Motivation
With the arrival of accurate data of waveforms provided by modern seismic arrays during the 1960’s, the degree of incoherency in the seismic signals became evident. The search for underlying physical mechanism for this effect lead to the seminal paper of Aki and Chouet (1975), which concluded that the coda signal is due to the backscattering of seismic waves off of heterogeneities of the earth. Since then, many models have attempted to explain the scattering of waves at different length scales and at different times in recorded seismograms. The model of Gusev and Abubakirov (1987) used a Monte Carlo approach to compute coda energy envelopes. They determined that the most important contribution of seismogram incoherence comes from forward scattering rather than backscattering, at the beginning of the seismograms and at close distances. They also show that at close and for the early portion of the energy envelopes of coda, the scattering process does not resemble the diffusion process at first. Later portions of the coda envelopes show diffusion process is a good assumption. Scattering is the main contributor to the duration of strong ground motion. Many methods of simulation of synthetic ground motion, particularly methods that make use of stochastic Green’s functions can incorporate high-frequency (HF) signal content with empirically observed duration of ground motion (e.g. Graves and Pitarka, 2010; Motazedian and Atkinson, 2005). There are some methods that include scattering in HF synthetics, such is the case of Zeng et al. (1995), Mai et al. (2010) and Mena et al. (2010). The first method simply adds a uniformly distributed stochastic process to the synthetic ground motion after the first direct S-arrival. The latter two methods use a hybrid approach where the HF contribution is given by the convolution of a scatterogram with the source (either as a point or finite fault source).

Inclusion of Scattering in Synthetic Seismograms
Jin et al. (1994) and Mayeda and Walters (1996) show that at different frequency bands, the coda energy envelopes exhibit different durations for different tectonic regions as shown in Figure 1. We make use of the different durations of coda energy envelopes at different frequency bands to simulate synthetic scatterograms using the theory of sigma oscillatory process of Priestley (1965). The coda envelopes are determined from observed regional seismicity, with parameters such as the extinction length, $L_e$ and the seismic albedo, $B_0$ for different frequency bands. The analytical solution of the coda envelope we use are explained in the work of Zeng (1991) which is very

![Figure 1: Inverted scattering parameters for different tectonic regions and frequency bands (Modified from Jin et al., 1994).](image-url)
similar to the analytically derived solution for multiple scattering found by Zeng et al. (1991). In Figure 1 we show results of inverted $L_e$ and $B_0$ from Jin et al. (1994) for different tectonic regions. For each frequency band corresponding to the inverted coda envelope parameters we simulated a stochastic process (scatterogram) with the method of Liang et al. (2007) such that the envelope of the synthetic simulation matched the coda envelope. We then convolve synthetic scatterograms in the frequency domain with the crustal earth Green’s functions (see Figure (2) to obtain high-frequency Green’s functions with coda waves. We amplify the HF GFs with the quarter wavelength method of Boore and Joyner (1997) to account for the contribution of varying crustal structure with depth. With the HF Green’s functions we use the representation theorem to calculate synthetic strong ground motion. We stitch these HF with low-frequency (LF) ground motions in the wavelet domain. To compute the LF synthetics, we use the same kinematic rupture simulation as explained in Crempien and Archuleta (2014), where the fault source parameters are correlated based on the work of Schmedes et al. (2010). In Figure (2a) we show an example of computed GFs for a homogeneous crustal structure in red. In black, we show the same GFs convolved with scattering functions. Just by looking at this product of convolution, we can see a great increase in the amount of strong ground motion duration. In Figure (2b) we show computed synthetic transverse seismogram using GFs with and without scattering in black and red respectively. It must be noted that the scatterograms do not include any anelastic attenuation, even though the envelope duration do take into consideration the effects of anelasticity. Once the convolution between the homogeneous GF and the scatterogram is done, the effects of anelasticity are automatically included if the Q and kappa parameters have been considered in the homogeneous GFs.
Summary
We have included scattering in synthetic GFs by convolving scatterograms with simplified GFs. The scatterograms have different duration of strong motion at different frequency bands, which are constructed to match the theoretical coda envelope observed at different tectonic regions. This is done using the method of Liang et al. (2007). Once scattering is included in HF GFs, we use the representation theorem to convolve the HF GFs and a synthetic kinematic rupture scenario to obtain HF synthetic ground motion. We stitch the HF ground motion with LF synthetics computed with the same kinematic rupture scenario in the wavelet domain. As a final product we obtain broadband synthetic ground motion. All the present work has been included into the UCSB Broadband Synthetic Ground Motion Code.

References