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Kona, Hawaii
April 12, 2007

Exploratory Modeling of Extreme Peak Ground Accelerations

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Outline

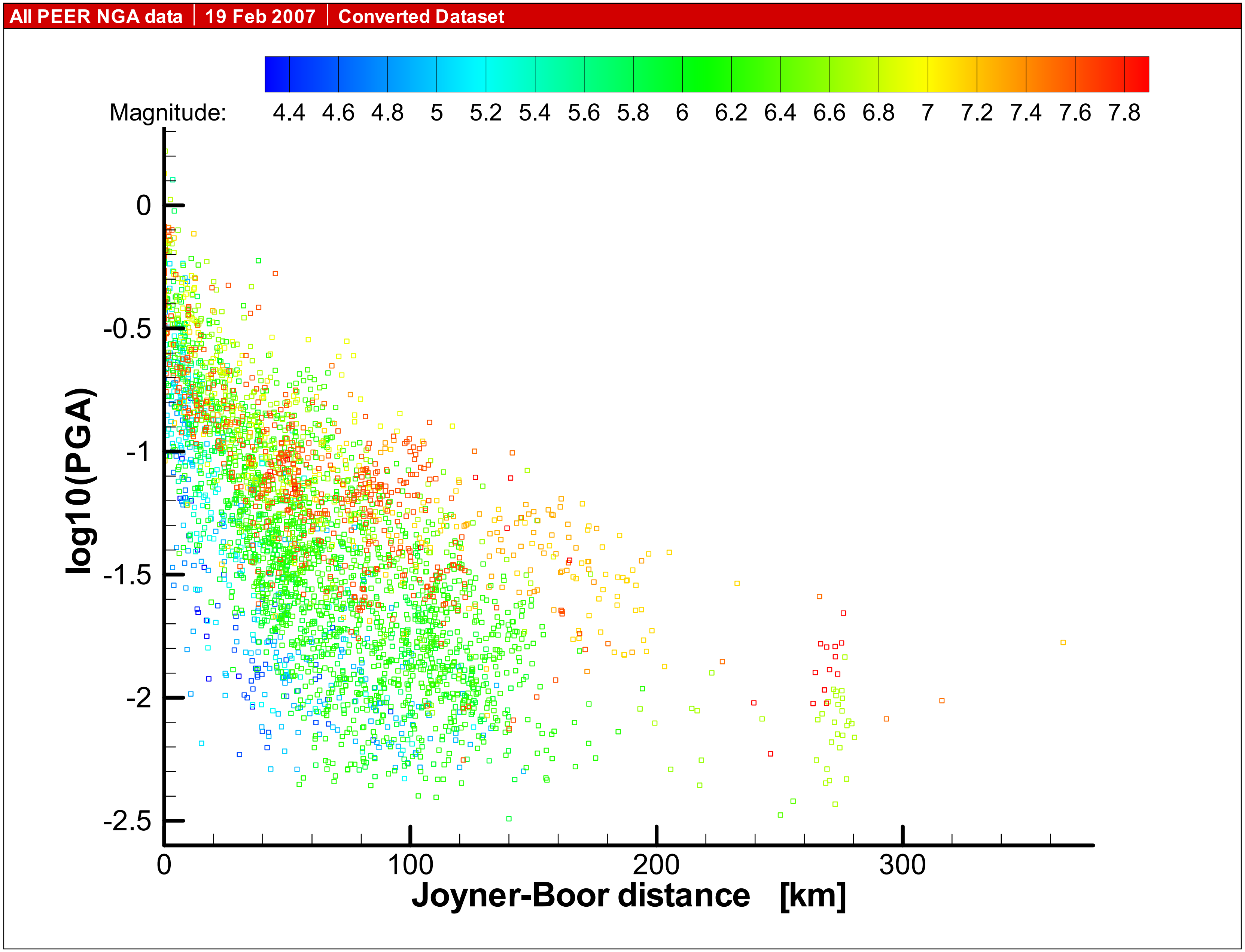
- Background
- Methodology
  - Characteristics of tails of distributions
  - Principle of tail equivalence
- Application
- Summary

Background

- NRC regulations at 10 CFC Part 63 for disposal of high-level waste at Yucca Mountain require that events that have a probability of occurrence greater than 1 in 10,000 in 10,000 years (> 10^{-8}/yr) be included in performance assessments
- Low-probability ground motions (e.g., ≤ 10^{-6}/yr) have been evaluated from probabilistic seismic hazard assessments
- Lognormal distribution assumption may lead to unrealistically large, low-probability ground motions

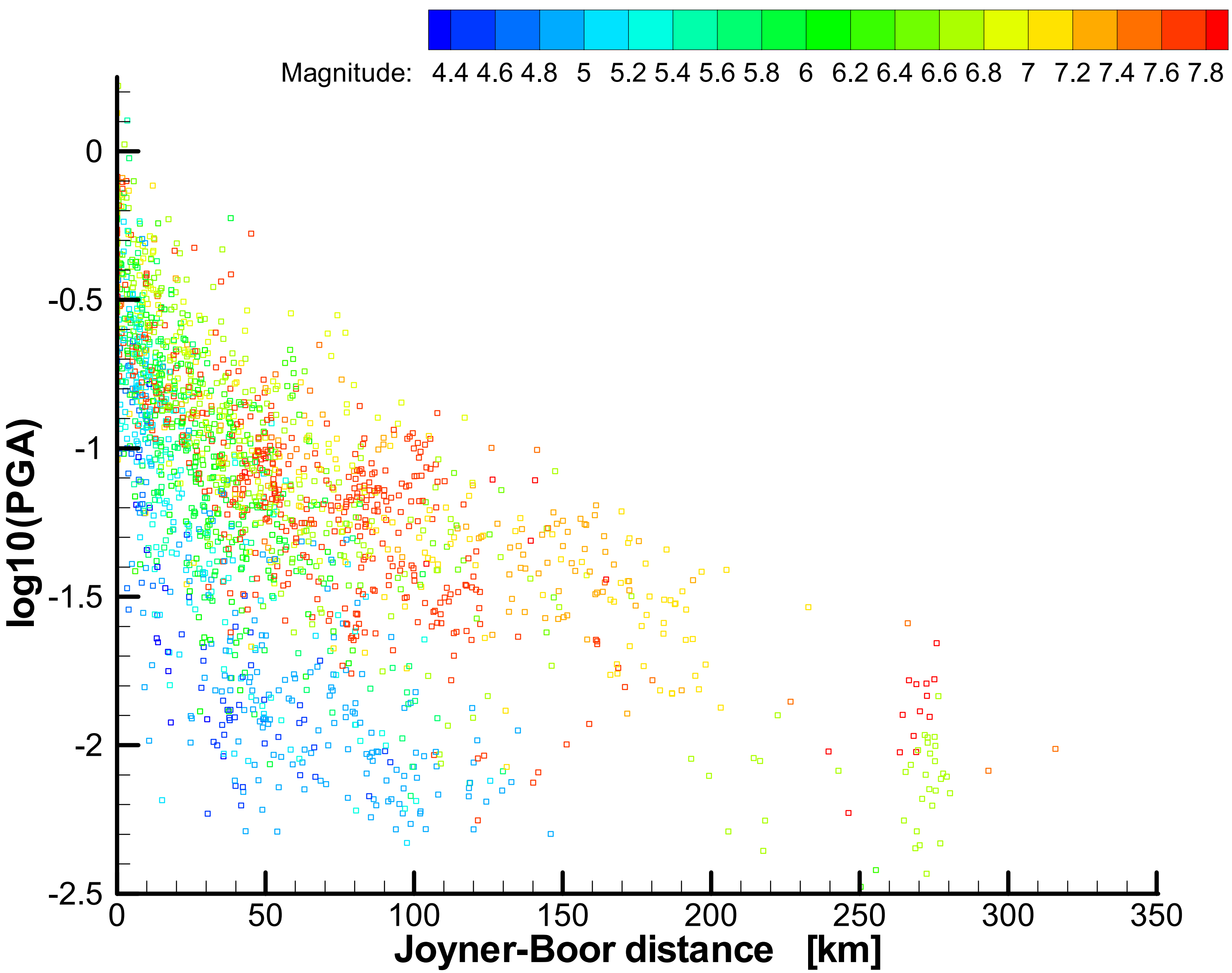
Methodology

- Show characteristics of right tails for ground motion parameter distributions (e.g., PGA) based on peak-over-threshold modeling
- Principle of tail equivalence
- Application to two datasets:
  - Pacific Earthquake Engineering Research (PEER), using the Next Generation Attenuation Models (NGA v7.3) by Chiou and Youngs
  - European Strong-Motion Database (EDS)
- Basic regression modeling of ESD data



Peak Ground Acceleration (PGA) is measured in multiples of “g”

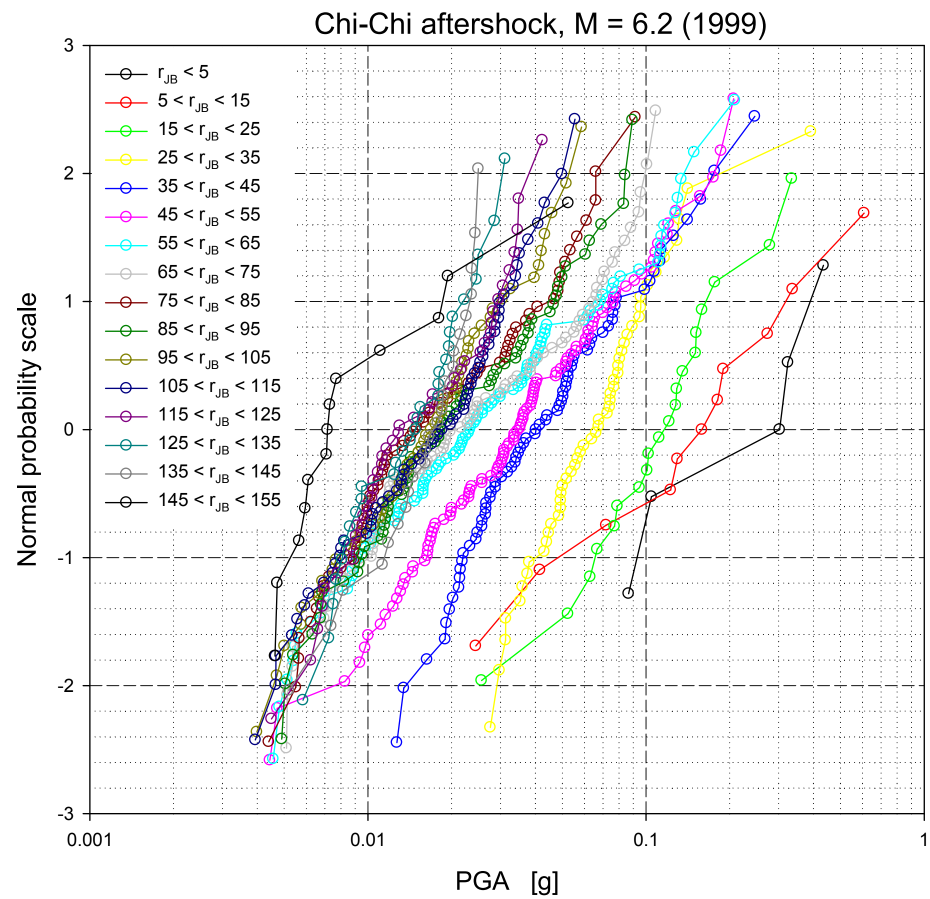
All PEER NGA data, except Chi-Chi | 20 Feb 2007 | Converted Dataset



PGA is measured in multiples of "g"

Is PGA Lognormally Distributed?

- 1999 Chi-Chi aftershock data for magnitude M = 6.2
  - Largest data set (>800)
  - Eliminates M dependence
- Empirical distribution of $\log_{10}$(PGA) plotted per r_{JB} distance bin
- Data generally follow lognormal model
  - At extreme upper ends most curves turn up, suggesting deviation from the lognormal assumption

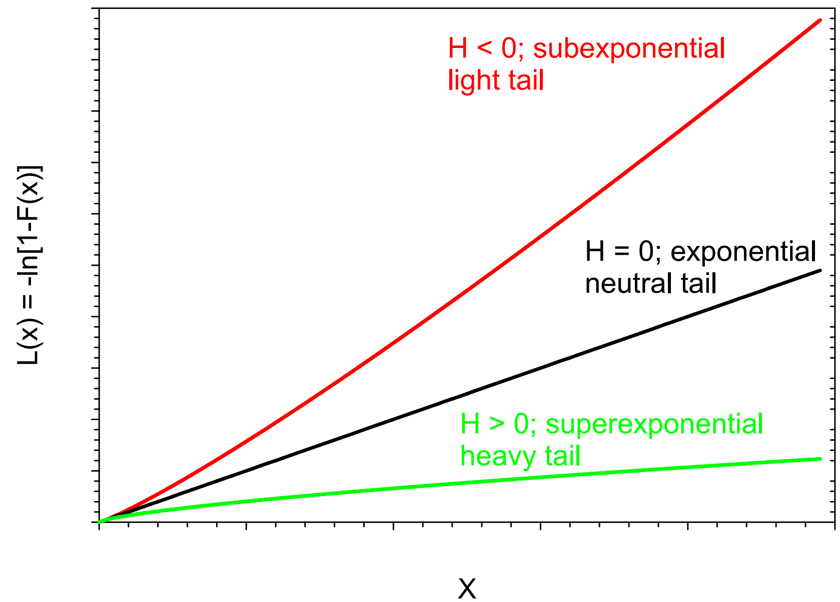


Tail Equivalence Principle

- **Tail equivalence:** two distributions, $F(x)$ and $G(x)$, are right-tail equivalent if for large x:

$$\lim_{x \to \infty} \frac{1 - F(x)}{1 - G(x)} = 1$$

- **Tail heaviness:** index *H* benchmarks tail against the exponential tail
  - Generalized Pareto Distribution (GPD) has a constant tail heaviness index $H = \xi$



$$H(x) = -\frac{L''(x)}{L(x)}$$

$$\text{with} \quad L(x) = -\ln\left[1 - F_X(x)\right]$$

Peak-Over-Threshold Analysis

- GPD arises as the limiting distribution for the excesses, X-λ, for large threshold λ (Pickands, 1975).

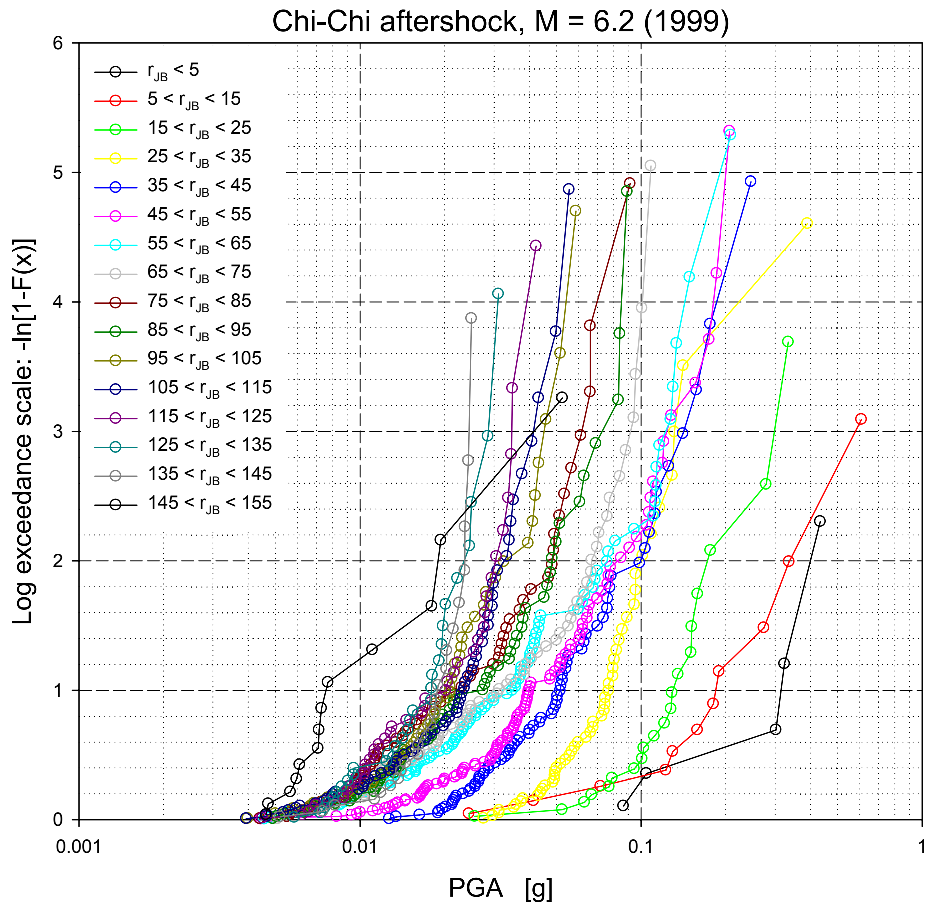
$$F_{GPD}(x) = 1 - \left[1 + \frac{\xi(x-\lambda)}{\delta} \right]_{+}^{-1/\xi}$$

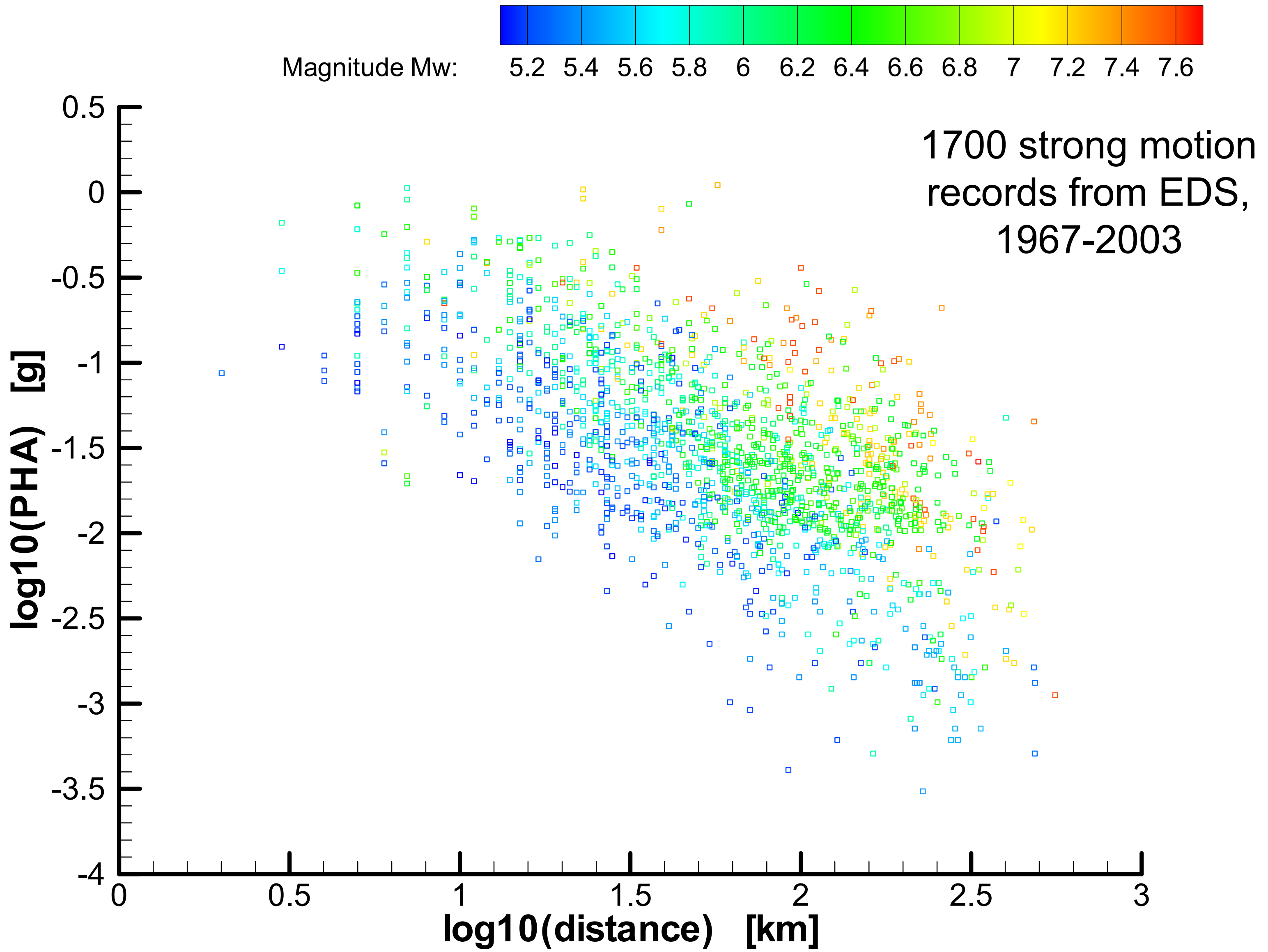
- GPD is successfully used in extreme order statistics estimation
  - Maximum wave crest height
  - Maximum pore size in material
  - Minimum wall thickness in drilling tubular

Pickands, J. "Statistical Inference Using Extreme Order Statistics." *The Annals of Statistics*. Vol. 3. pp. 119–131. 1975.

Tail Plots of Residuals

- PGA is bounded for almost every r_{JB} distance bin
  - Unbounded only for those bins with very few data
  - Unlike normal, the tail fit to the empirical distribution is not unbounded
- Maximum PGA bound drops with increasing r_{JB} distance





Peak Horizontal Acceleration (PHA) is measured in multiples of “g”

Regression Modeling

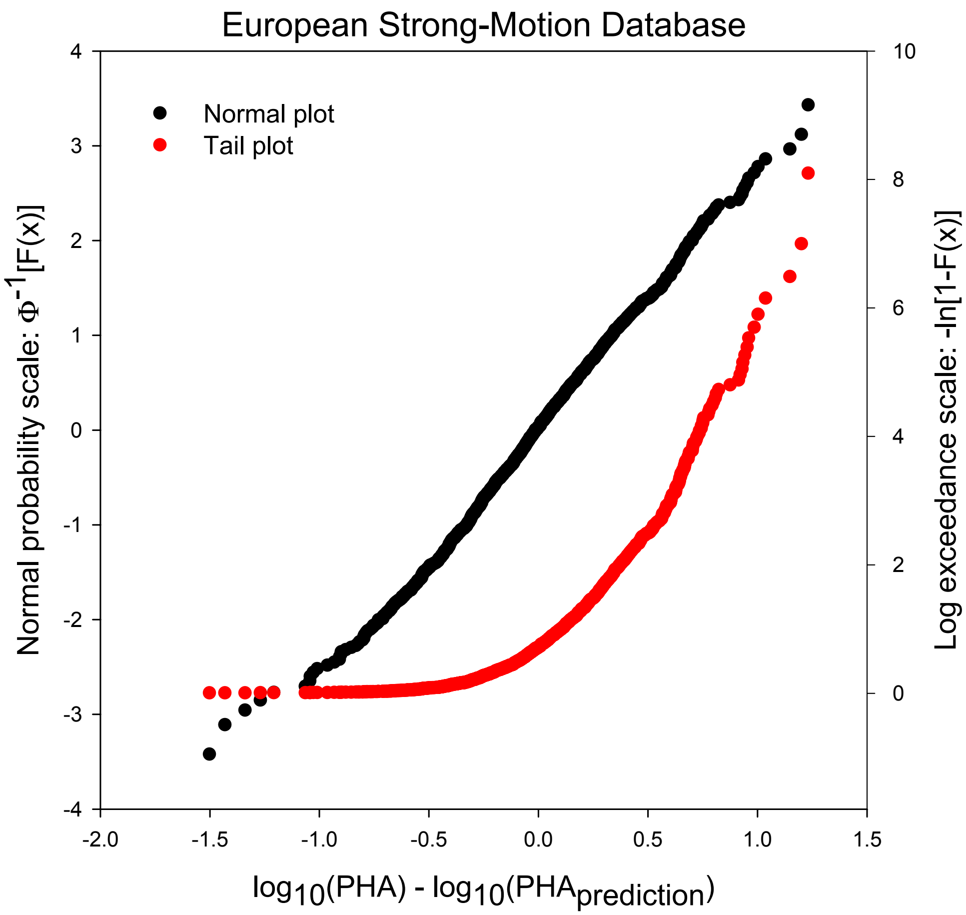
- Regression equation:

$$\log_{10}(PGA) = C_1 + C_2 M_w + C_3 \log_{10}(\Delta) + \varepsilon$$

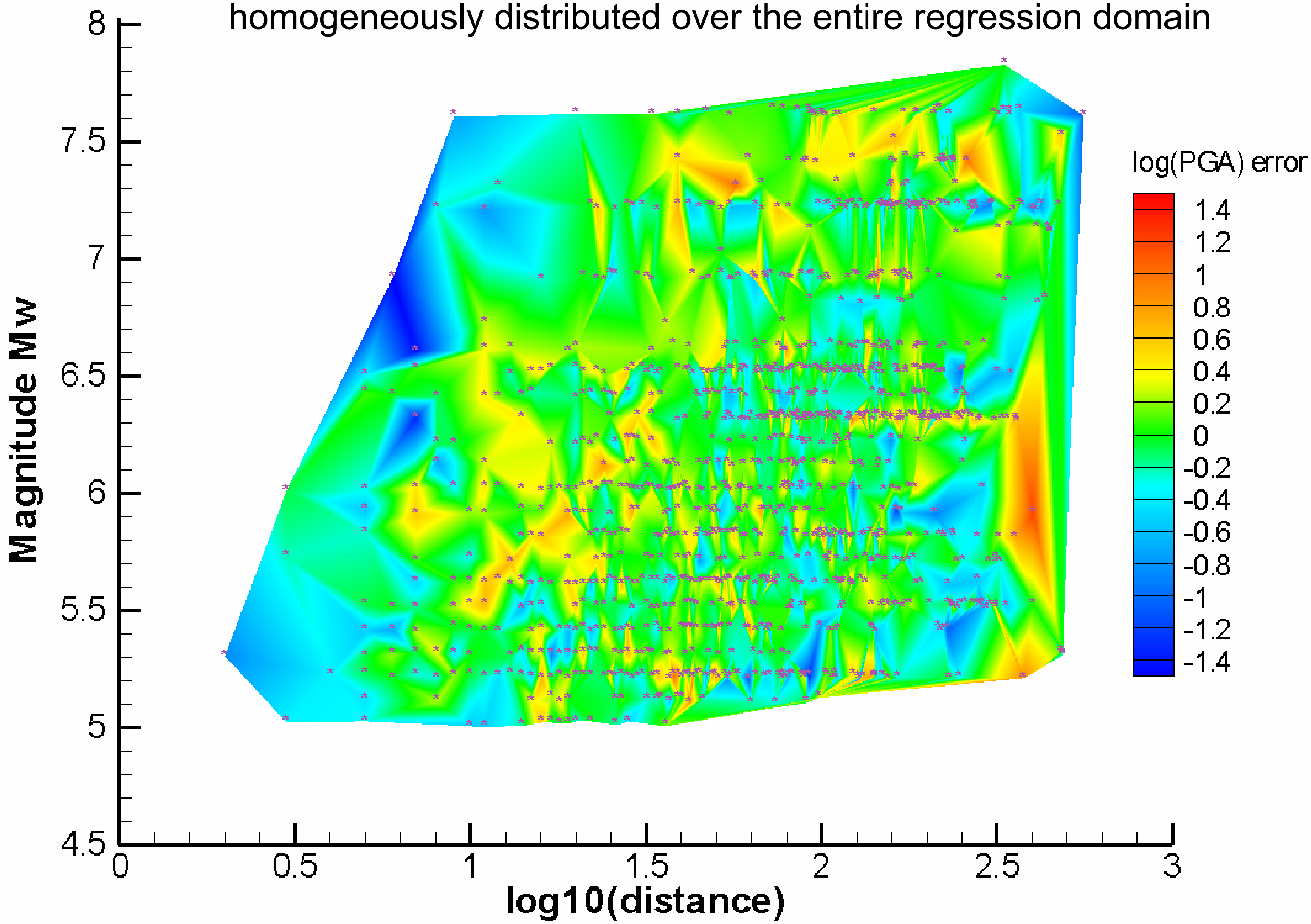
  - Regressor: magnitude M_w and distance Δ
- General assumptions of linear model
  - Normally distributed errors
  - Additive error model
- Normally distributed errors result in unrealistically large PGA at tails of distribution

Analysis of Regression Error

- Regression error generally follows normal distribution
  - Considerable, unexplained scatter remains after performing regression
  - $R^2 = 0.61$, $\sigma_\varepsilon = 0.353$
- Tails deviate from normal assumption
  - Upper PGA scatter bound of roughly 1.3 orders of magnitude, or ~4σ levels, above the mean value



Contour plot of regression error reveals that the error is generally homogeneously distributed over the entire regression domain



Each * represents a point in ESD database

Summary

- Analysis of both worldwide PEER and European Strong-Motion Database indicates that
  - Log(PGA) residual is generally normally distributed
  - Deviations from lognormal are observed for tails of distribution
  - Slope of GDP curves in the peak-over-threshold analysis suggests overestimation of errors in the tails of the distribution and that there may be a logical upper bound on ground motions

Potential Areas of Future Work for Prediction of Maximum Ground Motion

- Occurrence—intensity model of earthquakes
  - M distribution is Weibull
- Effect of local geology and fault mechanism in regression estimate of mean PGA
- Tail modeling of extreme PGA
  - Comparison with normal distribution assumption
- Computation of contours for various return periods for entire database

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