Sigma for ENA

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Sponsored by EPRI/NEI/DOE

I’ve modified Norm’s presentation to start with some explanation of sigma (next 2 slides)

Effect of standard deviation of ground motion relation (given here in log(10) units) on seismic hazard analysis results

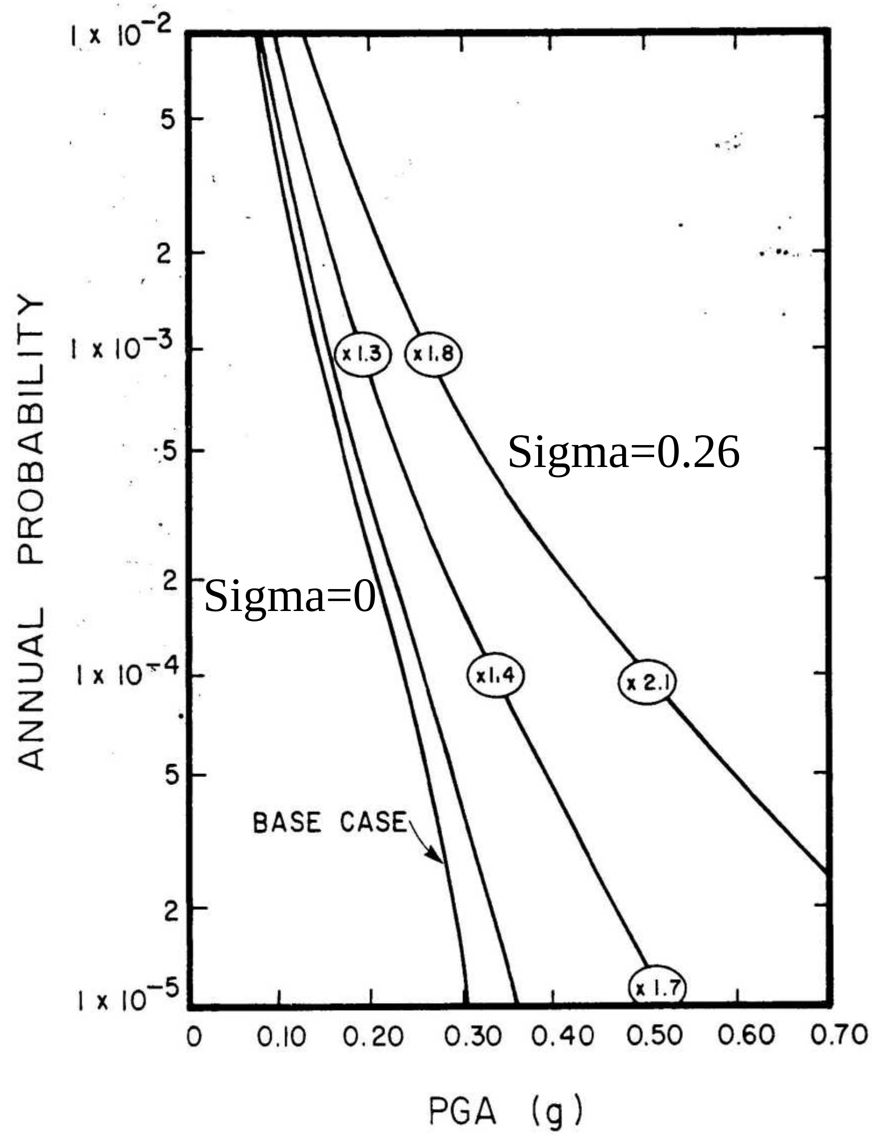
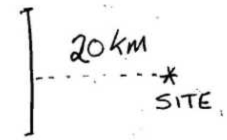


FIG. 10. Influence of σ_{lnk} on PGA for Vancouver, for a single input model, with σ_{lnk} = 0, 0.2, 0.4, and 0.6 (from *left* to *right*).

(From Atkinson and Charlwood, 1983)

Consequences of random variability in ground motion relations (why sigma really does increase the hazard)

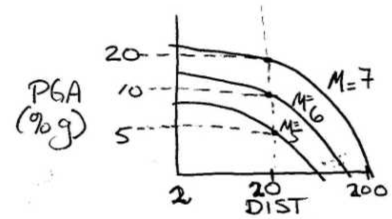
Example



Active fault in 100 YRS

$N_7 = 1$
$N_6 = 10$
$N_5 = 100$

Recurrence Info.



Ground motion relation

So at Dist = 20 km
Median PGA's are 5%g for M=5
10%g for M=6
20%g for M=7

Compute $N(\geq 10\%g)$ in next 100 years.

1) No random variability

$$N(\geq 10\%g) = [N(\geq 10\%g)]_{M=5} + [N(\geq 10\%g)]_{M=6} + [N(\geq 10\%g)]_{M=7}$$

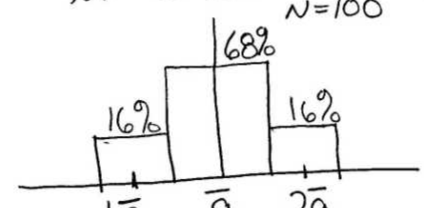
$$= [0]_{M5} + [10]_{M6} + [1]_{M7}$$

$$= 11$$

2) With random variability given by $\sigma_{\log k} = 0.3$
(factor of 2 on PGA for 1 std. deviation)

$$N(\geq 10\%)_g = [16]_{M5} + [8.4]_{M6} + [1]_{M7}$$

$$= 25$$



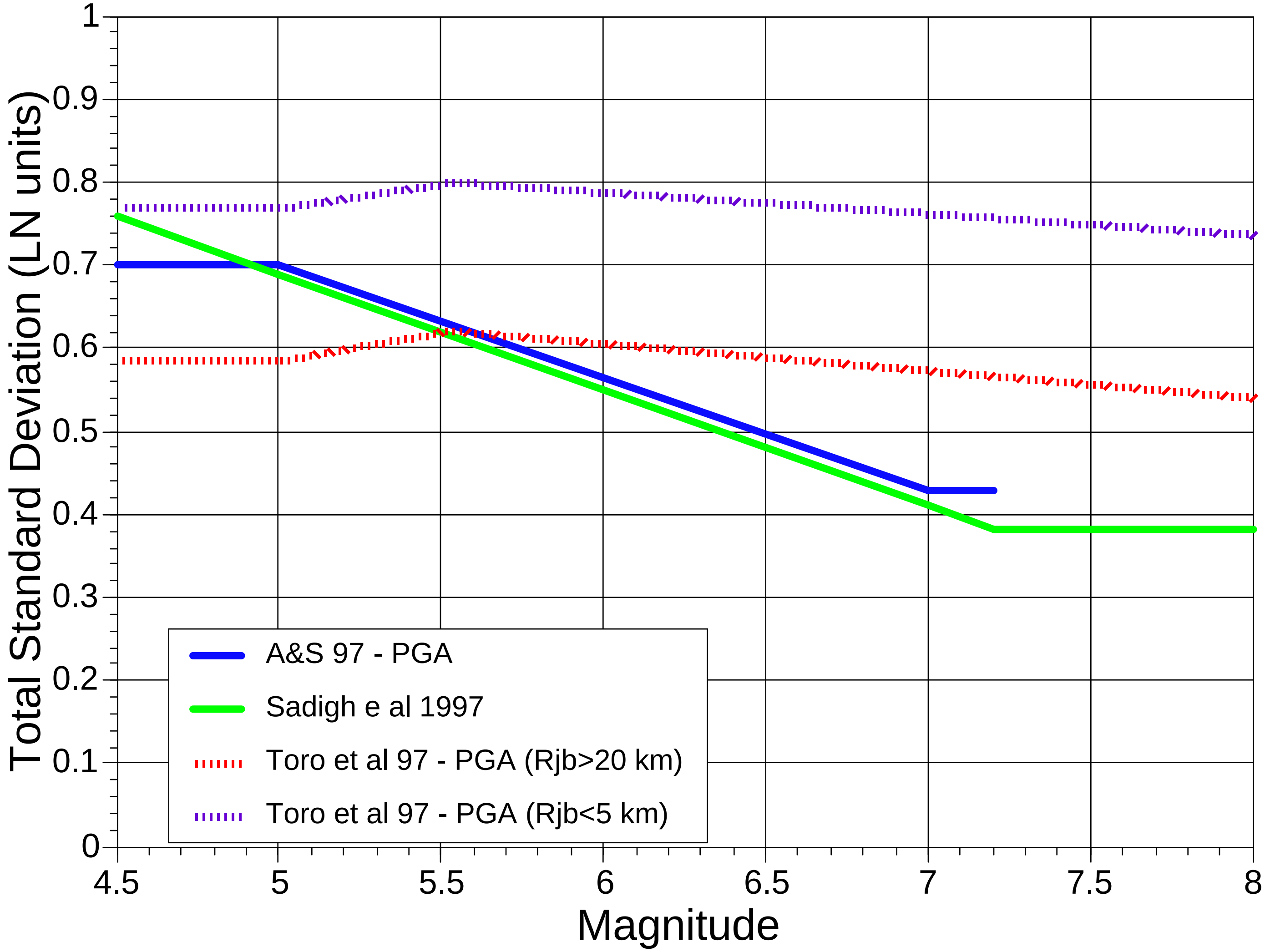
Distribution of PGA

Sigma for ENA
(back to Norm's presentation)

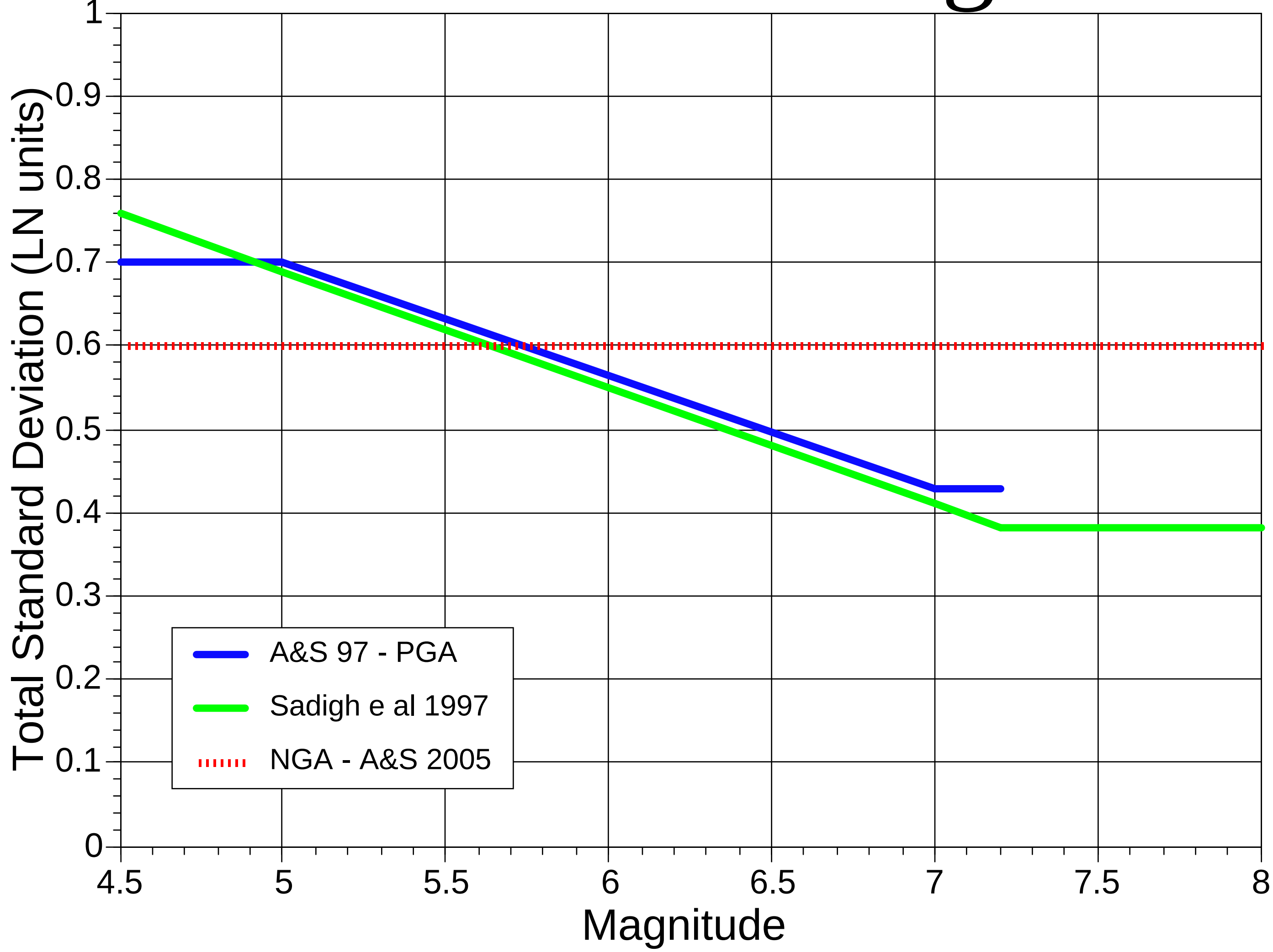
- PEER/Lifelines NGA project found a significant revision in sigma values for WUS
  - Improved meta data
  - More robust estimate of sigma
  - Sigma now independent of magnitude

- Are these WUS sigma values from the NGA study applicable to ENA?

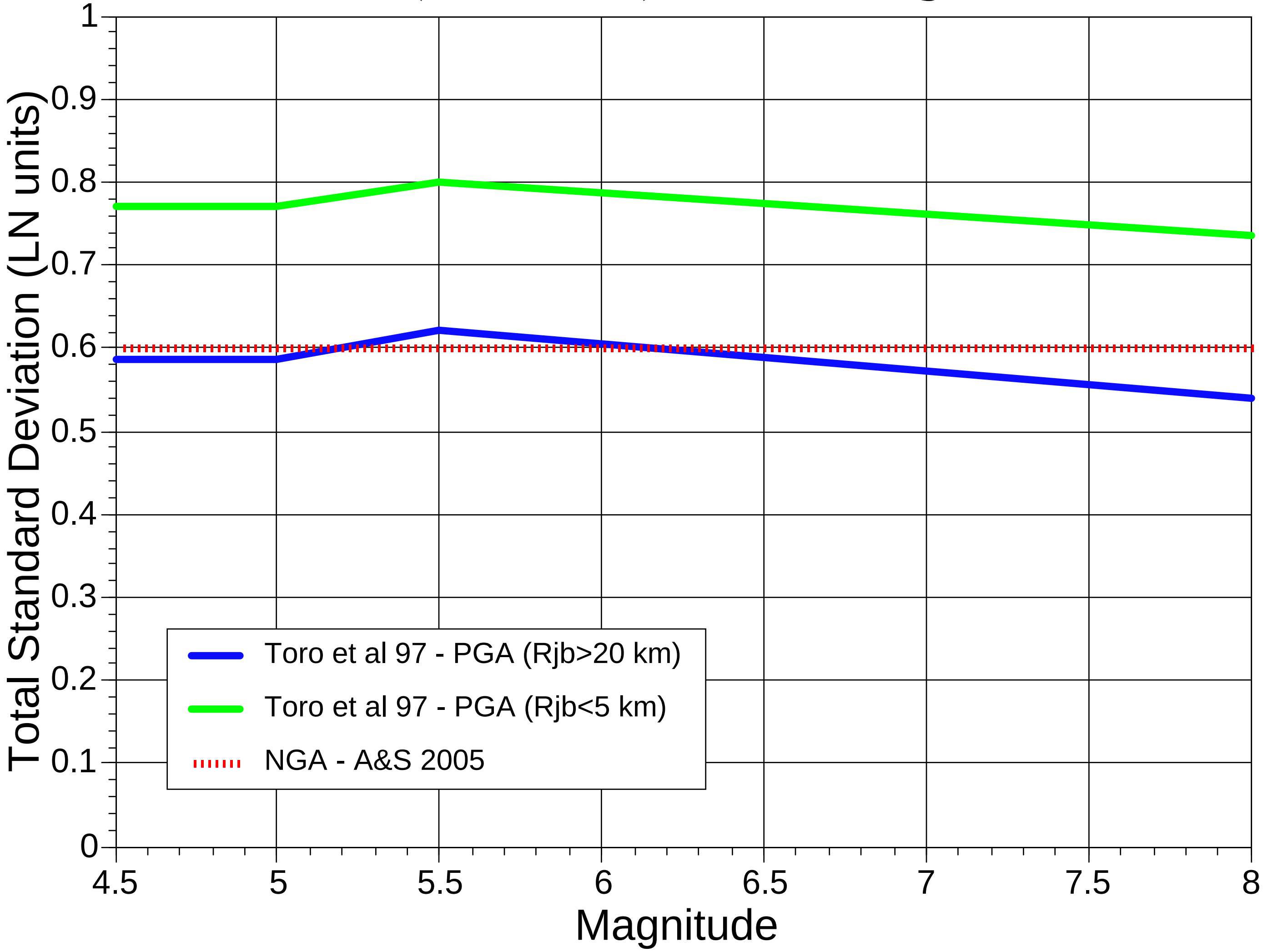
PGA Standard Deviation
WUS vs CEUS



NGA Models for WUS Show Constant Sigma



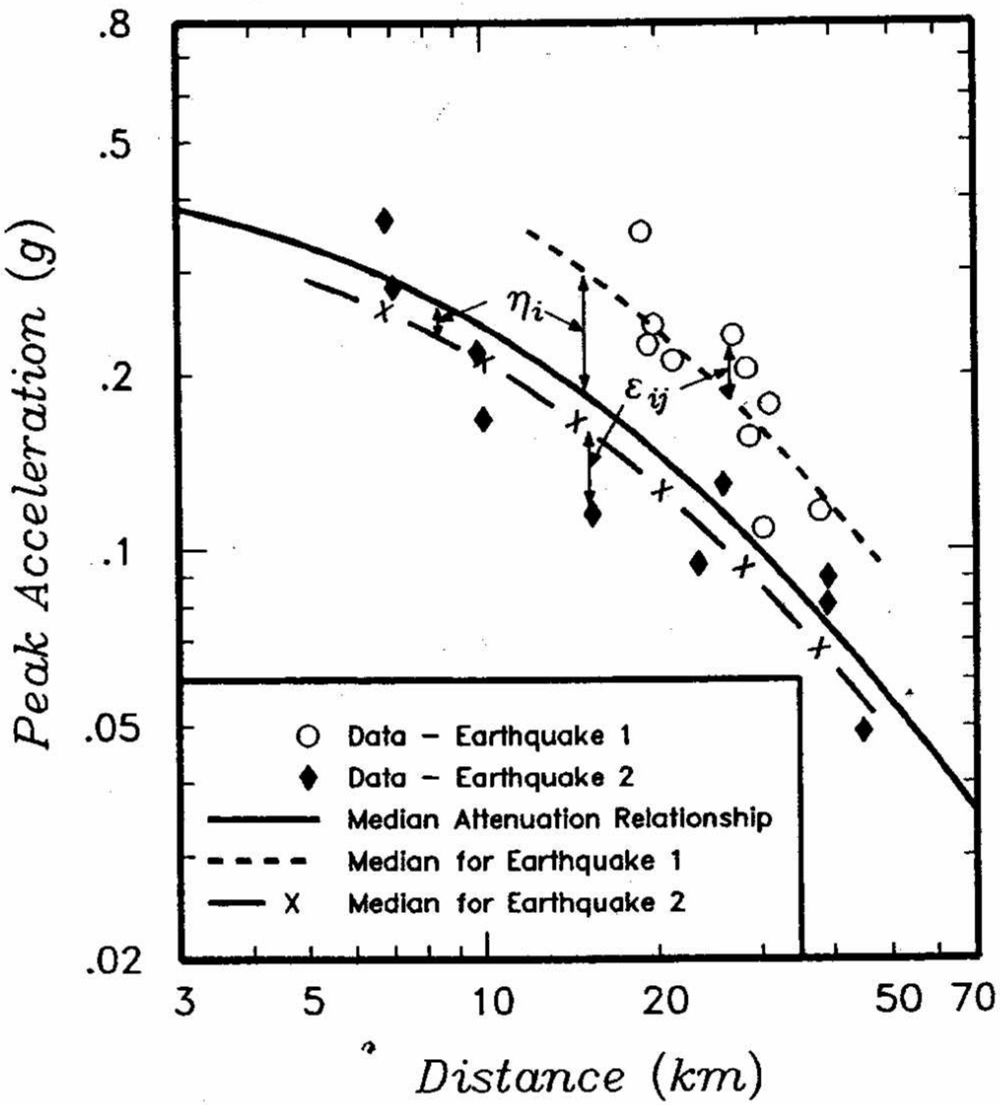
NGA Models Similar to Toro et al (1997) for Rjb>20 km



Parts of Total Standard Deviation

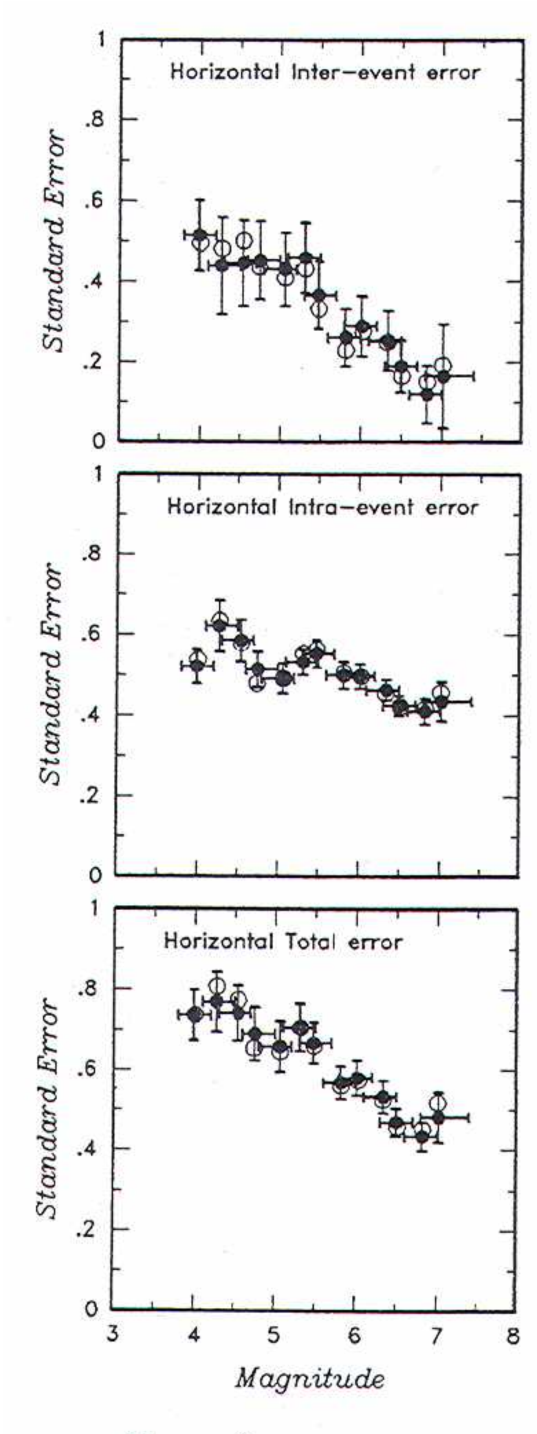
- Inter-event variability
  - Variation of the average offset of ground motion from median for a given earthquake
  - Average offsets call "Event Terms"
- Intra-event
  - Variation of ground motion within a single earthquake (about its own median)

Inter-Event and Intra-Event Terms



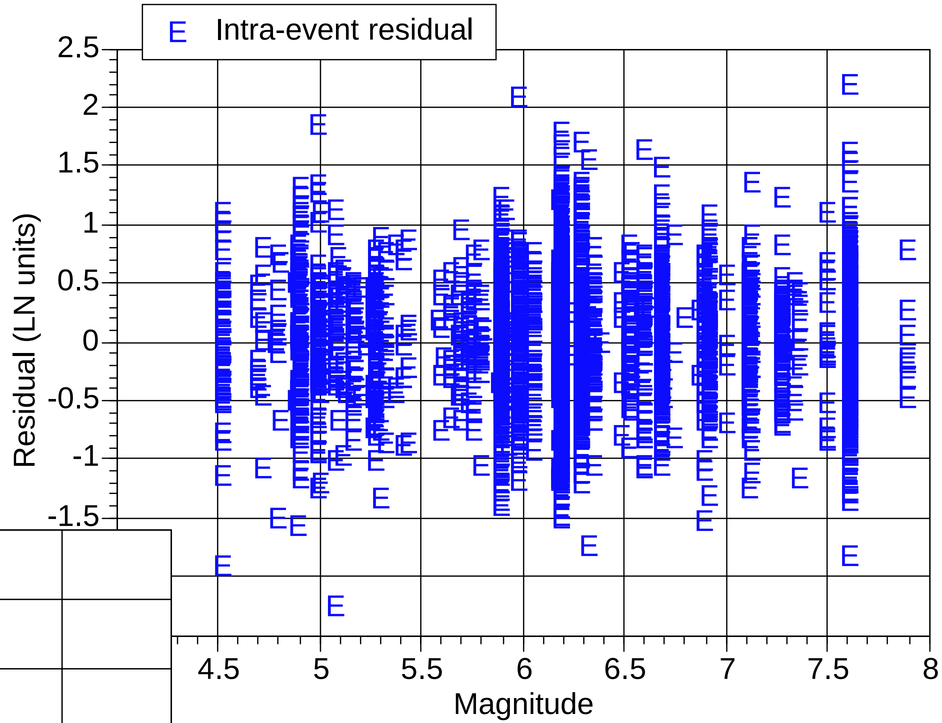
Magnitude Dependent Standard Deviation for PGA

(from 1997 Models)

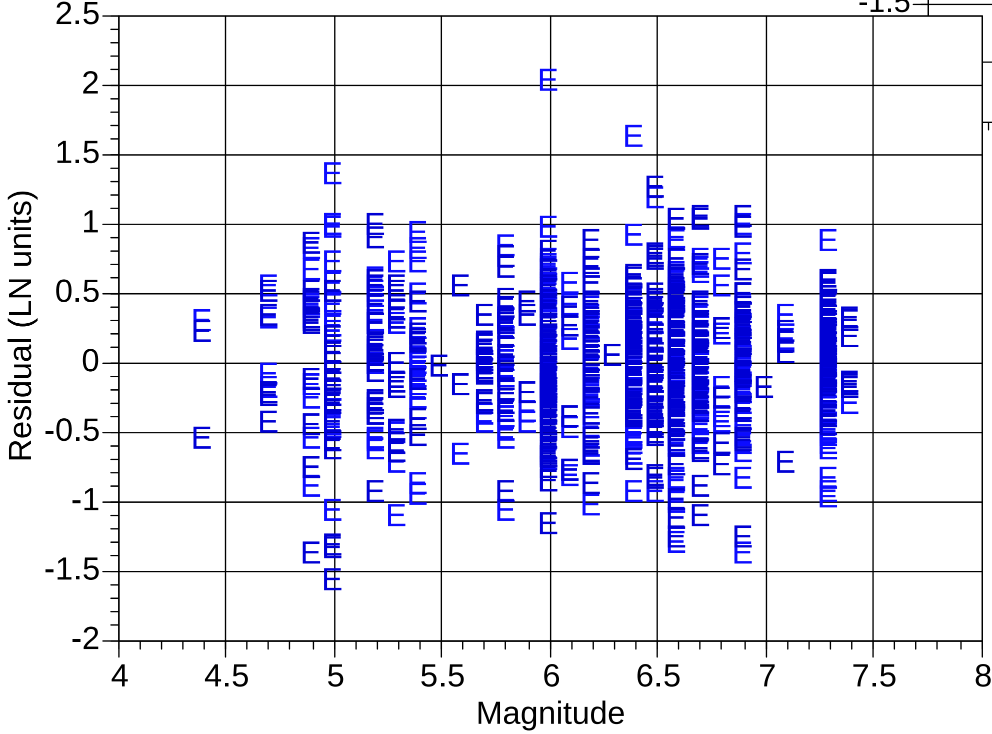


Intra-Event PGA Residuals

NGA A&S 2005

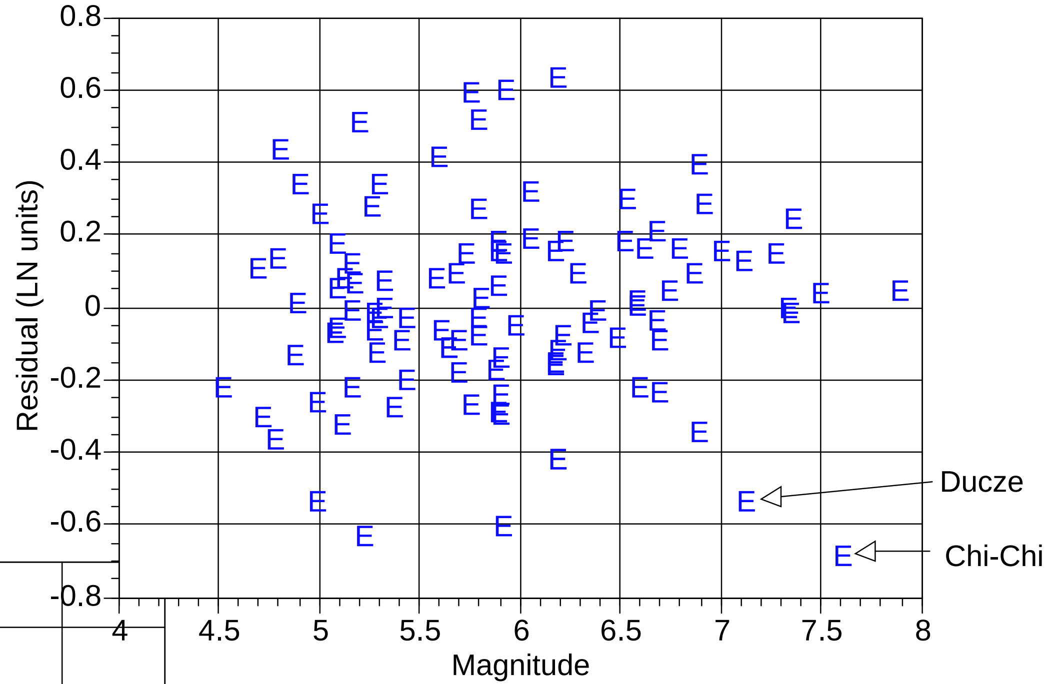


1997 A&S

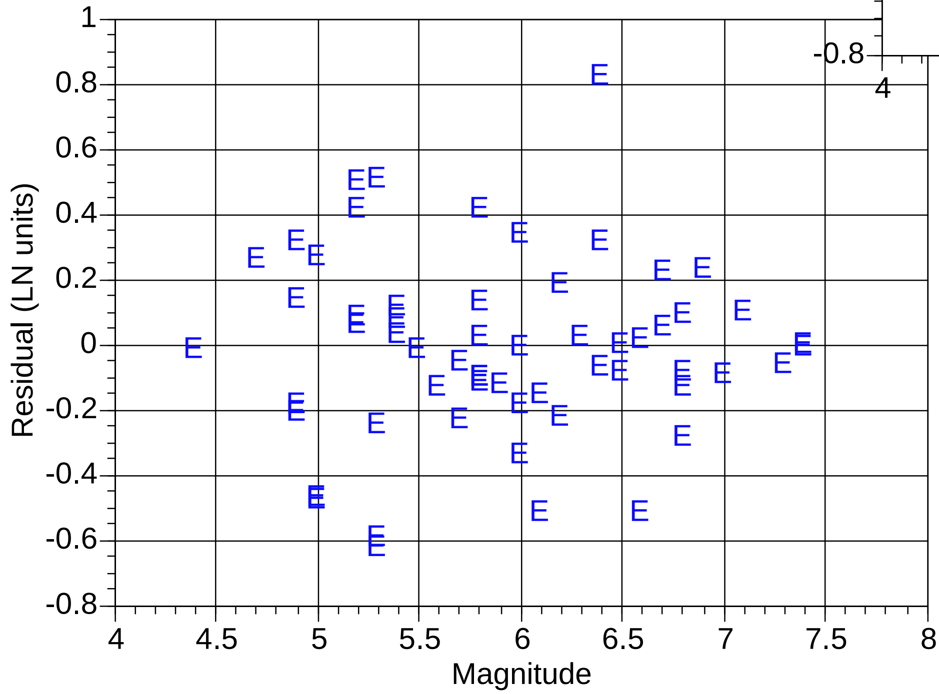


Inter-Event PGA Residuals

NGA A&S 2005



1997 A&S



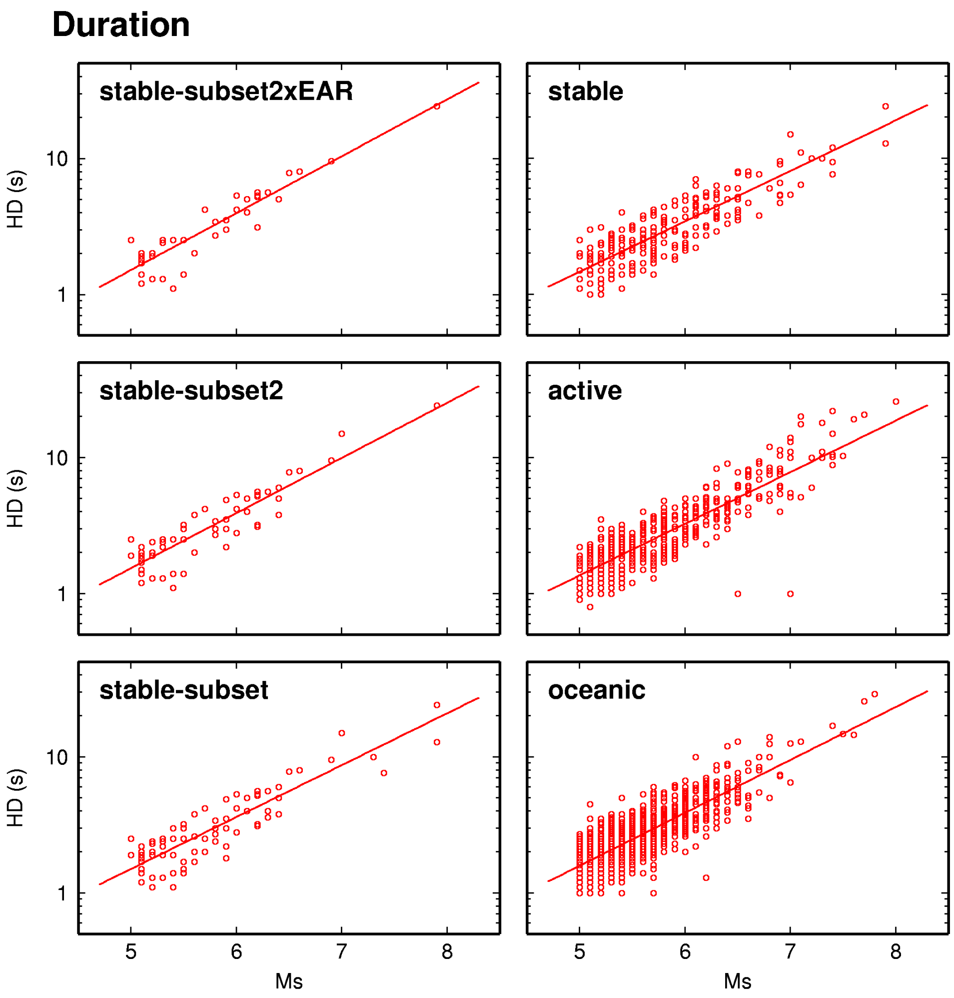
Magnitude Dependence of Standard Deviation

- Intra-event standard deviation
  - 1999 Chi-Chi mainshock (M7.6) σ=0.55 increased estimate for large magnitudes
  - Additional small magnitude earthquakes decreased estimate for small magnitudes
- Inter-event standard deviation
  - 1999 Chi-Chi and 1999 Duzce increased estimate for large magnitudes
    - Large negative residuals
  - Additional small magnitude earthquakes decreased estimate for small magnitudes

Evaluation of Applicability of WUS Sigma to ENA

- Checked causes for expected differences in inter-event and intra-event variability between ENA and WUS
  - Are sources (stress-drops more variable in ENA?
    - Used empirical data (network and catalog)
  - Is crustal structure (path) variability similar?
    - Considered crustal structure and depth distributions
    - Used numerical simulations
  - Is site variability similar?
    - Empirical site variability terms
- Conclusions
  - No basis for a significant difference in inter-event or intra-event variability between ENA and WUS

Variability of Source Duration from Global Catalogs



Active Regions

σ = 0.30 ± 0.01

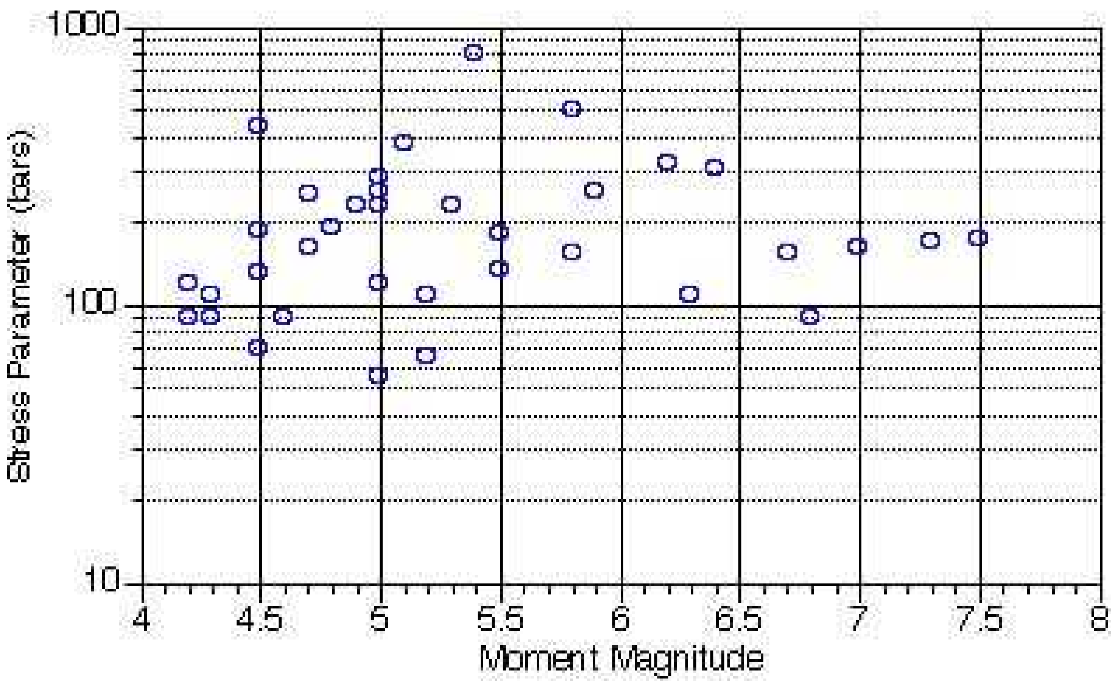
Stable Regions

σ= 0.25 - 0.29 ± 0.03

Variability is similar

Stress-Parameter Variability

From Atkinson & Boore (2005)



Sigma ln($\Delta\sigma$)=0.60

Inter-Event Sigma:
Sigma ln(Sa) = 0.6*0.74
= 0.44

WUS:
Inter-Event Sigma = 0.4

Path Variability

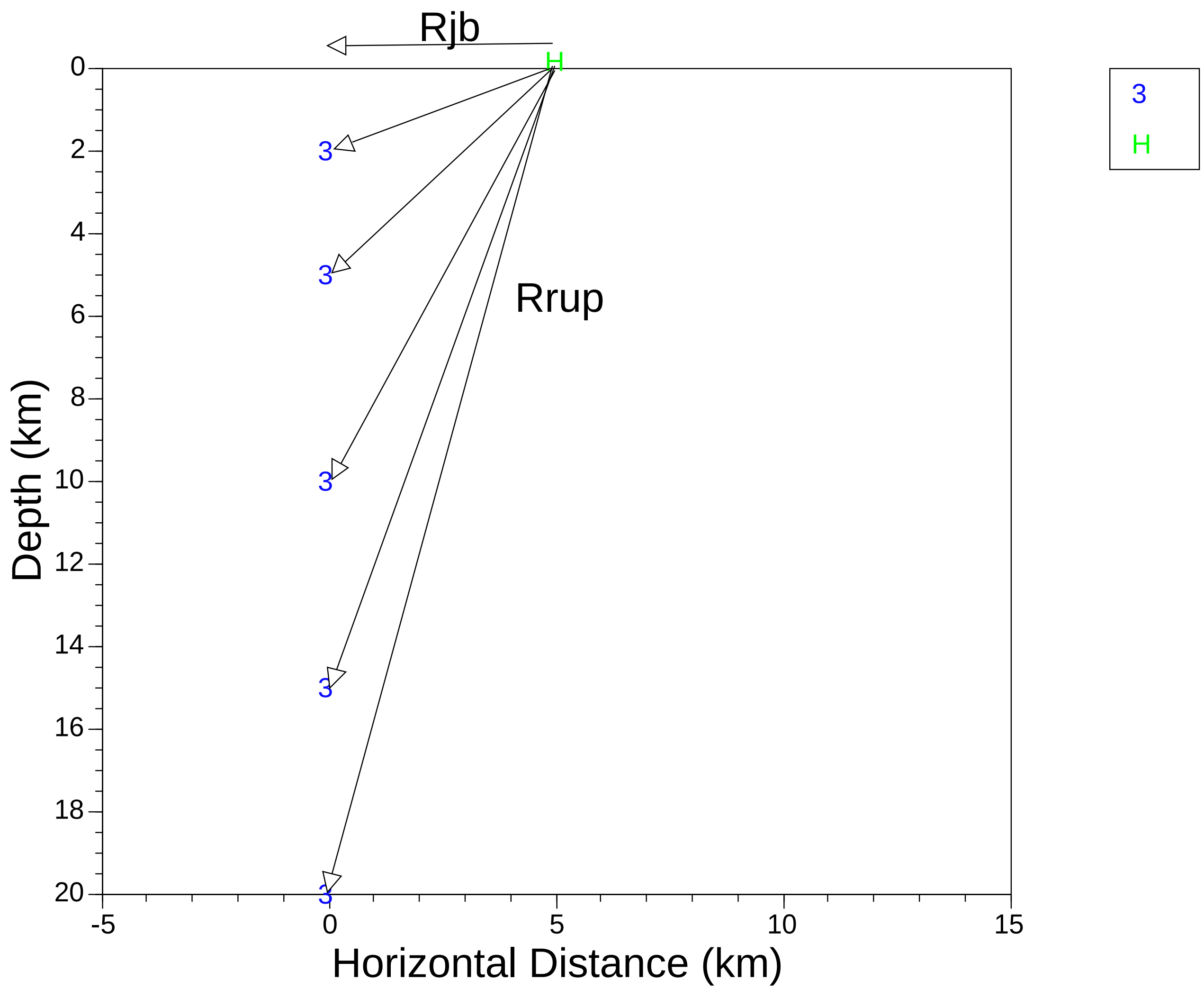
Sigma from crustal structure and depth distribution

Frequency	Active	Stable
PGA	0.20	0.16
25 Hz	0.21	0.17
10 Hz	0.23	0.17
5 Hz	0.23	0.21
2 Hz	0.21	0.20
1 Hz	0.33	0.30
0.5 Hz	0.33	0.28

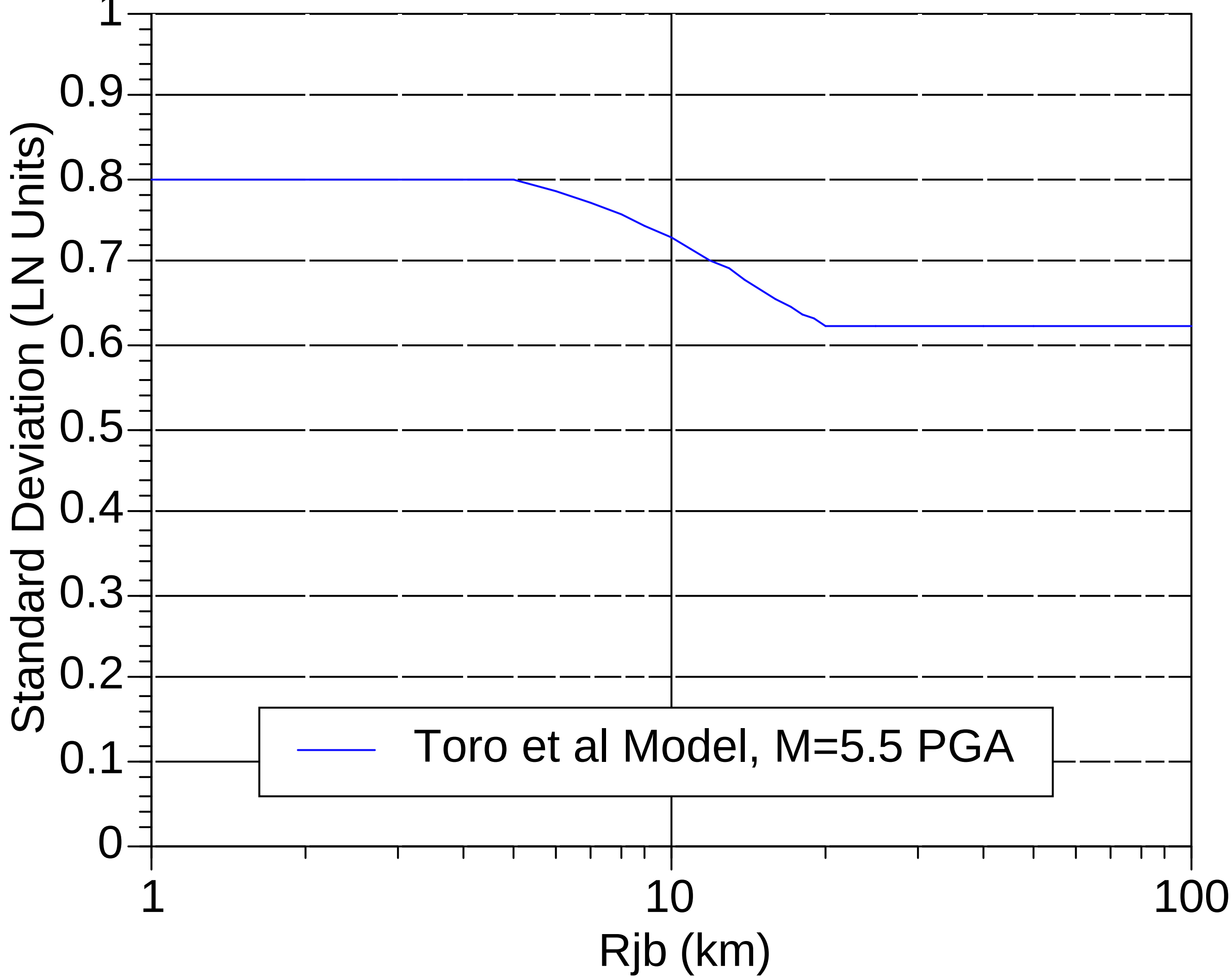
Increase in Sigma at Short Distances

- Ground motion models use JB distance metric which ignores depth
- Should sigma increase at short distances?

Use of Rjb can lead to increased variability for small R and small M

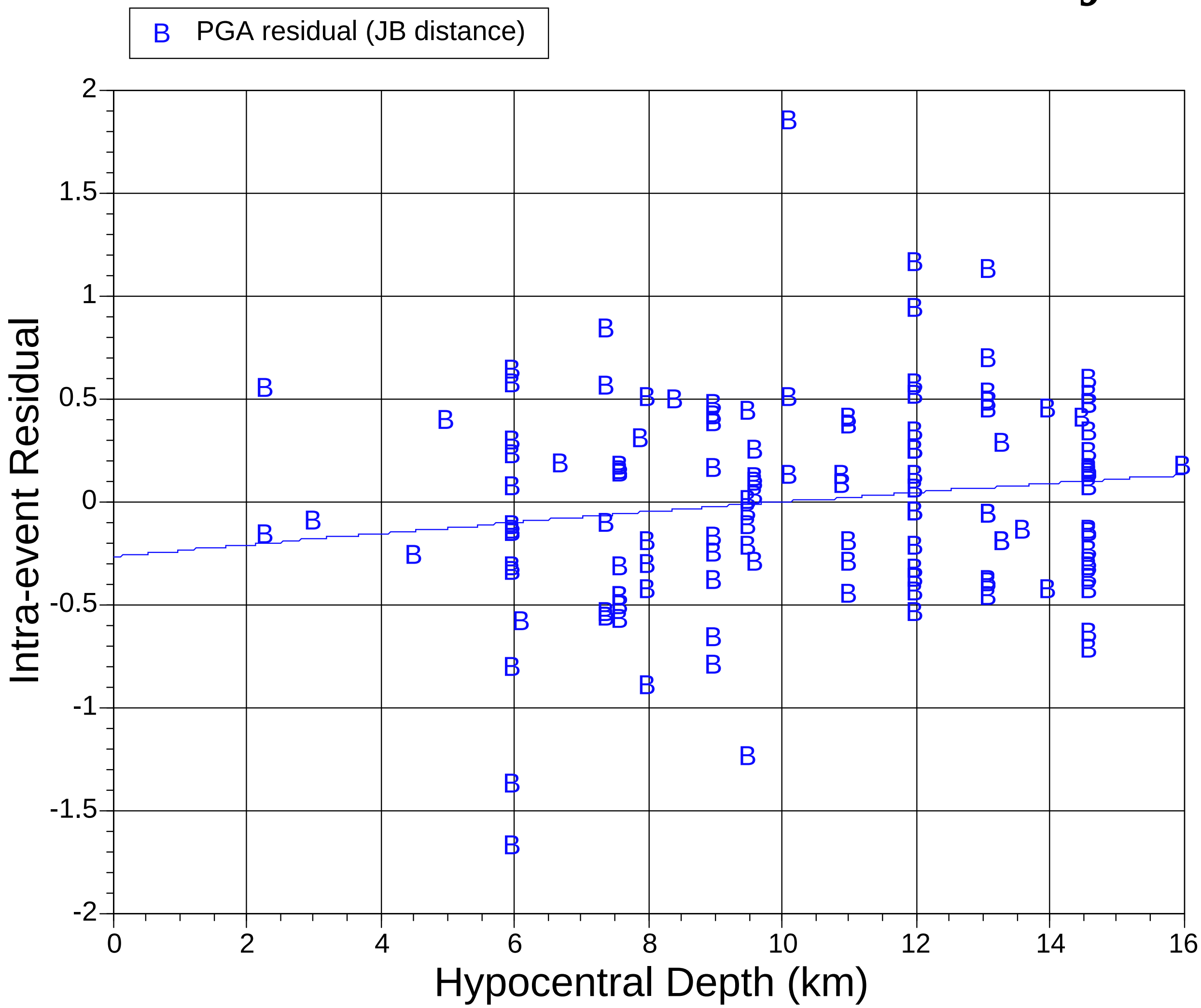


Distance Dependent Std Dev in Toro et al Model



WUS, M<6, Rjb<10

Model Based on Rjb

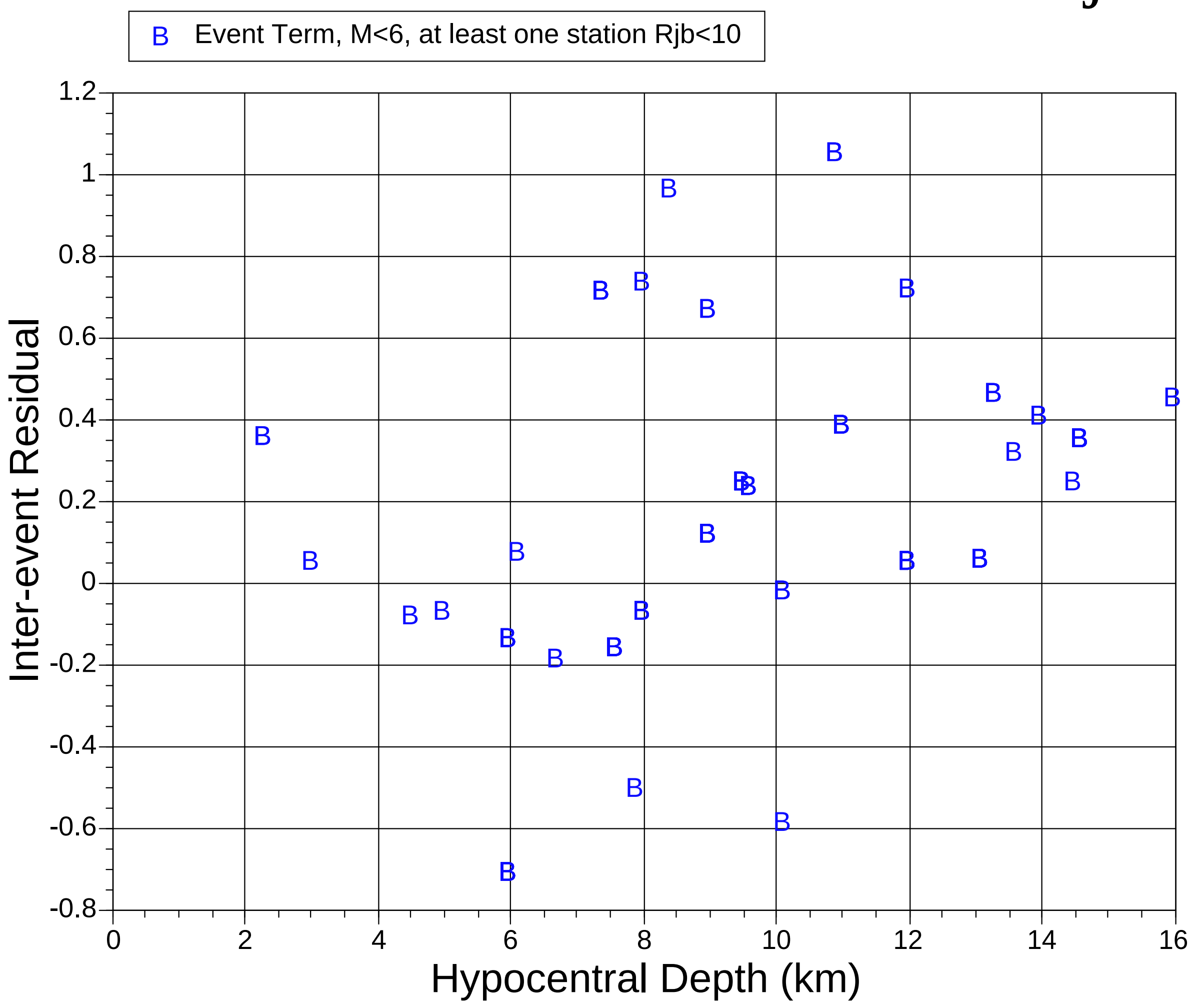


Residuals do not show expected trend

Inter-Event Variability for WUS

M<6 with at least one station w/Rjb<10

Model Based on Rjb



Trend of increase with depth

Short Distance Sigma

- Conclusion
  - No increase in sigma observed at short distances due to use of JB distance metric
  - Implies a correlation of stress-drop with depth
  - No need to increase sigma at short distances due to use of JB distance

GMA note: ENA data show no apparent dependence of stress drop on depth (Atkinson, 2004), But I would have expected to see one……

Conclusions from Comparison of WUS & ENA Sigma

- Inter-Event
  - ENA sigma is similar to WUS
- Intra-Event
  - Path:
    - ENA sigma is similar to WUS
  - Site
    - ENA may be smaller due to more homogeneous rock conditions
- Use of JB Distance
  - Preference to no increase in sigma at short distances

Recommended Sigma for ENA

- Model 1A
  - Use WUS inter-event and intra-event sigma
- Model 1B
  - Use WUS inter-event and reduced intra-event sigma to account for more homogeneous rock
- Close Distances
  - Small wt (0.1) to model with increase due to use of JB distance (not shown in next slide)

Recommend ENA Total Sigma

Frequency	Model 1A wt = 0.7	Model 1B wt = 0.3
PGA	0.62	0.60
25	0.70	0.67
10	0.70	0.67
5	0.70	0.67
2	0.70	0.67
1	0.73	0.70
0.5	0.75	0.72

Aleatory Variability from Numerical Simulations

(From Toro et al 1997)

- Two terms:
  - Parametric Variability
    - Based on range of ground motions due to varying parameters in the model for future earthquakes
  - Modeling Variability
    - Based on misfit in calibrations of simulation method
- Example (PGA) from EPRI 1993 (basis for Toro model)
  - Parametric due to stress-drop: σ_p =0.55 (M6)
  - Modeling variability; σ_m=0.32
  - Total = 0.64

Revised Aleatory Variability from Numerical Simulations (EPRI 2003)

- Example (PGA) from EPRI 1993
  - Parametric due to stress-drop is unchanged: σ_p =0.55 (M6)
  - Modeling variability increased due to misfit from larger set of earthquakes: σ_m=0.48 (increased from 0.32)
  - Total = 0.73 (increased from 0.64)
- Recommended Sigma based on WUS comparison is 0.60 - 0.62
- Why the discrepancy?
  - No clear cause for the discrepancy
  - May reflect unmodeled correlation between modeling and parametric variability
  - Still needs to be resolved

GMA note: modeled sigma based on my recent simulations (AB05) implies expected ENA sigma = 0.69 ln units --- lower than EPRI but higher than WNA empirical

Summary

- Magnitude dependence of standard deviation is not seen in NGA models
- Inter-event and intra-event variability is similar for WUS and ENA
- Distance dependence of Toro et al (1997) standard deviations may overestimate sigma at short distance.
  - This was included in the EPRI (2003) models
- WUS sigma is significantly smaller than updated sigma from numerical simulation (in EPRI 2003)
  - Cause for discrepancy not understood