EPRI (2004) CEUS Ground Motion Model

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EPRI CEUS Ground Motion Project

- Objective was to develop a representation of earthquake ground motion and its uncertainty for use in PSHA calculations for Early Site Permit (ESP) applications to hard rock sites in the CEUS
  - Update of EPRI-SOG (1989)
  - Focus on 1, 2.5, 5, and 10 Hz spectral accelerations
  - Range of application 0.5 to 100 Hz
- Build representation from existing CEUS Models
- Apply a SSHAC (1997) Level 3 process
  - Assessments made by one “entity”, the Technical Integrator (TI)
  - Guidance provided by a panel of experts through a series of workshops and document reviews
- Develop a reproducible process

Project Participants

Technical Integrator

- Marty McCann
- Bob Youngs
- Jim Marrone

Peer Review

- Carl Stepp
- Allin Cornell

Expert Panel

- Gail Atkinson
- Ken Campbell
- Richard Lee
- Walt Silva
- Paul Somerville
- Gabriel Toro

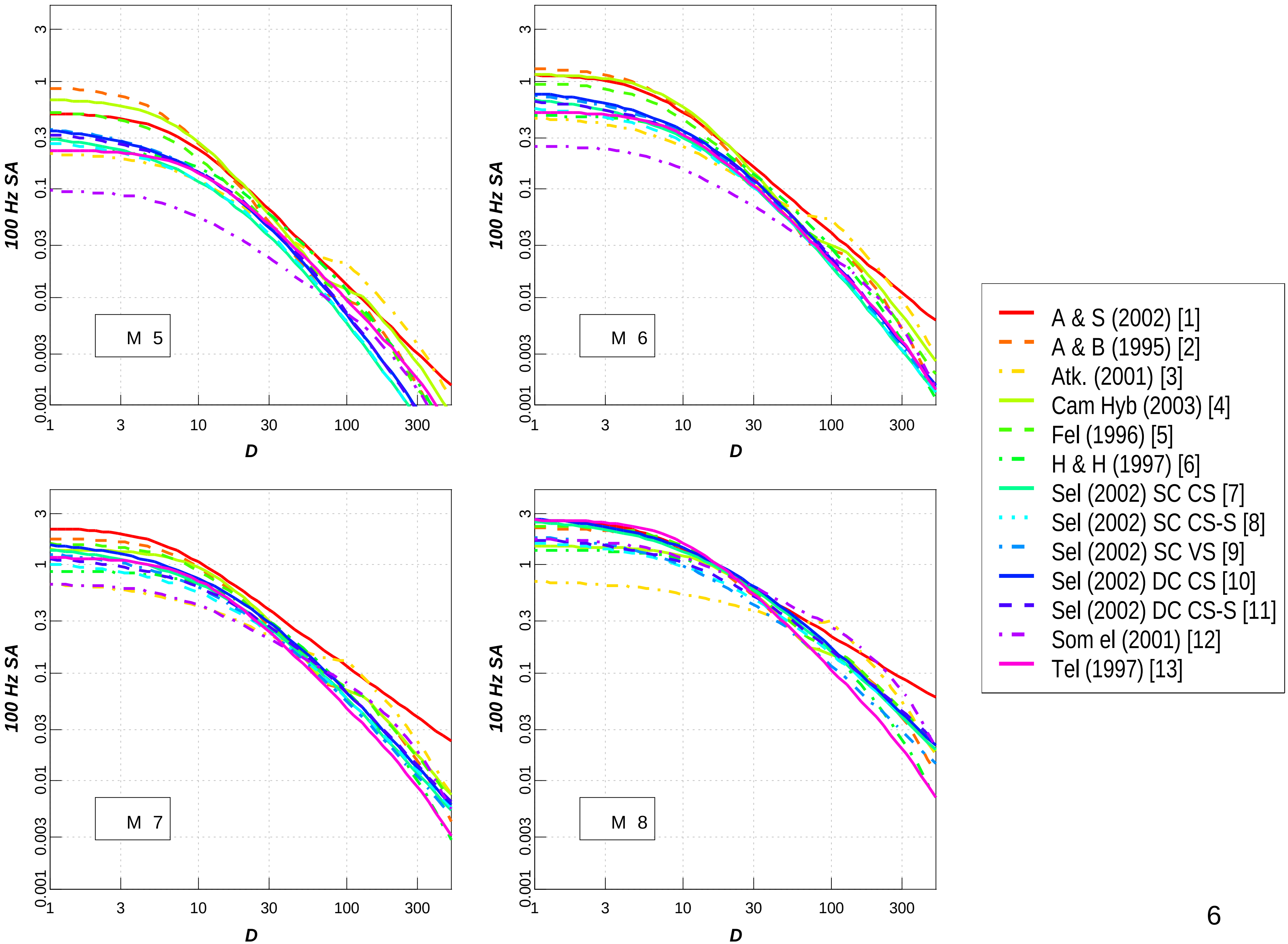
Model for Median Ground Motions and Their Epistemic Uncertainty

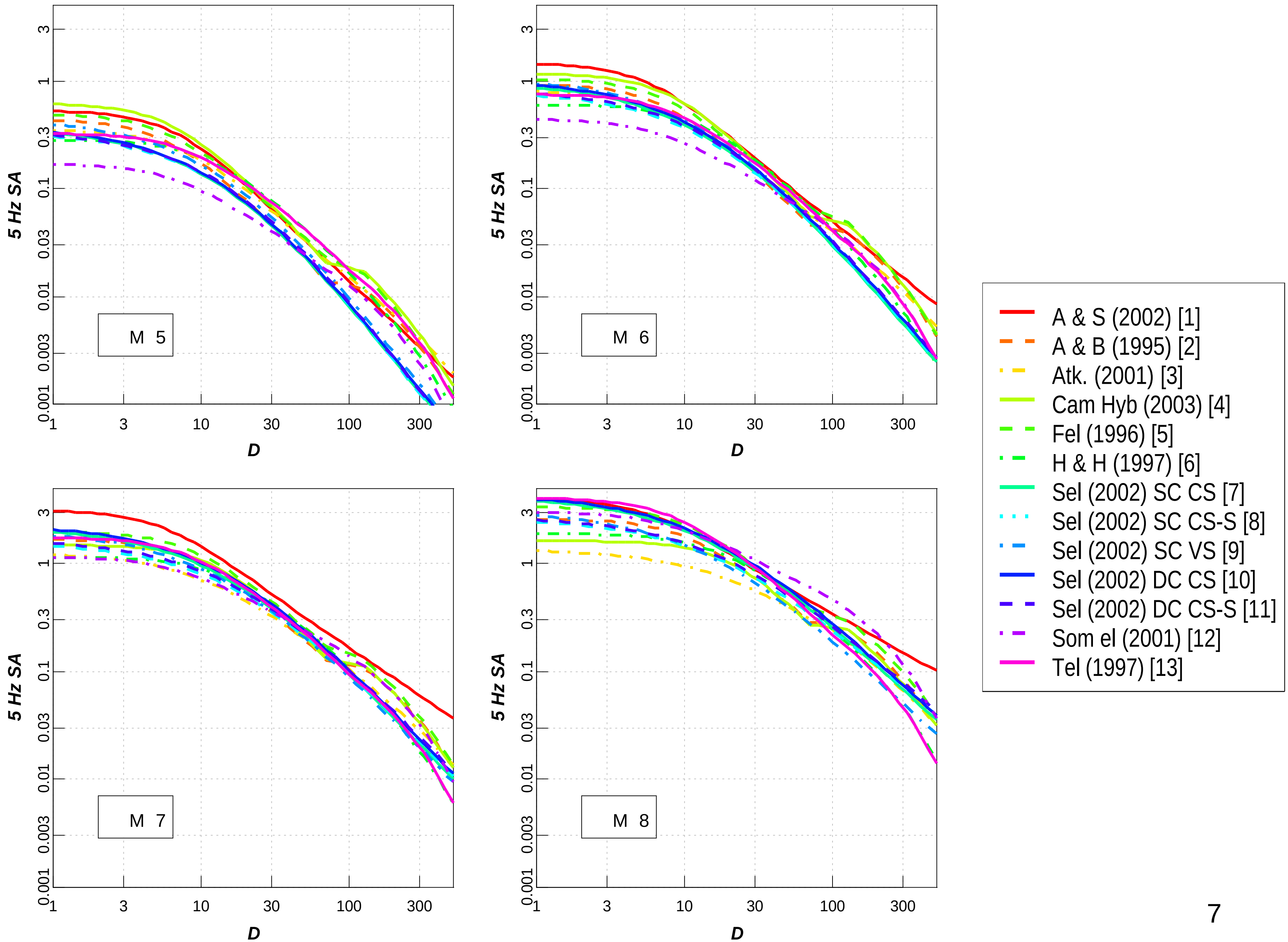
- Collect the set of existing usable ground motion models
  - “usable” means can provide ground motions for the range of magnitudes, distances and frequencies of interest to PSHA for ESP applications
- Group models into clusters based on similarity of modeling approach
- Develop intra-cluster weights based on fit to existing ground motion data

Median Ground Motion Models

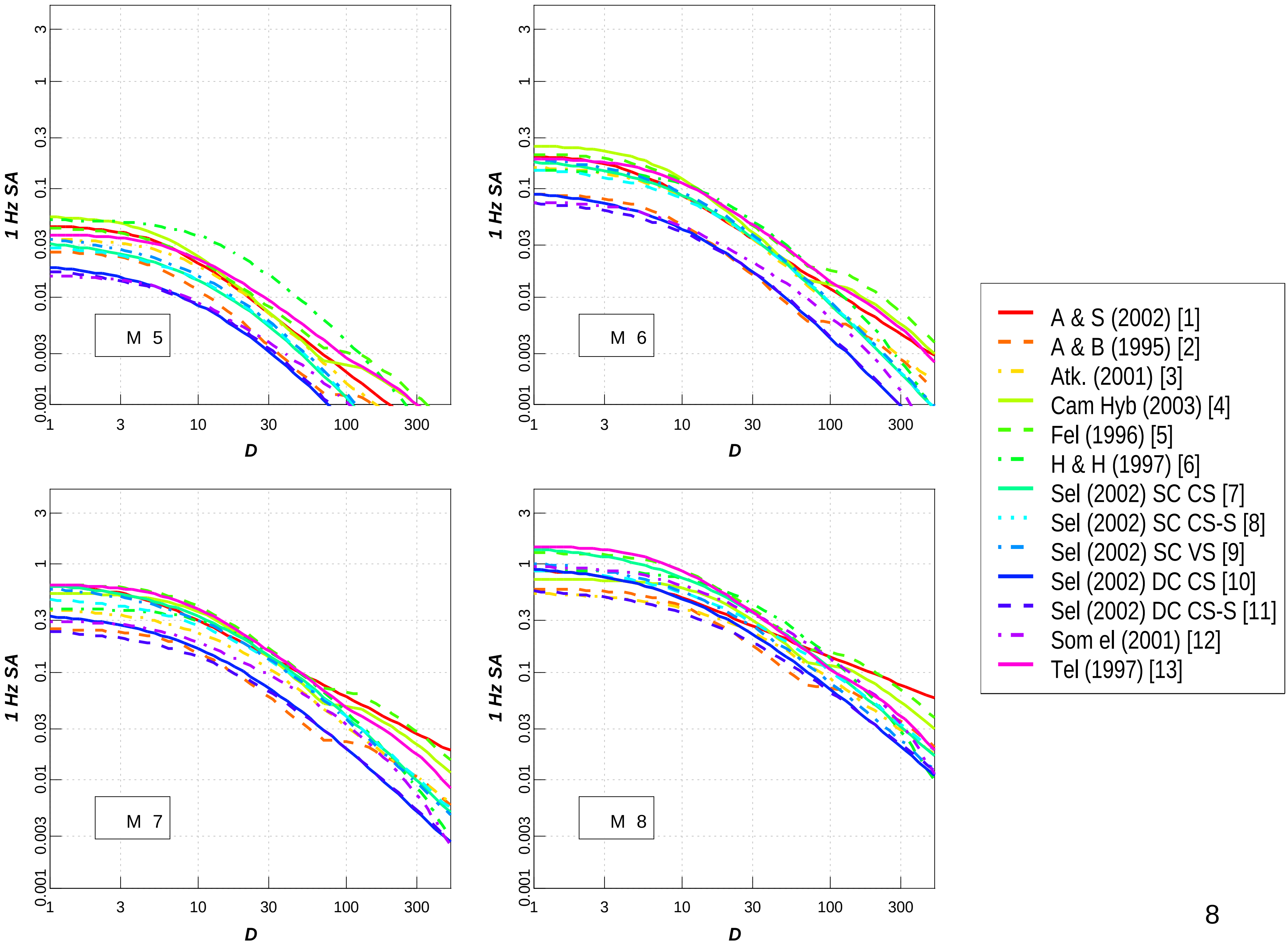
No.	Model	Type
1	Abrahamson and Silva (2002)	Hybrid[1]
2	Atkinson & Boore (1995)[2,4]	Spectral, Double-Corner
3	Atkinson (2001) using Sadigh et al. (1997)	Hybrid
4	Campbell (2003)	Hybrid
5	Frankel et al. (1996) [3,4]	Spectral, Single-Corner
6	Hwang & Huo (1997)	Spectral, Single-Corner
7	Silva et al. (2002) – SC-CS[5]	Spectral, Single-Corner
8	Silva et al. (2002) – SC-CS-S[5]	Spectral, Single-Corner
9	Silva et al. (2002) – SC-VS[5]	Spectral, Single-Corner
10	Silva et al. (2002) DC[5]	Spectral, Double-Corner
11	Silva et al. (2002) DC-S[5]	Spectral, Double-Corner
12	Somerville et al. (2001)	Finite Source/Greens Function
13	Toro et al. (1997)	Spectral, Single-Corner

[1] Hybrid refers to models that are derived from attenuation relationships in one region (e.g., western U.S.) and transformed, using seismological principles to obtain relationships for a target region.
[2] A parametric form of the Atkinson & Boore model was fit to ground motion values provided by the authors in their lookup table.
[3] A parametric form of the USGS model was fit to ground motion values provided by Art Frankel (Frankel, 2002).
[4] Models adjusted to Joyner-Boore distance (R_{JB}) using magnitude-dependent point-source depth distributions from Silva et al (2002).
[5] SC – single corner, DC – double corner, CS – constant stress drop, VS – magnitude-dependent stress drop, CS-S – constant stress drop with saturation


100 Hz SA
D
M 5
M 6
M 7
M 8
0.001
0.003
0.01
0.03
0.1
0.3
1
3
1
3
10
30
100
300
A & S (2002) [1]
A & B (1995) [2]
Atk. (2001) [3]
Cam Hyb (2003) [4]
Fel (1996) [5]
H & H (1997) [6]
Sel (2002) SC CS [7]
Sel (2002) SC CS-S [8]
Sel (2002) SC VS [9]
Sel (2002) DC CS [10]
Sel (2002) DC CS-S [11]
Som el (2001) [12]
Tel (1997) [13]



M 5
M 6
M 7
M 8
5 Hz SA
D
A & S (2002) [1]
A & B (1995) [2]
Atk. (2001) [3]
Cam Hyb (2003) [4]
Fel (1996) [5]
H & H (1997) [6]
Sel (2002) SC CS [7]
Sel (2002) SC CS-S [8]
Sel (2002) SC VS [9]
Sel (2002) DC CS [10]
Sel (2002) DC CS-S [11]
Som el (2001) [12]
Tel (1997) [13]

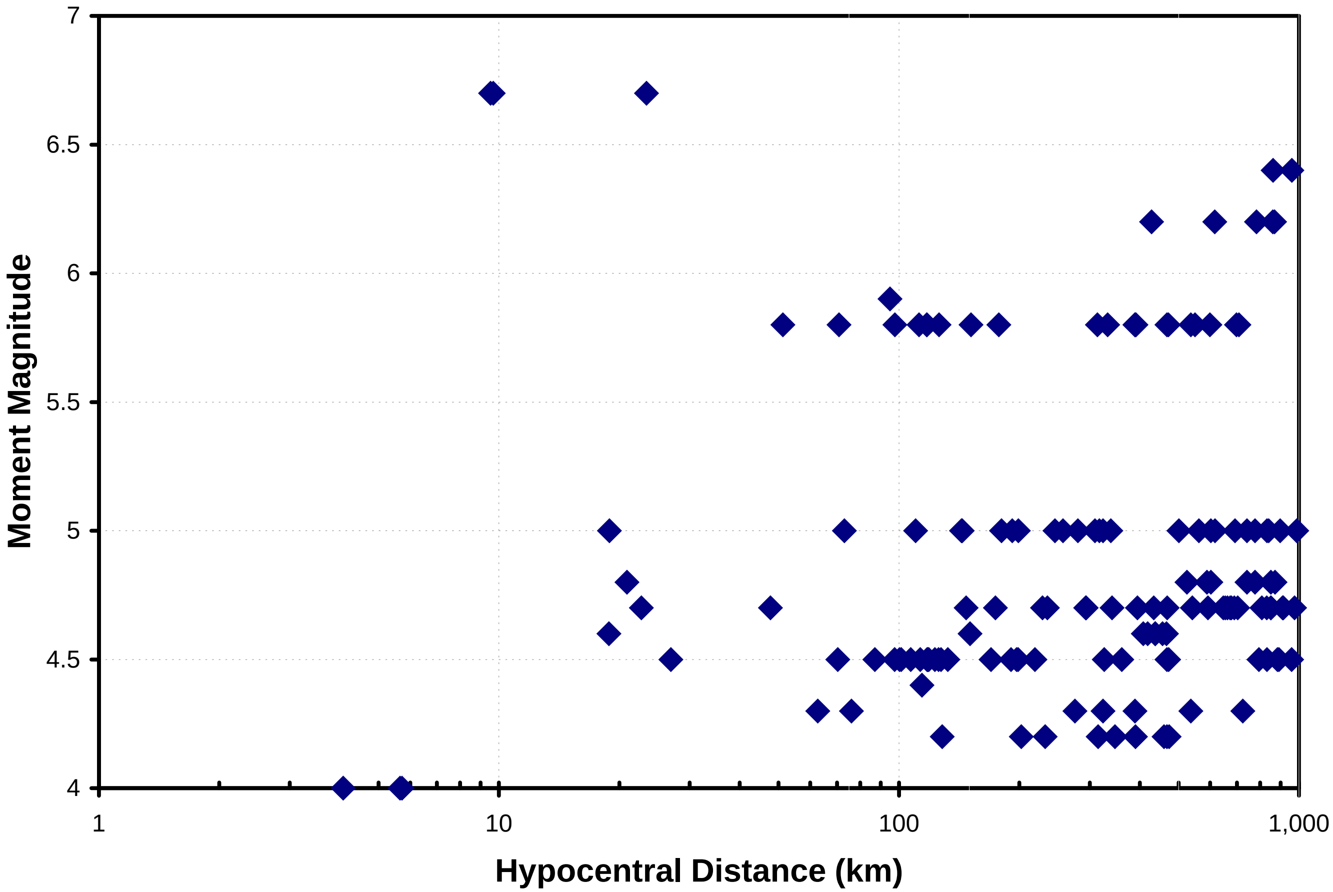


M 5
M 6
M 7
M 8
1 Hz SA
D
3
1
0.3
0.1
0.03
0.01
0.003
0.001
1
3
10
30
100
300
A & S (2002) [1]
A & B (1995) [2]
Atk. (2001) [3]
Cam Hyb (2003) [4]
Fel (1996) [5]
H & H (1997) [6]
Sel (2002) SC CS [7]
Sel (2002) SC CS-S [8]
Sel (2002) SC VS [9]
Sel (2002) DC CS [10]
Sel (2002) DC CS-S [11]
Som el (2001) [12]
Tel (1997) [13]

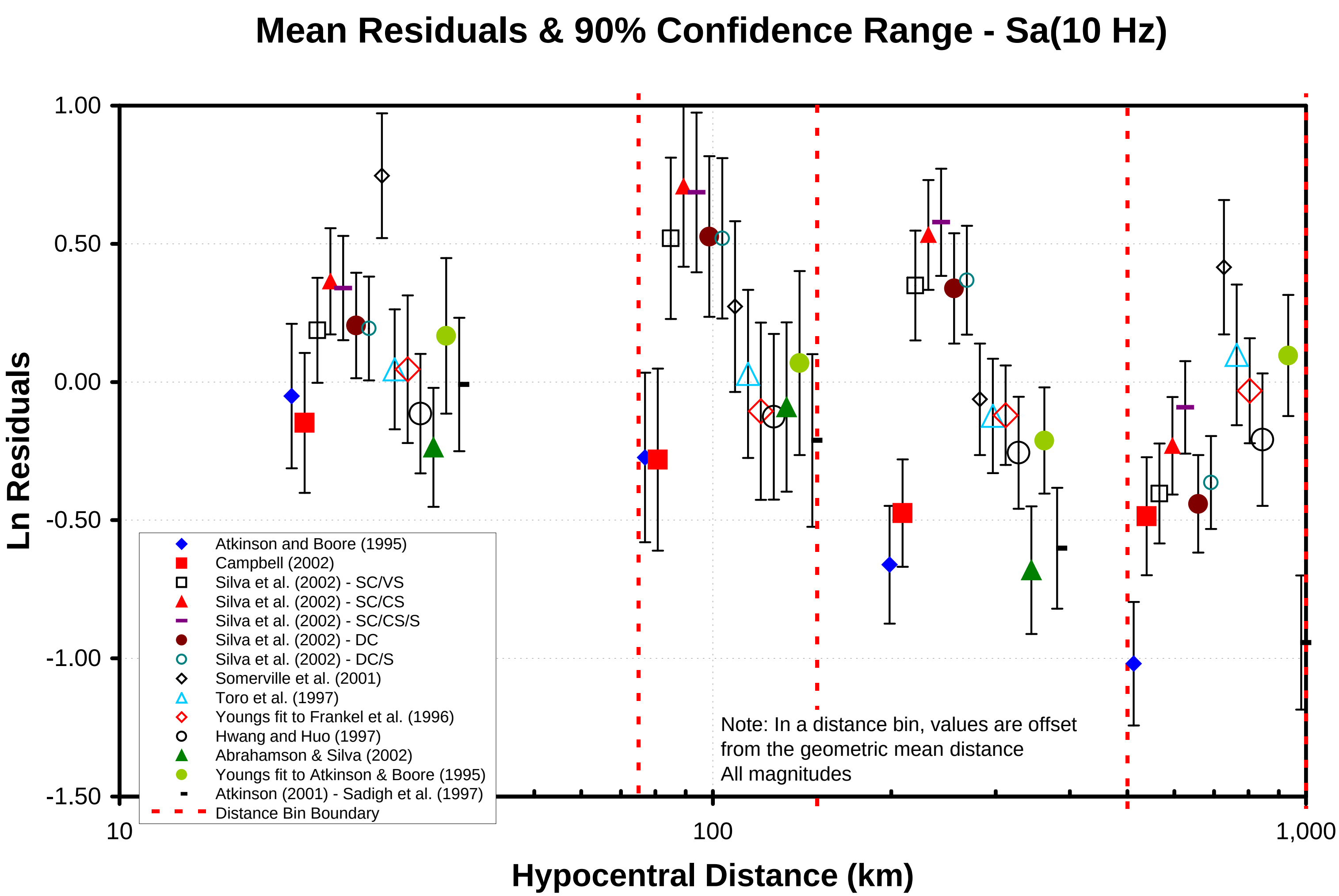
CEUS Ground Motion Data

Date	Earthquake	M	Date	Earthquake	M
3/1/1925	Charlevoix, Quebec, CAN	6.4	1/31/1986	Painesville, OH	4.8
11/1/1935	Timiskaming, CAN	6.2	7/12/1986	St. Marys, OH	4.5
9/5/1944	Cornwall (CAN) - Massena, NY	5.8	11/23/1988	Saguenay, CAN (F1)	4.2
3/25/1976	New Madrid, MO	4.6	11/25/1988	Saguenay, CAN	5.8
1/19/1982	Franklin Falls, NH	4.3	4/27/1989	New Madrid, MO	4.7
3/31/1982	New Brunswick (A13)	4.0	9/26/1990	Cape Girardeau	4.7
10/7/1983	Goodnow, NY	5.0	10/19/1990	Mount-Laurier Quebec, CAN	4.5
11/9/1985	Nahani, CAN (F1)	4.6	5/4/1991	New Madrid, MO	4.4
12/23/1985	Nahani, CAN	6.7	1/1/2000	Temiscamingue Region, Quebec, CAN	4.7
12/25/1985	Nahani, CAN (A1)	5.0			

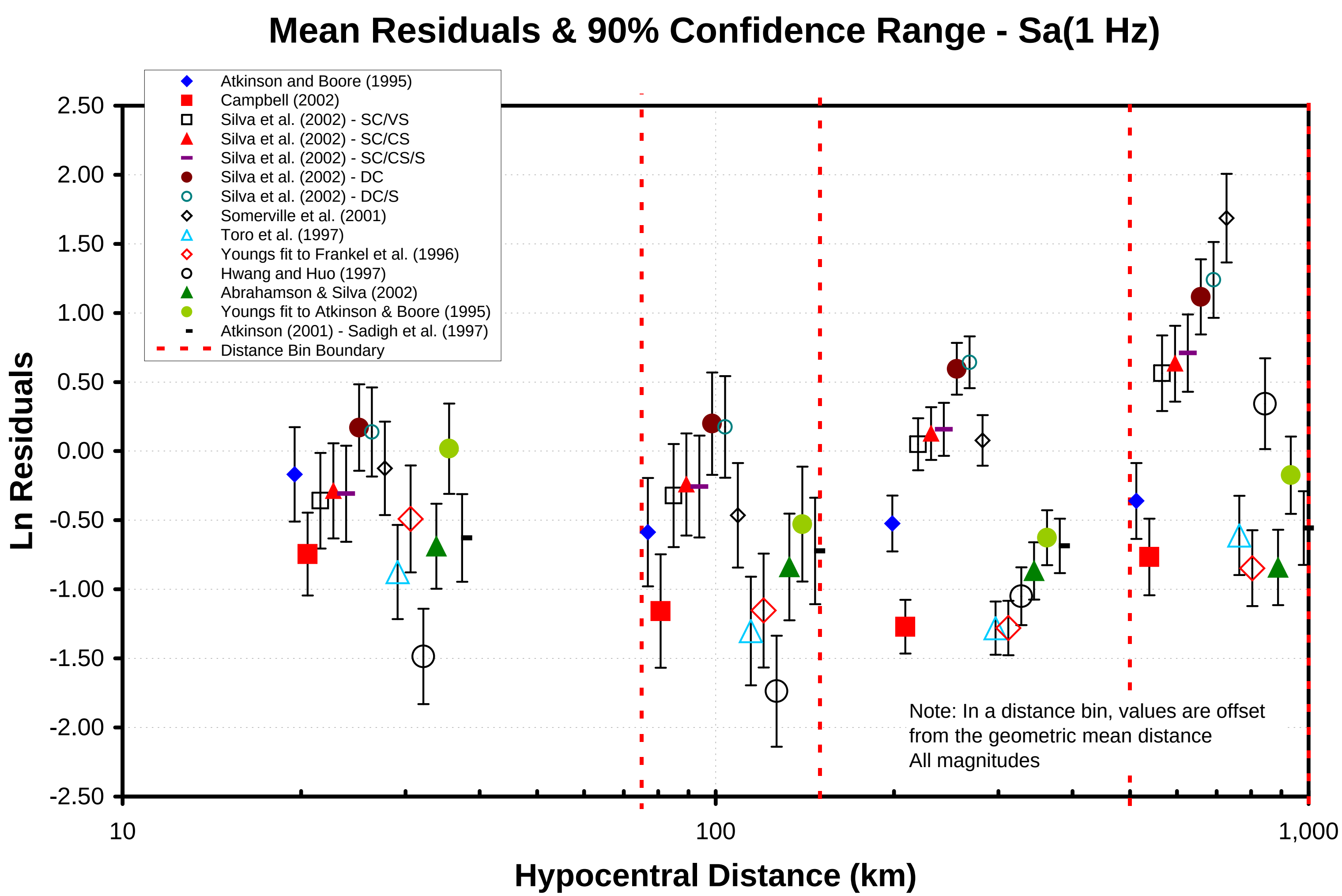
CEUS Ground Motion Data Distribution



Measure of Fit of Individual Models to CEUS Ground Motion Data



Measure of Fit of Individual Models to CEUS Ground Motion Data



Intra-cluster Weights Based on Variance Between Model and Data

Averaged over 1, 2.5, 5, and 10 Hz

$$\sigma^2_{Fit} = \mu^2_{Residual} + \sigma^2_{Residual}$$

Cluster No.	**Model Type**	**Models**	**Weights**[1]
1	Spectral, Single Corner	Hwang & Huo (1997) Silva et al. (2002) – SC-CS Silva et al. (2002) – SC-CS-S *Silva et al*. (2002) – SC-VS[1] Toro et al. (1997) Frankel et al. (1996)	0.037 0.192 0.148 0.560 0.029 0.034
2	Spectral, Double Corner	Atkinson & Boore (1995) Silva et al. (2002) DC Silva et al. (2002) DC-S	0.714 0.154 0.132
3	Hybrid	Abrahamson & Silva (2002) Atkinson (2001) & Sadigh et al. (1997) Campbell (2003)	0.336 0.363 0.301
4	Finite Source/Greens Function	Somerville et al. (2001) [1]	1.0

Median Ground Motions (cont'd)

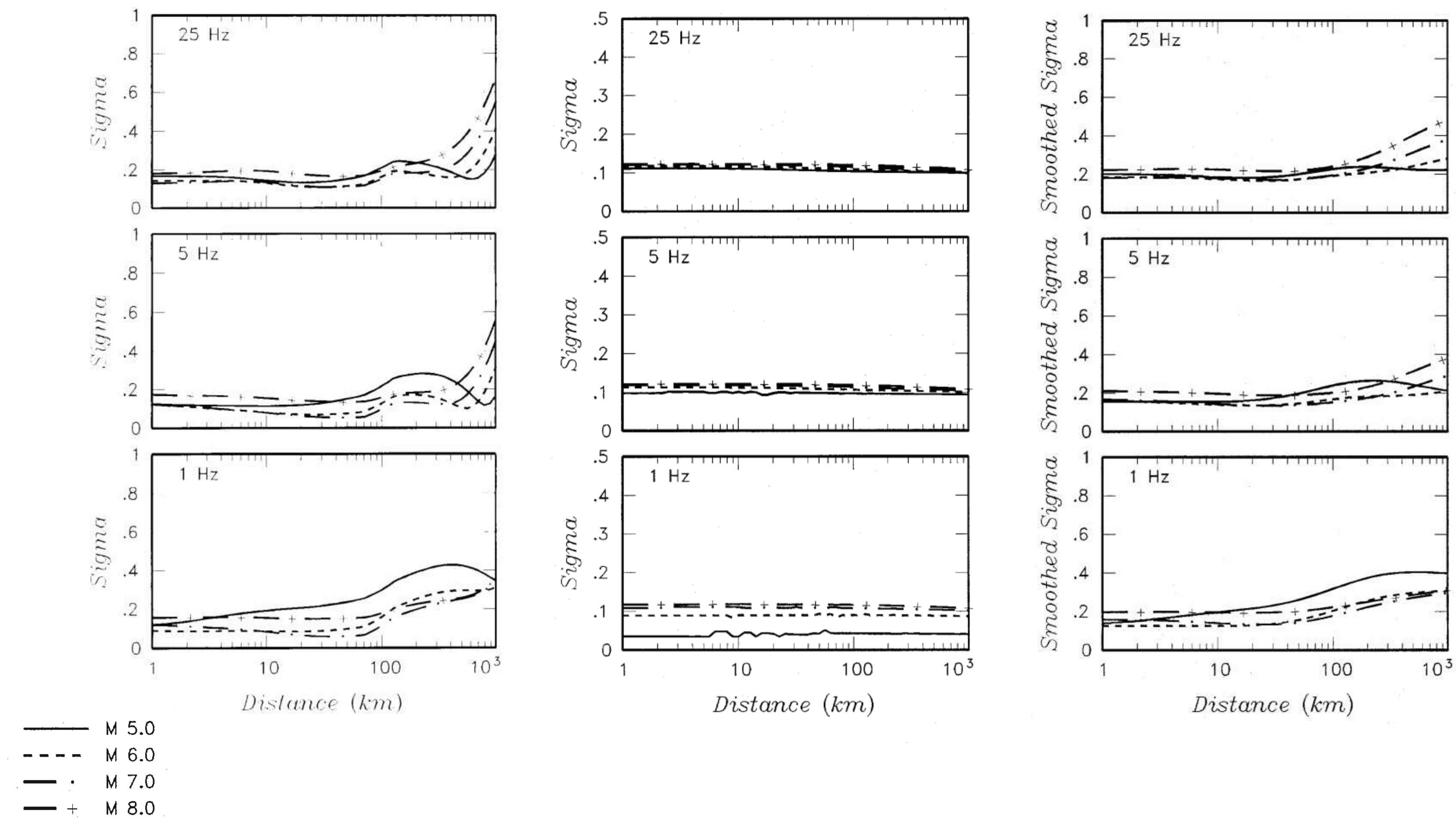
- Use intra-cluster weights to develop "cluster median" ground motions and initial estimate of intra-cluster epistemic uncertainty
- Incorporate additional epistemic uncertainty not represented by the set of models in a cluster
- Fit the cluster median and 5th and 95th percentiles using a representative functional form
- Develop a set of inter-cluster weights

Additional Epistemic Uncertainty

Uncertainty Component	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Cluster 4**
Intra-cluster variability	Represented by Cluster	Represented by Cluster	Represented by Cluster	0
Source uncertainty	Added Additional Uncertainty	Added Additional Uncertainty	Added Additional Uncertainty	Added Additional Uncertainty
Path uncertainty	Represented by Cluster	Represented by Cluster	Represented by Cluster	Added Additional Uncertainty
Median fit uncertainty	Included	Included	Included	0

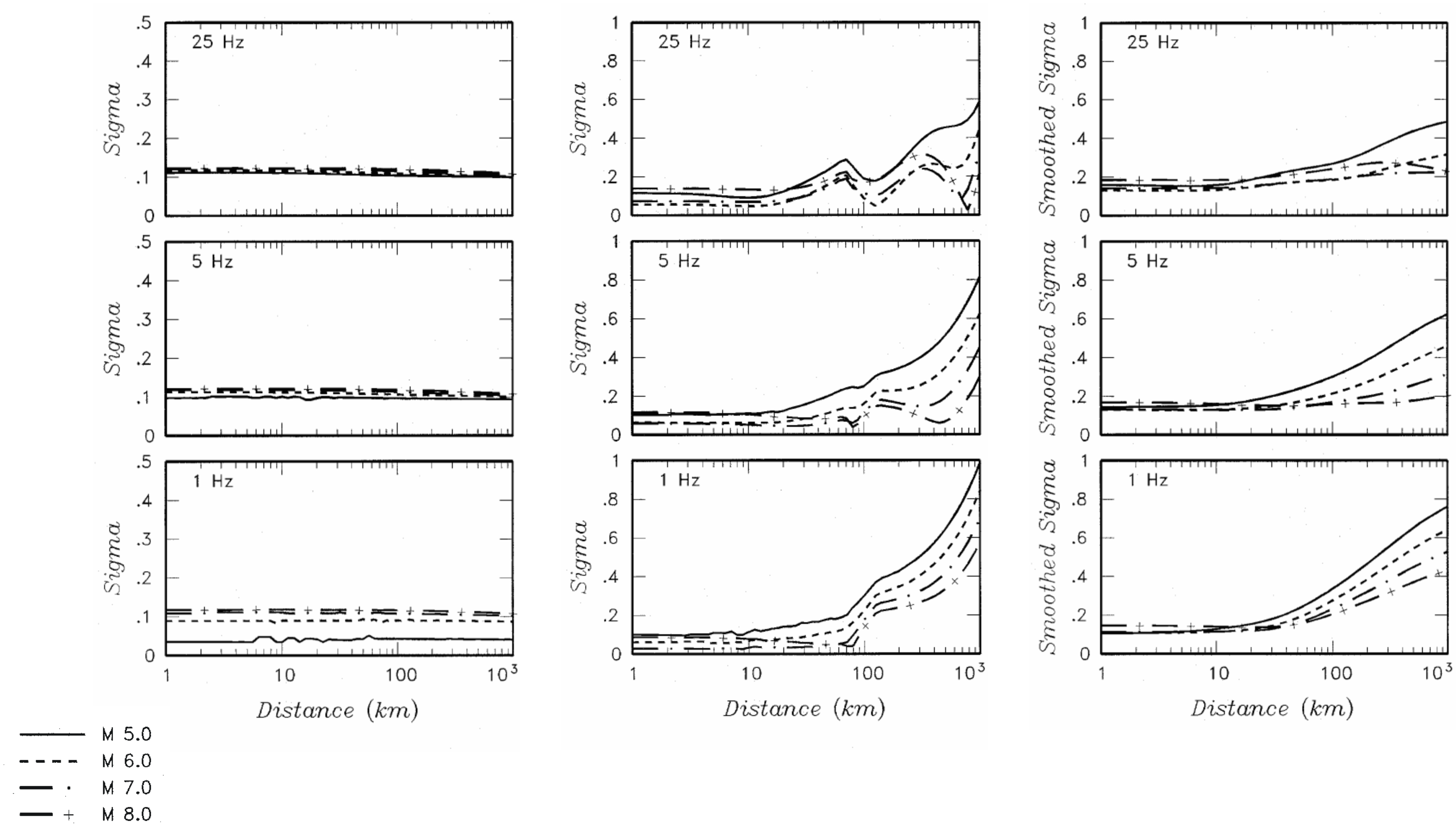
Examples for Cluster 1

Intra-cluster from weighted models + Uncertainty due to source variability $\sigma_{\ln(\Delta\sigma)} = 0.16$ = Smoothed Total Intra-cluster Uncertainty

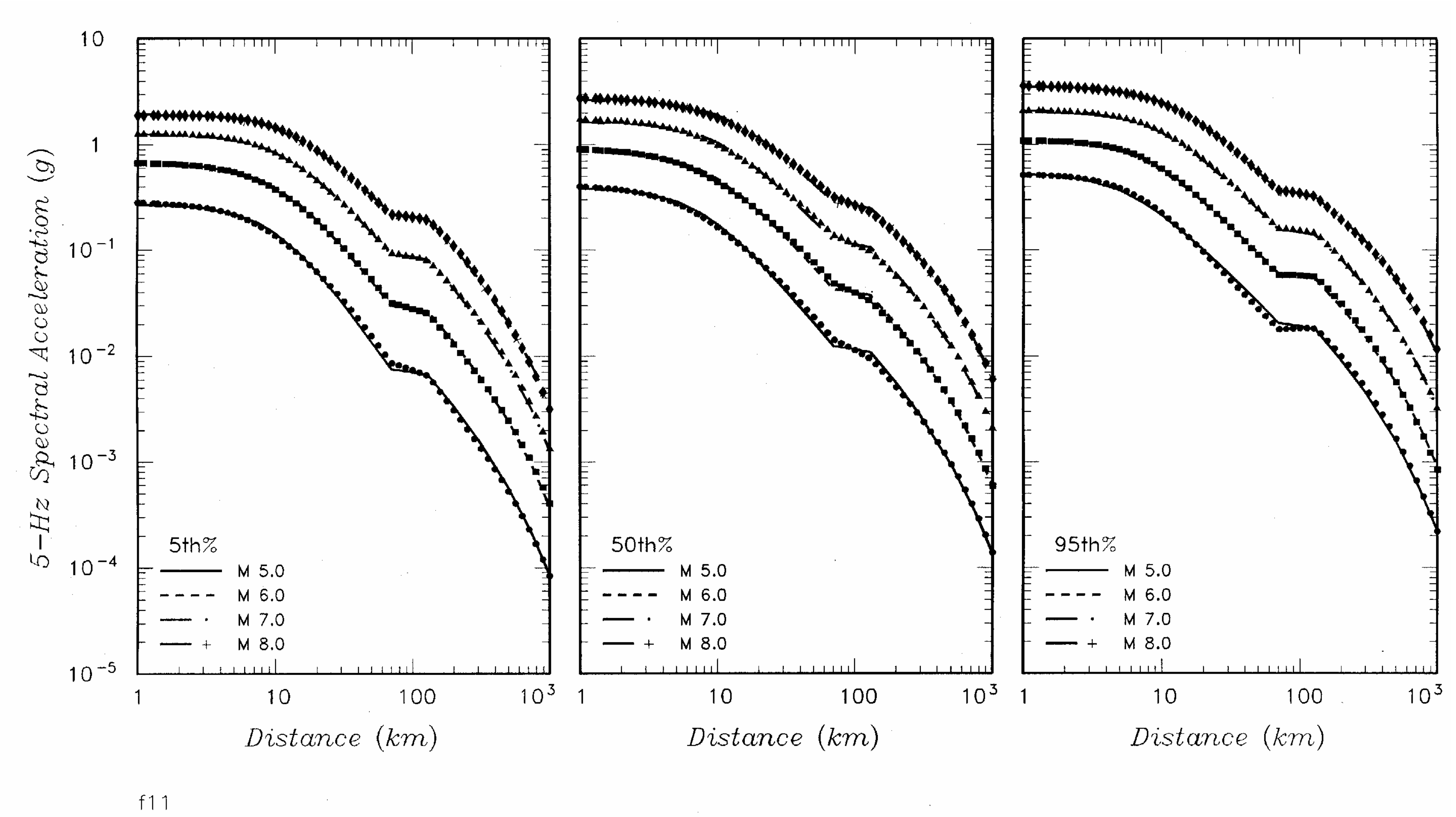


Examples for Cluster 4

Uncertainty due to source variability $\sigma_{\ln(\Delta\sigma)} = 0.16$ + Uncertainty due to path variability from stochastic models = Smoothed Total Intra-cluster Uncertainty



Example of Fitted Relationships for Cluster 2



Inter-Cluster Weights for Median Models

- Consistency with CEUS ground motion data (relative weight between cluster medians)
- Cluster Modeling Principles
  - Degree of incorporation of “seismological principals”
  - Degree of incorporation of epistemic uncertainty

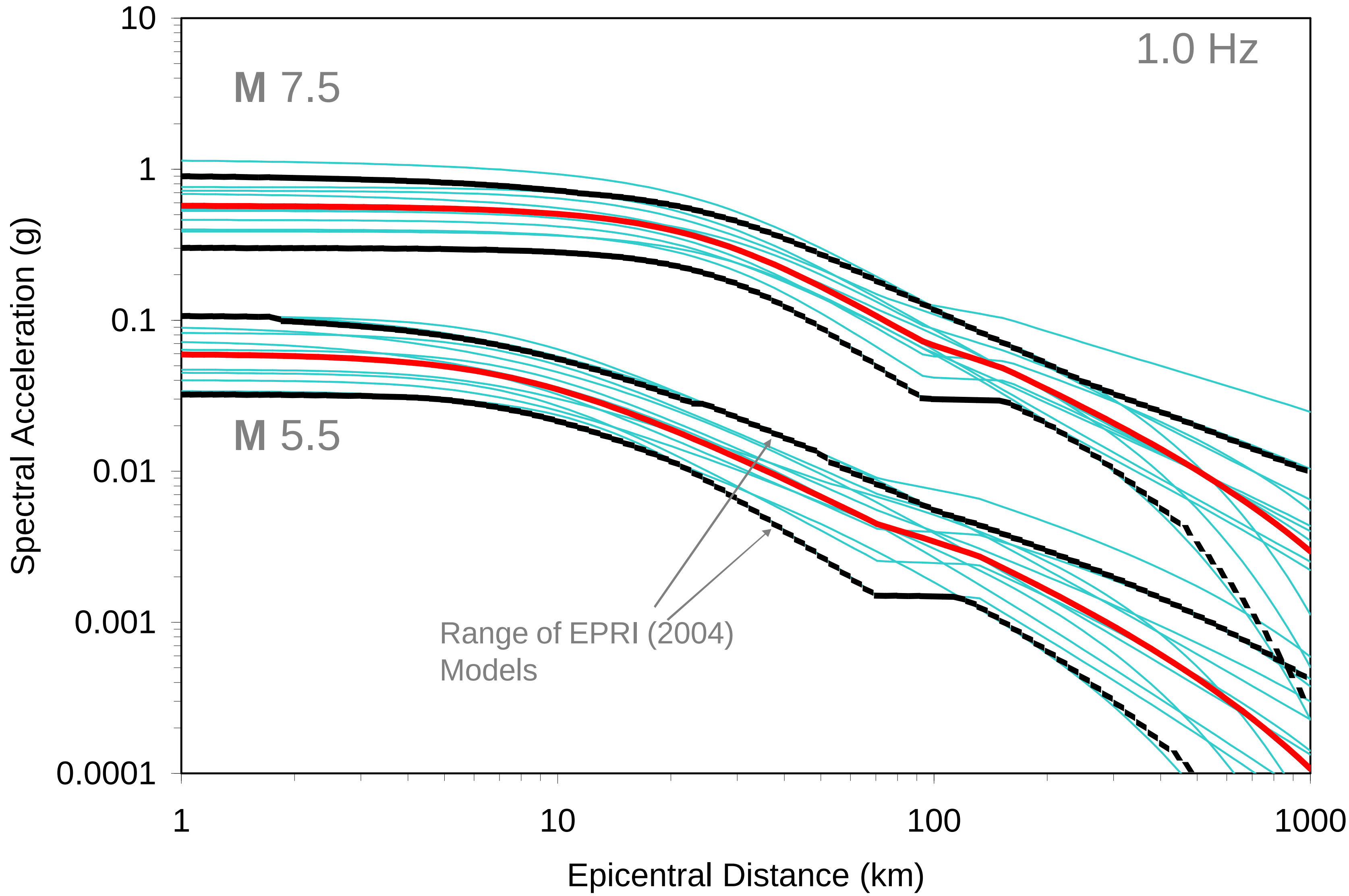
Inter-Cluster Weighting

	Seismological Principles		
Consideration of Uncertainty	**High**	**Medium**	**Low**
Explicit Modeling of Epistemic Uncertainty	10	8	3
Model only Parametric Variability	7	5	1
No Consideration of Uncertainty	4	3	1

		Clusters			
		1	**2**	**3**	**4**
	Seismological Principles	Medium	Medium	Medium	High
Uncertainty Index	**Explicit Modeling of Epistemic Uncertainty**	0.40	0.20	0.50	0.00
	Only Parametric Variability	0.60	0.80	0.50	1.00
	No Consideration	0.0	0.0	0.0	0.00
	Relative Score	**6.2**	**5.6**	**6.5**	**7**
	Final Weight	**0.245**	**0.221**	**0.257**	**0.277**

	Importance Weights		
	0.25	0.75	
Cluster	**Consistency With Data**	**Modeling Principles**	**Composite Weight**
1	0.3639	0.245	0.275
2	0.5869	0.221	0.312
3	0.0135	0.257	0.196
4	0.0357	0.277	0.217

Comparison of 1 Hz Model with Individual Relationships



Application Guidance

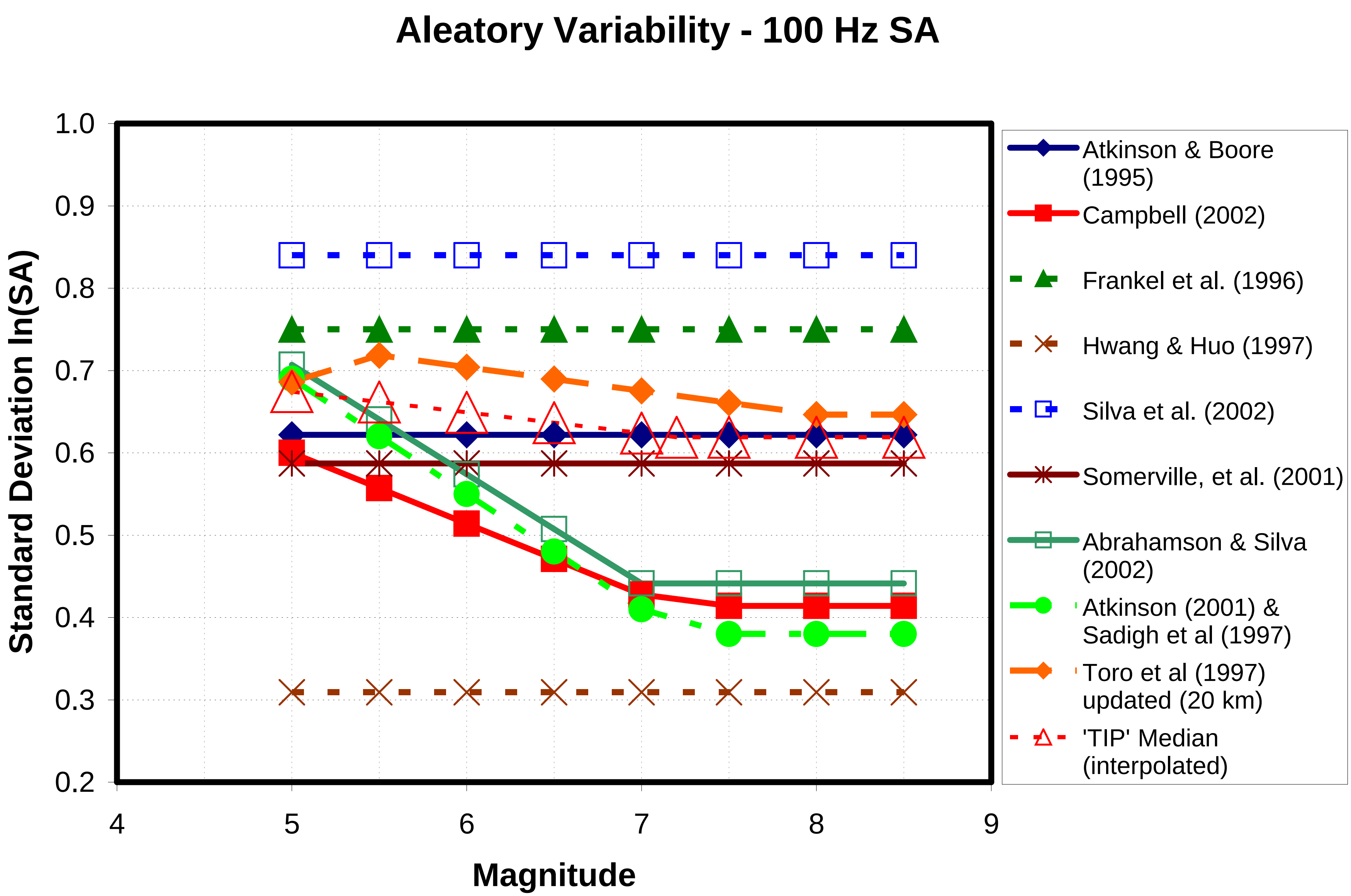
- Twelve models to represent the uncertainty in median ground motions
- Recommend not using Cluster 4 for seismic sources where hazard is dominated by **M** < 6 events
- Provided adjustments to median models for use in the Gulf Coast region

Aleatory Uncertainty Models

- Developed independently from median models
- Based on existing models
- Two sets of estimates
  - Empirical WUS translated to CEUS
  - Parametric combined with modeling

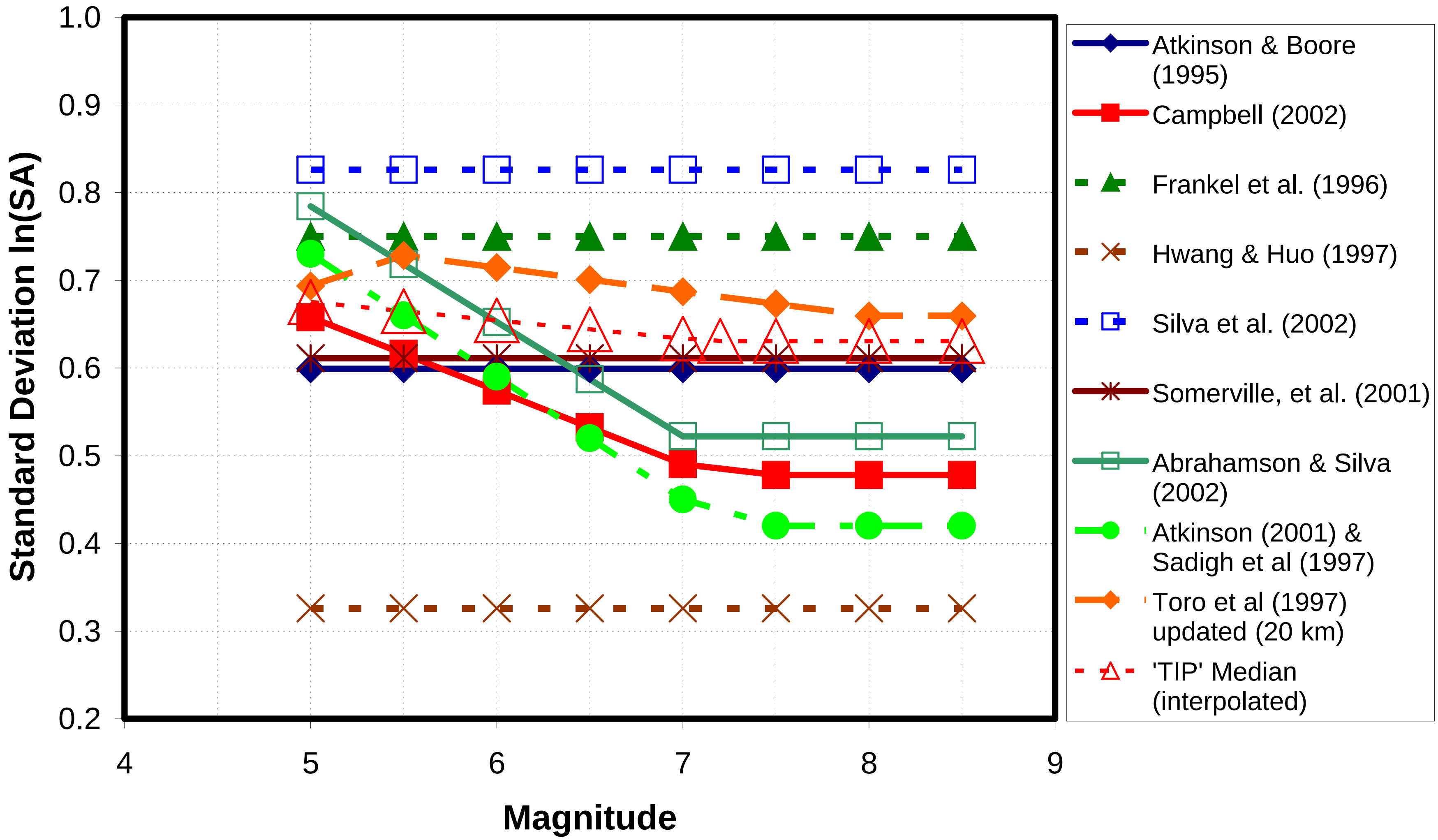
Aleatory Variability Models

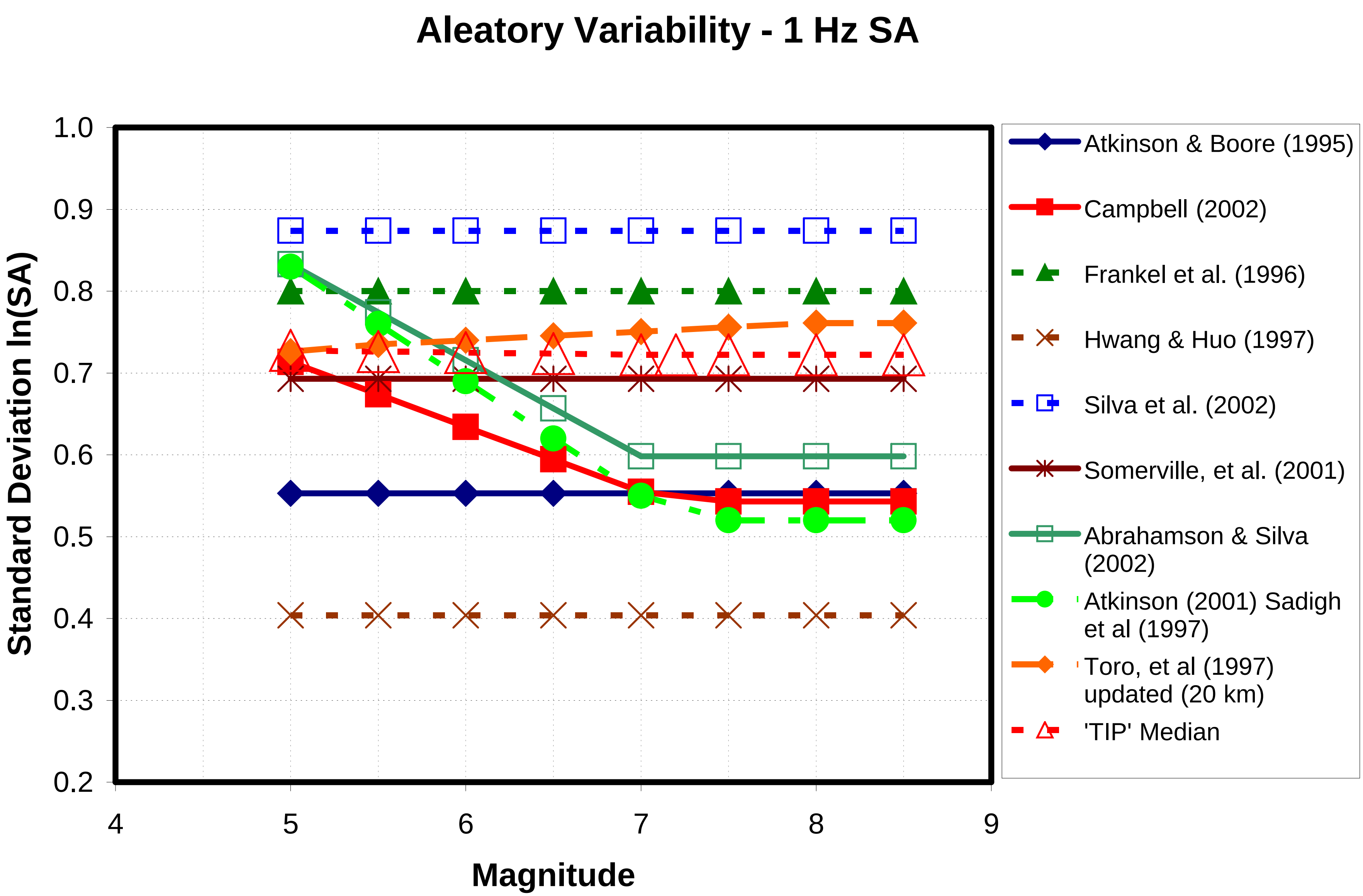
Model	Basis
Abrahamson and Silva (2002)	Empirical WUS, Adjusted
Atkinson & Boore (1995)	Empirical CEUS
Atkinson (2001) using Sadigh et al. (1997)	Empirical WUS
Campbell (2003)	Empirical WUS, Adjusted
Frankel et al. (1996)	Direct Assessment
Hwang & Huo (1997)	Parametric
Savy et al. (2002) – “TIP”	Demonstration SSHAC Assessment
Silva et al. (2002)	Parametric plus Modeling
Somerville et al. (2001)	Parametric plus Modeling
Toro et al. (1997) with updated modeling	Parametric plus Modeling



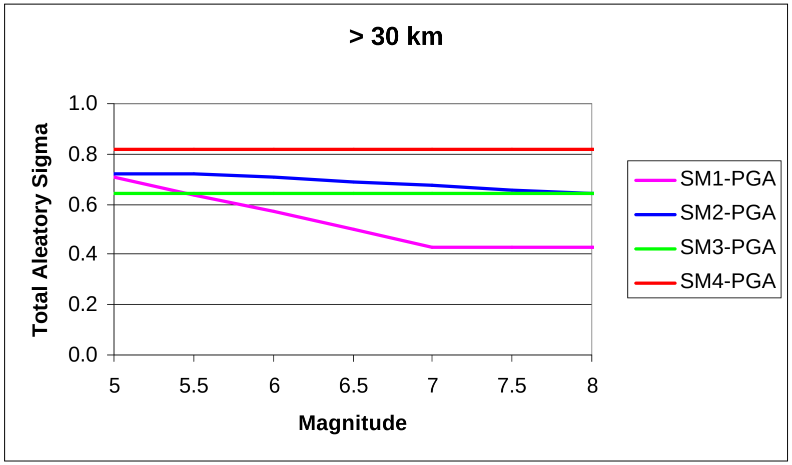
Aleatory Variability - 100 Hz SA
Standard Deviation ln(SA)
Magnitude
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
4
5
6
7
8
9
Atkinson & Boore (1995)
Campbell (2002)
Frankel et al. (1996)
Hwang & Huo (1997)
Silva et al. (2002)
Somerville, et al. (2001)
Abrahamson & Silva (2002)
Atkinson (2001) & Sadigh et al (1997)
Toro et al (1997) updated (20 km)
'TIP' Median (interpolated)

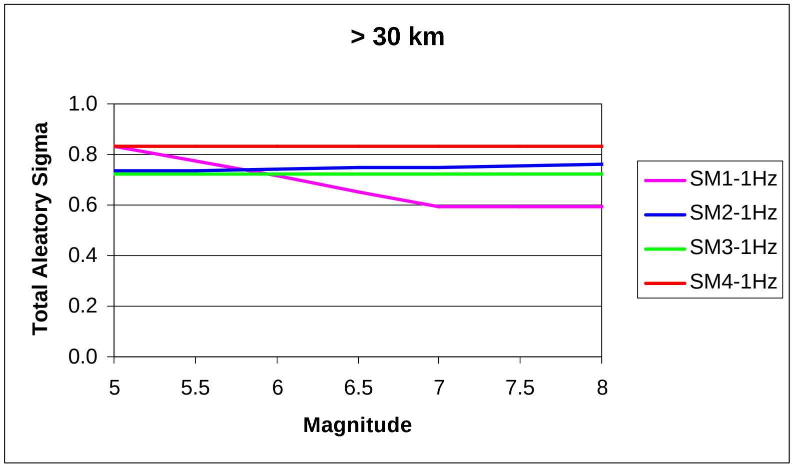
Aleatory Variability - 5 Hz SA




Aleatory Variability - 1 Hz SA
Standard Deviation ln(SA)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
4
5
6
7
8
9
Magnitude
Atkinson & Boore (1995)
Campbell (2002)
Frankel et al. (1996)
Hwang & Huo (1997)
Silva et al. (2002)
Somerville, et al. (2001)
Abrahamson & Silva (2002)
Atkinson (2001) Sadigh et al (1997)
Toro, et al (1997) updated (20 km)
'TIP' Median

Aleatory Models



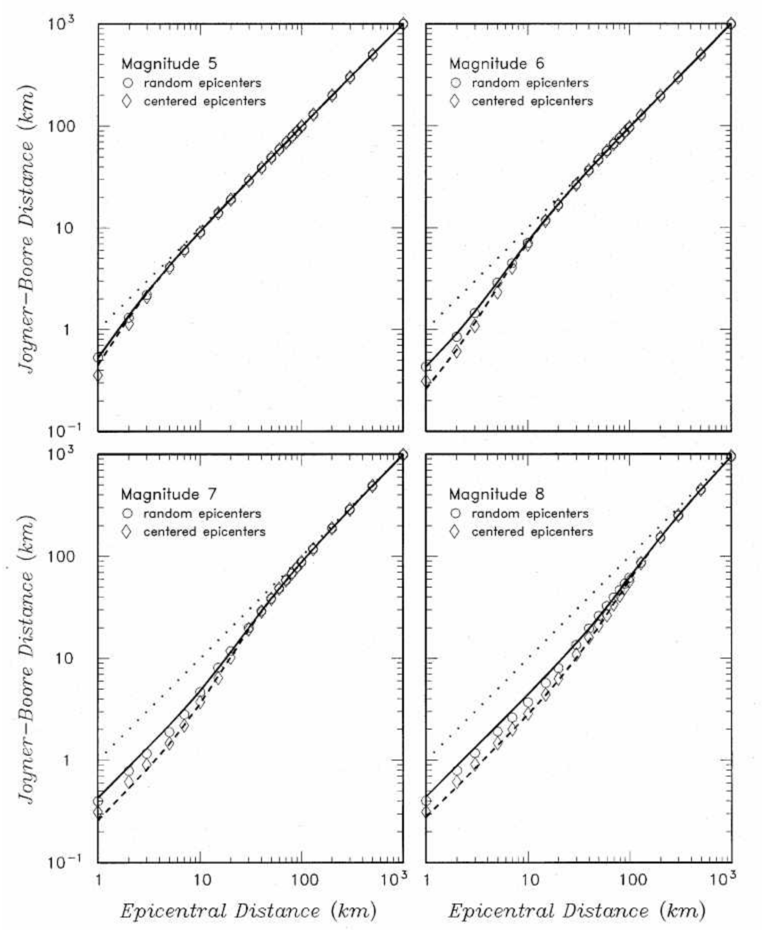


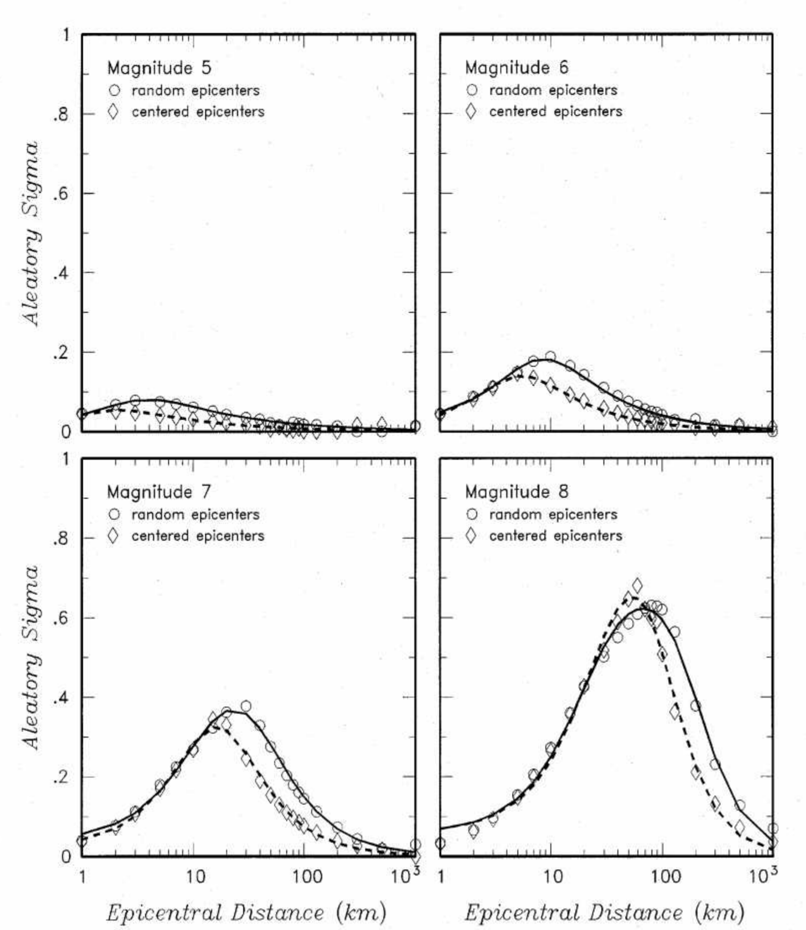
- Model 1 based on WUS empirical (Abrahamson and Silva, 2002)
- Model 2 based on Toro et al. (1997) with updated modeling component
- Model 3 based on Savy (2002)
- Model 4 based in Silva et al. (2002)

Adjustments for Use in CEUS PSHA

- Distance measure was treated as closest distance to rupture or closest distance to surface projection of rupture (Joyner-Boore distance)
  - Distance adjustment needed when modeling earthquakes as spatially distributed epicenters in PSHA
  - Additional magnitude and distance dependent aleatory variability added for random orientation of ruptures about epicenters
  - Alternatively, include representation of rupture distributions directly in the PSHA calculation
- Additional aleatory variability added to account for “point source” depth distribution effects at short distances for models using Joyner-Boore distance (e.g. Toro et al.,1997)

Adjustments for Epicenter Representations of Earthquakes in PSHA





Aleatory Variability Due to Point-Source Depth Distribution used with Joyner-Boore Distances