UCLA
Earthquake Engineering

Title
Selection of a Global Set of GMPEs for the GEM-PEER Global GMPEs Project

Permalink
https://escholarship.org/uc/item/6pn9s2hg

Authors
Stewart, Jonathan P
Douglas, John
Di Alessandro, Carola
et al.

Publication Date
2012-09-24

Copyright Information
This work is made available under the terms of a Creative Commons Attribution License, availalbe at https://creativecommons.org/licenses/by/4.0/

eScholarship.org Powered by the California Digital Library
University of California

Selection of a Global Set of GMPEs for the GEM-PEER Global GMPEs Project

J.P. Stewart
University of California, Los Angeles, USA

J. Douglas
BRGM, Orleans, France

C. Di Alessandro, Y. Bozorgnia, and N.A. Abrahamson
PEER Center, UC Berkeley, CA, USA

D. M. Boore
US Geological Survey, Menlo Park, CA, USA

K. W. Campbell
EQECAT, Beaverton, OR, USA

E. Delavaud
ETH, Zurich, Switzerland

M. Erdik
KOERI, Istanbul, Turkey

P. J. Stafford
Imperial College London, United Kingdom

SUMMARY:
Ground-motion prediction equations (GMPEs) relate a ground-motion parameter (e.g. peak ground acceleration) to a set of explanatory variables describing the source, wave propagation path and site conditions. In the past five decades many hundreds of GMPEs for the prediction of PGA and linear elastic response spectral ordinates have been published. An accompanying paper discusses the pre-selection of GMPEs undertaken within the framework of the Global Earthquake Model (GEM) Global GMPEs project, coordinated by the Pacific Earthquake Engineering Research Center (PEER). Here, we discuss the following step undertaken to reduce the long list of pre-selected models down to a more manageable number for global hazard assessments. The procedure followed, consisting of an examination of the multi-dimensional (e.g. magnitude, distance and structural period) predicted ground-motion space in various ways and published quantitative tests of the GMPEs against observational data not used for their derivation, is discussed and illustrated for subduction zones.

Keywords: ground motion prediction equations, attenuation relations, Global Earthquake Model, seismic hazard assessment, tectonic regionalization.

1. INTRODUCTION

Ground-motion prediction equations (GMPEs) relate a ground-motion parameter (e.g. peak ground acceleration, PGA) to a set of explanatory variables describing the source, wave propagation path and site conditions. These independent variables invariably include magnitude, source-to-site distance and local site conditions, and often style-of-faulting (mechanism). There have been significant efforts recently to include additional parameters to model ground motions more realistically. In the past five decades many hundreds of GMPEs for the prediction of PGA and linear elastic response spectral ordinates have been published, which are summarized in a series of public reports by the second author (e.g., Douglas, 2011). Therefore, the seismic hazard analyst is faced with the difficult task of deciding which GMPEs to use for a given project. This decision is a critical step in any hazard assessment because the resulting predicted spectra are strongly dependent on the GMPEs chosen.

This paper discusses the selection of GMPEs undertaken within the framework of the Global Earthquake Model (GEM) Global GMPEs project, coordinated by the Pacific Earthquake Engineering Research Center (PEER). The overall GEM-PEER project is described by Di Alessandro et al. (2012). The first step of the GMPE selection process was made by pre-selecting from all the available models the most robust GMPEs. As described by Douglas et al. (2012), this Task 2 of the GEM-PEER project led to the choice of roughly ten GMPEs for each of three major tectonic regimes (shallow crustal earthquakes in active regions; subduction zones; stable continental regions, SCRs). For applications within GEM, the list of the pre-selected GMPEs in Task 2 is too long as the final selected GMPEs will be used by GEM for seismic hazard analysis of the entire world. Therefore, for practical reasons (e.g. calculation times) the selected number of GMPEs for each tectonic environment should be in general less than that used for local and regional hazard analyses. However, it is important that epistemic uncertainty in ground motion prediction is accounted for in the Global GMPEs project by selecting a range of GMPEs that cover the center, body and range of opinion.

It should also be noted that GMPE development is a continuously evolving research area, and new and/or updated GMPEs are developed as more empirical and simulated data become available and our knowledge of ground-motion hazard expands. Thus, the set of GMPEs proposed within Task 3 should not be viewed as a very long-term recommendation and it is subject to change.

In this paper, we describe the procedure adopted in Task 3 of the GEM-PEER project to select a relatively small set of about three recommended GMPEs for each major tectonic regime. The procedure is illustrated for the example of subduction-zone GMPEs.

2. SELECTION PROCESS AND FACTORS CONSIDERED

The GEM Task 3 core working group (the paper authors) met by web conference on two occasions to discuss the selection of GMPEs for subduction zones. In addition, discussions continued by email within the working group and occasionally with GMPE developers for clarification of certain aspects of their models. The GMPEs were selected from the candidate list produced in Task 2 (provided in Douglas et al., 2012), and the desired number of GMPEs selected was three. All members of the working group were present for at least one of the meetings, and all were included on the relevant correspondence including copies of slides, meeting minutes, and instructions for providing input to the working group chairs (John Douglas and Jonathan Stewart).

In the first meeting, the working group decided on the criteria to be considered in the selection of GMPEs from the list provided in Task 2. There was agreement that relevant criteria for consideration in GMPE selection include:

1. Giving more emphasis to GMPEs derived from international data sets than from local data sets. Exceptions can be made when a GMPE derived from a local data set has been checked internationally and found to perform well.
2. Giving more emphasis to GMPEs that have attributes of their functional form that we consider desirable, including saturation with magnitude, magnitude dependent distance scaling and anelastic attenuation terms.
3. If we have multiple GMPEs that are well constrained by data but exhibit different trends, it is desirable to capture those trends in the selected GMPEs to properly represent epistemic uncertainty.

In the selection process, we decided not to down-weight GMPEs with difficult to implement parameters (e.g., basin depth terms or depth to top of rupture), because those issues can be overcome with appropriate parameter selection protocols (e.g., Kaklamanos et al., 2011). We also decided not to down weight GMPEs that either lack site terms or whose modelling of site response is non-optimal (e.g., lack of nonlinearity) because GMPEs can be evaluated for a reference rock site condition in hazard analysis and site effects subsequently added in a hybrid process (Cramer, 2003; Goulet and Stewart 2009).

To assist the working group members in making their selections according to the criteria above, two major compilations of information were prepared before the web conferences. First, so-called trellis plots were formulated that show spectral shapes for various magnitude and distance combinations, magnitude-scaling trends for different distance bins, distance-scaling trends for different magnitude bins, site effect terms, hypocentral depth-scaling terms, and standard deviation terms. Second, information from the literature was compiled on GMPE-data comparisons, giving emphasis to those studies that undertake formal analysis of residuals to provide insight into GMPE performance. These two data compilations are described further for the example of subduction zones in Sections 3 and 4 of the paper.

Individual members of the working group provided their recommendations for GMPE selection either orally as part of an open discussion and/or in written correspondence to the group facilitator (C. Di Alessandro). The working group chairs reviewed the input received, including their own, and made recommendations.

3. COMPARATIVE GMPE SCALING (TRELLIS PLOTS)

All of the GMPEs pre-selected in Task 2 (Douglas et al., 2012) were programmed within Matlab. The predicted median ground motions and their aleatory variability from these implementations were checked against the graphs in the original references and against the results from previous implementations in other languages. As a standardized way of comparing the behavior of the GMPEs over the entire magnitude-distance (and other independent variables, e.g. site classification) range of interest to GEM, many trellis charts were drawn for the programmed GMPEs. These charts seek to display the multi-dimensional (magnitude, source-to-site distance, structural period etc.) predicted ground-motion space in various ways to understand the considered ground-motion models better. The aim is to help identify outliers with clearly nonphysical behavior but also to help guide the selection of models to capture the true epistemic uncertainty (e.g. the decay rate appears to be regionally dependent so it is important that this variation is captured).

The first type of these graphs (Figure 1) show predicted response spectra (color/line style coded for each GMPE) where each graph within the trellis has an x-axis of period and a y-axis of pseudo-spectral acceleration (PSA). The trellis has a super x- and y-axis of magnitude and distance, respectively and each graph within the trellis has its own axes with a common scale. This type of chart allows the experts to see how the spectrum predicted by each GMPE compares to the others over the magnitude-distance range of interest, e.g. are there any models that are consistently high or low or any with a different spectral shape? Because of the requirements imposed by the planned application of the GMPEs within GEM at the physical extremes of magnitude and source-to-site distance, the GMPEs were evaluated from the smallest magnitude considered of importance within the seismotectonic regime of interest (often M_w 5) up to close to the largest magnitude that we feel possible in each of the different seismotectonic regimes and to the closest and farthest distance thought important on a global scale. Dotted lines are used for predictions for magnitudes and distances outside the limits of applicability stated by the GMPE developers or the range of data used for their derivation. However, since the goal of the GEM Global GMPEs project is to propose ground-motion models that work over all ranges of interest to GEM even the dotted lines were inspected by the experts. The idea is to thoroughly examine the models even outside their ‘comfort zone’ (Bommer et al., 2010).

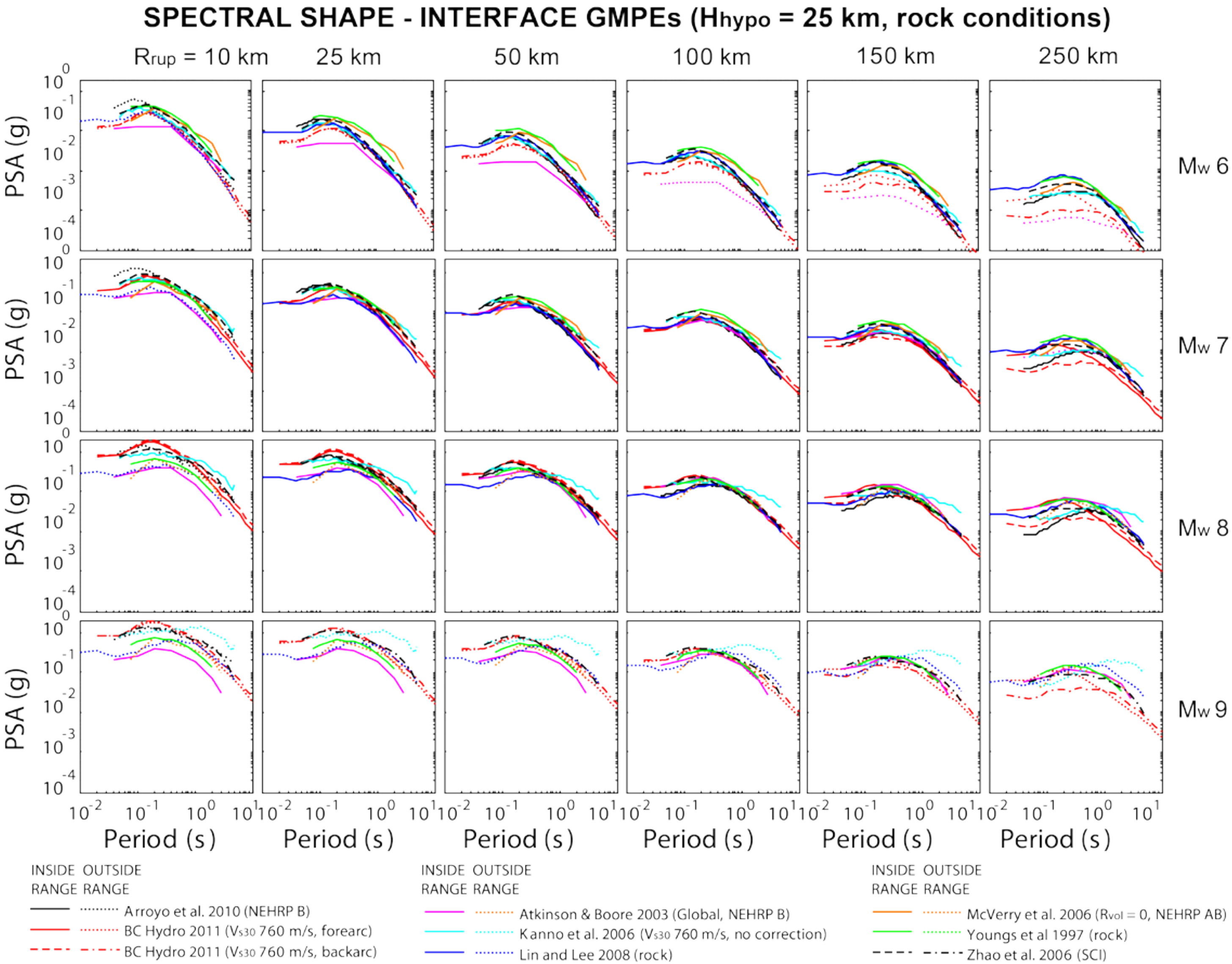

Figure 1. Trellis chart showing predicted PSAs for pre-selected subduction GMPEs for various interface earthquake scenarios for rock site conditions. Dashed lines indicated where the scenario falls outside the magnitude-distance range of validity of the model.

The second type of graph plotted within trellis charts (Figure 2) are plots of predicted PSA against magnitude within a trellis chart with super x- and y-axes of period and source-to-site distance, respectively. This directly shows the magnitude scaling of ground motions. There are theoretical reasons why magnitude scaling is nonlinear and numerous observational studies have provided evidence for it, which is particularly important when magnitude is pushed very high (M_w>8). The third set of trellis charts (Figure 3) are similar to the previous type but show scaling with distance for different magnitudes and periods. These plots show the decay rate for the various models, which can vary, for example, because of different anelastic attenuation representing variable crustal structures.

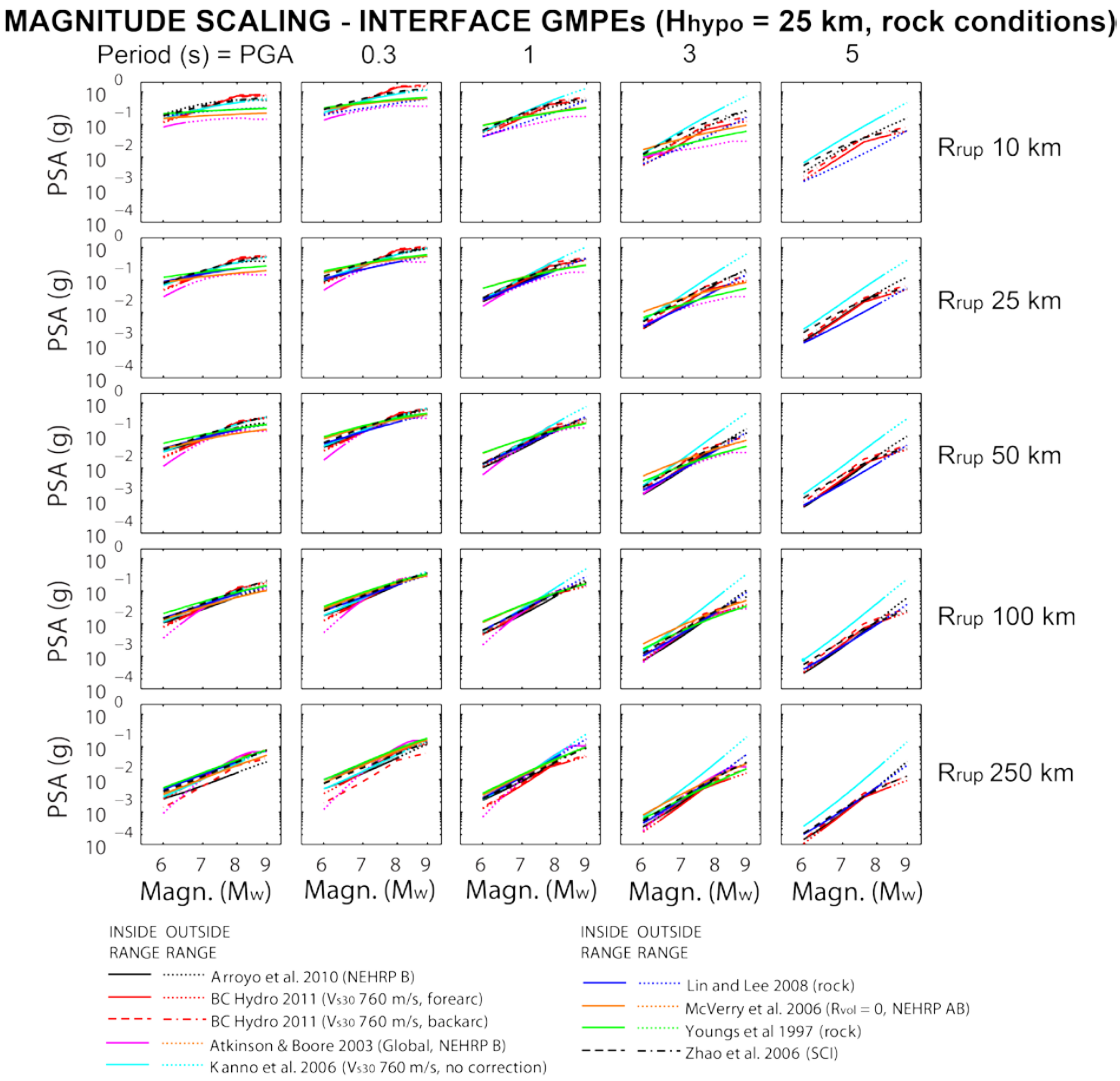

Figure 2. Trellis chart showing magnitude-scaling of predicted PSAs for pre-selected subduction GMPEs for various structural periods and source-to-site distances for rock site conditions. Dashed lines indicated where the scenario falls outside the magnitude-distance range of validity of the model.

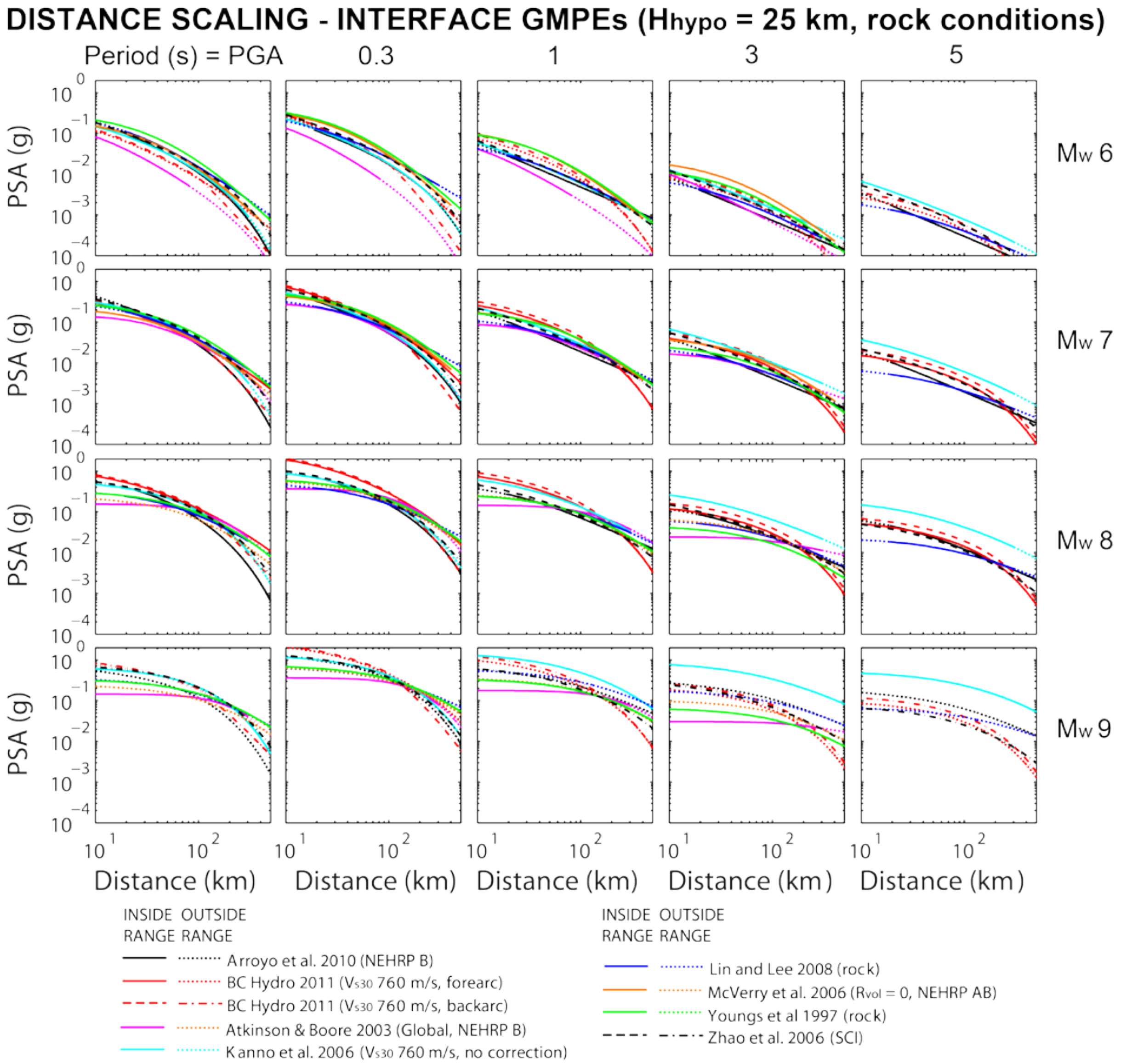

Figure 3. Trellis chart showing decay of predicted PSAs for pre-selected subduction GMPEs for various structural periods and magnitudes for rock site conditions. Dashed lines indicated where the scenario falls outside the magnitude-distance range of validity of the model.

Specifically for intraslab subduction earthquakes, the fourth type of chart shows the scaling with focal depth within a trellis chart of super axes of period and magnitude (not shown here). The final set of trellis charts (Figure 4) are similar to the first set (predicted median spectra) but show the predicted inter-event, intra-event and total aleatory variabilities (sigma) as a function of magnitude, distance and period.

Examining the trellis charts for the subduction-zone GMPEs shows that the Kanno et al. (2006) model is an outlier, particularly at long periods, when evaluated for very large interface earthquakes (Figure 1) because linear magnitude-scaling is assumed (Figure 2). This suggests that this model is not a good candidate since this behavior may lead to erroneous hazard analyses for locations where very large events are possible. In addition, the sigmas associated with this model are higher than other models (Figure 4) suggesting that the functional form is too simple to model the behavior of subduction ground motions. Predictions from the Atkinson and Boore (2003) for interface events are typically a lower bound on estimates from the other considered GMPEs (Figure 1), except at long distances from very large earthquakes where the flat decay curve leads to high predicted PSAs (Figure 3). Predictions from the other GMPEs are more grouped particularly within the rough center of the distribution of available data from subduction zones (M_w 6 to 7 and R from 50 to 150km) (Figure 1). The different GMPEs predict magnitude-dependent distance decay and nonlinear magnitude-scaling for M_w >7.5 (Figures 2 and 3).

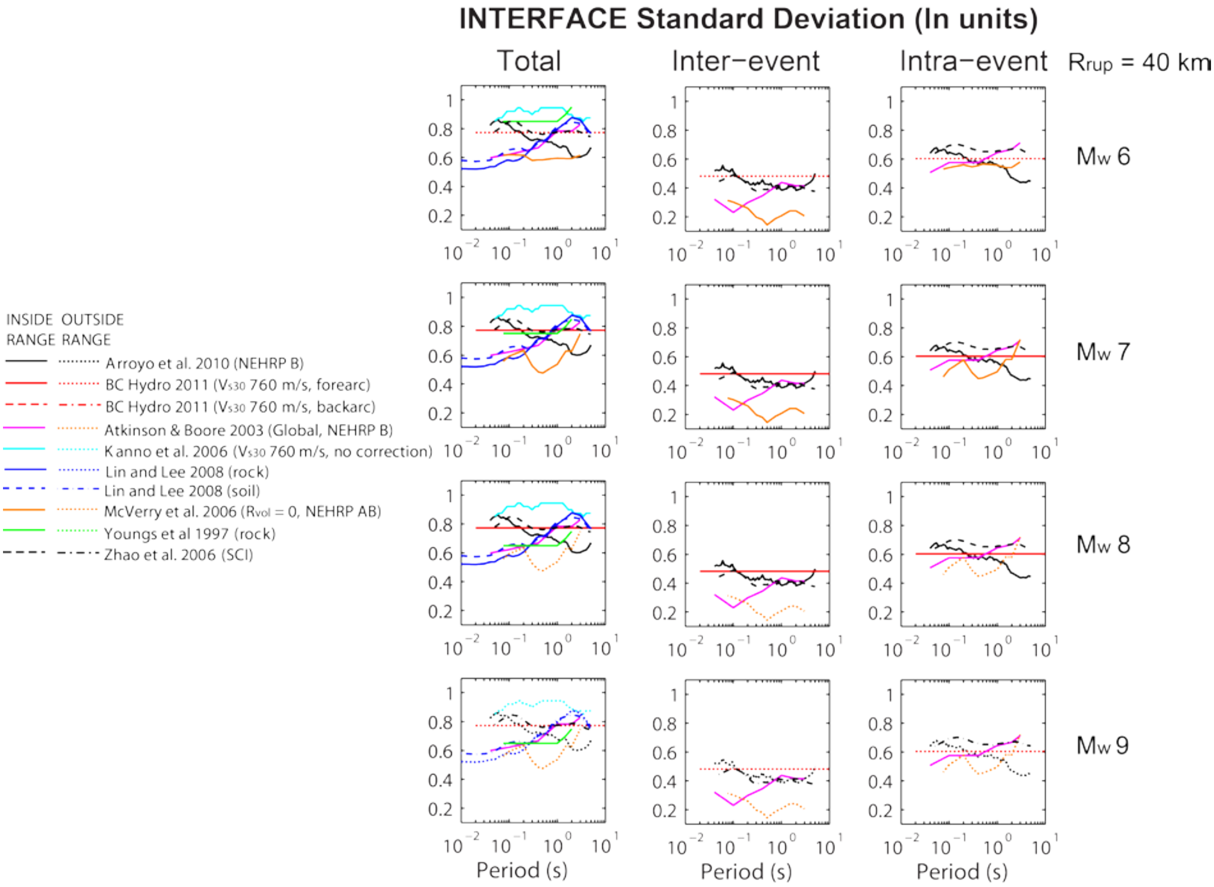

Figure 4. Trellis chart showing inter- (between) and intra-(within) event and total natural log standard deviations of the pre-selected GMPEs for various interface earthquake scenarios.

4. GMPE-DATA COMPARISONS

In most cases, GMPEs are developed from the regression of strong motion data, so model-data comparisons are integral to the process by which they are prepared. Nonetheless, GMPE-data comparisons were considered a critical component of the selection process. GMPEs derived for SCRs are generally based on ground-motion simulations and, therefore, model-data comparisons are even more important for these equations. The value of these comparisons is often derived from the comparison data set being beyond the parameter space considered for the original GMPE. For example, the data may be derived from a different region from that used in the original model development, which can be useful for studies of model applicability to the data region and regional variations of ground motions generally. Another significant example specific to subduction zones is the recent availability of data sets from large-magnitude earthquakes (M_w 8.8 Maule Chile and M_w 9.0 Tohoku Japan) well beyond the upper bound magnitudes available during GMPE development.

Most GMPE-data comparisons in the literature consist of plots of ground motion intensity measures versus distance along with GMPE median trend curves. Plots of this type have limited applicability for formal analysis of GMPE performance because it can be difficult to judge trends when the data span a very wide range on the y-axis and because event-specific bias (event terms) are seldom taken into account. Accordingly, we generally restrict our literature compilation to studies that include a formal analysis of residuals into the GMPE-data comparisons.

The two general methods of residual analyses performed are: (1) the maximum likelihood approach of Scherbaum et al. (2004) and its extension to normalized intra- and inter-event residuals distributions by Stafford et al. (2008), which are intended to judge the overall fit of model to data; and (2) analysis of intra- and inter-event residuals specifically targeted to investigations of GMPE scaling with respect to magnitude, distance, and site parameters (Scasserra et al., 2009). Results of the latter approach applied to the Maule (Chile) and Tohoku (Japan) data (Boroschek et al, 2012; Stewart et al., 2012) were particularly useful in identifying different distance attenuation trends from these large events. In the case of the Maule Chile data, the relatively slow distance attenuation of the Atkinson and Boore (2003) model provided a good fit to the data; whereas the Tohoku data attenuated relatively fast with distance and was better matched by the model of Zhao et al. (2006).

5. CONCLUSIONS

In this brief article we have presented the method used to select the final set of ground-motion models to be proposed by the GEM-PEER Global GMPEs Project, using the subduction-zone GMPEs as an illustrative example. The Task 3 core working croup (the authors of this paper) came up with consensus selections based on the types of criteria and information shown above and following intense discussion for the three main tectonic regimes (shallow crustal seismicity in active regions, stable continental regions and subduction zones). Our reasons for proposing each GMPE, and why others were not selected, were detailed in written documents and presentations, along with the material that led to our decisions. At the Global GMPEs plenary meeting in Istanbul on 17th to 18th May 2012, to which all experts of the project were invited, these arguments for each choice were carefully presented and the experts' feedback sought during the second day of the meeting, which focussed on this key step of the project. The wider Task 3 group consists of roughly 30 experts with worldwide experience of ground-motion modelling from dozens of countries. Based on the feedback from these experts final sets of GMPEs for the different regimes were defined and proposed to GEM, for use in their hazard assessments. The interested reader is referred to the final reports of the Global GMPEs Project for details of our recommendations.

ACKNOWLEDGMENTS

This study was funded by the GEM Foundation as part of the Pacific Earthquake Engineering Research Center's (PEER's) Global GMPEs project. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect those of the sponsoring agencies.

REFERENCES

Abrahamson, N., Gregor, N., Addo, K. (2012). BCHydro ground motion prediction equations for subduction earthquakes, *Earthquake Spectra*, submitted.

Arroyo, D., García, D., Ordaz, M., Mora, M.A., Singh, S.K. (2010). Strong ground-motion relations for Mexican interplate earthquakes, *Journal of Seismology*, **14:4**, 769–785.

Atkinson, G. M., Boore, D. M. (2003). Empirical ground-motion relations for subduction zone earthquakes and their application to Cascadia and other regions, *Bulletin of the Seismological Society of America*, **93:4**, 1703–1729.

Bommer, J.J., Douglas, J., Scherbaum, F., Cotton, F., Bungum, H., Fäh, D. (2010). On the selection of ground-motion prediction equations for seismic hazard analysis, *Seismological Research Letters*, **81:5**, 783-793.

Boroschek, R., Contreras, V., Kwak, D.Y., Stewart, J.P. (2012). Strong Ground Motion Attributes of the 2010 M_w 8.8 Maule Chile Earthquake, *Earthquake Spectra*, accepted.

Cramer, C. H., 2003. Site specific seismic hazard analysis that is completely probabilistic, *Bulletin of the Seismological Society of America*, **93**, 1841–1846.

Di Alessandro, C., Bozorgnia, Y., Abrahamson, N.A., Akkar, S., and Erdik M. (2012). GEM - PEER Global Ground Motion Prediction Equations Project: An Overview, *Proceedings of the Fifteenth World Conference on Earthquake Engineering*, Lisbon, Portugal.

Douglas, J. (2011). Ground motion prediction equations 1964-2010, *Rpt PEER 2011/102*, Pacific Earthquake

Engineering Research Center, UC Berkeley, April.
Douglas J., Cotton, F., Di Alessandro, C., Boore, D.M., Abrahamson, N.A., and Akkar, S. (2012). Compilation and critical review of GMPEs for the GEM-PEER global GMPEs project, *Proceedings of the Fifteenth World Conference on Earthquake Engineering*, Lisbon, Portugal.
Garcia, D., Singh, S.K., Herraiz, M., Ordaz, M., Pacheco J.F. (2005). Inslab earthquakes of central Mexico: Peak ground-motion parameters and response spectra, *Bulletin of the Seismological Society of America*, **95:6**, 2272–2282, doi: 10.1785/0120050072.
Goulet, C.A., Stewart, J.P. (2009). Pitfalls of deterministic application of nonlinear site factors in probabilistic assessment of ground motions, *Earthquake Spectra*, **25:3**, 541-555.
Kanno, T., Narita, A., Morikawa, N., Fujiwara, H., Fukushima, Y. (2006). A new attenuation relation for strong ground motion in Japan based on recorded data, *Bulletin of the Seismological Society of America*, **96:3**, 879–897, doi: 10.1785/0120050138.
Kaklamanos, J., Baise, L.G., Boore, D.M. (2011). Estimating unknown input parameters when implementing the NGA ground-motion prediction equations in engineering practice, *Earthquake Spectra* **27**, 1219-1235.
Lin, P.-S., Lee, C.-T. (2008). Ground-motion attenuation relationships for subduction-zone earthquakes in northeastern Taiwan, *Bulletin of the Seismological Society of America*, **98:1**, 220–240, doi:10.1785/0120060002.
McVerry, G.H., Zhao, J.X., Abrahamson, N.A., Somerville, P.G. (2006). New Zealand acceleration response spectrum attenuation relations for crustal and subduction zone earthquakes, *Bulletin of the New Zealand Society for Earthquake Engineering*, **39:4**, 1–58.
Scasserra G., Stewart, J.P., Kayen, R.E. and Lanzo, G. (2009). Database for earthquake strong motion studies in Italy. *J. Earthquake Eng.*, **13:6**,852–881.
Scherbaum, F., Cotton, F., Smit, P. (2004). On the use of response spectral reference data for the selection and ranking of ground motion models for seismic hazard analysis in regions of moderate seismicity: The case of rock motion, *Bulletin of the Seismological Society of America* **94:6**, 2164-2185.
Stafford, P.J., Strasser, F.O., Bommer, J.J. (2008). An evaluation of the applicability of the NGA models to ground motion prediction in the Euro-Mediterranean region, *Bulletin of. Earthquake Engineering* **6**, 149-177.
Stewart, J.P., Midorikawa, S., Graves, R.W., Khodaverdi, K., Miura, H., Bozorgnia, Y., Campbell, K.W. (2012). Implications of M_w 9.0 Tohoku-oki Japan earthquake for ground motion scaling with source, path, and site parameters, *Earthquake Spectra*. Submitted.
Youngs, R.R., Chiou, S.-J. Silva, W.J., Humphrey, J.R. (1997). Strong ground motion attenuation relationships for subduction zone earthquakes, *Seismological Research Letters*, **68:1**, 58–73.
Zhao, J.X., Zhang, J., Asano, A., Ohno, Y., Oouchi, T., Takahashi, T., Ogawa, H., Irikura, K., Thio, H.K., Somerville, P.G., Fukushima, Y., Fukushima, Y. (2006) Attenuation relations of strong ground motion in Japan using site classification based on predominant period, *Bulletin of the Seismological Society of America*, **96:3**, 898–913, doi: 10.1785/0120050122.