The relation between the distance decay of narrow band-pass-filtered accelerograms and the Fourier acceleration spectra (FAS) of the accelograms

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Wu et al. (2016) convincingly show that the peak amplitudes of coda normalized, narrow band-pass-filtered seismograms from aftershocks of the 2011 Mineral, Virginia, earthquake decay much more rapidly than 1/R, as shown in Figure 1, from their paper:

Near-Source Geometrical Spreading in the Central Virginia Seismic Zone 949

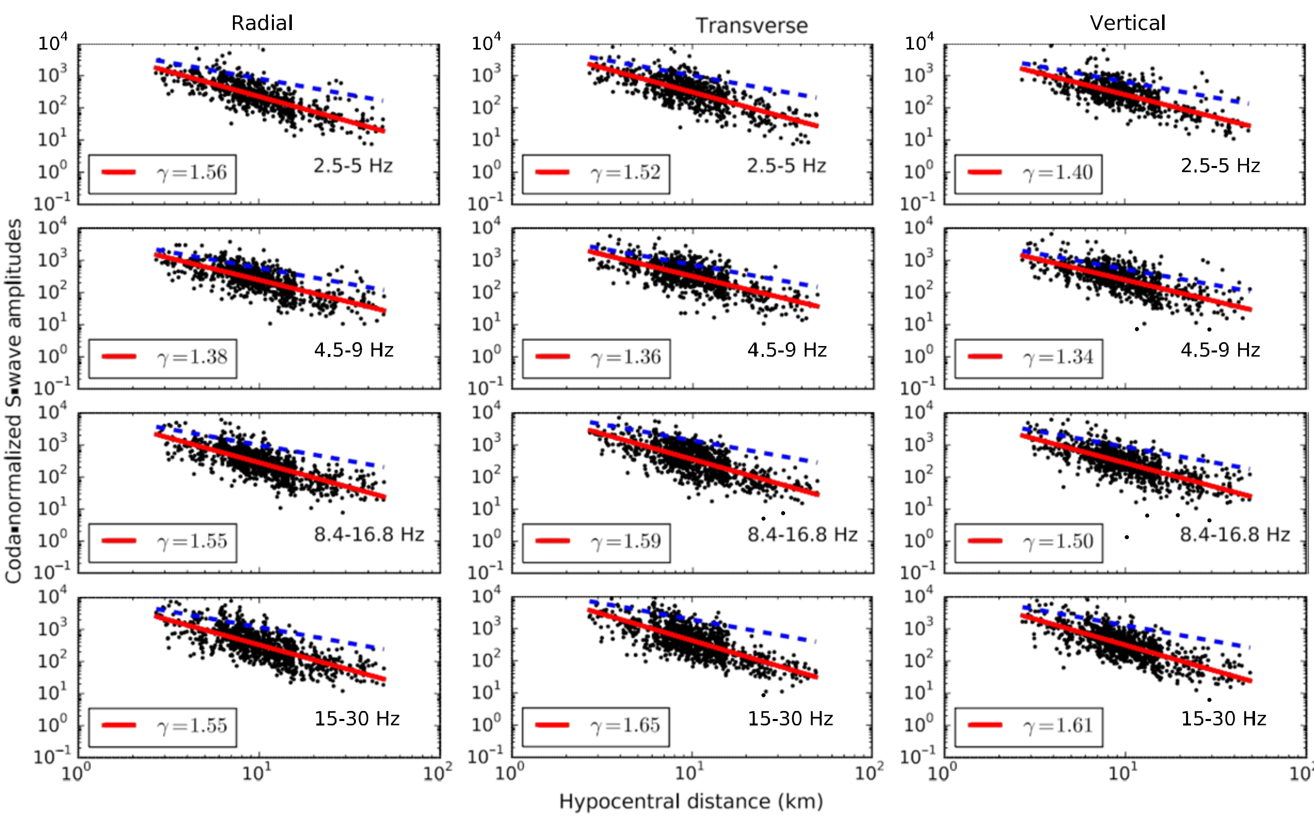

Figure 4. Plots of coda-normalized S-wave peak trace envelope amplitudes (small dots) versus hypocentral distance in four octave-wide frequency bands, centered at 3.75, 6.75, 12.6, and 22.5 Hz. The left column shows radial-component amplitudes, the center column shows transverse-component amplitudes, and the right column shows vertical-component amplitudes. The solid lines show least-squares fits to the data. The corresponding geometrical spreading coefficients γ are shown at the lower-left corner of each subplot. The dashed lines indicate the slope of geometrical spreading of R^{-1} ($\gamma = 1$) in a homogeneous whole space. The color version of this figure is available only in the electronic edition.

Figure 1. Reproduction of Figure 4 in Wu et al. (2016).

The purpose of these notes (***the first draft, subject to change!***) is to suggest that the decay of the FAS of the unfiltered records is less rapid than that of the narrow band-pass-filtered records, because of the effect of duration increasing with distance. If this is correct, then it would be an error to use the Wu et al. (2016) geometrical spreading in stochastic model simulations that include a distance-dependent duration.

To investigate the relation between the amplitude decay of narrow band-pass-filtered records and the underlying FAS of the unfiltered records, I did a simulation study using my SMSIM program a_ts_drvr (Boore, 2005). I used the BCA10D params file used in my NGA-East simulations (Boore, 2015). This model has a 1/R geometrical spreading for all distances (and a constant Q=2850; I also used κ_0=0.006). I simulated motions for **M**=3 (Wu et al. used events with m_{bLg} from 1.8 to 3.6) at rupture distances of 5, 10, 20, 35, and 50 km (Wu et al. used records out to 50 km). I generated 20 acceleration time series for each magnitude and distance, and I narrow-band-pass-filtered the time series using the program BLPADFLT in my TSPP suite of processing programs (Boore, 2013). Wu et al. (2016) used 10 octave-wide band-pass filters, from 1-2 Hz to 15-30 Hz. I did my simulations for their 2.5-5.0 Hz filter.

I considered two model of the path duration: 1) a duration of 1 s, with no dependence on distance; 2) the Boore and Thompson (2015) (BT15) distance dependence of duration for ENA (shown in Figure 2). Note that the duration measure used by BT15 is closely tied to the simulations in the SMSIM stochastic model calculations, it might not agree with other definitions; see the BT papers for a discussion.

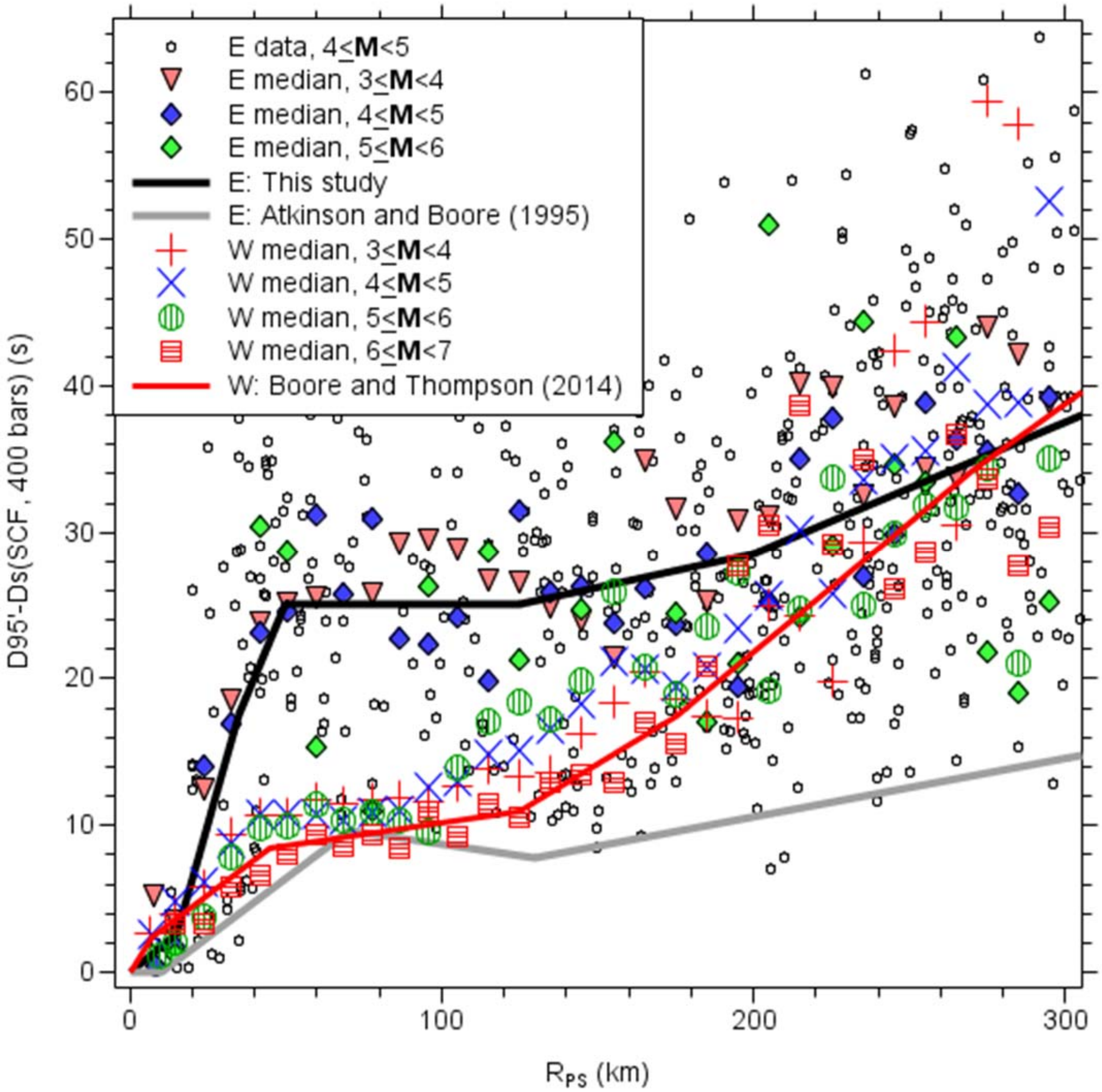

Figure 02. The medians in various magnitude (**M**) and point-source distance (R_{PS}) bins of the path duration $D_P = D'_{95} - D_S$ for data both from eastern North America ("E") and active crustal regions ("W"). The source duration D_S is given by $1/f_c$, in which the corner frequency f_a is given by the single-corner frequency model with a stress parameter of 400 bars. Guided primarily by the medians for the **M** = 4 to 5 range (the individual data points for this magnitude range are shown by the small open circles) we subjectively derived a path duration function consisting of joined linear segments ("This study"). For comparison, D_P used in some previous simulations of motions in ENA (Atkinson and Boore, 1995) and the recent path duration for active crustal regions (Boore and Thompson, 2014) are also shown. (Figure 3 in BT15).

Note that there is a rapid increase of duration within 50 km, followed by an almost flat portion; the simulations in this note only went to 50 km, and therefore did not include the flat portion. A caveat: there can be considerable scatter in the durations, as shown by the small unfilled circles; the BT15 model represents a median of the individual data points, and the data for the aftershocks used by Wu et al. (2016) might not be well represented by the median function (which was used in the SMSIM calculations that form the basis for these notes).

These are the steps used in my analysis:

1. For each duration model (constant with distance; BT15), generate 20 simulated motions at five distances, for **M**=3.

2. Narrow band-pass filter the records, using a filter from 2.5 to 5.0 Hz

3. Tabulate the peak motions of the filtered records

4. Compute the geometric and arithmetic means of the tabulated peak motions

5. Plot the amplitudes against distance.

Figure 3 shows the results:

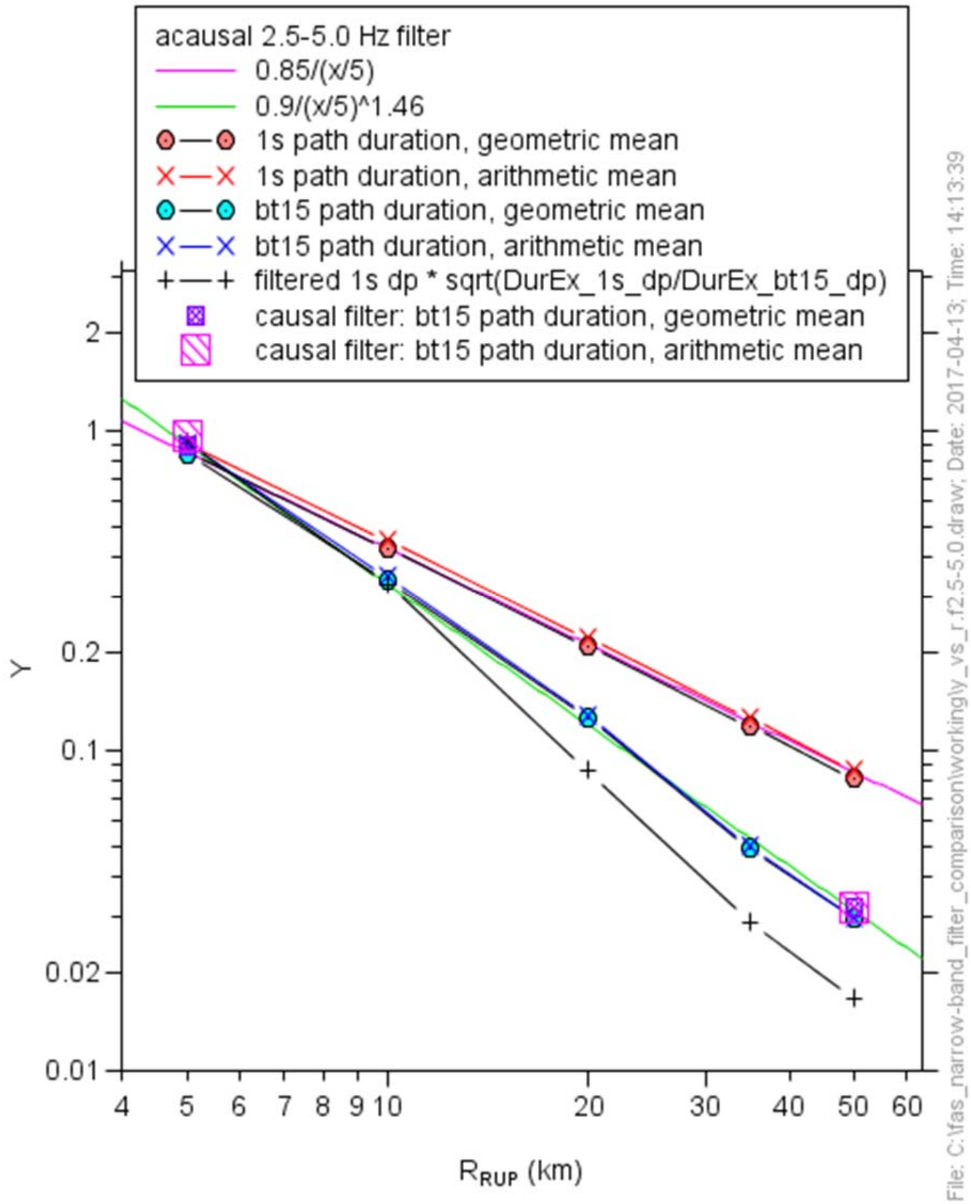

Figure 3.

Before discussing some of the findings from this figure, note that there is little difference in the two types of means.

The red symbols show the motions when a constant path duration of 1 s is used. The magenta line is an eye-ball fit of a line with 1/R decay to the simulated motions. Note the good agreement with the simulations, confirming that if there is no increase of duration with distance that the distance decay of the peak of the narrow band-pass-filtered motion will agree with that of the underlying model of FAS (1/R, in this case). I am ignoring *Q* effects (a maximum reduction of only 5% at 50 km and 3.5 Hz, the center of the 2.5-5.0 pass band: $\exp\left(\frac{-\pi\times 3.5\times 50}{2850\times 3.7}\right)=0.95$).

The results for the BT15 duration model decay much more rapidly than 1/R (the figure includes an eye-ball fit with a line decaying as $1/R^{1.46}$). I used an acausal band-pass filter, whereas Wu et al. (2016) used a causal filter (M. Chapman, written commun., 2017). To see if the type of filter made a difference, I repeated the simulations for the BT15 duration model and distances of 5 and 50 km using a causal band-pass filter; as shown in Figure 3, the results are similar to those using an acausal filter.

The steeper decay of the motions is fundamentally related to the relation between the FAS and the duration; this relation forms the basis of the stochastic method. If the motion described by a given FAS is spread out over a longer duration, the peak amplitudes must necessarily decrease, Since the narrow band-pass filter is basically extracting a peak in a narrow time window, that peak will decrease if the motions are spread out over a duration that increases with distance. Note that this effect will be more pronounced for small **M** than for large **M**, because the overall duration, which is the sum of the source duration and the path duration, will be dominated by the path duration for small events; for the M=3 event considered here and the stress parameter of 172 bars, the source duration is only 0.07 s, whereas the path duration ranges from 0.9 s at 5 km to 25 s at 50 km.. A rough approximation of the decrease in amplitudes due to spreading out the motions over a longer duration is given by the square root of the ratio of the durations for the two duration models, at each distance. Reducing the constant duration model amplitudes by the square root of the duration ration gives the black pluses and line shown in Figure 3.

If the BT15 duration model applies to the aftershocks used by Wu et al., the results here suggest that the underlying FAS of the ground motions decay slightly faster than 1/R (Wu et al. find decay of 1.56 and 1.52 for the radial and transverse motions, respectively, and my simulations for a 1/R decay predict a decay of the filtered motions of about 1.46, suggesting that the actual decay of the FAS is about 1.1).

Suggested future work: determine the duration of the data used by Wu et al. (2016), keeping in mind the duration measure used by BT15. With a duration model appropriate for the data, do simulations for more filter frequencies and distances, the goal being to extract the decay of the underlying FAS model.

References

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