Seismological Society of America Meeting 2007
Kona, Hawaii
April 12, 2007

Exploratory Modeling of Extreme Peak Ground Accelerations

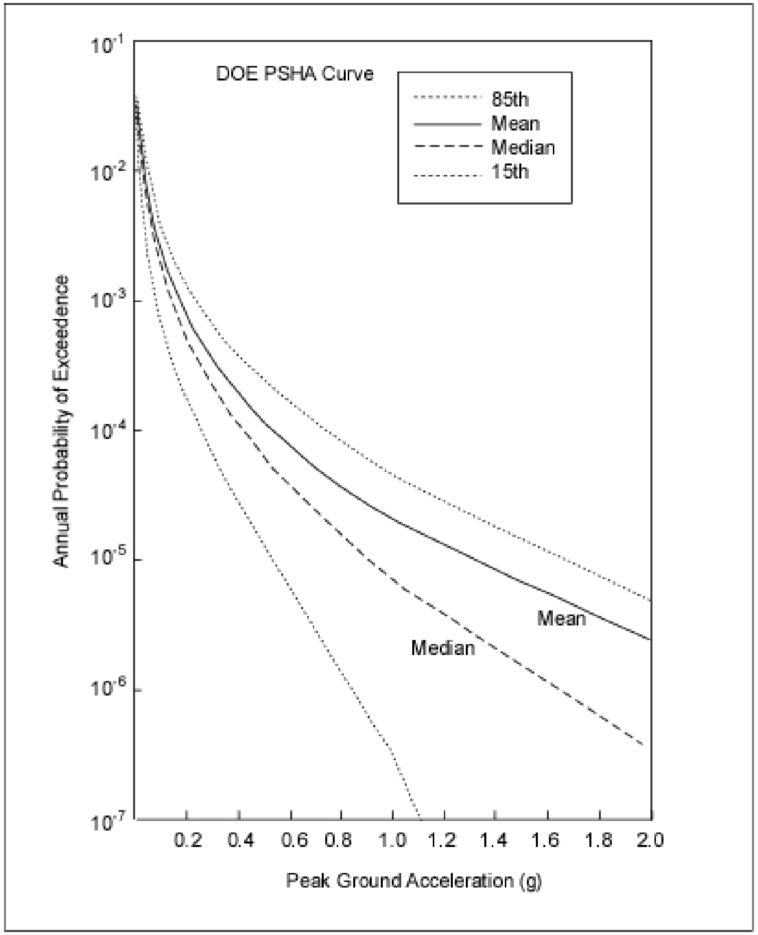
Luc Huyse – Mechanical and Materials Engineering Division, Southwest Research Institute®, San Antonio, TX
John Stamatakos – Center for Nuclear Waste Regulatory Analyses, Geosciences and Engineering Division, Southwest Research Institute®, San Antonio, TX
Sarah Gonzalez – U.S. Nuclear Regulatory Commission (NRC), Rockville, MD

Background

- NRC regulations for disposal of high-level waste at Yucca Mountain require that any performance assessment used to demonstrate compliance must consider only events that have at least a one chance in 10,000 of occurring over 10,000 years

- Low-probability ground motions (e.g., ≤ 10^{-6}/yr) have been evaluated as part of probabilistic seismic hazard assessment

- Is the lognormal distribution assumption appropriate for low-probability ground motions?



DOE Probabilistic Seismic Hazard Curve for Yucca Mountain, CRWMS M&O. "Probabilistic Seismic Hazard Analyses for Fault Displacement and Vibratory Ground Motion at Yucca Mountain, Nevada, Final Report." I.G. Wong and J.C. Stepp, coordinators. Report SP32IM3, WBS 1.2.3.2.8.3.6. 3 Volumes. Oakland, California: CRWMS M&O. 1998.

Methodology

- Test if large ground motions arise because the underlying distributions are assumed to be normal or lognormal

- Show characteristics of right tails for ground motion parameter distributions (e.g., peak ground acceleration) based on peak-over-threshold modeling

  - Principles of tail equivalence

  - Generalized Pareto Distributions (GPD)

  - Application to two datasets:
    - Pacific Earthquake Engineering Research (PEER), using the Next Generation Attenuation Models (NGA v7.3) by Chiou and Youngs

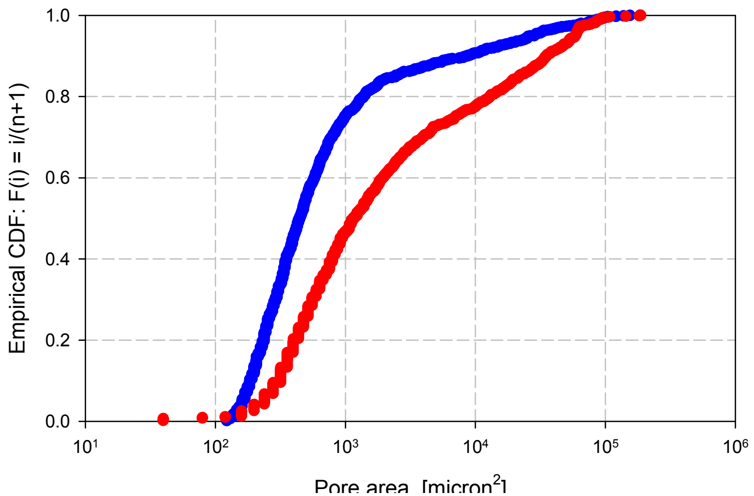
    - Simple regression modeling of European Strong-Motion Database (ESD)

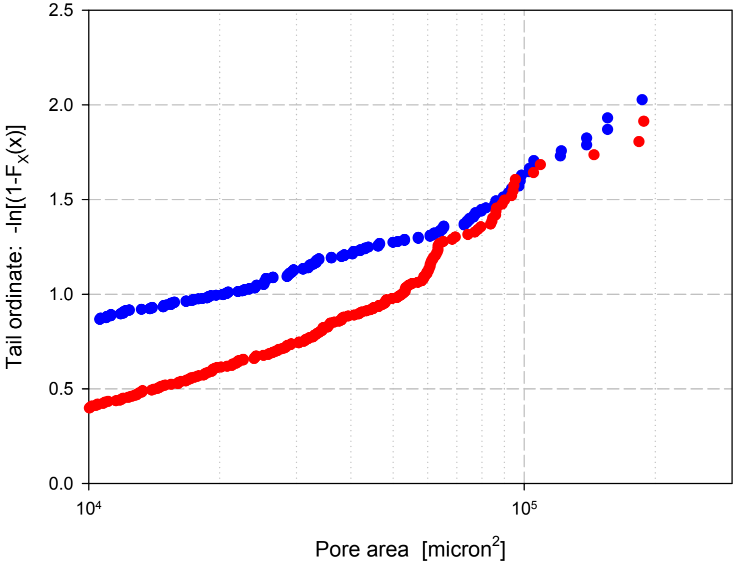
Tail Equivalence Principle

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

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

- **Example:** Two pore size distributions are generally quite different but are right-tail equivalent



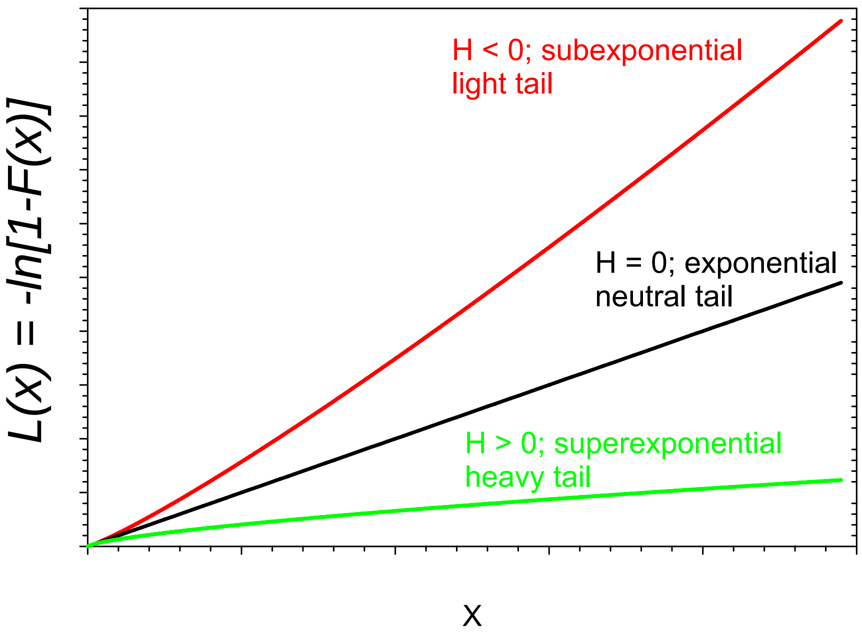


Tail Equivalence Principle

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

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

$$L(x) = -\ln[1-F(x)]$$



Peak-Over-Threshold Analysis

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

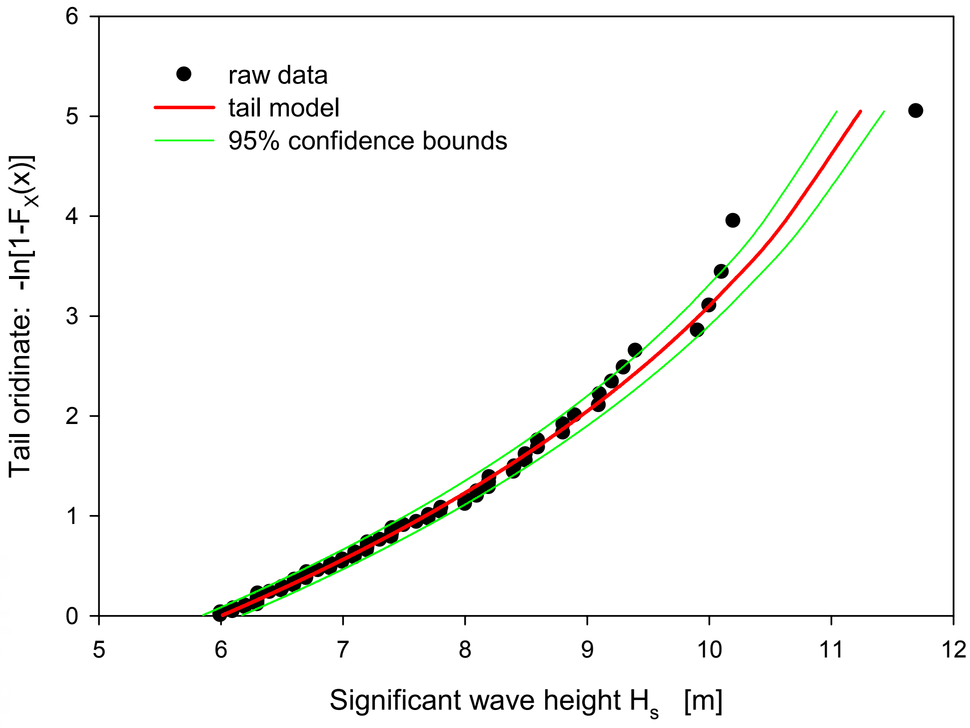
$$F_{GPD}(x) = 1 - \left[1 + \frac{\xi(x-\lambda)}{\delta} \right]_{+}^{-1/\xi}$$

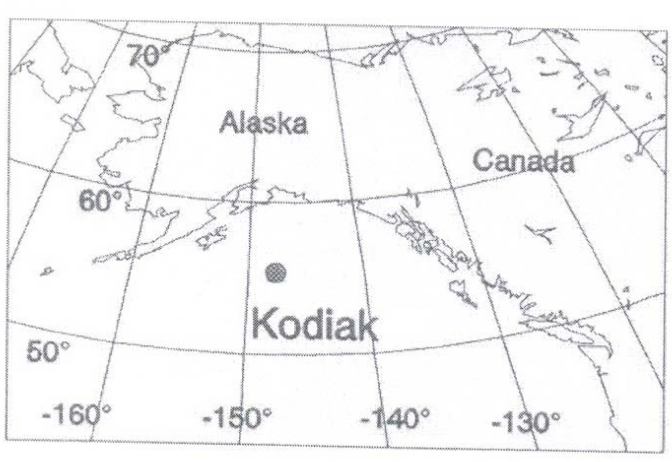
- GPD is successfully used in extreme order statistics estimation
  - Maximum wave crest height
  - Maximum pore size in material
  - Minimum wall thickness in drilling tubular

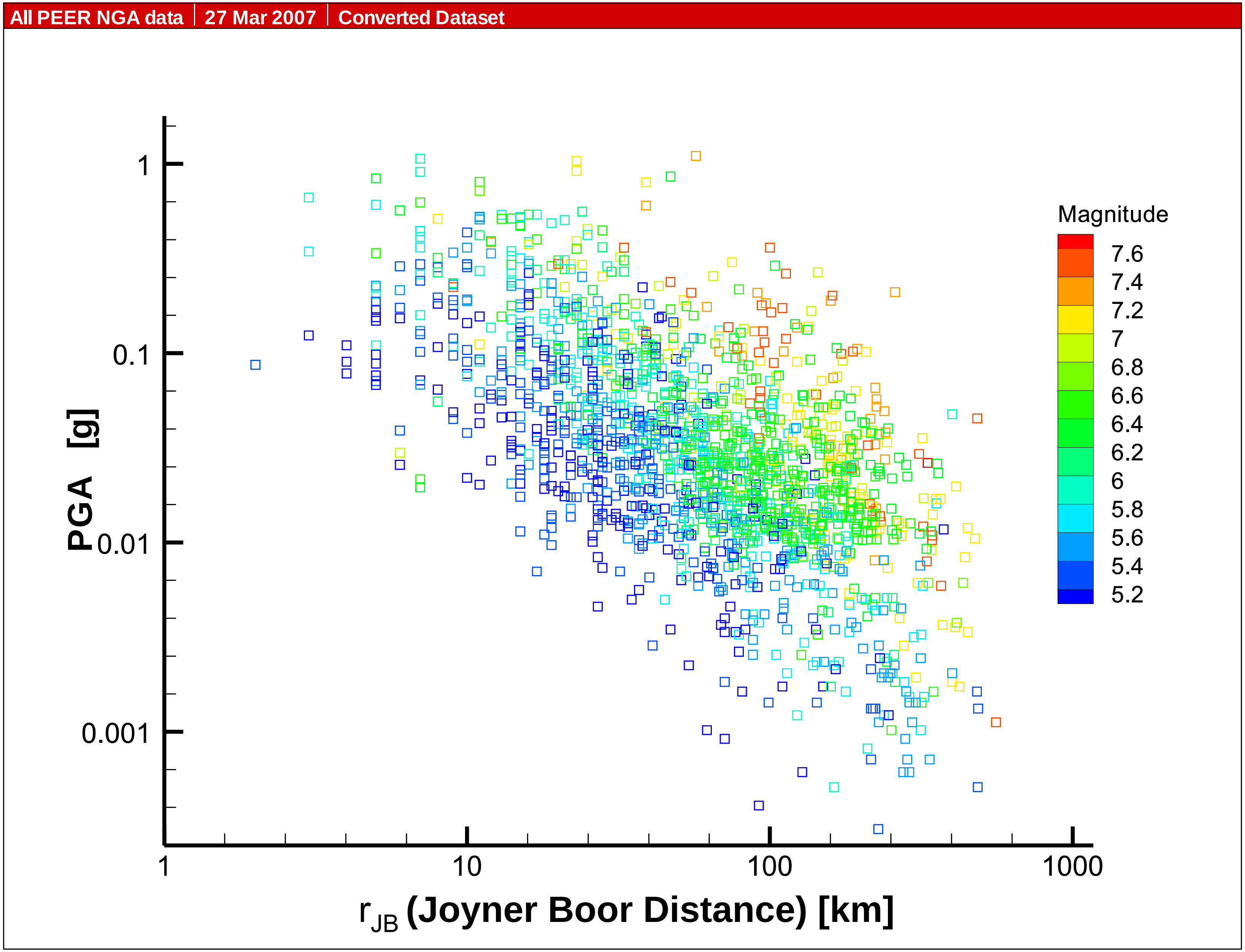
Pickands, J. "Statistical Inference Using Extreme Order Statistics." *The Annals of Statistics*. Vol. 3. pp. 119–131. 1975.

Peak-Over-Threshold Analysis

- Kodiak, Alaska
  - Hindcast data set for 78 severe storms from 1956-1975
  - Use GPD to model the significant wave height of all severe storms (H_s > 6m)

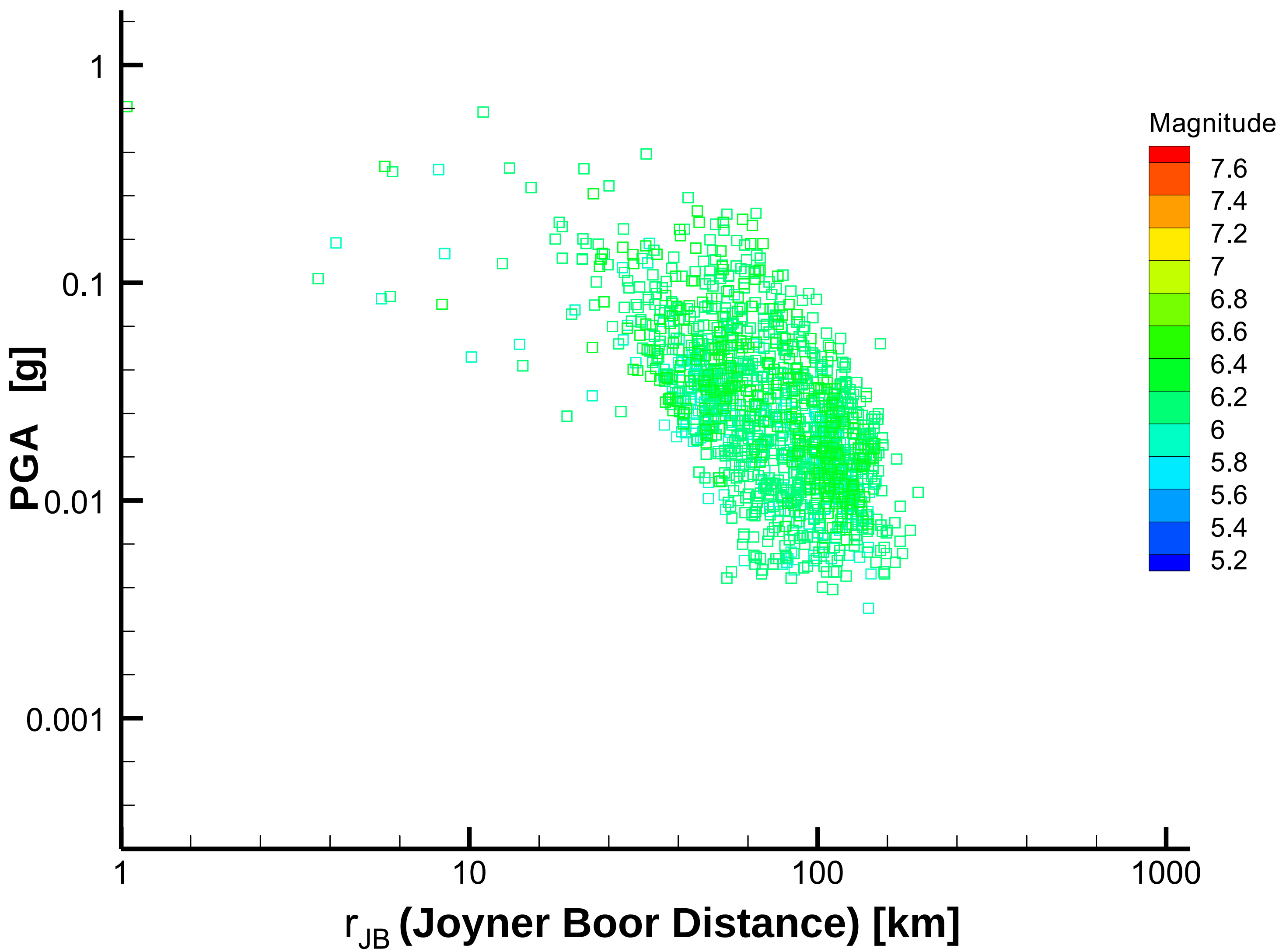






Peak Ground Acceleration (PGA) is measured in multiples of "g." To convert kilometers (km) to miles multiply by 0.62.

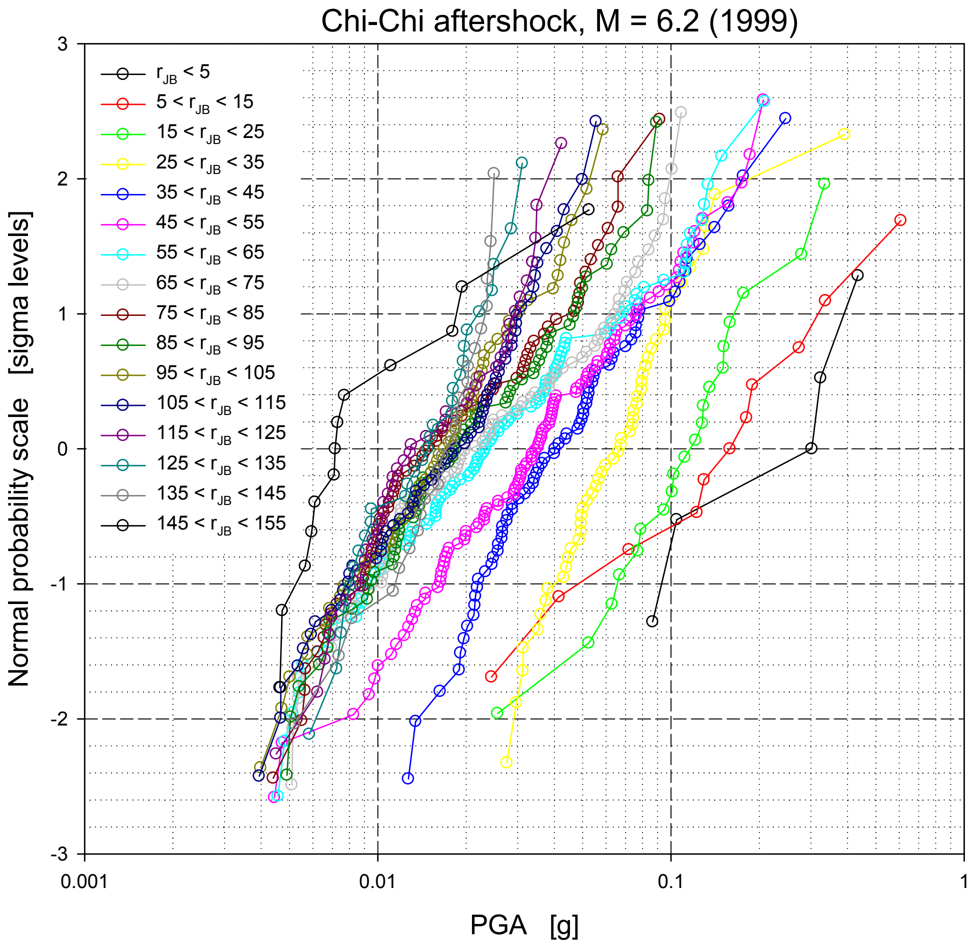
Chi-chi PEER NGA data only | 27 Mar 2007



Peak Ground Acceleration (PGA) is measured in multiples of “g.“ To convert kilometers (km) to miles multiply by 0.62.

Is PGA Lognormally Distributed?

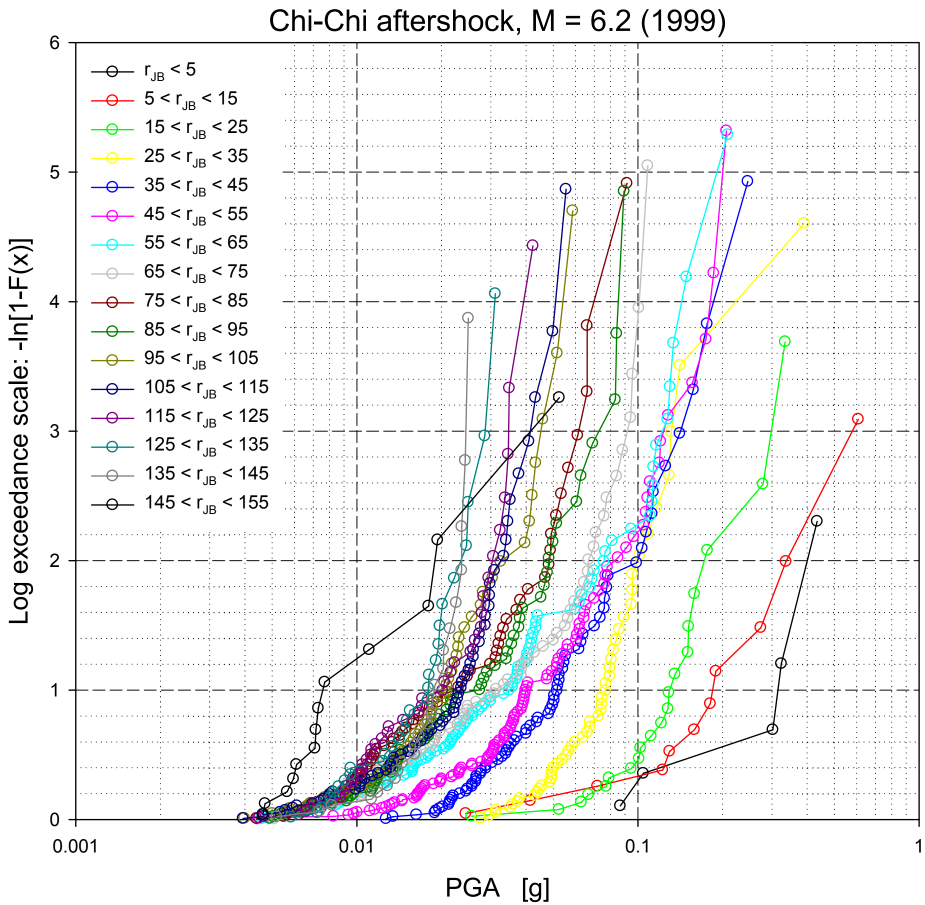
- 1999 Chi-Chi aftershock data for magnitude M = 6.2
  - Large data set (>800)
  - Eliminates dependence on magnitude
- Empirical distribution of $\log_{10}$(PGA) plotted for each Joyner Boor distance (r_{JB}) bin
- Data generally plot as lognormal distribution except at tails



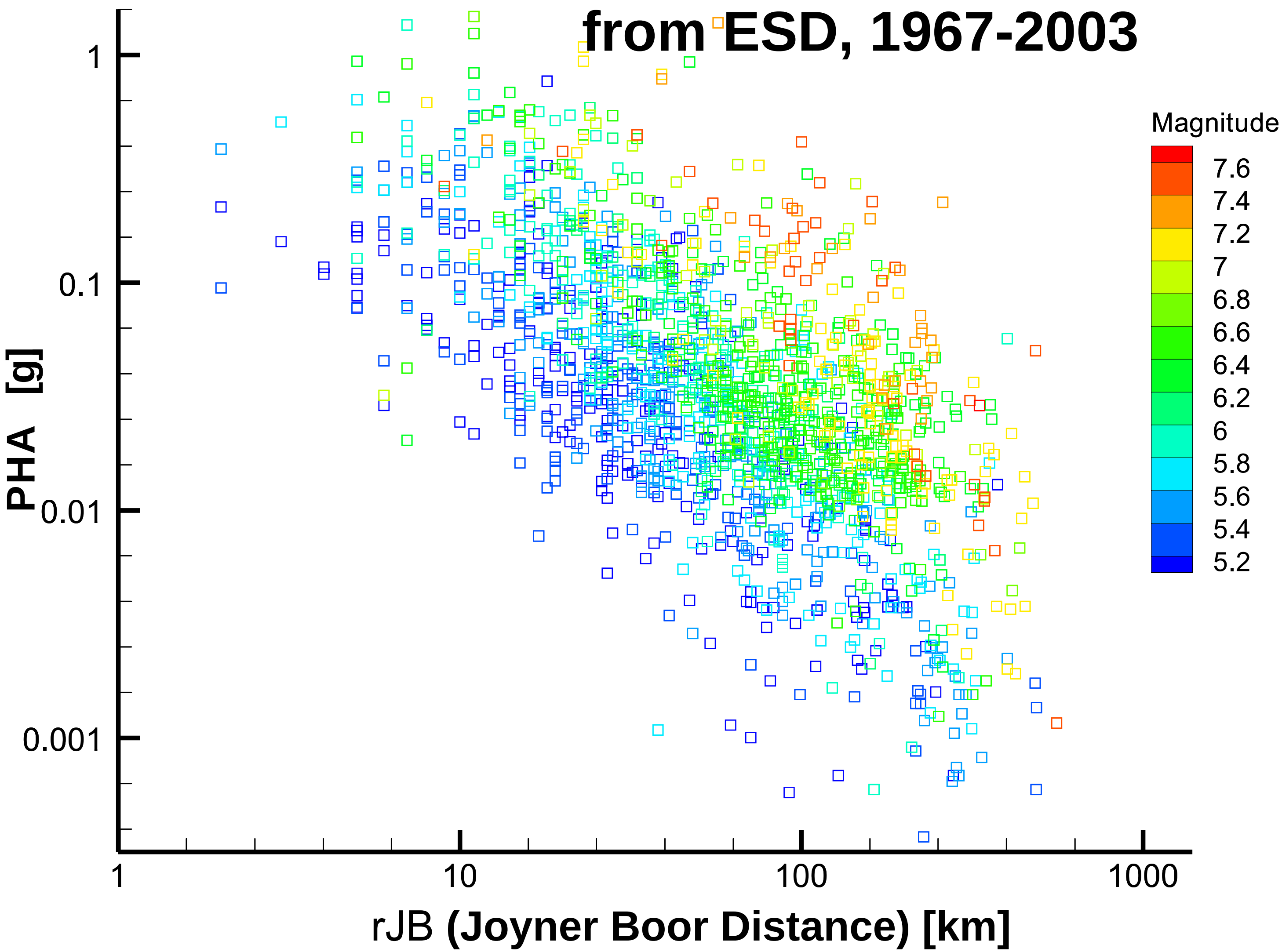
Tail Plots of Residuals

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

- Maximum PGA bound drops with increasing r_{JB} distance



1700 strong motion records from ESD, 1967-2003



Peak Ground Acceleration (PGA) is measured in multiples of "g." To convert kilometers (km) to miles multiply by 0.62.

Regression Modeling of Ground Motion

- Regression equation:

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

  - Regressor: magnitude M_w and distance Δ

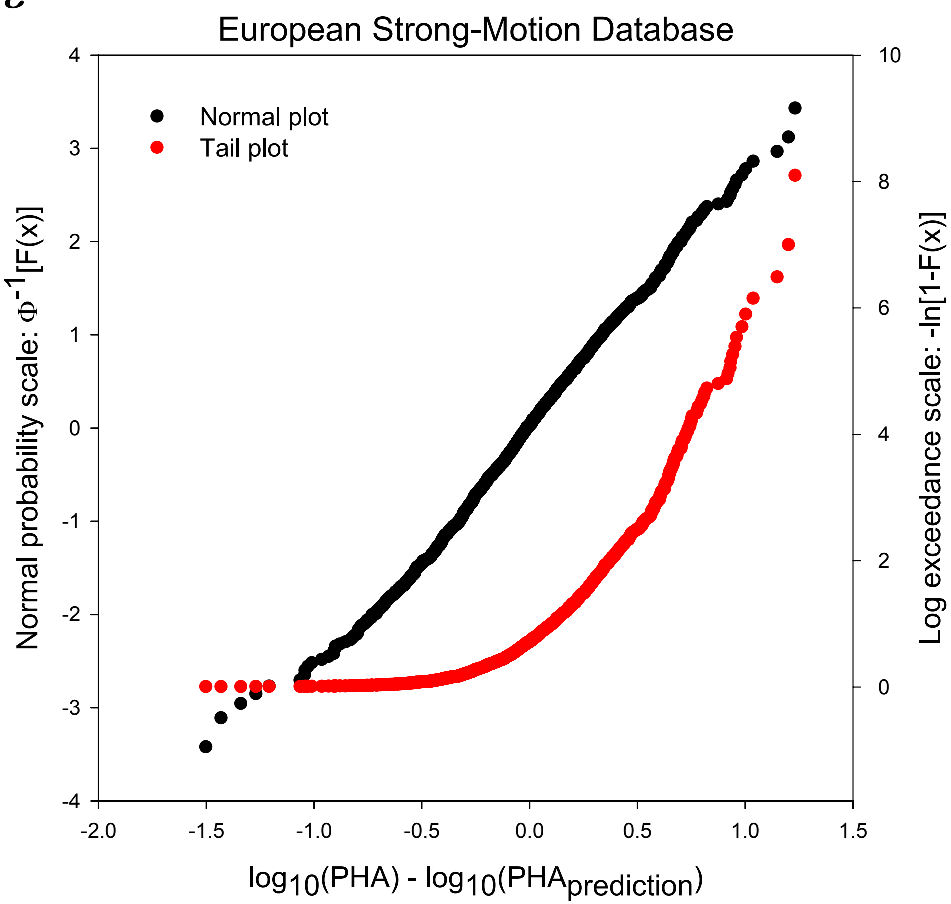
- General assumptions of linear model
  - Normally distributed errors
  - Additive error model

- Do normally distributed errors result in unrealistically large PGA at tails of distribution?

Analysis of Regression Error

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

- 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 or lognormal assumption



$\varepsilon = \log_{10}(PGA) - \log_{10}(PGA_{prediction})$

Summary

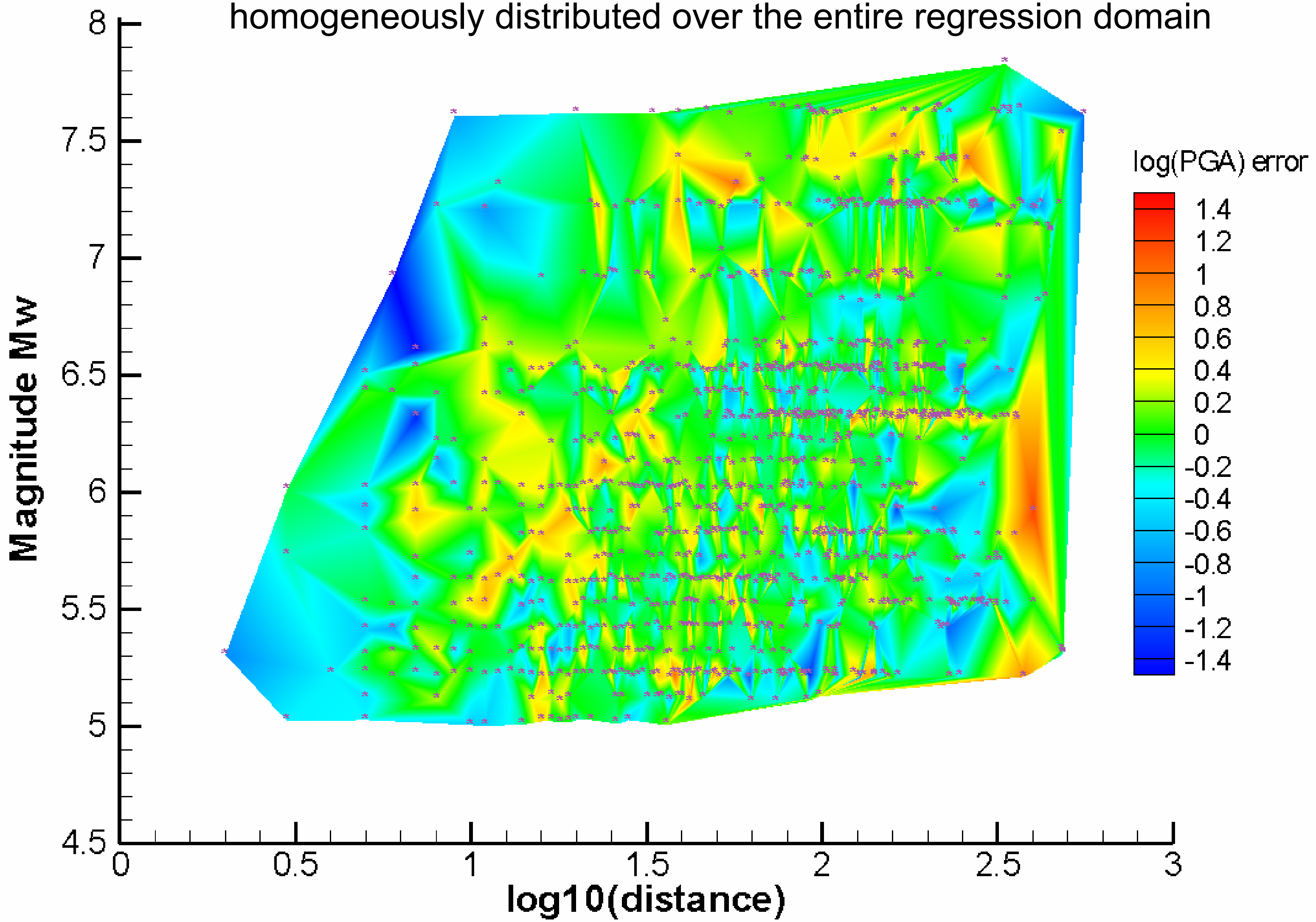
- Analysis of both worldwide PEER and European Strong-Motion Database indicates that:
    - Although log(PGA) residual is generally assumed to have a normal or lognormal distribution, deviations from normal or lognormal are observed for tails of PGA distributions
    - Application of GPD to earthquake data may show logical (statistical) upper bound to ground motion

Disclaimer

This presentation describes work performed by the Center for Nuclear Waste Regulatory Analyses (CNWRA) for the U.S. Nuclear Regulatory Commission (NRC) under Contract No. NRC–02–02–012. The activities reported here were performed on behalf of the NRC Office of Nuclear Material Safety and Safeguards, Division of High-Level Waste Repository Safety. This presentation is an independent product of the CNWRA and does not necessarily reflect the view or regulatory position of the NRC. The NRC staff views expressed herein are preliminary and do not constitute a final judgment or determination of the matters addressed or of the acceptability of a license application for a geologic repository at Yucca Mountain.

BACK UP SLIDES

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