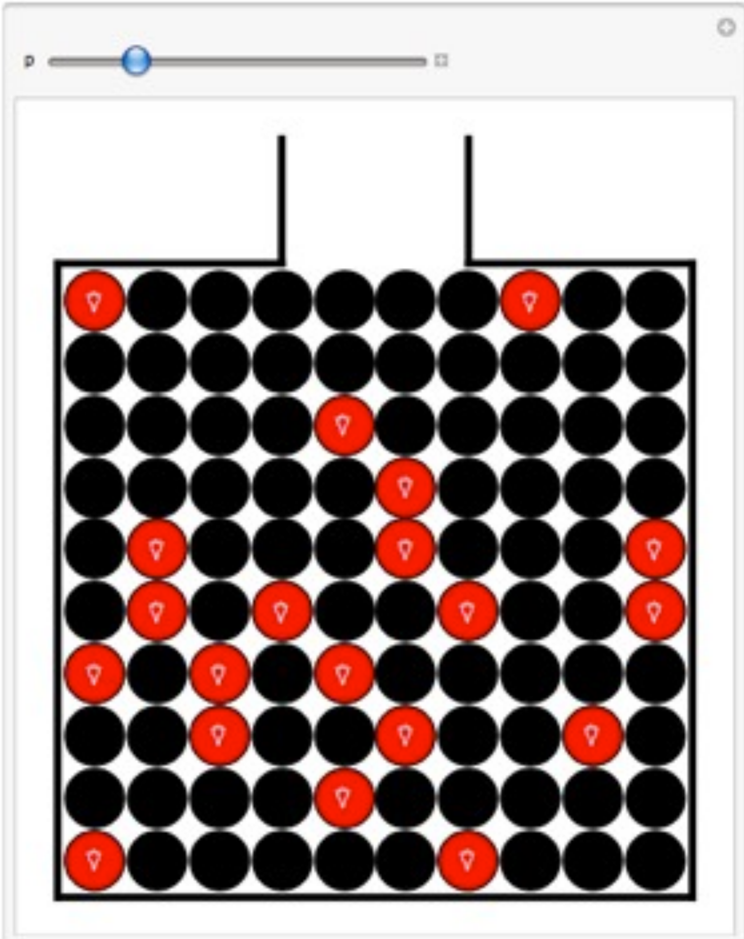
Principle



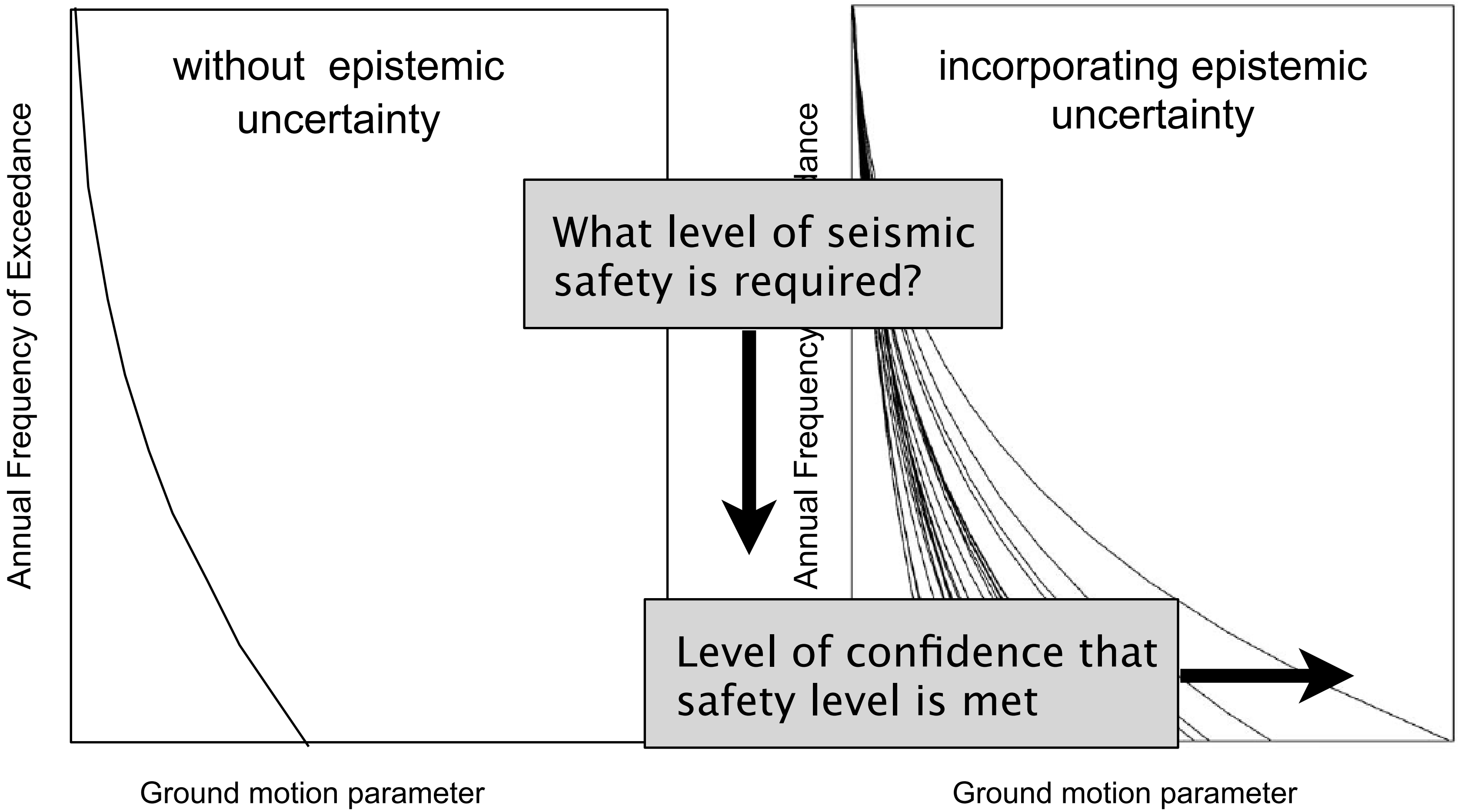



# How to quantify subjective probabilities?

## DeFinettiGame.cdf



# From a single hazard curve to a distribution of hazard curves




Details: Bommer, J. J. , and F. Scherbaum (2008). The use and misuse of logic-trees in PSHA, *Earthquake Spectra,* **24**(4),997-1009 .

# Wrapping up

- Seismic hazard is ground-motion hazard, not earthquake hazard
- In the context of PSHA, ground motion is treated as random variable
- The seismic hazard curve is only one way to represent the distribution function of ground motion
- The reciprocal of the exceedance rate of a particular ground motion level is called return period
- Ground motion corresponding to large return periods can either be caused by typical ground motion from rare events or by untypical ground motion from frequent events.

# Some rules of thumb for simple situations

- **Hazard at large return periods**
  - Variability of ground motion distribution (sigma of Log-normal PDF of ground motion) has large effect.
  - Often dominated by sources close to the site of interest and extremely sensitive with respect to the ground motion model (in particular its variability).
- **Hazard at short return periods**
  - The occurrence rate of earthquakes becomes more important
  - Seismic hazard driven by sources from the whole seismic region and rather insensitive to the ground-motion model.
- The influence of maximum and minimum magnitudes are comparatively moderate in PSHA.


THE END