SDSU BBP Module Extension: Ground Motion Correlation, Duration, and Multi-Segment Ruptures

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Summary

The SDSU module, merging low-frequency deterministic signals with high-frequency scattering functions (Olsen and Takedatsu, 2015), participated in and passed the SCEC Broadband Platform validation exercise, where the focus was on validating simulated median pseudo-spectral accelerations for large earthquakes in western and eastern US and Japan, as well as NGA-west1 GMPEs. Here, we prepare the SDSU module for the next generation seismic hazard analysis.

We have incorporated inter-frequency correlation in the FAS domain as a post-processing method into the current SDSU Broadband ground motion generator module. Using our improved method, the BB results for 7 western U.S. events with Mw5.0-7.2 show that the empirical inter-frequency correlations of EAS are well predicted in the SDSU module for a large number of realizations from a single event with unbiased goodness-of-fit of the spectral accelerations in the presence of correlated synthetics. This in itself is an important step toward validating the BB codes in FAS rather than SA space. A further validation of the correlated synthetics comes from an improved fit of the RotD100/RotD50 ratio, a proxy metric proposed by Burks and Baker (2014).

We have updated and validated the SDSU BBP module in terms of ground motion duration. 50-realization significant duration estimates from the updated SDSU module were generally improved of the WUS and Japanese events. Finally we verify a multi-segment rupture implementation of the SDSU module with 1- and 3-segment Landers approximations.

Finally, we have participated in the weekly BBP group efforts toward validating the codes for additional events. We are working on validating the CA San Simeon event, the Japanese events Chuetsu-Oki and Iwate events, and have revisited the Niigata and Tottori events. We obtain satisfactory Goodness-of-fits for all these events.

Completed Work

Inter-frequency Correlation

The current SDSU module does not incorporate realistic period-to-period correlations of FAS into the simulations, as shown by the resulting period-to-period correlation coefficients of 50 realizations for Loma Prieta validation event from the current SDSU broadband synthetics compared with the empirical result (Figure 1, left).

The Effective Amplitude Spectrum (EAS) of FAS are used as the intensity measure in our study, which is the geometric mean of the two horizontal FAS components,

$$EAS(f) = \sqrt{\frac{1}{2}\left(FAS_{HC1}^2(f) + FAS_{HC2}^2(f)\right)}.$$

The within-event residual is the misfit between an individual EAS observation at a station and the earthquake-specific median prediction. The epsilon (ϵ) of the within-event residuals are the individual residual components normalized by their respective standard deviations. By the normalization, the epsilon is standard normally distributed.

To improve the FAS correlations in the current SDSU module, we develop a post-processing method to implement period-to-period correlations into the SDSU broadband synthetics. Making use of the empirical covariance matrix Σ (real, symmetric and positive definite) for the period-to-period correlation of FAS regressed from NGA-W2 database by Bayless and Abrahamson, we first apply the Cholesky decomposition of Σ,

$$\Sigma = KK^T,$$

where K is a lower triangular matrix. An uncorrelated normal random variable R is then generated with zero mean and a constant standard deviation, $\sigma = 0.2$, for each realization. The random variable is multiplied by K to get a correlated normal random variable S with zero mean and covariance equals $\sigma^2\Sigma$,

$$S = KR.$$

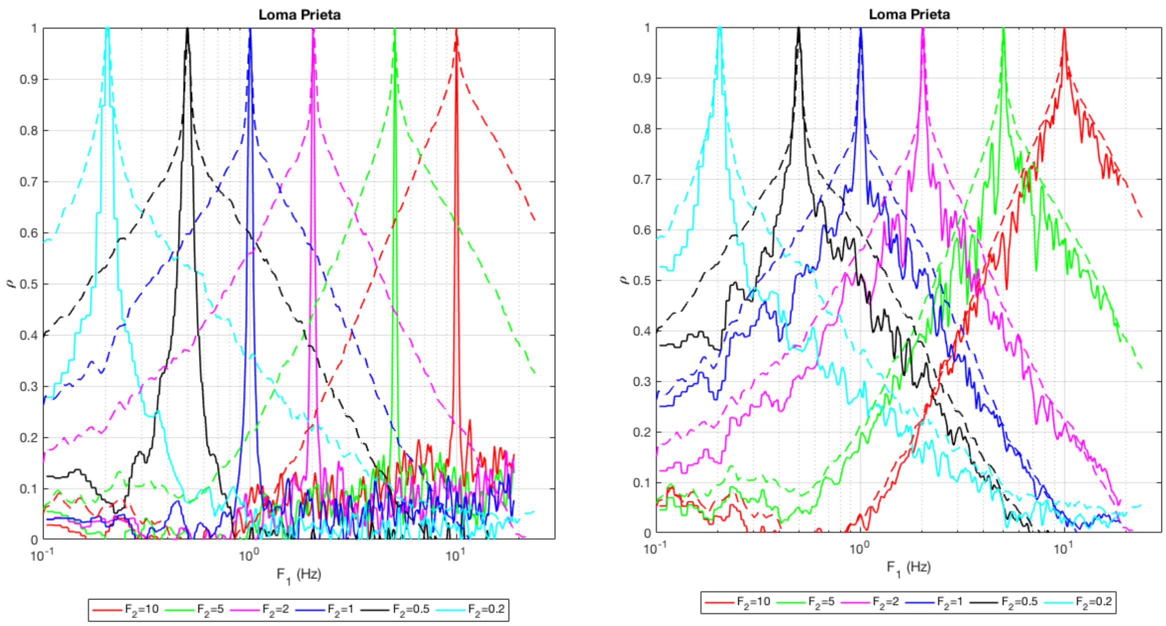


Figure 1. The period-to-period correlation coefficients of epsilon at reference frequencies 0.2Hz, 0.5Hz, 1Hz, 2Hz, 5Hz and 10Hz from the (left) previous version and (right) the improved SDSU module of 50 realizations for Loma Prieta event (solid lines) and the empirical correlation coefficients (dashed lines).

Next, we multiply the exponential of the correlated normal random variable with the amplitude of the Fourier transform (keeping the phase unchanged) of the original velocities calculated before. Finally, the ground motion time series with realistic period-to-period correlations are generated by an inverse Fourier transform.

This post-processing method generates acceleration time series that are compatible with the original results from current SDSU module. Figure 1 (right) shows the resulting period-to-period correlation coefficients of 50 realizations for the Loma Prieta event from the improved SDSU broadband synthetics with the correlations implemented compared with the empirical result. Using the post-processing method, the period-to-period correlations can be well simulated for both low-frequency and high-frequency parts.

Another indication that the improved inter-frequency correlation improves the match to data comes from a comparison between observed and modeled ratios of RotD100 and RotD50 values, a proxy metric proposed by Burks and Baker (2014). Figure 2 shows the ratios from data and SDSU synthetics without and with the inter-frequency correlation included. It is clear that the correlation greatly improves the fit between the metric for data and synthetic, primarily by lowering the ratio for the shorter ratios in the synthetics.

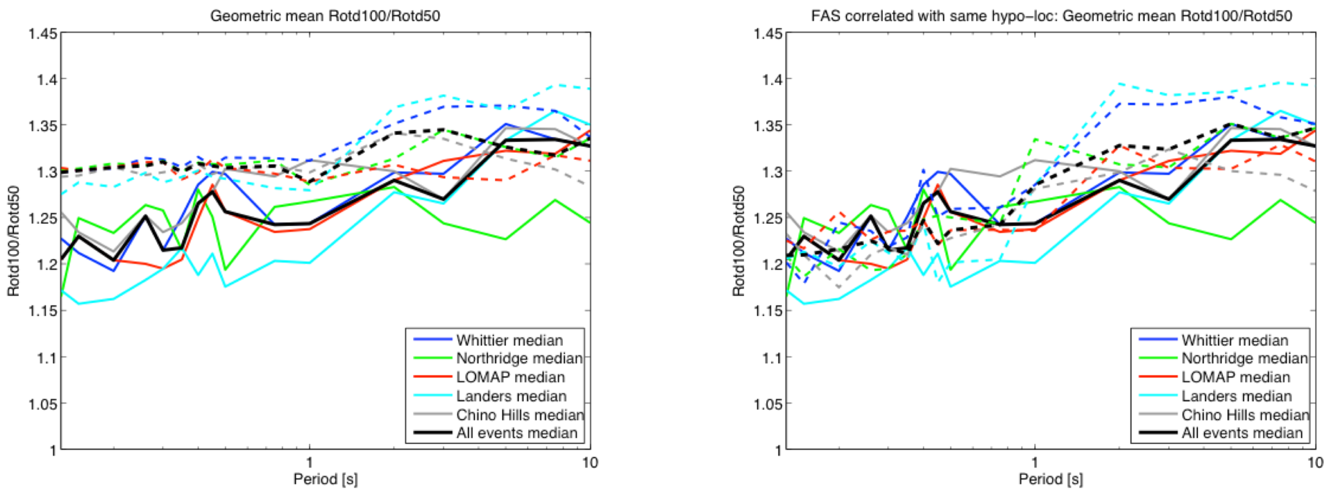


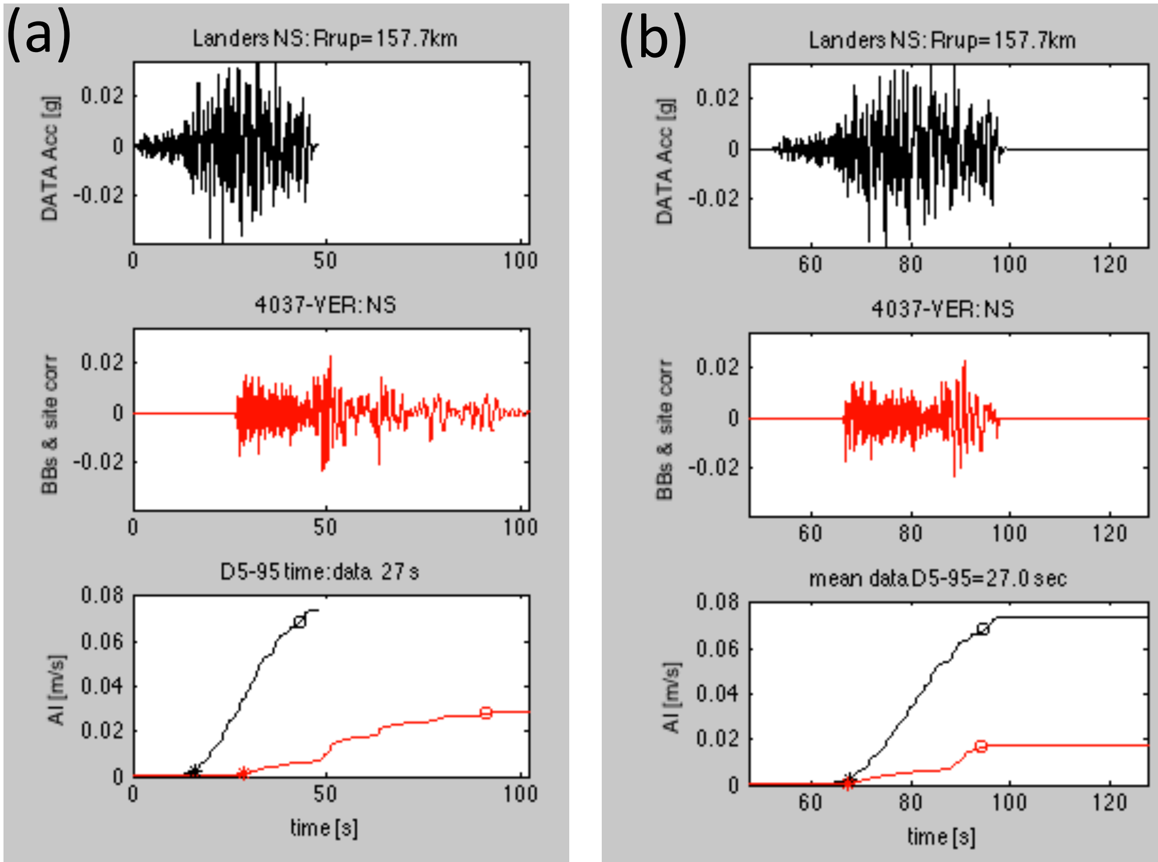
Figure 2. Comparison of RotD100/RotD50 ratios for 5 western US events and their median values for data and synthetics from the SDSU BBP module (left) without and (right) with inter-frequency correlation.

Spatial correlation of ground motions. We have started working on adding spatial correlation to the SDSU BBP module, which is the focus of current work. We are using the model by Loth and Baker (2013), which is developed for PSA.

Signal Duration. The current technique of estimating the goodness-of-fit (GOF) for durations (Anderson set of GOF metrics recently implemented on the BBP) aligns synthetic and recorded time series to the time of the 5% energy and cuts the synthetic time series when the data record ends; this technique can provide a biased GOF value when the data is truncated (i.e., due to too short of a recording window, see Fig. 3).

We find that the synthetics should **not** be truncated to provide a fair comparison, which is how we have conducted our validation. We have eliminated data records that appear to be truncated (e.g., Fig. 3, right). We have conducted the analysis on the HF component only, as the 1D Green's Functions controlling the LFs are a separate issue. Figure 4 shows an example of $Ds_{5\text{-}95\%}$ durations for the Loma Prieta, Whitter and Northridge events, for the previous and updated SDSU module, illustrating the general trend of decreasing the durations and their standard deviations for all events. We did the analysis for all of the SCEC validation events, and generally obtained an improved fit to the durations of the data, a general trend.

Multi-segment Rupture for the SDSU Module. In addition, we have enabled the Landers scenario with a 3-segment fault configuration. Figure 5 shows the 5-95% BB durations for the 1-segment and 3-segment fault configurations, after stations where the data was truncated were removed. The fit for the durations is improved for the 3-segment rupture, although still underpredicting. The PSA bias is showed in Figure 5 for 1- and 3-segment approximations, showing a minimal improvement for the latter. Currently, the BBP group is working its way through a series of validation events, and as we encounter more multi-segment ruptures, we will further test the SDSU module.



No alignment, truncation

Alignment to 5% energy and truncation

Figure 3. Illustration of the undesirable effects of using the (default) truncation of the synthetics alignment in calculating the GOF on the SCEC BBP. (top) Truncated data, (middle) synthetics (left) untruncated and (right) truncated, and (bottom) Arias Intensity comparison of data and synthetics in the two cases.

Validation of additional events. We have participated in the weekly BBP collaboration, and validated events Chuetsu-Oki and Iwate (Japan) as well as San Simeon (CA). We obtain satisfactory goodness-of-fit for the median SAs for these events, and will continue this process for the remaining events.

References:

Burks, L. S., and Baker, J. W. (2014). “Validation of ground motion simulations through simple proxies for the response of engineered systems.” Bulletin of the Seismological Society of America, 104(4) 1930-1946.

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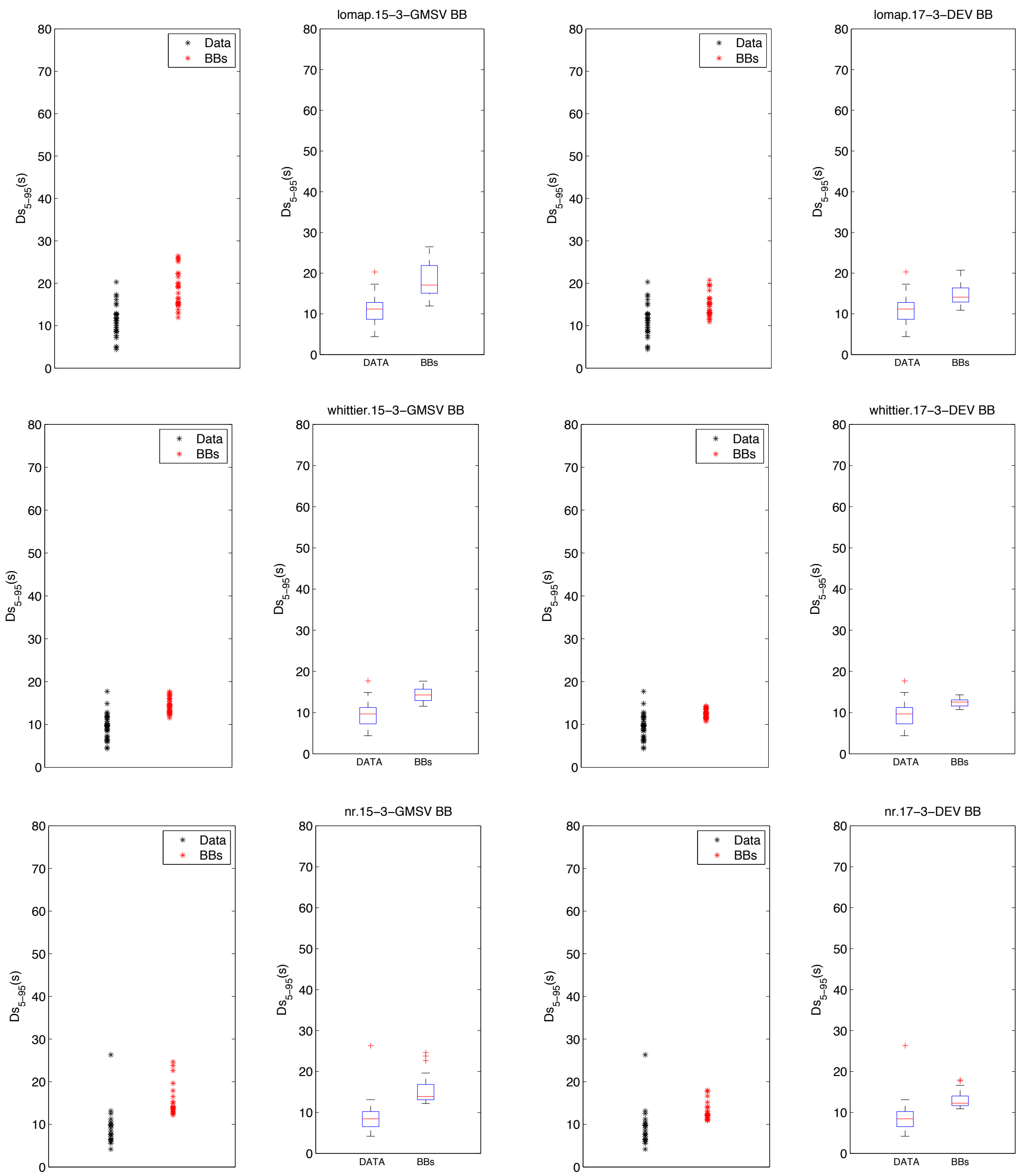

Figure 4. Comparison of $Ds_{5\text{-}95}$% duration for (top) Loma Prieta, (center) Whittier, and (bottom) Northridge (left two panels) for the old code to (right two panels) the updated SDSU module.

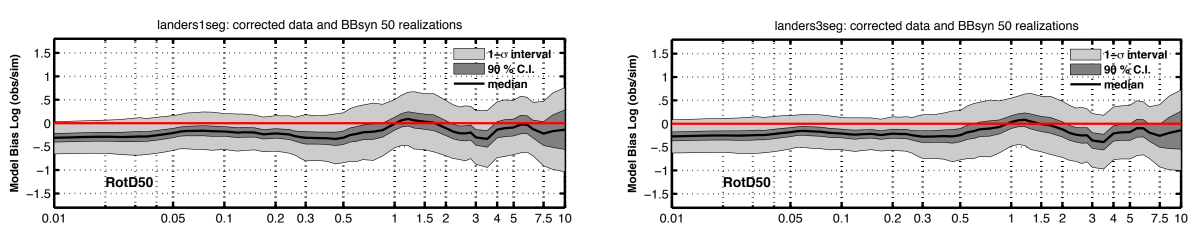

Figure 5. Comparison of PSA bias for 50 realizations of Landers with (left) 1 segment and (right) 3 segments. The bias is slightly smaller for the 3-segment simulations.