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A DATABASE OF EASTERN NORTH AMERICA GROUND MOTIONS FOR THE NEXT GENERATION ATTENUATION EAST PROJECT

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ABSTRACT

A five-year Next Generation Attenuation (NGA) East project to develop new ground motion prediction equations for stable continental regions (SCRs), including eastern North America (ENA), has begun at the Pacific Earthquake Engineering Research (PEER) Center funded by the Nuclear Regulatory Commission (NRC), the U.S. Geological Survey (USGS), the Electric Power Research Institute (EPRI), and the Department of Energy (DOE). As part of a pre-project effort, the NRC has funded the initial development of an ENA database of ground motions similar to the NGA active-tectonic-regions strong-motion database. This initial effort focused on database design and collection of appropriate M≥4 ENA broadband and accelerograph records to populate the database. Ongoing work will focus on adding records from smaller ENA earthquakes and from other SCRs such as Europe, Australia, and India. Currently, horizontal and vertical component records from 26 ENA M≥4 earthquakes from 2000 on have been collected and prepared (instrument response removed, filtering to acceptable-signal band, determining peak and spectral parameter values, quality assurance, etc.) for the database, including the April 18, 2008 M5.2 Mt. Carmel, Illinois mainshock and three M4 aftershocks. Geologic Survey of Canada (GSC) strong motion recordings, previously not available, will also be added as they become available. The additional earthquakes increase the number of ground motion recordings in the 10 – 100 km range, particularly from the Mt. Carmel events and the 2005 M5.0 Riviere du Loup, Quebec, Canada earthquake. Records from soil sites (Vs30 < 1500 m/s) are also being added to the database, which are needed for developing a Vs30 term in NGA East ground motion prediction equations (gmpes). Available source (location, magnitude, focal mechanism, etc.) and site (geology, Vs profile, Vs30, etc.) information is being gathered as part of this effort and included in the ground motion database. The goal is to complete the ENA database and make it available in 2011 followed by an SCR database in 2012. Comparisons of ground motion observations from three recent M5 ENA earthquakes with current gmpes suggest that current gmpes reasonably match M5 observations at short periods, particularly at distances less than 200 km. However, at one second period, current gmpes over predict M5 ground motion observations.

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Introduction

The goal of the Next Generation Attenuation (NGA) East ground motion database effort is to collect and uniformly process available stable continental region (SCR) ground motion data recorded on various site conditions (not just hard rock) for use in developing new SCR ground motion prediction equations. Collecting ground motion information out to 10 s, if possible, on both horizontal and vertical components is a target of this effort. Eastern North America (ENA) ground motion data is an important component of the SCR dataset. Consequently, the Nuclear Regulatory Commission (NRC) funded a two year pre-project effort to initiate the development of an ENA database of ground motions, including data processing protocols and data gathering for $M \geq 4$ ENA earthquakes starting in 2000 (Cramer, 2008; Cramer et al., 2009). As a result, broadband and accelerograph waveforms from 26 ENA $M \geq 4$ earthquakes since 2000 have been collected and processed, and available source and site information gathered.

The NGA East project began in the second half of 2009 at the Pacific Earthquake Engineering Research (PEER) Center. The NGA East project is funded by the NRC, the U.S. Geological Survey (USGS), the Electric Power Research Institute (EPRI), and the Department of Energy (DOE). The ground-motion-database working group of the NGA East project is focusing on the collection and processing of (1) additional ENA records from earthquakes in the $2.5 \leq M < 4$ range with five or more records within 100 km of the event, (2) Canadian strong motion data not previously available, (3) older important ENA records, and (4) available SCR records worldwide, including data from Australia, India, Europe, South Africa, and possibly Korea and China. The desired time line for completing this effort is by 2011 for the ENA portion of the database and by 2012 for the SCR portion of the database.

Data and Processing

Figure 1 presents the locations of the selected $M \geq 4$ earthquakes from the initial ENA data gathering effort. The 28 events shown include 22 earthquakes since 2000, 2 events from 1997 and 1999, and the mainshock and three aftershocks of the 2008 M5.2 Mt. Carmel, IL earthquake. These events are listed in Table 1. Waveforms (time-histories or time-series) and ancillary information were downloaded from the IRIS data center (mainly records from the USGS Advanced National Seismic System and the Lamont-Doherty Cooperative Seismic Network) and the Canadian national data center (CNDC). Additional data for some events was obtained from the Center for Earthquake Research and Information (CERI), St. Louis University (SLU), Virginia Institute of Technology (VT), and Weston Observatory (NESN).

Data processing has followed the protocol developed during the first year of the pre-project effort and documented in Cramer (2008). Data processing is done using the software Seismic Analysis Code (SAC) (Goldstein and Snoke, 2005; Goldstein et al., 2003). Downloaded uncorrected waveforms in SAC format are reviewed for obvious problems like clipping and missing data. Then they are instrument corrected and transformed to acceleration, velocity, and displacement time-histories using the SAC TRANSFER command. Initial filtering is done within the TRANSFER command using an acausal frequency-domain cosine-tapered filter with bandpass corners at 0.05 and 100 Hz (see Cramer, 2008 for a test on the efficacy of this filter visa via Butterworth filtering – results are essentially the same). The whole record Fourier

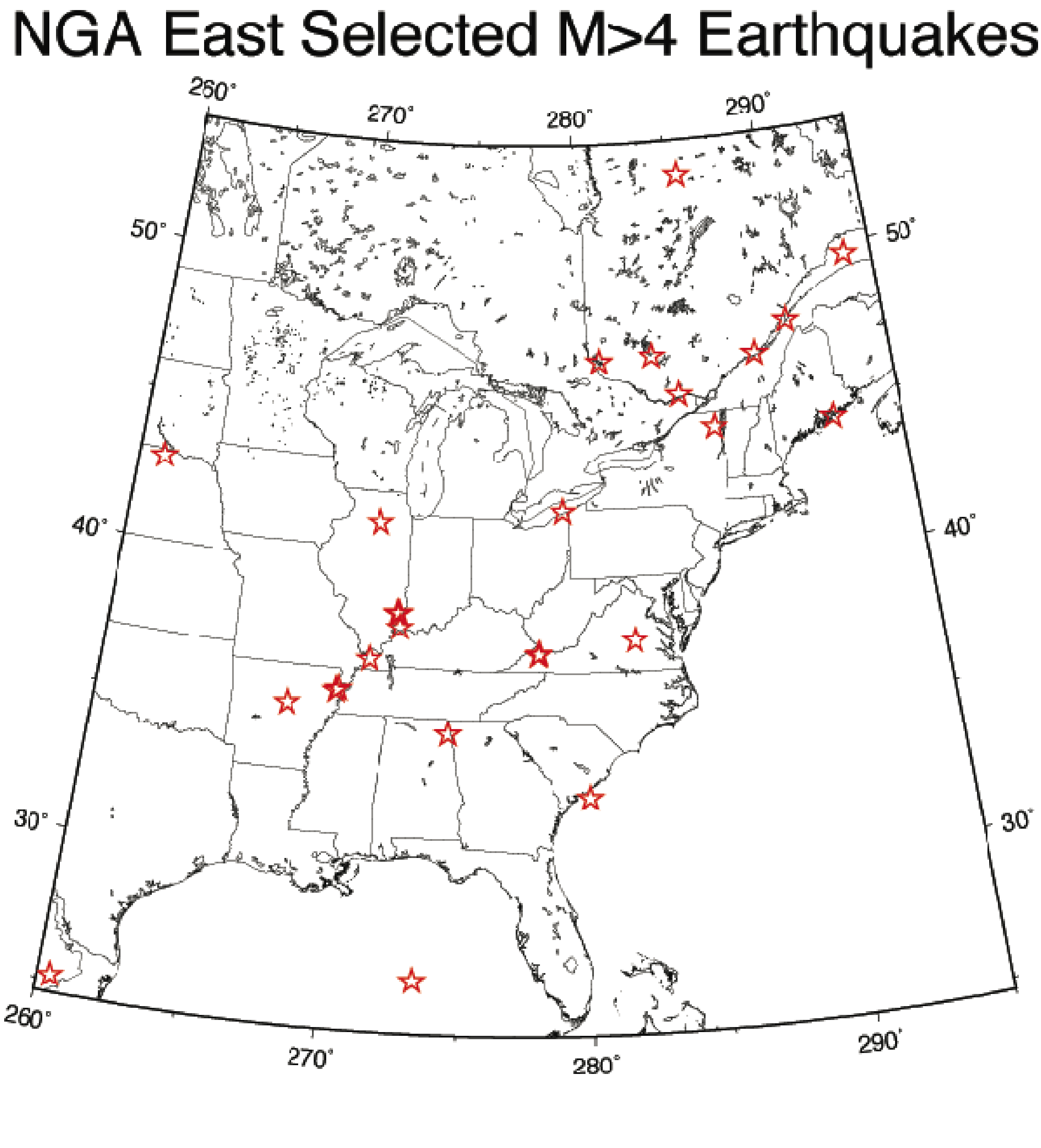

Figure 1. Location of M≥4 ENA earthquakes processed in 2009.

spectrum is compared to the pre-event noise Fourier spectrum to determine the frequency band of good signal to noise and to set the final bandpass filter corners. Final acceleration, velocity, and displacement time histories are then obtained using the SAC TRANSFER command on the original waveforms with the final filter corner frequencies. Final filtering corner frequencies are retained both in the final SAC time-history files and in a filter corner data file for each event. Data quality concerns are also recorded in a text file for each event for use in developing the final NGA East data flat file for distribution to ground motion prediction equation (gmpe) developers.

Information about source (location, magnitude, focal mechanism, etc.) and site (geology, Vs profile, Vs30, etc.) parameters for these events has been collected from available sources (Cramer et al., 2009). The available site Vs information is limited to about 20 percent of the recording stations for which seismic recordings are available, mainly in the central US, Charleston, SC, and southeast Canada regions. A separate geotechnical working group will address determining the needed site information for the NGA East project.

Table 1. List of M≥4 earthquakes in ENA between January 1, 2000 and April 25, 2008 plus two earthquakes in 1997 and 1999.

No	Date	Time	Event Name	Location	Mag	Mag Type	Lon	Lat
1	11/6/1997	2:34:33	Cap-Rouge	15 km west of Quebec City	5.1	mblg	-71.41	46.8
2	3/16/1999	12:50:48	Cote-Nord	60 km south of Sept-Iles, Quebec	4.5	Mw	-66.32	49.61
3	1/1/2000	11:22:57	Kipawa	SW corner of Quebec, 298 km NW of Ottawa	5.2	mblg	-78.930	46.888
4	1/26/2001	3:3:20	Ashtabula	NY, on Lake Erie, E of Cleveland	4.4	mblg	-80.802	41.942
5	5/4/2001	6:42:13	Enola	Arkansas, 54 km N of Little Rock	4.7	mblg	-92.194	35.205
6	4/20/2002	10:50:48	Au Sable Forks	NE NY, SW of Plattsburgh	5.2	Mw	-73.699	44.513
7	6/5/2002	20:17:37	LacLaratelle	mid-Quebec, 819 km N of Montreal	4.5	mblg	-74.410	52.890
8	6/18/2002	17:37:15	Caborn	SW corner Indiana	5.0	mblg	-87.780	37.987
9	11/3/2002	20:41:57	Boyd	N-Central Nebraska	4.3	mblg	-98.896	42.768
10	11/11/2002	23:39:30	Charleston	Atlantic, offshore Charleston, SC	4.4	mblg	-79.936	32.404
11	4/29/2003	8:59:39	Little River	NE corner Alabama	4.9	mblg	-85.629	34.494
12	6/6/2003	12:29:34	Bardwell	W end of Kentucky	4.0	Mw	-88.980	36.870
13	10/12/2003	8:26:7	Bark Lake	Quebec, 182 km NNW of Ottawa	4.5	mblg	-76.370	47.010
14	12/9/2003	20:59:14	Jefferson	W of Richmond, VA.	4.5	mblg	-77.903	37.587
15	4/6/2004	19:1:3	St Teresa	Mexico, ESE of Monterrey, MX, S of TX	4.5	Md	-99.532	25.172
16	6/28/2004	6:10:52	Prarie Cntr	N Illinois, 116km WSW of Chicago	4.2	Mw	-88.900	41.460
17	2/10/2005	14:4:54	Milligan Rdg	NE Arkansas, 71 km NNW of Memphis	4.1	Mw	-90.250	35.760
18	3/6/2005	6:17:49	Riviere du Loup	in the St. Lawrence, 154 km NE of Quebec	5.3	mblg	-69.730	47.750
19	5/1/2005	12:37:32	Shady Grove	NE Arkansas, 77 km NNW of Memphis	4.2	Mw	-90.150	35.830
20	2/25/2006	1:39:22	St-Sixte	S Ontario, 45 km NE of Ottawa	4.5	mblg	-75.230	45.660
21	9/10/2006	14:56:8	Gulf	Gulf of Mex., 423km WSW of St. Petersburg, FL.	5.8	Mw	-86.606	26.319
22	10/3/2006	0:7:38	Acadia	Near Acadia National Park, Maine	4.3	mblg	-68.145	44.345
23	11/2/2006	17:53:2	Marvin	SW Virginia	4.3	mb	-81.920	37.200
24	11/23/2006	10:42:57	Skeggs	SW Virginia	4.3	mblg	-81.975	37.157
25	4/18/2008	9:36:59	Mt Carmel	Illinois	5.2	Mw	-87.890	38.450
26	4/18/2008	15:14:17	Mt Carmel	Illinois	4.6	Mw	-87.890	38.480
27	4/21/2008	5:38:30	Mt Carmel	Illinois	4.0	Mw	-87.824	38.473
28	4/25/2008	17:31:1	Mt Carmel	Illinois	4.2	Mw	-87.870	38.450

Initial Results

This section discusses the distribution of ENA recordings as a function of magnitude and distance, the strategy for collecting needed ENA recordings within 100 km, and selected comparisons with current ENA gmpes.

Magnitude versus Distance

Figure 2 presents a plot of broadband and accelerometer ground motion observations as a function of magnitude and distance for the currently collected horizontal components. Most of the 2959 observations are from pairs of horizontal components at a recording site. A similar plot of the 1654 observations from vertical component recordings shows the same pattern as Figure 2 and hence is not shown here. Beyond 100 km from the event, there are lots of observations in the M 4-6 range. The data shown for M5.8 is from the 2006 Gulf of Mexico event, which may not have originated in SCR crust but was added for completeness so gmpe developers can decide the appropriateness of using this data. The observations from the 1988 Saguenay M5.8-6.0 earthquake (not shown in Figure 2) are also being added to the database for completeness and to give gmpe developers an option of including that ground motion dataset in their gmpe development process. The only M7 SCR earthquake with available ground motion observations is the 2001 M7.6 Bhuj, India earthquake. Bodin et al., 2004 show that the portion of western India in which the Bhuj earthquake occurred has very similar crustal attenuation properties as ENA and hence the limited observations of Cramer and Kumar, 2003 will be included as an option for gmpe developers to use.

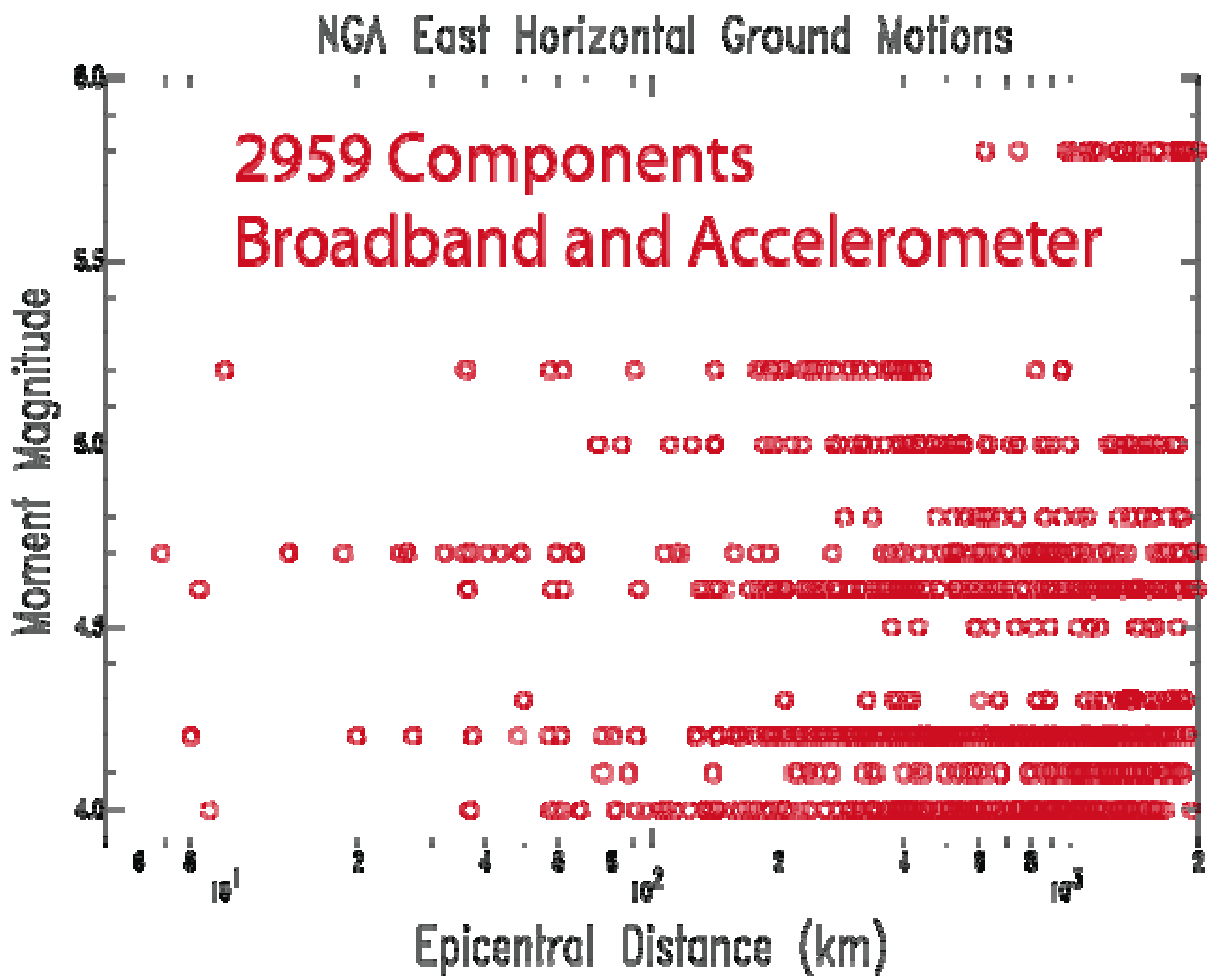

Figure 2. ENA M≥4 ground motion observations since 2000.

Observations less than 100 km

Obviously in Figure 2, there are not a lot of ground motion observations for distances less than 100 km. This is a very important distance range for gmpes. Most of the observations less than 100 km are from the 2005 Riviere du Loup, Canada M4.7 earthquake and the 2008 Mt. Carmel, IL M5.2 earthquake and its M4 aftershocks. Fortunately there were six ANSS and SLU accelerographs within 100 km of the Mt. Carmel events as the broadband data were clipped or distorted for distances less than 150 km. For the Riviere du Loup earthquake, the three broadband seismometers within 30 km of that event were clipped or near clipping but collocated accelerographs provide reliable data. The accelerometer data for the Riviere du Loup earthquake are being released as part of the GSC contribution to NGA East (John Adams, written communication) and these data are included in Figure 2.

The current strategy is to collect the available ENA data from $2.5 \leq M < 4$ earthquakes with 5 or more stations within 100 km for the period 2000-2009 to supplement the $M \geq 4$ data already collected. An initial review of candidate earthquakes that satisfy those criteria indicates there are three Charleston, SC events from 2008-2009, at least four events from the Charlevoix seismic zone in Canada, four or more events in the Ottawa area of Canada, two events in Lake Ontario, and several events, possibly up to 50, located in the New Madrid seismic zone. These events collectively should provide significant observations from distances less than 100 km and should be included in the ENA database by the end of 2010.

Comparisons with Current Gmpes

Comparisons of the observations from M5 events with current gmpes suggest good agreement at short periods and at distances less than 200 km. There is some current gmpe overestimation of ground motions at greater distances for short periods and at all distances for 1.0 s spectral acceleration (Sa). The earthquakes used in this comparison are the 2002 M5.0 Au Sable Forks, the 2005 M4.7 Riviere du Loup, and the 2008 M5.2 Mt. Carmel earthquakes.

Figure 3 presents the peak ground acceleration (PGA) observations for these three earthquakes. The current gmpes have been properly adjusted for differing distance measures, particularly at close distances, for the epicentral distance used in the plots. Additionally, the gmpes are for hard rock conditions for the plot on the left of Figure 3 because most of the stations for the 2002 and 2005 events are on hard rock, and for NEHRP B/C boundary (V_{s30} = 760 m/s) for the plot on the right of Figure 3 because most of the stations for the 2008 event are on soils. Out to 400 km for the 2002 event and 500 km for the 2005 event, the recording stations are on hard rock. Beyond those distances recording stations are on a mix of rock and soil site conditions and the scatter in the data increases, as expected. At distances less than 200 km the current gmpes are in good agreement with the observations. Beyond 200 km, the 2002 and 2005 data seem to be to the low side of the current gmpes. The Riviere du Loup is a Mw 4.7, so the current gmpe curves should be lowered by a factor of two and the observations would be more consistent with current gmpes, except at distances less than 100 km where observations would be high relative to the gmpes. For the 2008 event, the observations agree well with the current gmpes.

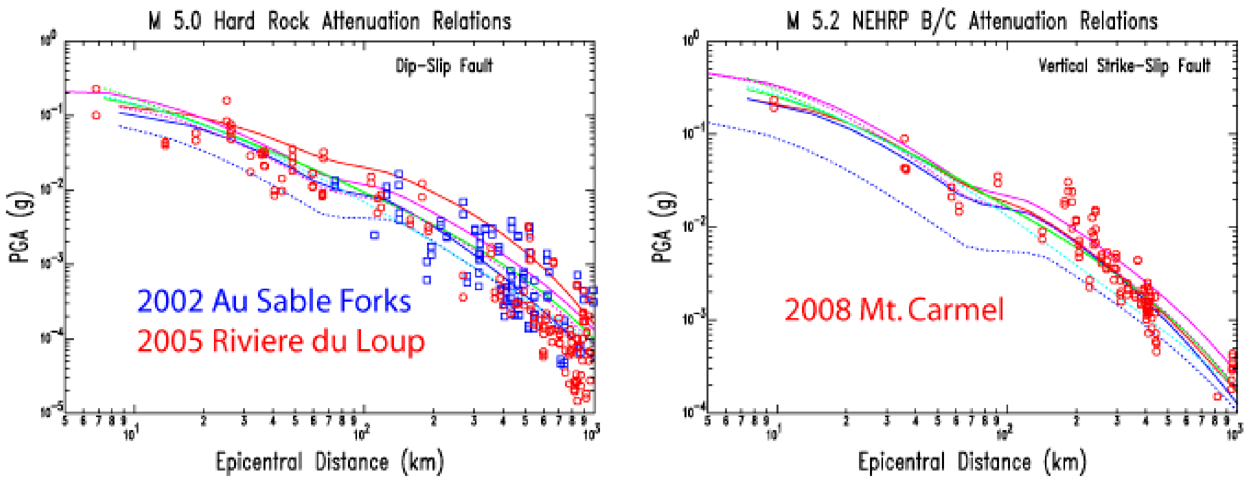

Figure 3. PGA comparisons of earthquake ground motion observations with current gmpes for ENA. The left plot shows 2002 Au Sable Forks (blue squares) and 2005 Riviere du Loup (red circles) with M5.0 ENA hard-rock gmpes. The right plot shows 2008 Mt. Carmel (red circles) with M5.2 firm-rock (NEHRP B/C boundary) gmpes.

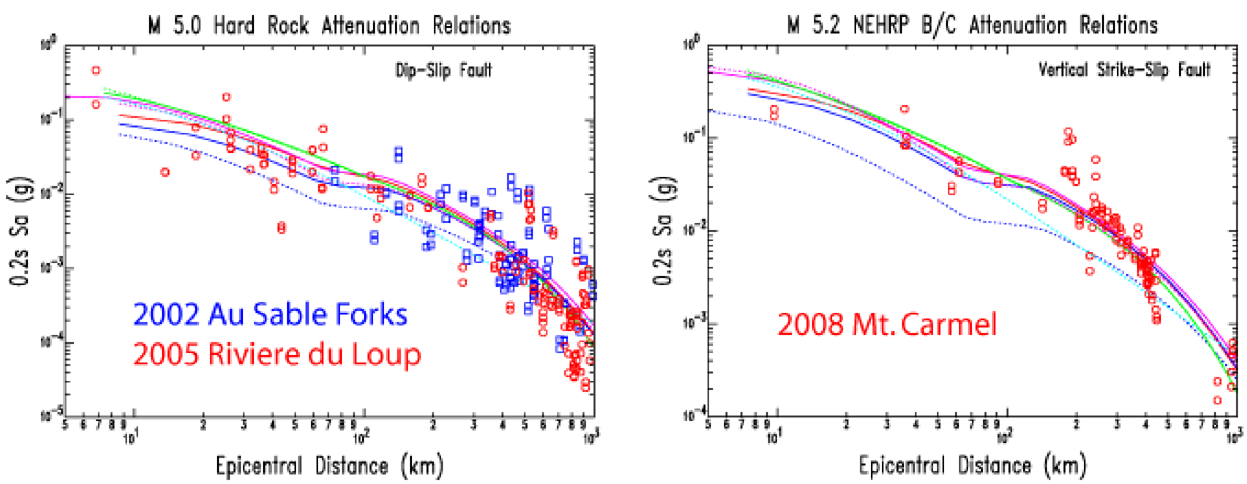

Figure 4. 0.2 s Sa comparisons of earthquake ground motion observations with current gmpes for ENA. The presentation is the same as in Figure 3.

Figure 4 presents the 0.2 s Sa observations for the three earthquakes. The presentation in Figure 4 is the same as in Figure 3. The trends and comparisons between the observations and the current ENA gmpes are very similar to those for PGA in Figure 3.

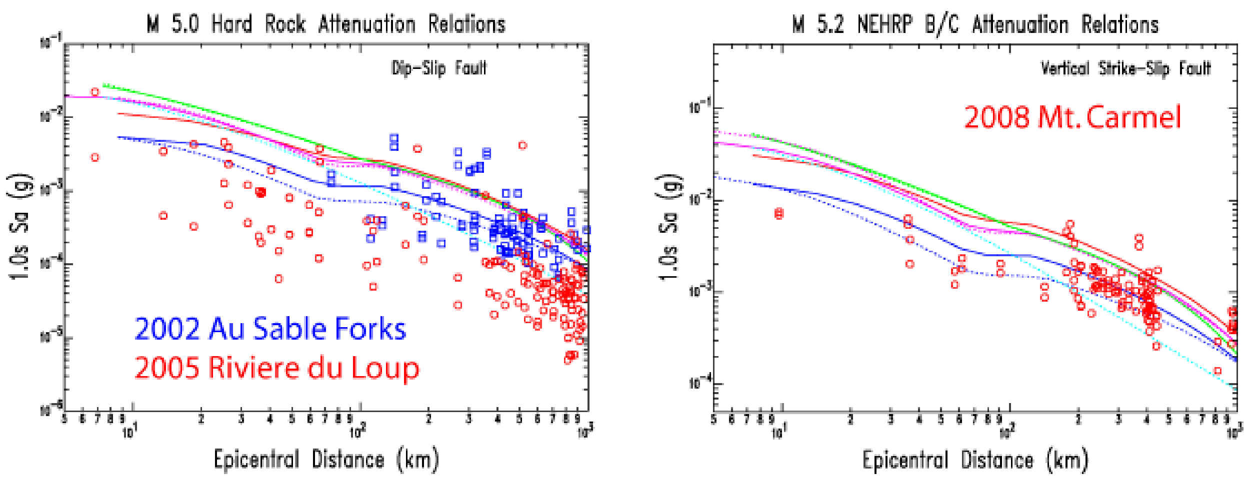

Figure 5. 1.0 s Sa comparisons of earthquake ground motion observations with current gmpes for ENA. The presentation is the same as in Figure 3.

Figure 5 presents the 1.0 s Sa observations for the three earthquakes. The presentation in Figure 5 is the same as in Figure 3. Clearly for 1.0 s Sa, the observations fall to the low side or below the current gmpes at all distances and for all site conditions. This suggests that for this period the current gmpes over predict M5 ground motions.

Completion of Database

Planned future work includes the completion of both the ENA and SCR databases and combining them into one SCR database. The ENA portion of the database will include M≥4 events and selected 2.5≤M<4 earthquakes as outlined above. Canadian strong motion waveforms will be added from the GSC as part of this project (John Adams, verbal communication) as will key older ENA earthquake records (Walt Silva, verbal communication) as these data are made available.

For the SCR portion of the database, recordings from Australia and India and possibly Europe, South Africa, Korea, and China will be incorporated. Published Australian datasets from 2004 and earlier in the 2≤M<5 range are being made available to the project (Trevor Allen, verbal communication). CERI recorded aftershocks of the 2001 Bhuj earthquake and can make that dataset of 2≤M≤5 events available. SCR records from Europe and South Africa and possibly Korea and China may also be contributed to the NGA East SCR database.

A target completion date for the ENA portion of the database is by 2011. For the SCR portion of the database, a target completion time line is by 2012, depending on the amount of data to be processed and included. An initial NGA East flat file for distribution to gmpe developers for review is scheduled for October 2010 with a final version to be made available by 2012 so the project can proceed to ENA/SCR gmpe development. Web access to the ENA/SCR waveforms is planned to be available after the completion of the SCR database.

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