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GEOLOGICAL SURVEY OF CANADA
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Canada

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Estimated seismic design values for Canadian Missions abroad: equivalents to 2015 National Building Code of Canada

J. Adams[1], D. Young[1,2], and S. Halchuk[1]

[1]Canadian Hazards Information Service, 7 Observatory Crescent, Ottawa, Ontario
[2]formerly Global Affairs Canada, 125 Sussex Drive, Ottawa, Ontario

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ABSTRACT

Seismic hazard values are estimated for 226 Canadian Missions abroad. We started with results from the GEM global seismic hazard model, supplemented by values from the literature. The available values were adapted as necessary by applying spectral shape and magnification factors to get the spectral acceleration values needed. The factors required were derived from Canadian seismic hazard results. The hazard values are intended for screening purposes to assess safety of Missions and continuity of consular services in the context of the 2015 National Building Code of Canada.

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1 INTRODUCTION

The Department of Global Affairs Canada (GAC[1]) has embassies and related outposts ("Missions") in cities around the world that may be susceptible to earthquake shaking. It wishes to consider the 2015 National Building Code of Canada (NBCC2015) provisions during future construction projects or retrofit of existing buildings in order to provide a comparable level of safety, security and function as it does in Canada. The 5th Generation seismic hazard model, which forms the basis of the design values in NBCC2015, is discussed in Adams et al. (2015).

NBCC2015 uses 5%-damped spectral acceleration ("Sa(T)") for various periods[2], T, at the 2% probability of non-exceedance in 50 years ("2%/50yr"), and it updates the NBCC2005 values that were referenced in the 2008 version of this work (Adams et al., 2008, henceforth AHA08).

The past decade has seen a dramatic increase in the number of probabilistic seismic hazard assessments (PSHAs) available, and specifically the number of Missions for which Sa(T) values at 2%/50yr are available. The Global Earthquake Model (GEM) has led a new global assessment of seismic hazard that updates and replaces the Global Seismic Hazard Assessment Program (GSHAP) of 1999. As the GEM assessment was still underway during the compilation of this report, its preliminary values have been supplemented by a literature search; together these provide the best starting point for our project.

A good context for the seismic hazard assessments in our report is given by the earthquake map of the ISC-GEM catalogue (Figure 1). While not all regions with high seismic hazard have had large earthquakes during the short, 111-year period represented, many have.

A key part of this report is a digital spreadsheet that adapts and adjusts available seismic hazard information by the methods discussed in this report, and for each Mission presents design values as used in NBCC2015. The user guide for the spreadsheet is in Section 10.

"Design values" in this report refer to the seismic hazard values equivalent to Table C-2 of NBCC2015, which lists Sa(T) and PGA for various localities in Canada. The values can be the basis of an engineering design or assessment, but must be adjusted for site conditions. Furthermore, the engineer should satisfy themselves that the quality of the estimate is appropriate for the scope of work and its consequences.

Although values from the spreadsheet and tables may be displayed to 3 decimal places, the appropriate level for use is at most 2 significant figures.

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[1] GAC is formally still known as DFATD (Department of Foreign Affairs, Trade and Development).

[2] Sa(T) at 0.2, 0.5, 1.0, 2.0, 5.0 and 10.0 second periods is used by NBCC2015 for seismic design; PGA is provided chiefly for anti-seismic geotechnical engineering.

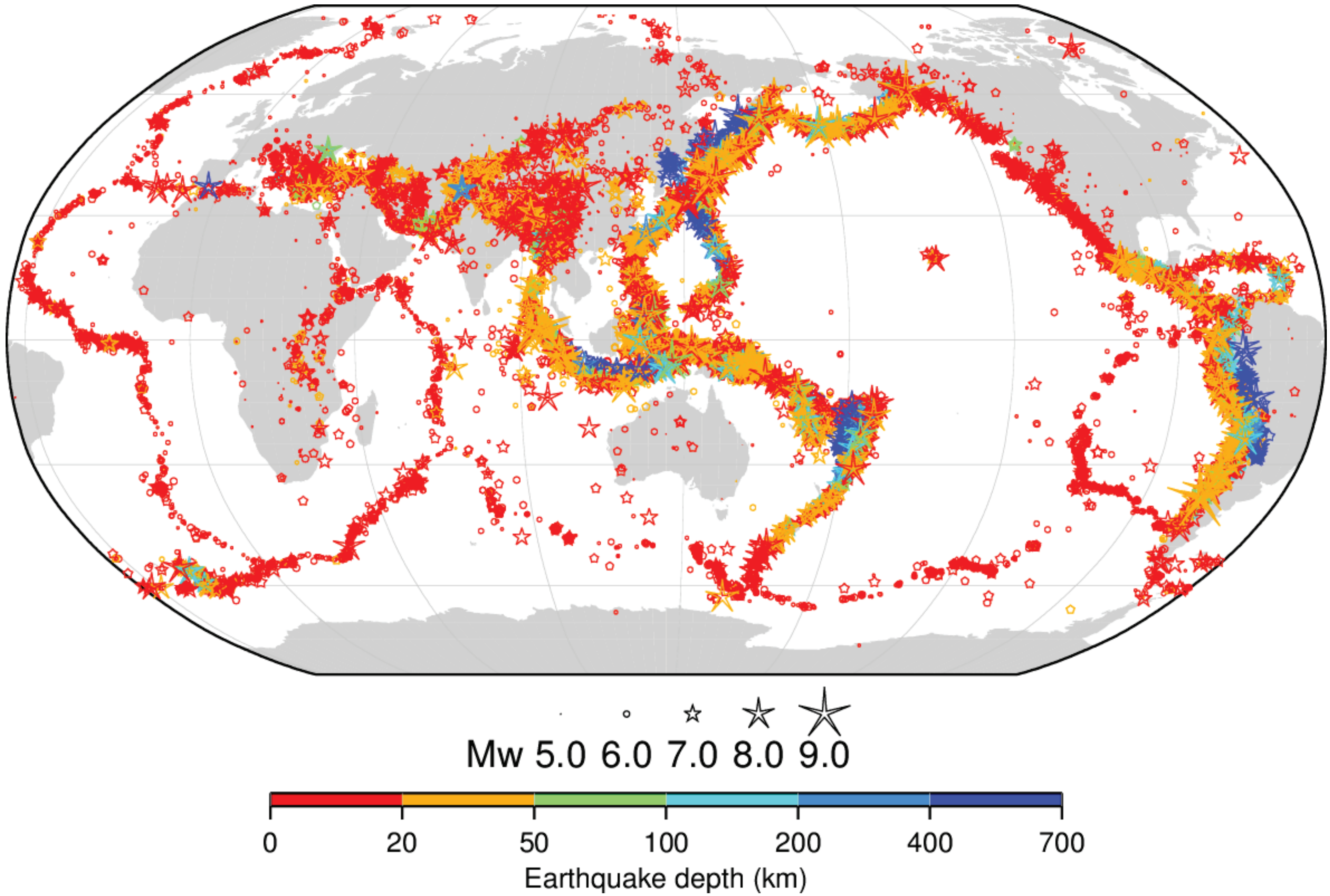

Figure 1. Map of the 1904-2015 ISC-GEM catalog, Version 6, indicating the seismicity of the world (downloaded from http://www.isc.ac.uk/iscgem/overview.php on 2019-05-03).

2 HISTORY OF PREVIOUS ASSESSMENTS FOR CANADA'S MISSIONS

2.1 June 2005 screening report

In June 2005 the Geological Survey of Canada (GSC) was asked by Public Works and Government Services Canada (PWGSC) to provide seismic hazard values to be used in screening decisions for the long-term management, upgrade or rebuilding of Canada's Missions abroad. The request was for a ranking of Missions at short and long periods. Two spreadsheets of calculations and values were provided (details are given in AHA08), providing "Adjusted PGA" and "Estimated Sa(1.0)"; they were for ranking and not design, and furthermore they reflected approximate ground motions for a probability of about 10%/50 years.

2.2 June 2007 request for design values equivalent to NBCC2005

In June 2007 the Department of Foreign Affairs and International Trade (DFAIT) approached the GSC to provide spectral design values for Canadian Missions abroad that could be used for design assessment purposes equivalent to NBCC2005. The adopted approach, replacing a failed approach also documented in AHA08, was an extension of the screening method to provide 2%/50yr PGA and Sa(T) values. The 2008 method was as follows:

1. Values for PGA were determined for each Mission from the GSHAP map.
2. Canada and U.S. values were converted to rock.
3. A manual adjustment was made to certain values, this produced an "adjusted 10%/50yr PGA" value.
4. A spectral shape category was assigned to each Mission depending on its tectonic environment.
5. Depending on the spectral shape category, the "adjusted 10%/50yr PGA" was multiplied by a spectral shape factor to give the estimated PGA and estimated Sa values at 2%/50yr.
6. Values for low hazard regions that fell below the lowest values used for seismic design in Canada were replaced by those lowest Canadian values.
7. Values for U.S. Missions were replaced by IBC values.

Our current report uses some of the same methodology.

3 CURRENT STATE OF GLOBAL KNOWLEDGE

Seismic hazard assessment across the globe is still uneven in terms of technique, though the GEM project has often applied standard methods. In countries with well-developed seismic hazard maps (and the seismic design codes that flow from them) some use the hazard at the 10% in 50 years (i.e., ~0.0021 per annum) probability level, and some still use Peak horizontal Ground Acceleration (PGA) as the measure of shaking severity. Instead, the use of spectral acceleration (Sa(T)) at the 2% in 50 years probability level is considered to provide better earthquake-resistant designs, and has been the basis for seismic design in North America since the mid-2000s (2005 National Building Code of Canada and 2006 "International" Building Code in the U.S.). Compared to 2008, many more countries now have seismic hazard maps that give shaking in terms of spectral acceleration at the probability level of 2% in 50 years (i.e., 0.000404 per annum).

3.1 GSHAP (1999)

The previous world-wide project was the 1992-1999 Global Seismic Hazard Assessment Program (GSHAP). This enormous project used local, national and regional experts to produce a 10%/50 year PGA map, and was published in 1999 (Giardini et al., 1999). Documentation, the map, and the numerical values are still available on the web at https://www.gfz-potsdam.de/en/GSHAP/. Other than proprietary maps created mostly within the insurance/reinsurance industry, GSHAP provided the only global map of seismic hazard for nearly two decades. The greatest strength of the GSHAP process was the use of local and regional experts with their access to the best local earthquake catalogs and local information on the causes and rates of earthquakes. The greatest weakness was the same – the local and regional experts produced different estimates of the hazard for adjacent regions. Furthermore, there were inconsistencies in assembling the global map. For example, the seismic hazard for Canada and the U.S. was derived from mature national models, simply blended at the border, but their reference ground condition differed from the rest of the world. GSHAP's deficiencies, listed in AHA08, should not diminish the tremendous advance that the GSHAP project achieved in harnessing experts to produce the 1999 map.

3.2 Global Earthquake Model (2009-2020 onwards)

The GEM foundation (www.globalquakemodel.org) was initiated by the OECD's Global Science Forum in 2009 as a non-profit organization whose goal is to become one of the world's most complete sources of risk resources and a globally-accepted standard for seismic risk assessment. Towards this end, GEM has developed the OpenQuake (OQ) hazard and risk calculation engines. OQ is free, open-source software that has been collaboratively developed and tested. NRCan has adopted the OQ engine to determine hazard for the NRCan's 6th Generation seismic hazard model, intended for use in the 2020 edition of the NBCC. GEM has implemented more than 30 models, developed with regional, national and local collaborators, to form a global collection known as a mosaic (Pagani et al., 2020). GEM's global assignment of models is displayed in Figure 2. Not all models were available at the time this report was completed, and some Missions (for example island countries) lie outside the regional models. Although GEM has attempted to blend the mosaic model's results across model borders, we still saw some discontinuities attributed to its assembly from regional subsets (e.g. near Panama).

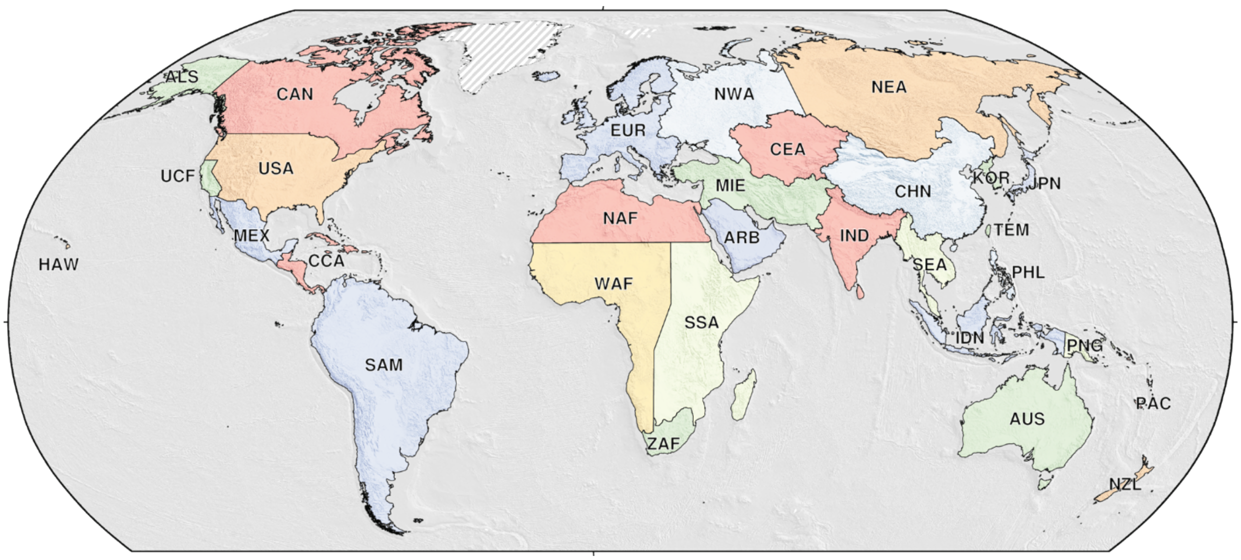

Figure 2. Regionalization of the globe for GEM's seismic hazard mosaic. Letter abbreviations are not necessarily consistent with those used in the spreadsheet. Downloaded from https://www.globalquakemodel.org/hazard-model-documentation on 2019-05-03. A similar map appears as Figure 1 of Pagani et al. (2020).

A key strength of the GEM approach is that it uses the improved ISC-GEM catalog (111 years), tectonic input from the long-term (thousands of years) displacement on active faults such as the ones shown in Figure 3 for northwestern South America, and short-term (decades) global deformation rates derived from GPS monitoring. The fault and GPS parts of the models complement the activity represented by the last century's earthquakes (Figure 1).

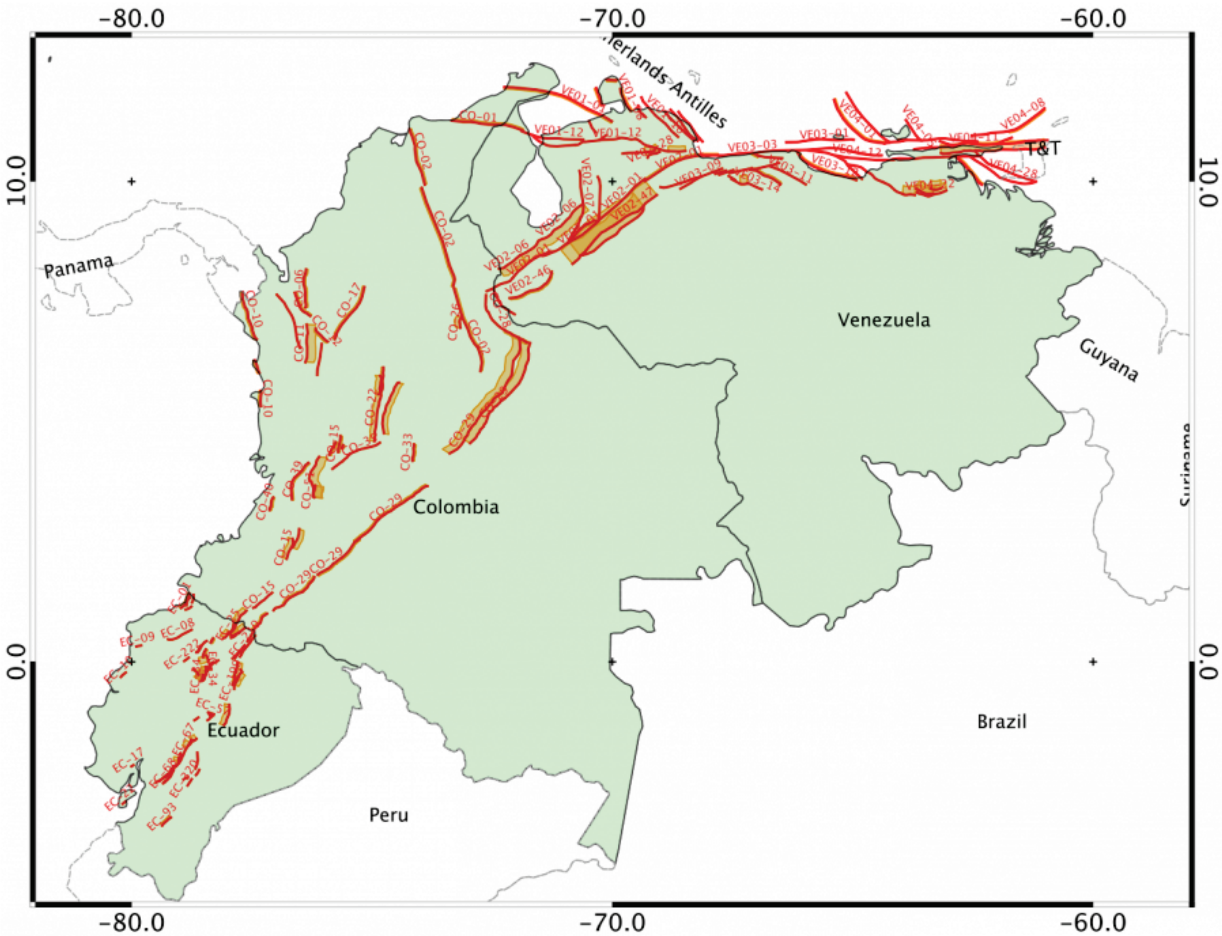

Figure 3. Map of northwestern South America showing the active faults considered in the model. Downloaded from **https://sara.openquake.org/hazard_rt2** on 2019-05-03.

The GEM global hazard map (for PGA at 10%/50yr probability and on B/C site class[3] with Vs30 760 or 800 m/s) was released in December 2018 (https://www.globalquakemodel.org/gem). A low-resolution image of the GEM map is given as Figure 4.

A comparison back to the GSHAP map (Figure 5) shows in a general way the changes in estimated hazard that will be reflected in our current report, when considered relative to AHA08. On Figure 5, when the identified change is coloured:

- Green – both models are above or below the 0.1 g level
- Red – GEM2018 is giving higher values than GSHAP1999 (e.g. southern India)
- Blue - GEM2018 is giving lower values than GSHAP1999 (e.g. Australia)

[3] Where site class is used as in NBCC2015 it is capitalized thus: “Site Class”. The B/C site class represents hazard at the boundary between Site Class B and Site Class C.

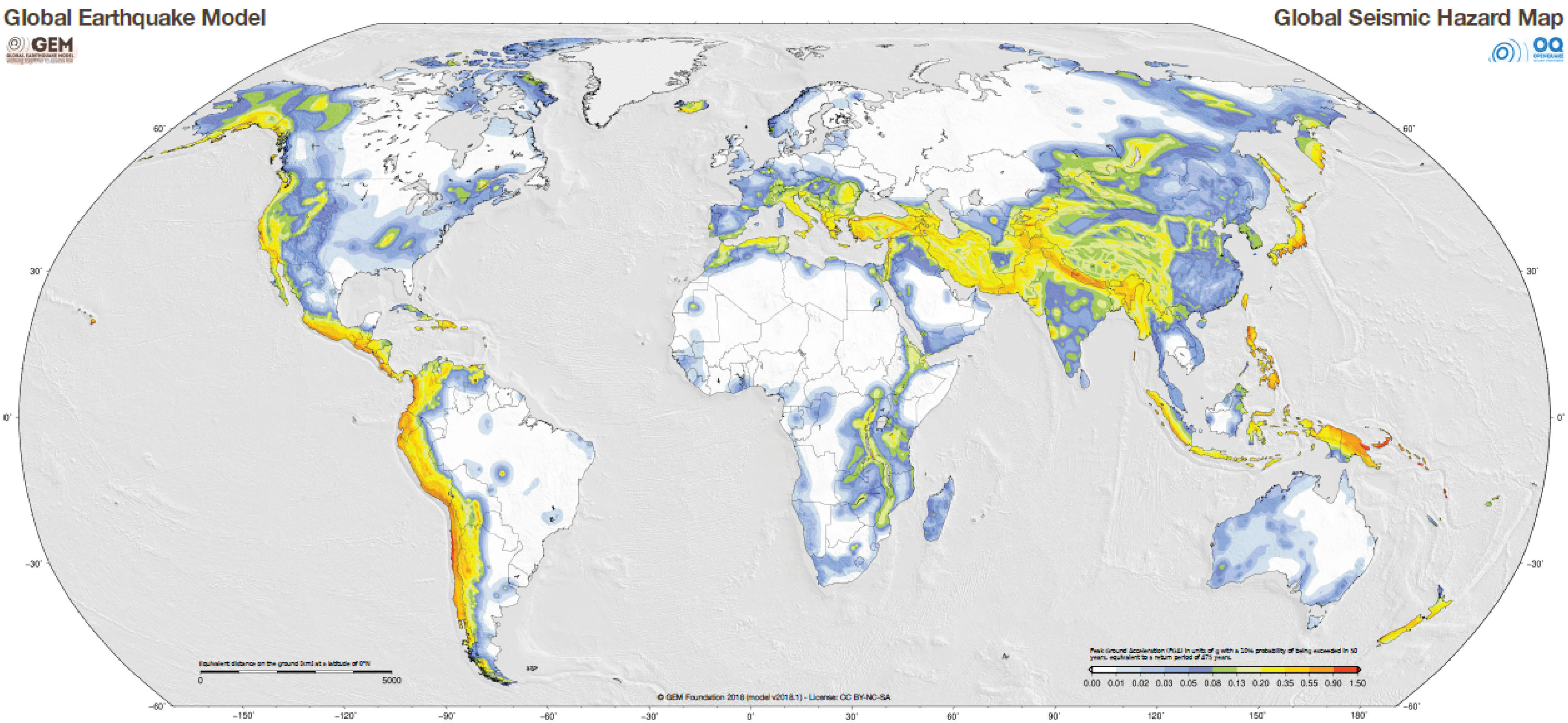

Figure 4. The GEM Global Seismic Hazard Map, v. 2018.1. This map shows PGA with a 10% probability of being in exceeded in 50 years, on the reference soil conditions (Vs30=760-800m/s). This is a low-resolution version of a 52 MB file at https://hazard.openquake.org/gem/images/home/gem_global_seismic_hazard_map_v2018.1.pdf accessed on 2019-05-01.

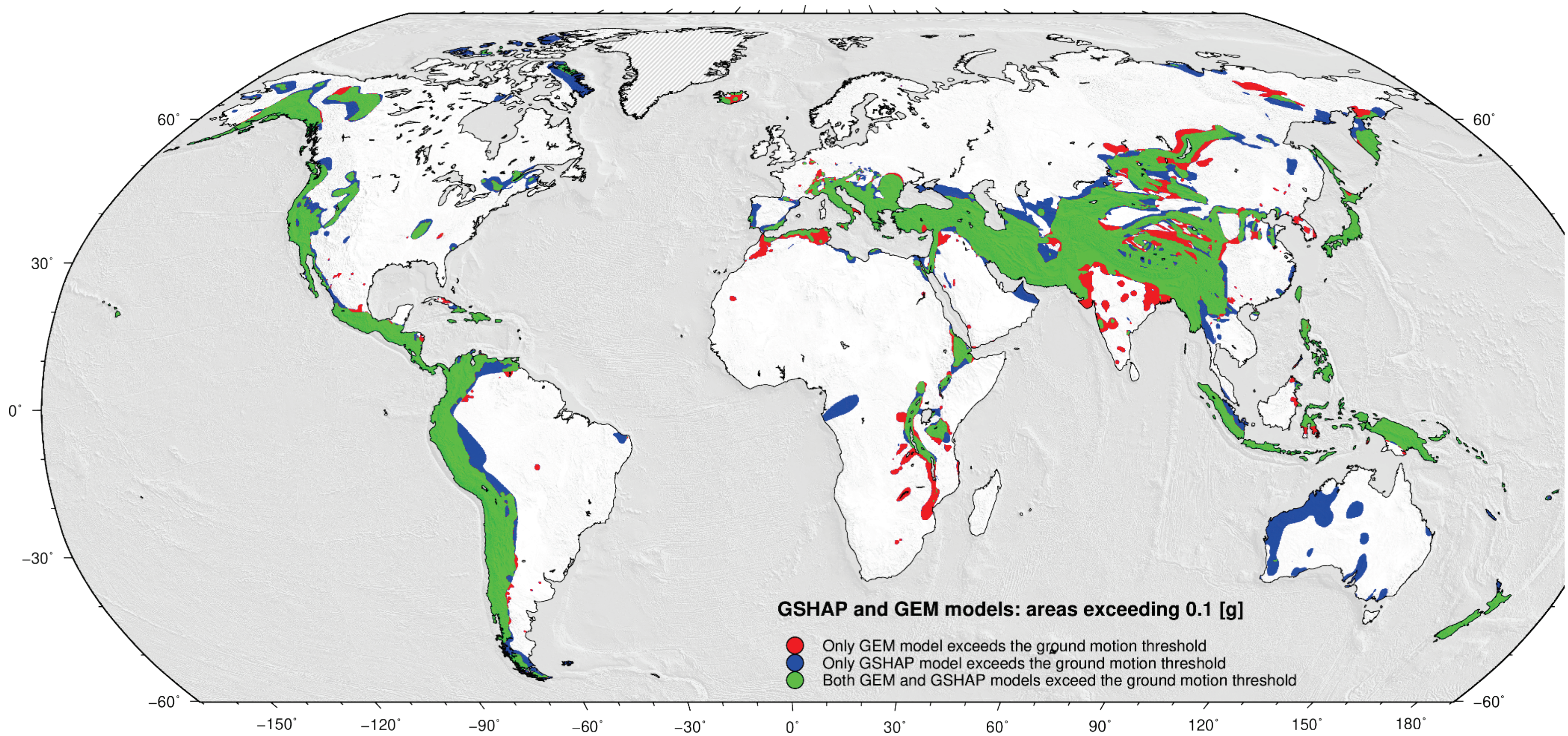

Figure 5. GEM's comparison of its 2018 mosaic map to the 1999 GSHAP map for regions exceeding 0.1 g PGA at a probability of 10%/50 yr. Map originally accessed from https://www.globalquakemodel.org/hazard-model-documentation on 2018-12-07. A similar map appears as part of Figure 4 of Pagani et al. (2020).

3.2.1 Philosophical criticisms of GEM

One of the characteristics of GEM models is that they rely heavily on smoothed seismicity to represent the hazard away from active faults. This approach is also been used in the US, but is not currently used in Canada. One outcome of the approach is that seismic hazard often forms bulls-eyes, much higher than for neighbouring regions. These bulls-eyes are sometimes due to a particular, well-known damaging earthquake that has been used to determine seismic hazard in its historical context. North American earthquake examples are Charleston (South Carolina) and Grand Banks (south of Newfoundland). Depending on the earthquake recurrence-rate hypothesis employed, the estimated seismic hazard might be too high in these regions. Some bulls-eyes may result from clusters of earthquakes that represent late aftershocks of early historic or prehistoric mainshocks, in which case the rates for smaller earthquakes may be correct but the implied rates for repeats of the (hypothetical) mainshocks are too high. This problem is a quandary for national seismic hazard mapping agencies, and the tendency is to "respect the historic record" though this may mean protecting against past earthquakes that are very unlikely to recur, and not protecting against future earthquakes that occur in different places. Issues like this were discussed by Adams and Halchuk (2003) for the construction of the model used for NBCC2005. Therefore in some places the estimated seismic hazard may be too high, and might be reduced by a site-specific study. The hazard estimated by GEM for Buenos Aires includes contributions from clusters of earthquakes near Buenos Aires, and these increase its hazard relative to nearby Montevideo (which is in a similar seismotectonic environment). A site-specific study for Buenos Aires might show that GEM's estimated higher hazard is not justified.

A more subtle flaw may be where the GEM seismic hazard model does not include some major contributor to seismic hazard, and in our view underestimates the true hazard. Some of this is unavoidable (we can't know all the unknowns) but in other cases examining the broader context might avert underestimation. One way that the GEM model improves on GSHAP (which was largely based on historical earthquakes) is that GEM includes GPS deformation rates, i.e. where the deformation rate is high but the known seismicity is low (or is for a very short history) the inferred rates of activity were increased to match the deformation rate. This has removed some of the egregious lower-hazard sections along plate boundaries, such as those existing on the GSHAP map of the Caribbean – Central America region (compare with AHA08's Figure 6).

3.2.2 Examples of issues with GEM Mosaic models

While GEM represents tremendous effort and is to be applauded, there inevitably are issues that arise because of various decisions and judgements that needed to be made. Two examples follow.

3.2.2.1 **South America Mmax**

For the continental low/moderate seismicity part of South America the Mmax (largest considered earthquake; Figure 6) was derived by:

“ adding an increment of 0.3 to the magnitude of the largest observed earthquake in a SSZ {sic, seismic source zone}. If the maximum observed magnitude was lower than 6.0, Mmax was set to 6.0. For Brazil background source zone the observed maximum magnitude was set as Mmax.” (Online documentation https://sara.openquake.org/hazard_rt7 accessed on 2018-11-27).

That type of choice for Mmax has been widely thought to be unconservative, and the equivalent region of Canada has Mmax set to 7.0 ± 0.2 based on global analogs. We consider any Mmax below approximately 6.8 to be too low for stable continental regions, but using a lesser value may not reduce the estimated hazard appreciably, and in any event the regions with assigned Mmax <6.8 generally already have low hazard. For site-specific evaluation of particular Missions in stable continental regions, we recommend examination of the Mmax values in the accepted source, and a sensitivity analysis when they are less than 6.8.

3.2.2.2 **Hazard cut-off distance – South American examples**

GEM typically used a cut-off distance of 300 km, that is, shaking from earthquakes farther away was not included. Although this is usually satisfactory, and is a reasonable compromise for computational efficiency, it may be insufficient for some sites. For example, long-period shaking in some low-seismicity sites on the Malayan peninsula needs to consider the shaking from great earthquakes on the west edge of Sumatra and on its offshore subduction zone, all sources more than 300 km distant. We ran the GEM-South America model and found that Sa(2.0) hazard run with a cut-off distance of 600 km was appreciably higher for Santiago (+39%; the northern end of the 1960 rupture is ~500 km away), La Paz (+11%; the subduction zone is ~330 km to the west), and Georgetown, Guyana (+166%, but absolute values still very low; southern end of the Caribbean subduction zone is ~400 km away), but insignificantly different for other Missions. For the final hazard estimates we retained the values calculated with the 600-km cut-off.

3.2.2.3 **Basin effects**

The GEM results do not include the amplifying effects of the deep sedimentary basins that underlie many of the Mission’s cities (M. Pagani, pers. comm. 2019). The amplification is most important for long-period seismic hazard, and may be an additional consideration for Missions in tall buildings underlain by deep basins.

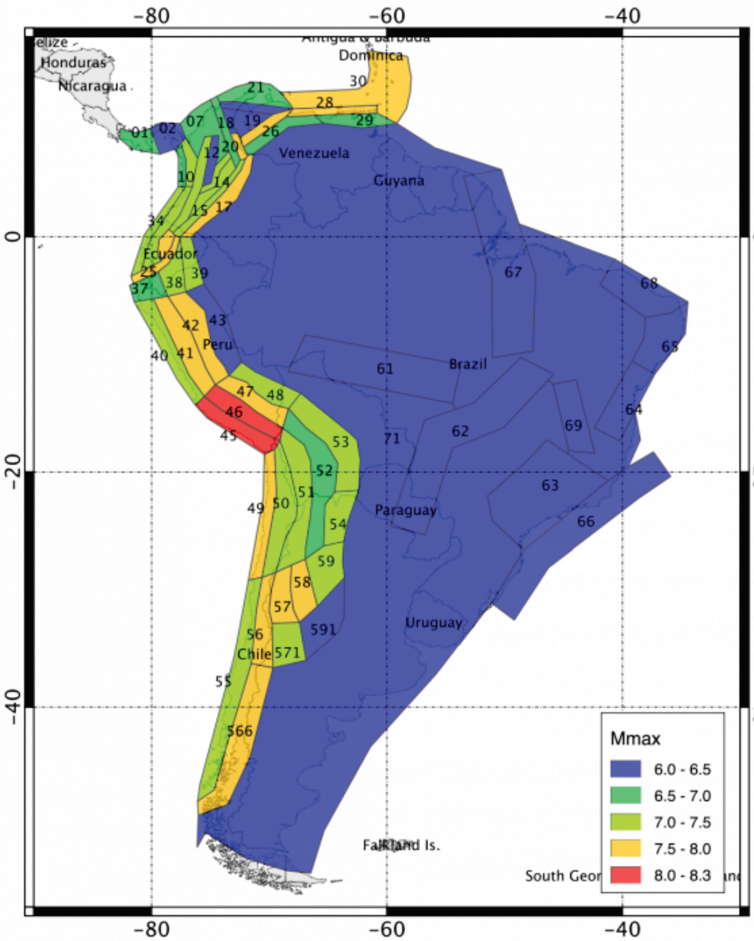

Figure 6. Mmax used in GEM's South American model. Note the low Mmax for the shield region of the continent. Downloaded from https://sara.openquake.org/hazard_rt7 on 2019-05-03.

4 SOURCES USED FOR 2020 ASSESSMENT

The sources include the GSHAP map, the GEM mosaic map, various GEM models that contributed to the mosaic map, national and regional seismic hazard models, and publications on PSHA for various regions and countries. During our project GEM provided access to an increasing number of the preliminary regional models. By the project's end we had access to some, but not all, of the models that were used to compute the hazard for the 2018 global mosaic map. Although GEM hopes to eventually provide a 1-stop source for global seismic hazard estimates, we chose to establish the hierarchy of sources in section 4.1.

When the spreadsheet indicates a source, that source is the basis for the values presented, but seldom do all of the reported values appear in the source. For example, the online GEM-Mosaic tool is the source for 34 Missions, but the only value available from the source is the 10%/50yr value for PGA; all of the 2%/50yr values we report are derived. The derivation involves various adjustments discussed in Section 5.

4.1 Hierarchy for choice of sources

The hierarchy below allowed us to obtain hazard at the probability, site class and some of the periods used in NBCC2015 for many of the Missions. Numbers in square brackets represent number of missions using the choice thus [12]; where there are just a few, the missions are named.

1. Most recent national models from
    a. Canada [1, Saint-Pierre, Saint-Pierre et Miquelon] plus representative Canadian cities [12] to give context to the international values
    b. U.S.A [16]
    c. Australia [2], and
    d. New Zealand [2]
2. Regional models for
    a. Europe (SHARE) [49] and
    b. The Middle East (EMME) [4]
3. Individual publications as specified later in this report (see Section 4.2) [7]
4. GEM seismic hazard models released for hazard calculations (see Appendix 1) [Total: 109]
    a. CCARA - Caribbean and Central America [19]
    b. EMME – Middle East [5]
    c. India [17]
    d. Japan [7]
    e. Mexico [10]
    f. North Africa [4]
    g. South America [20]
    h. Sub-Saharan Africa [12]
    i. West Africa [15]
    j. Korea [2]
5. Values from the interactive GEM mosaic map [32] (where the underlying models had not yet been released, e.g. China)
6. GSHAP values [2, Kyiv and Moscow]
7. Values from a representative Canadian city with low hazard (Winnipeg) for sites with low hazard undefined by any of the above [4: Bangui, Port-Louis, Cancun, and Hamilton (Bermuda)]

4.2 Choice to use seismic hazard from select publications

During the course of the work we found many country- or region-specific published seismic hazard assessments. A complete citation list is given in Appendix 2. The list also includes a few papers not explicitly referenced in the spreadsheet. Because of the varied choices, decisions and judgements used by the various authors, in general we have preferred the GEM model values to publication-sourced seismic hazard estimates because of GEM's fairly standardized approach to PSHA. Although we flagged them as "superseded" we the spreadsheet retains values from many published reports as they may be of value in the site-specific evaluation of particular Missions. Relevant sources to a specific Mission can be found from the "quick search" tab of the spreadsheet under "Available sources".

In a few cases we judged the seismic hazard values from a published report to be preferred to any of the GEM values. Some of the dissatisfaction with the GEM-Mosaic model is because of the crudeness of our required adjustment to get 2%/50yr spectral values from the mapped 10%/50yr PGA values (as is discussed below in section 5.5.1). In making the choices below we have tended to accept the higher values (because they are conservative), but 2%/50yr values from future releases of GEM's underlying regional models may suggest the need to revise the choices.

a. Hong Kong, Hong Kong. The 2015 publication by Pappin et al. gives higher 2%/50yr short period hazard than extrapolated from the GEM-mosaic map. However, the paper appears to confirm the short-period GEM-Mosaic values for Guangzhou.
b. Dubai and Abu Dhabi, United Arab Emirates. The 2012 paper by Irfan et al. provides some 2%/50yr spectral values; these values are somewhat higher than from GEM-EMME (but much lower than the 1999 GSHAP-based values).
c. Bangkok, Thailand, and Phnom Penh (PSD), Cambodia. For Southeast Asia (Myanmar and Vietnam through to Indonesia), the choice of the preferred source is less certain. The comprehensive USGS seismic assessment by Petersen et al. (2007) gives higher hazard for some Missions (e.g. Kuala Lumpur) than that derived from the GEM-mosaic model. This may be due to the USGS's use of older and outdated GMMs (so the GEM-mosaic results are retained for KL), but the differences for the lower hazard missions (Bangkok and Phnom Penh) are very large. For Bangkok, the USGS PGA estimates are a factor of 4 higher than the GEM-Mosaic derived estimates (<0.036 g). While Pailoplee and Charusiri (2016) similarly assess Bangkok as very low hazard (2%/50yr PGA = 0.03 g), the two low PGA values seem unreasonably low given the adjacency (within 100 km) of known active faults to the northeast and (especially) southwest documented in Pailoplee and Charusiri (2016). On balance, we have chosen to retain the USGS results for Bangkok and Phnom Penh.
d. Riyadh, Saudi Arabia. The "Seismic Shock" report (Maynard, 2017) indicates 10%/50yr PGA below 0.01 g; we used 0.01 g, and get a 2%/50yr value slightly higher than Winnipeg's.
e. Nuuk, Greenland. The 2007 paper by Voss et al. gives only a 10%/50yr PGA value, but the extrapolated 2%/50yr values from that are slightly higher those calculated at 2%/50yr from the Canadian Model.

5 METHODS USED FOR 2020 ASSESSMENT

5.1 Determination of Mission location

Geographical coordinates for the Missions were provided by Global Affairs Canada. Coordinates are based on the primary Mission property, not necessarily ancillary properties. In general, the exact coordinates do not matter in many parts of the world, as the hazard gradient is often low and the Mission's value can be taken as representative of the entire city (should the Mission be relocated within the city). In higher seismic hazard areas, and particularly where there is an asymmetry in earthquake distribution, the hazard gradient may be steeper and checking may be warranted. For Missions located close to active faults the seismic hazard can be extremely sensitive to the distance from the closest fault. California is a good example (https://www.usgs.gov/media/images/main-faults-northern-and-central-california) where the position of the faults is quite well known, so the hazard varies greatly over short distances. In many other parts of the world the tectonic situation is similar, but the faults are more poorly known. For such Missions the sources used in the GEM model (e.g. Figure 6) may be too crude, and use of a local zoning map (or site-specific hazard analysis) should be investigated.

5.2 Determination of seismic hazard values from the chosen source

The available seismic hazard values were extracted from the chosen source for each Mission. For many of the National, Regional, and GEM model sources we were able to directly calculate 2%/50yr hazard values for some of the required spectral periods. Values for additional periods needed to be determined as in Section 5.8. Some publications give tabulated hazard values we could use directly (even if they still needed to be adjusted to the 2%/50yr probability), but others only provided figures showing maps or Uniform Hazard Spectra (UHS). In those cases we read-off the hazard values, but recognize that those values contain some additional uncertainty relative to tabulated values. Values from the interactive GEM mosaic map (and GSHAP map) were only available for 10%/50yr PGA, and need to be adjusted as in Section 5.6.

5.3 Assignment of site class to obtained values

For certain models the calculation engine (OpenQuake or USGS) can provide spectral values for arbitrary V_{S30} values. For these, the models were run with V_{s30}=450 m/s, which is the Canadian reference site condition for NBCC2015. In most other cases the reference site condition for the provided hazard values is clearly stated, with the Class B - Class C boundary ("B/C", or V_{s30} = 760 m/s) being common. Some models provide values at V_{s30}=800 m/s, which we took to be effectively B/C (as did GEM), as the difference in amplification is only a few percent.

In one case (Riyadh) it was not possible to determine the site condition for the seismic hazard values from the reference supplying them. Therefore the following logic was used to provide a default condition. Judging by the site conditions used in studies with clear attribution the common conditions are B, B/C or C; it is unlikely to be Class A or D or E. Class C is uncommon in publications (though used in Canada) and the amplification difference between B and B/C is small (less than 10%) so therefore Class B/C was used as the default.

5.4 Adjustment of obtained site class values to reference Site Class C values

The obtained values on their site class were adjusted to reference Class C by using the F(T) factors in NBCC2015. For values given at B/C an average of the Class B and Class C F(T) values was used. For T= 0.15, T=3, and T= 4 s amplification factors were interpolated from the F(T) tables.

5.5 Assignment of a spectral shape category to use PGA hazard values

The core basis for AHA08 was the use of scaled spectra pinned to PGA, which was the same as the basis for NBCC1970. The 1985/1990/1995 NBCC used a modified approach involving two-parameters, PGA and Peak horizontal Ground Velocity (PGV), but NBCC2005 and subsequent editions abandoned the scaled-spectrum approach in favour of site-specific UHS. While many more localities had Sa(T) values available in 2019, the hazard values for some localities are still based on 10%/50yr PGA and use an updated AHA08 method.

5.5.1 Fundamental weakness of the anchored spectral shape method

In many seismotectonic environments (e.g. Montreal) there is a single population of earthquakes that is the source of the shaking hazard. For these there can be a good relationship between the actual spectra and spectra estimated by applying a spectral shape to the PGA value (e.g., see Figure 11 later in the report). In others (e.g. Vancouver) there may be multiple nearby sources, each with a population of earthquakes, but their combination can still be matched by a standard spectral shape (but a different shape from the one used for Montreal). However, there are some places with low levels of nearby seismicity that are affected by very large earthquakes that are quite distant. A Canadian example is Kamloops which is in a relatively low seismic area, but affected by great earthquakes (M ~9) on the Cascadia subduction zone ~400 km to the west. As the waves from such great earthquakes travel distances of hundreds of kilometres they lose most of their short-period energy to attenuation, but the long-period energy is efficiently propagated. For regions like those, applying a spectral shape – even a Plate Margin shape – to a locality's PGA can underestimate the long-period shaking expected. A particular concern when using the spectral shape method is the southwest coast of the Persian Gulf. The cities on this coast have generally low levels of local seismicity but are affected by large earthquakes in the Zagros of southern Iran. Another concern would be the Malayan Peninsula which sit in low seismicity regions but is shaken by great earthquakes on the Sumatra subduction zone. In such places there might be an underestimate of the long period hazard, of concern chiefly if Missions are evaluating very tall buildings.

5.6 Choice of spectral shapes

The appropriate spectral shape is dependent on the sizes and distance of the earthquakes contributing. The four spectral shapes (categories) used by AHA08 were considered sufficient and were retained:

- Continental regions of Low Seismicity (CLS, Canadian example = Winnipeg)
- Continental regions of Moderate Seismicity (CMS, Canadian example = Montreal)
- Plate Margin regions (PM, Canadian example = Chilliwack)
- Plate Boundary regions where the site is either very close to active faults or relatively near subduction zones capable of generating great (magnitude >8) earthquakes (PB, Canadian examples = Victoria and Village of Queen Charlotte)[4]

The reason for the continental vs plate margin/boundary difference is that the different nature of the crust in these regions changes the spectral shape. Within the "continental" pair different spectral shapes arise from the relative contributions of nearby and distant earthquakes. Although fundamentally the split between CLS and CMS is based on shaking level, the split between CMS and PM is not. Within the "plate margin/boundary" pair the boundary regions are very close to great earthquakes, while margin regions tend to be affected by great, but more distant events. The proximity to highly-active, high slip-rate faults is considered a key deciding factor, with "boundary" cities being within ~100 km and "margin" cities being at larger distances. In some cases where the effect of more distant earthquakes extends onto stable continental crust "plate margin" will be used where "continental moderate seismicity" might otherwise be appropriate (e.g. Cancun). The assignment between low and moderate continental seismicity is generally based on the Sa(0.5) hazard value, but with some discretion in the range 0.08 – 0.125 g. In every case the spectrum from a site-specific PSHA should trump the spectral shape assignments in this report.

Like AHA08, the factors used in this report to adjust and extend the UHS were obtained by inspection of Canadian seismic hazard results generated by GSC's 5th Generation seismic hazard model that was used for NBCC2015. The method used for each ground motion parameter (GMP, being PGA and Sa(T), where T is the period) was as follows. For the Continental regions of Low Seismicity, the factors were calculated directly from the 5th Generation Stable Canada model (because the factors are spatially invariant). For the remaining three categories, contour maps of the ratio (seismic hazard for GMP at 2%/50yr) / (seismic hazard for PGA at 10%/50yr) were constructed (see Appendix 3). From these maps, representative values were determined by

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[4] The PB ratios were chosen to reflect the ratios for southern Vancouver Island, a region dominated by subduction zone earthquakes. A side study suggests that Plate Boundary ratios from strike-slip plate boundaries like the Haida Gwaii (Queen Charlotte Islands) have lower ratios. The PB ratios used may over-estimate the long-period hazard near strike-slip plate boundaries if the only hazard parameter available is 10%/50yr PGA. Examples from this report would be Yangon, Hanoi and Cebu.

inspection. The values for the 28 factors are given in Table 1 and the approximate ranges for each factor are given in Table 2. AHA08 relied on these factors for most Missions, but in 2019 we had many more 2%/50yr values, so only 38 Missions used them.

Table 1. Spectral shape factors, representing ratio of (2%/50 yr Spectral and PGA) to 10%/50 yr PGA for each period (in seconds).

Spectral Shape Category		0.01	0.2	0.5	1	2	5	10
Continental Low Seismicity	1	3.68	6.21	3.68	1.84	0.75	0.15	0.08
Continental Moderate Seismicity	2	2.70	4.00	2.30	1.30	0.70	0.17	0.07
Plate Margin	3	2.20	5.00	4.40	2.80	1.80	0.80	0.30
Plate Boundary	4	2.20	4.40	4.10	2.70	1.80	0.50	0.20

Table 2. Ranges of spectral shape factors (Table 2) that exist in Canada

Spectral Shape Category		PGA	Sa(0.2)	Sa(0.5)	Sa(1.0)	Sa(2.0)	Sa(5.0)	Sa(10.0)
Continental Low Seismicity	1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Continental Moderate Seismicity	2	2.3-3.2	3.5-4.6	2.0-2.5	0.9-1.6	0.5-0.9	0.15-0.2	0.04-0.09
Plate Margin	3	1.9-2.5	4.2-5.5	3.9-4.7	2.4-3.5	1.6-2.4	0.65-1.2	0.2-0.4
Plate Boundary	4	1.9-2.5	3.6-4.9	3.0-5.0	1.8-4.0	0.9-2.4	0.25-0.7	0.07-0.3

Note: for the Continental Low Seismicity category the hazard values are spatially invariant, so range is shown as N/A

5.7 Discussion of the spectral shapes

The spectral shape factors from Table 1 are displayed in Figure 7. PGA is plotted at a period of 0.01 second for convenience; note that most seismic codes do not permit any decrease in spectral amplitude below the 0.2 second value. Effectively, for a constant PGA of 1 unit at 10%/50yr, Figure 7 shows how the 2%/50yr UHS would vary by tectonic category. All the curves have a similar shape, with a decrease from 0.2 seconds to longer periods, which is a characteristic of almost all UHS on firm ground. Figure 7 also shows clearly the different proportions of short-period energy to be expected: the CLS regions have a much higher Sa(0.2) for a given 10%/50yr PGA than do the other categories. For PGA in CLS regions the shape factor (3.7) is high relative to the other regions (~2.5) because contributions to the 10%/50yr PGA hazard from events less than magnitude 4.75 (only significant in very low seismicity regions) are discarded as not being of engineering significance.

A different representation of the spectral shapes can be made by normalizing the factors at T=0.5 seconds, a period in the mid-range for many structures (Table **3**; Figure 8).

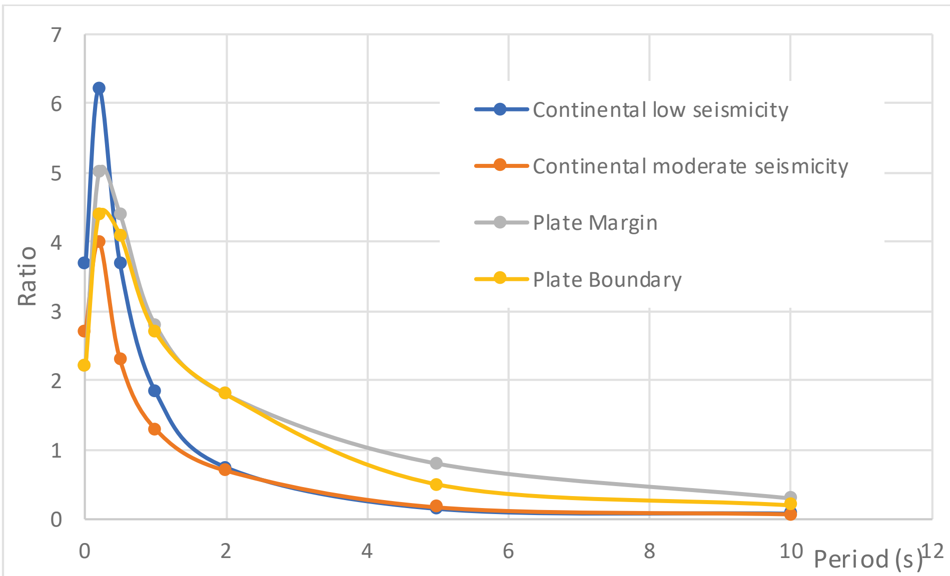

Figure 7. Ratio of (2%/50 yr Spectral and PGA) to 10%/50 yr PGA (PGA is plotted at 0.01 s).

Table 3. Ratio of (2%/50 yr Spectral and PGA) to 10%/50 yr PGA normalized at T=0.5 s

Spectral Shape category		Period (s)						
Region		**0.01**	**0.2**	**0.5**	**1**	**2**	**5**	**10**
Continental Low Seismicity	1	1.00	1.69	1.00	0.50	0.20	0.04	0.02
Continental Moderate Seismicity	2	1.17	1.74	1.00	0.57	0.30	0.07	0.03
Plate Margin	3	0.50	1.14	1.00	0.64	0.41	0.18	0.07
Plate Boundary	4	0.50	1.07	1.00	0.66	0.44	0.12	0.05

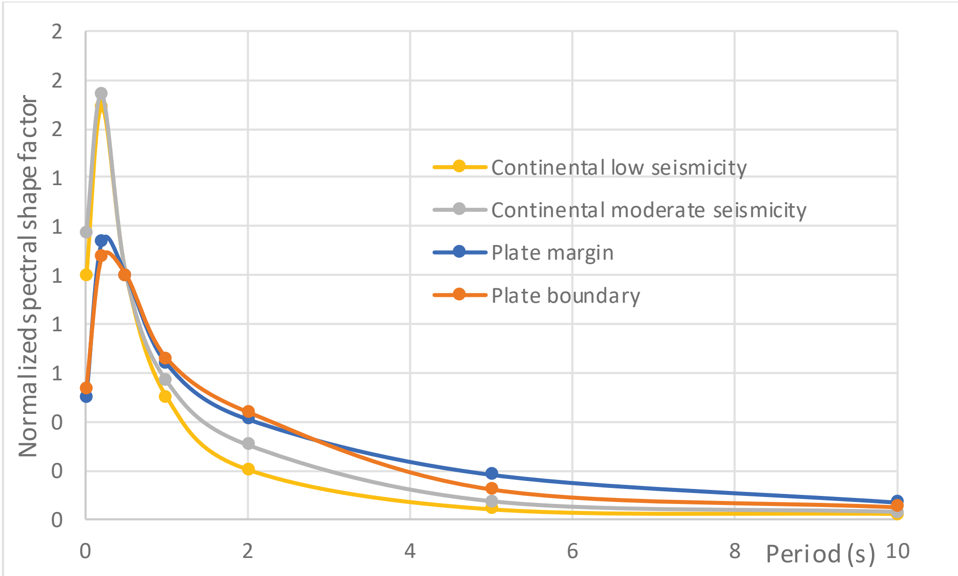

Figure 8. Spectral shape factors normalized at T=0.5 s (PGA is plotted at 0.01 s).

Figure 8 shows more clearly that the spectral shapes for the pair of continental categories (CLS and CMS) are quite similar, as are those for the pair plate margin/boundary regions (PM and PB). The difference between the two pairs is quite considerable, with the continental sites having much more short-period energy and less long-period energy (relative to their 10%/50yr PGA). This is the expected difference, as the seismic hazard of plate margin and plate boundary regions is dominated by great earthquakes that generate much long-period energy; such great earthquakes are rare-to-absent in stable continental regions. Note also that the CMS and PM curves have a relatively larger long-period hazard than CLS and PB; this arises because of greater contributions from more distant large earthquakes.

5.7.1 Slightly different spectral shapes from those derived in 2008

Figure 9 compares the spectral shape ratios in this report with those derived in 2008. It can be seen that while the overall shape is similar, the ratios from NBCC2015 are consistently higher than those given in 2008. We ascribe this difference to the inclusion of more aleatory uncertainty in the 5th Generation model used for NBCC2015; one effect of this is to increase the 2%/50 PGA estimate relative to the 10%/50 PGA estimate (+15% for plate margin & boundary; but due to the steeper hazard curve +25% for Continental), while at 2%/50 the ratios between PGA and Sa(T) are very similar. After adjusting for this difference, the shape of the curves is seen to be more similar (Figure 10).

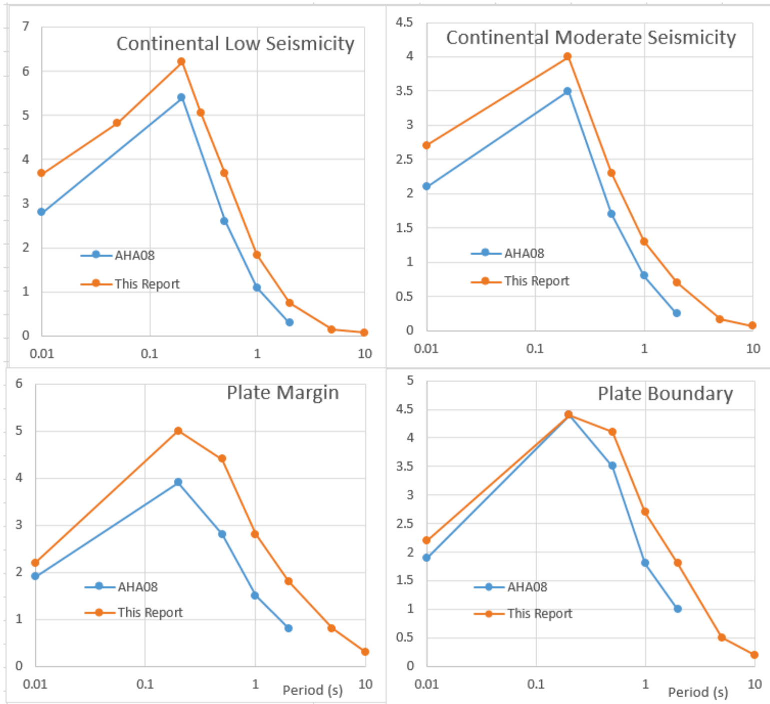

Figure 9. Comparison of 2008 and this report's ratios for predicting 2%/50yr PGA and Sa(T) from 10%/50yr PGA.

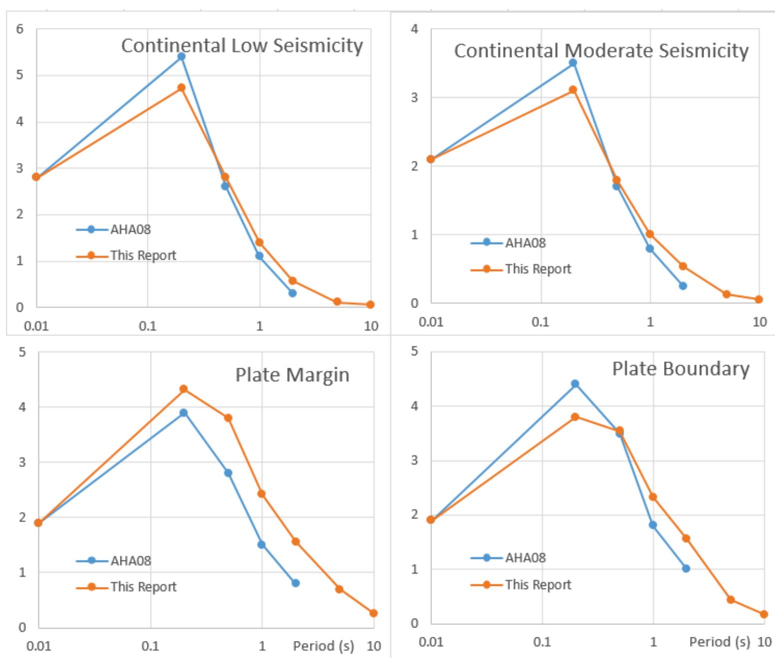

Figure 10. Closer comparison of 2008 and this report's ratios for predicting 2%/50yr PGA and Sa(T) from 10%/50yr PGA after the difference in the PGA values is adjusted.

5.8 Generating hazard for periods where 2%/50yr Sa(T) was not available

We have provided estimated values for the spectral values used in NBCC2015 plus PGA. Where we have obtained actual values by running GEM's models for other periods (such as 0.1s and 0.3 s) we have provided them, but we have not otherwise attempted to estimate values for those periods (they may be obtained by log-log interpolation). However, some sources did not provide all the required periods, and for these, two estimation methods were applied.

5.8.1 Missing periods below T=1 s

For Dubai, Abu Dhabi and San Juan (Puerto Rico) we used the Canadian Sa(0.5)/Sa(0.2) ratio for the indicated spectral shape to get Sa(0.5).

5.8.2 Missing periods above T=1 s

Certain sources provide only T≤1, T≤2 or T≤4 s values, chiefly because the GMMs they use do not extend to very long periods. In these cases extrapolation is required to give Sa(2), Sa(5) and Sa(10) values. The extrapolation was generally done by determining ratios such as Sa(10)/Sa(2) and Sa(5)/Sa(4) from the NBCC2015 2%/50yr hazard results for each spectral category (using ratio maps referred to in Appendix 4) and applying the available appropriate ratio to the longest-period Sa hazard value available. As an example, for the SHARE results the longest period available is 4 s, so the Sa(5) and Sa(10) values were obtained by spectral-model shape D of the spectral shape which provides the factors to adjust Sa(4) to Sa(5) and Sa(10)[5]. This extrapolation is usually less sensitive to the nearby local seismicity than is the determination of ratios relative to PGA (as was discussed in Section 5.5.1); nevertheless these estimates must be considered less reliable than any calculated values.

5.8.3 Periods not required by NBCC2015

We have provided estimated values for the spectral values used in NBCC2015 plus PGA. Where we have obtained actual values for other periods such as 0.1s and 0.3 s we have provided them, but we have not estimated values for those periods for other Missions.

5.9 Adoption of floor seismic hazard values

In some regions the GEM models were constructed such that for sites more than a set distance (often 300 km) from every seismic source, the seismic hazard is zero. The seismic hazard in many of these sites is indeed very low, but the non-inclusion of potential seismic sources means that the zero value is inappropriate. However we have left the zero values in the main

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[5] The letter model shapes represent the spectral shape category normalized to the period of the longest available hazard value. Explicitly for this example the value in cell AS30 on tab "Seismic Hazard Values (2%)" uses the model shape D of spectral shape category 3, the applicable ratio of which can be found in tab "Ratios(2%)" cell H35.

spreadsheet tab "Seismic Hazard Values (x%)" columns E:Q (where x% corresponds to the PoE in 50 years). For these, and other locations with non-zero but low hazard, the hazard values in columns AH:AT of the 'Seismic Hazard Values (x%)' and 'Superseded_Unused reports(2%)' tabs are highlighted in blue if they are below Winnipeg's.

Winnipeg represents the lowest seismic hazard in Canada and is indicative of what we think is the lowest seismic hazard for all land regions of the globe, i.e. a lower floor to seismic hazard. Therefore, for the final screening values on the "2020GAC_Missions List" tabs, we substituted any lower value by its Winnipeg value[6], and give the source as "Floored by Winnipeg". The original source model can be identified in cell P315 of the "Quick search" tab. The substitutions were made for 29 localities, about 13% of the total. For Nassau (Bahamas) we adopted the spectral values for nearby Miami as the floor; those have slower decay of long period values than does Winnipeg.

6 CHECKING THE SPECTRAL SHAPE METHOD'S RESULTS

More global locations now provide seismic hazard estimates at both 2%/50 and 10%/50 years, so some additional quality assurance checks can be made.

6.1 Canada

Since Canadian hazard values were used to determine the amplification factors, it is not surprising that the application of the factors in Table 1 to the known 10%/50yr PGA comes close to reproducing the actual 2%/50 values. Figure 11 shows the UHS for selected cities as taken from NRCan website for 2015 values, and as estimated by the above method. We judge the agreement to be satisfactory, although the linear scaling of the abscissa obscures some larger percentage differences (and cost implications for design) for long-period structures in low-hazard regions. The differences give us a minimum estimate for the uncertainty in the global results.

6.2 South America

A second check comes from the comparison of GEM-SouthAmerica "SARA" values for 2%/50yr from GEM with those predicted by applying the spectral shapes to the same model's 10%/50yr PGA values (Table 4). It can be seen at short periods, where the shaking at those periods is most plausibly related to PGA, the predictions are mostly within ±25%, quite close for screening purposes. At mid to long periods the predictions are too large by a factor of 2. Although this is not ideal, it is consistent with a screening process where it is better to screen-in a facility (for later examination) than to wrongly screen it out.

[6] Note: Any extrapolated or changed data is highlighted in grey, bolded and italicized in those tabs

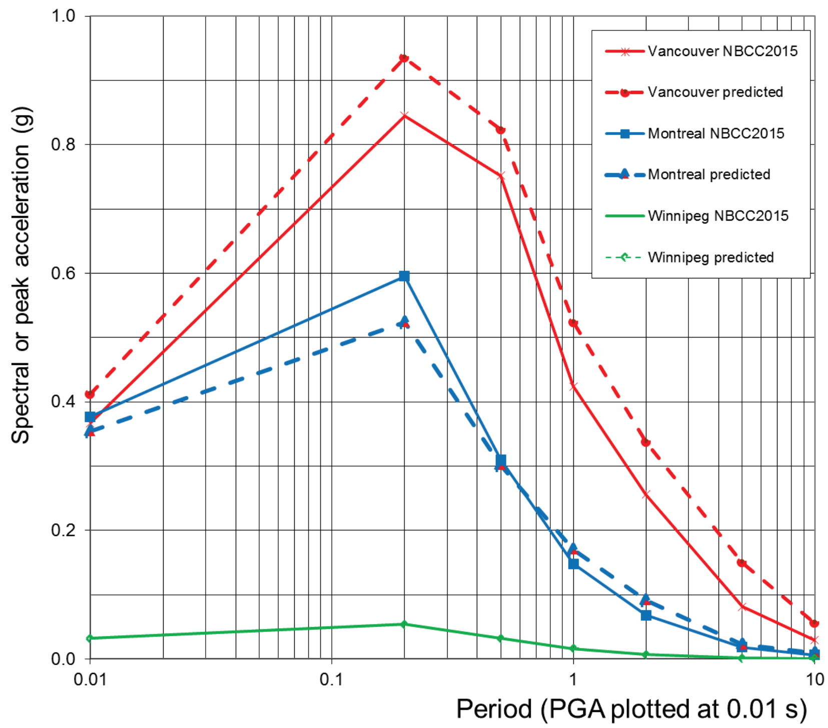

Figure 11. Comparison of 2%/50yr NBCC2015 and predicted (ratio-derived) UHS for Vancouver, Montreal, and Winnipeg (for which the predicted is the NBCC2015 value; see text).

Table 4. Percentage difference between SARA 2%/50yr hazard value and those predicted by applying the spectral shapes to the 10%/50yr PGA SARA value. Red cells are those where the predicted values exceed the SARA values.

Mission	Country	Shape		Period			
			PGA	**0.2**	**0.5**	**1**	**2**
Guayaquil	ECUADOR	4	28	7	49	80	173
Quito	ECUADOR	3	35	30	84	136	303
Lima	PERU	3	13	6	39	59	114
Cartagena	COLOMBIA	4	0	-11	46	109	264
Bogota	COLOMBIA	3	18	16	68	107	222
Santiago	CHILE	4	28	10	63	100	198
La Paz	BOLIVIA	3	26	32	103	158	275
Caracas	VENEZUELA	4	11	-7	30	55	134
Port of Spain	TRINIDAD AND TOBAG	4	10	-7	31	56	137
Buenos Aires	ARGENTINA	2	-24	-33	-16	15	56
Sao Paulo	BRAZIL	1	26	-5	17	50	N/A
Belo Horizonte	BRAZIL	1	-26	-25	9	54	95
Rio de Janeiro	BRAZIL	1	13	-13	6	36	N/A

7 OTHER ADJUSTMENTS AND CHOICES

In 2008 a series of manual adjustments were made to seven of the GSHAP values including Hanoi, Port-au-Prince, and Beijing to improve the consistency of the GSHAP values. Such adjustments are very subjective, both in terms of whether they should exist and their size. Therefore a retrospective evaluation is given below.

7.1 Evaluation of AHA08 manual adjustments.

Retrospectively it is interesting to examine the manual adjustments made in 2008. Table 5 shows the 2008 factors, the reason for them, and the comparison of the adjusted 2008 hazard to the 2020 hazard estimates (which are largely based on GEM results). The large manual adjustments for Hanoi and Bridgetown proved perspicacious; the moderate adjustments were correct for Chandigarh, too low for Port-au-Prince, and much too low for Beijing. The smaller adjustments for the remaining Missions (1.5) proved to be slightly too low (2 would have been better). These outcomes should be remembered when considering the manual adjustments recommended for 2020 (see below).

Table 5. 2008 Manual adjustment factors and their 2020 evaluation.

Country	Mission	Adjustment factor	2008 Reason	2020 Evaluation (relative to final AHA08 value)
VIETNAM	Hanoi	7	Close to a major plate boundary (Red River Fault) but few recent earthquakes	Approximates AHA08; is higher for T> 1 s
BARBADOS	Bridgetown	4	Consistency along plate boundary, tempered by the current lower seismicity rate	Equals AHA08
INDIA	Chandigarh	2	History of great earthquakes	Approximates AHA08
HAITI	Port-au-Prince	2	Consistency along plate boundary	Exceeds AHA08 by a factor of 1.5
CHINA	Beijing	2	Regional smoothing of hazard; nearby large prehistoric earthquake	Exceeds AHA08 by factors of 2-4 times
NICARAGUA	Managua	1.5	Consistency along plate boundary	Exceeds AHA08 by factor of 1.2 times
EL SAVADOR	San Salvador	1.5	Consistency along plate boundary	Exceeds AHA08 by factor of 1.5 times
GUATEMALA	Guatemala City	1.5	Consistency along plate boundary	Exceeds AHA08 by factor of 1.5 times
PANAMA	Panama	1.5	Adjusted to Camacho (1997) for 10%/50yr	Exceeds AHA08 by factor of 1.3 times

7.2 Manual adjustments for 2020

As in AHA08 we have felt that good judgment requires making a small number of adjustments to the preferred source hazard values. These are in addition to the preferred use of certain publications in Section 4.2, which generally give hazard higher than the GEM values. The adjustments are implemented to increase the UHS uniformly; that is, they are not applied to just long-period or short-period hazard values.

The coastal part of Ghana close to Accra has higher seismicity than most of the West African coast. For Accra the 2017 paper by Ahulu at al. gives values for PGA and spectral acceleration at 0.1, 1 and 2 seconds at 10%/50yr. We have chosen not to convert the 10%/50yr Sa(T) values to 2%/50yr, but note that the converted 2%/50yr PGA (0.6 g) is much higher than the GEM-West Africa value of 0.2 g. For this reason, we have included a manual adjustment of 2 implying that the GEM model underestimates the hazard for Accra. A site-specific hazard may be able to confirm the GEM values, and lower the estimated hazard.

For Hanoi the issue is the activity of the nearby Red River Fault and the location of the Mission relative to the fault. AHA08 applied a manual adjustment to the GSHAP value (see section 7.1), and this gives spectral values slightly higher than those extrapolated from the GEM-Mosaic PGA value. The model used for the GEM-Mosaic value has not been released, and the high hazard (2%/50yr PGA of perhaps 0.6 g at Class B/C) from Petersen et al. (2004) supports continuing a high hazard value for Hanoi until the basis for the GEM-Mosaic model can be examined or an alternative modern PSHA can be found. Accordingly, a new manual adjustment of 1.5 is applied to the GEM-Mosaic value.

For Yangon there is considerable uncertainty in the hazard due to a gradient away from the Sagaing fault, which shows as a prominent seismic hazard ridge on the GEM-Mosaic and the USGS Southeast Asia maps. However the highest hazard comes from the Pailoplee et al. (2009) Thailand and region paper, with a 2%/50yr PGA value about three times that derived from the GEM-Mosaic 10%/50yr value (Pailoplee et al. (2009) also give much higher hazard for Vientiane). The higher values might relate to the GMMs used, or to local seismic source factors like the position of the Sagaing Fault. To be conservative, a manual adjustment of 2 is applied to the GEM-Mosaic value for Yangon.

For Mexico, the authors' preferred model (B) in the paper "A Probabilistic seismic hazard assessment of the Trans-Mexican Volcanic Belt, Mexico based on historical and instrumentally recorded seismicity" (Bayona Viveros et al., 2017) gives similar hazard values to GEM-Mexico at Guadalajara and Mexico City at short periods, but for long periods their hazard is about 60% higher than the GEM-Mexico value. We also note that the US National model for San Diego gives hazard values ~40% larger than GEM-Mexico for nearby Tijuana at short periods, but similar hazard at long periods. For long periods, we take concordance of the San Diego - Tijuana results to indicate the GEM-Mexico values are acceptable despite the above discrepancy for

Guadalajara and Mexico City from the above paper. In summary, we have accepted the GEM values, though it appears that the short-period hazard in Tijuana may need re-evaluation.

An unusual possible adjustment for Johannesburg and Pretoria was rejected. For both cities almost all of the seismic hazard comes from nearby events induced by gold mining to the southwest of Johannesburg, and thus farther away from Pretoria (Fig. 12). Because these earthquakes are unlikely to exceed a fairly-low maximum magnitude (perhaps 5.5 – 6.0, vs ~7.0+ for natural earthquakes) they are expected to give very strong short-period, short-duration shaking near their source, but not sustained long-period shaking. Therefore a manual adjustment of 0.5 could be applied to halve just the long-period hazard values (for T>1 s). Note that older masonry structures can be susceptible to the strong short-period shaking but tall modern buildings are not. Due to the complexity in applying this adjustment to just some periods it has not been implemented.

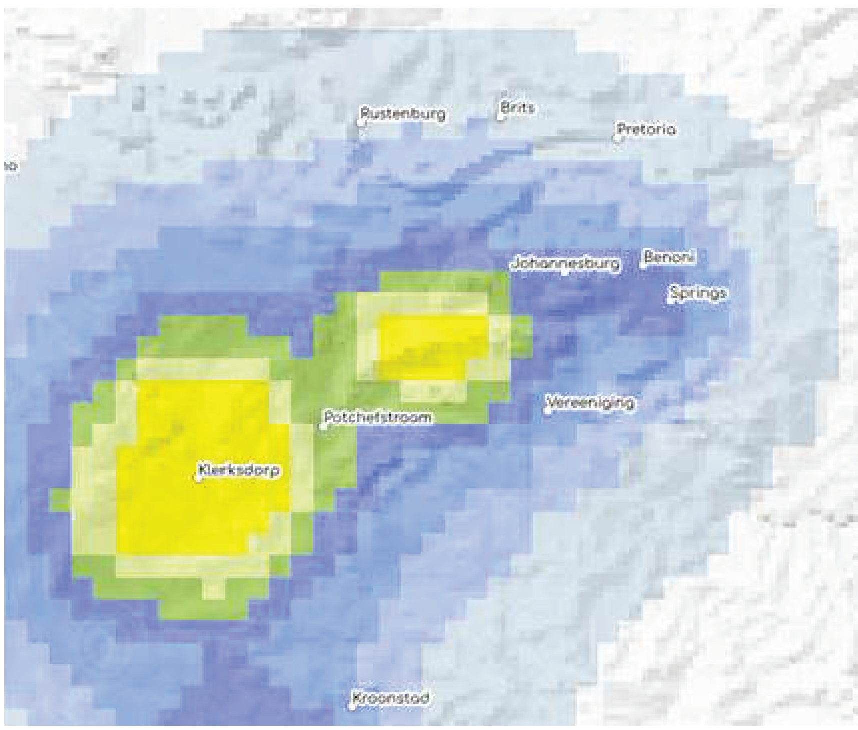

Figure 12. Detail of GEM-Mosaic seismic hazard map shown in Figure 4, for the region near Johannesburg and Pretoria.

7.3 Other choices and observations

Denver. We note that the UHS for Denver do not have the expected smooth shape at long periods. The complex shape may arise from the fact that Denver lies close to the boundary between the US-east and US-west models.

Kabul. For this report we chose GEM-EMME, but there are three other sources of seismic hazard estimates: EMME, GEM-India, and USGS-Afghanistan. GEM-EMME is similar to EMME at long periods, but is higher at short periods. At long periods, GEM-EMME is slightly lower than GEM-India and is lower than USGS-Afghanistan. Although a conservative approach would suggest using USGS-Afghanistan for long periods, it dates to 2007, and we consider that the difference in the hazard estimate probably results from the use of newer ground motion models.

Korea. We note that while Kim et al. (2017) for Seoul has similar hazard values for T< 1s, its long period values are higher than GEM-Korea's. Values extrapolated from the GEM-Mosaic map 10%/50yr PGA using the ratio method are considerably higher (factor of 5 at 5 s). We are concerned that the GEM-Korea model probably used a 300 km cut-off (see Section 3.2.2.2), and may have excluded long-period contributions from Japanese earthquakes. In conclusion, we adopt the GEM-Korea results, but note that the long period values might require attention if they become important for design.

Pakistan. The GEM-India model overlaps with the GEM-EMME model in Pakistan, so values from both models are available. GEM-India's values are consistently a factor of two to three higher for periods greater than 1 s. Because of the unresolved difference we preferred to use the GEM India model for the three Pakistan Missions.

Ponta Delaga, Azores. The alternative hazard estimates based on the Carvalho et al. (2001) paper are about 35% higher for all periods. GEM-Mosaic values are retained because it would have used newer ground motion models.

8 SCREENING VALUES AT HIGHER PROBABILITY LEVELS

Having established the 2%/50 year hazard values to be used for screening, there was a further request to provide hazard values at the higher probability levels of 10%/50yr and 5%/50yr. Those probability values are used for assessing retrofit needs in Canada (e.g. NBCC 2015 Commentary L), and will be used for Performance Based Design (to be introduced in NBCC2020).

As a first step, where possible, we computed the high-probability hazard values directly from the Canadian, USGS SHARE, EMME and GEM models.

Where high-probability hazard values were not available, either for localities not currently covered by GEM models or for periods not available from the GEM models, we decided to multiply the already-obtained 2%/50yr screening values by simple ratios that provide approximate values at the higher probability levels. The ratios were determined by choosing a Canadian city in each seismotectonic regime and using the ratios of its 10%/50yr and 5%/50yr hazard values to its 2%/50yr values. The cities used were:

- Winnipeg for CLS,
- Montreal for CMS,
- Chilliwack for PM, and
- Victoria for PB.

The method is crude but consistent with a screening approach. However, the precision of some of the high probability hazard values in low seismicity regions (e.g. Winnipeg for Sa(10.0) hazard) means that the ratios are sometimes extremely uncertain and the reported 0.43 ratio to get 10%/50yr Sa(10.0) might actually lie in the range 0.3 to 0.5. The practical significance of this is low, as the numerical uncertainty is worst for the low-hazard regions where the consequences are already very low.

It can be seen from Table 6 that the ratios differ by probability level and period; these differences are consistent with the steeper slopes of the hazard curves as one moves from high seismicity to low seismicity regions. Note that the approach used will not necessarily recover the input starting values used to generate the 2%/50yr screening values (i.e. the starting PGA at 10%/50yr will not be the same as the report's PGA at 10%/50yr). Thus some high probability UHS such as Sofia and Bucharest have a kink between the computed and screening values, typically at 2 or 4 s, representing the change in the derivation methods (here they are calculated 10%/50yr at short periods, and adjusted 2%/50yr at long periods).

Table 6. Ratios applied to the 2%/50yr screening values to estimate values at 10%/50yr and 5%/50yr probabilities.

Apply ratio for	to get	**PGA**	**Sa(0.2)**	**Sa(0.5)**	**Sa(1.0)**	**Sa(2.0)**	**Sa(5.0)**	**Sa(10.0)**
Continental low seismicity	5%/50yr	0.50	0.54	0.56	0.57	0.55	0.54	0.71
Continental low seismicity	10%/50yr	0.27	0.31	0.34	0.31	0.29	0.38	0.43
Continental moderate seismicity	5%/50yr	0.58	0.57	0.56	0.57	0.56	0.53	0.59
Continental moderate seismicity	10%/50yr	0.35	0.34	0.35	0.35	0.35	0.31	0.34
Plate margin	5%/50yr	0.69	0.69	0.70	0.68	0.66	0.58	0.62
Plate margin	10%/50yr	0.49	0.50	0.51	0.48	0.45	0.35	0.38
Plate boundary	5%/50yr	0.72	0.72	0.71	0.68	0.65	0.57	0.56
Plate boundary	10%/50yr	0.53	0.53	0.51	0.46	0.43	0.31	0.30

RESULTS

8.0 Results

The results of the estimation process are sorted by Sa(0.2) in Table 7 and coloured by Sa(0.5) in Figure 13. These were prepared from the spreadsheet and can be displayed through the GoogleEarth kml file included with this Open File. Comparable NBCC2015 values for representative Canadian cities are inserted to give an indication of the relative seismic hazard level[7]. Figure 14 contains some examples of UHS prepared using the spreadsheet. The derived values are for Canadian Site Class C (Vs30 $\simeq$ 450 m/s), and would need adjustment to actual site conditions at a Mission.

8.1 Uncertainty in the results

Assessment of the results in Table 7 is not complete without considering the uncertainties. There are three main sources of uncertainty:

A. The uncertainty in the accessed values
B. The uncertainty in the manual corrections (if any)
C. The uncertainty in the spectral shape factors

Although we have applied a considered process, described in Section 4, to select the hazard value we start with, we have no control over, and little knowledge about, uncertainty source A for most of the sources. As we mention above, there may be regional or local problems with the GEM model, and where values have come from other sources the quality of the assessment has been deemed "acceptable for screening" not necessarily "fully OK".

The manual adjustments in Section 7.2 are very crude, and the uncertainty in their values is large. While they may be sufficient for more accurate ranking of the Missions, they are not sufficiently rigorous to justify large expense. Site-specific seismic hazard assessments may be required.

The uncertainty in the spectral shape factors is an uncertainty that can be estimated from the variation across Canada (maps in Appendix 3). Table 2 suggests uncertainties of ±10-20% at short periods increasing to more than ±50% at 2.0 seconds. The check against GEM-South America results in Section 6.2 suggests agreement within ~25% at short periods, but that the long periods are >50% too high. Overall we think that the uncertainty in the design values in Table 7 is about ±20% for a majority of values, but users should be aware that the uncertainty for their specific Mission could be much larger. Therefore, although values from the spreadsheet and tables may be displayed to 3 decimal places, the appropriate level for use is at most 2 significant figures.

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[7] La Malbaie, site of the highest short-period onshore hazard in Canada, lies 80 km downstream from Quebec City.

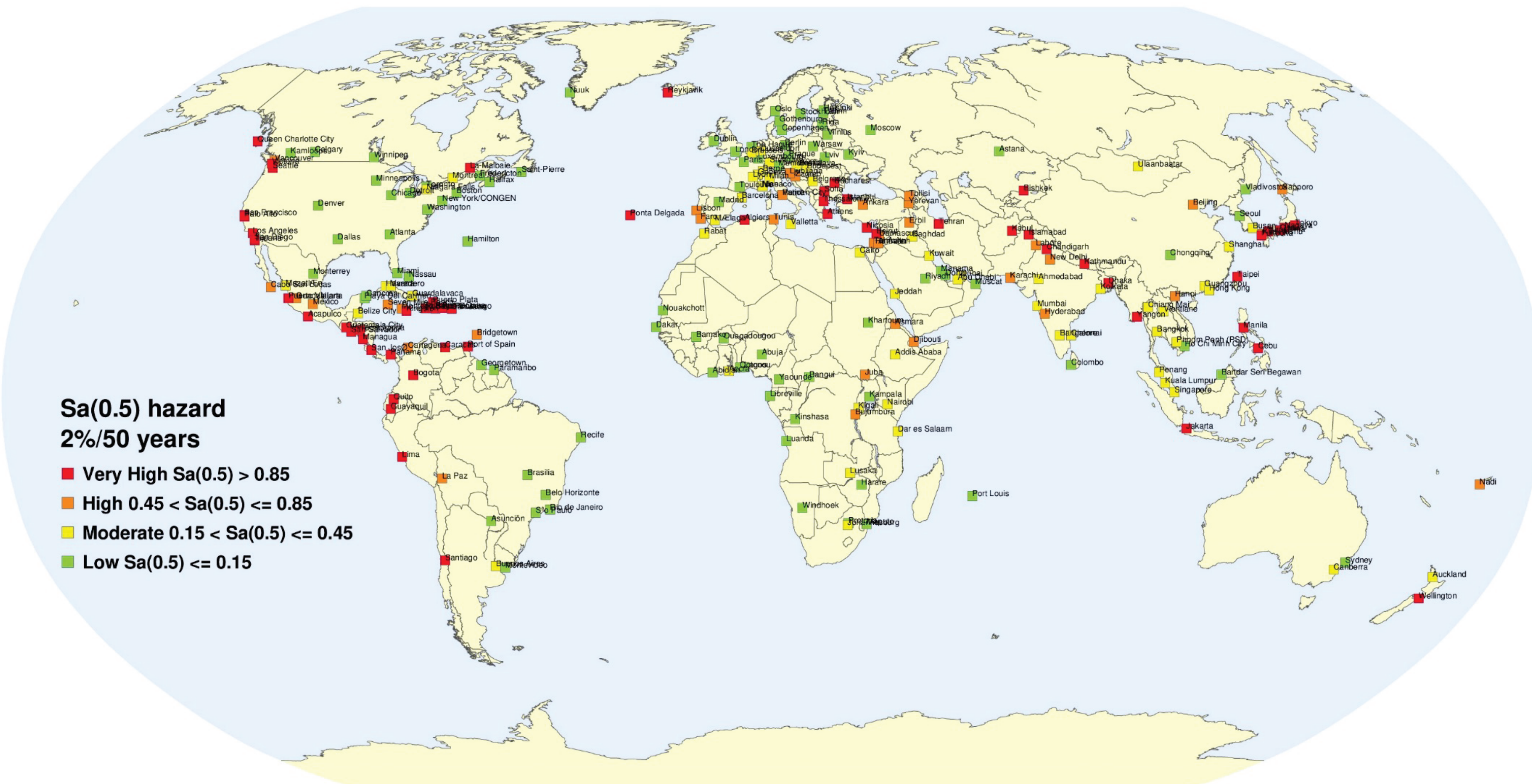

Figure 13. Map of the missions, along with Canadian reference locations, divided into 4 broad categories by their Sa(0.5) value

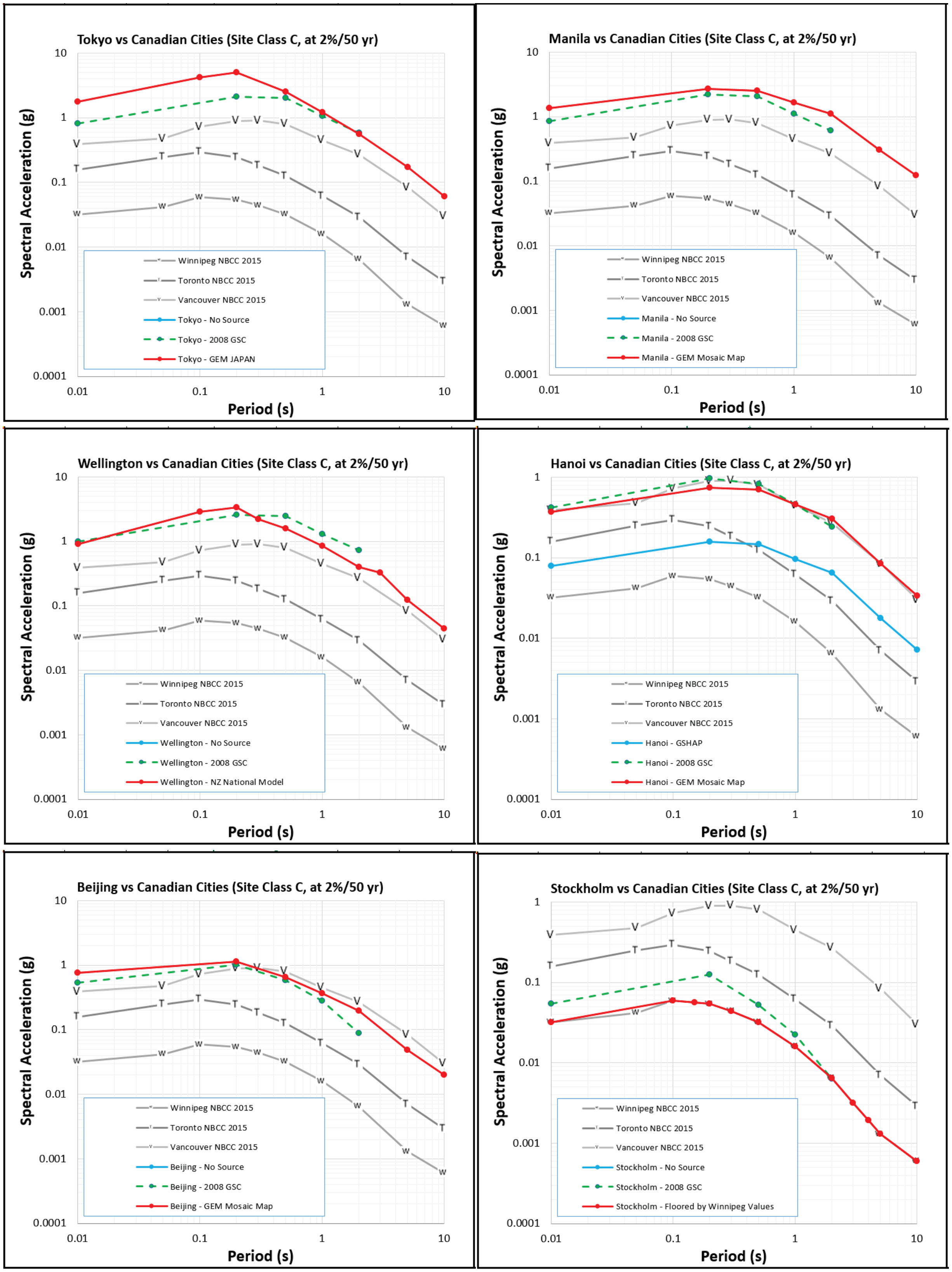

Figure 14. Examples of design UHS for selected cities that were generated using the "quick search" tab of the spreadsheet.

Table 7. Estimated design values for Missions abroad and representative Canadian cities (green). Two sets of results are presented, the left ordered in terms of Sa(0.2) and the right ordered in terms of Sa(2.0); the hazard for both sets is given in terms of g.

Country	Mission	Sa(0.2)	Country	Mission	Sa(2.0)
JAPAN	Tokyo	5.0	MYANMAR	Yangon	1.13
GUATEMALA	Guatemala City	4.1	PHILIPPINES	Manila	1.11
MEXICO	Acapulco	4.0	PAKISTAN	Islamabad	0.80
EL SAVADOR	San Salvador	4.0	JAPAN	Nagoya	0.80
ECUADOR	Quito	3.9	NEPAL	Kathmandu	0.74
JAPAN	Nagoya	3.5	UNITED STATES	Palo Alto	0.70
NICARAGUA	Managua	3.5	PHILIPPINES	Cebu	0.68
NEW ZEALAND	Wellington	3.4	JAPAN	Osaka	0.67
COSTA RICA	San José	3.3	MEXICO	Acapulco	0.63
CHILE	Santiago	3.2	GUATEMALA	Guatemala City	0.58
PERU	Lima	3.2	PERU	Lima	0.57
UNITED STATES	Palo Alto	3.2	JAPAN	Tokyo	0.56
ECUADOR	Guayaquil	3.1	EL SAVADOR	San Salvador	0.55
NEPAL	Kathmandu	3.0	INDONESIA	Jakarta	0.54
JAPAN	Osaka	2.9	INDIA	Chandigarh	0.53
JAPAN	Hiroshima	2.8	NICARAGUA	Managua	0.51
MYANMAR	Yangon	2.8	ECUADOR	Guayaquil	0.49
PHILIPPINES	Manila	2.7	CHILE	Santiago	0.48
IRAN	Tehran	2.6	KYRGYZ REP.	Bishkek	0.48
JAMAICA	Kingston	2.5	JAPAN	Hiroshima	0.46
HAITI	Port-au-Prince	2.4	COSTA RICA	San José	0.45
DOMINICAN REP.	Santo Domingo	2.4	ECUADOR	Quito	0.45
LEBANON	Beirut	2.4	TAIWAN	Taipei	0.43
PAKISTAN	Islamabad	2.4	TURKEY	Istanbul	0.43
UNITED STATES	Los Angeles	2.3	PAKISTAN	Lahore	0.43
ALGERIA	Algiers	2.2	AZORES	Ponta Delgada	0.43
MEXICO	Puerto Vallarta	2.1	ICELAND	Reykjavik	0.43
DOMINICAN REP.	Puerto Plata	2.1	CANADA	Queen Charlotte	0.42
AFGHANISTAN	Kabul	2.1	UNITED STATES	San Francisco	0.41
TRINIDAD AND TOBAGO	Port of Spain	2.1	JAMAICA	Kingston	0.41
UNITED STATES	San Francisco	2.0	NEW ZEALAND	Wellington	0.40
PANAMA	Panama	2.0	HAITI	Port-au-Prince	0.40
ICELAND	Reykjavik	2.0	BANGLADESH	Dhaka	0.39
JAPAN	Fukuoka	2.0	CANADA	Victoria	0.38
COLOMBIA	Bogota	2.0	JAPAN	Fukuoka	0.38
VENEZUELA	Caracas	1.9	PUERTO RICO	San Juan	0.37
JAPAN	Sapporo	1.8	UNITED STATES	Los Angeles	0.37
UNITED STATES	San Diego	1.8	GREECE	Athens	0.35
HONDURAS	Tegucigalpa	1.8	DOMINICAN REP.	Santo Domingo	0.35
UNITED STATES	Seattle	1.7	AFGHANISTAN	Kabul	0.34

GREECE	Athens	1.7
CANADA	La-Malbaie	1.7
PHILIPPINES	Cebu	1.7
JAPAN	Kitakyushu	1.6
TURKEY	Istanbul	1.6
INDIA	Chandigarh	1.5
GREECE	Thessaloniki	1.5
INDONESIA	Jakarta	1.5
BULGARIA	Sofia	1.5
CANADA	Queen Charlotte	1.4
GEORGIA	Tbilisi	1.4
DJIBOUTI	Djibouti	1.4
COLOMBIA	Cartagena	1.4
DOMINICAN REP.	Punta Cana	1.4
PAKISTAN	Karachi	1.4
KYRGYZ REP.	Bishkek	1.3
BARBADOS	Bridgetown	1.3
CANADA	Victoria	1.3
PUERTO RICO	San Juan	1.3
CYPRUS	Nicosia	1.3
MEXICO	Tijuana	1.3
CROATIA	Zagreb	1.3
PORTUGAL	Lisbon	1.3
PAKISTAN	Lahore	1.3
ISRAEL	Ramallah	1.2
AZORES	Ponta Delgada	1.2
MEXICO	Mexico	1.2
SLOVENIA	Ljubljana	1.1
JAMAICA	Montego Bay	1.1
CHINA (PEOPLE'S REP. OF)	Beijing	1.1
ROMANIA	Bucharest	1.1
SYRIA	Damascus	1.1
IRAQ	Erbil	1.1
INDIA	Hyderabad	1.1
BANGLADESH	Dhaka	1.1
TAIWAN	Taipei	1.1
TURKEY	Ankara	1.1
TUNISIA	Tunis	1.0
INDIA	New Delhi	0.99
BURUNDI	Bujumbura	0.97
SOUTH SUDAN	Juba	0.96
BOLIVIA	La Paz	0.96
ARMENIA	Yerevan	0.93
JORDAN	Amman	0.91
CANADA	Vancouver	0.90

HONDURAS	Tegucigalpa	0.34
IRAN	Tehran	0.34
TRINIDAD AND TOBAGO	Port of Spain	0.33
LEBANON	Beirut	0.32
DOMINICAN REP.	Puerto Plata	0.32
PANAMA	Panama	0.32
VENEZUELA	Caracas	0.31
VIETNAM	Hanoi	0.30
UNITED STATES	Seattle	0.29
JAPAN	Kitakyushu	0.29
GREECE	Thessaloniki	0.28
MEXICO	Tijuana	0.28
CANADA	Vancouver	0.27
UNITED STATES	San Diego	0.27
ALGERIA	Algiers	0.27
FIJI	Nadi	0.26
MEXICO	Puerto Vallarta	0.26
BULGARIA	Sofia	0.26
COLOMBIA	Bogota	0.25
ROMANIA	Bucharest	0.25
CYPRUS	Nicosia	0.24
KOREA, SOUTH	Busan	0.24
MEXICO	Mexico	0.23
DOMINICAN REP.	Punta Cana	0.21
JAPAN	Sapporo	0.21
INDIA	New Delhi	0.21
SYRIA	Damascus	0.20
CANADA	La-Malbaie	0.20
CHINA (PEOPLE'S REP. OF)	Beijing	0.20
PORTUGAL	Lisbon	0.19
PAKISTAN	Karachi	0.19
ISRAEL	Ramallah	0.19
GEORGIA	Tbilisi	0.19
BARBADOS	Bridgetown	0.18
ARMENIA	Yerevan	0.18
TURKEY	Ankara	0.18
JORDAN	Amman	0.17
CROATIA	Zagreb	0.16
JAMAICA	Montego Bay	0.16
MEXICO	Guadalajara	0.16
IRAQ	Erbil	0.15
DJIBOUTI	Djibouti	0.15
SLOVENIA	Ljubljana	0.14
CAYMAN ISLANDS	Seven Mile Beach	0.14
MEXICO	Cabo San Lucas	0.14

ISRAEL	Tel Aviv	0.88	COLOMBIA	Cartagena	0.14
PORTUGAL	Faro	0.87	ISRAEL	Tel Aviv	0.14
ITALY	Rome	0.86	PORTUGAL	Faro	0.14
VATICAN CITY (HOLY SEE)	Vatican City	0.86	ITALY	Rome	0.12
CAYMAN ISLANDS	Seven Mile Beach	0.81	VATICAN CITY (HOLY SEE)	Vatican City	0.12
MONACO	Monaco	0.81	BOLIVIA	La Paz	0.12
EGYPT	Cairo	0.79	THAILAND	Chiang Mai	0.12
ERITREA	Asmara	0.78	BURUNDI	Bujumbura	0.12
VIETNAM	Hanoi	0.75	UNITED ARAB EMIRATES	Dubai	0.11
MEXICO	Guadalajara	0.73	SOUTH SUDAN	Juba	0.10
FIJI	Nadi	0.72	TUNISIA	Tunis	0.10
FRANCE	Nice	0.71	ERITREA	Asmara	0.10
MEXICO	Cabo San Lucas	0.70	MEXICO	Mazatlán	0.10
KOREA, SOUTH	Busan	0.67	MONACO	Monaco	0.094
CUBA	Havana	0.66	INDIA	Hyderabad	0.093
HONG KONG	Hong Kong	0.66	MALAYSIA	Penang	0.091
ETHIOPIA	Addis Ababa	0.65	MALAYSIA	Kuala Lumpur	0.091
AUSTRIA	Vienna	0.64	SINGAPORE	Singapore	0.090
GHANA	Accra	0.64	RWANDA	Kigali	0.084
SLOVAKIA	Bratislava	0.63	KOREA, SOUTH	Seoul	0.084
SPAIN	Málaga	0.62	FRANCE	Nice	0.083
SWITZERLAND	Berne	0.62	INDIA	Kolkata	0.081
YUGOSLAVIA	Belgrade	0.60	LAOS	Vientiane	0.080
CANADA	Montreal	0.60	UNITED ARAB EMIRATES	Abu Dhabi	0.080
SWITZERLAND	Geneva	0.58	SWITZERLAND	Berne	0.080
ITALY	Milan	0.54	BELIZE	Belize City	0.079
INDIA	Kolkata	0.54	CUBA	Guardalavaca	0.078
INDIA	Mumbai	0.51	SAUDI ARABIA	Jeddah	0.075
BELGIUM	Brussels	0.50	YUGOSLAVIA	Belgrade	0.074
HUNGARY	Budapest	0.48	SWITZERLAND	Geneva	0.073
KOREA, SOUTH	Seoul	0.48	ETHIOPIA	Addis Ababa	0.072
GERMANY	Stuttgart	0.46	ITALY	Milan	0.071
INDIA	Bangalore	0.46	SPAIN	Málaga	0.070
NEW ZEALAND	Auckland	0.45	CANADA	Montreal	0.068
TANZANIA	Dar es Salaam	0.43	IRAQ	Baghdad	0.066
SPAIN	Barcelona	0.43	HONG KONG	Hong Kong	0.065
CUBA	Guardalavaca	0.43	KUWAIT	Kuwait	0.063
MALTA	Valletta	0.42	CANADA	Kamloops	0.063
IRAQ	Baghdad	0.42	AUSTRIA	Vienna	0.063
INDIA	Chennai	0.41	CHINA (PEOPLE'S REP. OF)	Shanghai	0.063
CUBA	Varadero	0.40	UNITED STATES	Atlanta	0.062
RWANDA	Kigali	0.38	SLOVAKIA	Bratislava	0.060
ARGENTINA	Buenos Aires	0.37	BELGIUM	Brussels	0.056
KUWAIT	Kuwait	0.37	GERMANY	Stuttgart	0.056
GERMANY	Düsseldorf	0.36	MALTA	Valletta	0.055

AUSTRALIA	Canberra	0.36
FRANCE	Lyon	0.36
CHINA (PEOPLE'S REP. OF)	Shanghai	0.36
MEXICO	Mazatlán	0.34
INDIA	Ahmedabad	0.33
THAILAND	Chiang Mai	0.33
UNITED STATES	New York/CONGEN	0.33
UNITED ARAB EMIRATES	Dubai	0.33
CANADA	Niagara Falls	0.32
KENYA	Nairobi	0.32
MOROCCO	Rabat	0.30
THAILAND	Bangkok	0.29
CAMBODIA	Phnom Penh (PSD)	0.29
ZAMBIA	Lusaka	0.29
UNITED STATES	Boston	0.29
CHINA (PEOPLE'S REP. OF)	Guangzhou	0.29
SOUTH AFRICA	Johannesburg	0.27
MONGOLIA	Ulaanbaatar	0.27
UKRAINE	Lviv	0.27
BELIZE	Belize City	0.26
MALAYSIA	Penang	0.25
MALAYSIA	Kuala Lumpur	0.25
SINGAPORE	Singapore	0.25
DENMARK	Copenhagen	0.25
CANADA	Toronto	0.25
UNITED STATES	Denver	0.24
UNITED ARAB EMIRATES	Abu Dhabi	0.23
FRANCE	Toulouse	0.22
LAOS	Vientiane	0.22
LATVIA	Riga	0.22
UNITED STATES	Atlanta	0.21
CANADA	Fredericton	0.21
SAUDI ARABIA	Jeddah	0.21
SRI LANKA	Colombo	0.20
CANADA	Calgary	0.19
ESTONIA	Tallinn	0.19
GREENLAND	Nuuk	0.19
CHINA (PEOPLE'S REP. OF)	Chongqing	0.19
GERMANY	Munich	0.18
FRANCE	Paris	0.18
NORWAY	Oslo	0.18
LUXEMBOURG	Luxembourg	0.17
UGANDA	Kampala	0.17
BRAZIL	Belo Horizonte	0.16

THAILAND	Bangkok	0.054
CAMBODIA	Phnom Penh (PSD)	0.054
OMAN	Muscat	0.054
CHINA (PEOPLE'S REP. OF)	Guangzhou	0.050
EGYPT	Cairo	0.050
NEW ZEALAND	Auckland	0.050
GERMANY	Düsseldorf	0.049
MOROCCO	Rabat	0.049
UNITED STATES	Chicago	0.048
HUNGARY	Budapest	0.048
SOUTH AFRICA	Johannesburg	0.048
FRANCE	Lyon	0.048
MONGOLIA	Ulaanbaatar	0.047
CUBA	Havana	0.047
UGANDA	Kampala	0.046
INDIA	Ahmedabad	0.044
INDIA	Mumbai	0.043
CUBA	Varadero	0.043
UNITED STATES	Dallas	0.042
AUSTRALIA	Canberra	0.037
KENYA	Nairobi	0.036
CANADA	Fredericton	0.036
CANADA	Calgary	0.036
SPAIN	Barcelona	0.036
UNITED STATES	Detroit	0.036
UNITED STATES	Boston	0.035
LUXEMBOURG	Luxembourg	0.034
SAINT-PIERRE ET MIQUELON	Saint-Pierre	0.033
GERMANY	Munich	0.033
GREENLAND	Nuuk	0.033
CHINA (PEOPLE'S REP. OF)	Chongqing	0.032
CANADA	Niagara Falls	0.032
GHANA	Accra	0.032
UNITED STATES	Denver	0.031
UNITED STATES	New York/CONGEN	0.031
FRANCE	Toulouse	0.031
TANZANIA	Dar es Salaam	0.029
CANADA	Toronto	0.029
CANADA	Halifax	0.029
ARGENTINA	Buenos Aires	0.028
UNITED STATES	Washington	0.027
UNITED STATES	Minneapolis	0.026
ZAMBIA	Lusaka	0.026
MOZAMBIQUE	Maputo	0.026

SWEDEN	Gothenburg	0.16
POLAND	Warsaw	0.16
UNITED STATES	Washington	0.15
OMAN	Muscat	0.15
VIETNAM	Ho Chi Minh City	0.15
MOZAMBIQUE	Maputo	0.15
AUSTRALIA	Sydney	0.15
CANADA	Kamloops	0.14
NETHERLANDS	The Hague	0.14
SAINT-PIERRE ET MIQUELON	Saint-Pierre	0.13
NAMIBIA	Windhoek	0.13
UNITED STATES	Chicago	0.13
SOUTH AFRICA	Pretoria	0.13
UNITED STATES	Detroit	0.12
CANADA	Halifax	0.11
UNITED STATES	Dallas	0.11
ANGOLA	Luanda	0.11
UNITED KINGDOM	London	0.10
MEXICO	Monterrey	0.10
CAMEROON	Yaounde	0.10
RUSSIA	Moscow	0.095
UKRAINE	Kyiv	0.095
ZIMBABWE	Harare	0.094
SPAIN	Madrid	0.092
CZECH REP.	Prague	0.088
BRUNEI	Bandar Seri Begawan	0.083
URUGUAY	Montevideo	0.081
BENIN	Cotonou	0.078
FINLAND	Helsinki	0.077
GERMANY	Berlin	0.075
SAUDI ARABIA	Riyadh	0.075
RUSSIA	Vladivostok	0.074
LITHUANIA	Vilnius	0.072
IVORY COAST	Abidjan	0.063
IRELAND	Dublin	0.063
BRAZIL	Recife	0.057
GUYANA	Georgetown	0.054
SUDAN	Khartoum	0.054
SWEDEN	Stockholm	0.054
SENEGAL	Dakar	0.054
NIGERIA	Abuja	0.054
UNITED STATES	Minneapolis	0.054
UNITED STATES	Miami	0.054
BRAZIL	São Paulo	0.054

NETHERLANDS	The Hague	0.026
LATVIA	Riga	0.023
UKRAINE	Lviv	0.022
DENMARK	Copenhagen	0.021
INDIA	Bangalore	0.021
ZIMBABWE	Harare	0.019
INDIA	Chennai	0.018
VIETNAM	Ho Chi Minh City	0.018
ESTONIA	Tallinn	0.018
SRI LANKA	Colombo	0.017
SWEDEN	Gothenburg	0.017
AUSTRALIA	Sydney	0.016
FRANCE	Paris	0.015
NORWAY	Oslo	0.015
UNITED STATES	Miami	0.015
BAHAMAS	Nassau	0.015
SOUTH AFRICA	Pretoria	0.015
BAHRAIN	Manama	0.015
SPAIN	Madrid	0.014
POLAND	Warsaw	0.013
UNITED KINGDOM	London	0.013
CZECH REP.	Prague	0.012
RUSSIA	Moscow	0.011
UKRAINE	Kyiv	0.011
BRUNEI	Bandar Seri Begawan	0.010
FINLAND	Helsinki	0.009
SAUDI ARABIA	Riyadh	0.009
RUSSIA	Vladivostok	0.009
GERMANY	Berlin	0.009
MEXICO	Monterrey	0.009
QATAR	Doha	0.009
LITHUANIA	Vilnius	0.008
BRAZIL	Belo Horizonte	0.008
IRELAND	Dublin	0.008
URUGUAY	Montevideo	0.007
GUYANA	Georgetown	0.007
ANGOLA	Luanda	0.007
CAMEROON	Yaounde	0.007
SUDAN	Khartoum	0.007
SWEDEN	Stockholm	0.007
SENEGAL	Dakar	0.007
NIGERIA	Abuja	0.007
IVORY COAST	Abidjan	0.007
BRAZIL	São Paulo	0.007

BRAZIL	Rio de Janeiro	0.054	BRAZIL	Rio de Janeiro	0.007
BRAZIL	Brasilia	0.054	BRAZIL	Brasilia	0.007
MALI	Bamako	0.054	MALI	Bamako	0.007
BURKINA FASO	Ouagadougou	0.054	BURKINA FASO	Ouagadougou	0.007
NIGERIA	Lagos	0.054	NIGERIA	Lagos	0.007
DEMOCRATIC REP. OF CONGO	Kinshasa	0.054	DEMOCRATIC REP. OF CONGO	Kinshasa	0.007
CANADA	Winnipeg	0.054	CANADA	Winnipeg	0.007
MAURITIUS	Port Louis	0.054	NAMIBIA	Windhoek	0.007
MEXICO	Playa Del Carmen	0.054	MAURITIUS	Port Louis	0.007
SURINAME	Paramaribo	0.054	MEXICO	Playa Del Carmen	0.007
MAURITANIA	Nouakchott	0.054	SURINAME	Paramaribo	0.007
BAHAMAS	Nassau	0.054	MAURITANIA	Nouakchott	0.007
BAHRAIN	Manama	0.054	GABON	Libreville	0.007
GABON	Libreville	0.054	BERMUDA	Hamilton	0.007
BERMUDA	Hamilton	0.054	BENIN	Cotonou	0.007
QATAR	Doha	0.054	MEXICO	Cancún	0.007
MEXICO	Cancún	0.054	CENTRAL AFRICAN REP.	Bangui	0.007
CENTRAL AFRICAN REP.	Bangui	0.054	PARAGUAY	Asunción	0.007
PARAGUAY	Asunción	0.054	KAZAKHSTAN	Astana	0.007
KAZAKHSTAN	Astana	0.054	BRAZIL	Recife	0.007

9 GUIDANCE FOR USERS

9.1 Intended use

The accompanying macro-enabled Microsoft Excel spreadsheet (filename: OF8627-MissionsSpreadsheet2020.xlsm; MD5 checksum: aafe090b0a28cefc4ba05d6ce4fd3701) provides estimated seismic values for seismic screening of embassy and Mission buildings. The values are chiefly based on the GEM (2%/50 year) preliminary values, supplemented with additional literature as discussed above. Soil adjustment factors are taken from NBCC 2015. Basin amplification effects are not included (see section 3.2.2.3). Hazard adjustment factors depend on the nature of the tectonic environment and were determined from Canadian hazard values. Where certain values were not available they were obtained through extrapolation or interpolation (greyed values)[8]. The colour of the tab indicates the probability level (e.g., green for the 2%/50yr). In addition to the following outline, a "Quick Start" guide is given as Appendix 5.

It is recommended that users re-open the attached spreadsheet for each session. Accessing any modified version may lead to incorrect results. Certain tabs are completely locked to prevent accidental user modification. These include tabs "Site Class Adjustment", "2008DFAIT_Missions List (2%)", "2008-2020 Comparison (2%)" and all (2%, 5% and 10%) "Ratios". The remaining

[8] This shading is not shown on the "Quick Search" tab.

tabs have specific cells and cell ranges locked. "Quick Search" is locked except for where user input is required for the tab to function. All "Superseded_Unused Reports", "Seismic Hazard Values" and "2020GAC_Missions Lists" tabs have had the original data locked, but the rest of the sheet remains unlocked so that the user may add their own data if desired. If this is not sufficient access, the password for the spreadsheet may be available by contacting GAC.

9.2 Quick Search tab

This worksheet is the main tool of the spreadsheet for the end user. This tool searches the available data for the specific location entered by a user, and presents that data clearly through tabulated values and plots. By default, values for three representative Canadian cities are added to the plots (in grey) for comparison.

The users can choose a mission location by either typing in the mission name, or using the drop-down list (Cell B314). If desired, the user can adjust the Probability of Exceedance (POE), Site Class, and Fundamental Period (Ta) as needed. Note that Site Class E adjustments are not available in this worksheet.

Once the required input information is entered, the final estimated hazard values will be tabulated below. If the user wants to compare the estimated values with another data source, they can do so by selecting a second source from the drop-down list located in the second tabled data row (cell B324). The names of all data sources available for the selected location will be shown to the right of the input data; these sources may change depending on what POE you are looking for.

9.3 GAC_Missions List tabs

The 2020 values provided are for Site Class C based on the sources we felt best represented the actual hazard; note that for the '2008DFAIT_Missions List (2%)' tab the values provided are for Site Class B. When looking through these worksheets, values that are greyed and in italics have been converted or estimated and are not provided directly from the sources. These worksheets will likely see minimal use from most users, as they can use the Quick Search tab to quickly find the information they are looking for.

9.4 Seismic Hazard Values & Superseded Unused Sources tabs

These worksheets provide the raw data gathered for all the sources used through the course of this study. The final sources that were used are stored in the "Seismic Hazard Values" Worksheets and additional sources that were found are stored in the "Superseded_Unused" worksheets.

The leftmost data set provides the raw data directly gathered from the associated source. Moving to the right the next columns list the Probability of Exceedance and reference site class used in the original source.

The next set of data, greyed in the worksheets, is either:

- For 2%/50 yr: The original data converted to Site Class C; or,
- For 5% and 10%/50 yr: The final 2% Hazard Values for each location.

The final values, presented as Site Class C at the appropriate exceedance level, are presented in the furthest right data set. These values should provide the full Uniform Hazard Spectrum for a given location through the use of adjustment or interpolation of the available data.

These tabs will likely see minimal use from most users, as they can use the 'Quick Search' tab to quickly find the information they are looking for. However, they can be used to add additional locations by users who are comfortable entering the data and ensuring all cell references remain appropriate.

9.5 2008-2020 Comparison tab

This tab provides a comparison between the 2008 and 2020 estimates for all locations that were included in both projects. The relatively low hazard values in some locations have the potential to cause large fluctuations in the percent difference between the two estimates; therefore, both the percent difference and the absolute difference are shown. The comparisons are presented with the assistance of colour gradients; Percent Difference (Red-Blue) and Absolute difference (Red-Green).

Using this tool, the user can quickly search through multiple locations to help determine if a re-evaluation is warranted based on the changes in hazard presented between the 2008 and 2020 estimates.

9.6 Additional Notes/Known Issues

- If macros are not enabled (refer to comments in Appendix 5) many fields may show as "#NAME?"
- Users should not sort the data that appears in the "Seismic Hazard Values" or "Superseded_Unused reports" tabs because it will break the cell references that are used in the "Quick Search Tool"
  - o The data can be sorted in the "2020GAC_Missions List(x%)" worksheets without causing errors on any other sheets. Additionally, these data sets will be the final estimated values for each location for the probability of exceedance "x" in 50 years.
- It has been noticed that some computers may experience a "#N/A" error in excel when copy and pasting data from this workbook to a different document. While the cause of this issue was not found, a simple solution was; double click into any cell in the work book (Empty or filled) and hit the Enter Key. This will reset the data and re-run the formulas in the workbook.
  - o Additionally, this error may carry over to the values copied from the spreadsheet; to prevent this, select "Paste Values" when pasting the data into the new document.

10 DISCUSSION

The seismic design values in the spreadsheet and Table 7 represent our best attempt to compile contemporary estimates, given the resources available. For the majority of Missions the seismic hazard is quite low, and even if the estimate is very uncertain the implications of that uncertainty are unlikely to be significant. Missions with moderate or high hazard fall into two classes:

A. Hazard is high or moderate, and there is a credible national assessment and seismic hazard code - It is recommended that the estimated values be compared to the national values. If the national values are higher, they should be adopted as they are likely more soundly based. If the national values are lower than the estimates, see class B.
B. Hazard is high or moderate but there is no credible national assessment (or only poor design codes) – It is recommended that the uncertainties in the analysis (both in the factors and in any manual adjustment) be considered very carefully before decisions are made. A site-specific analysis may be cost-effective.

11 CONCLUSIONS

Estimated seismic design values have been provided for 226 Canadian Missions abroad. The values are for the NBCC2015 Class C site condition (V_{S30} = 450 m/s) at a probability of 2% in 50 years. The method used is based on adopting available seismic hazard values and adjusting them by applying spectral-shape and magnification factors. The method generates values for the 2%/50yr spectral design parameters used by the 2015 National Building Code of Canada. Values at 10%/50yr and 5%/50yr were generated either directly or from the 2%/50yr values.

12 ACKNOWLEDGEMENTS

We thank David McCormack, head of the Canadian Hazards Information Service, for granting permission for us to undertake this study. Nick Ackerley provided a thorough internal review that improved the report. Marco Pagani and the GEM team provided invaluable feedback on our observations and comments as the work progressed. The investigations have helped us to further our knowledge on the state of global hazard analysis and will provide insight to future investigations in Canada. We also thank the Commissioning and Engineering Services Program of Global Affairs Canada for allowing one of us (Dylan Young) to participate in the project.

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APPENDIX 1 GEM Mosaic hazard models

GEM assembled its "mosaic" seismic hazard map from a number of regional (e.g. South America) and national (e.g. Canada) models (Fig. 2). We were given access to preliminary models and ran them to calculate seismic hazard for the Mission localities. Specifically, the hazard values used came from the model versions listed below.

GEM Central American - Caribbean	Model ccara_20180409.zip file date April 8, 2018, run with OQ version 3.3.2-1 Mar 8 2019
GEM JAPAN	Model jpn_20181010.zip file date October 8, 2018, run with OQ version 3.3.2-1 Mar 8 2019
GEM MEXICO	Model MEX-master.zip file date November 15, 2018, run with OQ version 3.3.2-1 Mar 8 2019
GEM NORTH AFRICA	Model NAF-master.zip file date November 19, 2018, run with OQ version 3.3.2-1 Mar 5 2019
GEM SOUTH AMERICA	Model SAM-master.zip file date November 19, 2018, run with OQ version 3.3.2 Apr 16 2019
GEM SUBSAHARA	Model SSA-master.zip file date November 21, 2018, run with OQ version 3.3.2-1 Mar 5 2019
GEM WEST AFRICA	Model WAF-master.zip file date November 21, 2018, run with OQ version 3.3.2-1 Mar 5 2019
GEM EMME	Model MIE-master.zip file date February 25, 2019, run with OQ version 3.5.0 Mar 28 2019
GEM INDIA	Model IND-master.zip file date March 25, 2019, run with OQ version 3.5.0 Aug 9 2019
GEM KOREA	Model KOR-master.zip file date September 3, 2019, run with OQ version 3.5.0 Sep 3 2019

Unlike GSHAP, the GEM models allow calculation to be performed for any specified site condition (parameterized in terms of Vs30); we ran them for the 450 m/s condition used as the reference soil condition (Site Class C) in NBCC2015.

APPENDIX 2 References & Sources for seismic design values

	Region Specific
Central America	• Benito, M. B., et al. "A New Evaluation of Seismic Hazard for the Central America Region." Bulletin of the Seismological Society of America, vol. 102, no. 2, 2012, pp. 504–523. http://dx.doi.org/10.1785/0120110015.
Caribbean and Central America	• "Caribbean C-America | GEM - Global Earthquake Model." Global Earthquake Model Foundation, https://storage.globalquakemodel.org/what/regions/caribbean_c_america/
Global	• Lemgo, U. "Global Seismic Hazard Assessment Program Map." Global Seismic Hazard Map, 21 Sept. 2010, http://gmo.gfz-potsdam.de//. • "Global Earthquake Model Foundation." GEM Foundation, http://www.globalquakemodel.org.
Middle East	• Danciu, L., et al. "The 2014 Earthquake Model of the Middle East: Ground Motion Model and Uncertainties." Bulletin of Earthquake Engineering, vol. 16, no. 8, Aug. 2016, pp. 3497–3533. http://dx.doi.org/10.1007/s10518-016-9989-1.
South America	• "SARA Project." Start [SARA Wiki], https://sara.openquake.org/
South East Asia	• Petersen, M. D., Dewey, J., Hartzell, S., Mueller, C., Harmsen, S., Frankel, A., & Rukstales, K. (2004). "Probabilistic seismic hazard analysis for Sumatra, Indonesia and across the Southern Malaysian Peninsula." Tectonophysics, 390(1), 141-158
	Country Specific
Afghanistan	• Boyd, O.S., Mueller, C.S., and Rukstales, K.S., 2007, "Preliminary Earthquake Hazard Map of Afghanistan." U.S. Geological Survey Open-File Report 2007-1137, 25 p.
Australia	• Burbidge, D., et al. "Atlas of Seismic Hazard Maps of Australia." Research Data Australia, Geoscience Australia, 2013, https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/77399
Azores	• Carvalho, A & Sousa, M & Oliveira, Carlos & Costa, A & Nunes, João & Forjaz, Victor-Hugo. (2001). "Seismic hazard for the Central Group of the Azores Islands." Bollettino di Geofisica Teorica ed Applicata. 42. 89-105.
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Egypt

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- Sawires, Rashad, et al. "Probabilistic Seismic Hazard Deaggregation for Selected Egyptian Cities." Pure and Applied Geophysics, vol. 174, no. 4, 2017, pp. 1581–1600. http://dx.doi.org/10.1007/s00024-017-1490-5.

Ghana

- Ahulu, Sylvanus T., et al. "Probabilistic Seismic Hazard Assessment of Southern Part of Ghana." Journal of Seismology, vol. 22, no. 3, 2017, pp. 539–557. http://dx.doi.org/10.1007/s10950-017-9721-x.

Greenland

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South Africa

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Taiwan	• Wang, Yu-Ju, et al. "Probabilistic Seismic Hazard Assessment for Taiwan." Terrestrial, Atmospheric and Oceanic Sciences, vol. 27, no. 3, June 2016, p. 325. http://dx.doi.org/10.3319/tao.2016.05.03.01(tem)
Thailand and adjacent	• Pailoplee, Santi, et al. "Deterministic and Probabilistic Seismic Hazard Analyses in Thailand and Adjacent Areas Using Active Fault Data." Earth, Planets and Space, vol. 61, no. 12, 2009, pp. 1313–1325, http://dx.doi.org/10.1186/bf03352984.
Tunisia	• Ksentini, A., and Najla Bouden R. "Updated Seismic Hazard Assessment of Tunisia." Bulletin of Earthquake Engineering, vol. 12, no. 2, 2013, pp. 647–670., http://dx.doi.org/10.1007/s10518-013-9548-y
United Arab Emirates	• Irfan, M., Khan, Z., El-Emam, M. & Abdalla, J. (2012). "Seismic Hazard Assessment and Spectral Accelerations for United Arab Emirates.", 15th World Conference on Earthquake Engineering, paper 5594, 10 pp. • Maynard, T. "Seismic Shock A New Earthquake Model for the Middle East." Lloyd's Insurance, 2017, Seismic Shock A New Earthquake Model for the Middle East, https://www.lloyds.com/news-and-risk-insight/risk-reports/library/natural-environment/seismicshock.
United States of America	• Shumway, A.M., 2019, "Data release for additional period and site class maps for the 2014 National Seismic Hazard Model for the conterminous United States (ver. 1.1, February 2019)" U.S. Geological Survey data release, http://dx.doi.org/10.5066/P9I6BPX5 • "U.S. Seismic Design Maps." U.S. Geological Survey, earthquake.usgs.gov/hazards/designmaps/usdesign.php.
City Specific	
Bishkek, Kyrgyzstan	• Ischuk, A., et al. "Probabilistic Seismic Hazard Assessment for the Area of Kyrgyzstan, Tajikistan, and Eastern Uzbekistan, Central Asia." Bulletin of the Seismological Society of America, vol. 108, no. 1, 2017, pp. 130–144., http://dx.doi.org/10.1785/0120160330
Hong Kong, Hong Kong	• Pappin, J. W., et al. "A Rigorous Probabilistic Seismic Hazard Model for Southeast China: a Case Study of Hong Kong." Bulletin of Earthquake Engineering, vol. 13, no. 12, 2015, pp. 3597–3623., http://dx.doi.org/10.1007/s10518-015-9798-y
Manila, Philippines	• Wong, I., Dawson, T. & Dober, M. (2008). "Evaluating the Seismic Hazards in Metro Manila, Philippines". 14th World Conference on Earthquake Engineering, paper 0109, 8 pp.

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China	• Xie, Furen, et al. "Seismic Hazard and Risk Assessments for Beijing–Tianjin–Tangshan, China, Area." Pure and Applied Geophysics, vol. 168, no. 3-4, 2010, pp. 731–738. http://dx.doi.org/10.1007/s00024-010-0115-z
Bermuda	• Caribbean Catastrophe Risk Insurance Facility. "Bermuda - Country Risk Profile." Country Risk Profiles | CCRIF SPC, Aug. 2013, http://www.ccrif.org/content/publications/risk_profiles.
Central America & Caribbean	• Shedlock, Kaye M. "Seismic Hazard Map of North and Central America and the Caribbean." Annali Di Geofisica, vol. 42, no. 6, Dec. 1999, pp. 977–997. http://dx.doi.org/10.4401/ag-3786
Central Asia	• Shahid, U, et al. "Probabilistic Seismic Hazard Assessment for Central Asia." Annals of Geophysics, vol. 58, 2015, http://dx.doi.org/10.4401/ag-6687.
Jakarta	• Irsyam, M., et al.. (2015). Development of seismic risk microzonation maps of Jakarta city. http://dx.doi.org/10.1201/b17438-6
Malaysia	• Loi, Daniel Weijie, et al. "Revisiting Seismic Hazard Assessment for Peninsular Malaysia Using Deterministic and Probabilistic Approaches." Natural Hazards and Earth System Sciences, vol. 18, no. 9, 2018, pp. 2387–2408. http://dx.doi.org/10.5194/nhess-18-2387-2018.

APPENDIX 3 Ratios for spectral shapes A

Contour maps for southeastern and southwestern Canada showing the ratio (seismic hazard for GMP at 2%/50yr)/ (seismic hazard for PGA at 10%/50yr). GMP is the ground motion parameter (Sa(T), where T is the period, or PGA) of interest. Representative ratios given in Table 1 were determined from these maps by inspection.

Order of figures is:

Natural Resources Canada | Ressources naturelles Canada

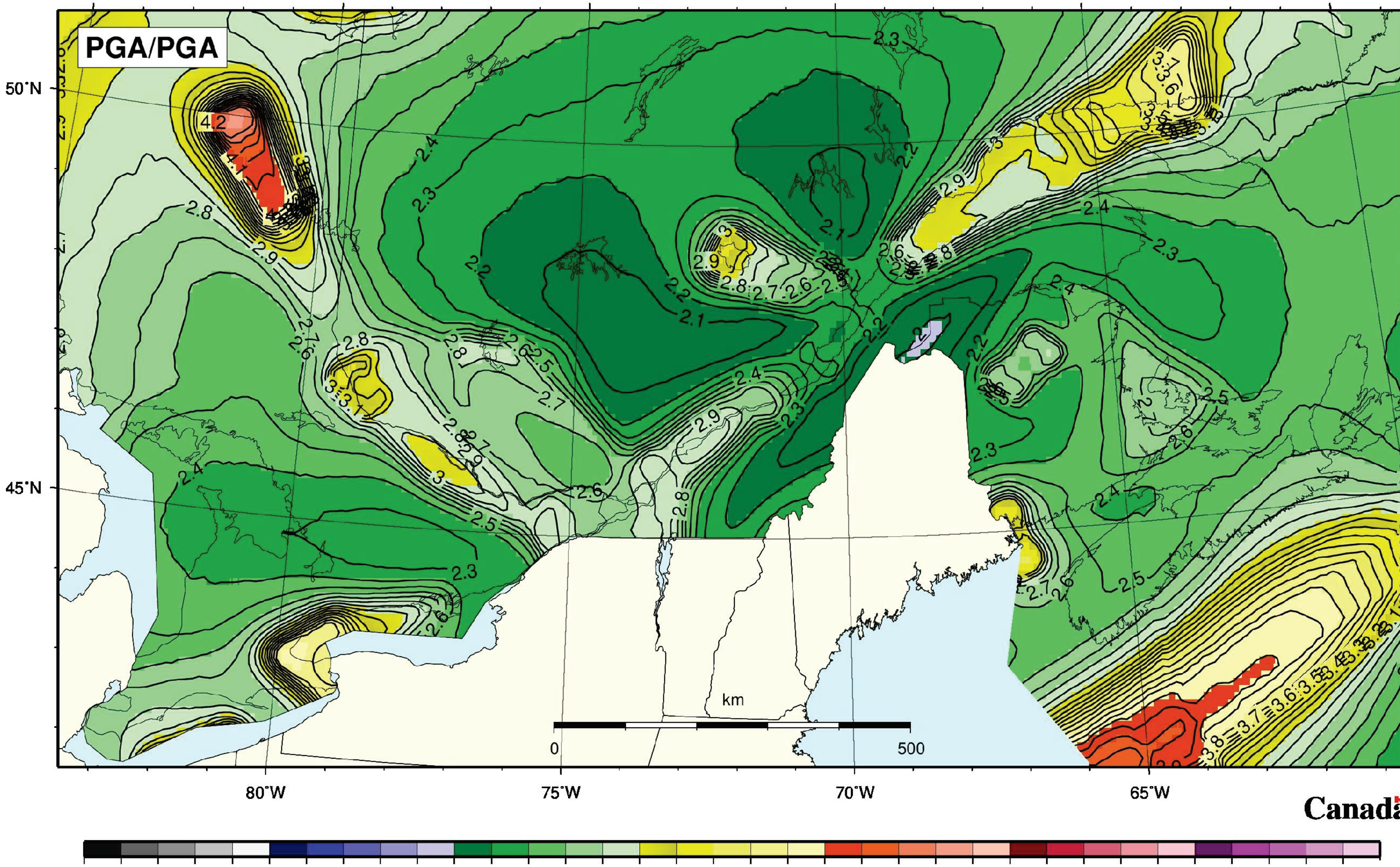


Figure A3-1. Ratio of 2%/50 year PGA /10%/50 year PGA for southeastern Canada

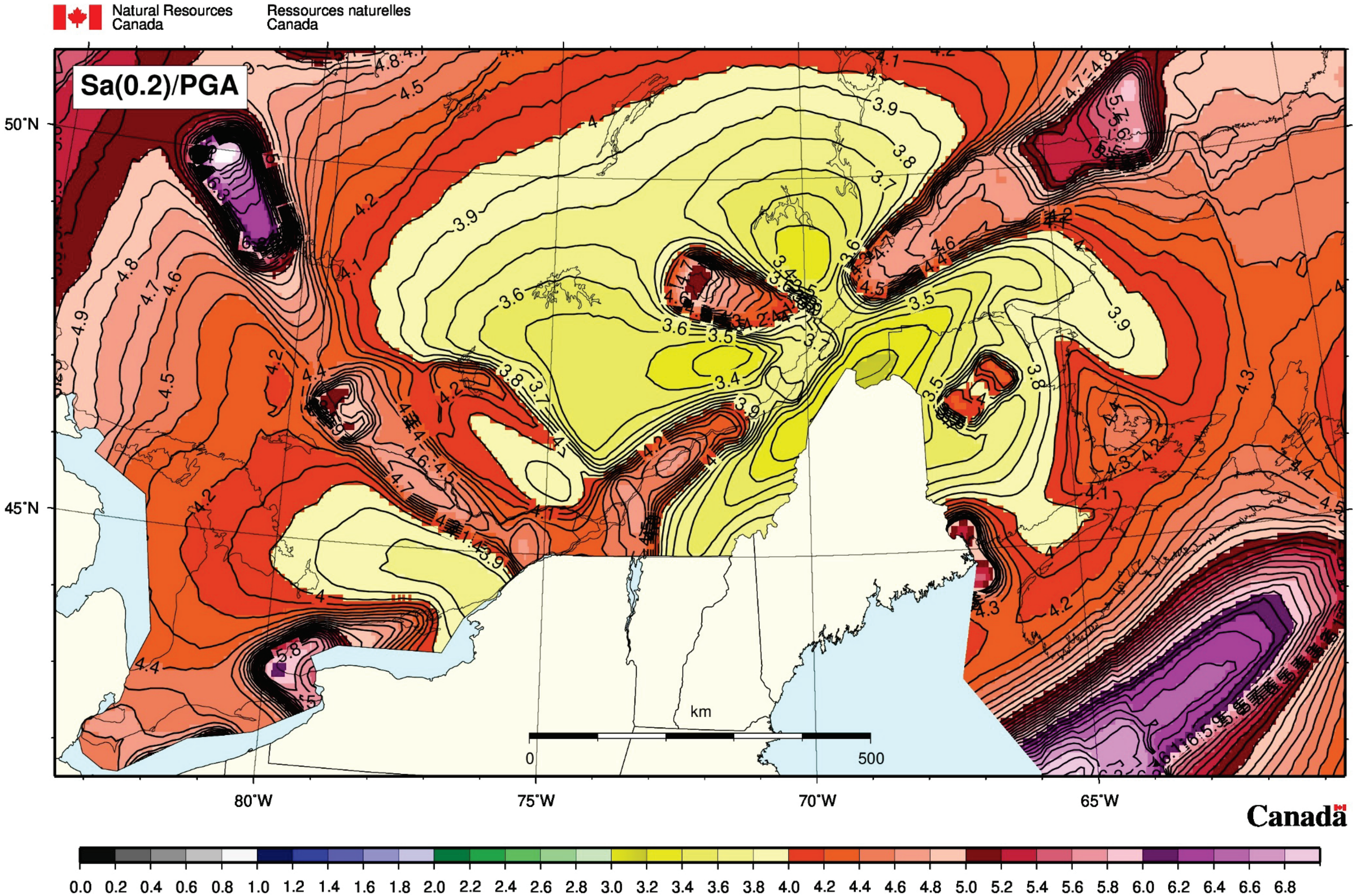


Figure A3-2. Ratio of 2%/50 year Sa(0.2)/10%/50 year PGA for southeastern Canada

Natural Resources Canada / Ressources naturelles Canada

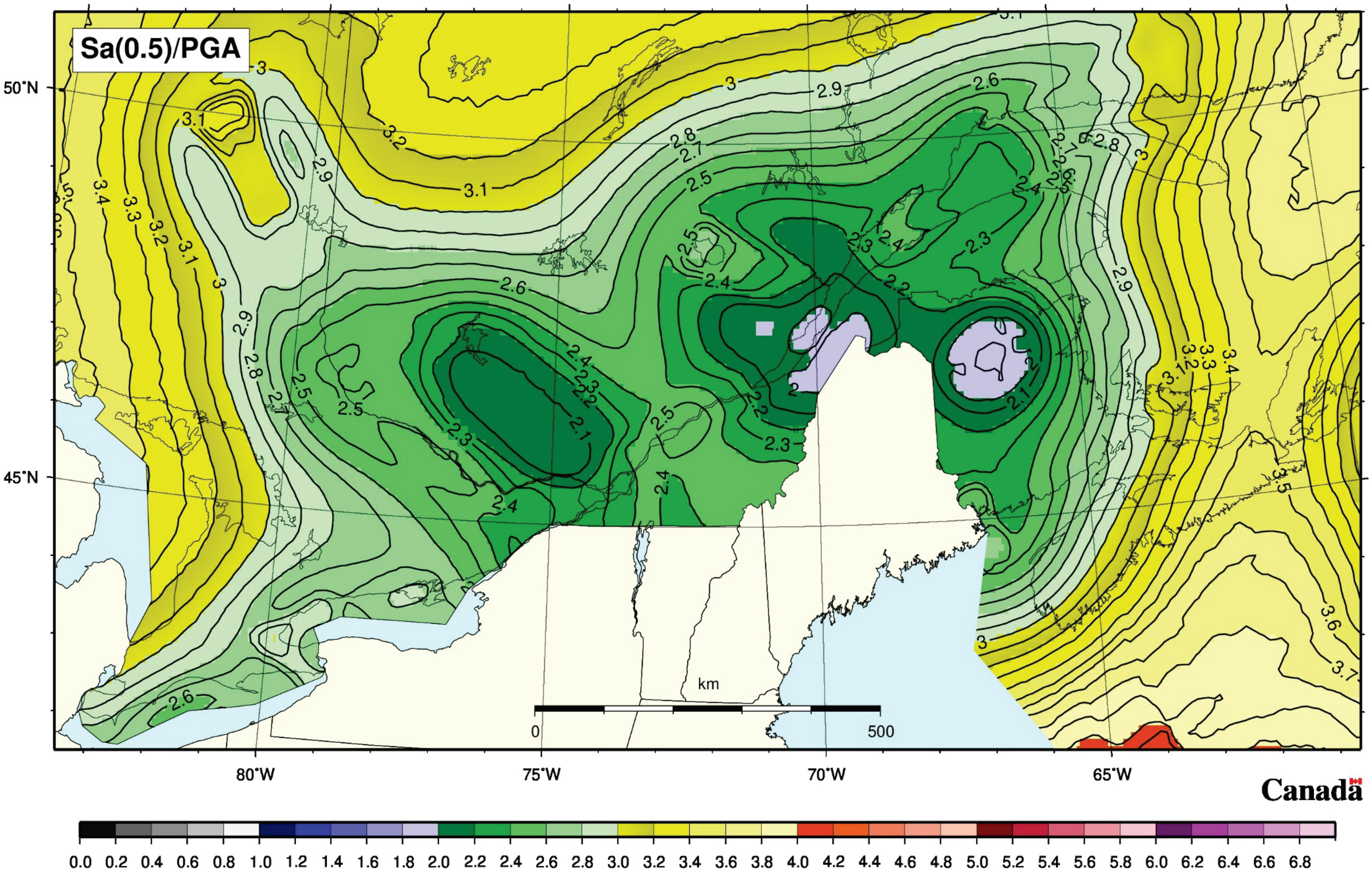


Figure A3-3. Ratio of 2%/50 year Sa(0.5) /10%/50 year PGA for southeastern Canada

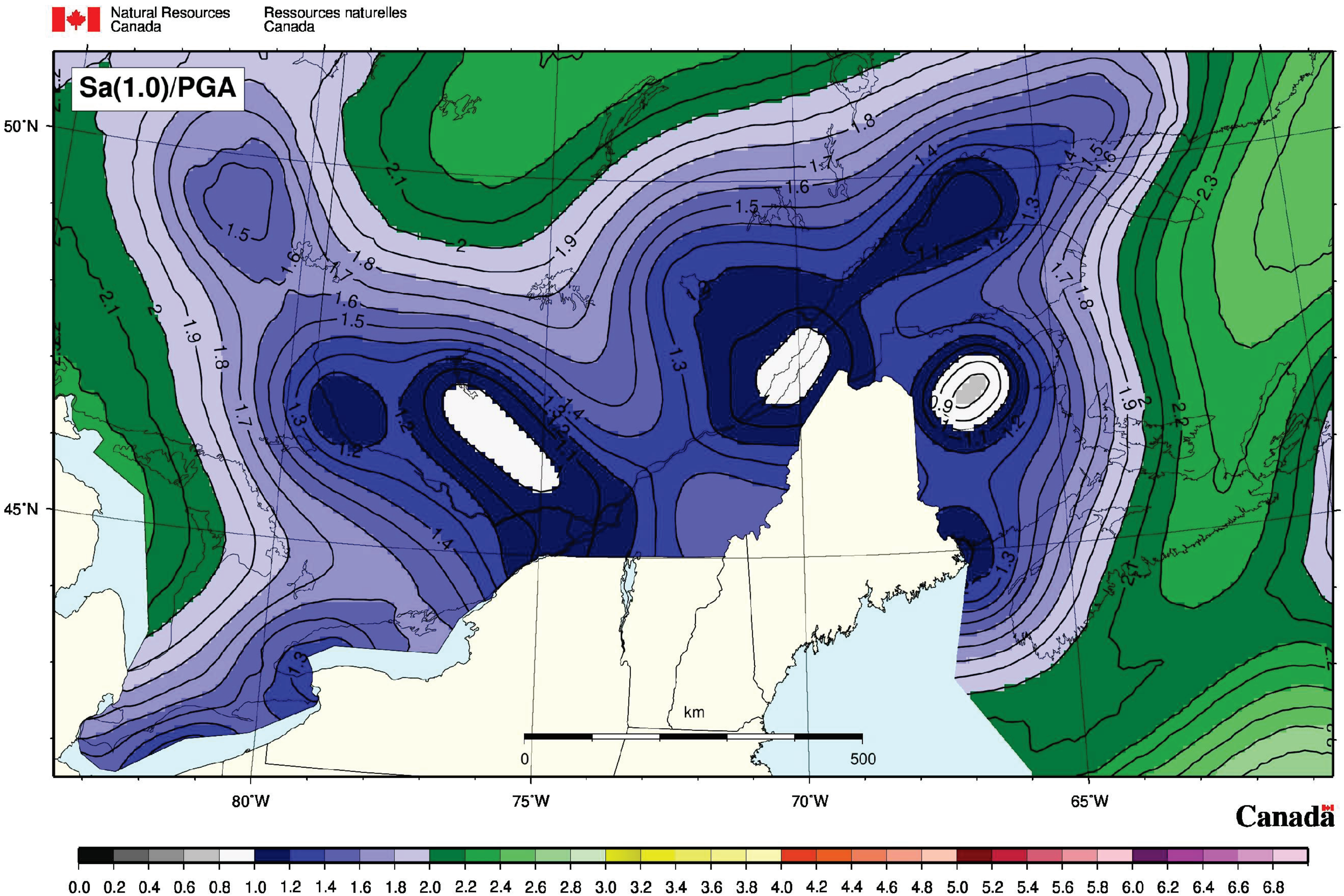


Figure A3-4. Ratio of 2%/50 year Sa(1.0) /10%/50 year PGA for southeastern Canada

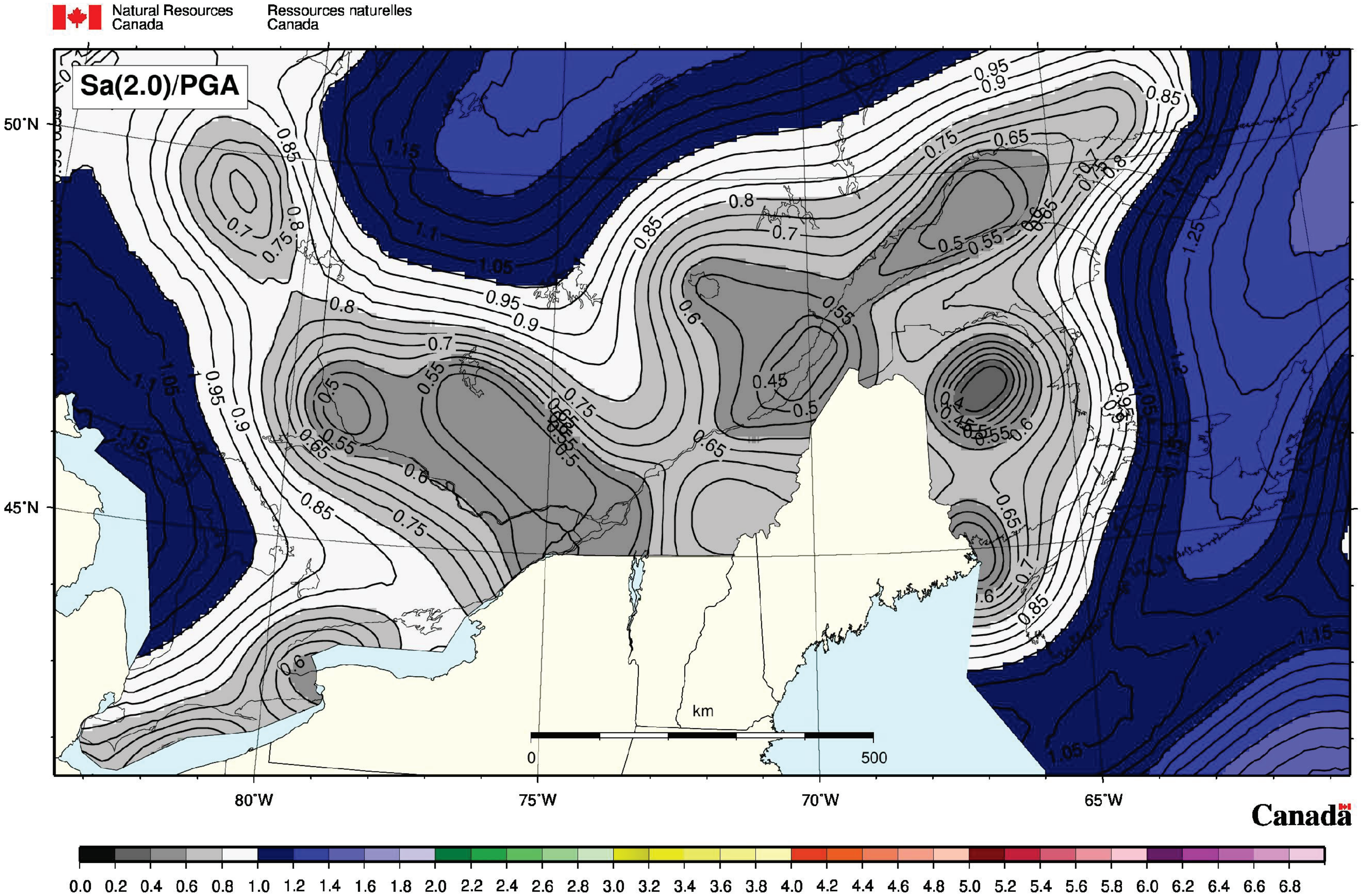


Figure A3-5. Ratio of 2%/50 year Sa(2.0) /10%/50 year PGA for southeastern Canada

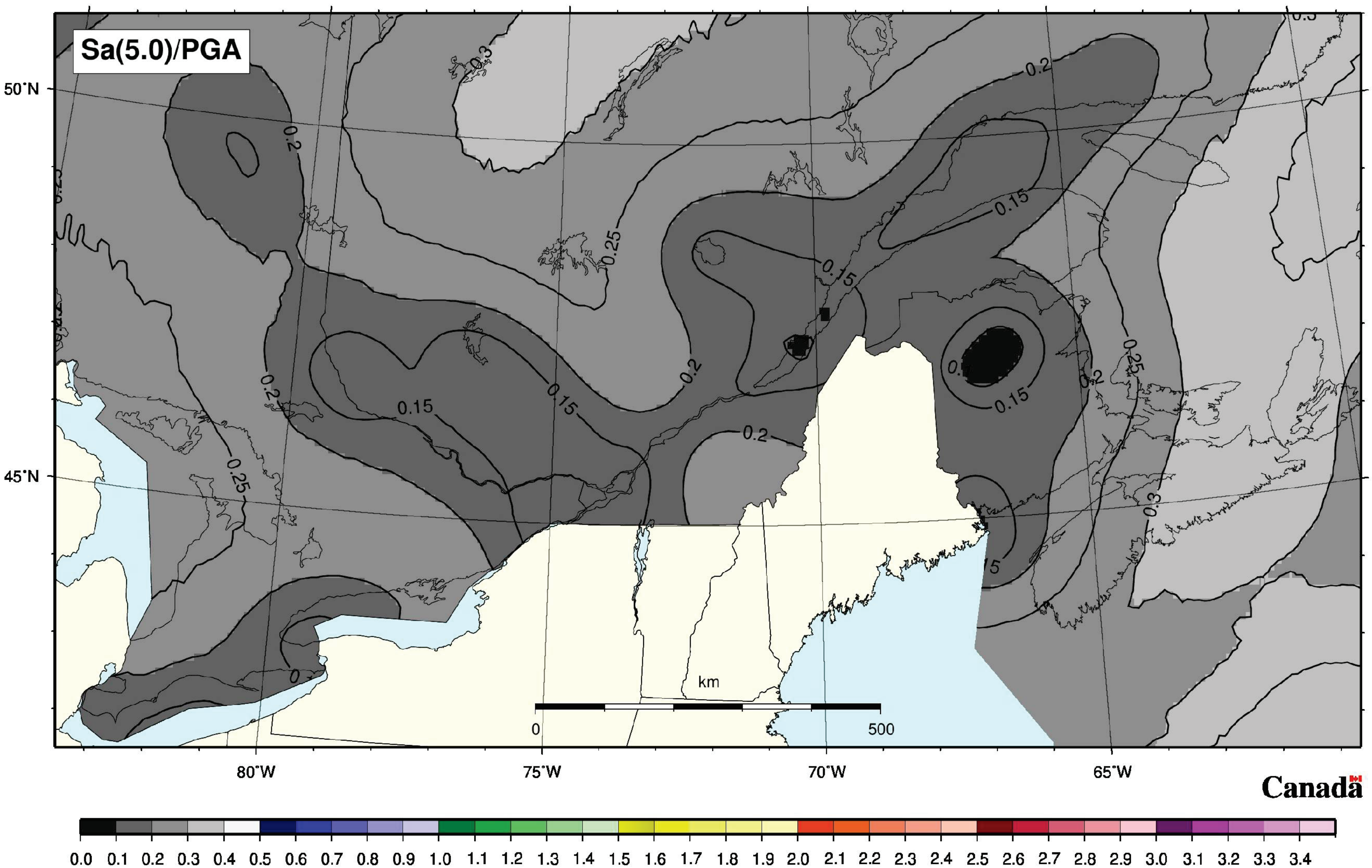


Figure A3-6. Ratio of 2%/50 year Sa(5.0) /10%/50 year PGA for southeastern Canada

Natural Resources Canada | Ressources naturelles Canada

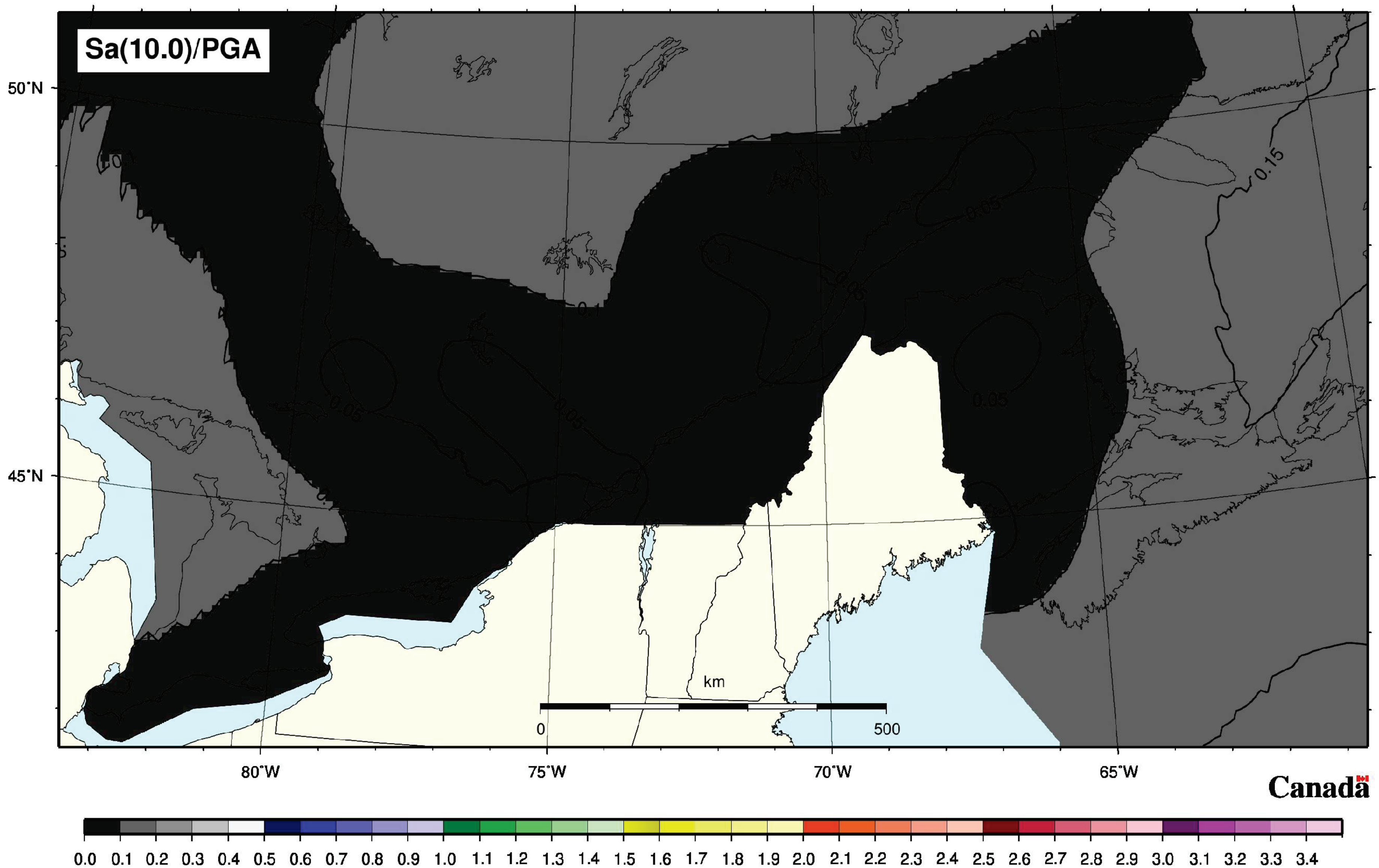


Figure A3-7. Ratio of 2%/50 year Sa(10.0) /10%/50 year PGA for southeastern Canada

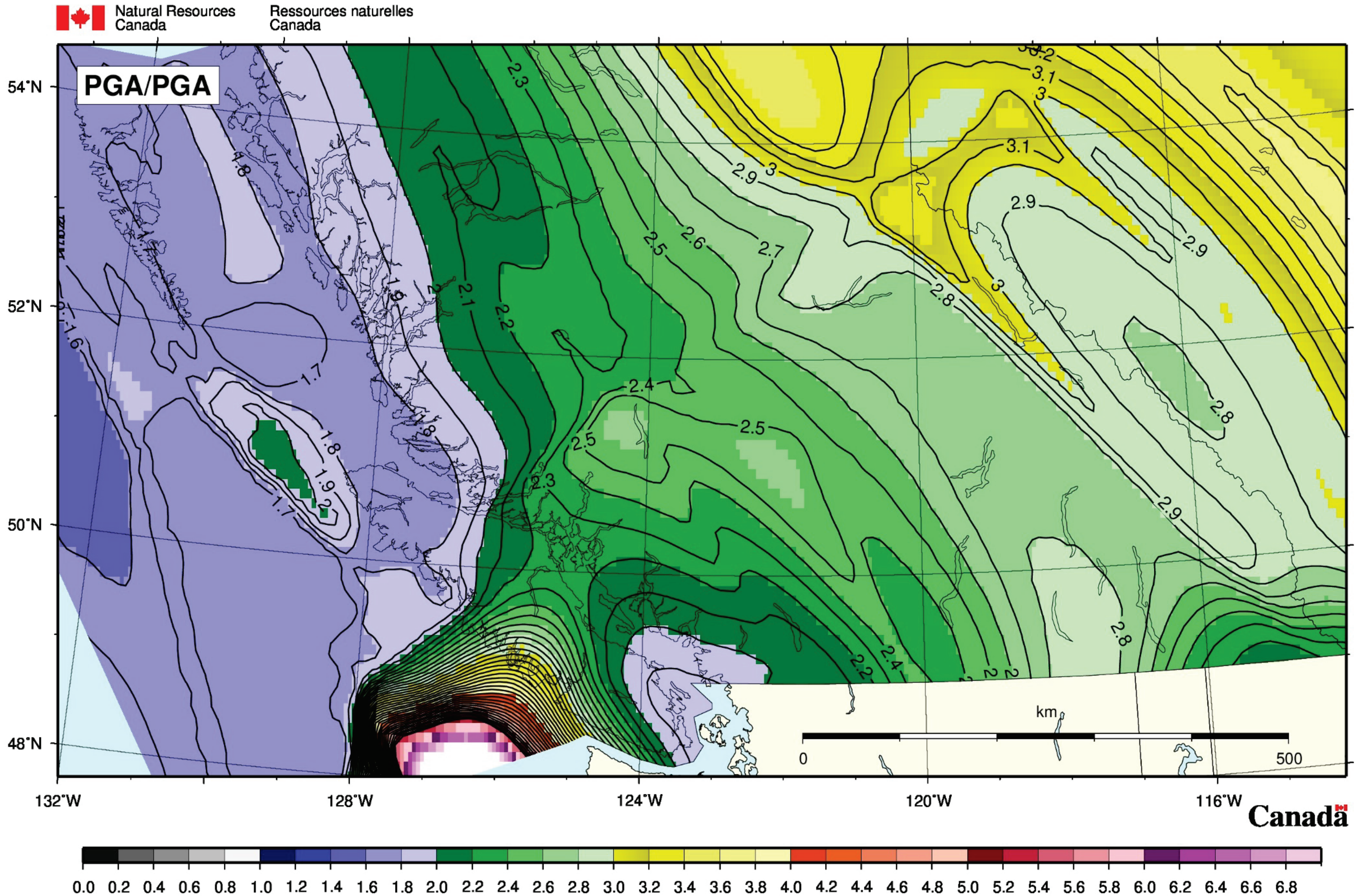


Figure A3-8. Ratio of 2%/50 year PGA /10%/50 year PGA for southwestern Canada

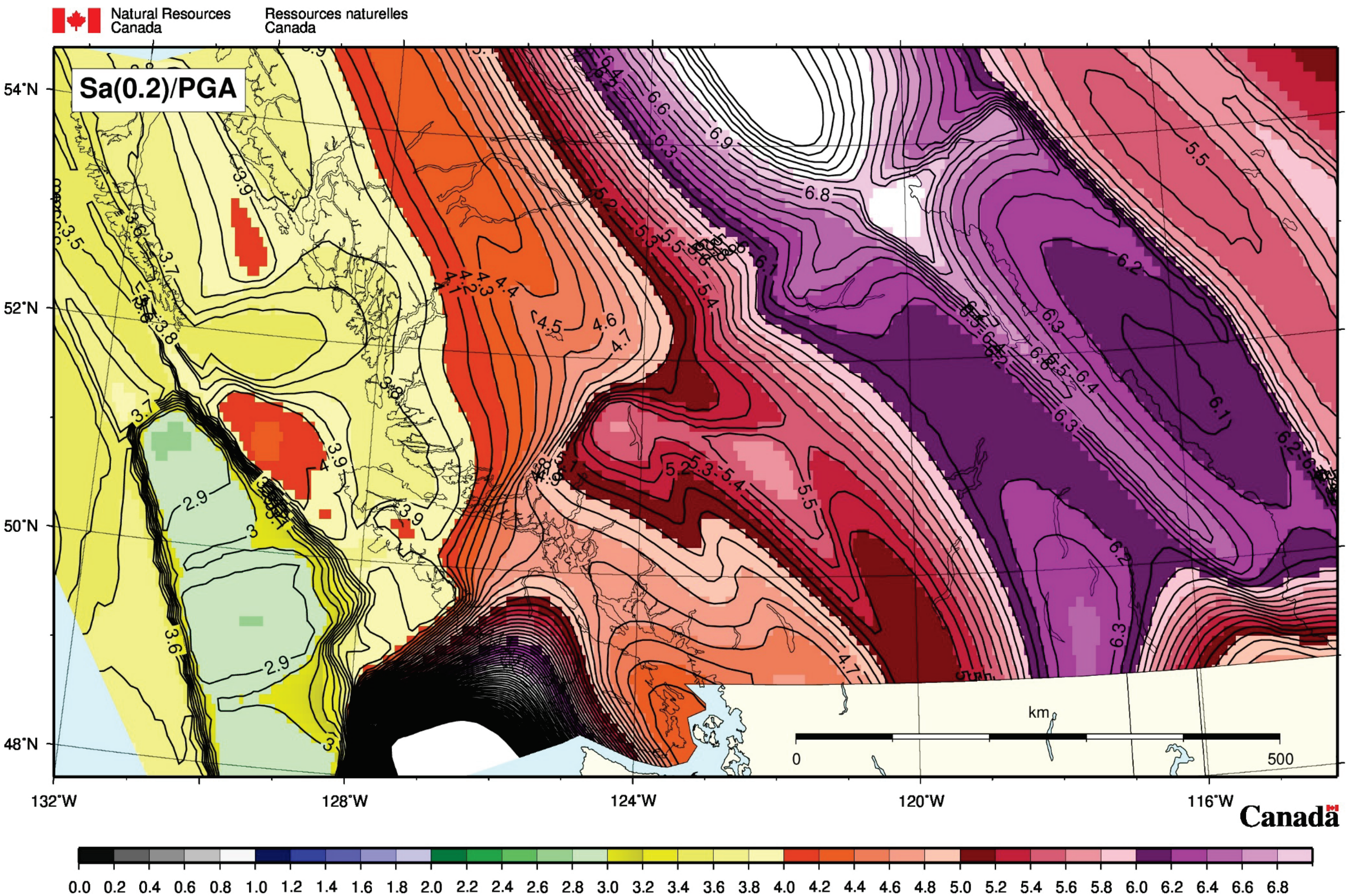


Figure A3-9. Ratio of 2%/50 year Sa(0.2) /10%/50 year PGA for southwestern Canada

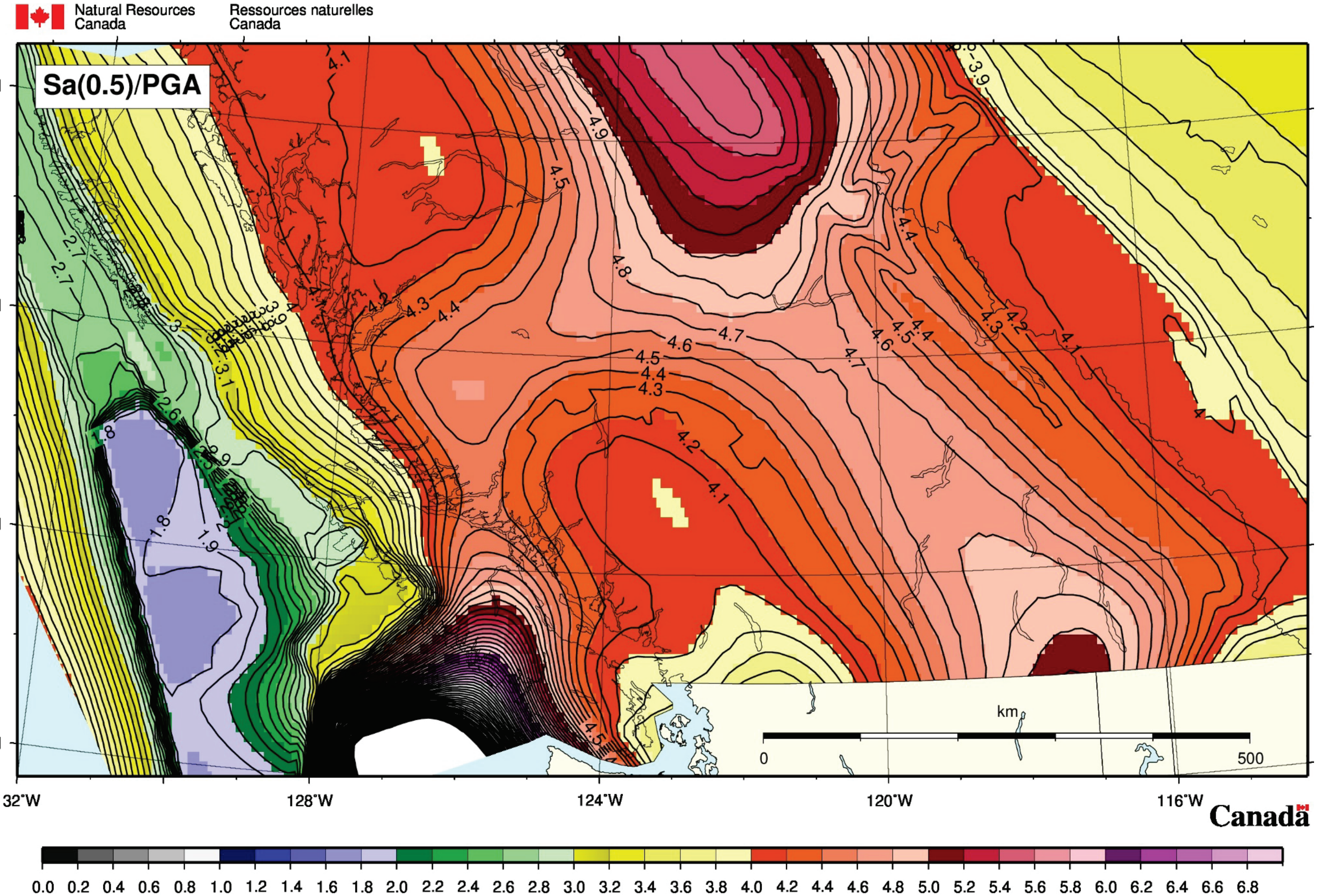


Figure A3-10. Ratio of 2%/50 year Sa(0.5) /10%/50 year PGA for southwestern Canada

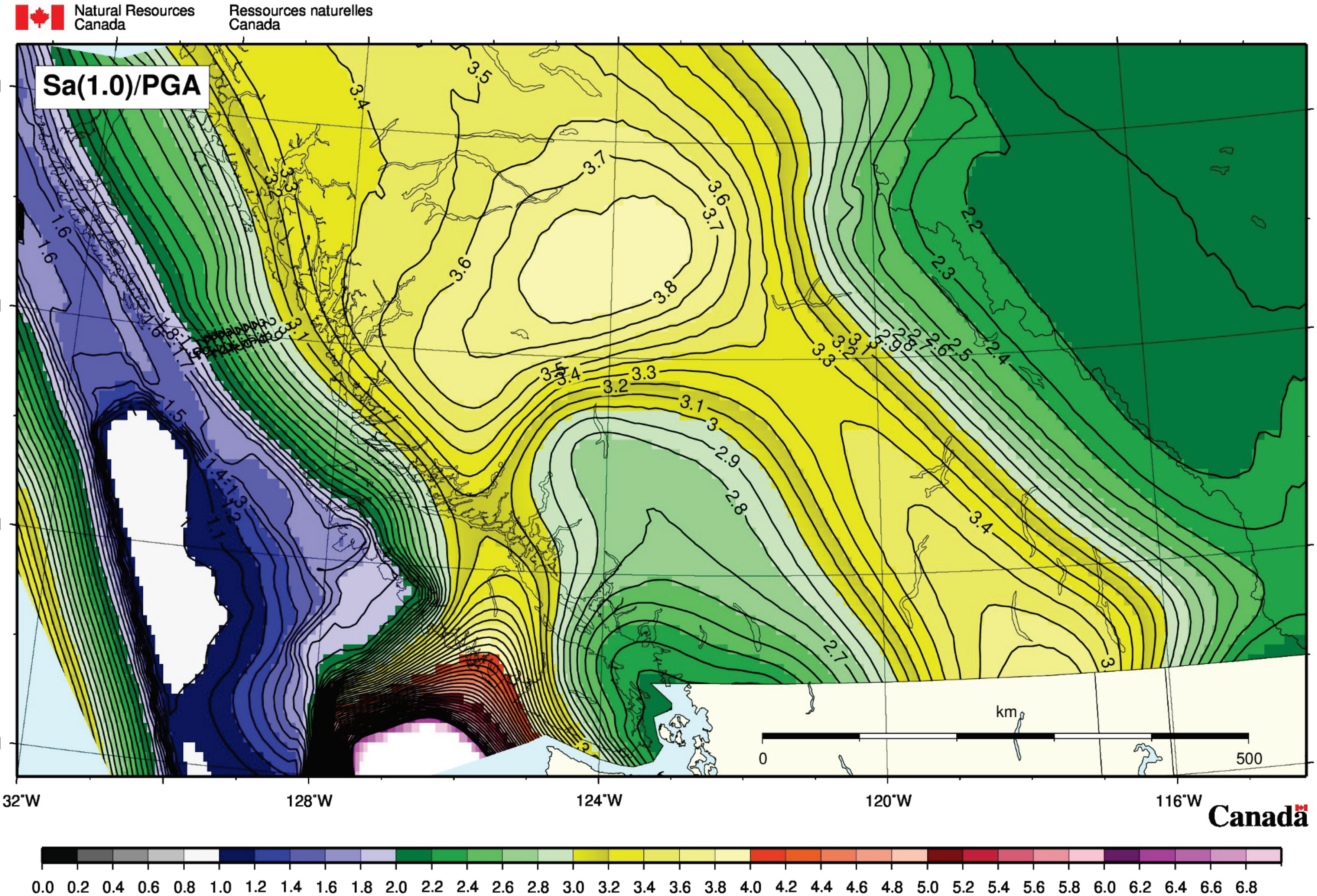


Figure A3-11. Ratio of 2%/50 year Sa(1.0) /10%/50 year PGA for southwestern Canada

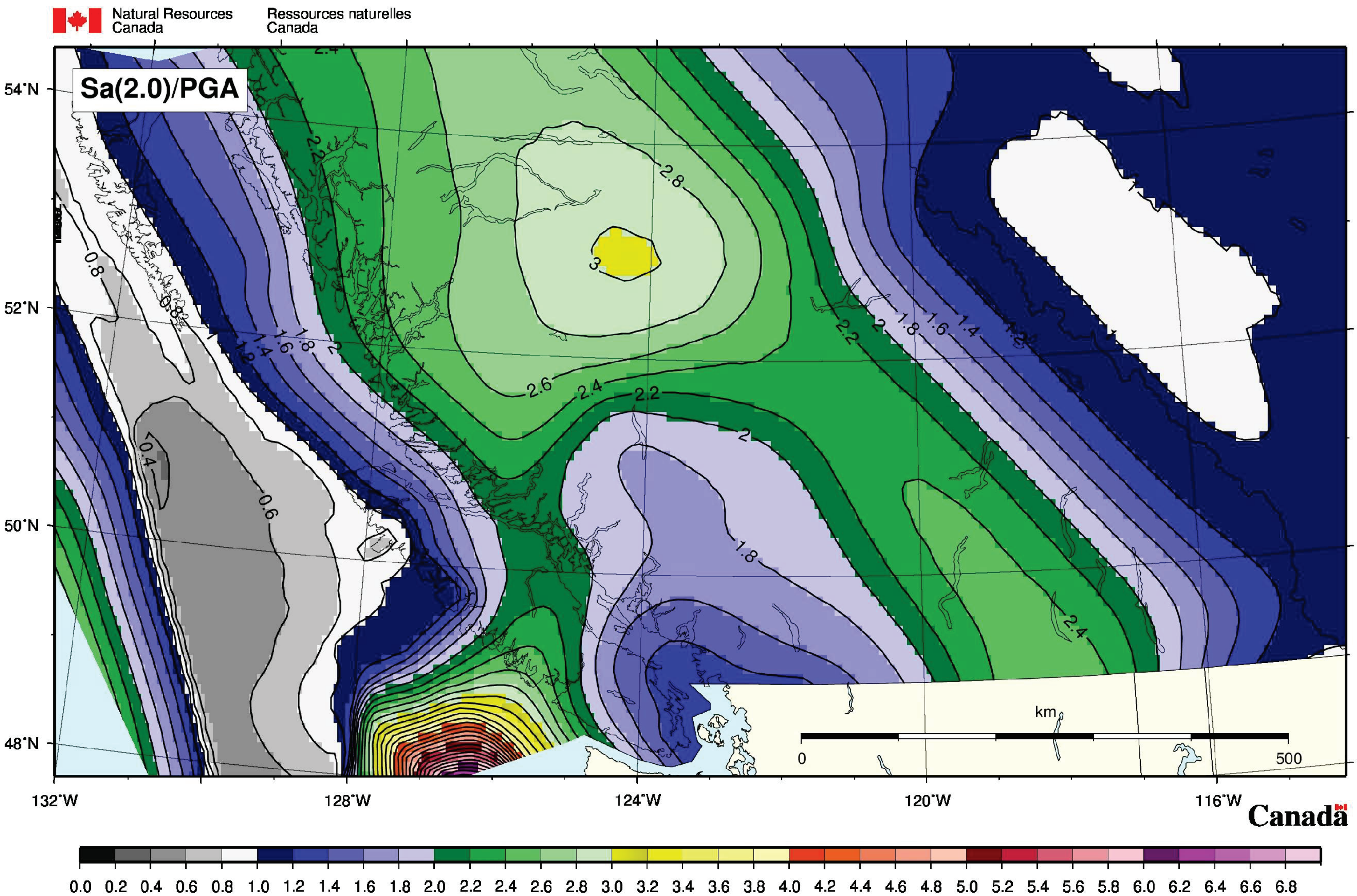


Figure A3-12. Ratio of 2%/50 year Sa(2.0) /10%/50 year PGA for southwestern Canada

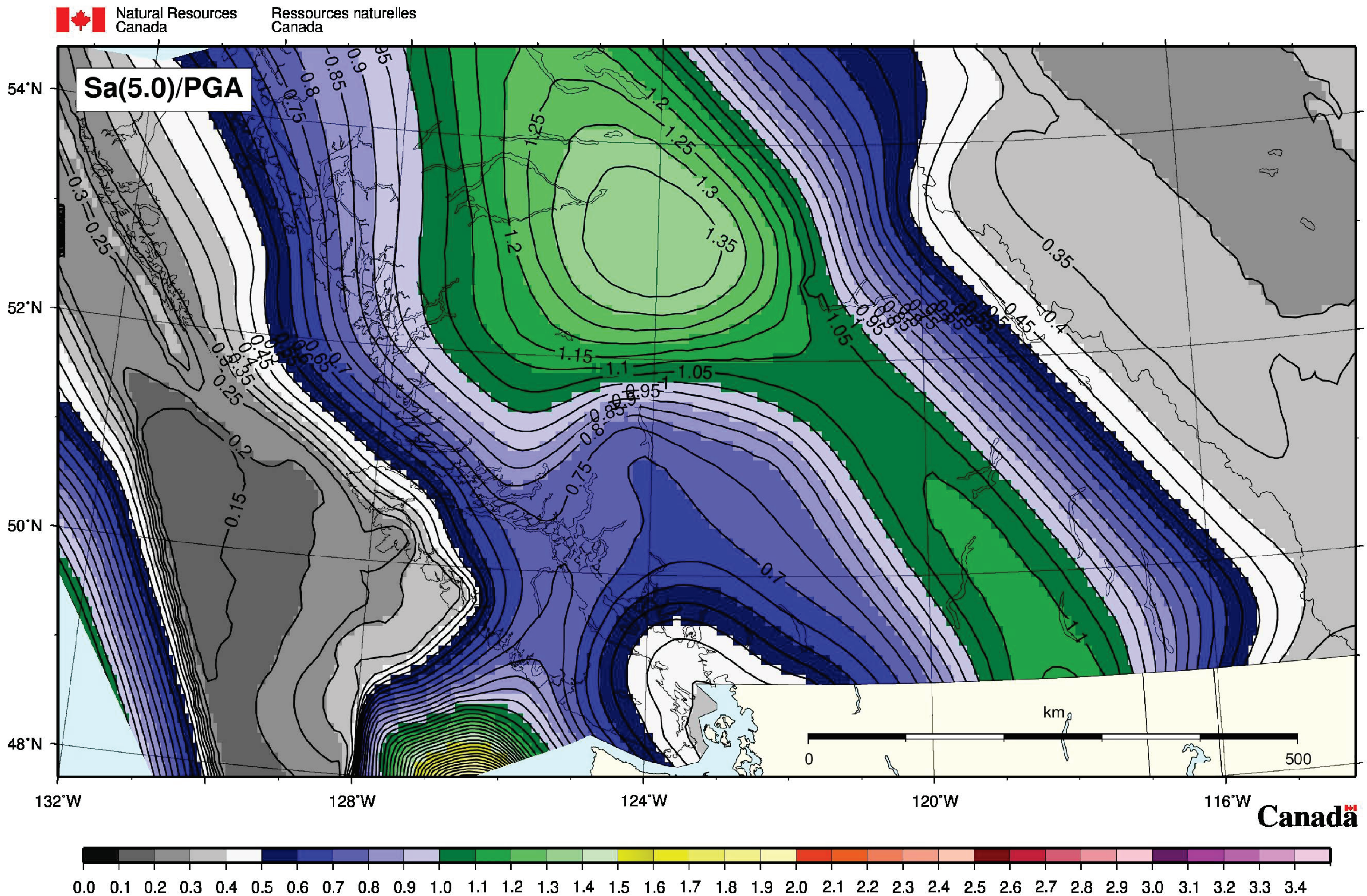


Figure A3-13. Ratio of 2%/50 year Sa(5.0) /10%/50 year PGA for southwestern Canada

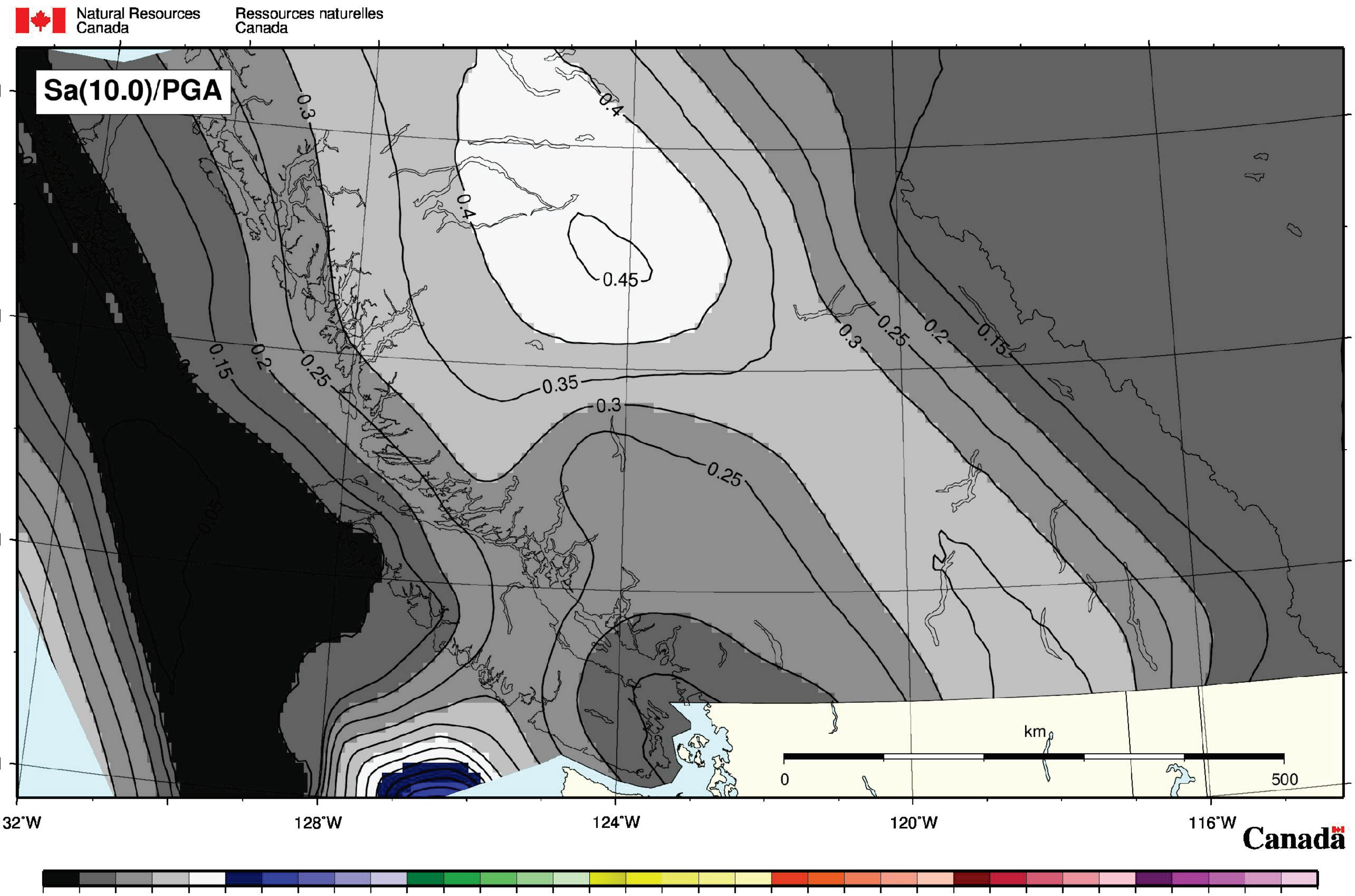


Figure A3-14 Ratio of 2%/50 year Sa(10.0) /10%/50 year PGA for southeastern Canada

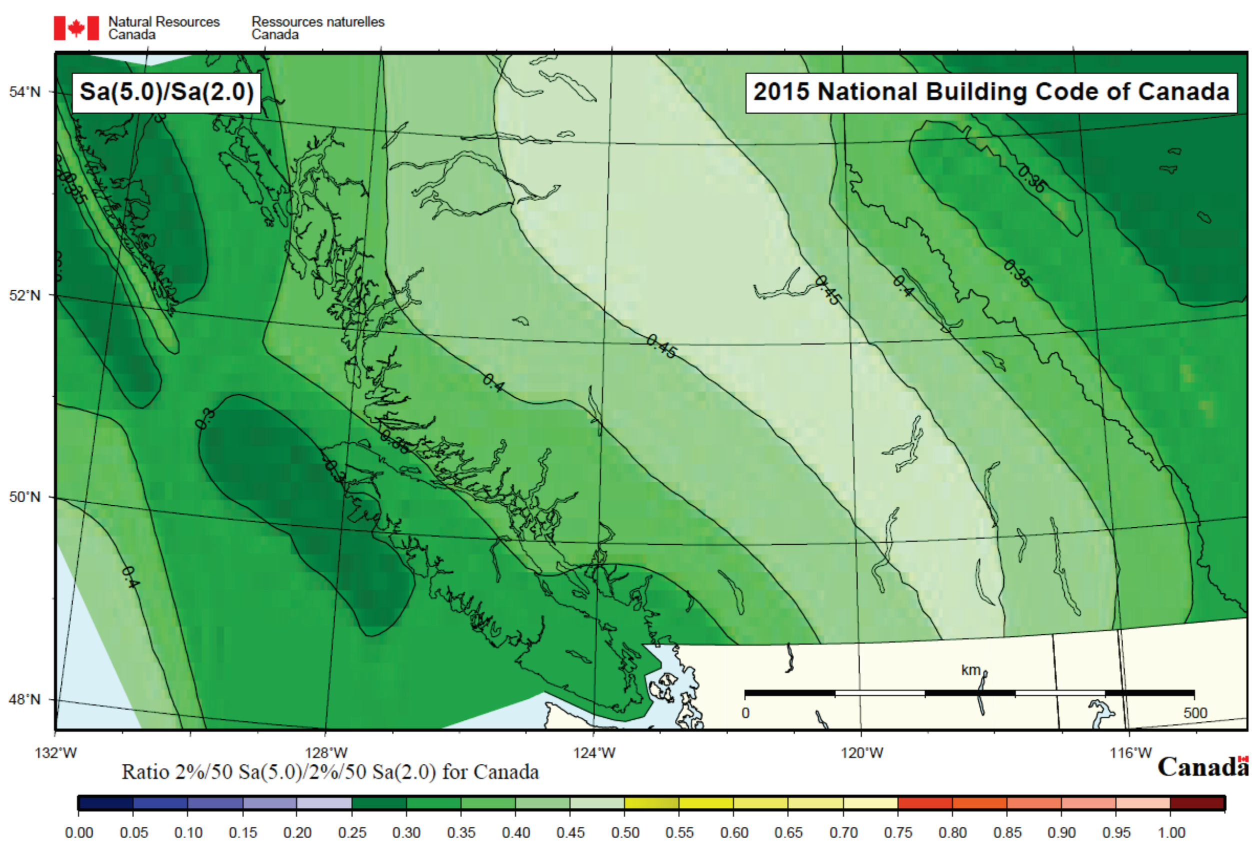
APPENDIX 4 Ratios for spectral shapes B, C, and D

Maps used to determine ratios for spectral shapes A are given in Appendix 3.

For spectral shapes B, C, and D a further 16 maps were used (see digital directory Appendix4_SE_SW_CanadaRatioMaps):

> Spectral shapes 1B, 1C, and 1D are spatially invariant (from Winnipeg values), so no maps
> B spectral shapes are from Sa(1.0) to Sa(2.0), Sa(5.0) and Sa(10.0) (SE and SW maps for each, so 6 maps)
> C spectral shapes are from Sa(2.0) to Sa(5.0) and Sa(10.0) (SE and SW maps for each, so 4 maps)
> D spectral shapes are from Sa(4.0) to Sa(5.0) and Sa(10.0) (SE and SW maps for each, so 4 maps)
> Also SE and SW maps for Sa(0.2) to Sa(0.5), so 2 more maps.

An example map for Sa(2.0) to Sa(5.0) (i.e. the ratio Sa(5.0)/Sa(0.2)) is included below.



APPENDIX 5 Quick Start Guide to Spreadsheet

The “Quick Search” tab is the main The “Quick Search” tab is the main tab for a summary of the seismic hazard for a single Mission. The tab is set up as a printable one-page summary. There are sections at the top and bottom of the page should the user wish to add headers/footers to the page.

Important note: Macros must be enabled for this Excel Workbook, otherwise nothing will work.
Enabling macros may pose security threats to your computer or organization’s network

Step-by-step instructions

Numbers in square brackets refer to the orange highlighted numbers on the spreadsheets, as shown in Fig 5-1.

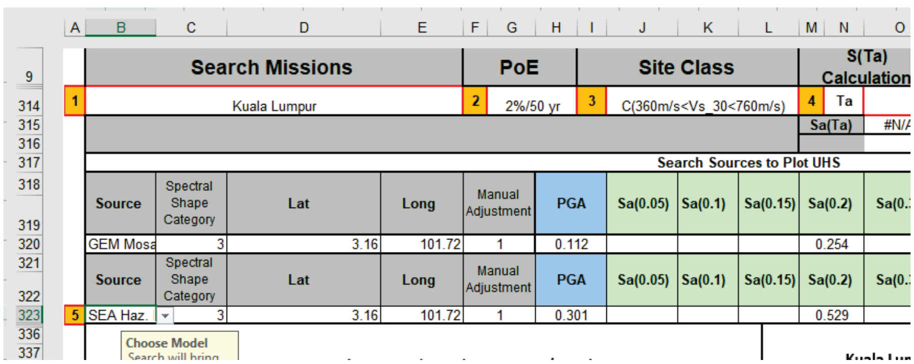


Figure 5-1. The five key cells (orange boxes) used to choose parameters.

A. Enable Macros for Excel Workbook (click “enable content” in the yellow box at the top of the spreadsheet). Nothing will work if this is not enabled.
B. Type mission name into [1].
    a. You can either type, or use the drop down list, to select missions
    b. As you type the mission names should autofill
    c. All accents must be included in the name (see Figures 5.2 and 5.3)

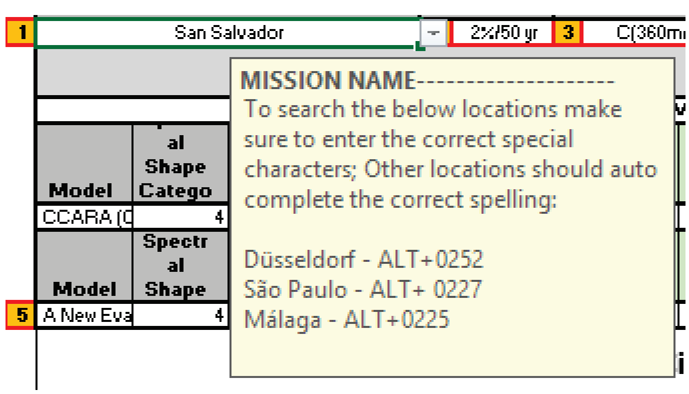


Figure 5.2: Tool tip when Mission name cell is selected.

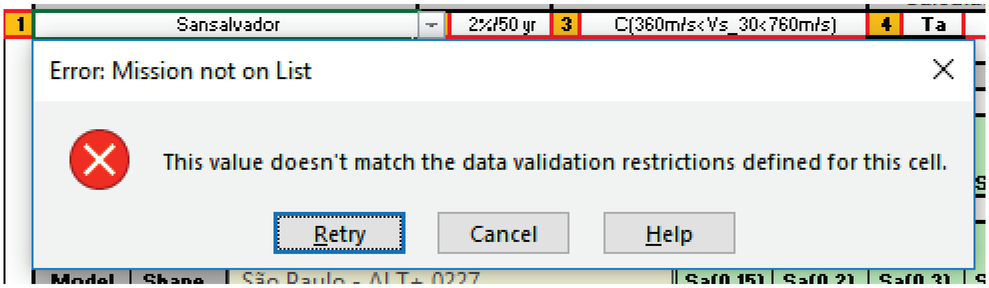


Figure 5.3: Error message if exact Mission name is not found; in this case a space was missing from the name.

C. Choose the probability of exceedance (PoE) from drop down list [2].
D. Choose the Site Class from drop down list [3].
   a. Site Classes A-D (including B/C boundary) are available
E. (Optional) Enter a period Ta into [4] to compute a linearly-interpolated Sa(Ta) value (using NBCC2015 rules) from the available values on the '2020DFAIT_Missions List(2%)' tab. Note the Sa(Ta) interpolation is only available for the 2%/50 yr hazard values.
F. (Optional) Under "Other Source", choose an additional available source to compare from second drop down list [5].
   a. The first (top) data set comes from the '2020DFAIT_Missions List(x%)' tab, where x corresponds to the PoE in 50 years entered in step C.
   b. If more than one additional model is available for the chosen locality, you can pull their data for comparison [5], one at a time.

Results

Available Sources

Available sources are listed in yellow cells towards the top right, and are categorized into 2 groups:

Seismic Hazard Values

This source has been evaluated to give the best estimate of the seismic hazard for the given location. These are the finalized values that appear in the '2020DFAIT Missions List(x%)' tab, where x corresponds to the PoE in 50 years entered in step C.

Superseded or unused sources

Any additional sources that we came across while building the database are reported here; these are supplementary data if a user wants to look at additional data sources.

Results are given in rows 320 and 323.

Row 320 contains best estimate of the seismic hazard for the given location.

Row 323 contains other estimates of the seismic hazard based on superseded or unused reports. The source displayed is the model selected in step F above. Only available models should show up in the drop down list. If 2%/50 year is selected, and if data is available, '2008 GSC' will be an option that appears.

Comparison to 2008 Values (right centre)

This section lists the 2020 and 2008 data and provides a percentage difference between the two. Note that it will always show 2%/50 year values, even when another selection is made.

2020v2008 Values (2% / 50 yr, Site Class C only)					
-100.00%			100.00%		
Source	PGA	Sa(0.2)	Sa(0.5)	Sa(1.0)	Sa(2.0)
2020	0.38	0.60	0.31	0.15	0.07
2008	0.43	0.78	0.33	0.14	0.05
	-13%	-24%	-7%	4%	39%

Figure 5-4: Comparison to 2008 values. Blue indicates a decrease since 2008, red indicates an increase since 2008

Uniform Hazard Spectrum Plots

Three plots showing Uniform Hazard Spectra (UHS) are available at the bottom of the page to give a visual representation of the hazard.

- The first plot (left) shows all available data as UHS on a log-log scale (with PGA plotted at 0.01 s)
- The second plot (centre) shows UHS for all periods greater than 0.1s, on a log-linear scale
- The third plot (right): compares the 2%, 5% and 10% UHS on one plot

The left-most two plots also show the UHS for Vancouver, Toronto and Winnipeg, as representative Canadian cities with high, moderate, and low hazard, respectively.

Plot titles, Site Class and probability of exceedance choices are based on the selections made in the above sections. Because the choices change greatly where the data plots, the position and formatting of the legend, and for Missions with long names the plot name, may need to be adjusted prior to printing.