The Stress-Parameter, Geometrical Spreading Correlation

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USGS National Seismic Hazard Map (NSHMp) Workshop on Ground Motion Prediction Equations (GMPEs)

for the 2014 Update

December 12-13, 2012

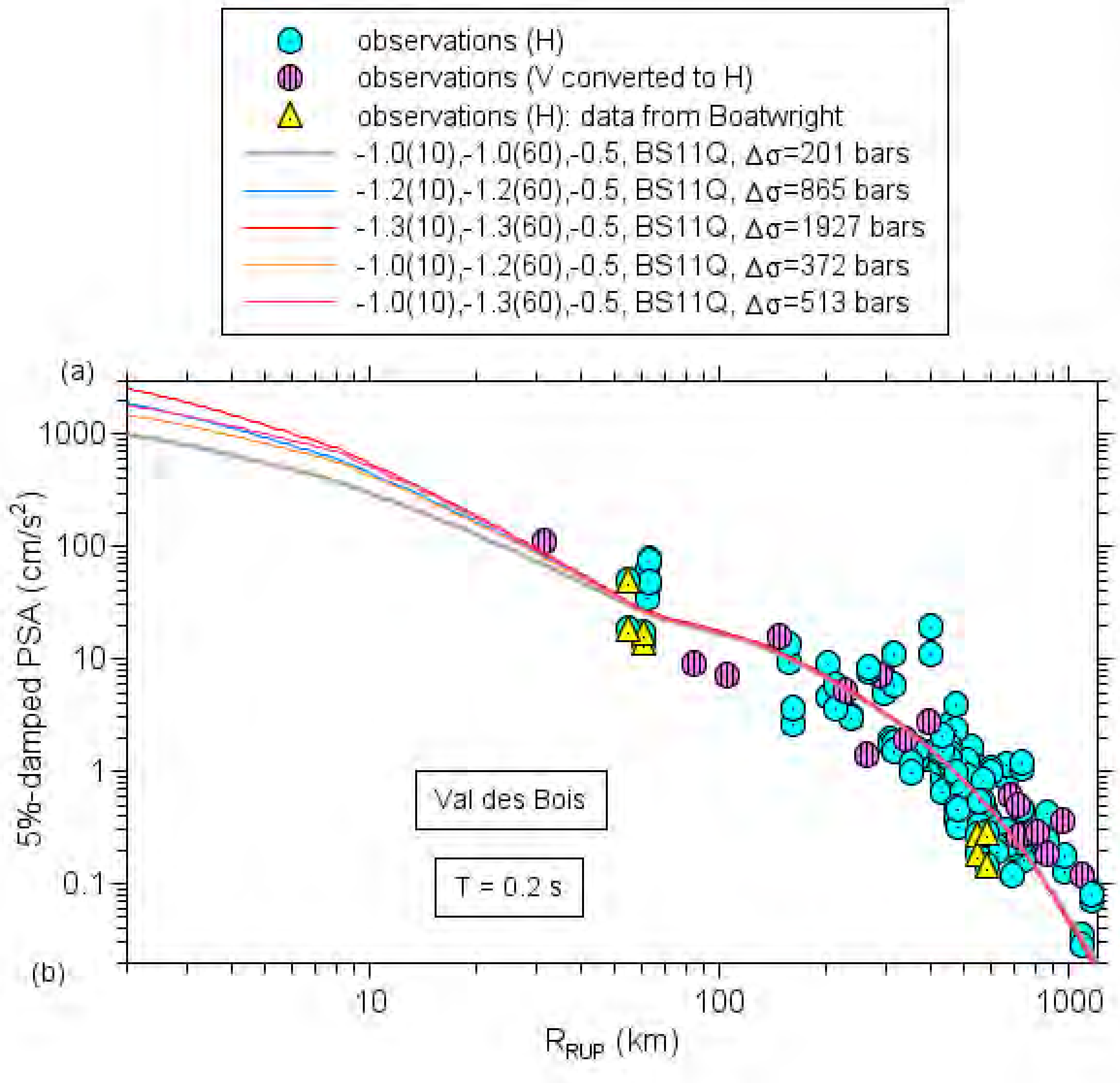
I-House, Berkeley, CA

Plus two additional topics

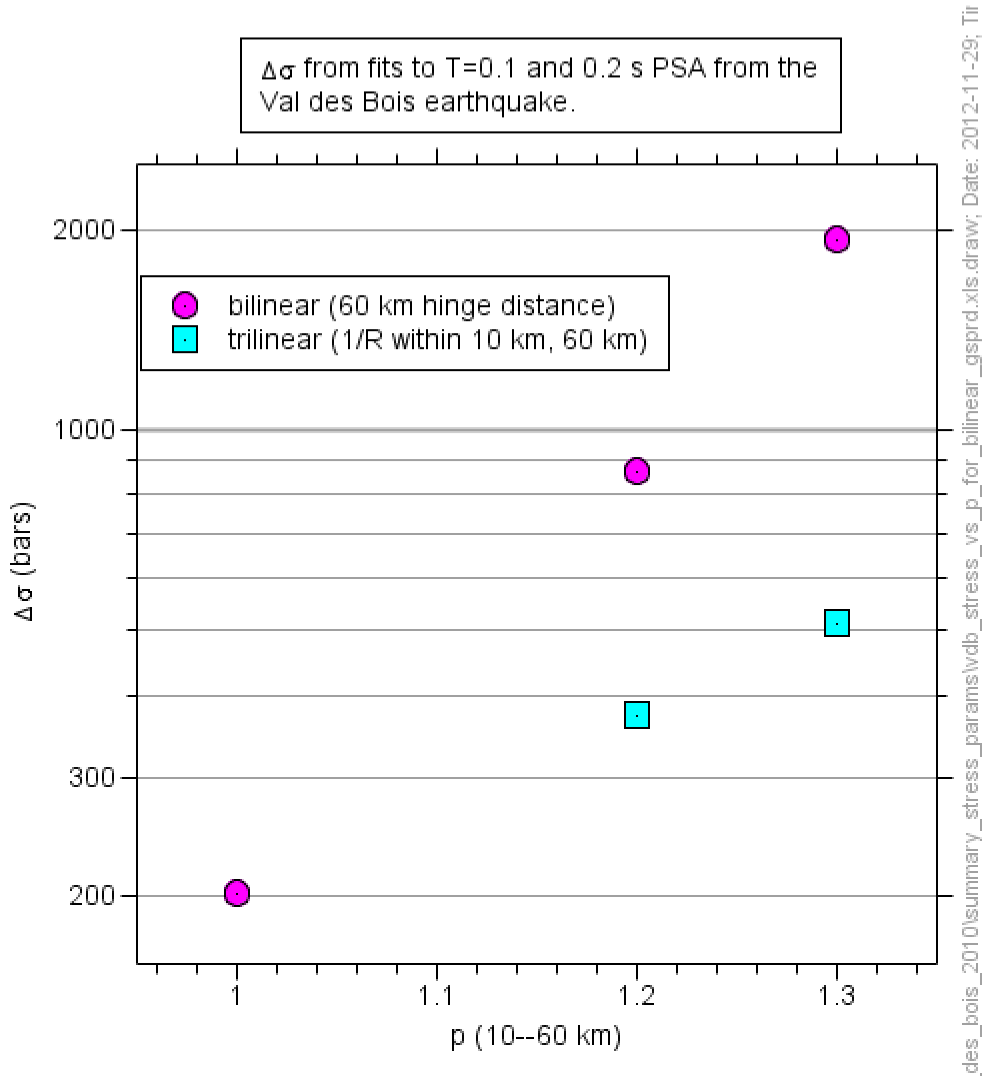
- The measure of ground motion used by NGA-West2
- Computing response spectra for low-kappa, low-sample rate records (a teaser only)

Δσ-attenuation model correlation

"When we try to pick out anything by itself, we find it hitched to everything else in the universe"—John Muir



observations (H)
observations (V converted to H)
observations (H): data from Boatwright
-1.0(10),-1.0(60),-0.5, BS11Q, Δσ=201 bars
-1.2(10),-1.2(60),-0.5, BS11Q, Δσ=865 bars
-1.3(10),-1.3(60),-0.5, BS11Q, Δσ=1927 bars
-1.0(10),-1.2(60),-0.5, BS11Q, Δσ=372 bars
-1.0(10),-1.3(60),-0.5, BS11Q, Δσ=513 bars
(a)
(b)
5%-damped PSA (cm/s²)
1000
100
10
1
0.1
10
100
1000
R_RUP (km)
Val des Bois
T = 0.2 s

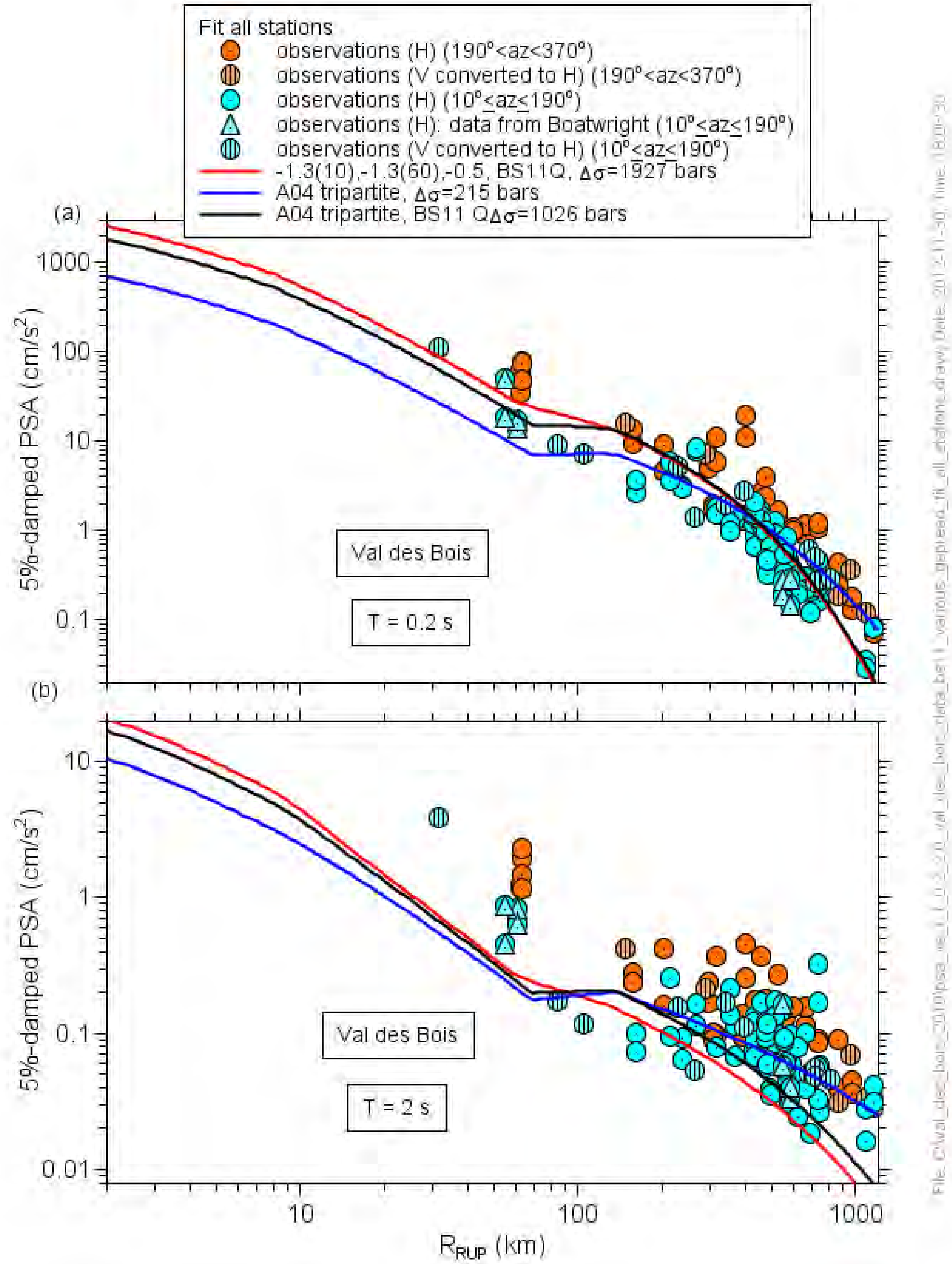


geometrical spreading ($1/R^p$)

Note separation of motion by azimuth; stress fits are for all data combined.

Note dependence of stress on Q model for same geometrical spreading (215 bars for A04 Q model, 1026 bars for BS11 Q model)

Note generally poor fit of T=2 s PSA



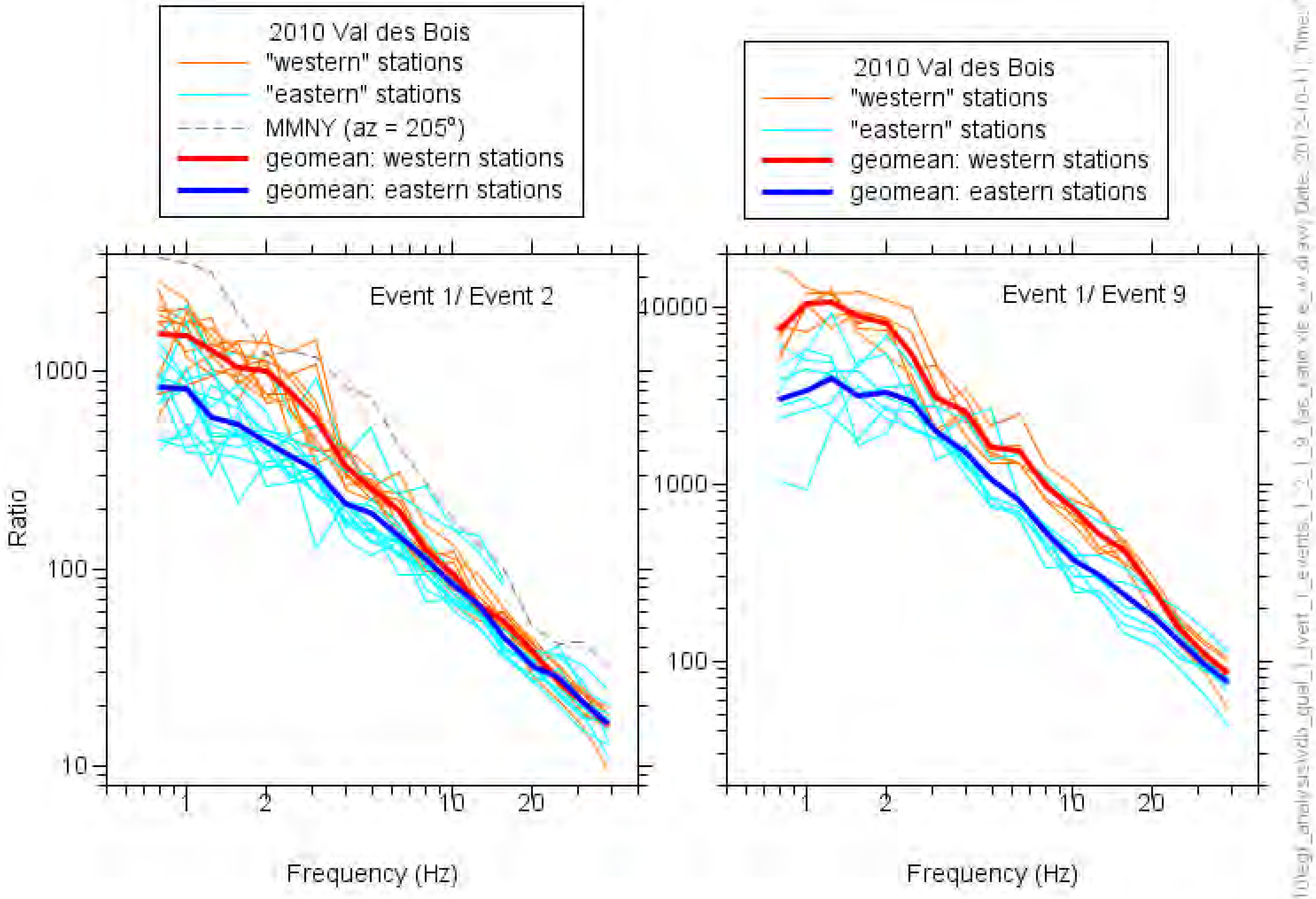
Use eGf to resolve ambiguity

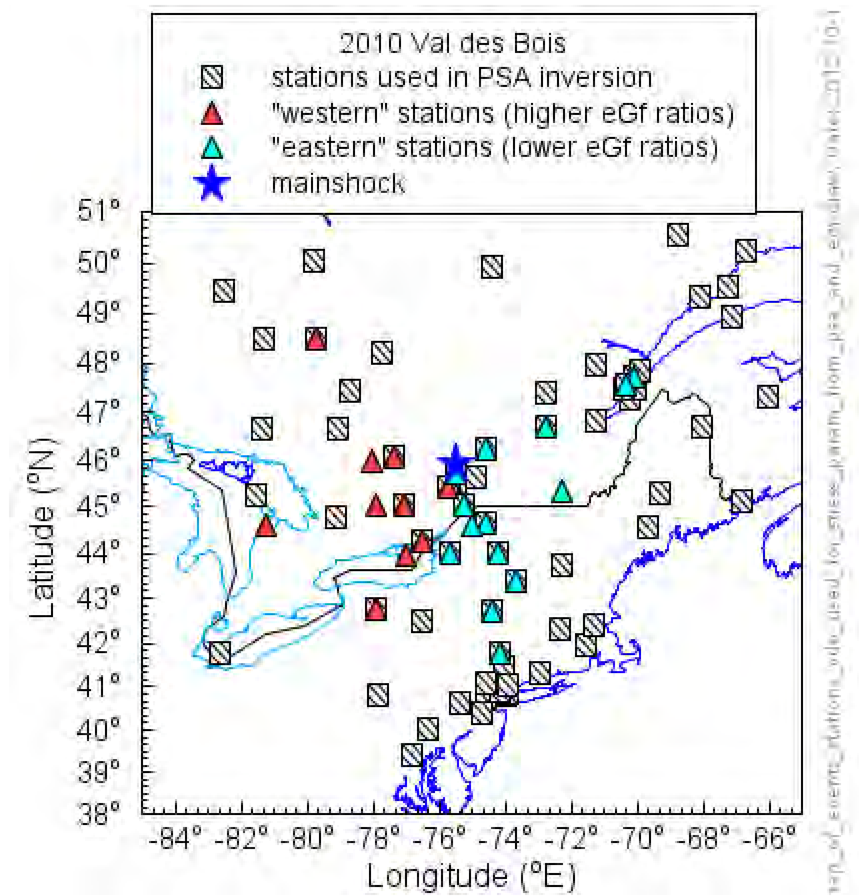
- Objective: Discriminate between attenuation models that fit observed short-period response spectra
- Strategy:
  - Generally too few observations at close distances to discriminate
  - Remove path effect by using empirical Green's function (eGf)
  - Find range of stress drops consistent with eGf
  - Find range of attenuation models fit to response spectra consistent with this range of stress drops
- Limitations:
  - Spectra too noisy at low frequencies to allow a good determination of the corner frequency of the larger event
  - Azimuthal dependence complicates analysis
- Use both H and V motions

Event information for the Val des Bois Earthquake

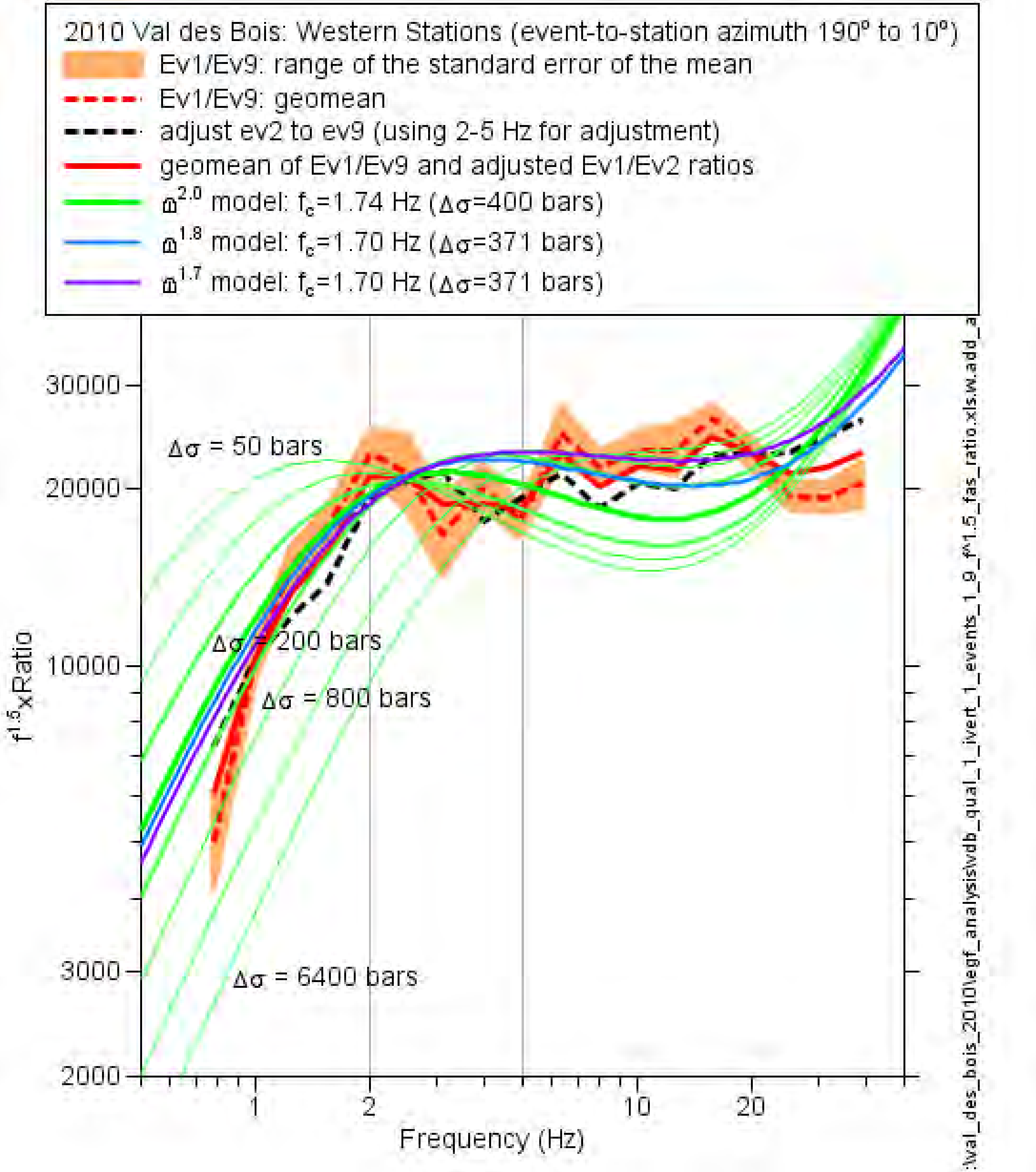
	Year	M	D	H	h(km)	Mn	M*
1	2010	6	23	17	16.4	5.8	5.07
2	2010	6	23	23	22.9	3.3	
9	2010	6	26	5	18.8	2.6	

$\Delta\sigma$


2010 Val des Bois
"western" stations
"eastern" stations
MMNY (az = 205°)
geomean: western stations
geomean: eastern stations
Event 1/ Event 2
Ratio
1000
100
10
1
2
10
20
Frequency (Hz)
2010 Val des Bois
"western" stations
"eastern" stations
geomean: western stations
geomean: eastern stations
Event 1/ Event 9
10000
1000
100
1
2
10
20
Frequency (Hz)

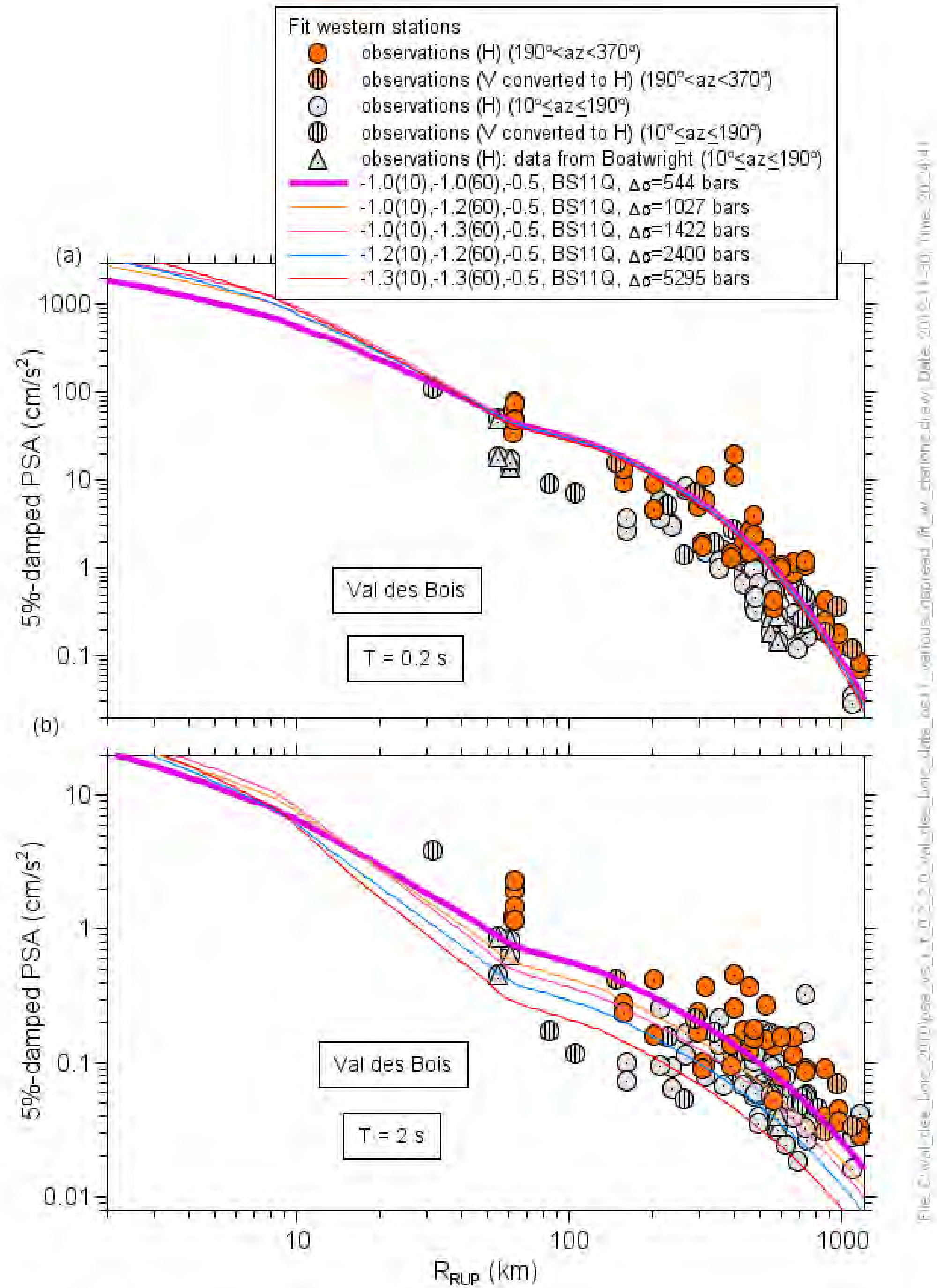

2010 Val des Bois
stations used in PSA inversion
"western" stations (higher eGf ratios)
"eastern" stations (lower eGf ratios)
mainshock
51°
50°
49°
48°
47°
46°
45°
44°
43°
42°
41°
40°
39°
38°
Latitude (°N)
-84° -82° -80° -78° -76° -74° -72° -70° -68° -66°
Longitude (°E)

$\Delta\sigma \approx 400$bars

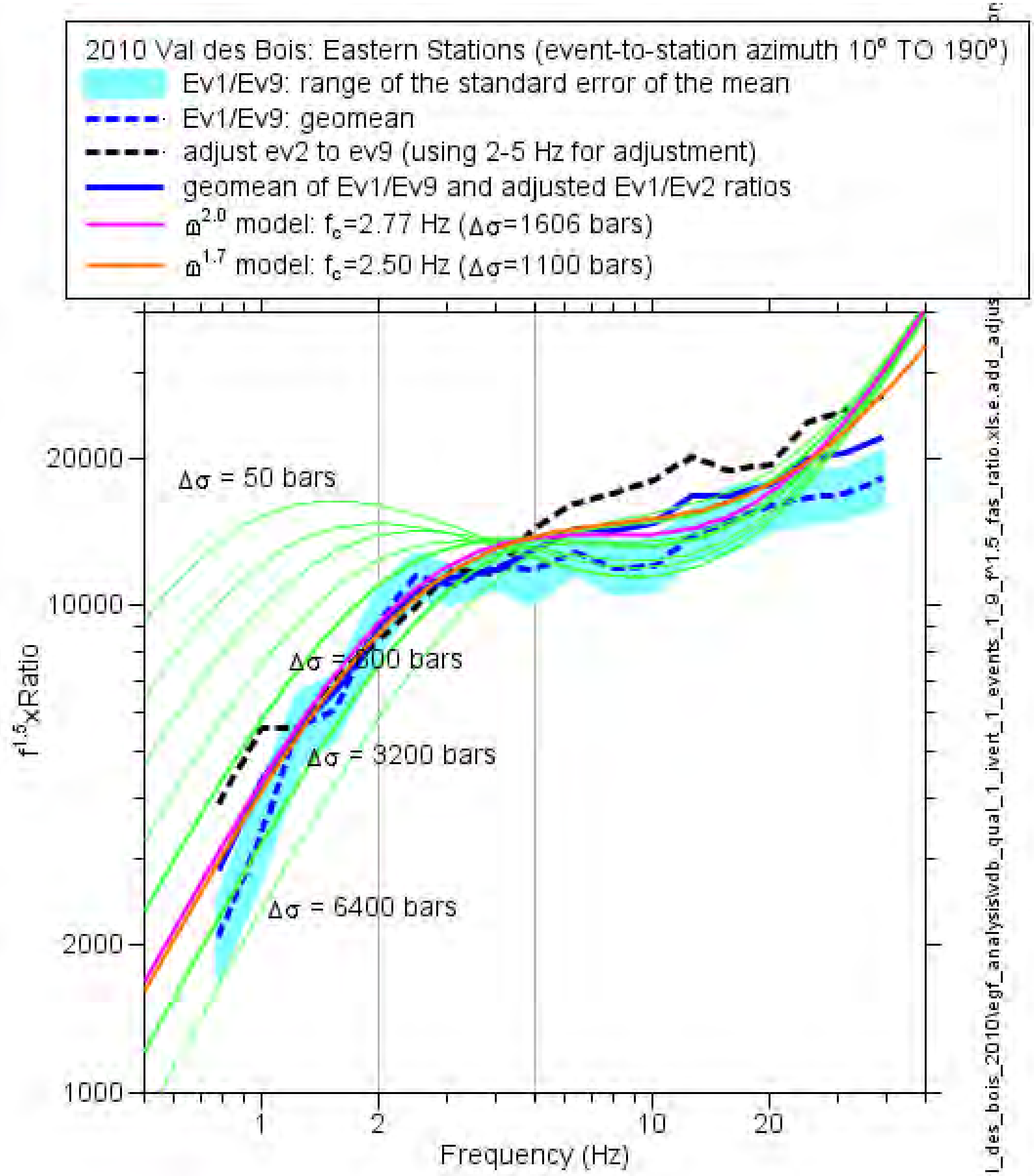


Note azimuthally dependent PSA

Δσ≈400bars only consistent with 1/R

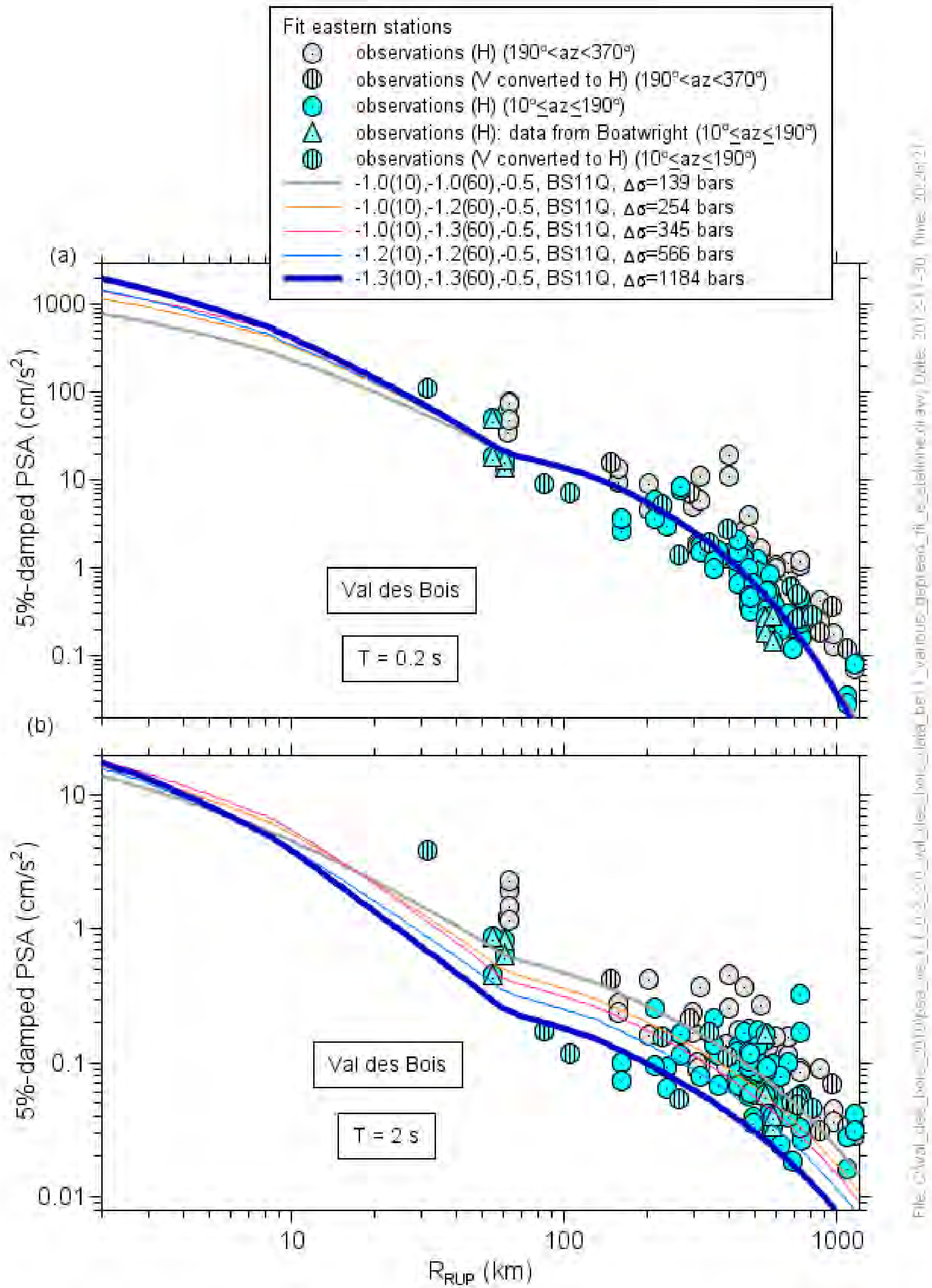


Δσ≈1600bars


2010 Val des Bois: Eastern Stations (event-to-station azimuth 10° TO 190°)
Ev1/Ev9: range of the standard error of the mean
Ev1/Ev9: geomean
adjust ev2 to ev9 (using 2-5 Hz for adjustment)
geomean of Ev1/Ev9 and adjusted Ev1/Ev2 ratios
ω^2.0 model: fc=2.77 Hz (Δσ=1606 bars)
ω^1.7 model: fc=2.50 Hz (Δσ=1100 bars)
Δσ = 50 bars
Δσ = 800 bars
Δσ = 3200 bars
Δσ = 6400 bars
20000
10000
2000
1000
f^1.5xRatio
1
2
10
20
Frequency (Hz)
val_des_bois_2010\egf_analysis\vdb_qual_1_ivert_1_events_1_9_f^1.5_fas_ratio.xls.e.add_adjus

Δσ≈1600bars only consistent with $1/R^p$, p > 1.3

$1/R^{1.3}$, Rt=60 km, not consistent with T=2 s data



Conclusions (stress-path correlation)

- Need consistency between model used to derive parameters and forward predictions using those parameters
- Pronounced azimuthal variation in motions around well-recorded ENA events
- eGf analysis has potential to resolve ambiguity due to stress-path correlation, but limited data bandwidth at low frequencies and azimuthal variations complicate the analysis

Relations between GM_AR, GMRotI50, and RotD50

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Presented at the
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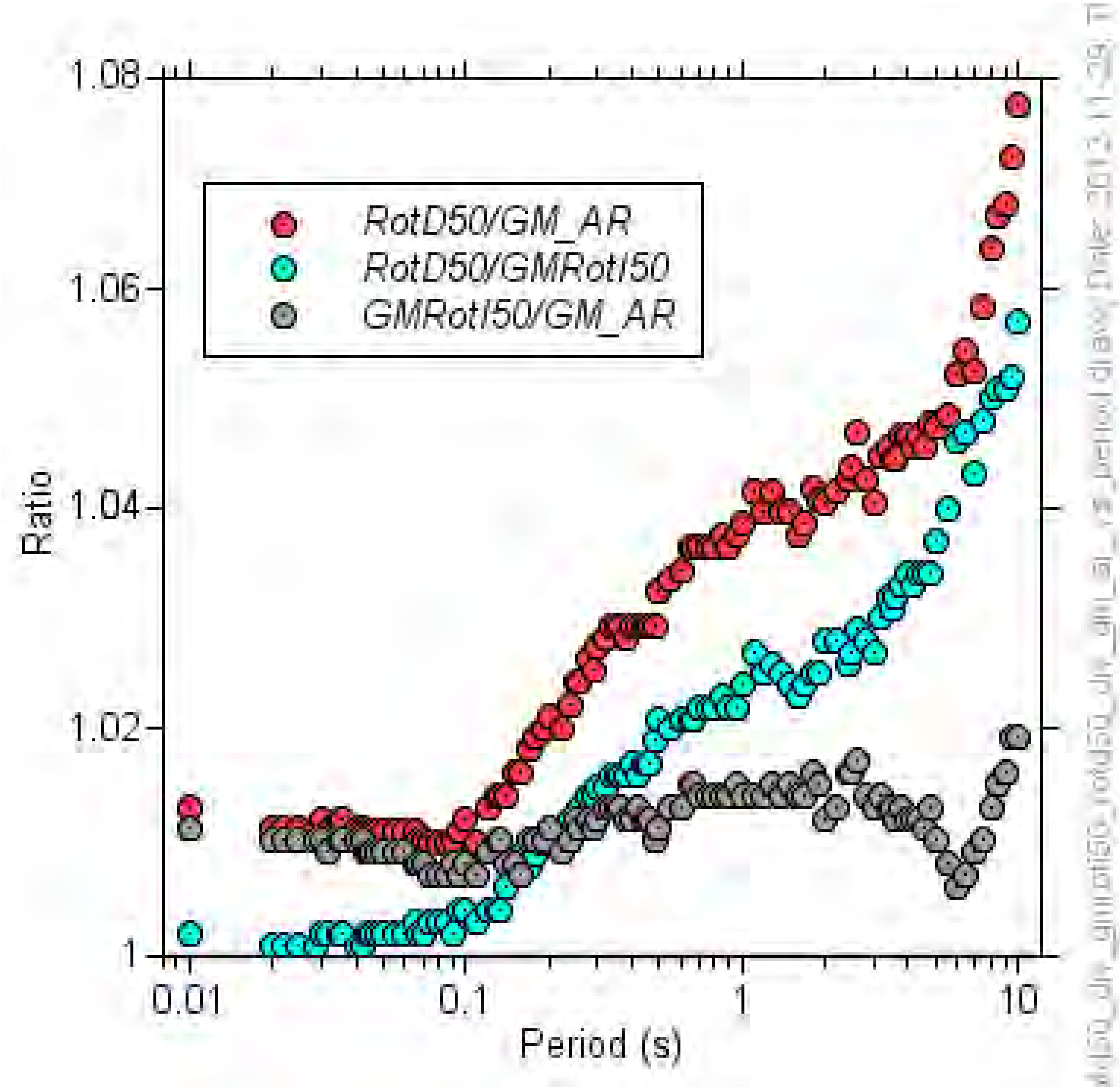
Computing RotD50

- Project the two as-recorded horizontal time series into azimuth Az
- For each period, compute PSA, store Az, PSA pairs in an array
- Increment Az by $\delta\alpha$ and repeat first two steps until Az=180
- Sort array over PSA values
- RotD50 is the median value
- RotD00, RotD100 are the minimum and maximum values
- **NO geometric means are used**

To convert GMPEs using random component as the IM (essentially, the as-recorded geometric mean), multiply by RotD50/GM_AR

To convert GMPEs using GMRotI50 as the IM (e.g., 2008 NGA GMPEs), multiply by RotD50/GMRotI50



References

Boore, D. M., J. Watson-Lamprey, and N. A. Abrahamson (2006). Orientation-independent measures of ground motion, *Bull. Seismol. Soc. Am.* **96**, 1502-1511.

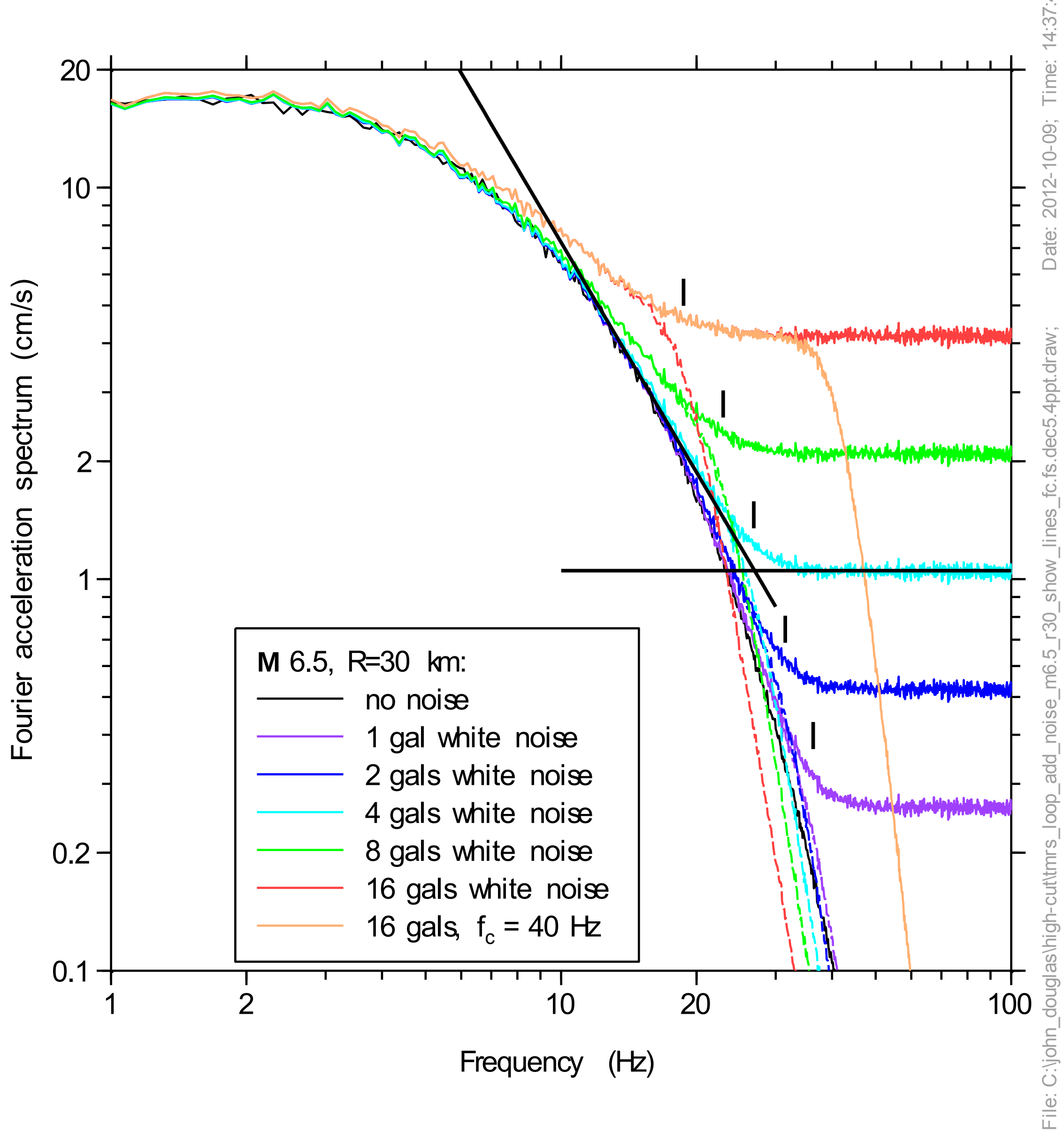
Boore, D. M. (2010). Orientation-independent, non geometric-mean measures of seismic intensity from two horizontal components of motion, *Bull. Seismol. Soc. Am.* **100**, 1830-1835.

Conclusions (Ground-motion intensity measure)

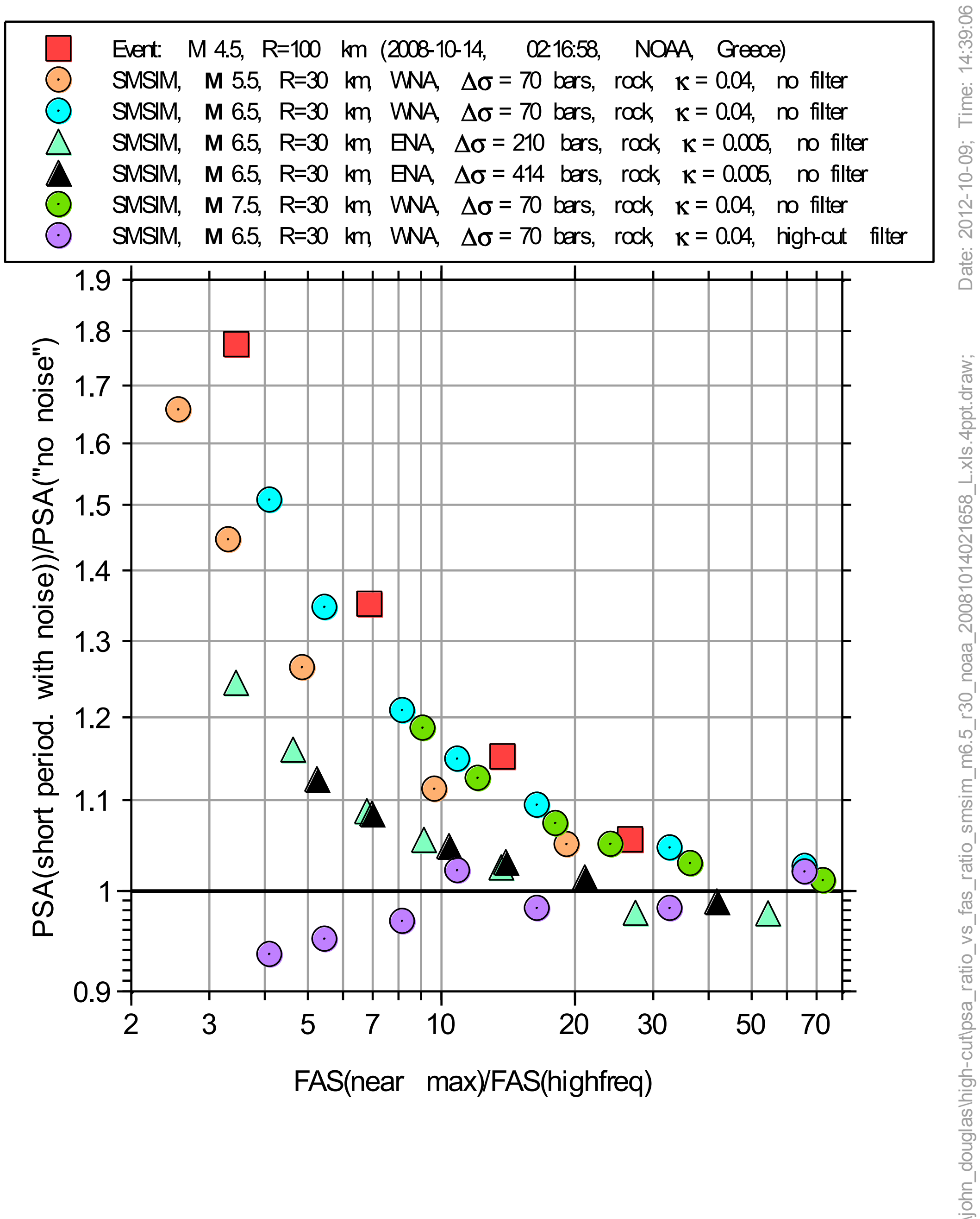
- WNA-E should use RotD50 for consistency with NGA-West2
- A factor of 1.04 for T=1 s. Is this important?
- Converting GMPEs in terms of random horizontal component, geometric mean, or GMRotI50 to RotD50 can be done using correlations shown in the figure (**although these were derived for NGA-W flatfile—should compare GM_AR, GMRotI50, and RotD50 for CENA data**)

Response Spectra for Low Sample Rate Data: A Simulation Study

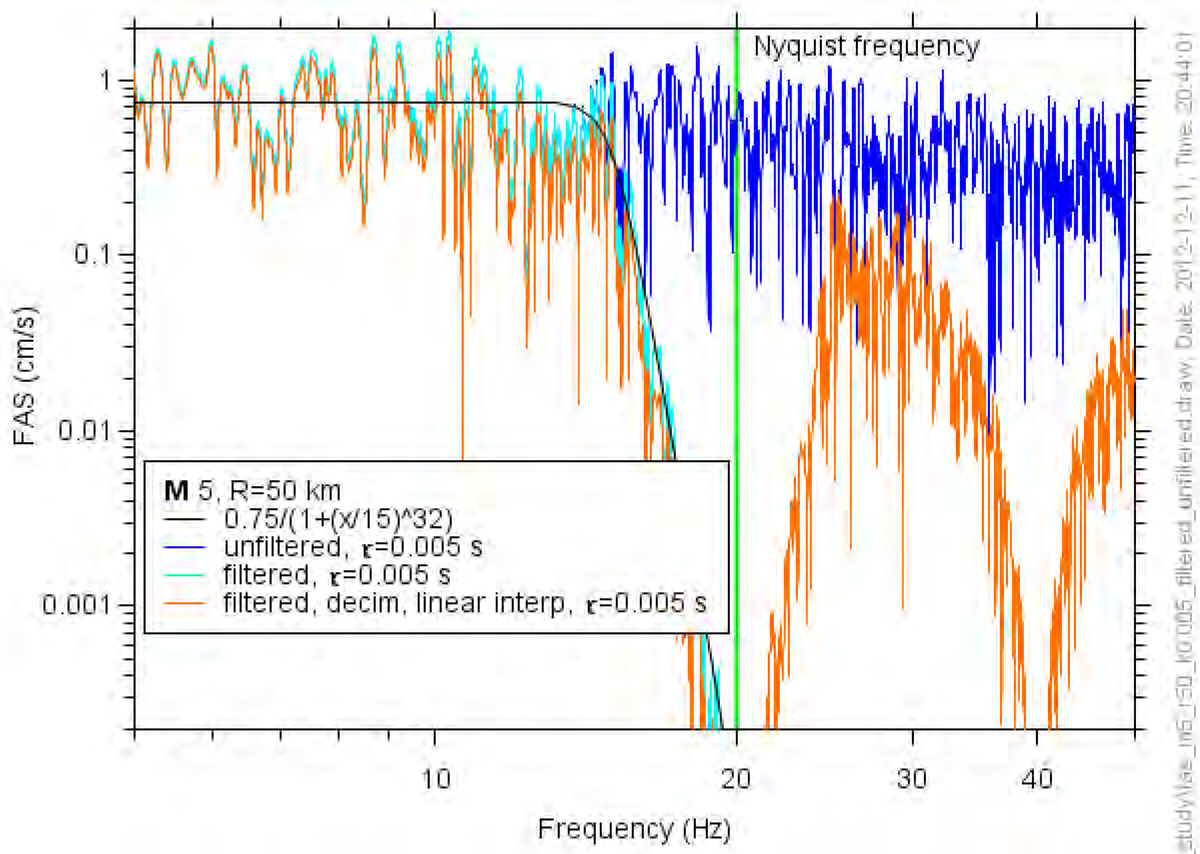
An issue discovered by Norm Abrahamson



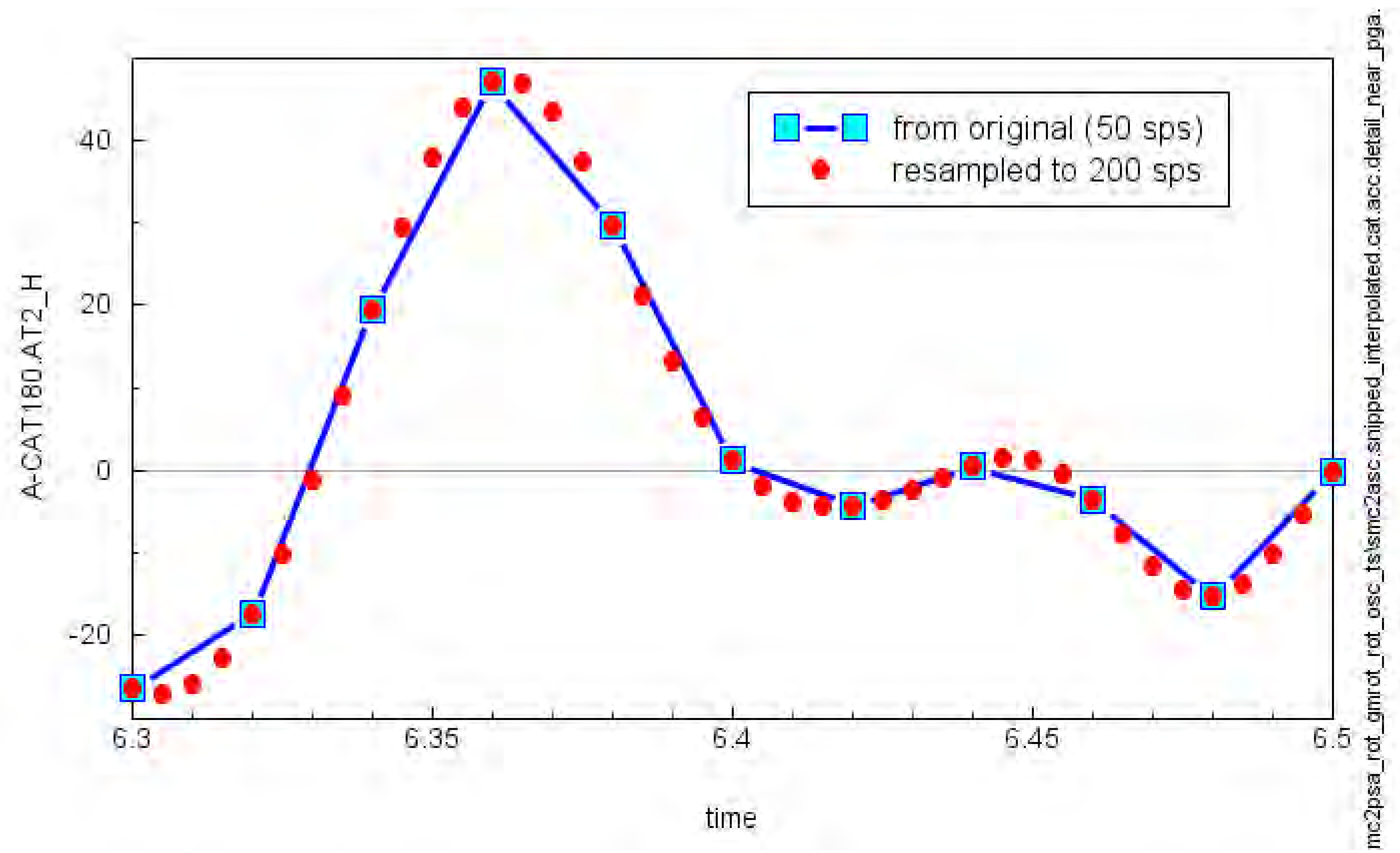
Douglas, J. and D. M. Boore (2011). High-frequency filtering of strong-motion records, *Bull. Earthquake Engineering* **9**, 395—409.



Event: M 4.5, R=100 km (2008-10-14, 02:16:58, NOAA, Greece)
SMSIM, **M** 5.5, R=30 km, WNA, $\Delta\sigma$ = 70 bars, rock, κ = 0.04, no filter
SMSIM, **M** 6.5, R=30 km, WNA, $\Delta\sigma$ = 70 bars, rock, κ = 0.04, no filter
SMSIM, **M** 6.5, R=30 km, ENA, $\Delta\sigma$ = 210 bars, rock, κ = 0.005, no filter
SMSIM, **M** 6.5, R=30 km, ENA, $\Delta\sigma$ = 414 bars, rock, κ = 0.005, no filter
SMSIM, **M** 7.5, R=30 km, WNA, $\Delta\sigma$ = 70 bars, rock, κ = 0.04, no filter
SMSIM, **M** 6.5, R=30 km, WNA, $\Delta\sigma$ = 70 bars, rock, κ = 0.04, high-cut filter
PSA(short period, with noise))/PSA("no noise")
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0.9
2
3
5
7
10
20
30
50
70
FAS(near max)/FAS(highfreq)
john_douglas\high-cut\psa_ratio_vs_fas_ratio_smsim_m6.5_r30_noaa_20081014021658_L.xls.4ppt.draw; Date: 2012-10-09; Time: 14:39:06

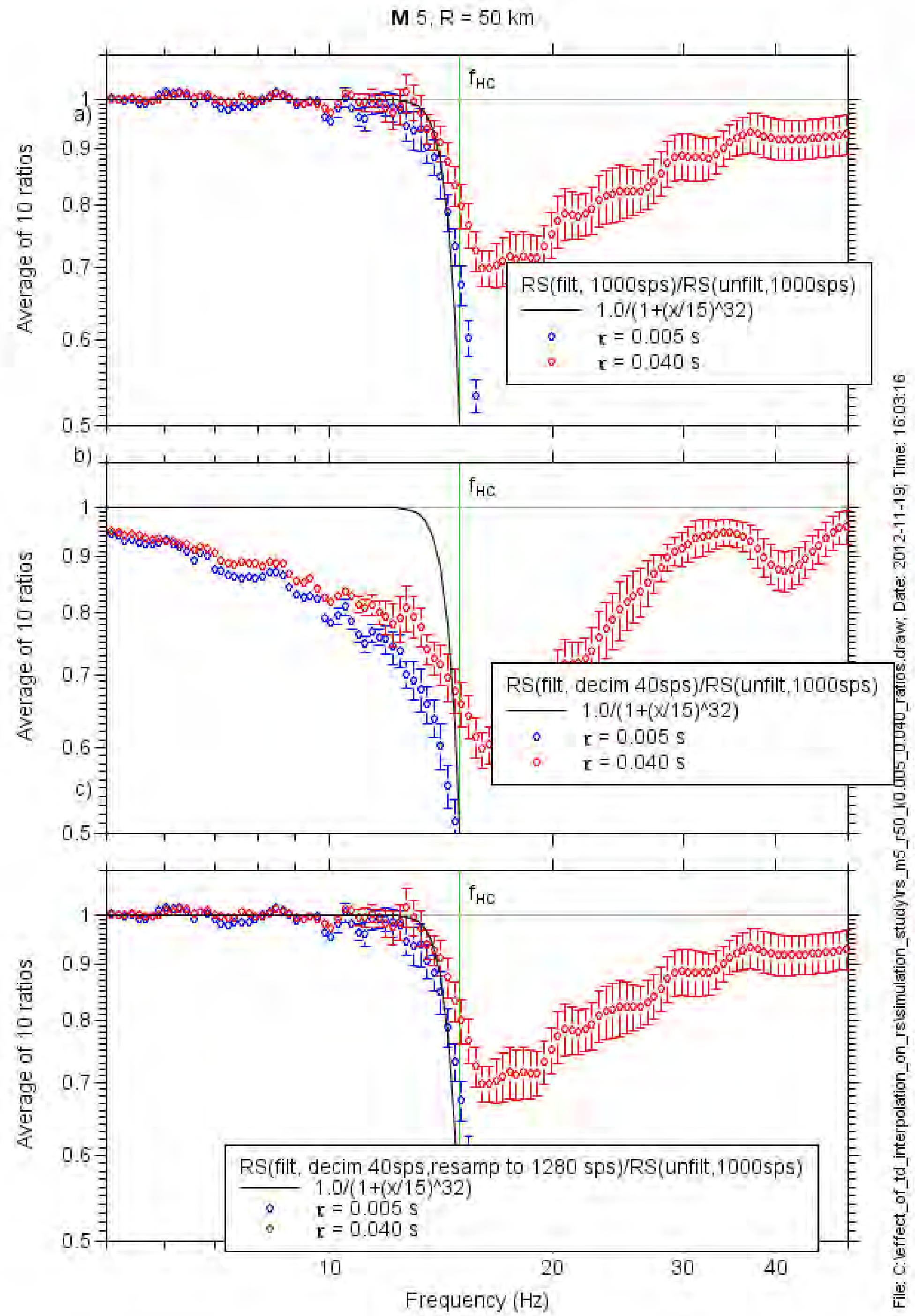


Representative Fourier acceleration spectra (the first of 10 simulations) for unfiltered and filtered time series computed for a **M** 5 earthquake at 50 km, assuming model parameters appropriate for eastern North America, except for .



from original (50 sps)
resampled to 200 sps
A-CAT180.AT2_H
40
20
0
-20
6.3
6.35
6.4
6.45
6.5
time
mc2psa_rot_gmrot_rot_osc_ts\smc2asc.snipped_interpolated.cat.acc.detail_near_pga.

Average of 10 ratios of response spectra, for simulations spanning the range of used in this study, plotted vs frequency for ease of comparison with the FAS in Figure 1.



Conclusions (Computation of PSA)

- Standard method for computing PSA can lead to significant bias (underestimation) of response spectra for frequencies less than the antialiasing filter frequency
- This is of most concern for situations where high-frequencies are little attenuated (low-kappa sites, close distances) and low-sample rate dataloggers are used (thus leading to abrupt changes in spectral level near the anti-aliasing corner frequency)

Conclusions (Computation of PSA)

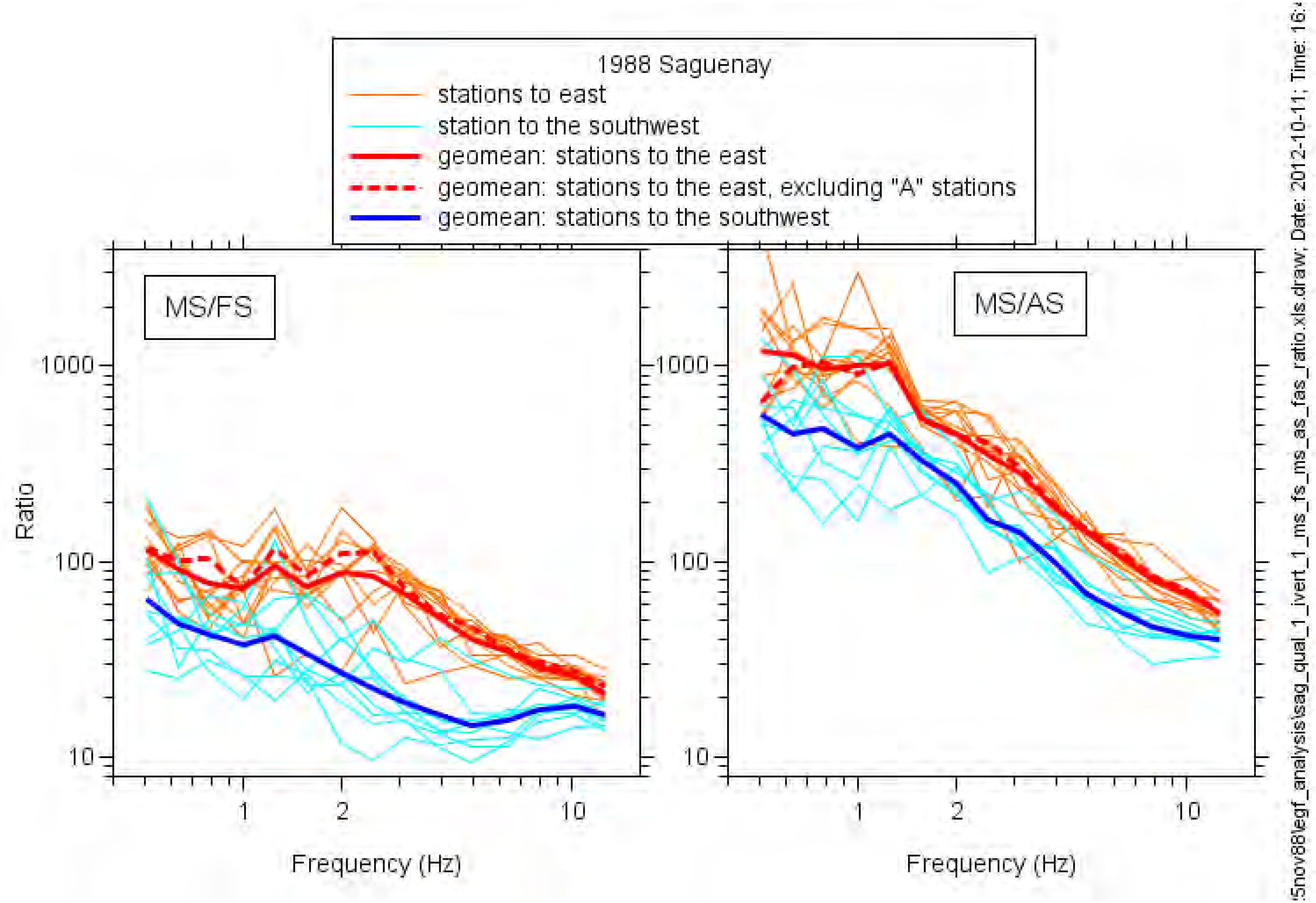
- Guidelines should be developed that can be used to decide on the usable short-period limit of the PSA
  - Simulation study should be extended to consider more M, R
  - Filtering, decimation, resampling steps should be done with data also
- Reprocess all records with resampling

End

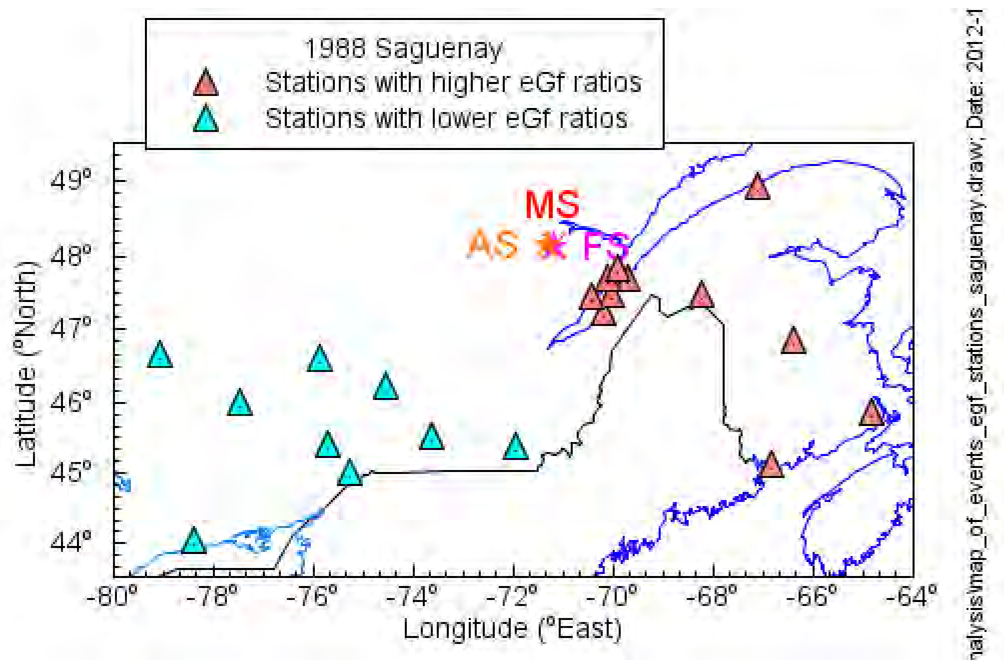
eGf and PSA inversions for three earthquakes:

- Val des Bois
- Saguenay (eGf only)
- Riviere du Loup

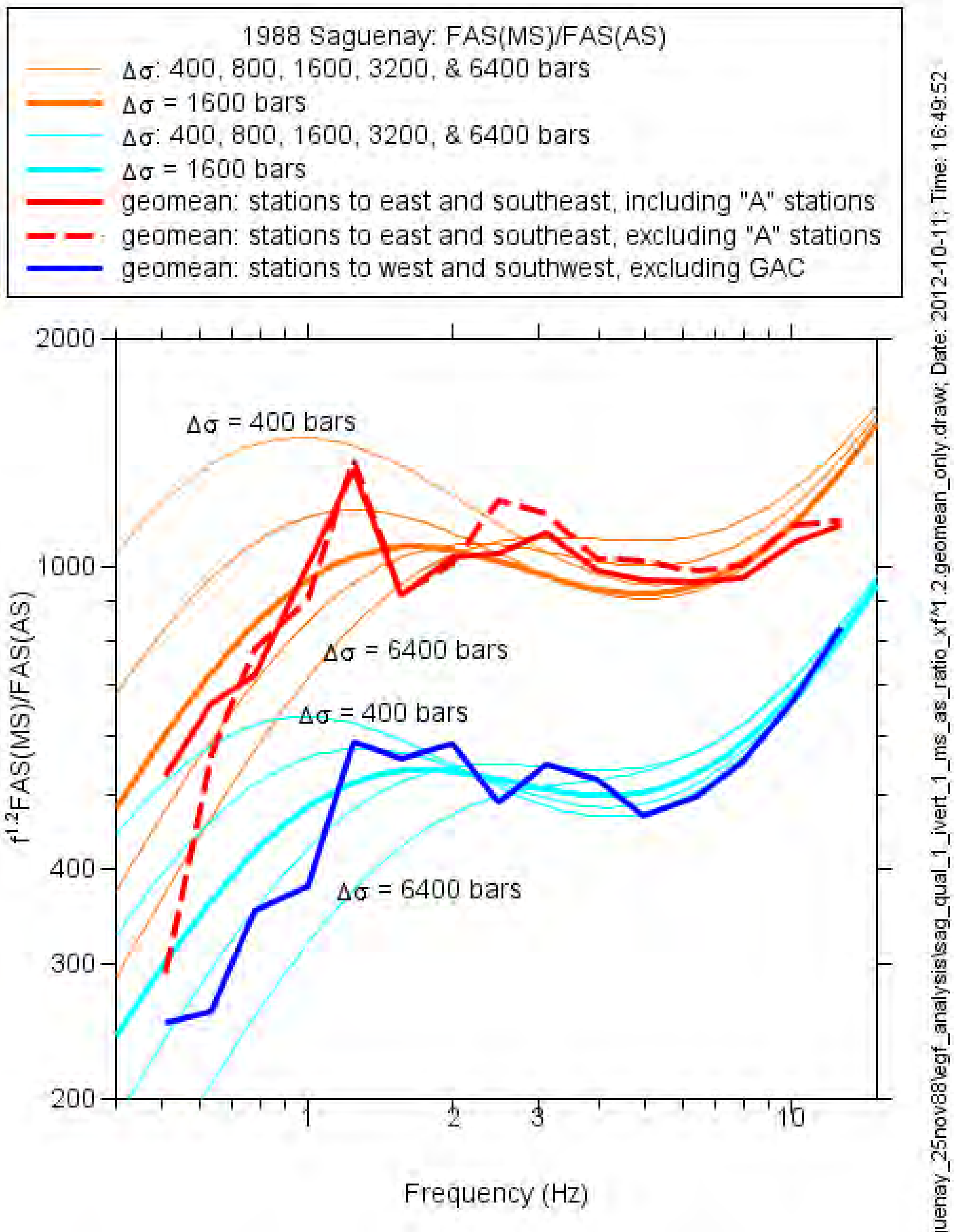
Saguenay



1988 Saguenay
stations to east
station to the southwest
geomean: stations to the east
geomean: stations to the east, excluding "A" stations
geomean: stations to the southwest
MS/FS
MS/AS
Ratio
1000
100
10
1
2
10
Frequency (Hz)
5nov88\egf_analysis\sag_qual_1_ivert_1_ms_fs_ms_as_fas_ratio.xls.draw; Date: 2012-10-11; Time: 16:


1988 Saguenay
Stations with higher eGf ratios
Stations with lower eGf ratios
MS
AS
FS
49°
48°
47°
46°
45°
44°
Latitude (°North)
-80°
-78°
-76°
-74°
-72°
-70°
-68°
-66°
-64°
Longitude (°East)
nalysis\map_of_events_egf_stations_saguenay.draw; Date: 2012-1

Δσ≈1600bars



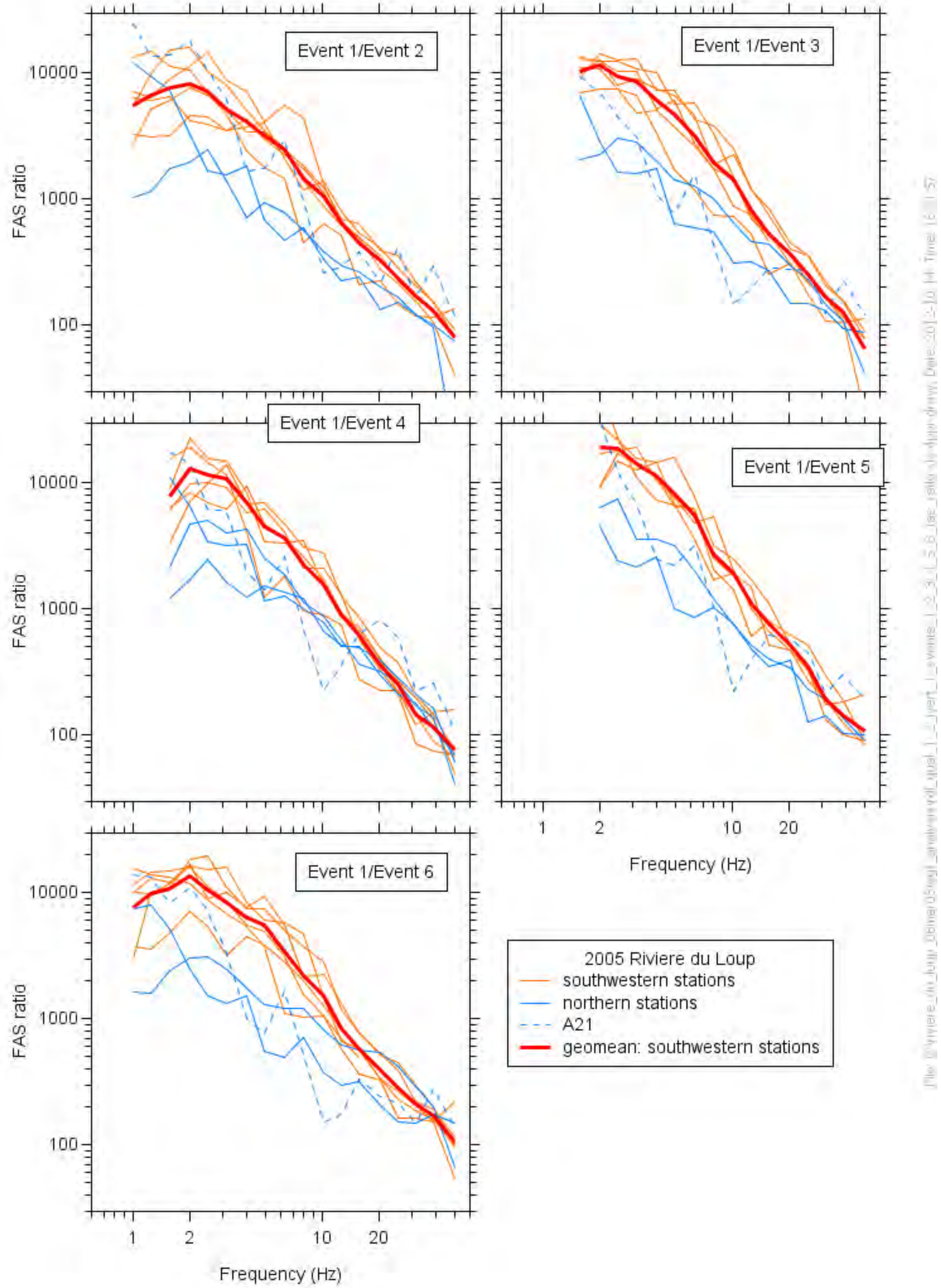
1988 Saguenay: FAS(MS)/FAS(AS)
Δσ: 400, 800, 1600, 3200, & 6400 bars
Δσ = 1600 bars
Δσ: 400, 800, 1600, 3200, & 6400 bars
Δσ = 1600 bars
geomean: stations to east and southeast, including "A" stations
geomean: stations to east and southeast, excluding "A" stations
geomean: stations to west and southwest, excluding GAC
Δσ = 400 bars
Δσ = 6400 bars
Δσ = 400 bars
Δσ = 6400 bars
2000
1000
400
300
200
1
2
3
10
Frequency (Hz)
f^1.2FAS(MS)/FAS(AS)
guenay_25nov88\egf_analysis\sag_qual_1_jvert_1_ms_as_ratio_xf^1.2.geomean_only.draw; Date: 2012-10-11; Time: 16:49:52

Val des Bois

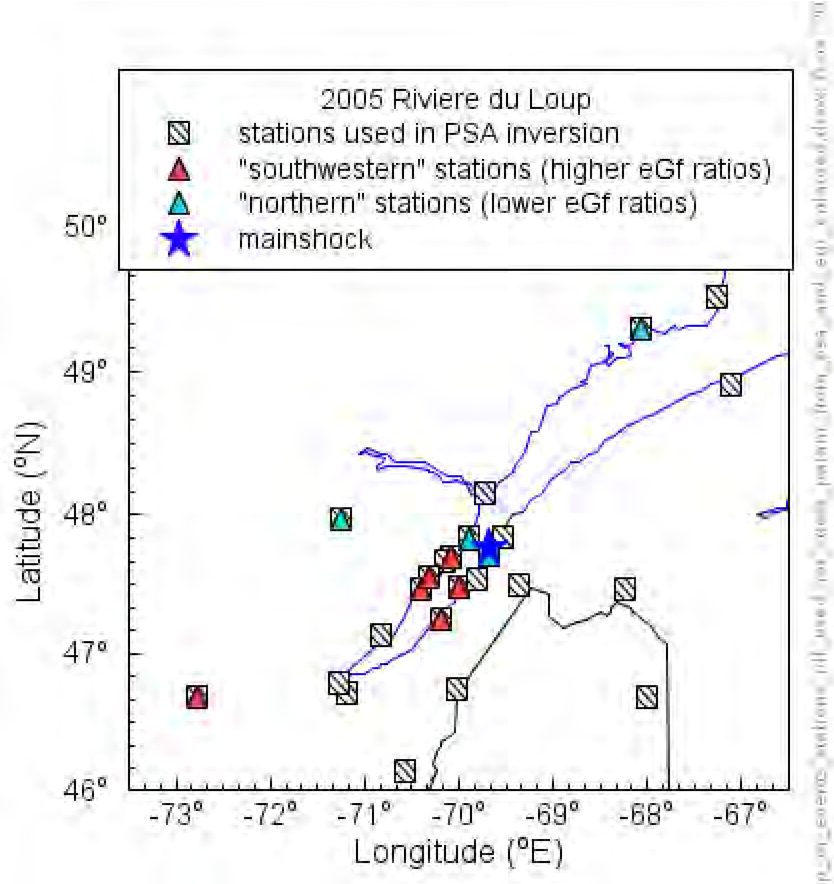
Riviere du Loup

Event information for the Riviere du Loup Earthquake

event	Year	Mo	Day	Hour	Min	Sec	eve-lat	eve-lon	Depth(km)	Mn	M*	$\Delta\sigma$ (bars)
1	2005	3	6	6	17	49	47.75	-69.73	13.3	5.4	4.67	512
2	2005	3	11	0	36	23	47.760	-69.730	12.7	2.3	2.1	279
3	2005	3	6	8	55	42	47.750	-69.730	13.9	2.1	2.0	312
4	2005	5	17	7	17	50	47.750	-69.730	14.4	2.1	2.0	342
5	2005	5	5	2	21	21	47.750	-69.730	14.3	2.0	1.8	441
6	2005	3	6	15	12	23	47.760	-69.730	15.1	2.0	2.0	75

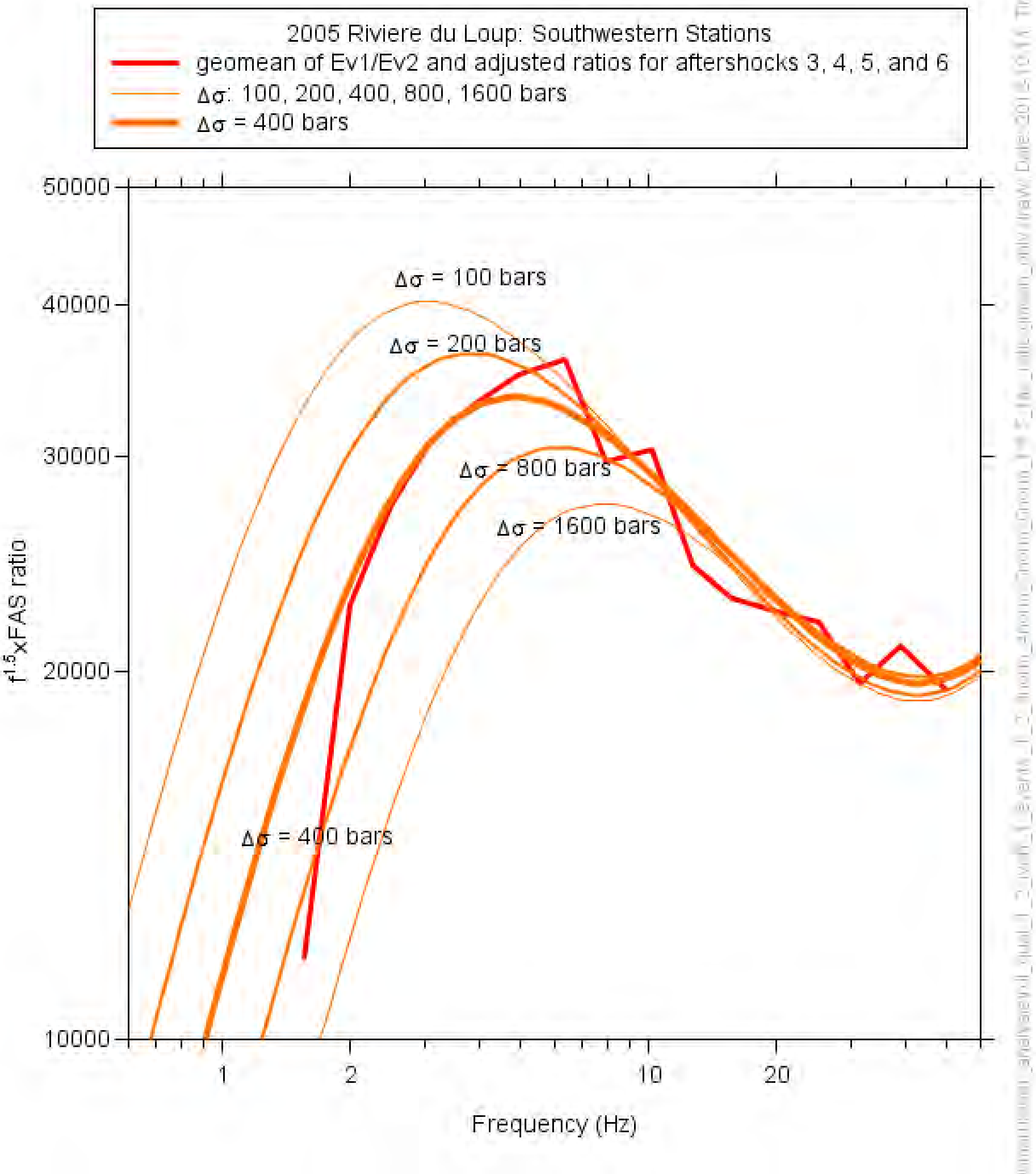


Event 1/Event 2
Event 1/Event 3
Event 1/Event 4
Event 1/Event 5
Event 1/Event 6
FAS ratio
10000
1000
100
1
2
10
20
Frequency (Hz)
2005 Riviere du Loup
southwestern stations
northern stations
A21
geomean: southwestern stations

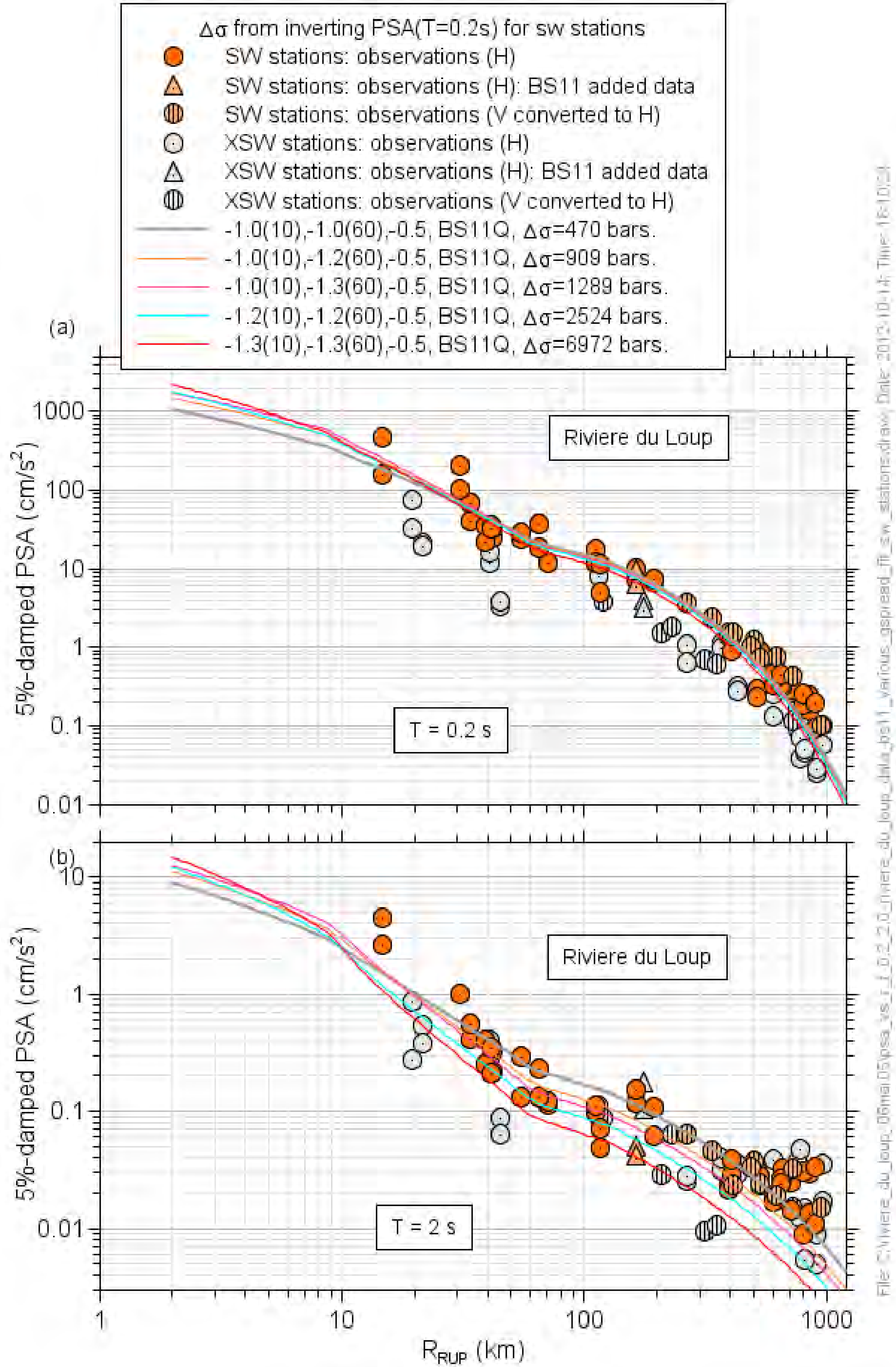


2005 Riviere du Loup
stations used in PSA inversion
"southwestern" stations (higher eGf ratios)
"northern" stations (lower eGf ratios)
mainshock
50°
49°
48°
47°
46°
Latitude (°N)
-73°
-72°
-71°
-70°
-69°
-68°
-67°
Longitude (°E)

$\Delta\sigma \approx 400$bars



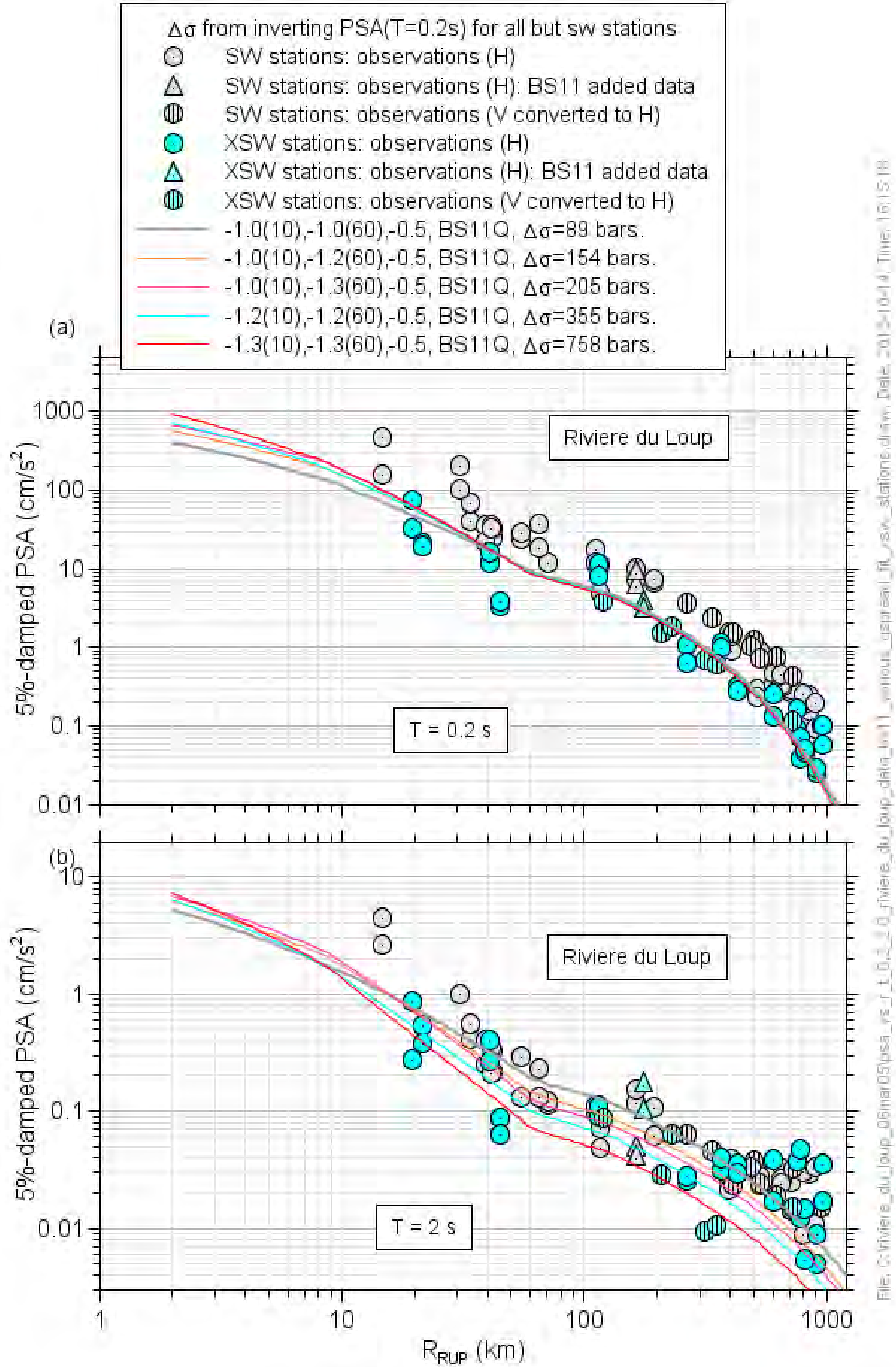
$\Delta\sigma \approx 400$bars only consistent with 1/R

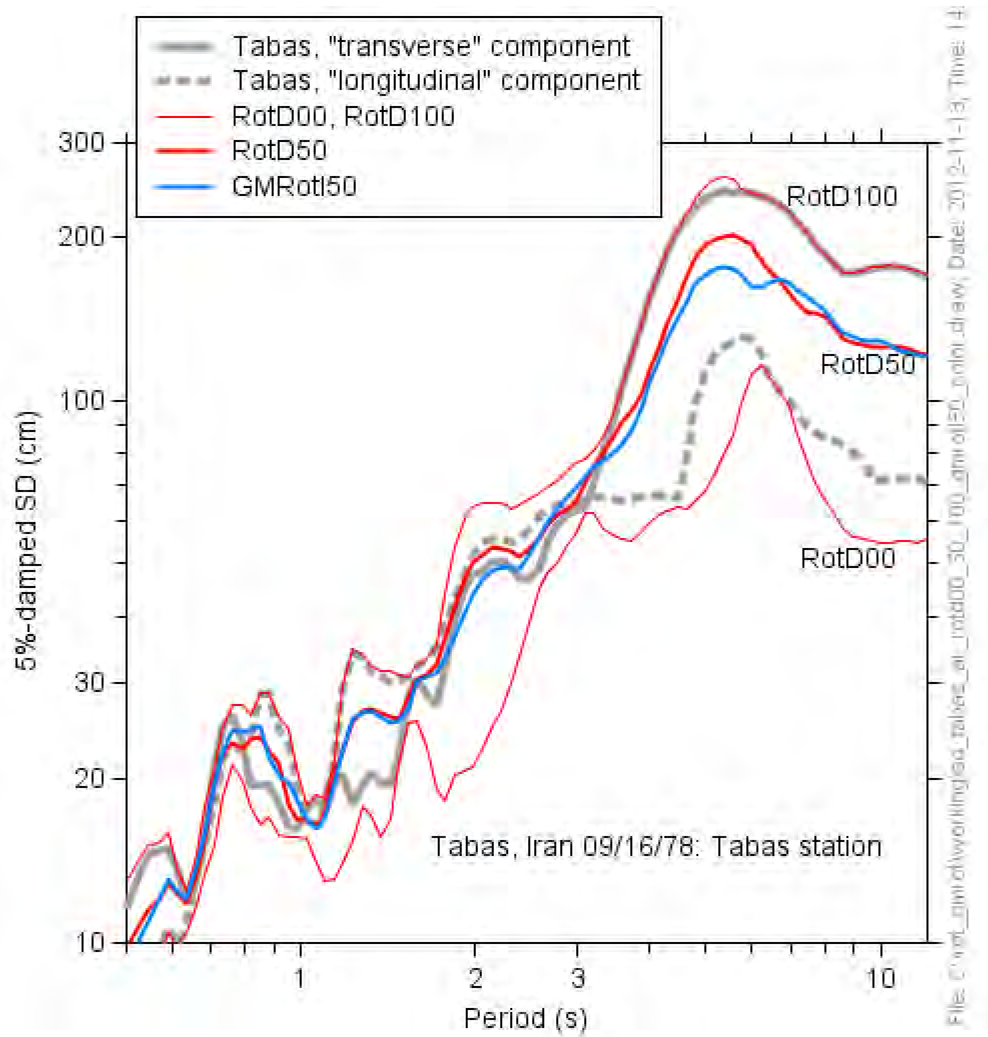


$1/R^{1.3}$, Rt=60 km, not consistent with T=2 s data

Not enough non-SW stations for eGf analysis

1/$R^{1.3}$, Rt=60 km, not consistent with T=2 s data





Tabas, "transverse" component
Tabas, "longitudinal" component
RotD00, RotD100
RotD50
GMRotI50
RotD100
RotD50
RotD00
Tabas, Iran 09/16/78: Tabas station
5%-damped SD (cm)
Period (s)
300
200
100
30
20
10
1
2
3
10