Evaluation of Regional Path/Source Effects from Recent Earthquakes

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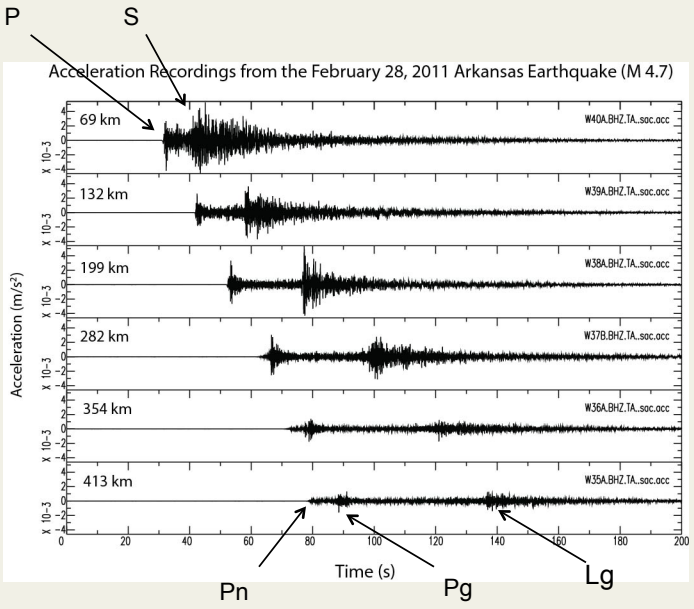
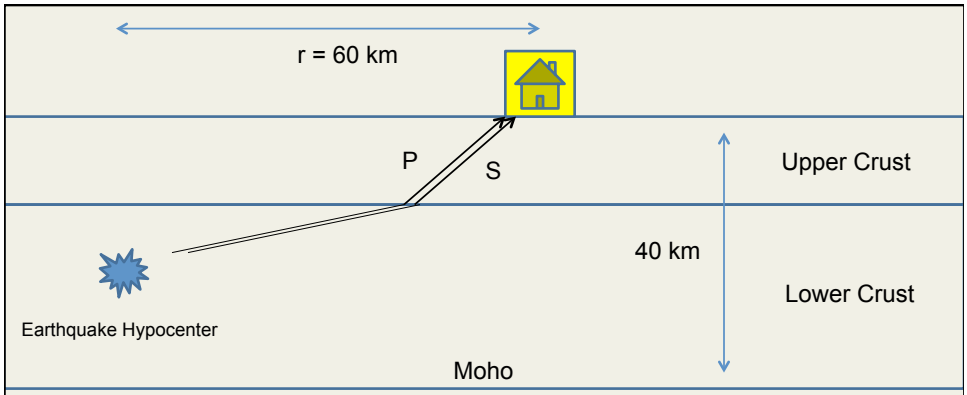
Outline

Review of crustal seismic wave propagation

Recent Observations

Quantification of model parameters for the Central U.S. and Gulf Coast Regions

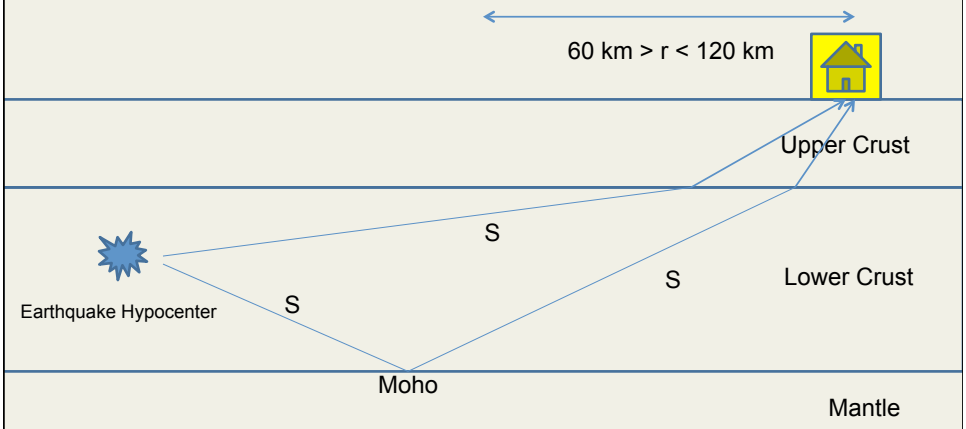




Near the source (epicenter distance less than approximately 60 km) the largest amplitudes on the seismogram are usually associated with the direct S wave.

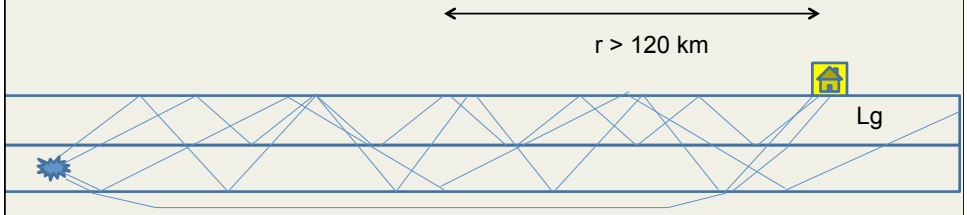
Maximum amplitude (A) decays inversely with hypocenter distance (r) or slightly faster

$$A = C\, r^{-1.3}$$



In the epicenter distance range between approximately 60 and 120 km, the direct S wave arrives at the surface at approximately the same time as large amplitude reflections from the Moho. The two phases combine to cause constant maximum amplitude in this distance range.

$$A = C\ 60^{-1.3}$$

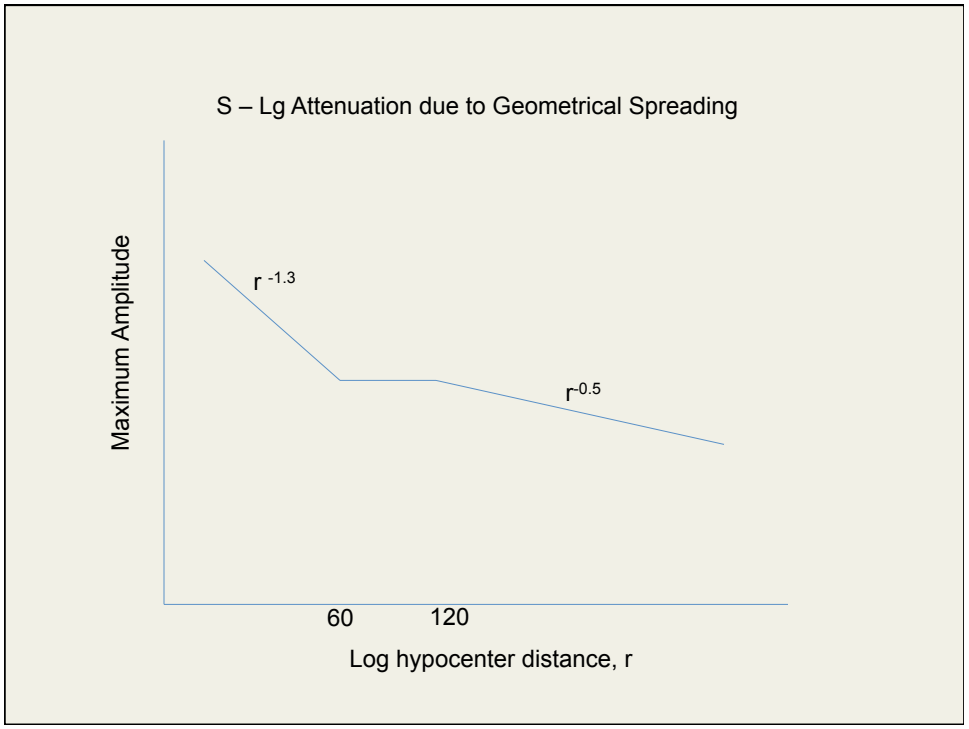


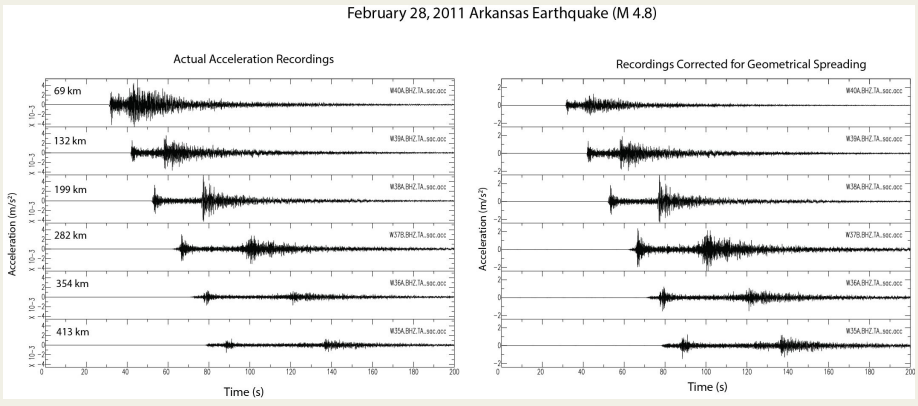
At distances greater than approximately 120 km, the maximum ground motion amplitudes at periods shorter than a few seconds in continental crust are associated with a packet of S waves that are post-critically reflected from the Moho, and any laterally extensive velocity discontinuities within the crust.

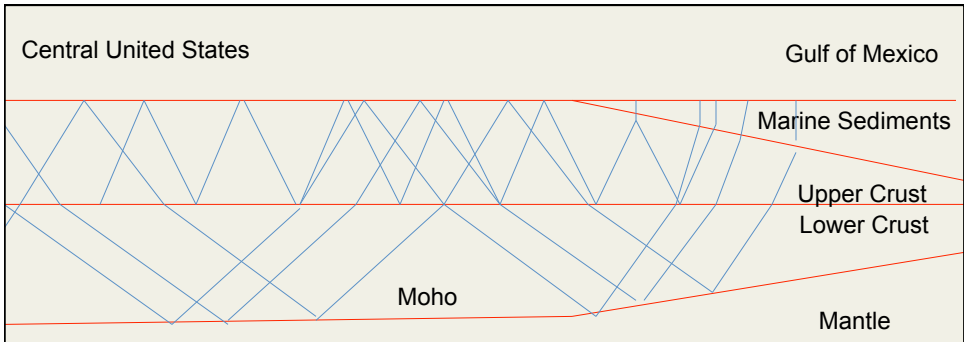
This crust-guided group of S waves propagates as a surface wave, and amplitude decays as $r^{-0.5}$.

In continental crust, the phase is referred to as Lg. Lg travels with group velocity near 3.5 km/s, and is a very efficient phase provided that crustal structure is laterally homogenous.

$$A = C\ 60^{-1.3}\ [r/120]^{-0.5}$$


S – Lg Attenuation due to Geometrical Spreading
Maximum Amplitude
r -1.3
r-0.5
60
120
Log hypocenter distance, r


February 28, 2011 Arkansas Earthquake (M 4.8)
Actual Acceleration Recordings
Recordings Corrected for Geometrical Spreading
69 km
132 km
199 km
282 km
354 km
413 km
Acceleration (m/s²)
Time (s)



Lg can be amplified and attenuated by lateral changes in crustal structure. Crustal thinning has been shown to strongly attenuate Lg wave amplitudes (Kennett, 1986).

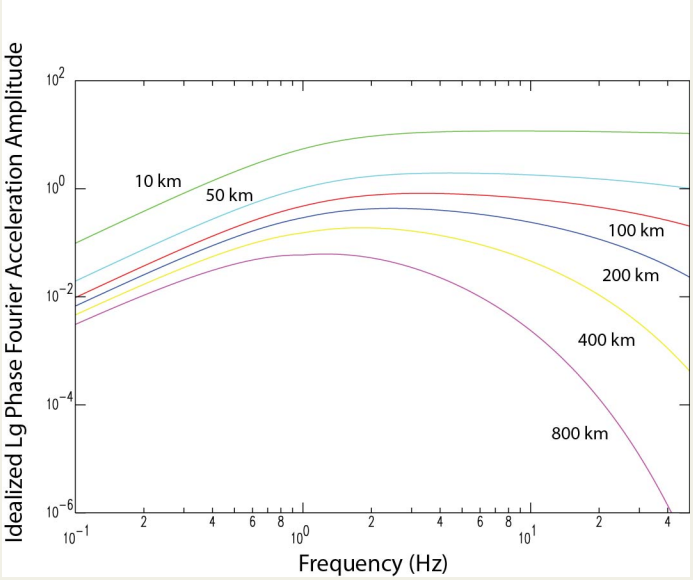
Changes in crustal structure are significant around the margins of the North American craton, in the Appalachian and Ouachita mountains and in regions that have experienced extensional tectonics, such as the Gulf Coast and along the Atlantic Seaboard.

Kennett, B.L.N. (1986). Lg waves and structural boundaries, Bulletin of the Seismological Society of America, 76, p. 1133-1141.

In addition of changes in amplitude due to purely geometrical effects, seismic waves experience amplitude attenuation due to anelastic processes.

Elastic wave energy is converted to heat. This effect is frequency dependent, and high frequency waves are attenuated more that low frequency waves, for a given length of path (or travel time).

This frequency-dependent behavior means that attenuation is conveniently studied in the frequency domain.



$$A(f) = S(f)\, G(r) \exp[-\pi f r / Q(f) \beta]$$

A(f) Fourier amplitude at distance r, for frequency f.

S(f) Fourier amplitude at unit distance (i.e., source amplitude)

G(r) Geometrical spreading (independent of frequency, depends on distance)

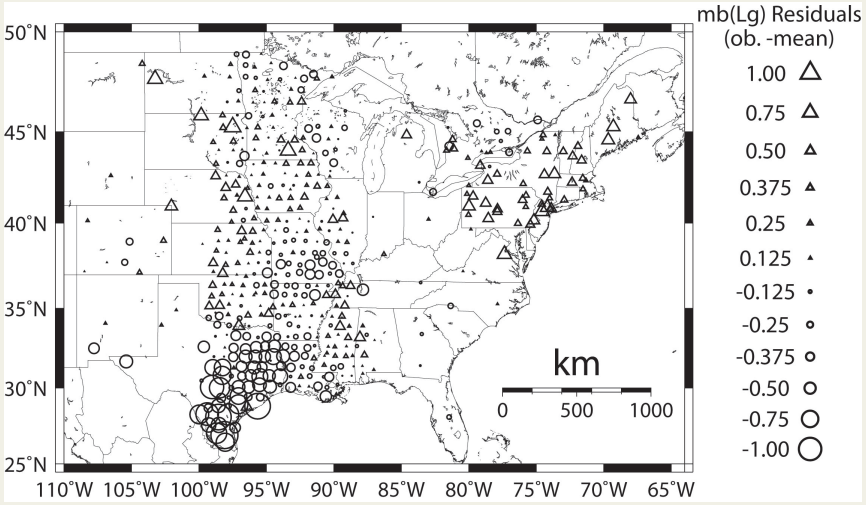
β S – Lg propagation velocity, approximately 3.5 km/s

Q(f) Quality factor: this is a material property that quantifies wave amplitude loss due to the transfer of elastic wave energy to heat. High Q implies little anelastic loss as a wave travels.

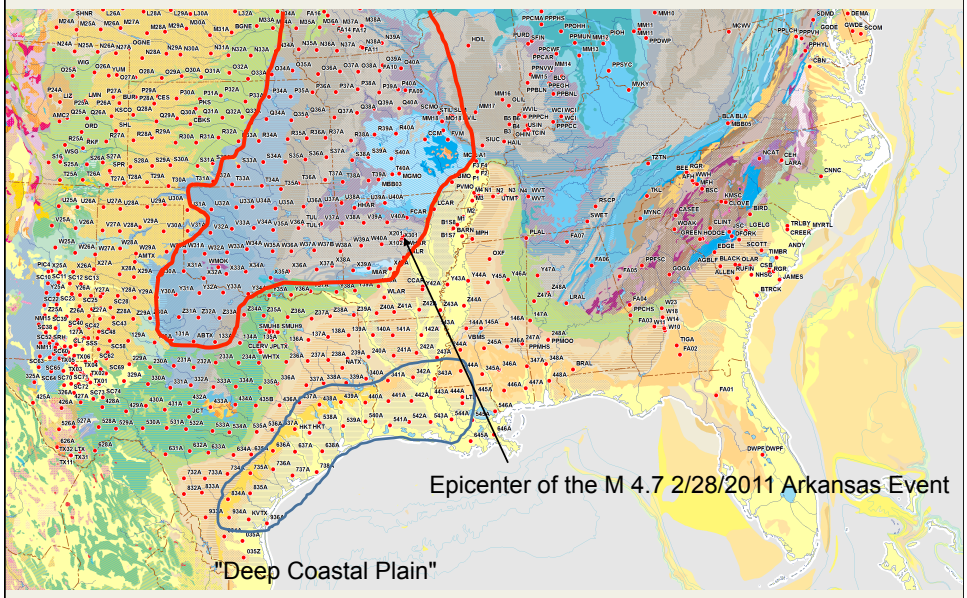
The task of the NGA-East path working Group to quantify G(r) and Q(f) for different regions of the Central and Eastern United States.

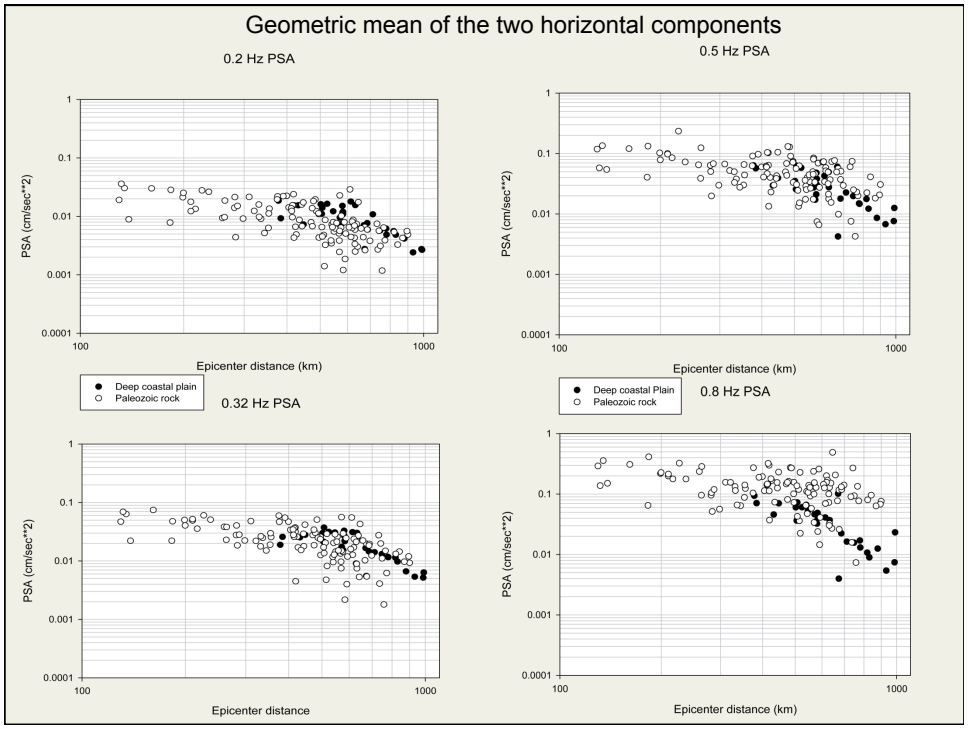
Magnitude residuals for the Mineral, Virginia, earthquake of August 23, 2011

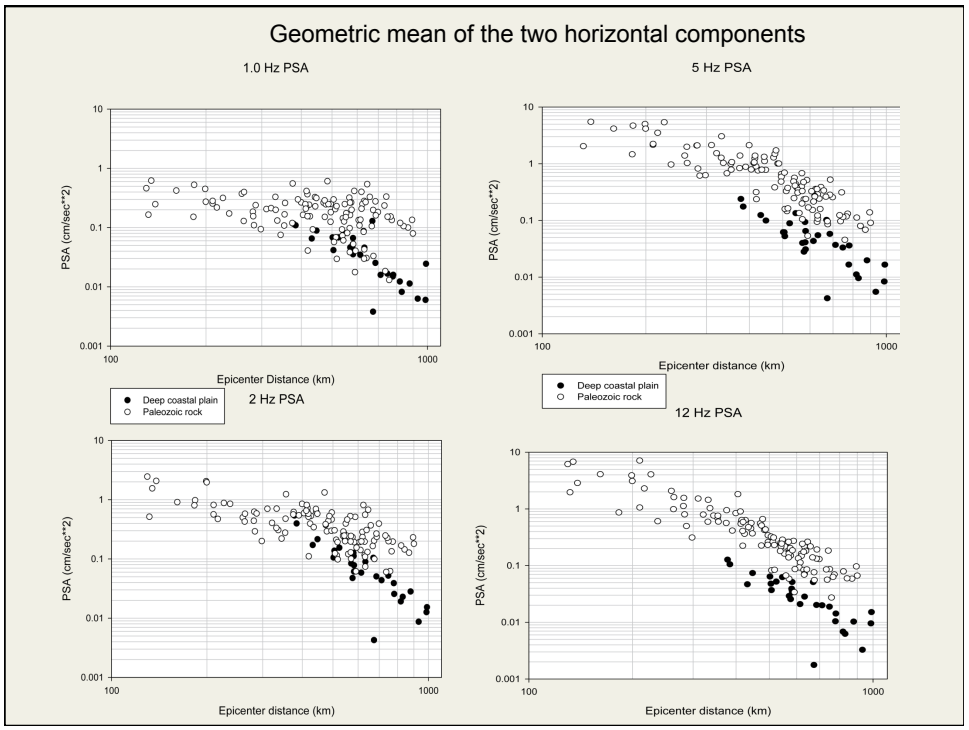
m_{bLg} magnitude is proportional to the logarithm of Lg wave amplitude at 1 Hz



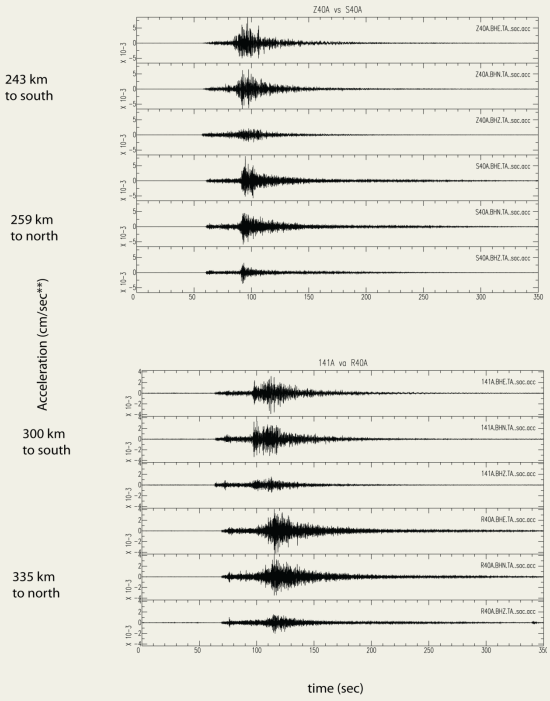
"Paleozoic Rock"



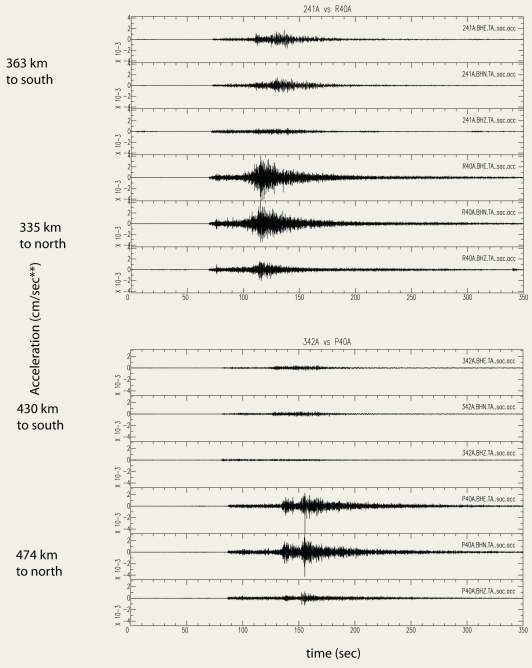

Geometric mean of the two horizontal components
0.2 Hz PSA
0.5 Hz PSA
0.32 Hz PSA
0.8 Hz PSA
PSA (cm/sec**2)
Epicenter distance (km)
Epicenter distance
Deep coastal plain
Deep coastal Plain
Paleozoic rock


Geometric mean of the two horizontal components
1.0 Hz PSA
5 Hz PSA
2 Hz PSA
12 Hz PSA
PSA (cm/sec**2)
Epicenter Distance (km)
Epicenter distance (km)
Deep coastal plain
Paleozoic rock

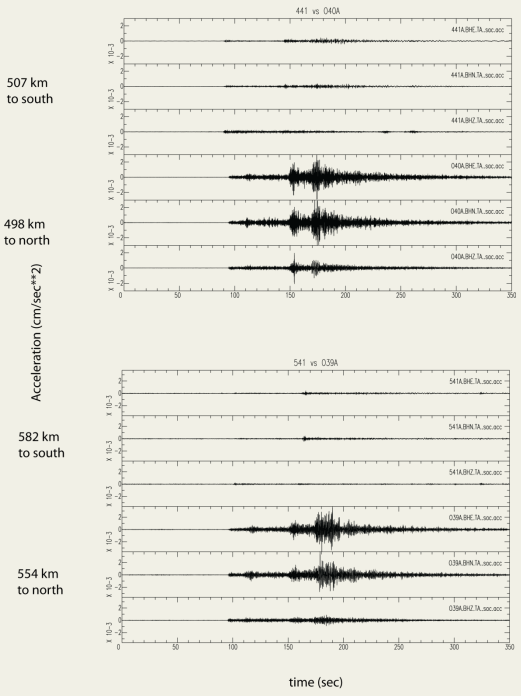
Comparison of seismograms to the north and south of the February 28, 2011 central Arkansas earthquake (M 4.7).

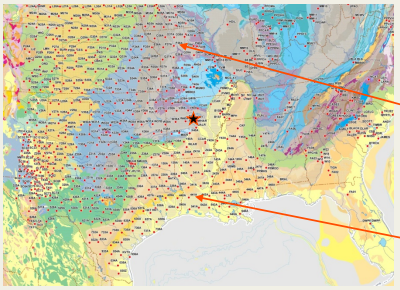


Comparison of seismograms to the north and south of the February 28, 2011 central Arkansas earthquake (M 4.7).

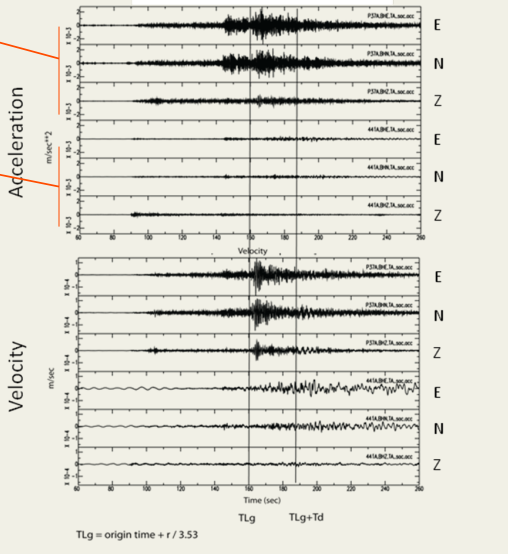


Comparison of seismograms to the north and south of the February 28, 2011 central Arkansas earthquake (M 4.7).





Upper: Acceleration recordings at station P37A (Missouri) and 441A (Louisiana). Lower: Velocity. Three component motions E-W, N-S, Vertical are indicated



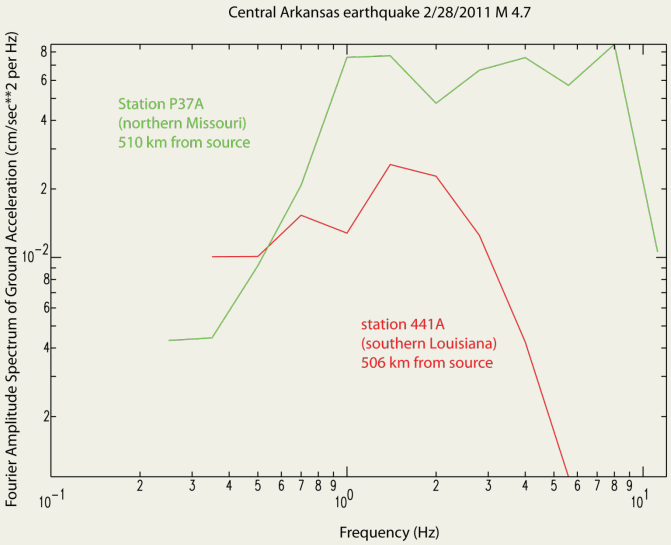
TLg = origin time + r / 3.53

Td = 8.71 + 0.026 r

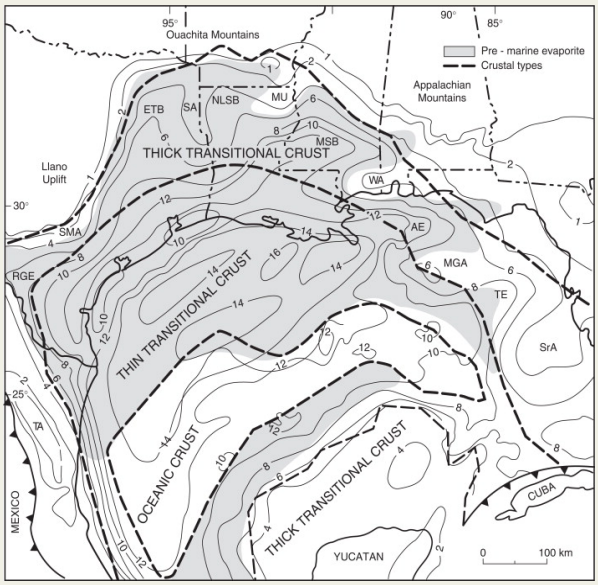
Definition of signal duration

$$\int_{t_0}^{t_0+t_d} a^2\,dt = 0.7\int_{t_0}^{t_0+150} a^2\,dt$$

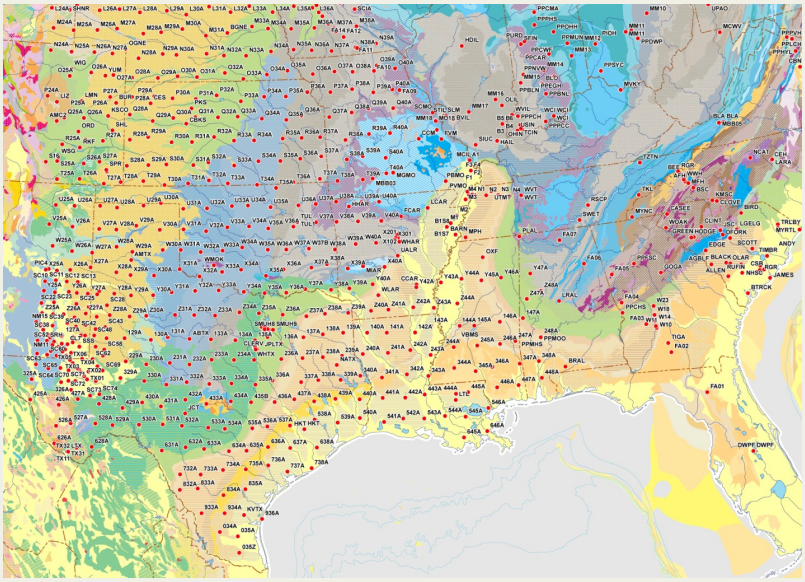
$$t_d = 8.71 + 0.026\Delta$$



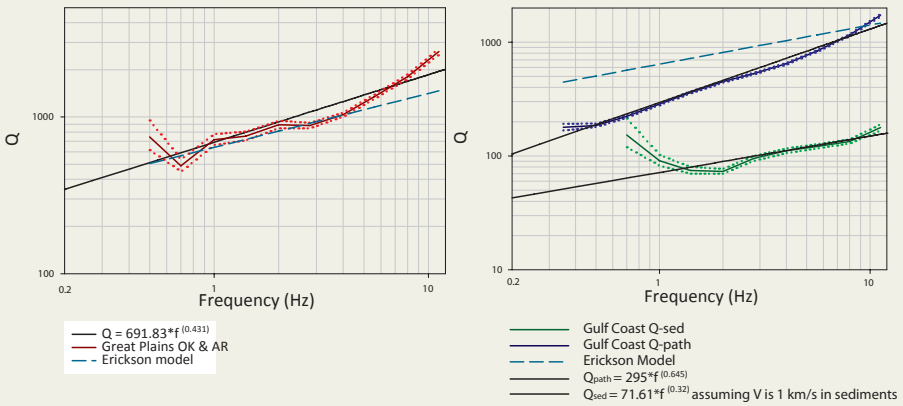
Lg signal amplitudes exceed noise amplitudes in equal-length time windows (Td) prior to the predicted P or Pn arrival time BY AT LEAST A FACTOR OF 5.



Crustal types, depth to basement (km), and original distribution of Jurassic Louann pre-marine evaporite beneath the Gulf of Mexico basin. *From Galloway,W.E. (2008) Depositional Evolution of the Gulf of Mexico Sedimentary Basin, in Sedimentary Basins of the United States and Canada, Vol. 5, pp 505-548, Elsevier.*



Geologic map showing the locations of EARTHSCOPE Transportable Array stations installed as of April, 2011, as well as other regional broadband stations.



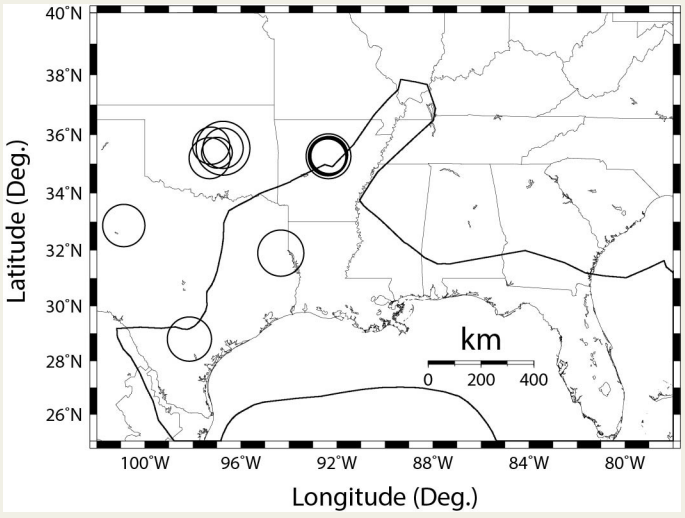
$$Ln\left[\frac{A_{ij}(f)}{S_i(f)G_{ij}(r)}\right] = R_j(f) - \frac{\pi r_{ij} f}{QV}$$

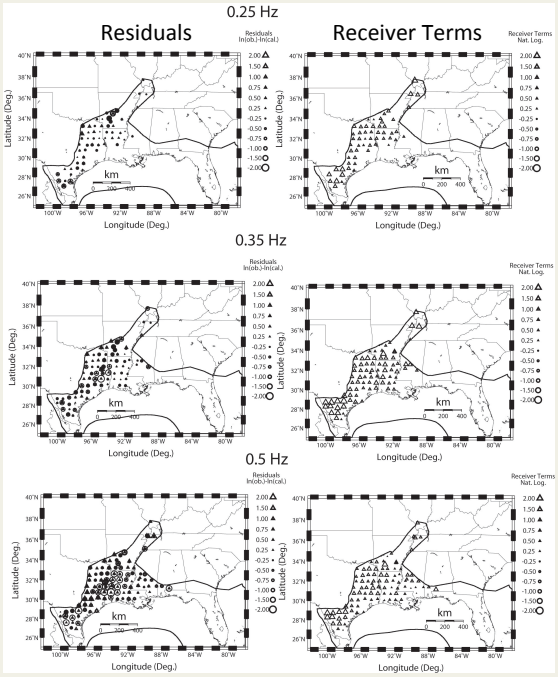
$A_{ij}(f)$ = Fourier acceleration amplitude (geometric mean of the two horizontal components),
$S_i(f)$ = Earthquake source amplitude spectrum,
$G_{ij}(r)$= Geometrical spreading (independent of frequency f),
$R_j(f)$ = Site amplitude term,
r_{ij} = hypocentral distance, from ith earthquake to the jth station.

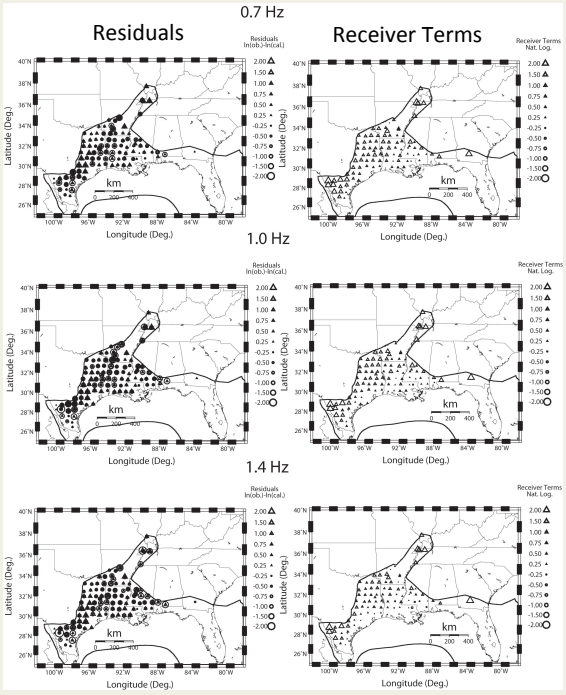
$$G(r) = r^{-1.3}, \quad r \leq 60\ km$$

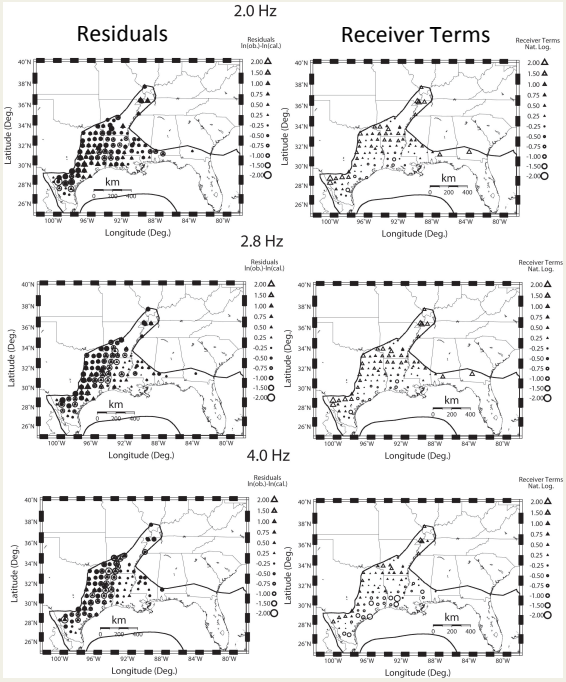
$$G(r) = 60^{-1.3}, 60 \leq r \leq 120\ km$$

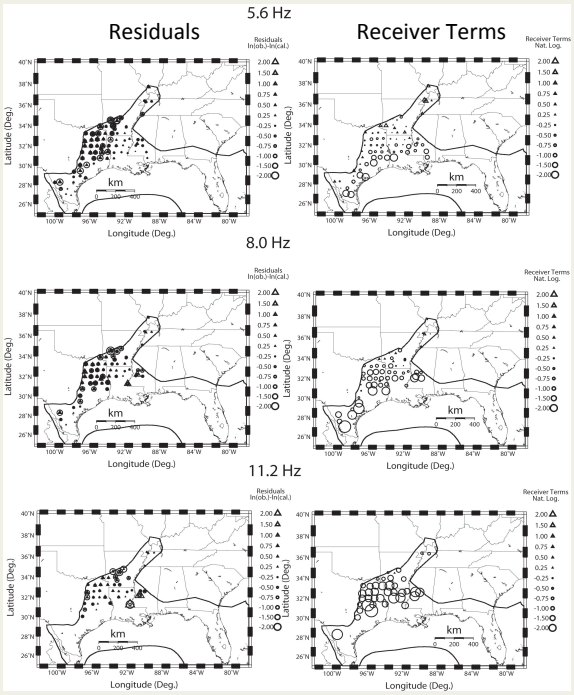
$$G(r) = 60^{-1.3}\left(\frac{r}{120}\right)^{-0.5}, r > 120\ km$$

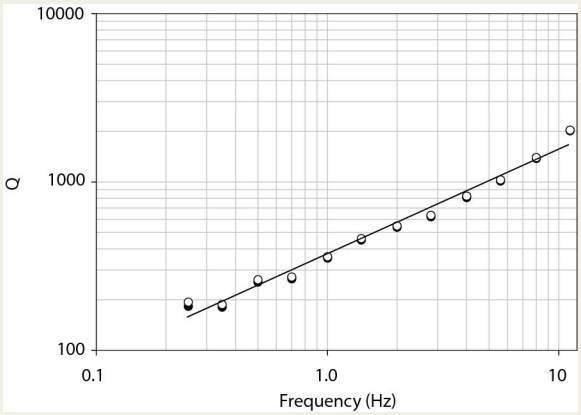



0.25 Hz
Residuals
Receiver Terms
0.35 Hz
0.5 Hz
Latitude (Deg.)
Longitude (Deg.)
km


0.7 Hz
Residuals
Receiver Terms
1.0 Hz
1.4 Hz
Latitude (Deg.)
Longitude (Deg.)
km


2.0 Hz
Residuals
Receiver Terms
2.8 Hz
4.0 Hz
Latitude (Deg.)
Longitude (Deg.)
km


5.6 Hz
Residuals
Receiver Terms
8.0 Hz
11.2 Hz
Latitude (Deg.)
Longitude (Deg.)
km

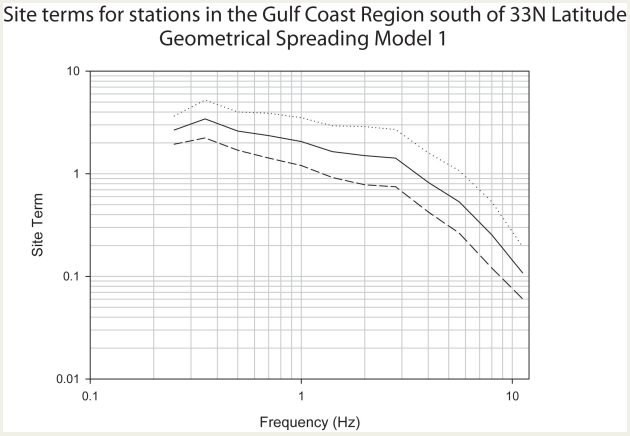


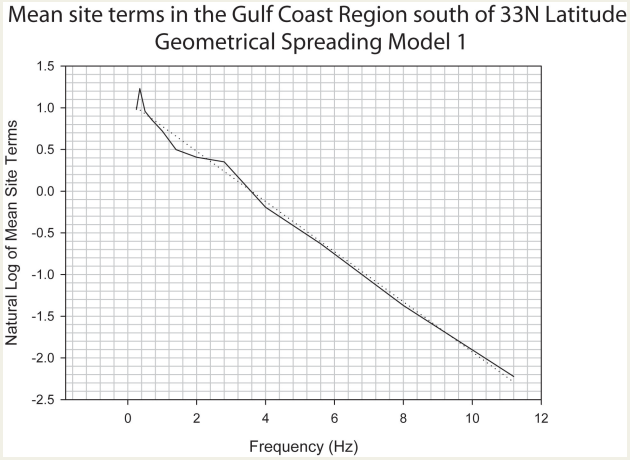
$$\log Q = (2.562 \pm 0.014) + (0.624 \pm 0.025) \log f$$

or

$$Q = 365 f^{0.624}$$

Site terms for stations in the Gulf Coast Region south of 33N Latitude
Geometrical Spreading Model 1





The dotted line shows a linear regression fit to the natural logarithm of the site terms, implying a K_o value of 0.096 +/- 0.010

Conclusions

Data recorded by the Earthscope transportable array from recent earthquakes in the central and eastern U.S. shows significant regional variation in geometrical spreading and Q.

The Gulf Coastal region shows particularly strong attenuation of Lg, which is likely the combined result of Lg blockage due to crustal thinning, and attenuation by thick deposits of low-velocity, low-Q marine sedimentary units.

Geometrical spreading in the near-source distance range (less than 100 km) remains a problem because the data are sparse.

Thank You!