Evaluating Alternative Site Adjustment Methods in Hybrid Broadband Ground-Motion Simulations of Small-Magnitude Earthquakes in New Zealand

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1. Introduction

Shallow site effects are usually incorporated in hybrid broadband ground-motion simulations through a posterior site factor (SF), which can be derived based on different site-response approaches. This study evaluates alternative methods to perform this adjustment by comparing observed and (adjusted) simulated ground motions from 212 small-magnitude (3.5≤Mw≤5.0) earthquakes recorded at 34 well-characterized strong-motion station (SMS) sites in New Zealand.

2. Methods

Table 1 summarises the methods considered in this study. The V_{S30}-based approach represents the conventional method, which is based on the site response scaling factor (f_{site}) from a semi-empirical ground-motion model (GMM) (e.g., CB14, BA18 models). Alternative approaches, based on the square-root-impedance (SRI) method and the theoretical 1D transfer function (TF_{SH1D}), that require a shear-wave velocity (V_S) profile, are also examined.

Table 1: Methods to compute the site factor (SF).

Method	SF Formulation	Site data
V_{S30}-based SF	$\frac{\exp[f_S(V_{S30,actual})]}{\exp[f_S(V_{S30,sim})]} = SF_{1,L} \cdot SF_{1,NL}$	V_{S30}
SRI-based SF - Full κ_0	$\left[\frac{A_{SRI,actual}}{A_{SRI,sim}} \cdot \frac{\exp(-\pi f \kappa_{0,actual})}{\exp(-\pi f \kappa_{0,sim})}\right] \cdot SF_{1,NL}$	V_S Profile
SRI-based SF - $\Delta\kappa_0$	$\left[\frac{A_{SRI,actual}}{A_{SRI,sim}} \cdot \frac{\exp(-\pi f \Delta\kappa_{0,actual})}{\exp(-\pi f \Delta\kappa_{0,sim})}\right] \cdot SF_{1,NL}$	
SH1D-based SF	$\left[\frac{TF_{SH1D,actual}}{A_{SRI,sim} \cdot \exp(-\pi f \Delta\kappa_{0,sim})}\right] \cdot SF_{1,NL}$	

Figure 1 illustrates the workflow for the application of the site factor for these alternative methods. The hybrid simulation method involves a separate treatment of the low-frequency (LF) and high-frequency (HF) components of the ground motion (in this case, with a transition frequency of 1 Hz). An SRI-based "normalization factor" is introduced to deal with existing differences between the LF and HF V_S profiles considered in the regional simulation ("simulated profiles").

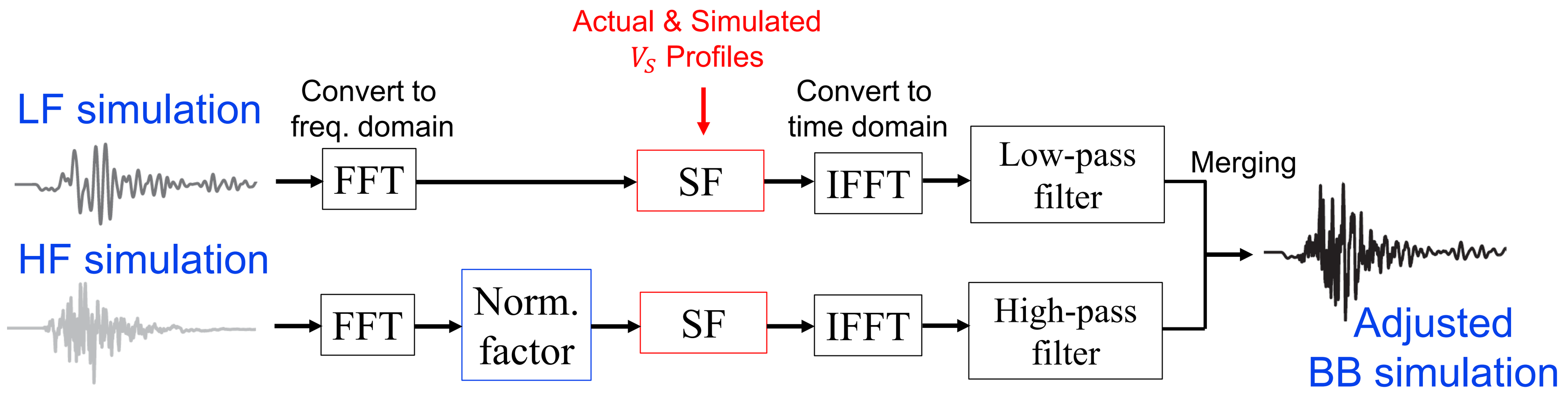

Figure 1: Workflow for adjusting simulated ground motions using a V_S profile.

3. Sites and events considered

Figure 2 shows the location of the 34 sites, 212 earthquake sources, and consequent 1372 ground motions considered. The site and earthquake data used is grouped into two clusters: Canterbury and Wellington.

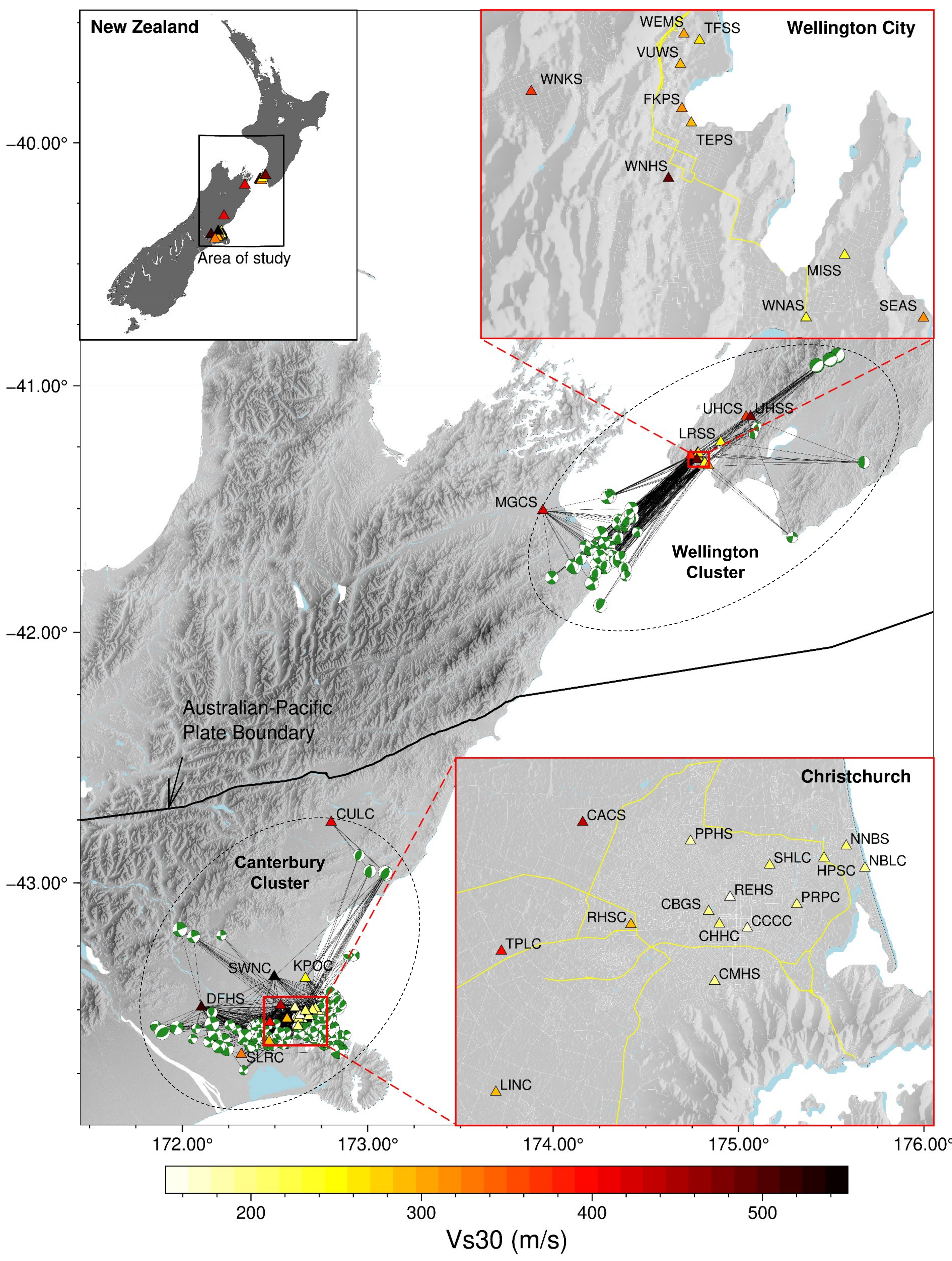

Figure 2: Location of the 34 SMS sites and 212 earthquake sources considered.

4. Results

Figure 3 illustrates the different site factors evaluated.

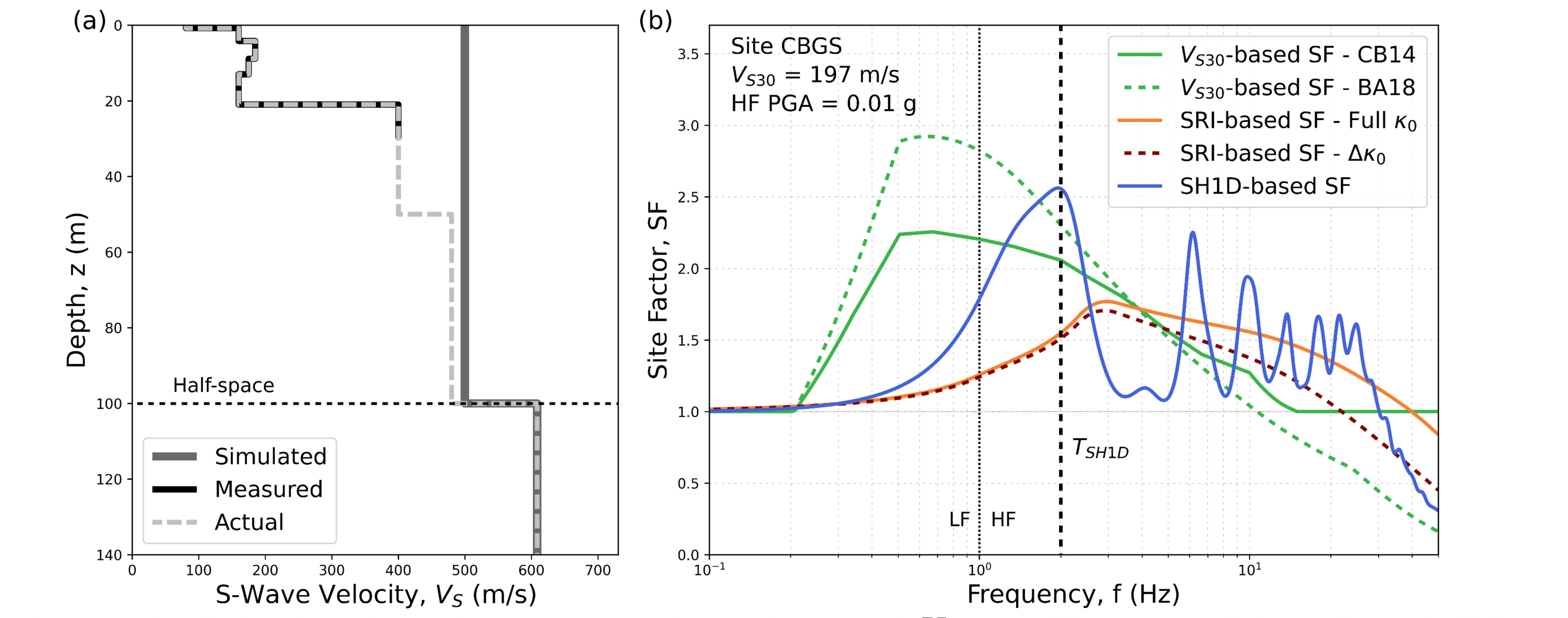

Figure 3: (a) Simulated, measured, and actual V_S profiles considered and (b) the different site factors obtained, for the site CBGS.

Figure 4 presents the global model bias and site-to-site standard deviation for pseudo-spectral acceleration (SA) and other intensity measures (IMs).

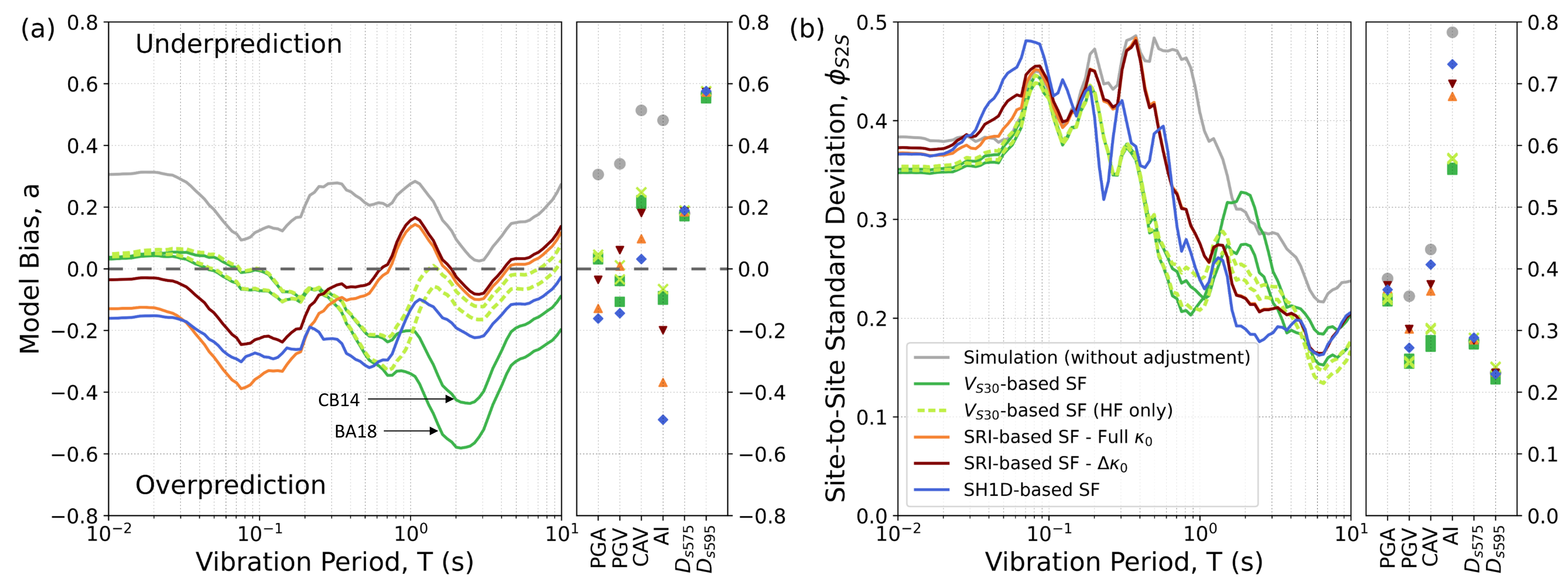

Figure 4: Global (a) model bias and (b) site-to-site standard deviation.

Figure 5 shows the results disaggregated by cluster (in terms of the mean systematic residual), revealing significant inter-cluster differences. Figure 5(b) shows that for the Wellington Cluster, the regional simulation (without adjustment) is already overpredicting the response for a wide range of vibration periods, complicating the validation of the site adjustments. In the case of the Canterbury Cluster (Figure 5a), whose basin is better modelled in the regional simulations, it is more feasible to assess the performance of the different methods.

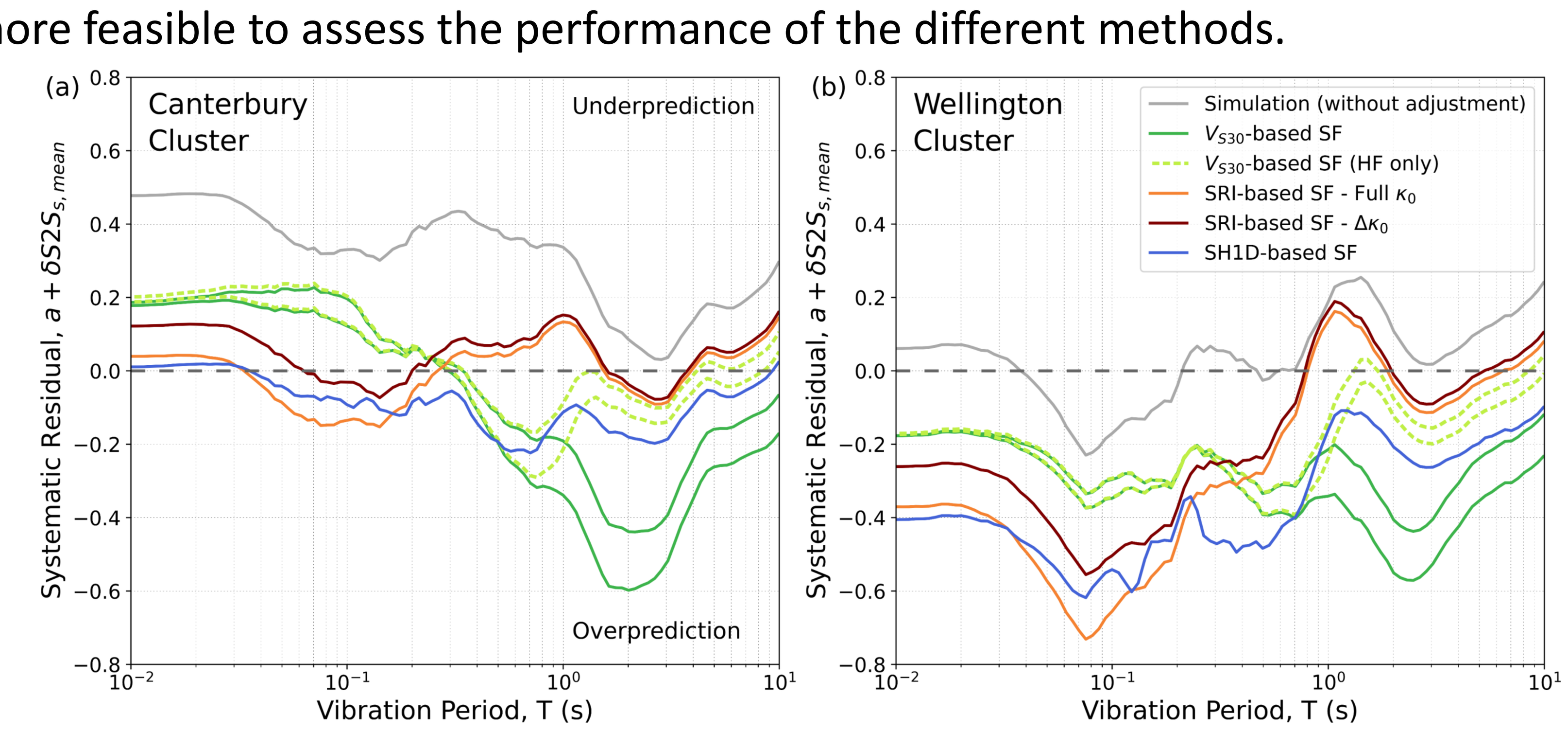

Figure 5: Systematic residuals for (a) Canterbury and (b) Wellington clusters.

Figure 6 presents the results for different sub-regions of Christchurch (Canterbury Cluster) with sites characterized by similar site conditions and locations. Figure 6(b) shows less bias at short vibration periods for the more site-specific methods at stiff sites. Figures 6(c) and 6(d) illustrate that for these two groups of sites with similar V_{S30} but different V_S profiles, the methods exhibit significant differences in their relative residuals, particularly around the (SH1D method) model period (T_{SH1D}).

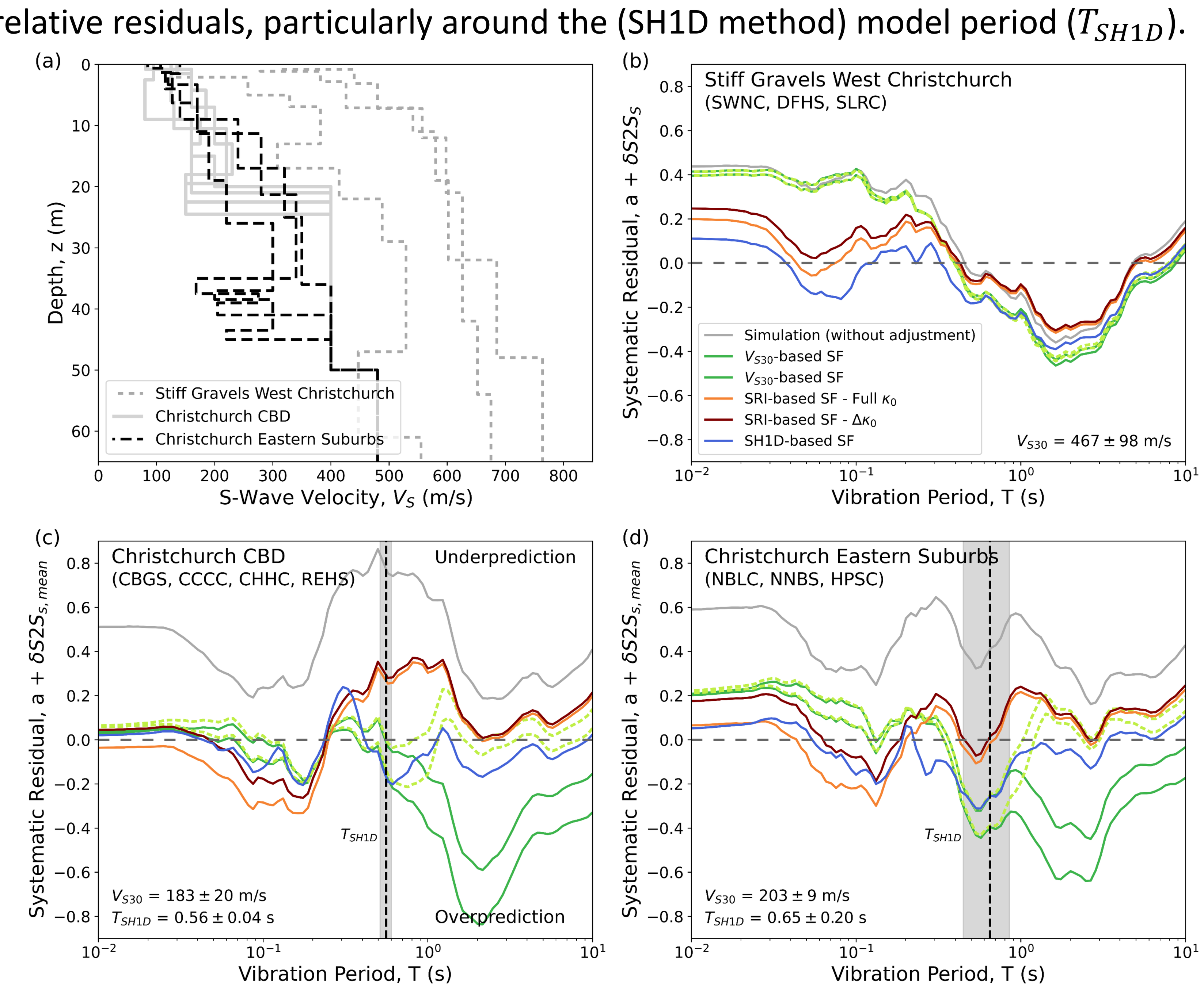

Figure 6: (a) Actual V_S profiles for three sub-regions of Christchurch, and their corresponding systematic residuals (b, c, and d).