Geometrical Spreading Determined from Coda-Normalized S-wave Amplitudes

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For workshop on GMPE's for Update of the National Seismic Hazard Maps
Dec. 12, 2012

Describing the Distance Decay of S-wave Spectral Amplitudes at less than 70 km distance

- S-wave Fourier spectral amplitude proportional to:

$$S(f)G(f)\, R^{-\gamma}\, e^{-\pi f t/Q(f)}$$

S(f)= source spectrum
G(f)= site amplification

- Used 7 earthquakes in Charlevoix area to study geometrical spreading at distances less than 70 km; data from the Canadian seismic network
- Used horizontal broadband records, except when clipped, then used accelerometer records
- Applied coda normalization technique (Aki, 1982): divide S-wave spectral amplitude by coda amplitude at fixed time after origin time of earthquake to remove site response and source term.

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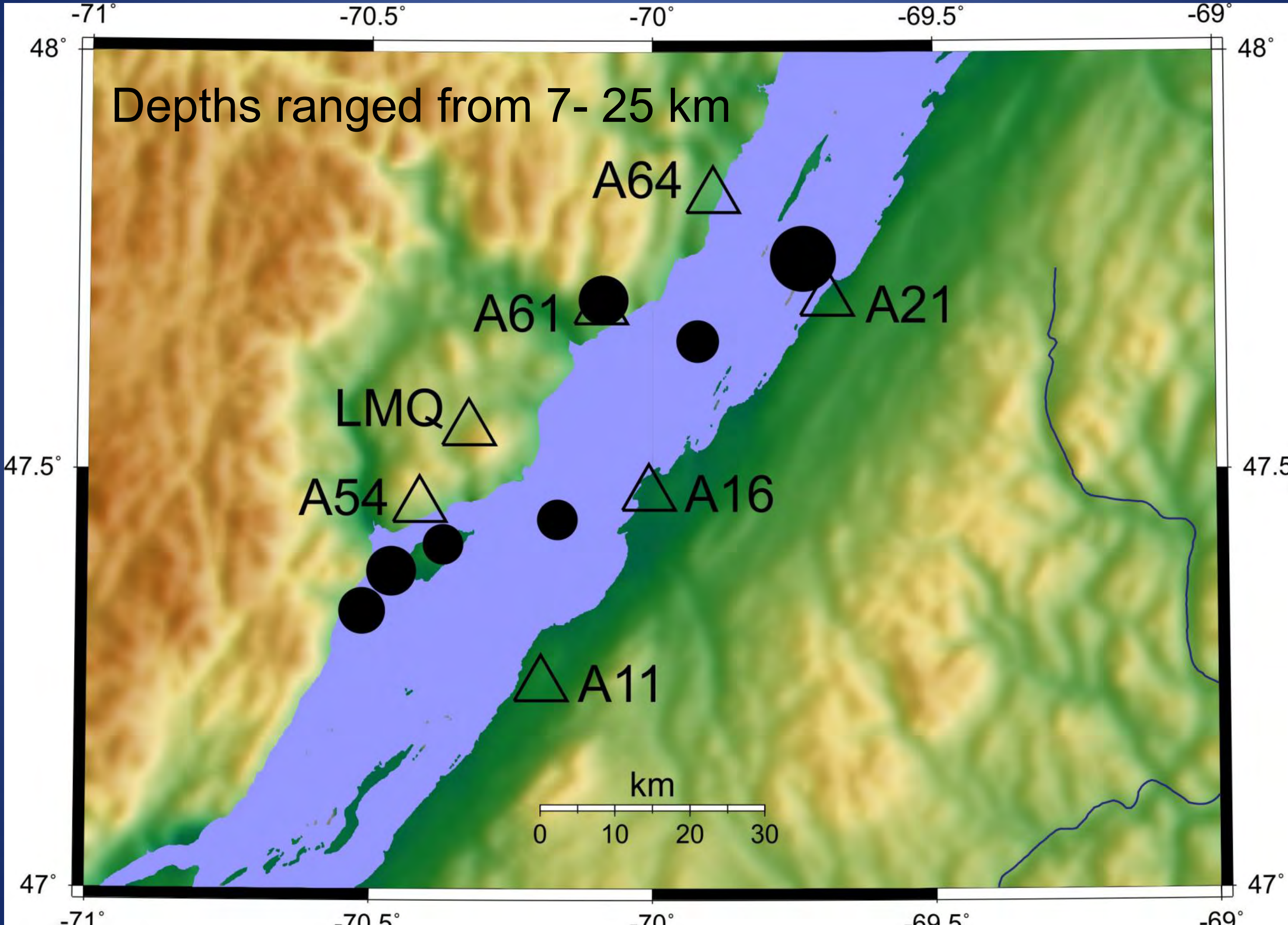
M_n of earthquakes studied ranged from 3.3 to 5.4 (locations and M_n from GSC)



Stations from the Canadian Seismic Network

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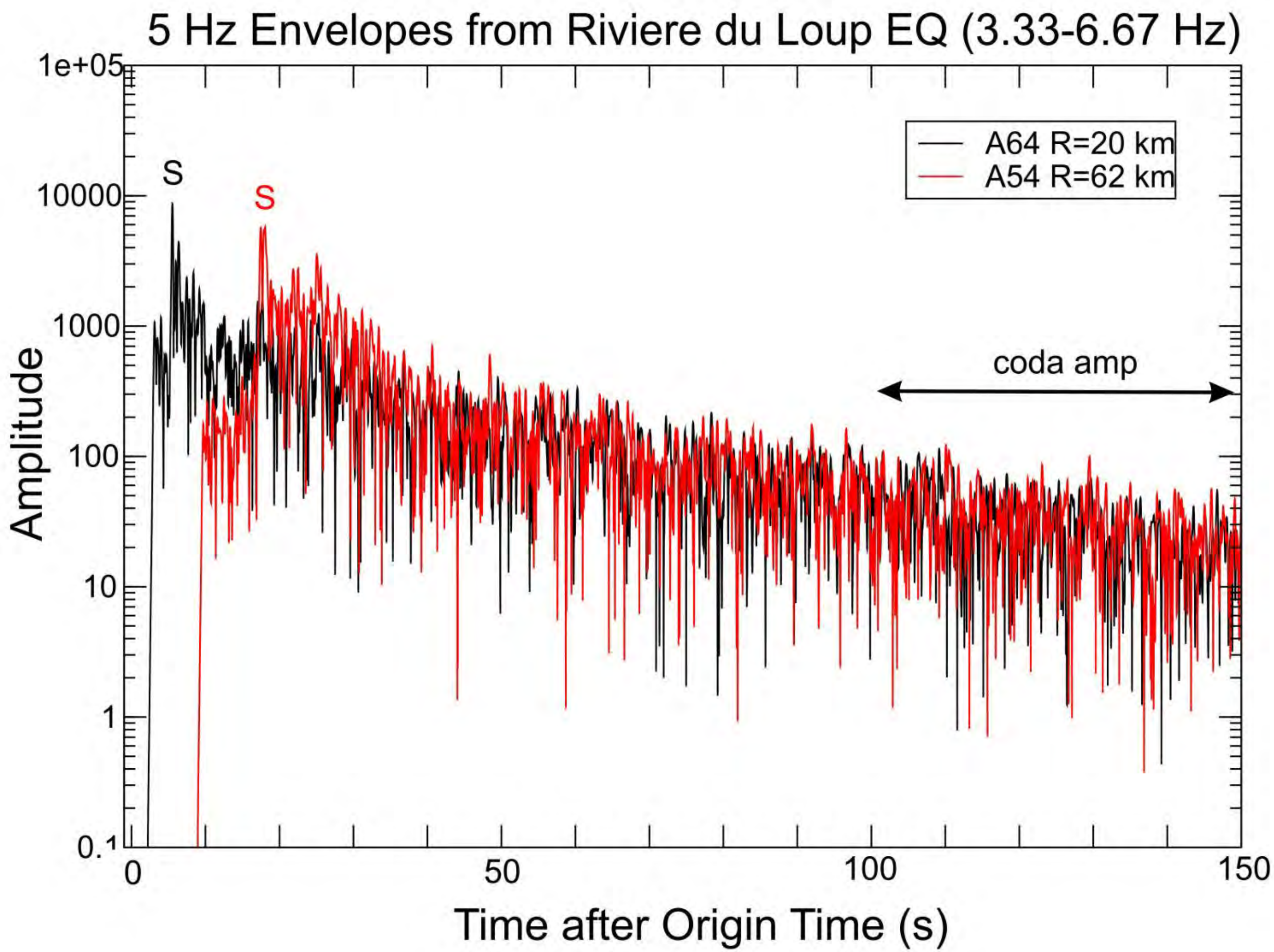
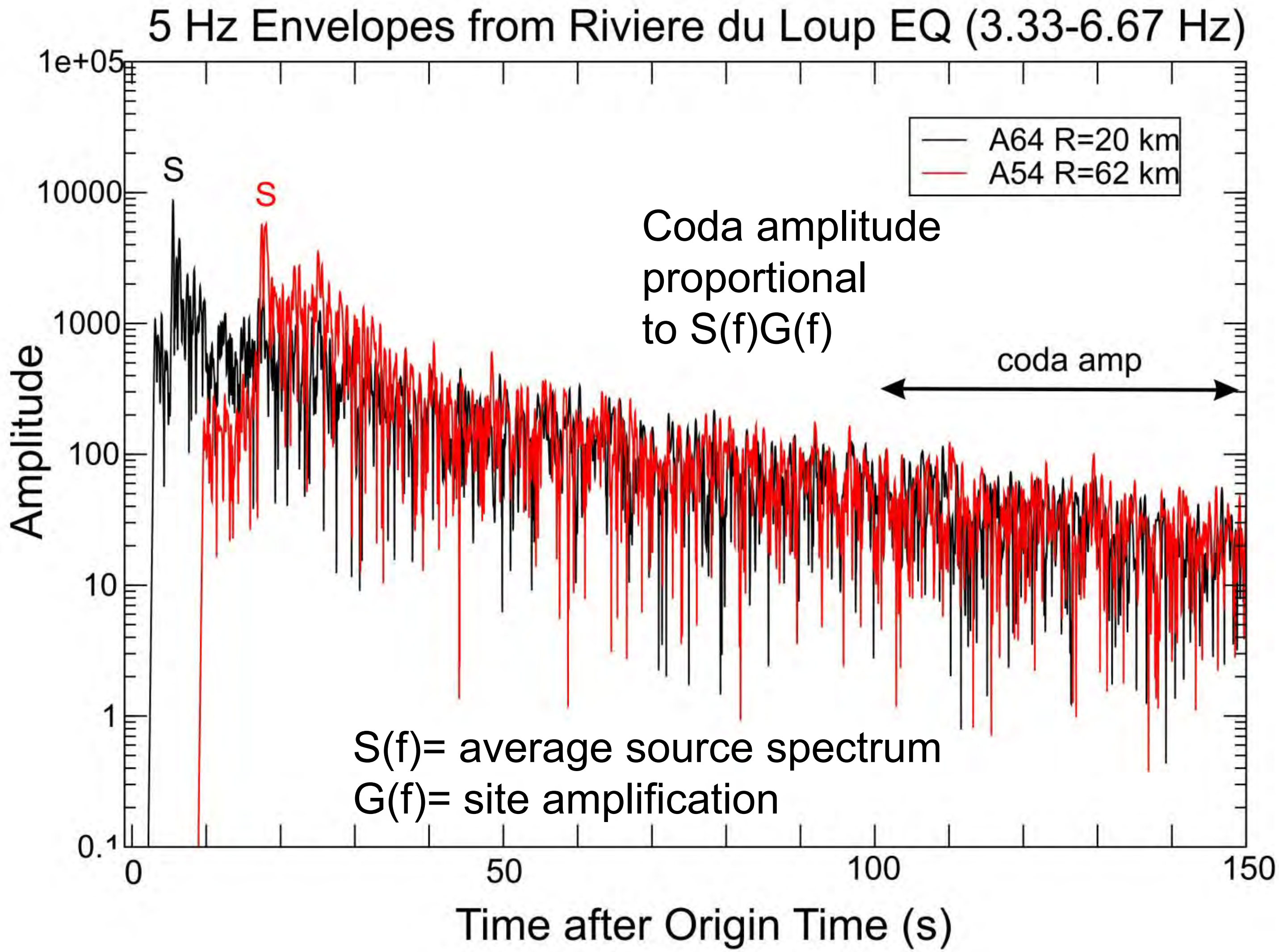
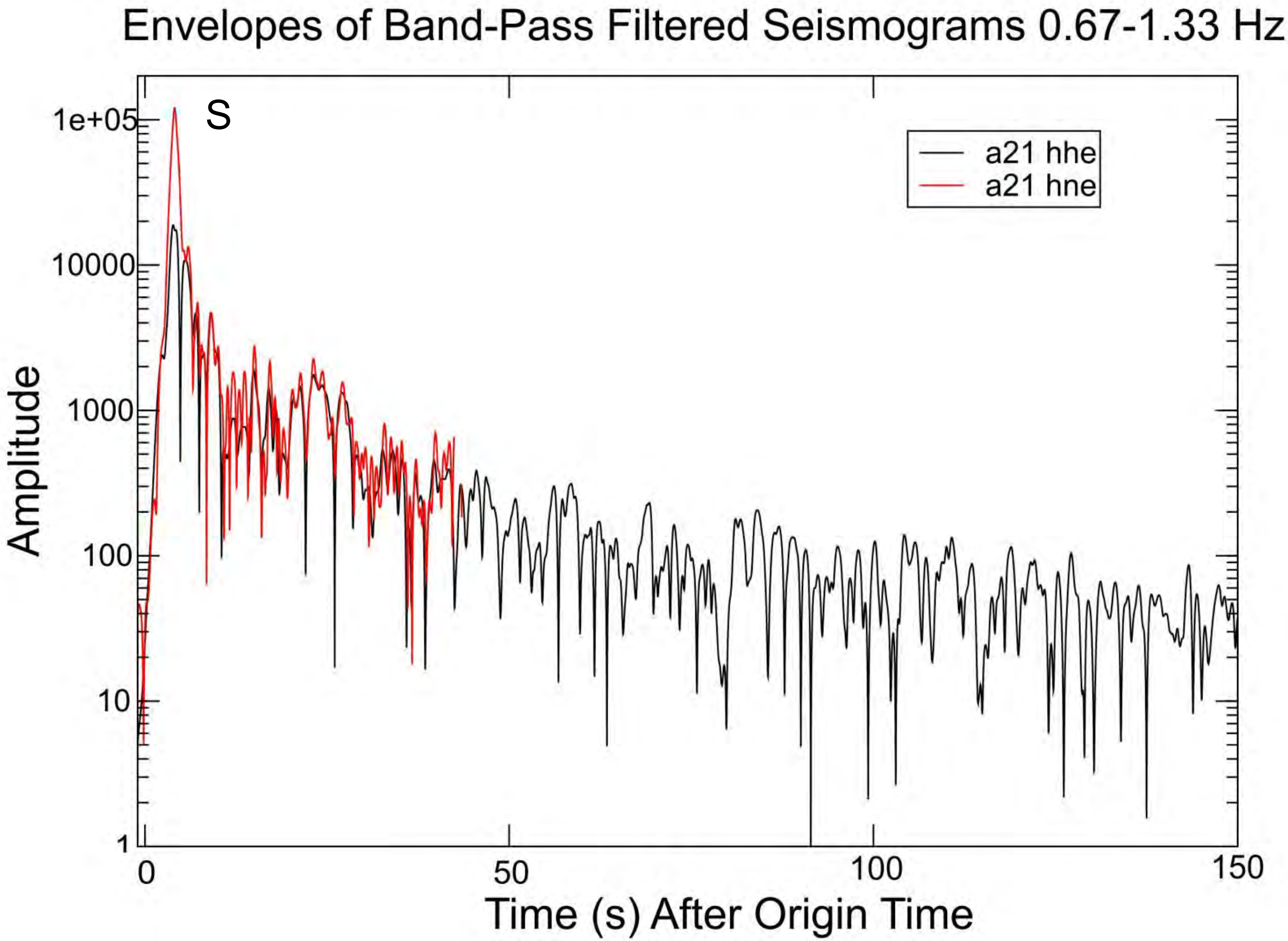


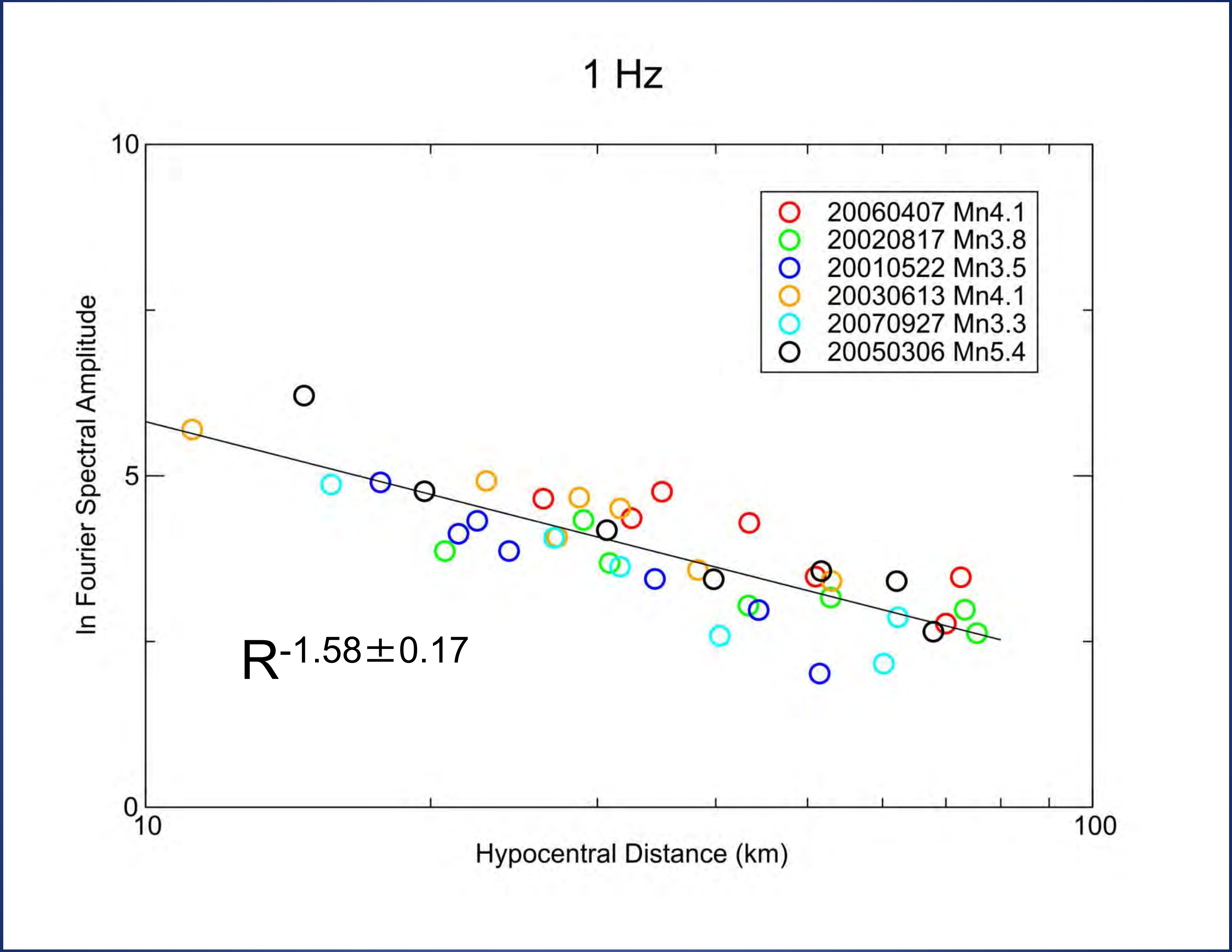
5 Hz Envelopes from Riviere du Loup EQ (3.33-6.67 Hz)
A64 R=20 km
A54 R=62 km
S
S
coda amp
Amplitude
1e+05
10000
1000
100
10
1
0.1
0
50
100
150
Time after Origin Time (s)

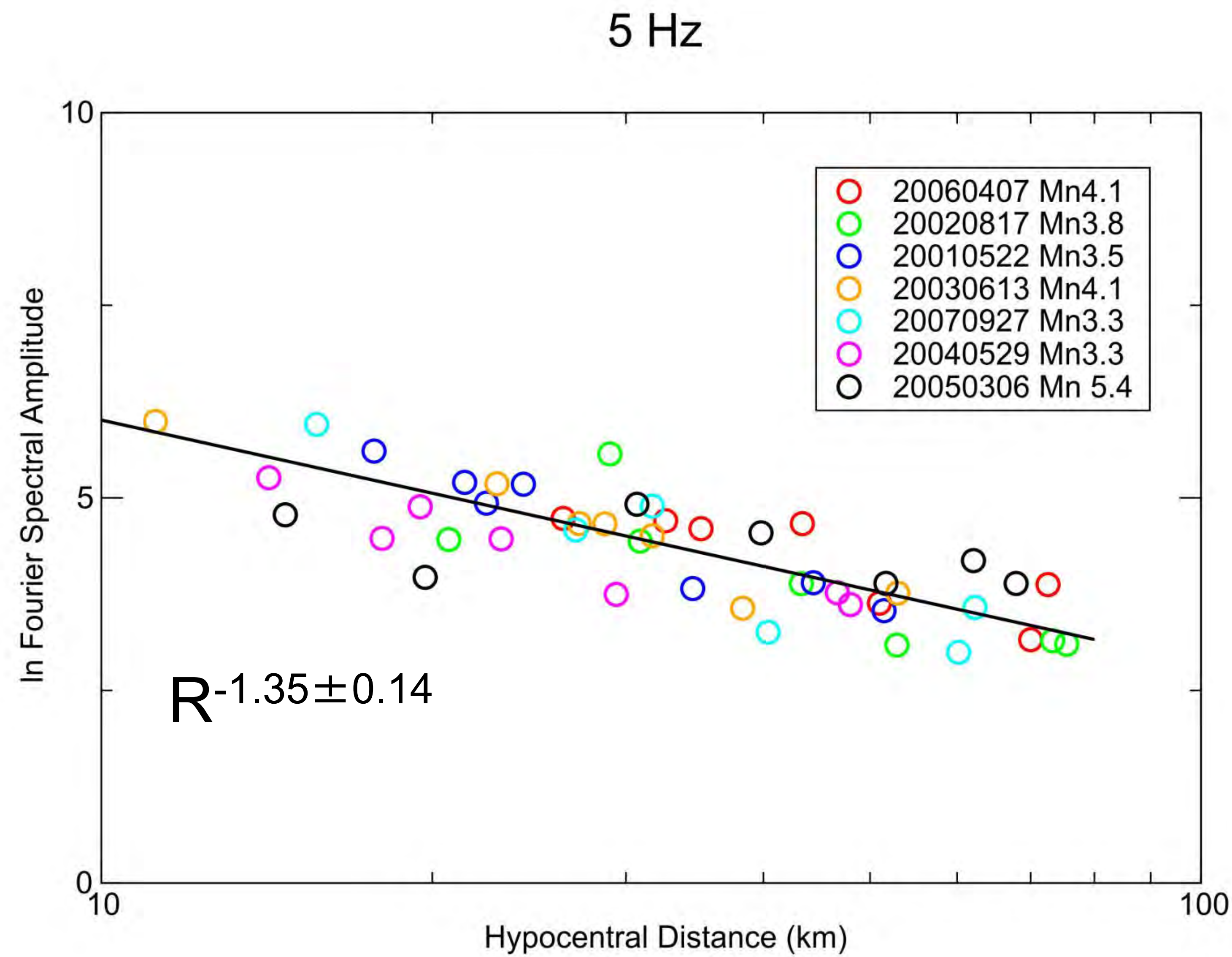


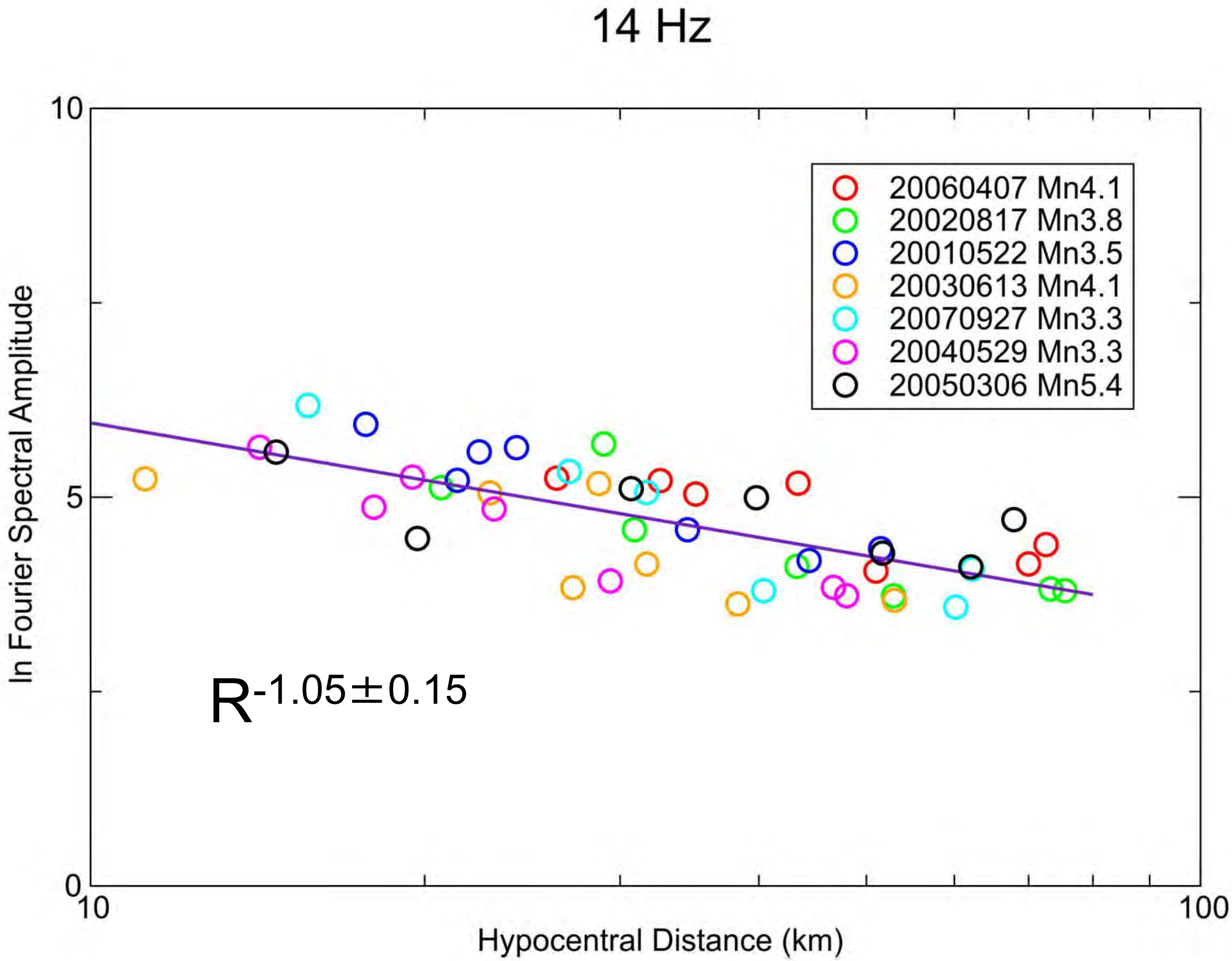
5 Hz Envelopes from Riviere du Loup EQ (3.33-6.67 Hz)
A64 R=20 km
A54 R=62 km
S
S
Coda amplitude
proportional
to S(f)G(f)
coda amp
S(f)= average source spectrum
G(f)= site amplification
Amplitude
1e+05
10000
1000
100
10
1
0.1
0
50
100
150
Time after Origin Time (s)



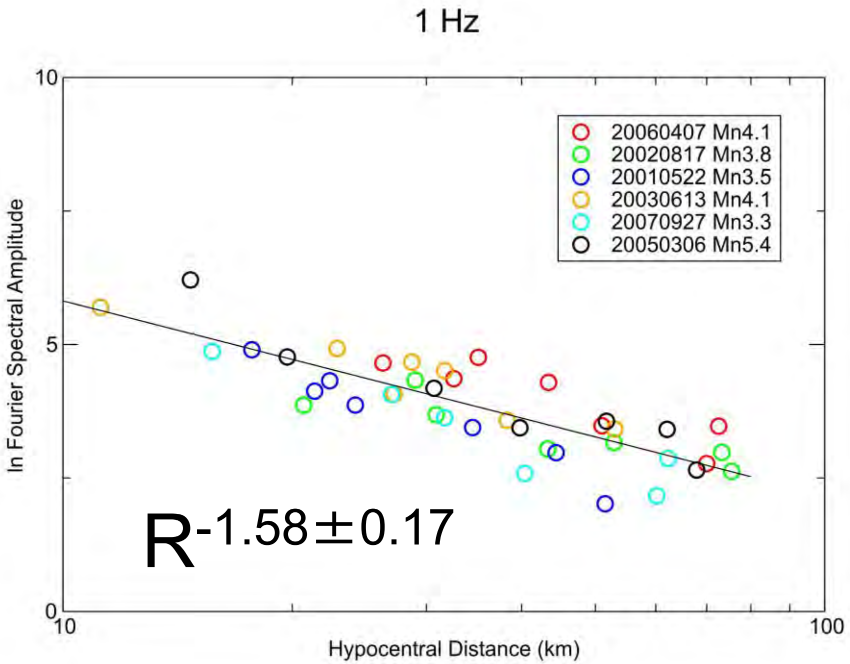
Envelopes of Band-Pass Filtered Seismograms 0.67-1.33 Hz
S
a21 hhe
a21 hne
1e+05
10000
1000
100
10
1
Amplitude
0
50
100
150
Time (s) After Origin Time

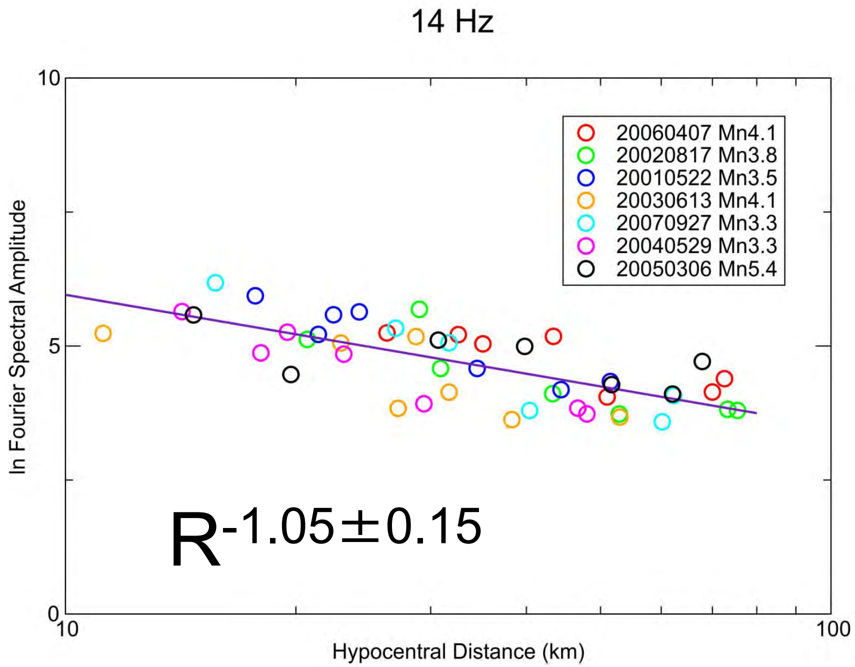

1 Hz
20060407 Mn4.1
20020817 Mn3.8
20010522 Mn3.5
20030613 Mn4.1
20070927 Mn3.3
20050306 Mn5.4
ln Fourier Spectral Amplitude
Hypocentral Distance (km)
10
5
0
10
100
R^{-1.58±0.17}


5 Hz
10
5
0
10
100
ln Fourier Spectral Amplitude
Hypocentral Distance (km)
20060407 Mn4.1
20020817 Mn3.8
20010522 Mn3.5
20030613 Mn4.1
20070927 Mn3.3
20040529 Mn3.3
20050306 Mn 5.4
$R^{-1.35\pm0.14}$

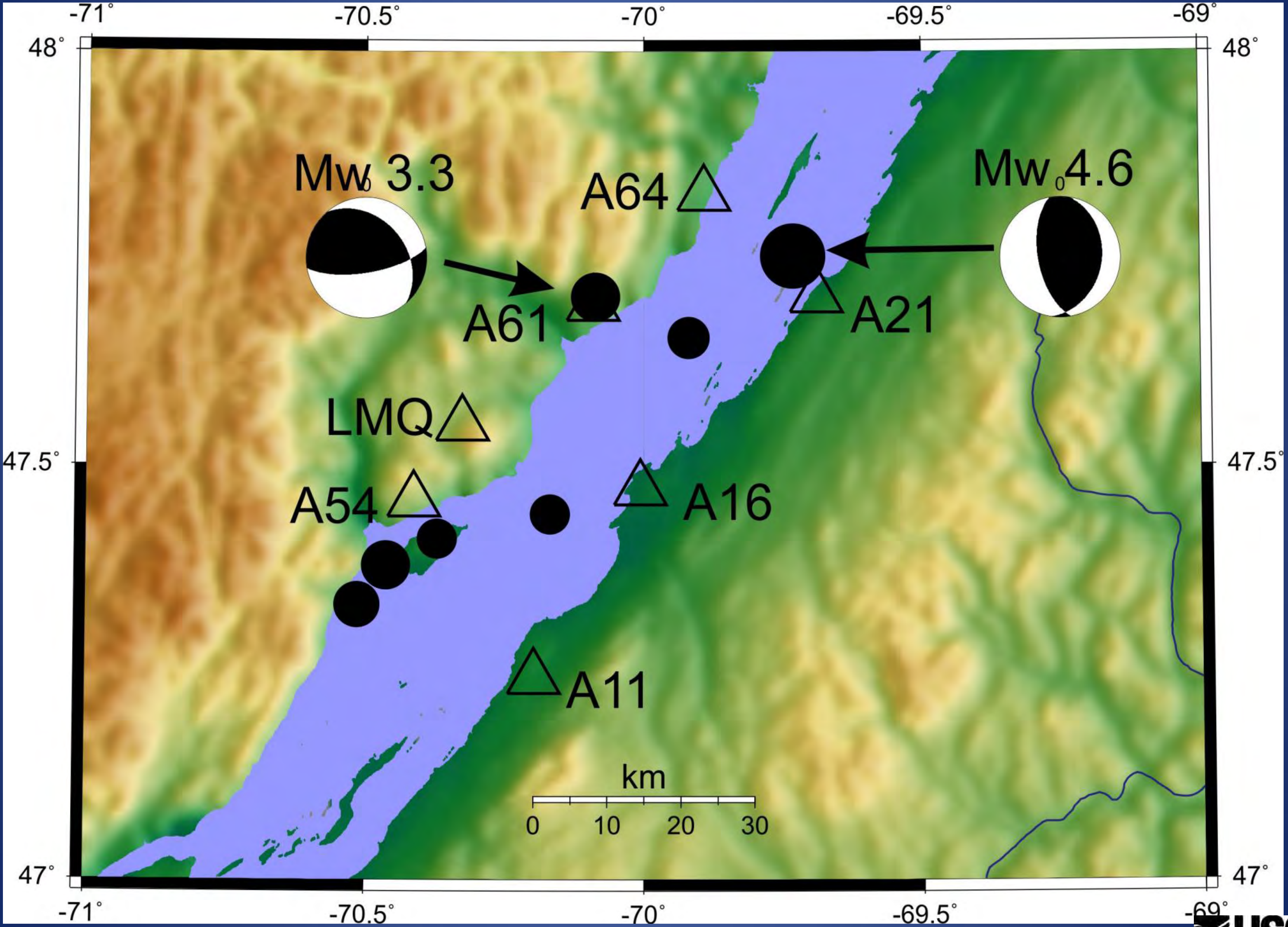


14 Hz
10
5
0
10
100
ln Fourier Spectral Amplitude
Hypocentral Distance (km)
20060407 Mn4.1
20020817 Mn3.8
20010522 Mn3.5
20030613 Mn4.1
20070927 Mn3.3
20040529 Mn3.3
20050306 Mn5.4
R-1.05±0.15


1 Hz
10
5
0
10
100
ln Fourier Spectral Amplitude
Hypocentral Distance (km)
20060407 Mn4.1
20020817 Mn3.8
20010522 Mn3.5
20030613 Mn4.1
20070927 Mn3.3
20050306 Mn5.4
R-1.58±0.17


14 Hz
10
5
0
10
100
ln Fourier Spectral Amplitude
Hypocentral Distance (km)
20060407 Mn4.1
20020817 Mn3.8
20010522 Mn3.5
20030613 Mn4.1
20070927 Mn3.3
20040529 Mn3.3
20050306 Mn5.4
R-1.05±0.15

Investigate role of radiation pattern and rupture directivity on distance decay of 1 Hz amp



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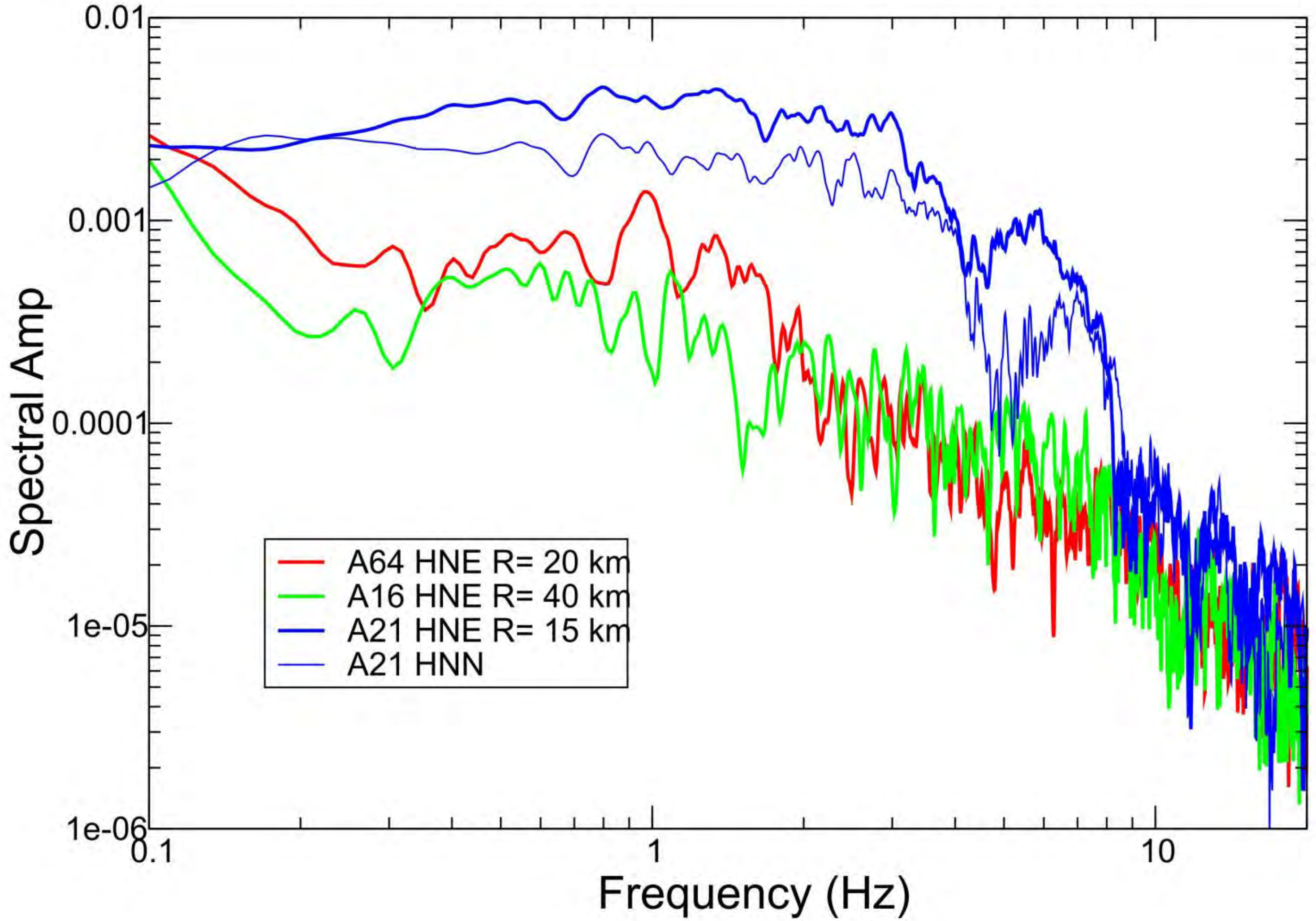
Riviere du Loup Displacement Spectra



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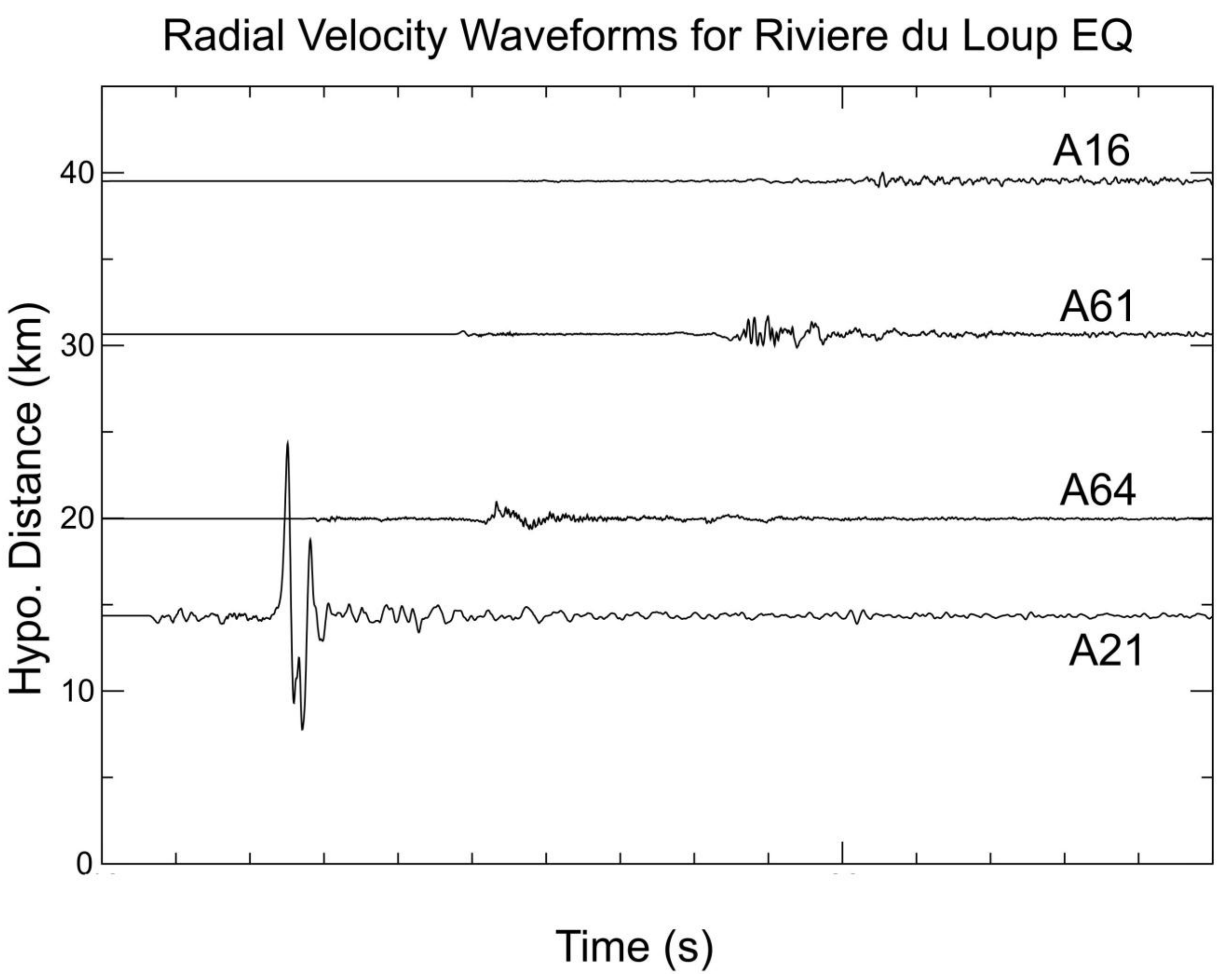
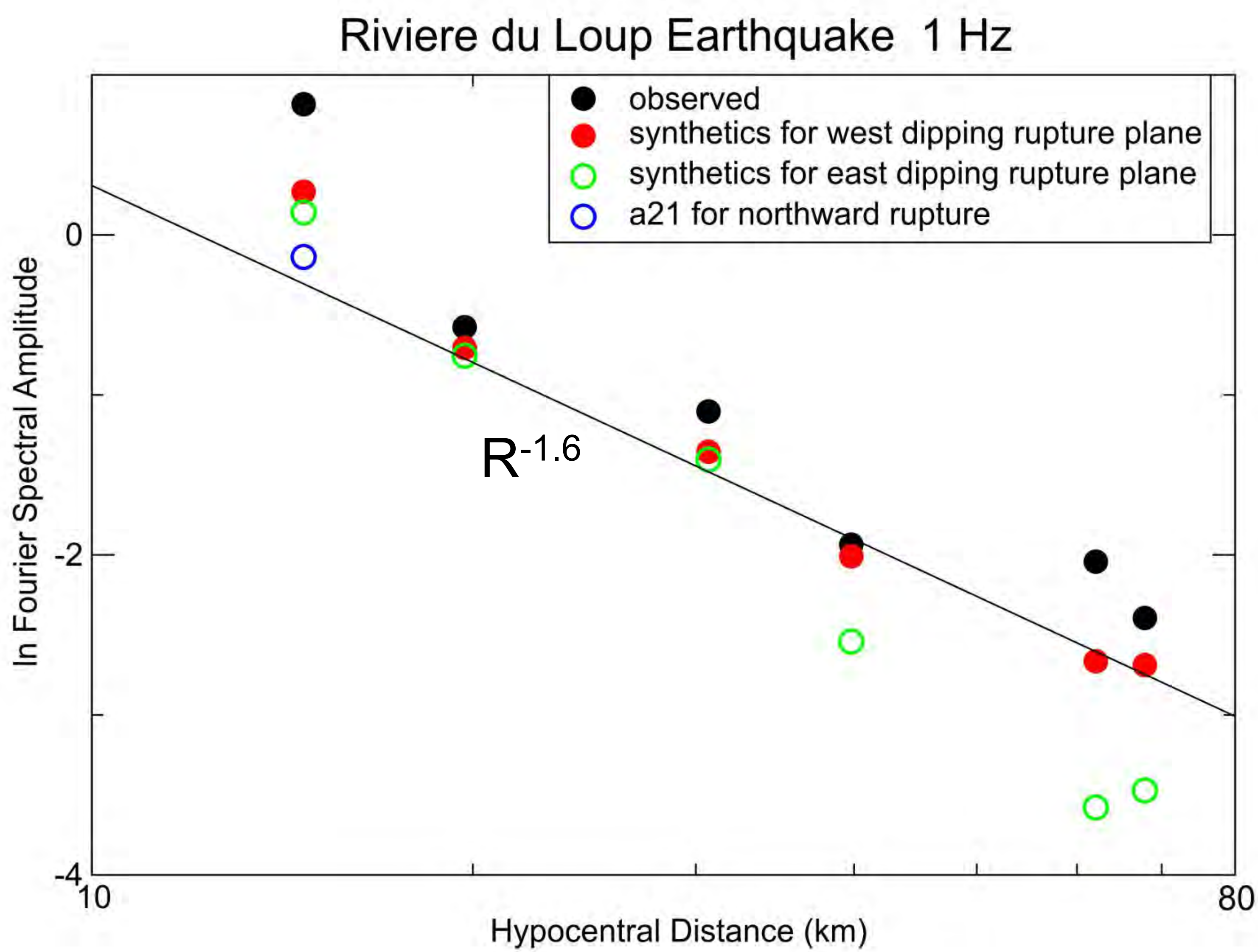


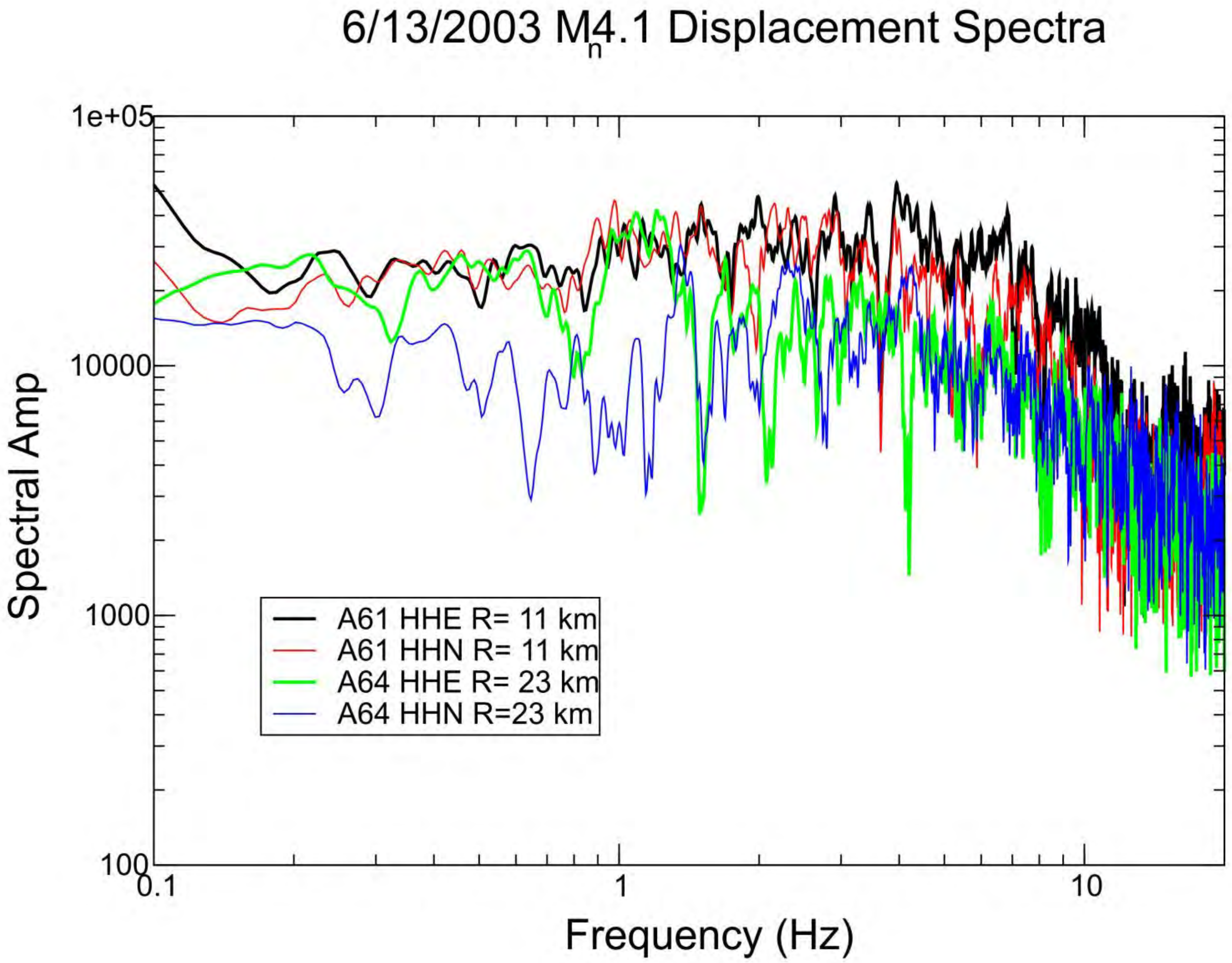
Radial Velocity Waveforms for Riviere du Loup EQ
A16
A61
A64
A21
40
30
20
10
0
Hypo. Distance (km)
Time (s)

Comparing observed spectral amplitudes with those from reflectivity synthetics from plane-layered velocity model

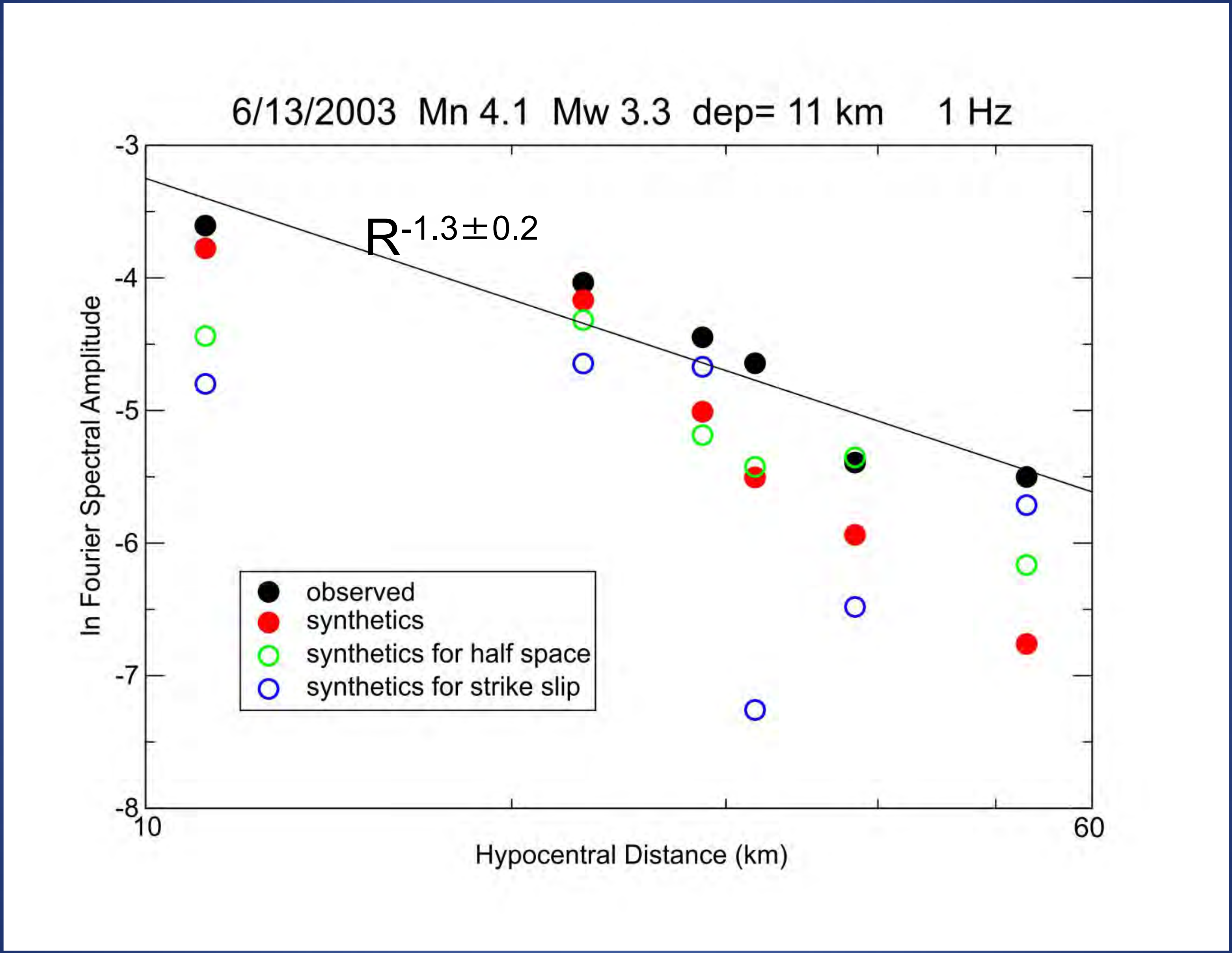
- For Riviere du Loup earthquake, used finite source with rupture directivity (1.4 x 1.4 km)
- For 6/13/2003 earthquake, used point source
- Used slip velocity of 5.4 m/s, twice that used for WUS earthquake comparison with NGA east (Frankel, 2009), implying dynamic stress drop of 200 bars; 1 Hz not sensitive to this
- Focal mechanisms and seismic moments from Bob Herrmann



Riviere du Loup Earthquake 1 Hz
observed
synthetics for west dipping rupture plane
synthetics for east dipping rupture plane
a21 for northward rupture
R-1.6
ln Fourier Spectral Amplitude
0
-2
-4
10
80
Hypocentral Distance (km)



6/13/2003 Mn4.1 Displacement Spectra
1e+05
10000
1000
100
0.1
1
10
Spectral Amp
Frequency (Hz)
A61 HHE R= 11 km
A61 HHN R= 11 km
A64 HHE R= 23 km
A64 HHN R=23 km



6/13/2003 Mn 4.1 Mw 3.3 dep= 11 km 1 Hz
$R^{-1.3\pm0.2}$
ln Fourier Spectral Amplitude
Hypocentral Distance (km)
-3
-4
-5
-6
-7
-8
10
60
observed
synthetics
synthetics for half space
synthetics for strike slip

Conclusions

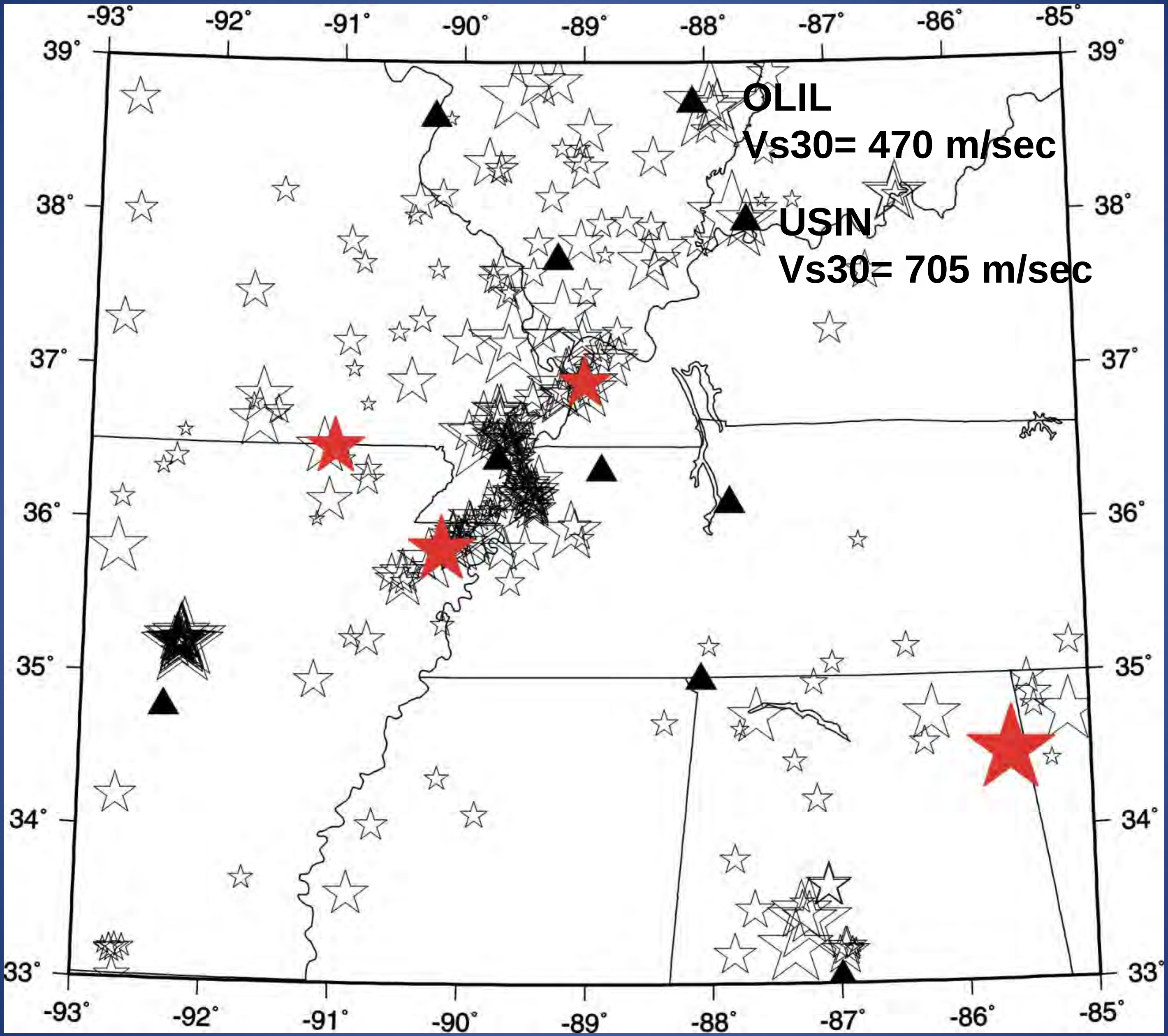
- Slower amplitude decay with distance of 14 Hz S-wave amplitude ($R^{-1.05}$) compared to 5 Hz ($R^{-1.35}$) and 1 Hz ($R^{-1.6}$). Apparent geometrical spreading depends on frequency
- $R^{-1.05}$ determined from 14 Hz data would be the steepest true geometrical spreading decay, since Q was not corrected for
- Based on results of synthetics, apparent geometrical spreading at 1 Hz is dependent on radiation pattern of source and, at least for Riviere du Loup earthquake, upward rupture directivity. Steep apparent geometrical spreading at 1 Hz is consistent with synthetics using radiation pattern and directivity

- Should not use frequency-dependent geometrical spreading and Brune spectral shape in stochastic simulations since close-in spectra do not have simple Brune shape
- Recommend use of R^{-1} geometrical spreading (dist < 70 km) based on high-frequency observations not contaminated by radiation pattern and directivity
- Apparent geometrical spreading at 1 Hz is dependent on rupture directivity and radiation pattern; better to use deterministic synthetics using plane layers for ≤ 1 Hz; should develop GMPE's for different focal mechanisms using various slip distributions and hypocenters on the rupture plane
- I am currently working on this procedure to make new ENA GMPE's using hybrid methodology for broadband synthetics (deterministic + stochastic) for finite faulting (Frankel, 2009)

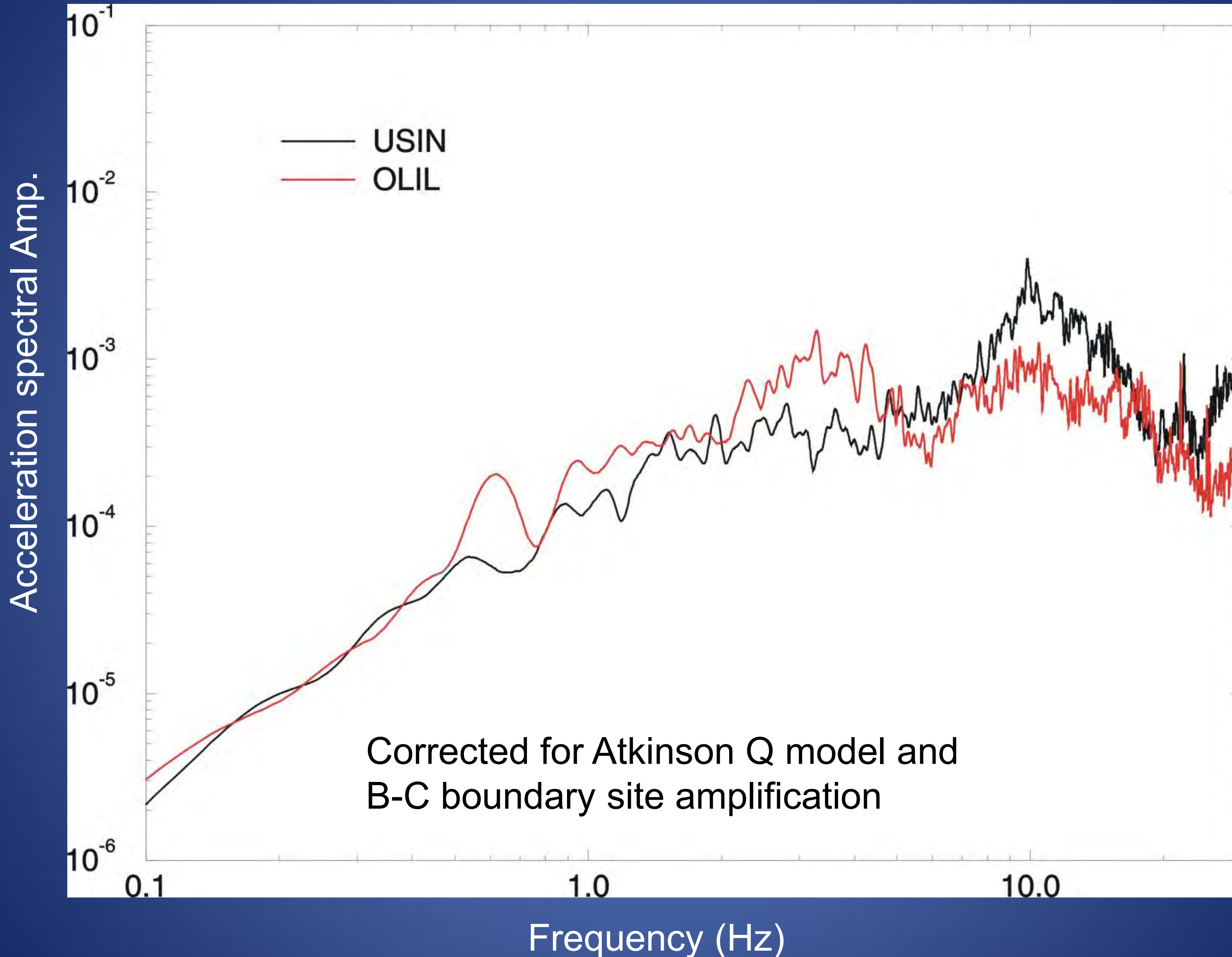
acknowledgments

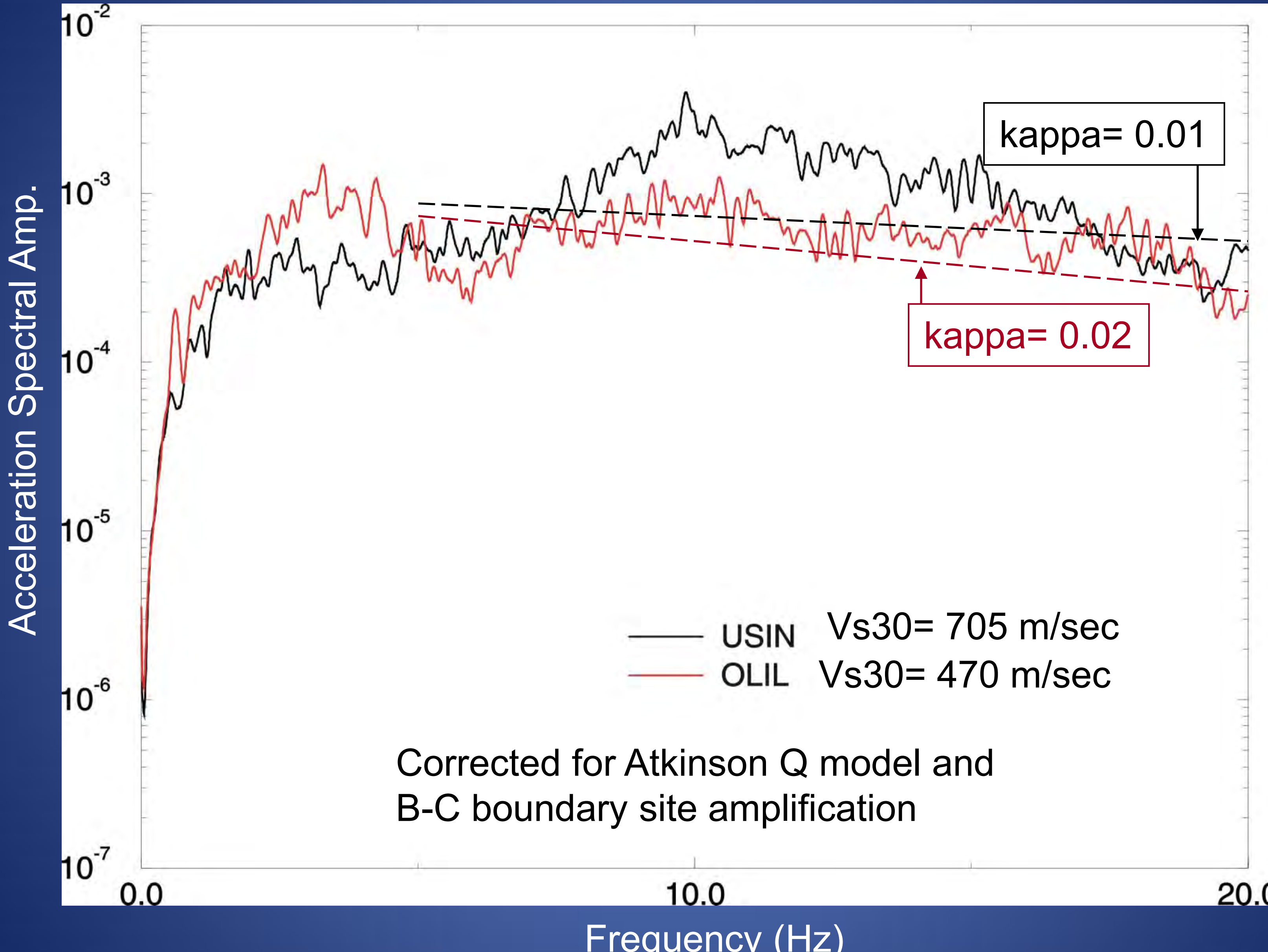
- Seismograms from Geological Survey of Canada; also used their hypocenters
- PEER- NGA East (Christine Goulet) supplied some of the data

What is kappa (high-frequency spectral falloff) for CEUS B-C sites? Vs30= 760 m/sec



5/1/05 earthquake, NE Arkansas, M4.2, fc= 2 Hz (at OLIL)





We used kappa=0.01 for CEUS B-C sites

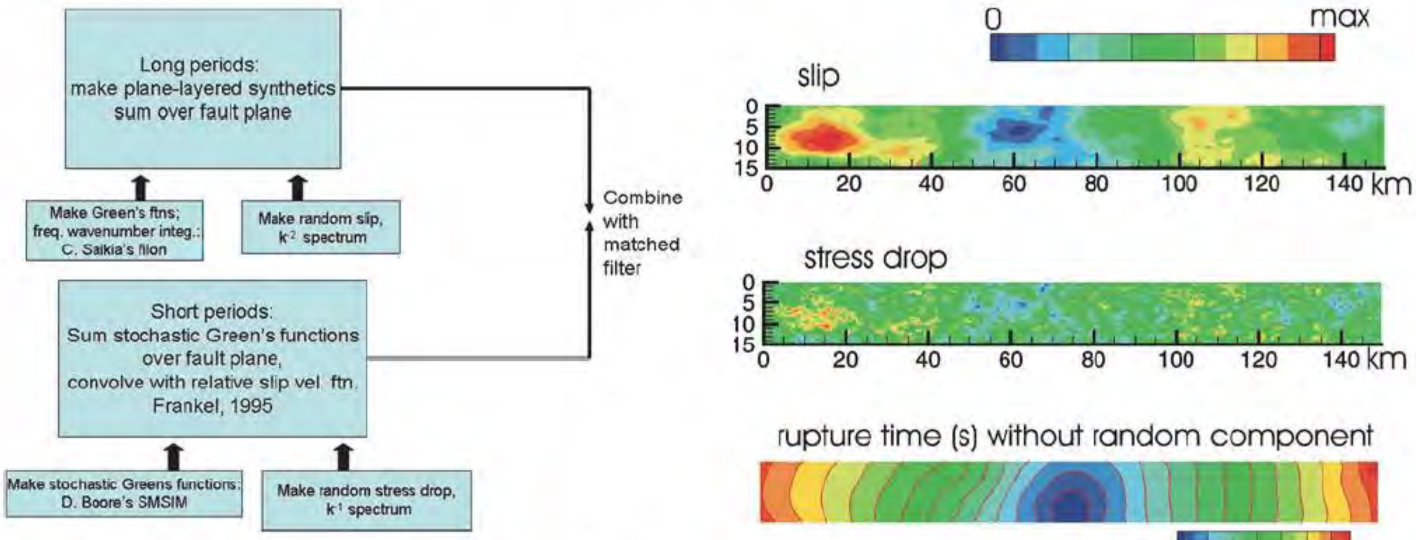


Figure 3. Flow chart showing the procedure to make broadband synthetics.

From Frankel (2009)

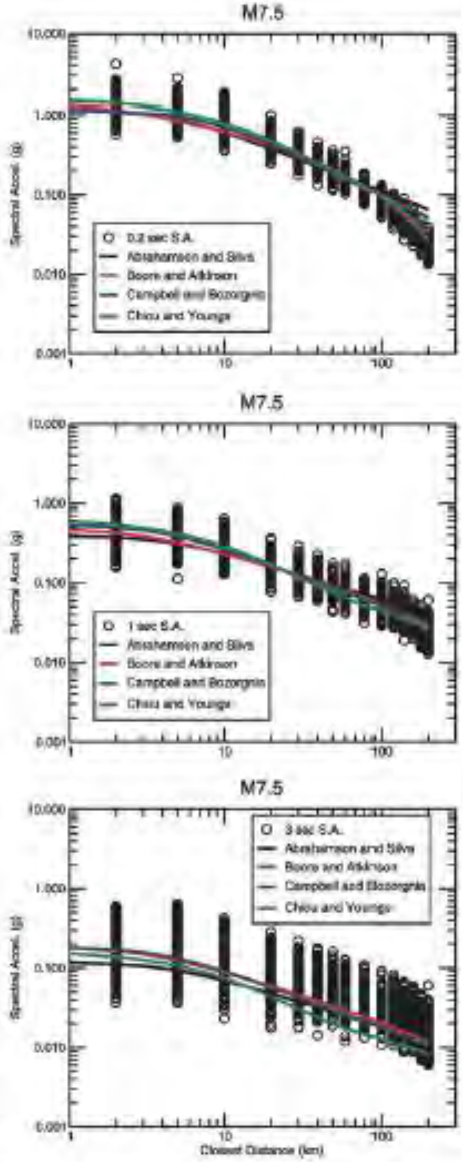


Figure 10. SAs (open circles) from the broadband synthetics of the nine simulations of *M* 7.5 earthquakes, for 0.2 (top panel), 1.0 (middle panel), and 3.0 sec periods (bottom panel). Solid lines are predictions of the median values from the NGA relations.

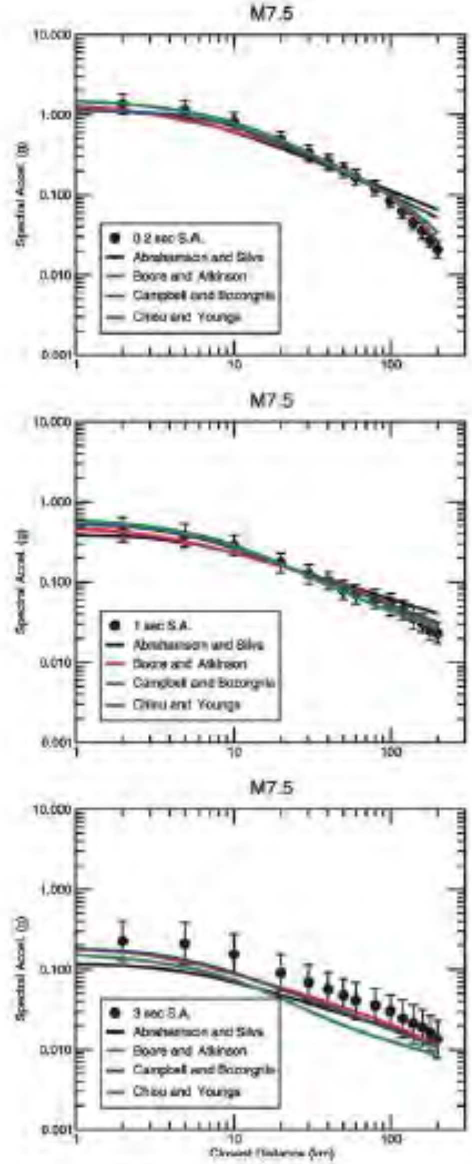


Figure 11. Median values of the SAs (solid circles with error bars for ±1 standard deviation, based on the variation between the values at each distance) at each distance for 0.2 (top panel), 1.0 (middle panel), and 3.0 sec periods (bottom panel) from the broadband synthetics for *M* 7.5 compared to the predictions from the NGA relations.

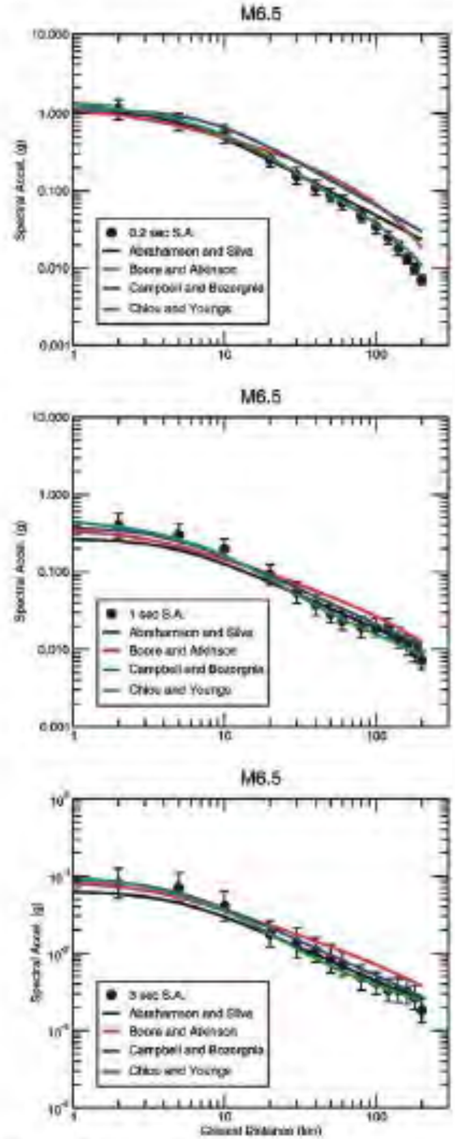


Figure 12. Median values of the SAs (solid circles with error bars for ±1 standard deviation) at each distance for 0.2 (top panel), 1.0 (middle panel), and 3.0 sec periods (bottom panel) from the broadband synthetics for *M* 6.5 compared to the predictions from the NGA relations.

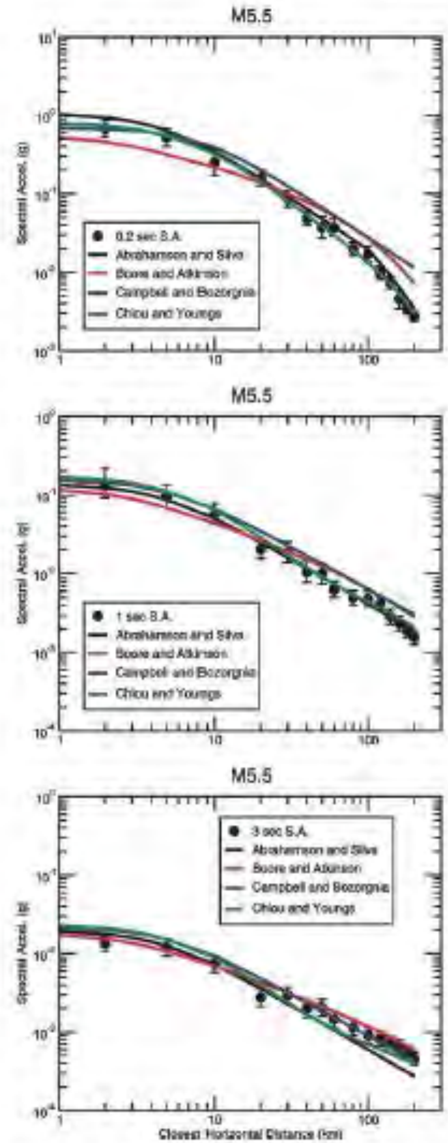


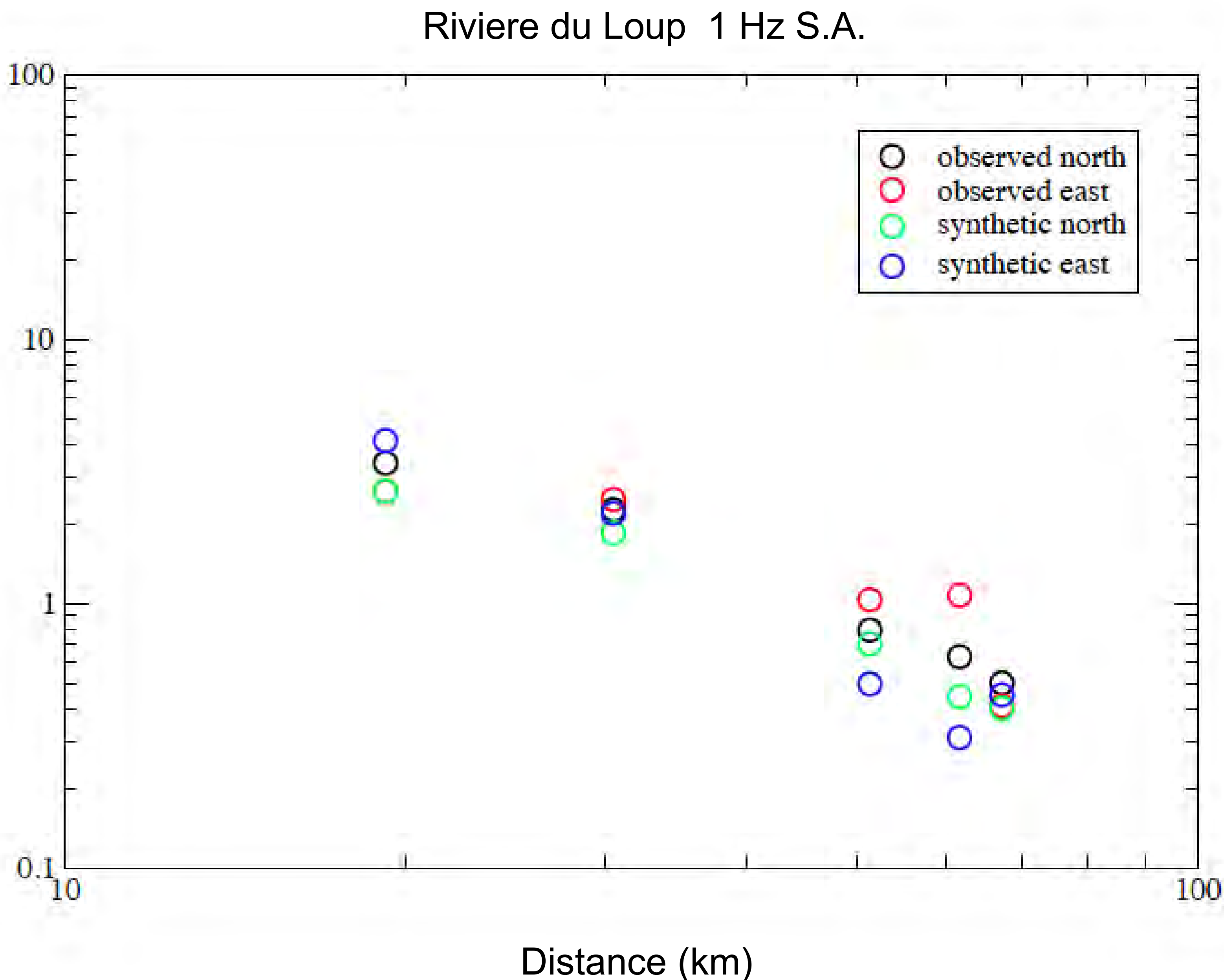
Figure 13. Median values of the SAs (solid circles with error bars for ±1 standard deviation) at each distance for 0.2 (top panel), 1.0 (middle panel), and 3.0 sec periods (bottom panel) from the broadband synthetics for *M* 5.5 compared to the predictions from the NGA relations.

For Riviere du Loup earthquake, used stress drop of 200 bars (stochastic synthetics) and average slip velocity of 5.4 m/s (deterministic synthetics).

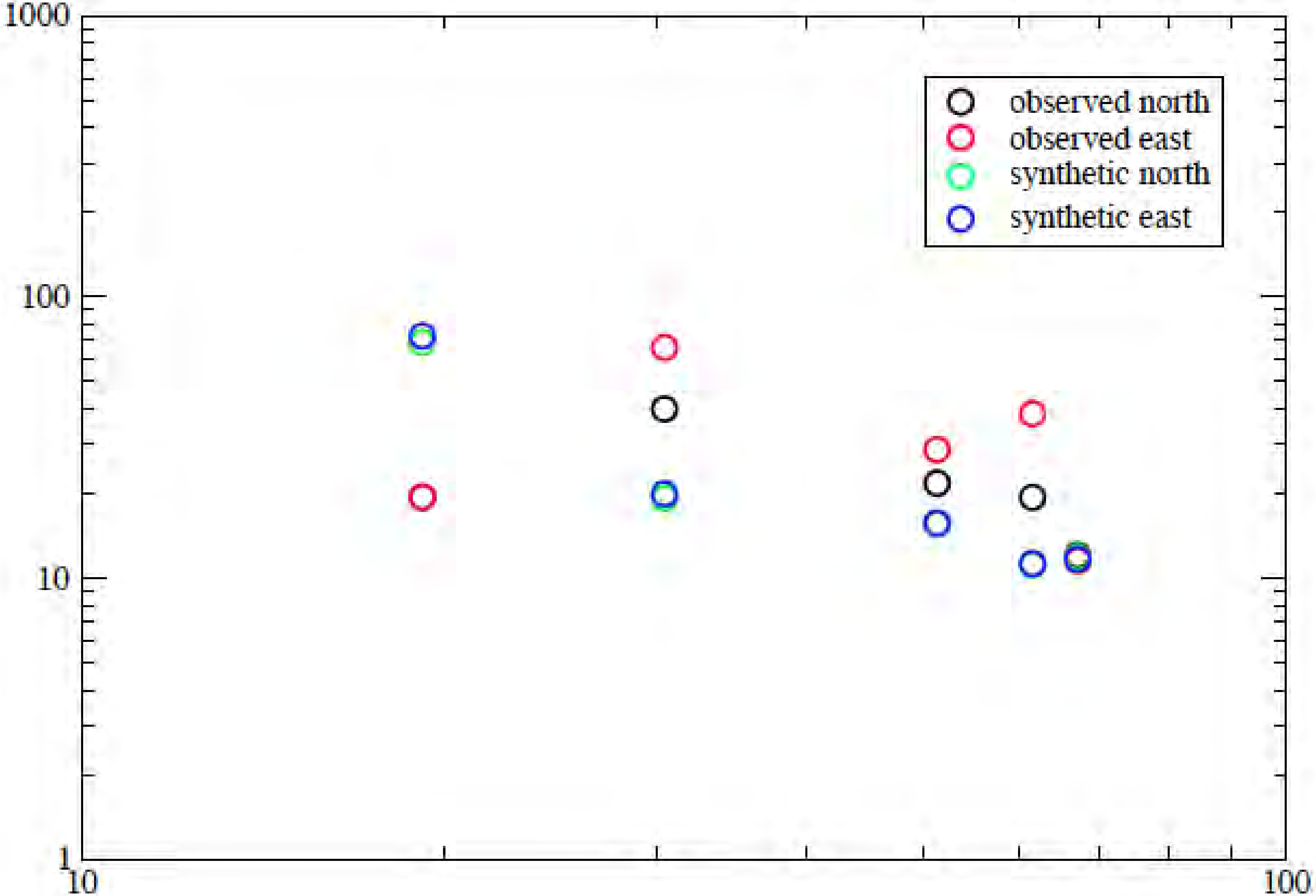
For Saguenay used 500 bar stress drop and 13.5 m/s slip velocity.

ENA crustal model from Hartzell and Mendoza and hard-rock site condition for stochastic synthetics

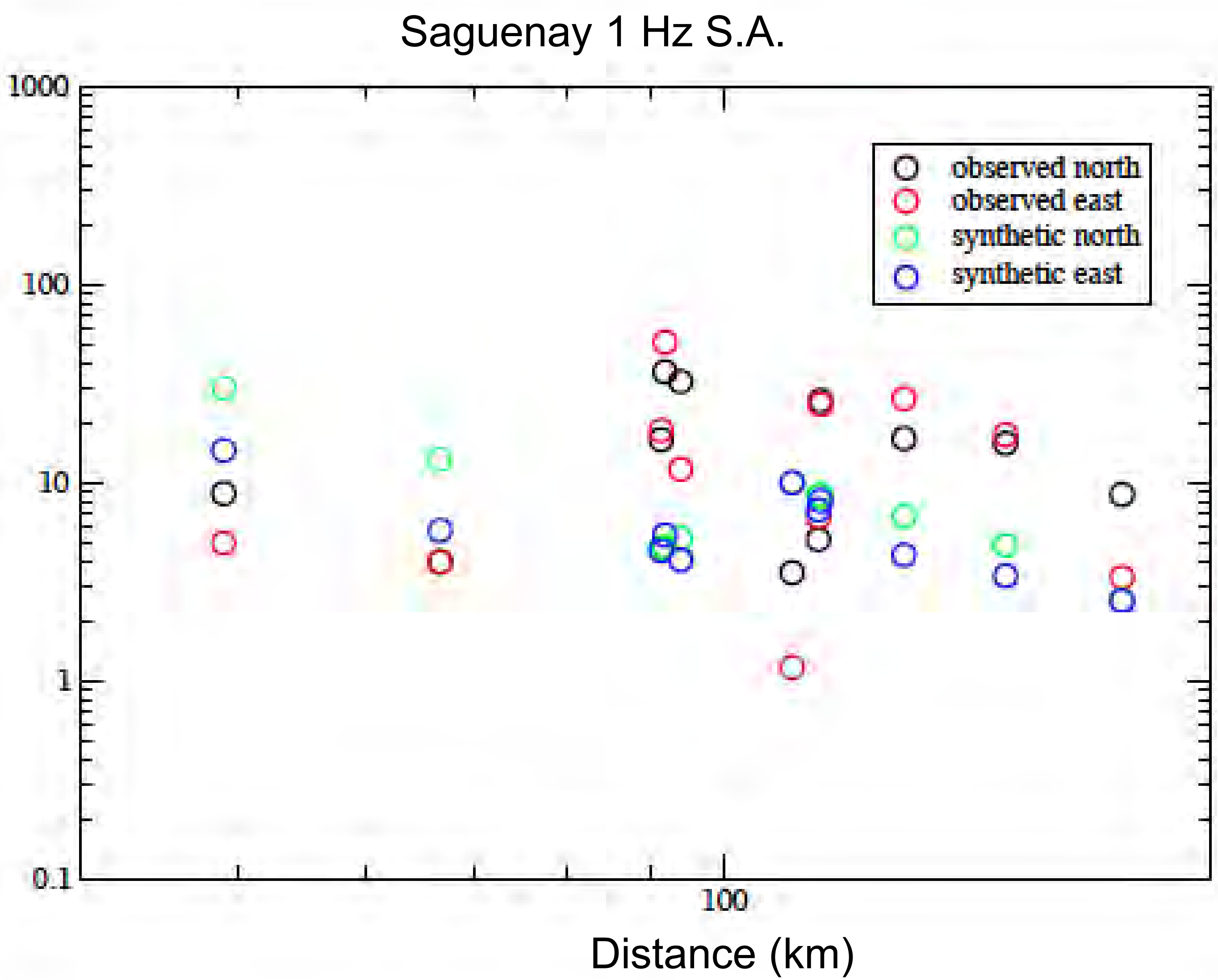
3 Hz crossover frequency between deterministic and stochastic synthetics


Riviere du Loup 1 Hz S.A.
100
10
1
0.1
10
100
observed north
observed east
synthetic north
synthetic east
Distance (km)

Riviere du Loup 5 Hz S.A.

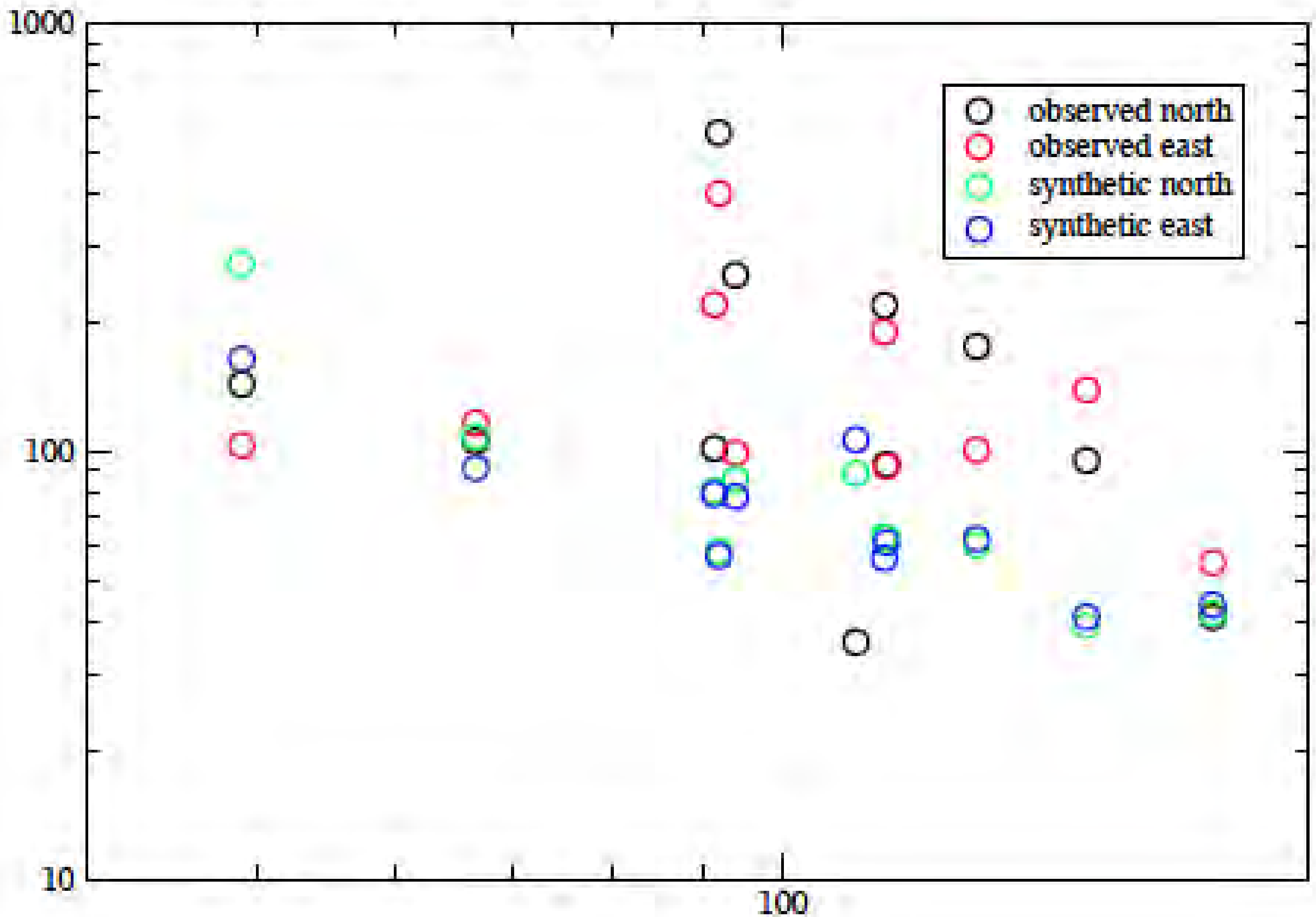


Distance (km)



Saguenay 1 Hz S.A.
1000
100
10
1
0.1
100
Distance (km)
observed north
observed east
synthetic north
synthetic east

Saguenay 5 Hz S.A.



Distance (km)

S-wave amplitude:

$$A_S(f,R) = P_{\theta\phi}S(f)G(f)I(f)R^{-\gamma}e^{-\pi f t_s/Q_S}$$

coda-wave amplitude at lapse time t_E :

$$A_C(f,t_E) = P_{ave}S_{ave}(f)G(f)I(f)C(f)t_E^{-2}e^{-\pi f t_E/Q_C}$$

$$A_S(f,R)/A_C(f,t_E) = R^{-\gamma}e^{-\pi f t_s/Q_S}F(f,t_E)P_{\theta\phi}S(f)/P_{ave}S_{ave}(f)$$

P = radiation pattern

S = source spectrum

G= site amplification

I = instrument response

C = scattering coeficient