Development of Regional Hard Rock Attenuation Relations for CEUS, Mid-Continent and Gulf Coast Areas

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http://www.pacificengineering.org

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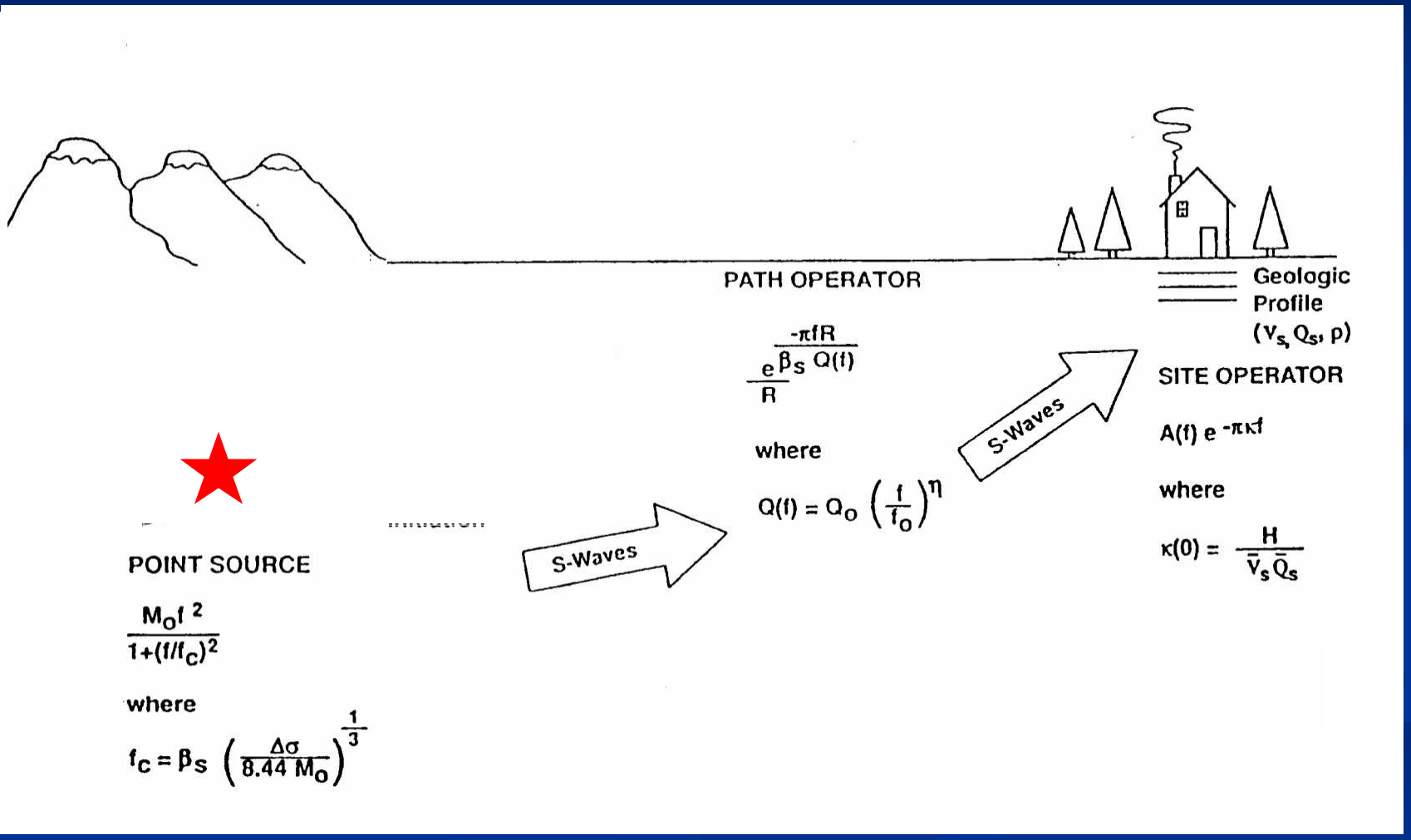
Introduction

- Stochastic Point Source Model
- Model Validation
- Input Parameter Variability
- Update Summary

Stochastic Point Source Model



Model Validation

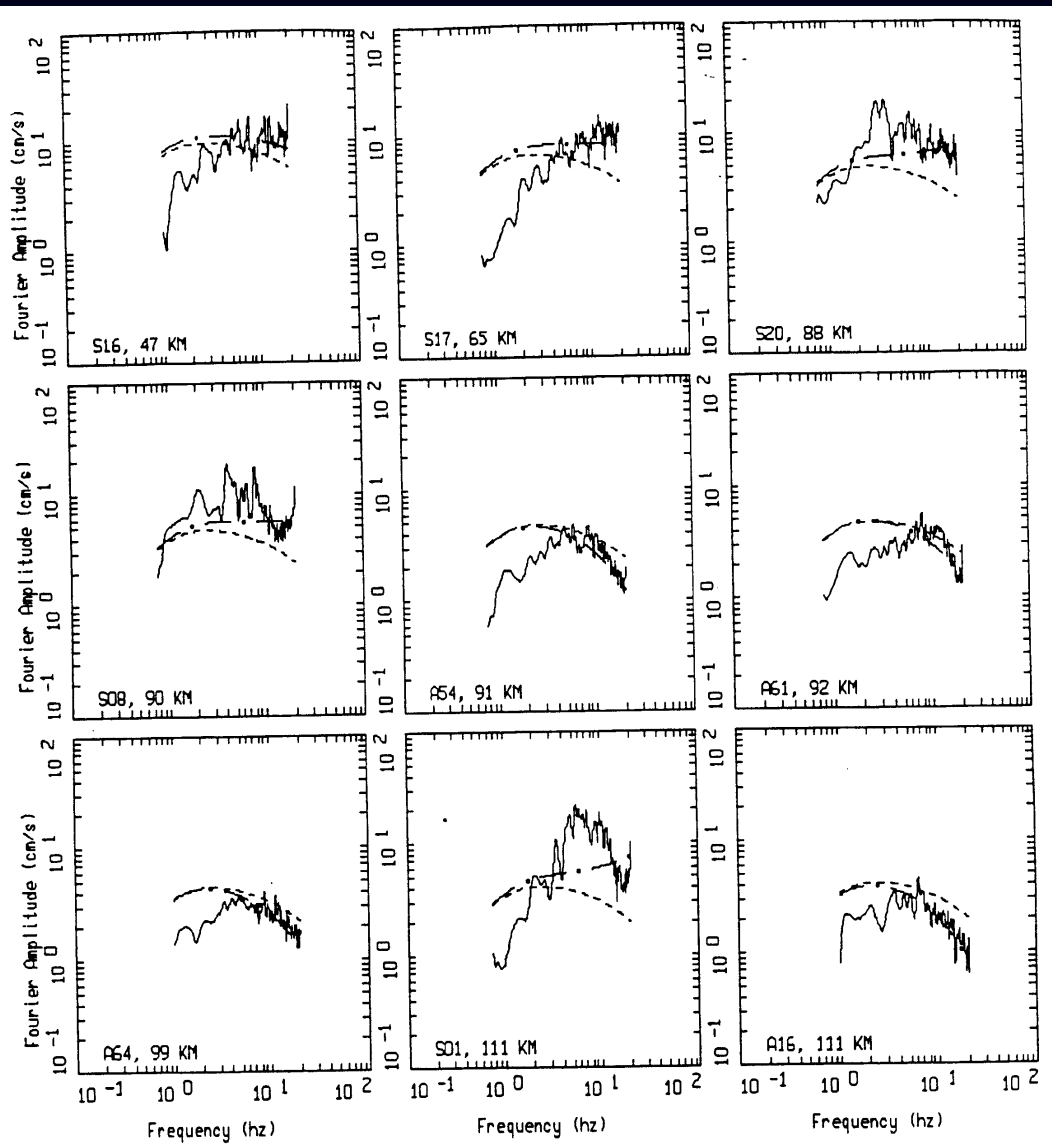
(Silva et al., 1997)

- 16 Earthquakes (M5.3 – M7.4)
- 503 Sites
  - 159 Rock
  - 344 Soil
- Distance Range: 1 – 460 km

Earthquake	M	Dist (km)	Rock Sites	Total Sites
1971 San Fernando	6.6	3 – 218	21	39
1978 Tabas	7.4	3 – 90	3	4
1979 Coyote Creek	5.7	3 – 30	3	10
1979 Imperial Valley	6.4	1 – 50	2	35
1979 Imperial Valley (AS)	5.3	12 – 52	0	16
1984 Morgan Hill	6.2	1 – 70	8	29
1985 Nahanni	6.8	6 – 16	3	3
1986 North Palm Springs	6.0	1 – 90	9	29
1987 Whittier	6.0	10 – 80	18	88
1987 Superstition Hills	6.4	1 – 28	1	12
1988 Saguenay	5.8	47 – 460	22	22
1989 Loma Prieta	6.9	5 – 90	33	53
1992 Little Skull Mtn.	5.7	15 – 98	8	8
1992 Landers	7.2	1 – 177	5	57
1992 Cape Mendocino	6.8	8 – 45	1	5
1994 Northridge	6.7	7 – 147	23	94

Saguenay EQ Inversion: Input Parameters

- 22 Rock Sites (Distances: 47 – 460 km)
- Crustal Model (Hartzell et al., 1994)
- Point Source Depth = 25.7 km
- Starting Stress Drop = 300 bars
- Starting Kappa = 0.008 sec



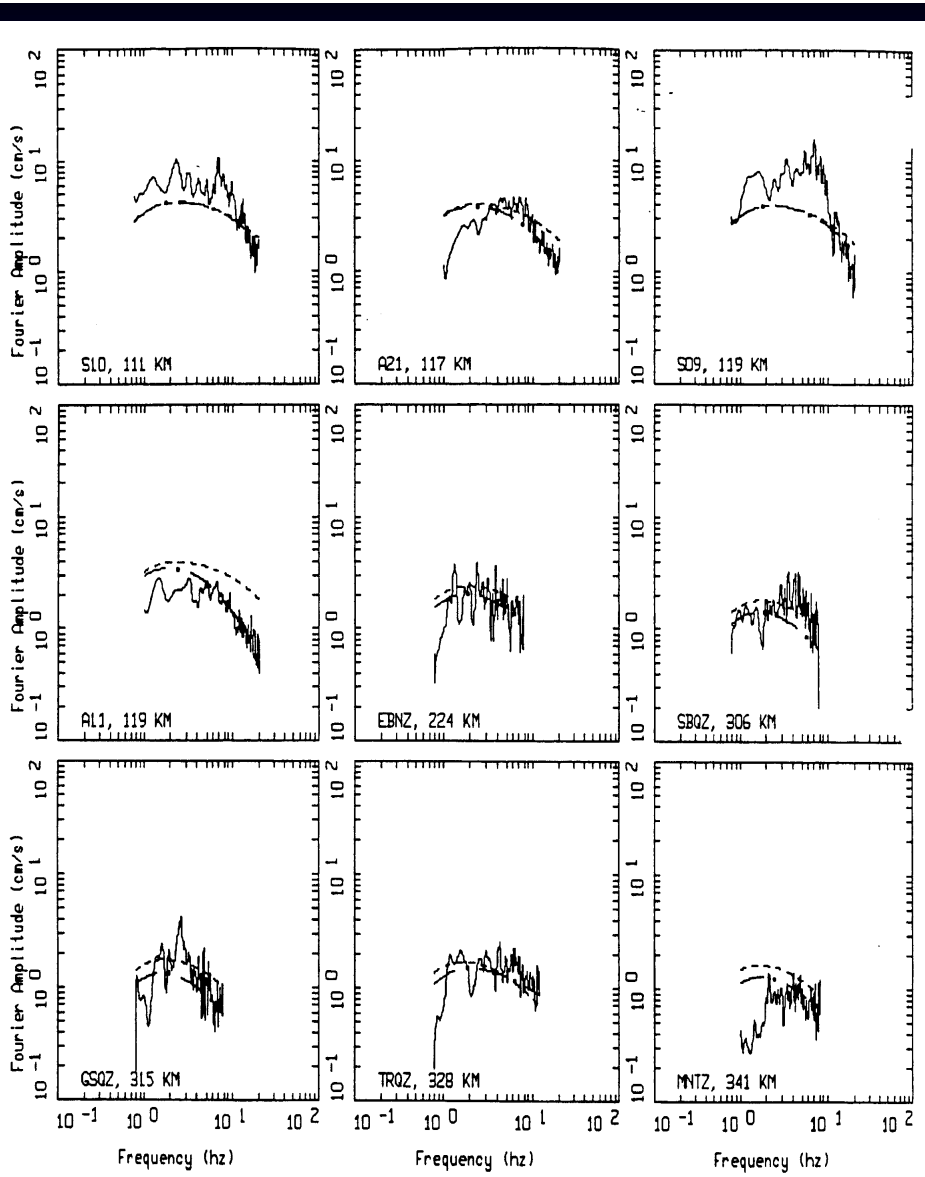
SAGUENAY EARTHQUAKE, M=5.8, PAGE 1 OF 3.

LEGEND

——— DATA

- - - - - INITIAL MODEL

— • — FINAL MODEL



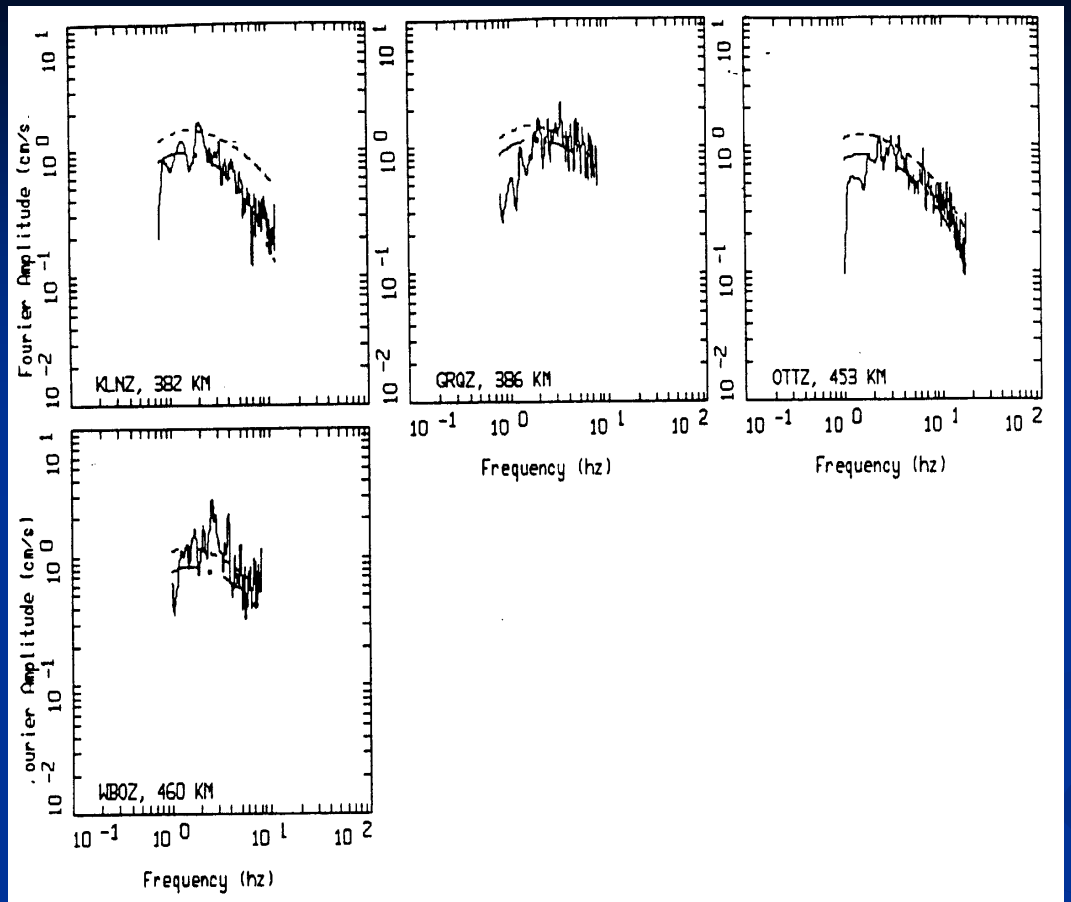
SAGUENAY EARTHQUAKE, M=5.8, PAGE 2 OF 3.

LEGEND

——— DATA

- - - - - INITIAL MODEL

— • — FINAL MODEL



SAGUENAY EARTHQUAKE, M=5.8, PAGE 3 OF 3.

LEGEND

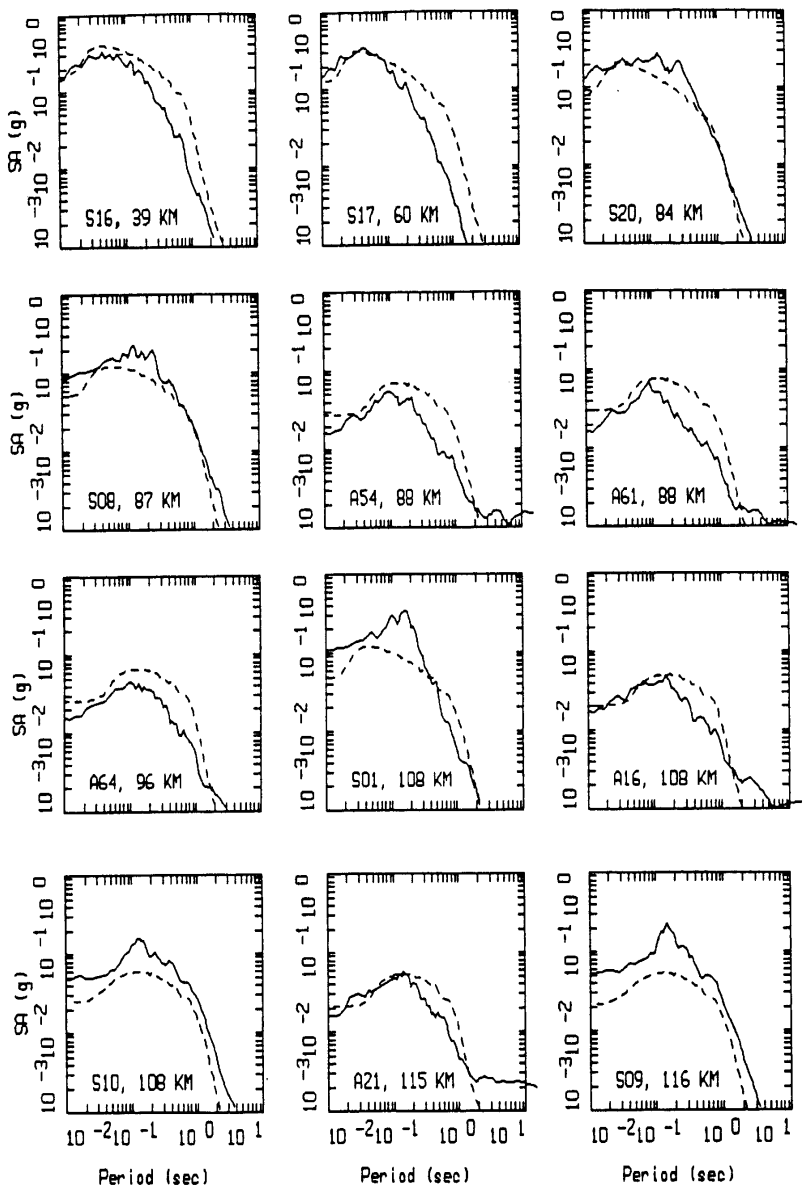
——— DATA

- - - - - INITIAL MODEL

— • — FINAL MODEL

Saguenay EQ Inversion: Results

- Stress Drop = 572.2 $\pm$ 25.4 bars
- Kappa Average = 0.023 sec
- $Q(f) = 351f^{0.84}$



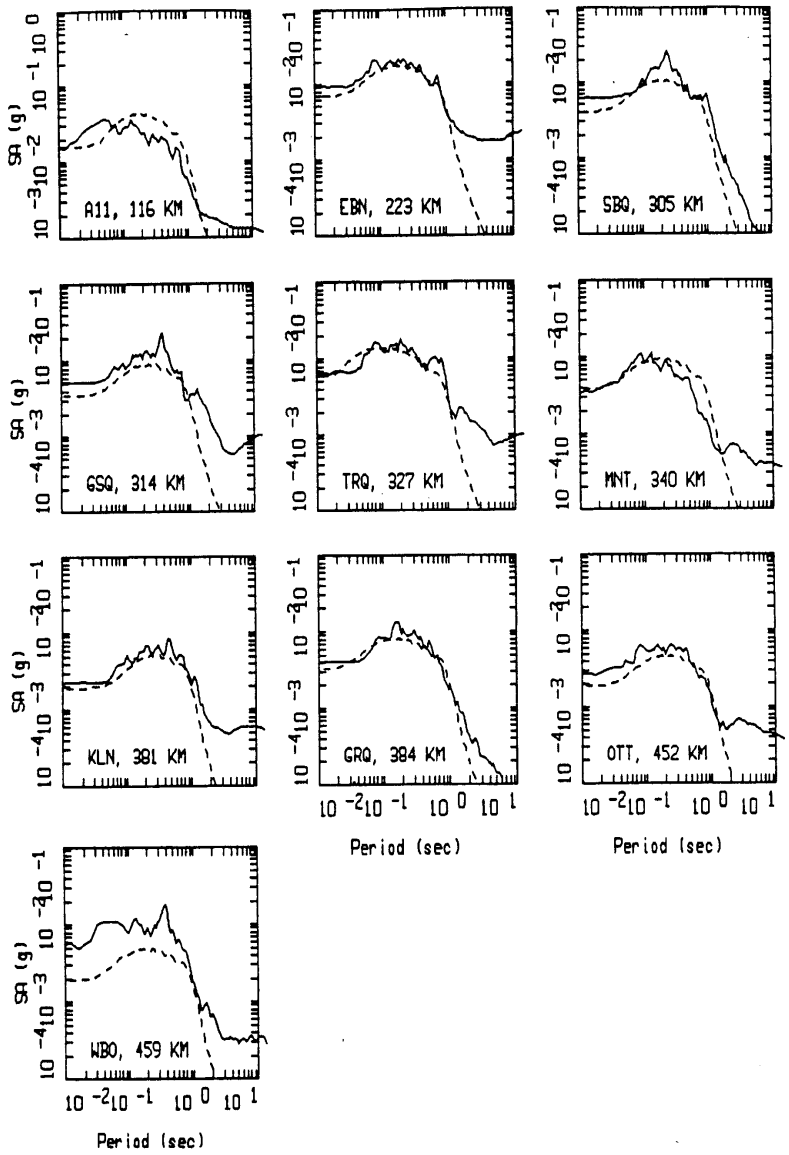
SAGUENAY, POINT SOURCE MODELING, PAGE 1 OF 2.

LINEAR.

LEGEND

——— DATA

----- MODEL



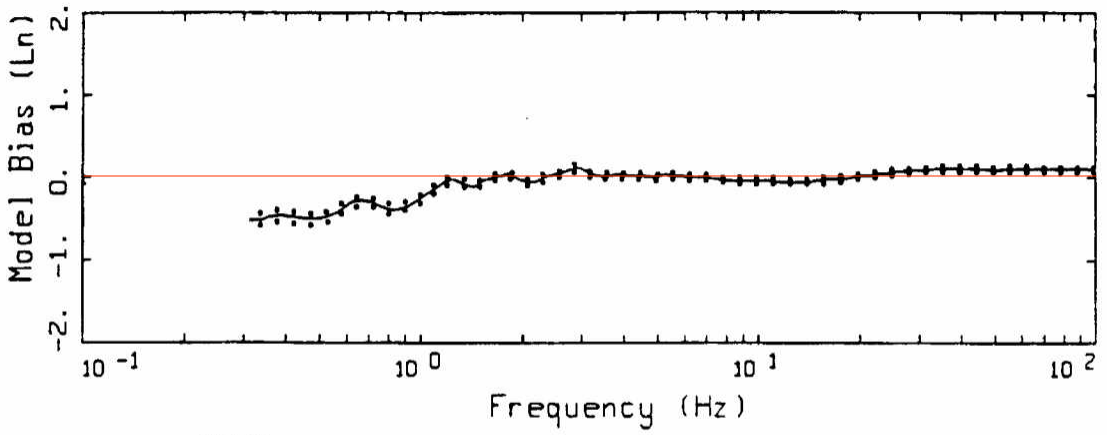
SAGUENAY, POINT SOURCE MODELING, PAGE 2 OF 2.

LINEAR.

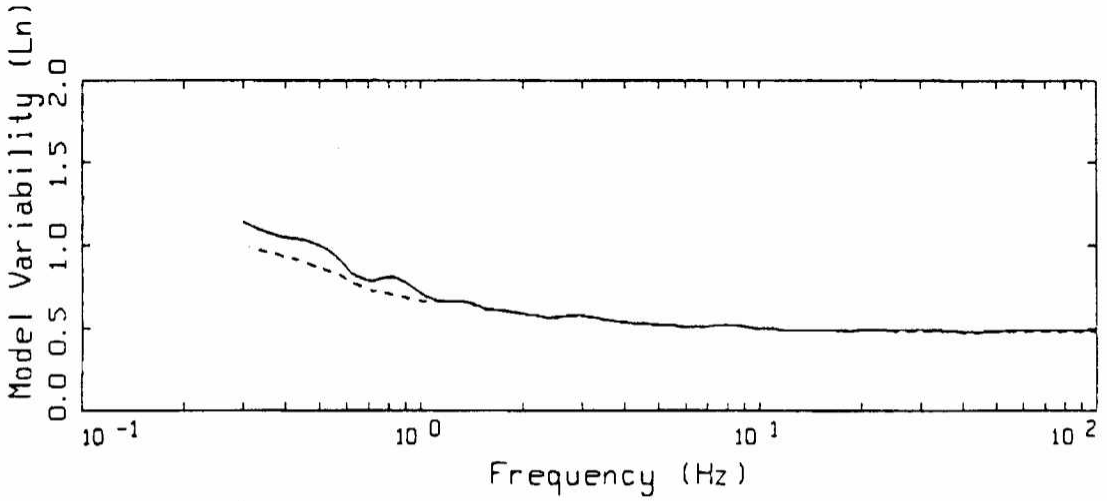
LEGEND

——— DATA

----- MODEL



LEGEND
MODELING BIAS
90% CONFIDENCE INTERVAL OF MODELING BIAS
90% CONFIDENCE INTERVAL OF MODELING BIAS



LEGEND
MEAN=0.0
BIAS CORRECTED

16 EARTHQUAKES POINT-SOURCE
NONLINEAR, ALL 503 SITES

Additional Earthquakes for Model Validation / Variability Update

Earthquake	Mag	Earthquake	Mag
1994 Northridge AS1	6.05	1999 Chi-Chi AS2	6.20
1994 Northridge AS2	5.20	1999 Chi-Chi AS3	6.20
1994 Northridge AS3	5.93	1999 Chi-Chi AS4	6.20
1994 Northridge AS4	5.13	1999 Chi-Chi AS5	6.30
1994 Northridge AS5	5.28	1999 Koaceli (Turkey)	7.51
1995 Kobe (Japan)	6.90	1999 Duzce (Turkey)	7.14
1999 Hector Mine	7.13	2000 Tottori (Japan)	7.3
1999 Chi-Chi MS	7.62	2002 Denali	7.9
1999 Chi-Chi AS1	5.90	2003 Bam (Iran)	6.6
		2004 Niigata (Japan)	6.8

Model Parameters

- Point Source Stress Drop ($\Delta\sigma$)
- Crustal Model
- Point Source Depth
- Q-model: $Q(f) = Q_o f^{\eta}$
- Geometrical Attenuation
- Kappa (Site term)

Point Source Stress Drop ($\Delta\sigma$)

- Magnitude dependent Stress Drop:
  - $M \leq 5.5$ = 160 bars
  - M6.5 = 120 bars
  - M7.5 = 90 bars
  - M8.5 = 70 bars
- Constant Stress Drop: 120 bars
- High, Medium, Low Stress Drop Models
- Variability: $\sigma_{ln} = 0.5$

Point Source Stress Drop ($\Delta\sigma$)

Earthquakes	Stress Drop (Bars)	σ_{ln}
All	46.9	0.47
Shallow Slip	30.6	0.37
Deep Slip	56.6	0.38

Crustal Models

- EPRI (1993) Mid-Continent Crustal Model

Thickness (km)	Vs (km/sec)	Density (cgs)
1.30	2.83	2.52
11.00	3.52	2.71
28.00	3.75	2.78
Half-Space	4.62	3.35

- EPRI (1993) Gulf Coast Crustal Model

Thickness (km)	Vs (km/sec)	Density (cgs)
7.00	2.31	2.37
8.00	3.05	2.58
15.00	3.76	2.78
Half-Space	4.74	3.40

Source Depth

- Magnitude Dependent Truncated Depth Distribution

Magnitude	Lower Bound (km)	Mean Depth (km)	Upper Bound (km)
4.5	2	6	15
5.5	2	6	15
6.5	4	8	20
7.5	5	10	20
8.5	5	10	20

$\sigma_{ln} = 0.6$

Q-Model

- Mid-Continent (Silva et al. 1997):

$$Q(f) = 351f^{0.84}$$

- Gulf Coast (EPRI 1993):

$$Q(f) = 300\ f^{0.30}$$

- $\sigma_{lnQo} = 0.4$

Geometrical Attenuation and Kappa

- Magnitude Dependent Far Field Attenuation:

  $R^{-(a+b(M-6.5))}$ where a=1.0296, b=-0.0422

  $R^{-(a+b(M-6.5))/2}$ for R> 80 km

- Kappa = 0.006 sec (EPRI, 1993)

DataSet

- 5 magnitudes: 4.5, 5.5, 6.5, 7.5, 8.5
- 9 Distances: 1, 5, 10, 20, 50, 75, 100, 200, 400
- 300 Realizations for each magnitude and distance pair
- Randomly Vary source depth, Stress Drop, Q_o, and top 100 feet of profile
- Total of 13,500 response spectra

Alternative Source Models

- Single Corner Model
  - Constant Stress Drop (120 bars)
  - Variable Stress Drop (Magnitude Dependent)
- Double Corner Model
  (Atkinson and Boore, 1995)

Saturation of Ground Motions

- Reduction in the scaling of ground motions as a function of magnitude
- Fictitious Depth term:

  $H = H' * \exp(-1.250+0.227M)$ for $M>6.5$

- Applied to Double Corner and Single Corner with Constant Stress Drop Models

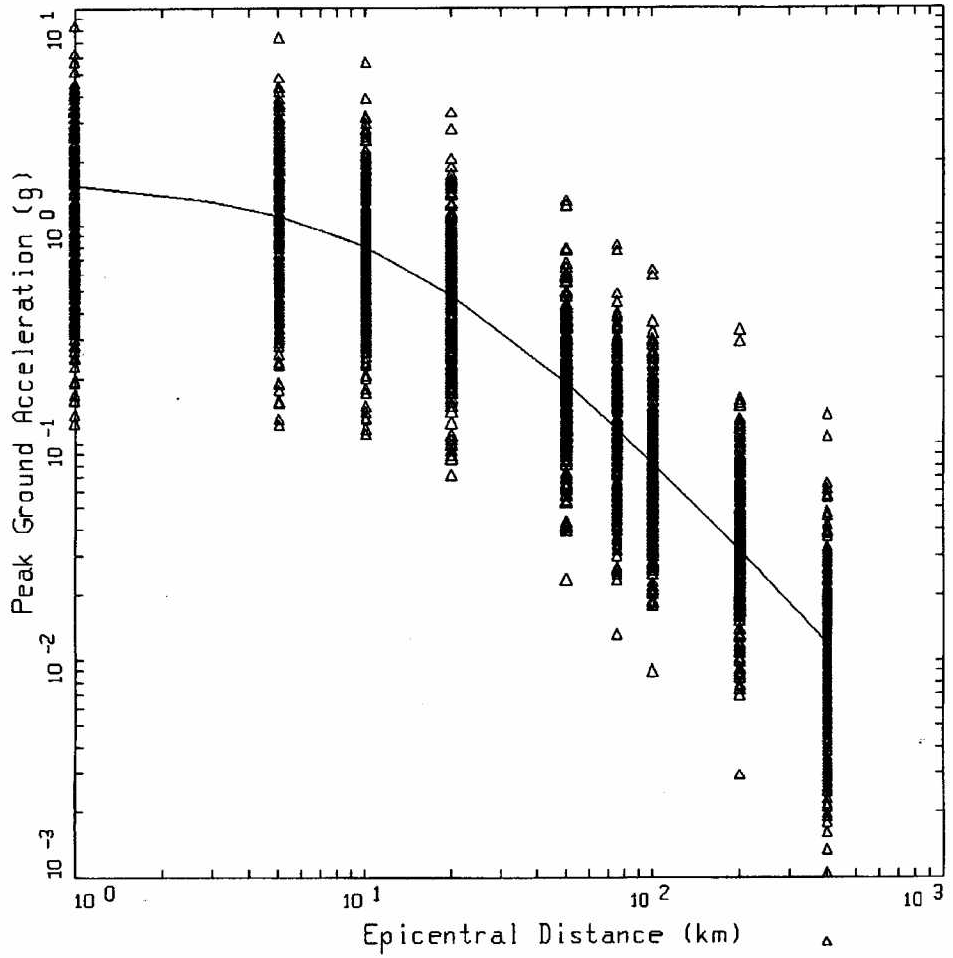
Summary of Ground Motion Models

- Single Corner Constant Stress Drop (Low, Medium, High)
- Single Corner Constant Stress Drop with Saturation (Low, Medium, High)
- Single Corner Variable Stress Drop (Low, Medium, High)
- Double Corner
- Double Corner with Saturation

Total CEUS Models = 22

Attenuation Model

$$\ln(Sa) = C_1 + C_2 M + (C_6 + C_7 M)\ln(R + \exp(C_4)) + C_{10}(M-6)^2$$

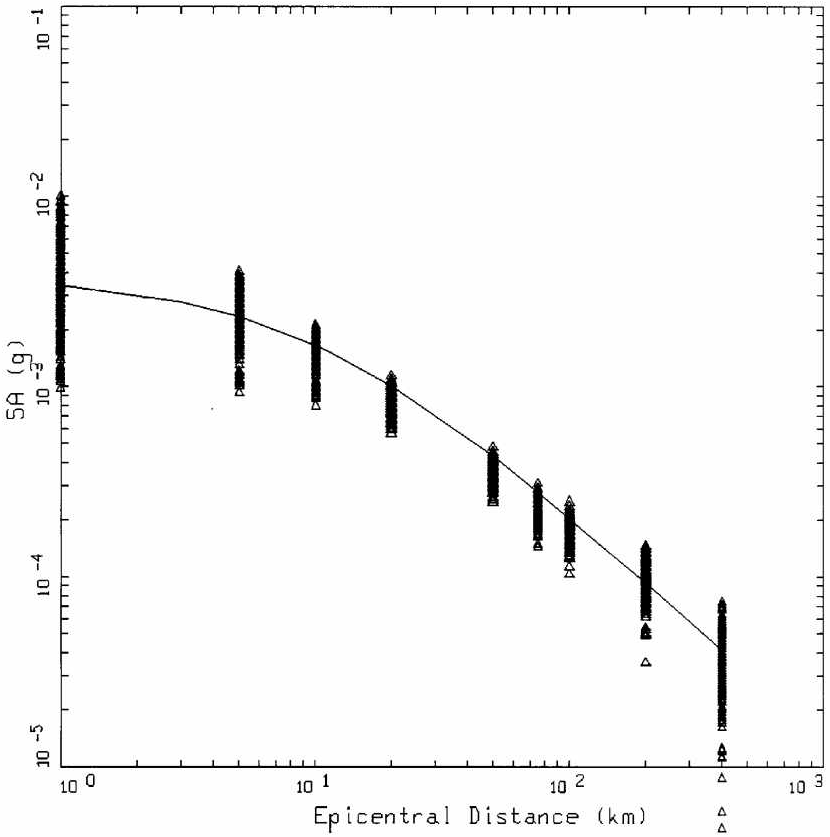


1 CORNER VARIABLE STRESS DROP
M=7.5, CEUS HARD ROCK, PGA

LEGEND

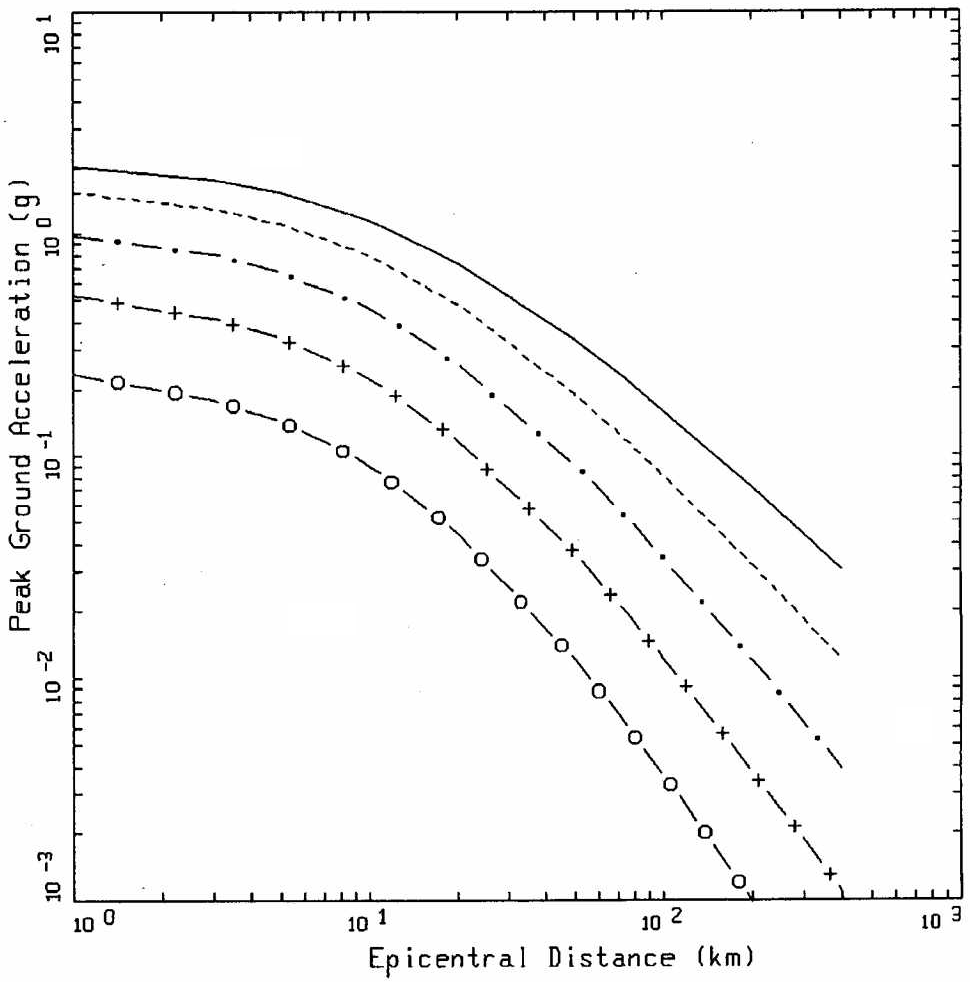
Δ Δ DATA: PGA

——— M=7.5, SIMGA=0.6912



1 CORNER VARIABLE STRESS DROP
M=5.5, CEUS HARD ROCK, 0.2HZ

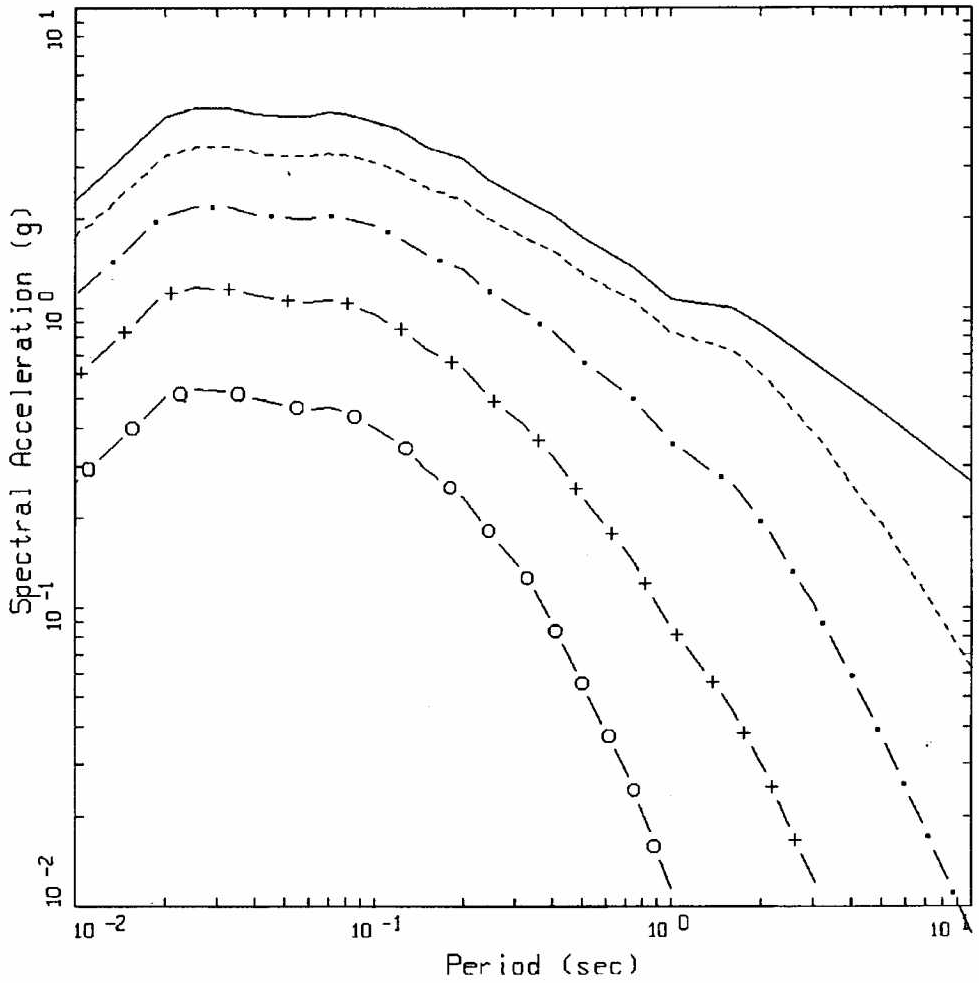
LEGEND
DATA: 0.20 HZ
M=5.5, SIGMA=0.3660



1 CORNER VARIABLE STRESS DROP
HARD ROCK, PGA

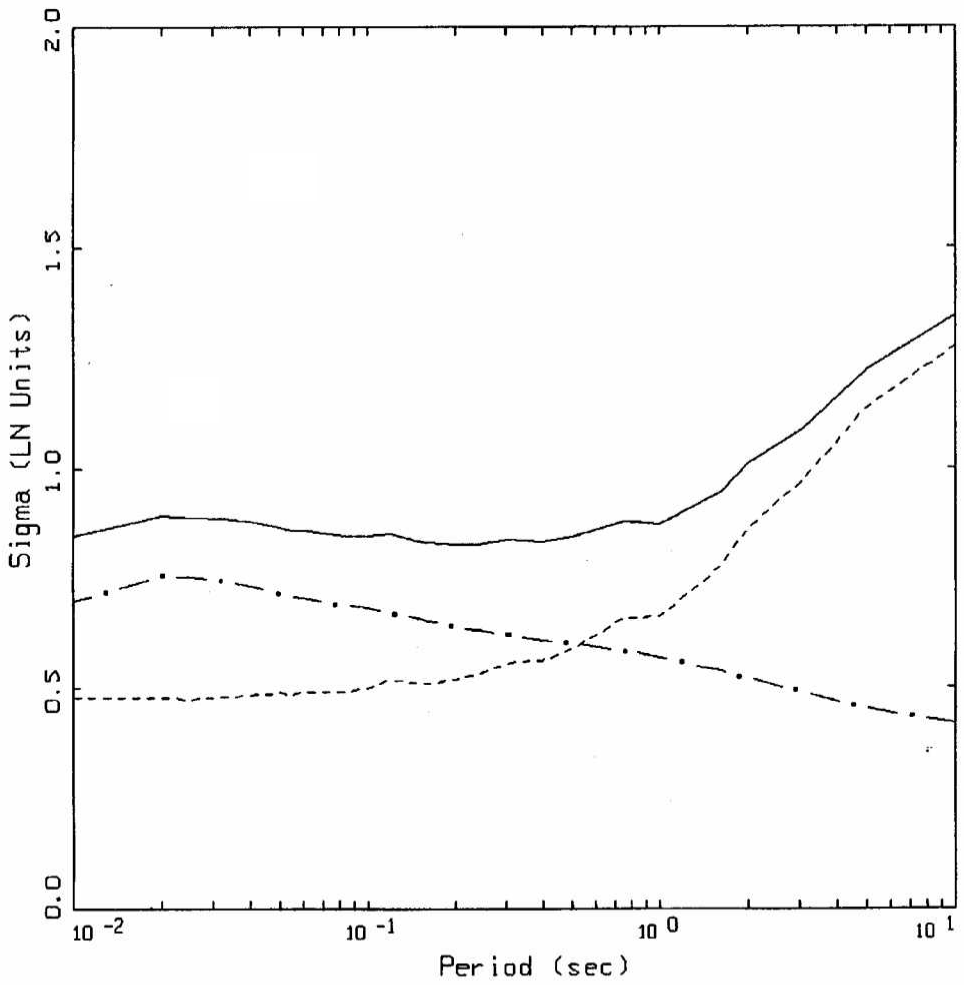
LEGEND

———	M=8.5, SIMGA=0.6912
- - - - -	M=7.5, SIMGA=0.6912
— • —	M=6.5, SIGMA=0.6912
— + —	M=5.5, SIGMA=0.6912
— o —	M=4.5, SIGMA=0.6912



1 CORNER VARIABLE STRESS DROP
DISTANCE=1 KM, HARD ROCK, SA

LEGEND
M=8.5
M=7.5
M=6.5
M=5.5
M=4.5



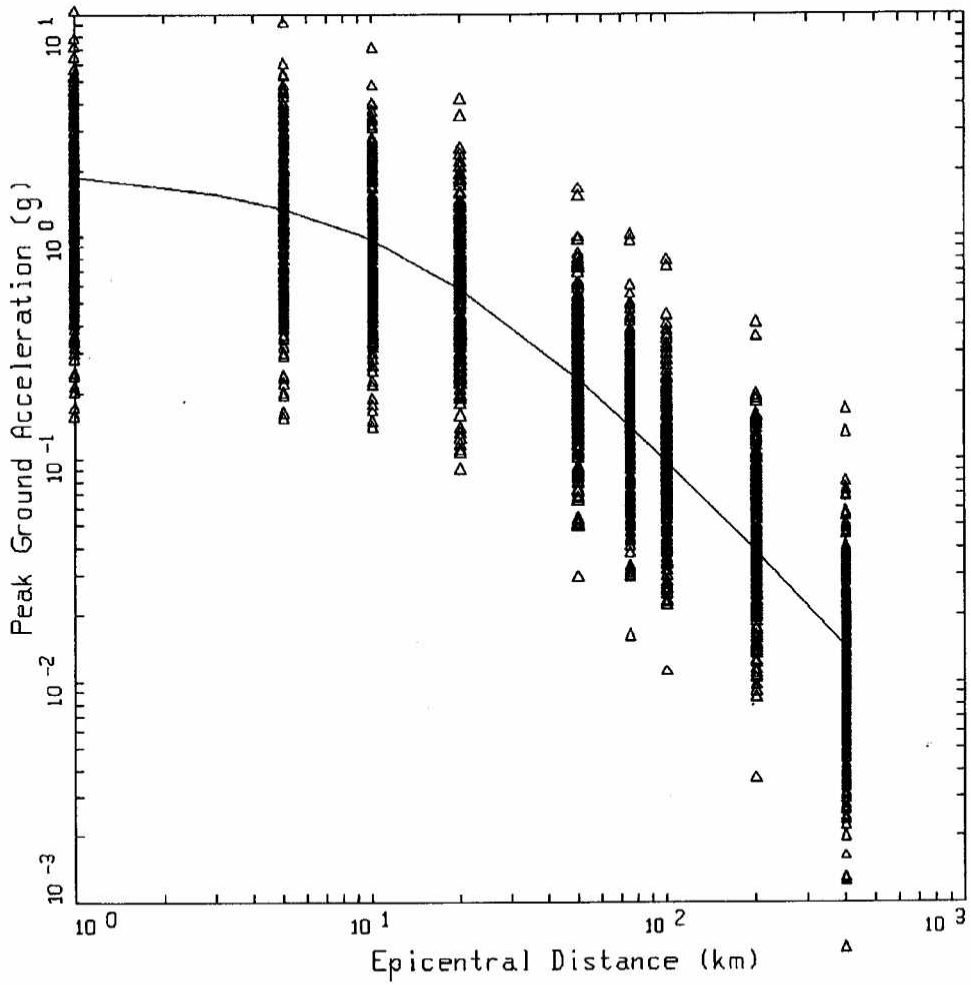
1 CORNER VARIABLE STRESS DROP
HARD ROCK, SIGMA

LEGEND

TOTAL SIGMA

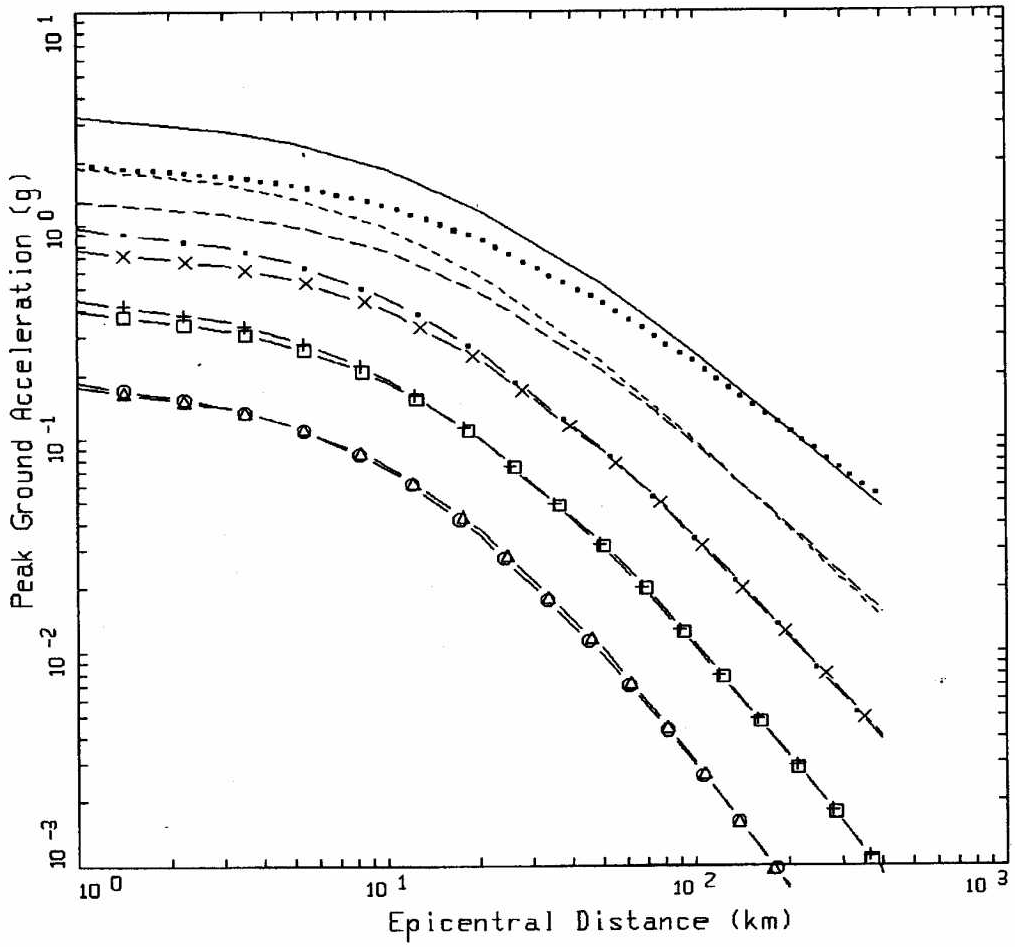
PARAMETRIC SIGMA

MODELING SIGMA (BIAS CORRECTED)



1 CORNER CONSTANT STRESS DROP
M=7.5, CEUS HARD ROCK, PGA

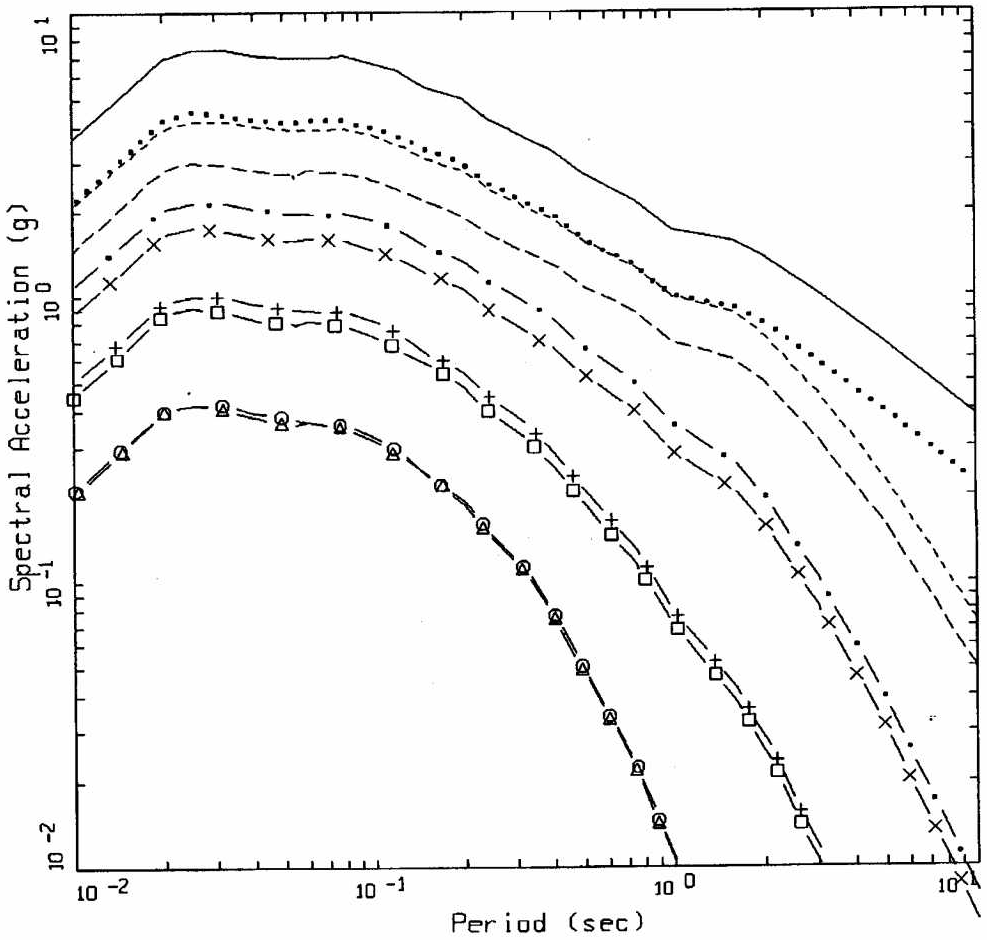
LEGEND
DATA: PGA
M=7.5, SIMGA=0.6886



1 CORNER CONSTANT STRESS DROP
HARD ROCK, PGA

LEGEND

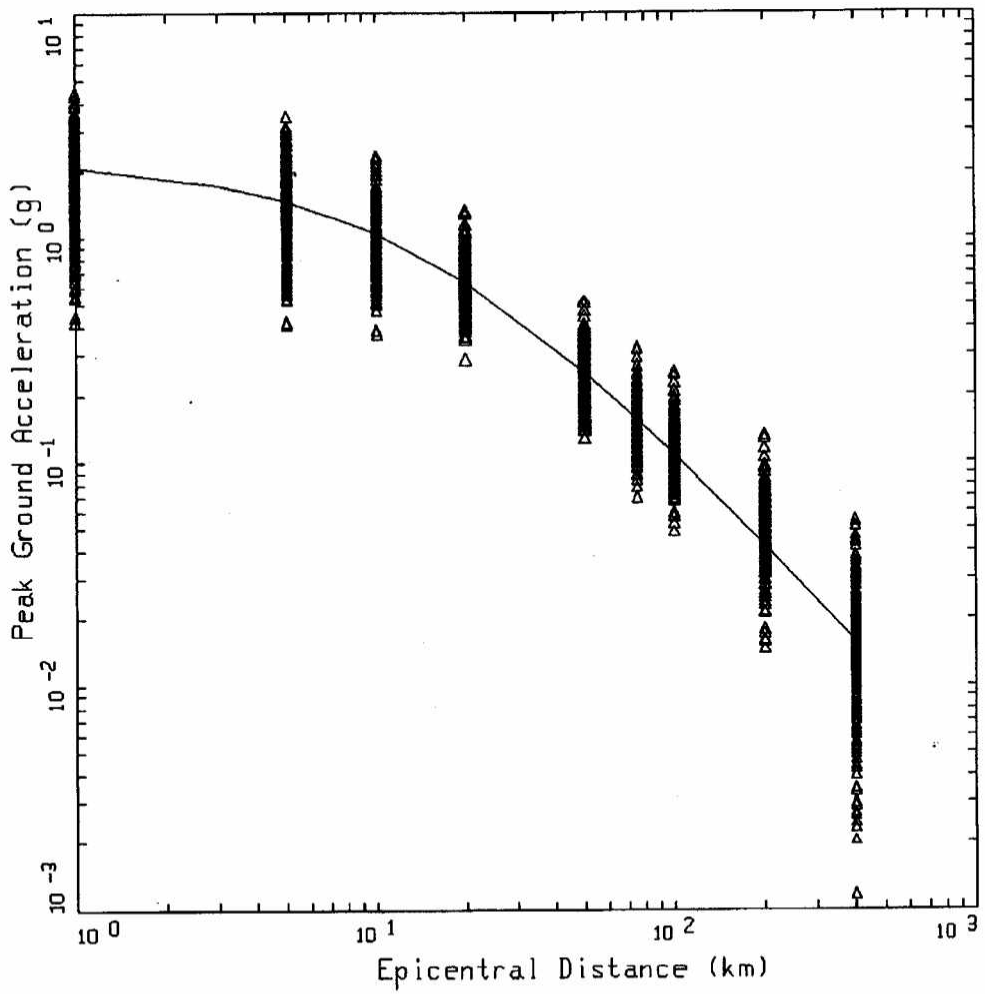
———	M=8.5, SIMGA=0.6886
- - - - -	M=7.5, SIMGA=0.6886
— • —	M=6.5, SIGMA=0.6886
— + —	M=5.5, SIGMA=0.6886
— o —	M=4.5, SIGMA=0.6886
• • • •	M=8.5 WITH SATURATION, SIMGA=0.6998
— — —	M=7.5 WITH SATURATION, SIMGA=0.6998
— × —	M=6.5 WITH SATURATION, SIGMA=0.6998
— □ —	M=5.5 WITH SATURAITON, SIGMA=0.6998
— △ —	M=4.5 WITH SATURATION, SIGMA=0.6998



1 CORNER CONSTANT STRESS DROP
DISTANCE=1 KM, HARD ROCK, SA

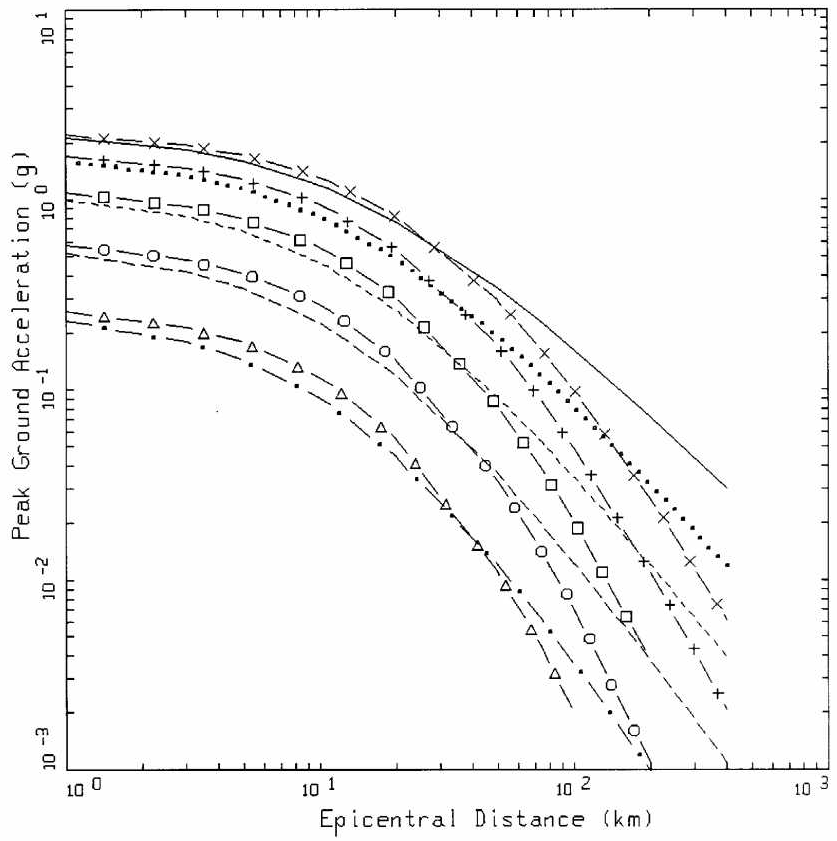
LEGEND

———	M=8.5
- - - - -	M=7.5
— • —	M=6.5
— + —	M=5.5
— ○ —	M=4.5
• • • •	M=8.5 WITH SATURATION
— — — —	M=7.5 WITH SATURATION
— × —	M=6.5 WITH SATURATION
— □ —	M=5.5 WITH SATURATION
— △ —	M=4.5 WITH SATURATION



2 CORNER
M=7.5, CEUS HARD ROCK, PGA

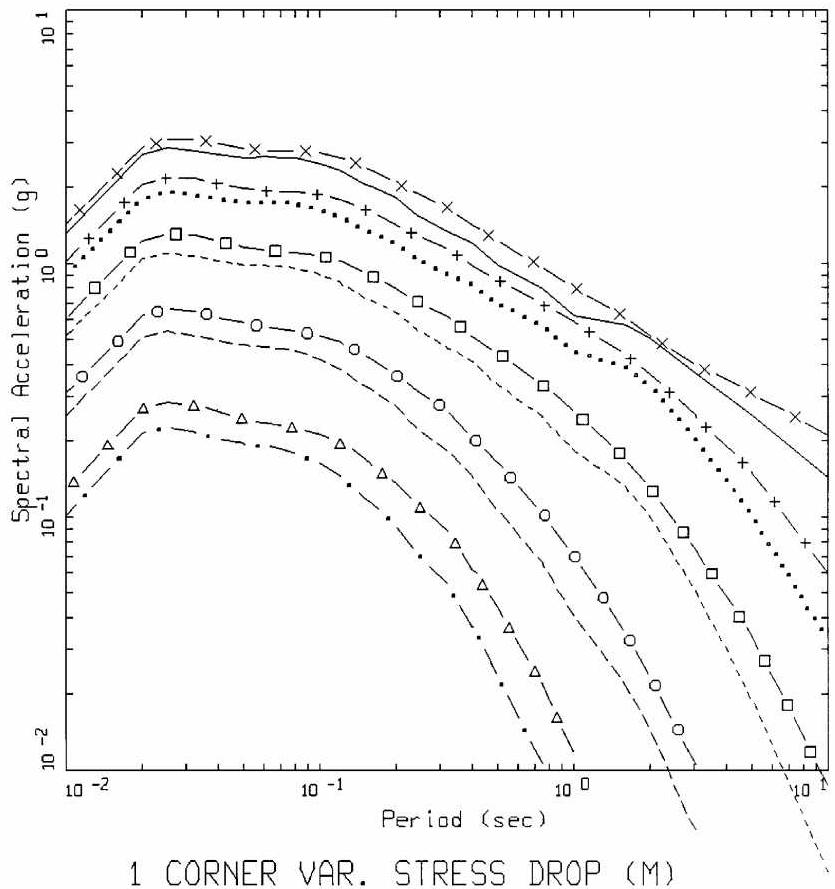
LEGEND
DATA: PGA
M=7.5, SIMGA=0.6912



1 CORNER VAR. STRESS DROP (M)
MIDCONTINENT AND GULF, PGA

LEGEND

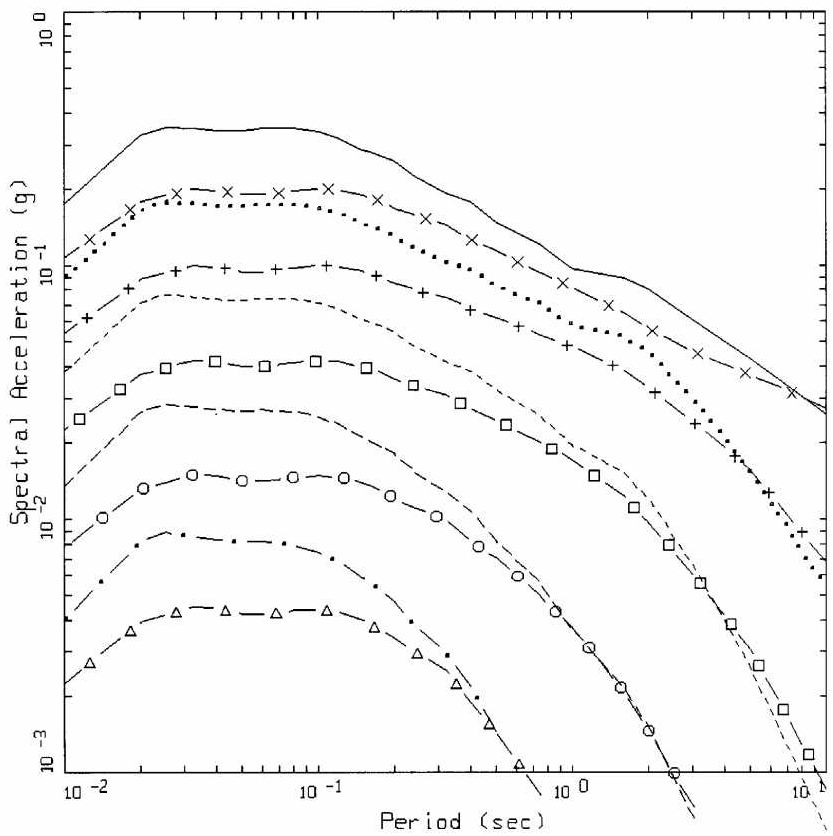
MIDCONTINENT: M=8.5, SIMGA=0.5592
MIDCONTINENT: M=7.5, SIMGA=0.5592
MIDCONTINENT: M=6.5, SIGMA=0.5592
MIDCONTINENT: M=5.5, SIGMA=0.5592
MIDCONTINENT: M=4.5, SIGMA=0.5592
GULF COAST: M=8.5, SIMGA=0.7666
GULF COAST: M=7.5, SIMGA=0.7666
GULF COAST: M=6.5, SIGMA=0.7666
GULF COAST: M=5.5, SIGMA=0.7666
GULF COAST: M=4.5, SIGMA=0.7666



1 CORNER VAR. STRESS DROP (M)
DISTANCE=10KM, MIDCONT.&GULF, SA

LEGEND

- MIDCONTINENT: M=8.5
- MIDCONTINENT: M=7.5
- MIDCONTINENT: M=6.5
- MIDCONTINENT: M=5.5
- MIDCONTINENT: M=4.5
- GULF COAST: M=8.5
- GULF COAST: M=7.5
- GULF COAST: M=6.5
- GULF COAST: M=5.5
- GULF COAST: M=4.5

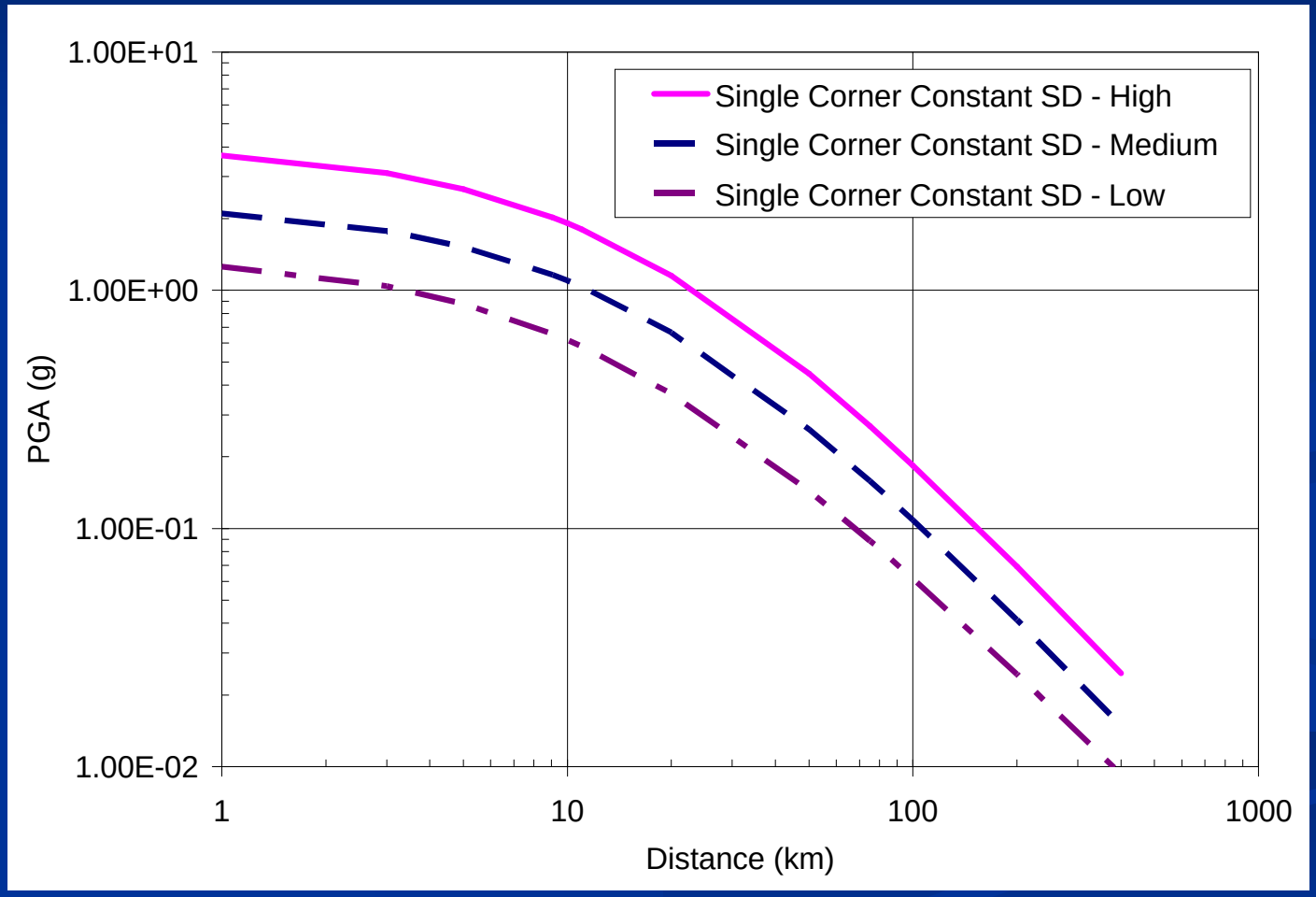


1 CORNER VAR. STRESS DROP (M)
DISTANCE=100KM, MIDCON.&GULF, SA

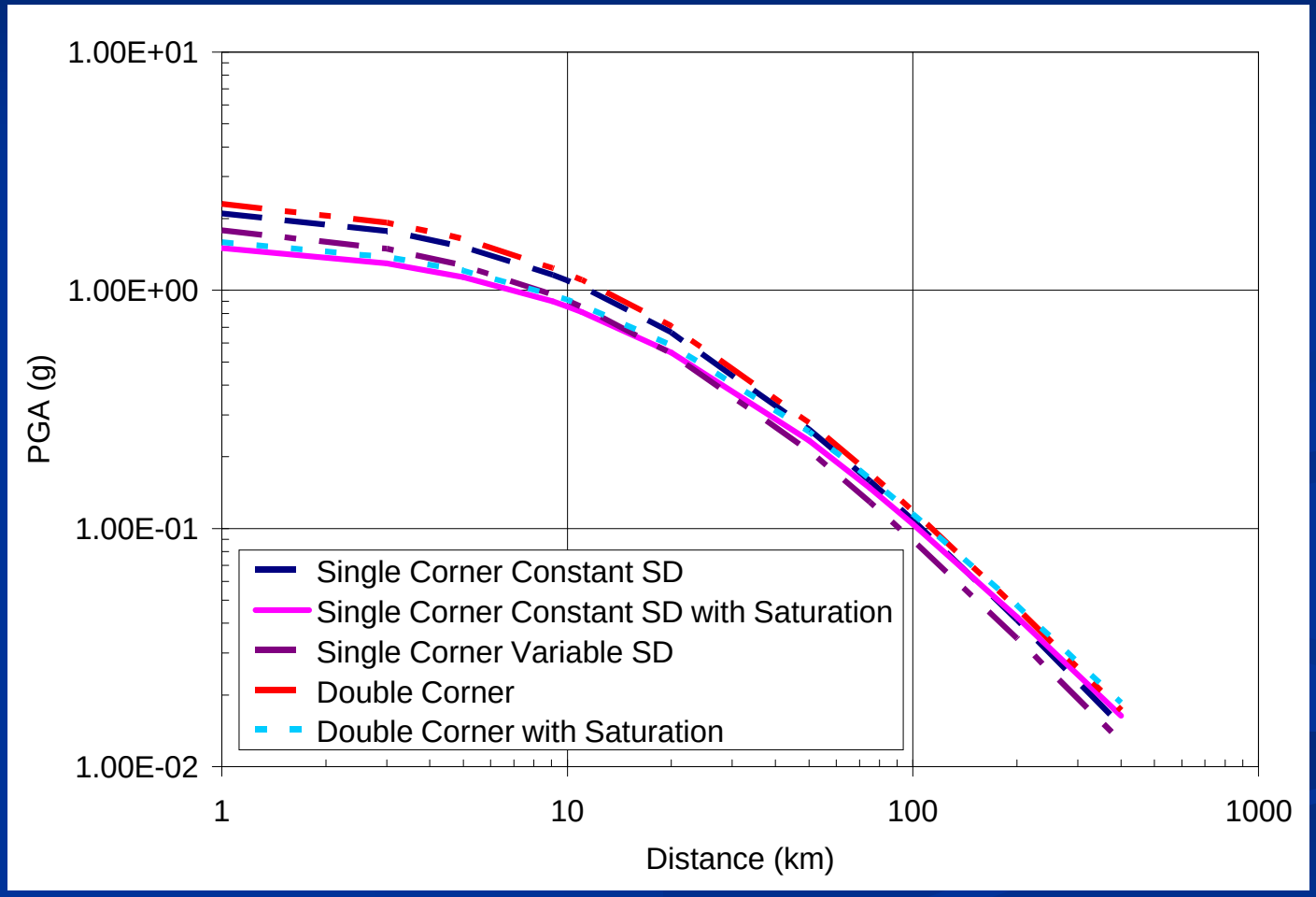
LEGEND

- MIDCONTINENT: M=8.5
- MIDCONTINENT: M=7.5
- MIDCONTINENT: M=6.5
- MIDCONTINENT: M=5.5
- MIDCONTINENT: M=4.5
- GULF COAST: M=8.5
- GULF COAST: M=7.5
- GULF COAST: M=6.5
- GULF COAST: M=5.5
- GULF COAST: M=4.5

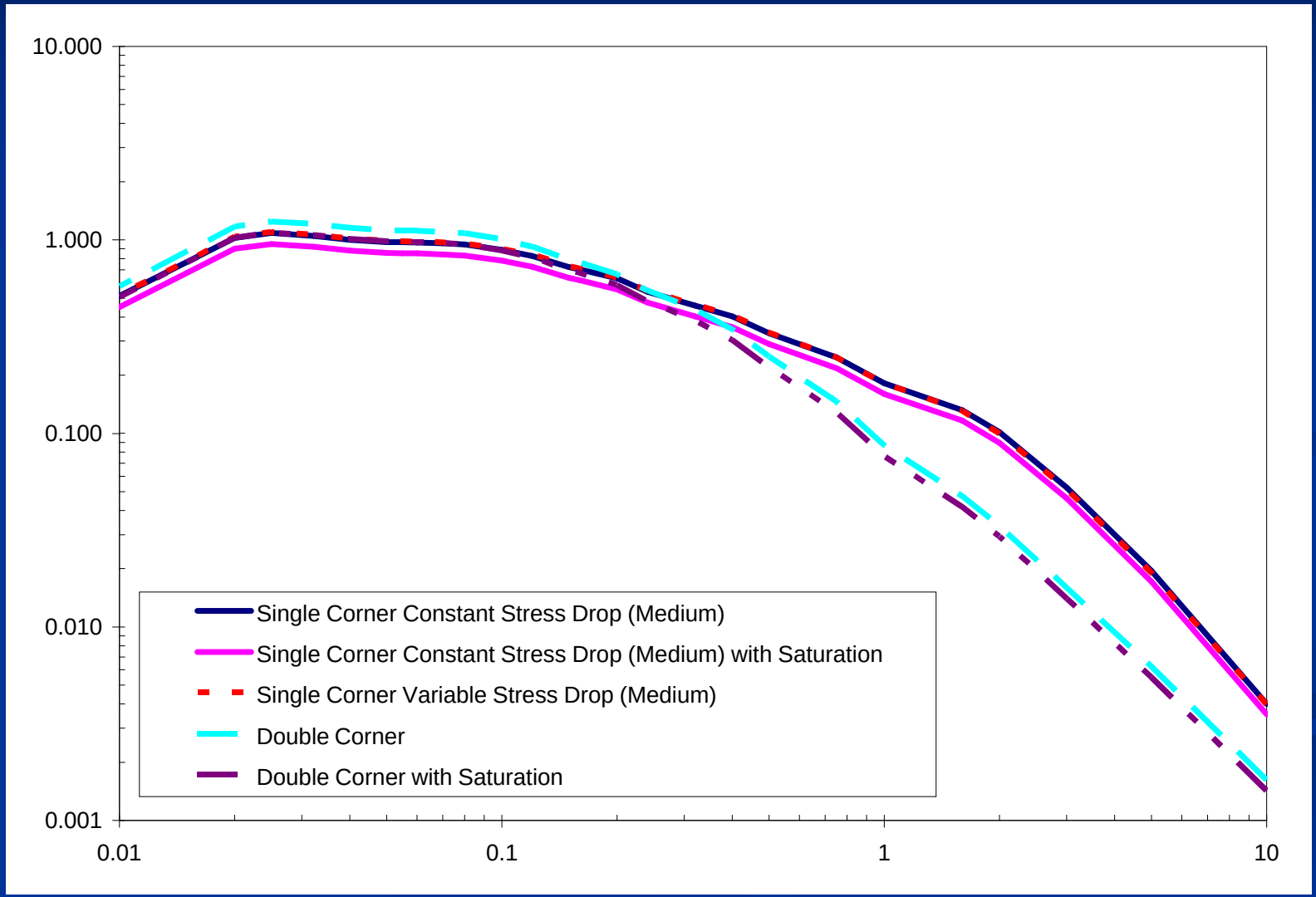
PGA - M7.5


1.00E+01
1.00E+00
1.00E-01
1.00E-02
PGA (g)
1
10
100
1000
Distance (km)
Single Corner Constant SD - High
Single Corner Constant SD - Medium
Single Corner Constant SD - Low

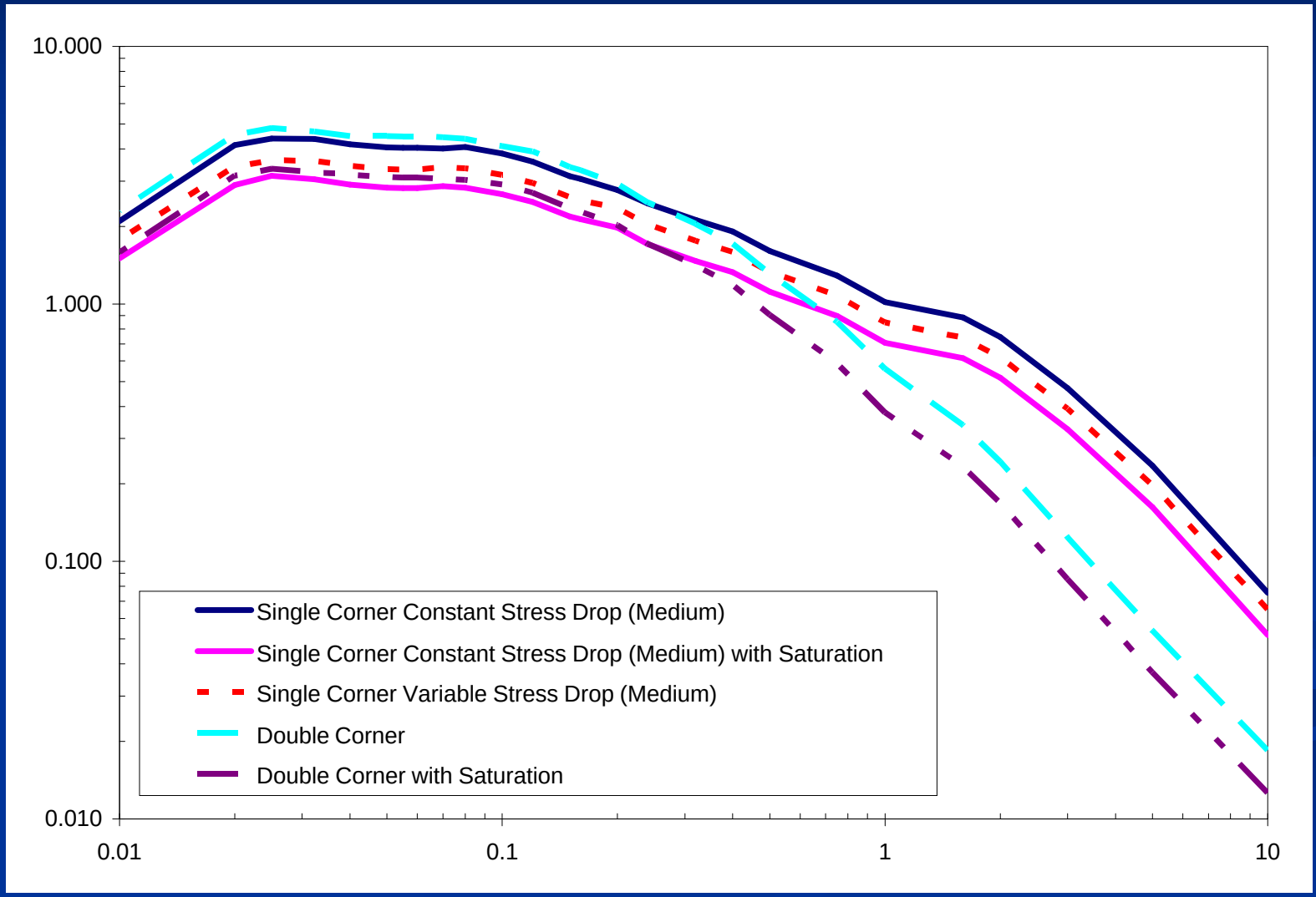
PGA – M7.5


1.00E+01
1.00E+00
1.00E-01
1.00E-02
PGA (g)
1
10
100
1000
Distance (km)
Single Corner Constant SD
Single Corner Constant SD with Saturation
Single Corner Variable SD
Double Corner
Double Corner with Saturation

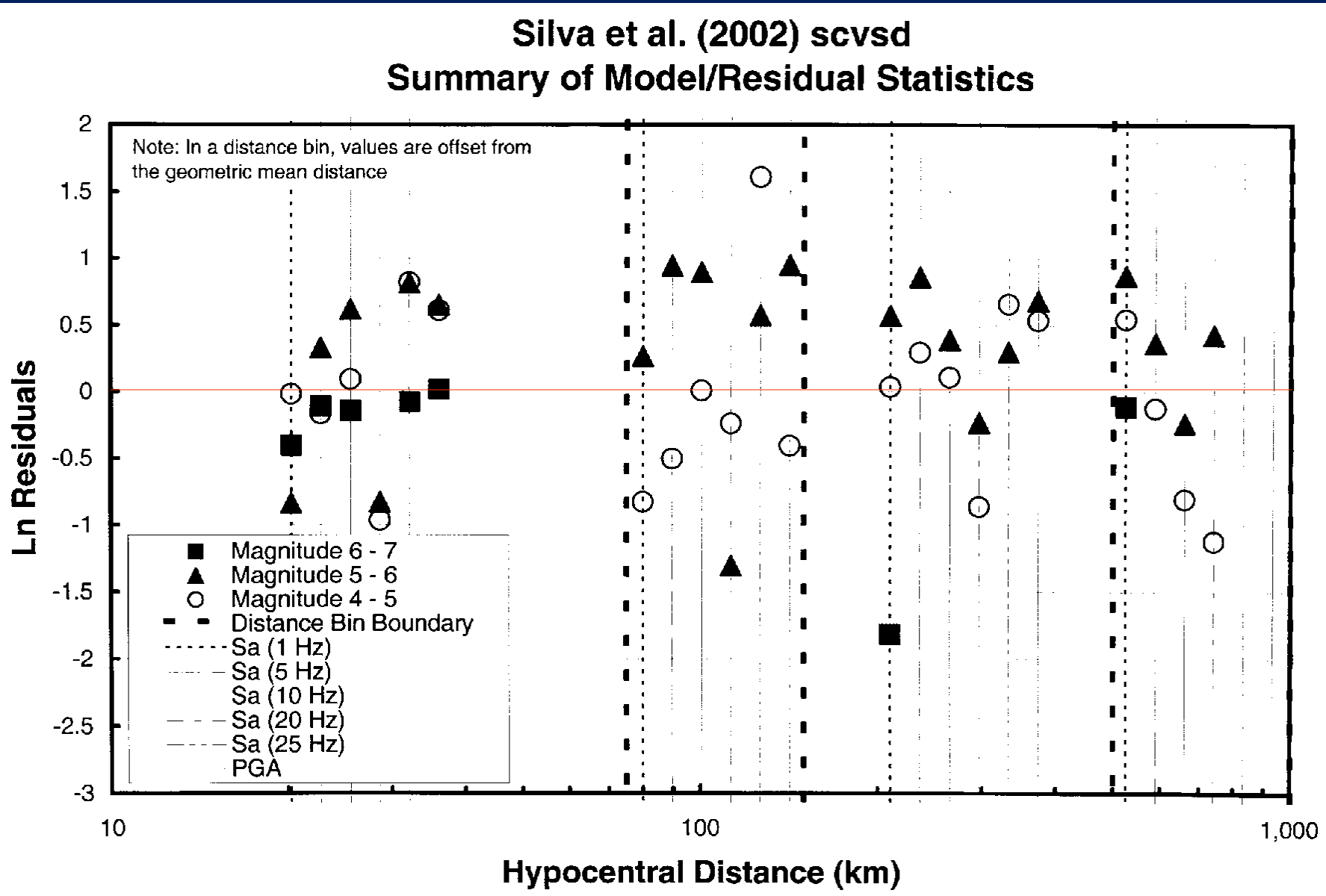
M6.5, Distance = 10 km



M7.5, Distance = 1 km



CEUS Residuals: Single Corner Variable Stress Drop



Ground Motion Model Updates

- Modeling Validation/Variability
- Point Source Stress Drop
- Geometrical Attenuation (NGA Empirical models)
- Saturation (NGA Empirical models)

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