4 Quantitative Analysis of Coda Window Length: How Much Length of Coda is Enough for Stable Amplitudes?

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4.1 Introduction

In earthquake source estimation, coda-derived source methods provide more stable source parameters than methods using direct waves due to the inherent averaging nature of coda waves (Mayeda and Walter, 1996; Mayeda et al., 2007). Unlike conventional direct-phase regional measurements (e.g., Pg or Lg), which take peak amplitude at the specific arrival time, the coda amplitude measurement through a relatively long time window can dramatically reduce the inter-station scattering by smoothing out 3-D path variability, source radiation pattern, and directivity effects (Mayeda and Malagnini, 2010).

Although a number of studies have shown this stability of the coda measurement, it is still unclear how much length of coda is enough for accurate measurements of coda amplitudes. Inappropriate short window measurement can not only lead to higher inter-station scatter of coda amplitudes, but can also give a distorted amplitude by using only earlier parts of a coda envelope, which shows a radical change in energy density with increasing lapse time. But long-lasting coda, which guarantee a stable measurement, are not always easy to obtain, because of small magnitude, low signal to noise ratio, and interfering aftershocks.

In this study, to address this unsettled question and quantify the optimum window length for accurate coda measurements, we analyze inter-station standard deviation of the coda ratios as a function of the time window length using an earthquake sequence data set that was well-recorded by a dense broadband seismic array. This allows us an in-depth look at the effects of coda on averaging over source radiation pattern and directivity and can help serve as a guide to future coda-based studies regarding how much window length is needed to get good measurements.

4.2 Data and Method

We use the broadband records of the 2008 Wells, Nevada seismic sequence to quantify the window length effect for coda amplitudes and source ratios in terms of reducing variance due to radiation pattern and directivity. Fortunately, because the EarthScope USAArray temporary seismic network was operating in this region at the time of the earthquakes, this sequence can offer a great opportunity with a number of high-quality records and perfect distances and azimuthal coverage.

The seismic sequence consists of an M 6 mainshock and its six aftershocks with magnitudes ranging between M 4.0 and 4.5. We select 162 broadband stations within about 500 km epicentral distance of the Wells mainshock. For each event at each station, we measure the coda amplitude for 24 narrowband frequencies ranging from 0.05 to 15 Hz. All amplitudes are measured from a one second window length to the end of the possible record for coda measurement based on signal to noise or existence of an interfering aftershock.

4.3 Preliminary Results and Discussions

Figure 2.7 shows the amplitude ratio between the mainshock and an M 4.4 aftershock for the direct Lg and coda waves. In general, the direct Lg amplitude ratios vary considerably with azimuth due to the source radiation pattern or directivity effects of the two events. The coda amplitude ratios with a relatively short window length (2nd row entries in Figure 2.7) behave similarly to the direct Lg ratio. With increasing window length ($T_l$), however, the azimuthal variations of the coda amplitude ratio decrease significantly.

To quantify a reduction of the standard deviation, we normalize the standard deviation values with the standard deviation values at the 1 second window length and divide the window length ($T$) by a central period ($T_0$). We found that normalized standard deviations linearly decrease with $\log_{10}$ scales of $T/T_0$, and the reduction rates depend on the central frequency (Figure 2.8). The higher frequency bands show a larger slope of reduction than lower frequency bands.

To find a best fitting curve, we used an empirical equation,

$$
\sigma \left( \frac{T}{T_0} \right) = \begin{cases} 
1 & (\tau < \tau_0) \\
1 - p \log_{10} \left( \frac{\tau}{\tau_0} \right) & (\tau > \tau_0)
\end{cases}
$$

where $p$ represents a reduction rate, while $\tau_0$ represents a starting point of decay with reduction rate $p$.

Though these preliminary results show very interesting properties of coda stability for the Wells, Nevada sequence, they leaves us with other questions and ideas that we wish to pursue in the near future, namely: 1) To what extent does the reduction rate, $p$, behave the similarly for other parts of the world? 2) Can a single functional form that is frequency-dependent be used to characterize coda amplitude error as a function of measurement window length? 3) We would like to study other sequences with good signal-to-noise ratio in a variety of different tectonic settings. 4) We plan to test the methodology...
using a much smaller subset of stations, since the large amounts of data are not usually common.

4.4 Acknowledgements

S.-H Yoo was supported by the National Research Foundation of Korea under Grant NRF-2010-357-C00135. K. Mayeda was partially funded through LLNL’s GNEM program.

4.5 References

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Figure 2.7: Coda amplitude ratios between the 2008 Wells mainshock and M 4.4 aftershock. Rightmost plots show the direct Lg amplitude ratios for given narrowband frequencies. The left side plots of the direct Lg ratio plots show the coda amplitude ratios with different window length (T_L) for the same frequency bands. The black circles in the subplot represent the location of the mainshock, and each colored circle represents a station. The small and large dotted circles represent 250 and 500 km iso-epicentral distance, respectively.

Figure 2.8: Normalized standard deviation versus normalized window length, T/T_0, for the mainshock and M 4.4 aftershock pair. The dotted lines represent a best fit model for each data set (gray symbols). The reduction rates of normalized standard deviation vary with frequency and linearly decrease in a log_{10} scale with T/T_0. To reach 50 % reduction, higher frequencies need much larger T/T_0 values than lower frequencies.