Online open-source applications for ground motion selection using the GCIM method

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ABSTRACT: This paper illustrates two online and freely available applications which can be used for ground motion selection. Ground motions are selected using the generalized conditional intensity measure (GCIM) method (Bradley 2010a, Bradley 2012c), which enables ground motion selection to be based on any general set of ground motion intensity measures, e.g. spectral ordinates, peak ground acceleration/velocity, significant duration, arias intensity, cumulative velocity, etc. Users can firstly perform seismic hazard analysis using OpenSHA (Field, et al. 2003), or their own prototype codes to obtain the 'target' GCIM distributions for ground motion selection (Bradley 2010b). Secondly, the OpenSHA output file can be uploaded to the ground motion selection application. The application is written in Javascript, with the source code on GitHub, and allows easy visualization of the intensity measure properties of the selected ground motion ensemble, as well as various diagnostic tests to ensure the selected ensemble is representative of the problem considered. It is emphasised that the use of such online and open-source software is critical to ensure an efficient uptake of novel methodologies in seismic performance assessment.

1 INTRODUCTION

Ground motion selection is known to be an important step in seismic hazard and risk assessment. There have been numerous procedures proposed for selecting ground motions ranging from somewhat ad-hoc guidelines specified in seismic design codes to more rigorous approaches which have found favour in the research-community, but are not yet applied routinely in earthquake engineering practice.

The most common method (often specified in seismic design codes) for selecting ground motion records for use in seismic response analysis is based on their 'fit' to a Uniform Hazard Spectrum (UHS). This is despite the fact that many studies (e.g. McGuire (1995), Naeim and Lew (1995), Bommer *et al*. (2000)) have highlighted the differences between the UHS and individual earthquake scenarios, and therefore its inappropriateness for use in ground motion selection. The reluctance of the earthquake engineering profession to depart from UHS-based selection of ground motions is arguably because of its simplicity to implement relative to methodologies with sounder theoretical bases.

The aim of the present paper is to illustrate two GUI-enabled software applications that have been utilized/developed to implement the recently developed Generalised Conditional Intensity Measure (GCIM) approach for ground motion selection (Bradley 2010a, Bradley 2012c).

2 REVIEW: GROUND MOTION SELECTION USING THE GCIM METHOD

2.1 Determination of the 'target' GCIM distributions

The fundamental basis of the GCIM approach is that for a given earthquake scenario (*Rup*) the joint distribution of a vector of intensity measures (i.e. $\boldsymbol{IM}|Rup$) has a multivariate lognormal distribution (Bradley 2010a). Characterisation of $\boldsymbol{IM}|Rup$, therefore requires the marginal distributions, $IM_i|Rup$,(typically from a ground motion prediction equation) and correlations between IM_i and IM_j for which several prediction equations already exist (Bradley 2011a, Bradley 2011b, Bradley 2011c, Bradley 2012a, Bradley 2012b, Bradley 2012c). The total probability theorem can then be used to construct the conditional distribution of any intensity measure given the occurrence of a specific value of another intensity measure. Mathematical details are discussed at length in Bradley (2010a). Figure 1a illustrates the deaggregation of SA(3.0s) for a generic site in Christchurch for the 10% in 50 year exceedance probability. Figure 1b-Figure 1d illustrate the computed GCIM distributions and random realizations (discussed subsequently) which provide the theoretical target for ground motion selection.

The subsequent section discusses the implementation of the GCIM method in OpenSHA. For those who prefer to use an alternative hazard analysis software, prototype Matlab files of the GCIM method are provided at: https://sites.google.com/site/brendonabradley/software/ground-motion-selection-gcim to enable users to easily port code across to their platform of choice.

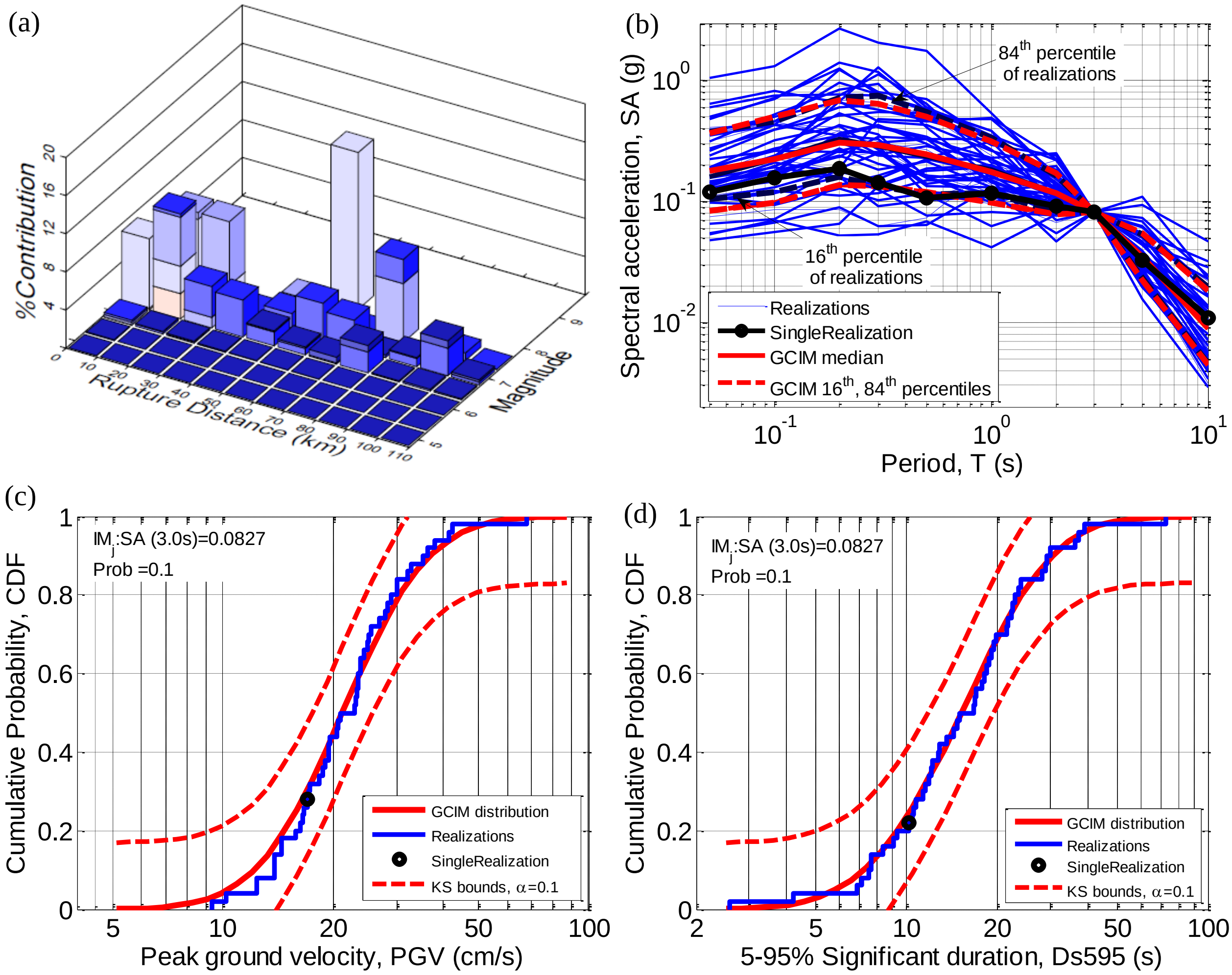

Figure 1. Example conditional distributions for the 10% in 50 year exceedance of SA(3.0s) for a site in Christchurch, New Zealand: (a) Deaggregation; (b) response spectral ordinates; (c) peak ground velocity; and (d) 5-95% significant duration. In figures (b)-(d) red lines illustrate the 'target' GCIM distribution while the blue lines illustrate the 'random' realizations which are directly utilized in the subsequent ground motion selection. Note that as the results are conditioned on SA(3.0s) then there is no uncertainty in this value as shown in Figure 1b.

2.2 Ground motion selection using the GCIM distributions

Using the GCIM distributions, Bradley (2012c) developed a ground motion selection procedure which can be used to select ground motions for any form of seismic response analysis. The selection algorithm is based on the use of random realizations from the conditional multivariate distribution of ground motion intensity measures (the blue lines shown in Figure 1b-Figure 1d) obtained from the GCIM approach. In addition to the usual inputs required for a seismic hazard analysis, the methodology requires only a weight vector specifying the importance of various intensity measures in selecting ground motions from a prospective ground motion database (Mathematical details are discussed at length in Bradley (2012c)). A key feature is that the generality of the GCIM methodology allows for ground motion selection based on only explicit measures of the ground motions themselves, as represented by the various IM's considered, rather than implicit causal parameters (e.g. source magnitude, source-to-site distance) which are presently used in other contemporary ground motion selection procedures. The procedure is holistic in that: (i) any level of complexity in ground motion selection for any seismic response analysis can be exercised; (ii) users explicitly understand the simplifications made in the selected suite of ground motions; and (iii) an approximate estimate of any bias associated with such simplifications is obtained.

The subsequent section discusses the implementation of the GCIM-based ground motion selection method in Javascript- and web-based online application. For those who prefer to use alternative software, prototype Matlab files of the application are provided at: https://sites.google.com/site/brendonabradley/software/ground-motion-selection-gcim to enable users to easily port code across to their platform of choice.

3 GCIM DISTRIBUTION COMPUTATION USING OPENSHA

In order to improve the ease at which the GCIM approach can be utilised, therefore increasing its potential for uptake in earthquake engineering practice, the method was implemented in the open-source software OpenSHA (Field, et al. 2003). OpenSHA is an object-oriented, web- and GUI-enabled, and freely available, software developed as a joint venture between SCEC and USGS (www.opensha.org/). Figure 2 illustrates the three key GUI control panels in the GCIM implementation, which are discussed briefly below.

- **Hazard curve calculator:** The Hazard Curve Calculator is used to obtain seismic hazard curves for the site of interest (as conventionally performed in PSHA). Using the Control Panel button, the "GCIM distributions" Control Panel can be selected.
- **GCIM control panel:** The analyst can first select the Intensity Measure Level (IML) or Probability of exceedance (from the seismic hazard curve), for which the GCIM distributions are desired. By using the "Add IMi", "Edit IMi", and "Remove IMi" buttons the analyst can then begin to specify the details of the various IMi's for which GCIM distributions are desired. The analyst can also specify additional details, such as the approximate CDF values to compute the GCIM distributions for.
- **Edit IMi control panel:** Using the Edit IMi Control Panel, firstly the IMi type (e.g. *PGA*, *SA*, *SI*, *IA*, etc.) can be defined. Only those IMi's for which correlation and ground motion prediction equations are available can be selected. Next, the ground motion prediction equation (IMR) which is used to predict the marginal distribution of the IMi, and also the IMi,IMj correlation relationship (ImCorrRel) can be defined, as well as their associated parameters. It is not shown in Figure 2, but separate IMR's and ImCorrRel's can be provided for different tectonic regions (e.g. Active Shallow Crustal, Subduction Interface etc.). The site parameters required by the IMR and ImCorrRel for the particular IMi are also shown in the Edit IMi Control Panel. Those site parameters which are specified in the Hazard Curve Calculator are shown, but cannot be edited. On the other hand, additional parameters which are required can be edited, and are stored for all of the different IMi's considered

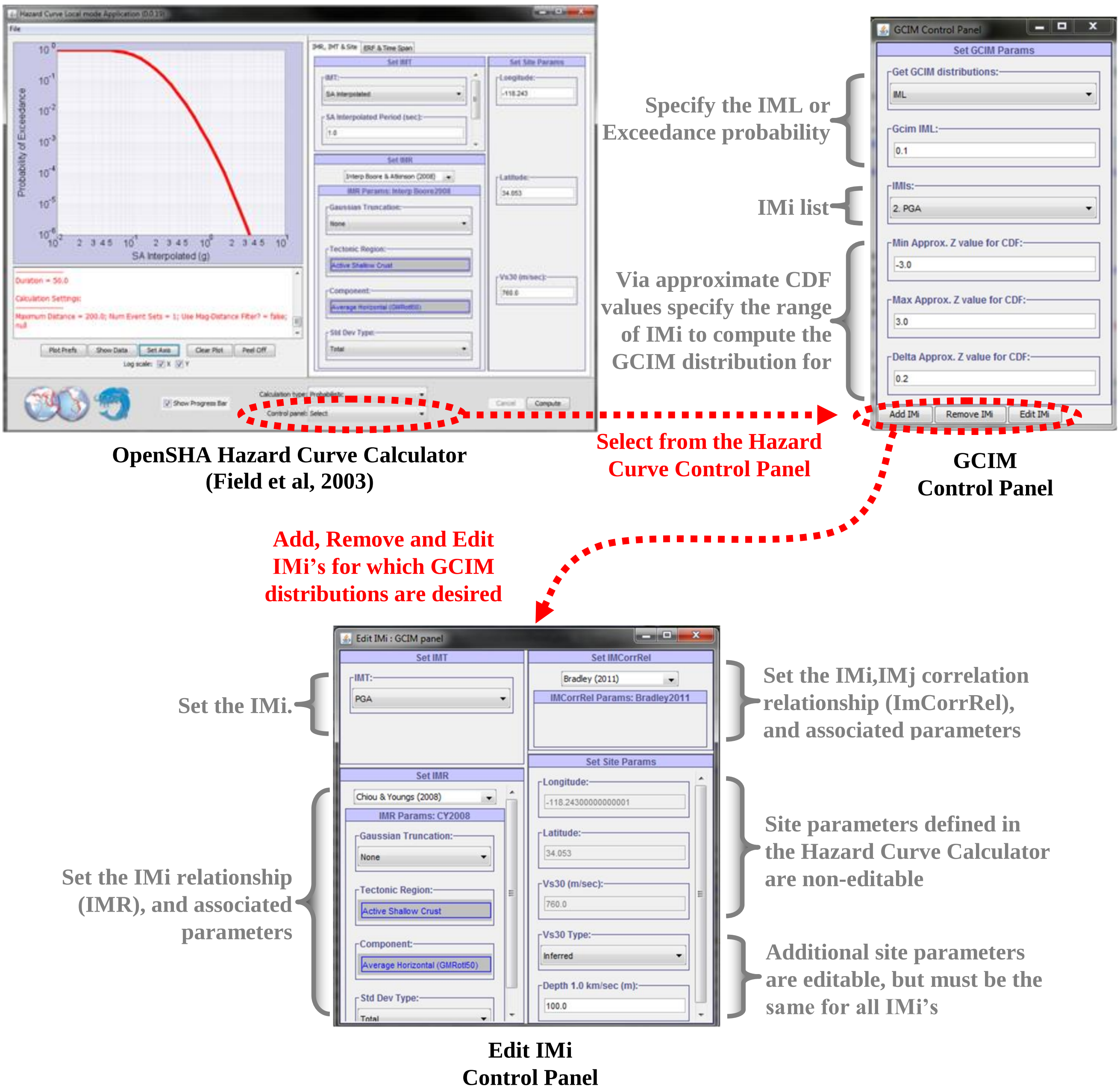

Figure 2. The OpenSHA hazard curve calculator and the implemented GCIM and Edit IMi control panels

4 A WEB-BASED GROUND MOTION SELECTION APPLICATION

Following the computation of the GCIM distributions using OpenSHA (or another prototype application) a subsequent software application was developed to enable GCIM-based ground motion selection. It is important to note that the use of two separate software tools is a conscious decision because of the different requirements for these two tasks. The computation of the GCIM distributions is a natural extension of PSHA and requires only the definition of the conditioning intensity measure (e.g. SA(3.0s) in Figure 1) and which other IMs to obtain distributions for. The process of ground motion selection is however significantly more iterative in nature with the potential for the analyst to perform the ground motion selection based on a specific weight vector and then upon inspecting the characteristics of the selected ground motions (i.e. comparison between the target and empirical distributions of the various intensity measures considered, as well as causal parameters such as magnitude and source-to-site distance, soil classification, and amplitude scale factor) decide to modify the weight vector and re-select ground motions. The use of two independent software seamlessly integrated by the use of compatible output and input files facilitates these different uses.

The developed application is written in Javascript, with the source code on GitHub, and allows easy visualization of the intensity measure properties of the selected ground motion ensemble, as well as various diagnostic tests to ensure the ensemble is representative of the problem considered. The application can be accessed through a web-browser via the link at: https://sites.google.com/site/brendonabradley/software/ground-motion-selection-gcimhttp://gm-selector.canterbury.ac.nz/. Figure *3* illustrates an annotated screenshot of the ground motion selection application, which is discussed briefly below.

- **The left panel** illustrates the uploading and display of the GCIM distributions and random realizations (the 'target'). The specifics of the input file are provided to assist the user to diagnose any unintended upload errors. Drop-down panels are used to enable the user to toggle between displaying the results for different intensity measures and interactive data values are provided to the user when the mouse pointer is placed at specific location on either of the displayed plots.
- **The right panel** illustrates the input of ground motion selection specifics as well as display of the IM properties of the selected ground motions. Currently the application allows for the selection of as-recorded ground motions from the Next Generation Attenuation (NGA) database, however the addition of other databases (e.g. K-Net) will be included in the near future. Users then specify the particular GCIM-based ground motion selection features that they desire (i.e. weight vector, number of ground motions to select etc.). Data displayed in both the left and right hand panels can be export in CSV format

Figure 4 illustrates a screen shot of the application where the drop-down panels on both the left and right sides have been changed (to SA(1.5s) on the left and D_{s595} on the right). The figure in the left panel illustrates GCIM distribution and random realizations for SA(1.5s), while the figure in the right panel provides a comparison of the properties of the selected records with respect to the GCIM distribution and random realizations for D_{s595}.

In addition to comparative plots of the considered intensity measures it is also insightful to understand the distributions of various causal parameters. Figure *5* illustrates cropped screenshots from the right hand panel of the application when the drop-down panel is changed to display the required amplitude scale factors and magnitude-distance distribution of the selected ground motions. While such distributions are not explicitly considered in the ground motion selection, as noted by Bradley (Bradley 2012c), an examination of such figures is useful in identifying the quality of the selected ground motions (which is dependent on the use of an appropriate intensity measure weight vector).

5 CONCLUSIONS

This paper has illustrated two online and freely available applications which can be used for ground motion selection based on the generalized conditional intensity measure (GCIM) method. Users can firstly perform seismic hazard analysis using OpenSHA to obtain the 'target' GCIM distributions for ground motion selection. The OpenSHA output file can be uploaded to the web-based ground motion selection application. The application is written in Javascript, with the source code on GitHub, and allows easy visualization of the intensity measure properties of the selected ground motion ensemble, as well as various diagnostic tests to ensure the selected ensemble is representative of the problem considered. It is emphasised that the use of such online and open-source software is critical to ensure an efficient uptake of novel methodologies in seismic performance assessment.

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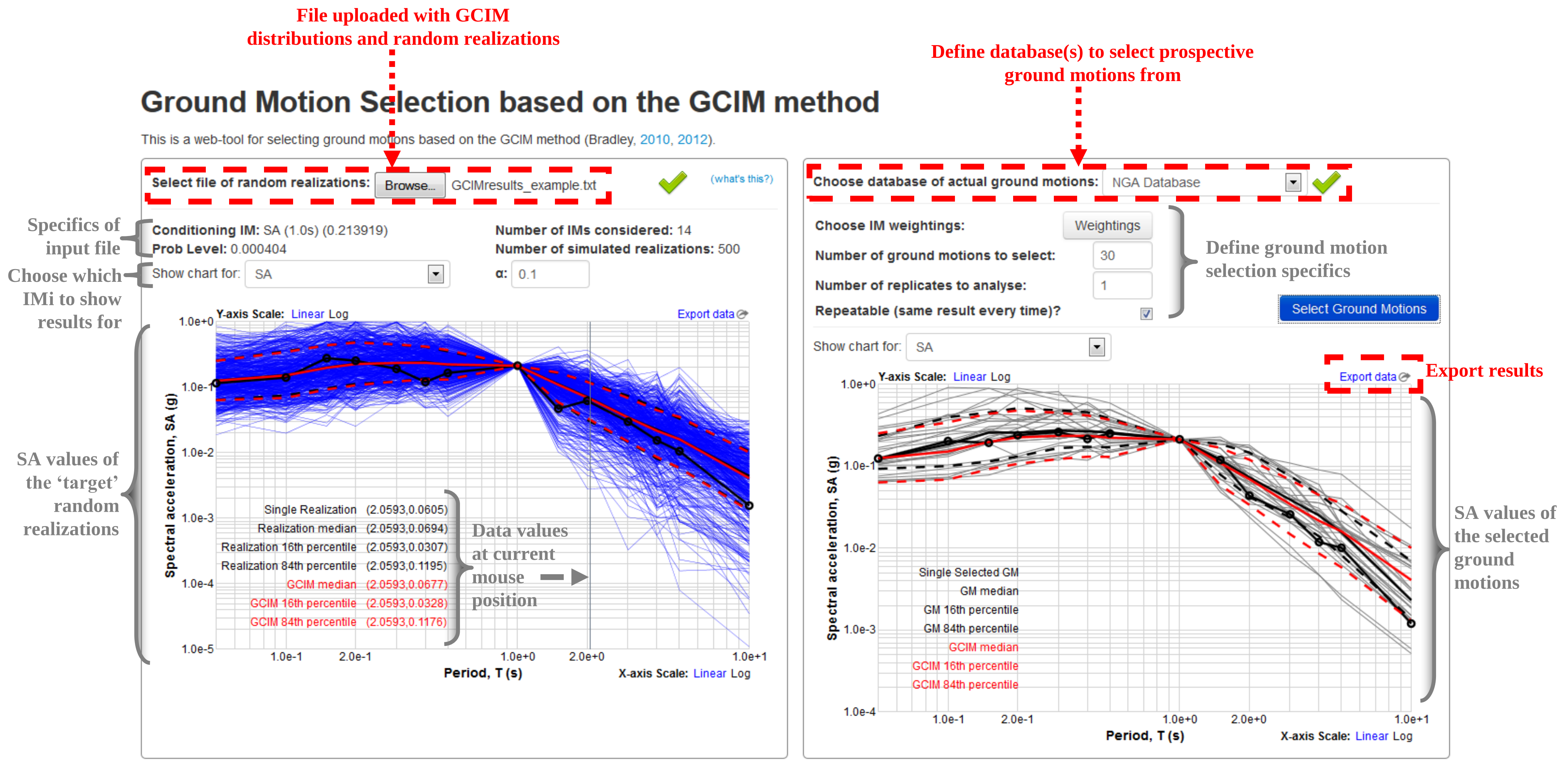

Figure 3. Screenshot of the Javascript-based web-enabled ground motion selection application. The left panel illustrates the uploading and display of the GCIM distributions and random realizations (the 'target'); and the right panel illustrates the input of ground motion selection specifics as well as display of the IM properties of the selected ground motions.

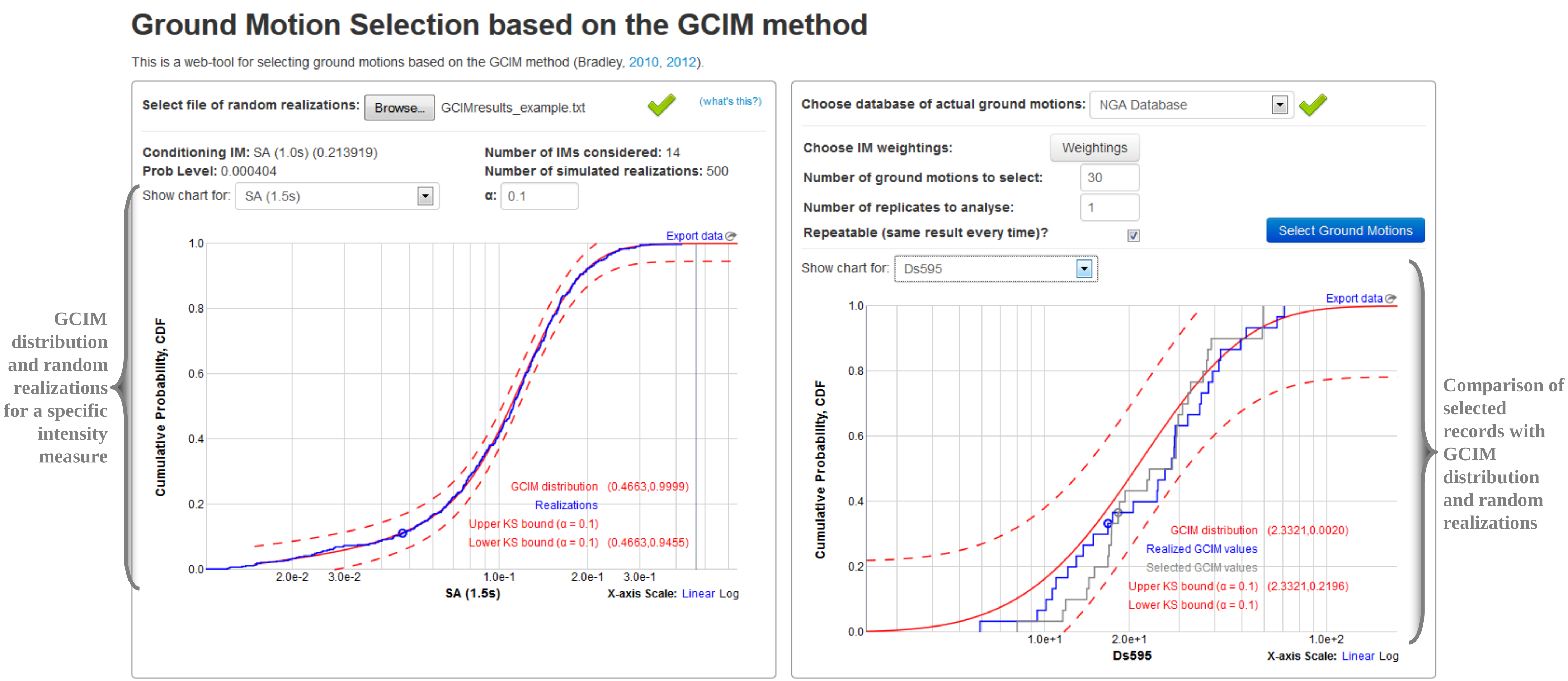

Figure 4. As for Figure 3, but illustrating the marginal distributions of specific intensity measures (SA(1.5s) in the left panel and D_{s595} on the right).

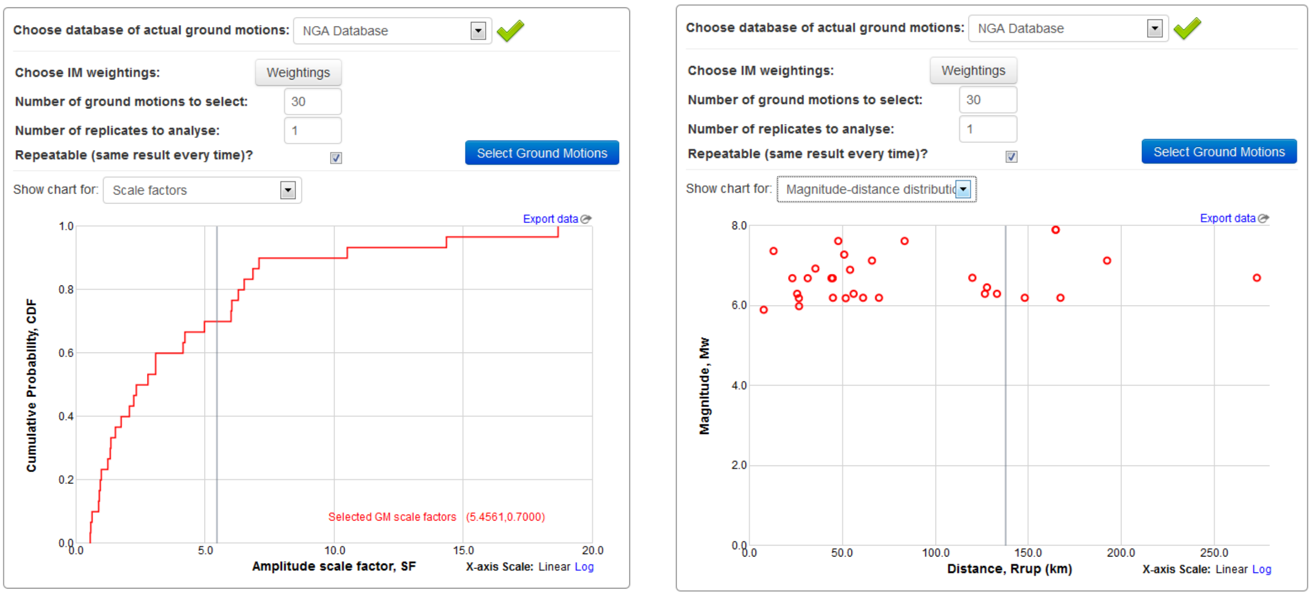

Figure 5. Illustration of additional details of the selected ground motions which can be displayed in the right panel of the web-based application: (a) distribution of the required amplitude scale factors (SF); and (b) magnitude (M_w) and source-to-site distance (R_{rup}) distribution.

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