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Crossing the Border: Assessing the differences between new Canadian and American seismic hazard maps

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ABSTRACT

The Geological Survey of Canada's new suite of seismic hazard maps will form the basis of seismic design codes in the year-2001 edition of the National Building Code of Canada. The USGS has released a similar set of maps in 1996 for the 1997 NEHRP. While there is general agreement in relative hazard levels, as shown by comparing hazard between Canadian and appropriate U.S. cities, hazard contours do not necessarily match across the border. Differences in the definition of source zones, choice of attenuation relations, and incorporating Cascadia subduction earthquakes all contribute to these cross-border differences.

INTRODUCTION

The Geological Survey of Canada (GSC) and the United States Geological Survey (USGS) have both recently completed a new generation of seismic hazard maps. At the border, the two agencies have a common set of recorded historical seismicity, share an understanding of the seismotectonics, and agreement on the probability levels and ground motion parameters to be mapped. While there is some similarity in how the seismic hazard model is constructed, the approaches differ in detail. For eastern Canada the GSC applied the Cornell-McGuire method to two new seismic source models, one historical and one geological. In the eastern US the USGS employed spatially-smoothed representations of historic seismicity (together with direct input for a few large earthquakes and a background source zone) to avoid using subjective source zones to calculate hazard. Hence not all the hazard captured by the GSC's "geological" model (e.g. how often large earthquakes may happen in areas of low historical seismicity) is represented in the USGS results. For western Canada the GSC used two source zone models but combined them with a deterministic estimate for a repeat of the 1700 A.D. Cascadia subduction earthquake. This is very different from the USGS's incorporation of Cascadia subduction earthquakes into its probabilistic model.

METHODS

The methods used by the GSC and the USGS have been well documented (e.g. Adams et al., 1995 and 1999a; Frankel et al., 1996). The GSC applies the traditional Cornell-McGuire (e.g. McGuire, 1993) method of delineating source zones based on historic seismicity and/or regional tectonics. Hazard is calculated with a customized version of the FRISK88 program (a proprietary product of Risk Engineering), which includes epistemic uncertainty. The GSC has adopted four models - two sets of probabilistic source zones that attempt to capture the spectrum of knowledge for seismicity and tectonics, a deterministic Cascadia model in southwestern Canada, and a newly-proposed probabilistic floor level for the "stable" part of Canada (see Adams, 1999b). The hazard values from these models are combined in a "robust" fashion (Adams et al., 1995, 1999a), i.e. by choosing the highest value from the four models calculated at each point. The "robust" approach preserves protection in areas of high seismicity while providing increased protection in regions of low historical seismicity that are geologically not unlikely to experience future large earthquakes.

The USGS employs spatially smoothed representations of historical seismicity for different magnitude events in combination with data from individual faults. Hazard is computed with a new suite of software developed by Frankel et al. (1996), with the assumption that earthquake occurrence is Poissonian with time-independent probability. Probabilistic hazard is calculated without the use of subjective source zones. Different magnitudes and completeness times were used to determine recurrence parameters in the western and eastern US. An adaptive weighting was used to ensure that the rate of earthquakes within any calculated cell did not fall below the historic value, the final values maintain the hazard in the areas of historic seismicity and provide some additional hazard to low seismicity regions.

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Strong Ground Motion Relations

The different physical properties of the crust in eastern and western North America, and different types of earthquakes, require the use of different strong ground motion relations. The Canadian and US choices are detailed below, with the references being given in Adams et al. (1999a) and Frankel et al. (1996). In Canada, the GSC placed the transition from eastern to western attenuation approximately 400 km east of the Rockies (near 106W at the border). In the United States, the USGS placed the boundary along the eastern edge of the Basin and Range province (near 114W). Hence, US sites east of this boundary are computed with eastern attenuation and can be expected to yield higher hazard estimates than for adjacent Canadian sites.

Region/earthquakes	**Canada**	**United States**
Eastern	Atkinson & Boore (1995)	Toro et al. (1993) + Frankel et al. (1996)
Western crustal	Boore et al. (1993, 1994)	Boore et al. (1994) + Sadigh et al. (1993) + Campbell and Bozorgnia (1994)
Western subcrustal	Youngs et al. (1997) @50 km depth	Youngs et al. (1997) @40 km depth
Cascadia subduction	Youngs et al. (1997)	Sadigh et al. (1993) + Youngs et al. (1997)

COMPARISONS AT THE CANADA-US BORDER

In Table 1 we group selected Canadian and US cities we consider to have similar seismic hazard. Where we believe that each agency's model is adequate, we provide both sets of results for PSA0.2 and PSA1.0 for a direct comparison. Site conditions used for the US calculations are slightly firmer than for Canada (760 m/s vs 560 m/s). Therefore we have increased the USGS PSA0.2 values by 10% and the PSA1.0 values by 15% in order to match their results to ours, factors we based on the NEHRP Fa/Fv ratios. The same factors were applied to the US values before we contoured Figures 1-3. For a second comparison, Figures 1a and 1b show that a significant overlap in coverage occurs along the eastern border of the two countries. Remembering that neither agency endorses the use of its hazard values beyond its border and that edge effects come into play near the bounds of each model, one can still see similarities and differences in the application of the two countries' methods to a common area of significant size.

In eastern Canada, GSC hazard values in the Appalachians are generally higher than USGS values. The GSC's regional model spreads the historical seismicity from northern New York to northern New Brunswick, whereas the USGS method concentrates the hazard in the historically active northern New Brunswick and southern New Hampshire regions. The cities of Fredericton and Portland show generally comparable hazard (Table 1), though for PSA0.2 the GSC has Fredericton higher than Portland, while the USGS has Portland higher than Fredericton. The similarities of the Charlevoix region occur because the USGS specifically adopted the magnitude recurrence slope determined by the GSC (beta=1.74, b=0.76). The steeper slope (beta=2.20, b=0.95) obtained by the USGS based on the entire eastern US catalogue and applied to the entire region generally results in lower hazard for historically active zones when compared to the GSC, which determines magnitude recurrence relations for most zones directly (compare hazard for northern Ohio (beta=2.05), Buffalo-Hamilton (beta=1.80), southern New Brunswick/Maine border region (beta=1.72), and the lower St. Lawrence (beta=1.93); all yielding higher hazard than from the USGS model (beta=2.20)).

The main difference in the east occurs where the GSC model attempts to provide protection to regions with few historical earthquakes. The regional zones of the GSC model generate hazard values that are up to twice those from the smoothed-historical USGS approach (e.g., compare Figures 1a and 1b at Tadoussac (46N 72.5W), and the upper Ottawa River, (46N 78W)). Despite these differences, the overall similarity in contour level and pattern is high. Hazard determined for both Montreal and Ottawa is quite comparable for both long and short periods (Table 1). We group Boston and New York with Montreal and Ottawa, rather than Fredericton and Portland (which have comparable calculated hazard according to the USGS), because of our understanding that New York lies near to the Iapetan passive margin and both New York and Boston lie near rift basins of the present passive margin. Thus we implicitly argue that the USGS's estimates, based on the short historical record, may have underestimated their long-term hazard. Around the southern Great Lakes, the long-period hazard for the three large cities determined by the GSC is slightly lower than that of the USGS, but the PSA0.2 values are slightly higher from the GSC model. When the hazard values from each agency are cut off at the border, the differences are minimal and most contours match well (Figs 2c and 2d).

Calgary and Denver are cities we judge to have broadly similar seismotectonic environments and although direct inter-comparison of results is not possible, the GSC places Calgary at a lower hazard level than the USGS places Denver. Kelowna and Spokane are both mid-cordilleran cities and have comparable hazard levels (Table 1). As was evident in the comparisons of the previous generations of hazard estimates (Basham et al., 1985), the USGS model still has more active earthquake sources contributing to the hazard in the northern Idaho-Montana region than does the GSC's model.
A western comparison of US and Canadian hazard estimates is shown in Figure 2a and 2b, which compare the GSC and USGS PSA0.2 and PSA1.0 estimates in the southwest border region (USGS's Alaska results are not yet available). Along the western portion of the border, different attenuation relations, the treatment of the Cascadia zone, and the implementation of individual fault models result in the USGS hazard being higher than the GSC values. For the Cascadia subduction zone, the USGS uses two scenarios which they include in their probabilistic model: a floating M8.3 earthquake somewhere in the zone every 110 years, or a M9 earthquake rupturing the entire zone every 500 years. The GSC treats the Cascadia earthquake as a deterministic magnitude 8.2 event, and consider its effects only where they exceed the probabilistic hazard from other earthquakes, chiefly along the west coast of Vancouver Island. The higher magnitude events in the USGS Cascadia scenarios, their shallower depths, and probabilistic treatment provide the larger coastal hazard values in the west.

Although GSC and USGS values are broadly the same for Vancouver and Victoria at high frequency,(Table 1), the long period hazard determined by the USGS is higher due to its treatment of the subduction earthquakes. The USGS's Seattle results are 50-80% higher than ours, perhaps because the underlying Seattle fault is included as a separate source by the USGS. The PSA1.0 estimates (Figure 2b) are also similar in the Puget Sound region. In the west, the PSA0.2 (Figure 2a) estimates match very well in the border region of Puget Sound, despite difference in modeling of the shallow and deep (Juan de Fuca Plate) seismicity, and different treatment of the Cascadia subduction earthquake. The San Francisco results, shown for comparison, indicate that even the Canadian cities with the highest seismic hazard are only half to a third as hazardous as this well-known California city.

DISCUSSION AND CONCLUSIONS

While many differences have been featured in this paper, it should be emphasized that the similarity in level and pattern across the Canada-US border is generally good. Despite the use of different methods and attenuation relations, values for cities in similar tectonic environments agree to within 50%. Given the similar (but not identical) earthquake catalog and strong ground motion relations, this level of imprecision is not unexpected. The general similarity in cross-border values allows generation of a smoothed hazard map for use in public education (Figure 3). A ramp function applied to grid points within 100 km of the border was used for the transition between each country's hazard values. This map does not include the "floor" value (11 %g for this map) proposed for the central, low-seismicity part of Canada based on world-wide craton seismicity (Adams et al., 1999b; compare their figure 1); this would have eliminated the lowest contour in Canada and it imposes a slightly higher hazard level than the 6-7 %g determined for adjacent north-central US.

We would emphasize that the accuracy of the calculated values is still uncertain. While this uncertainty may be relatively small for regions with many well-recorded large earthquakes (such as California), it may be much larger for eastern North American where there is very little data with which to test the ground motion predictions which have been based chiefly on small non-damaging earthquakes.

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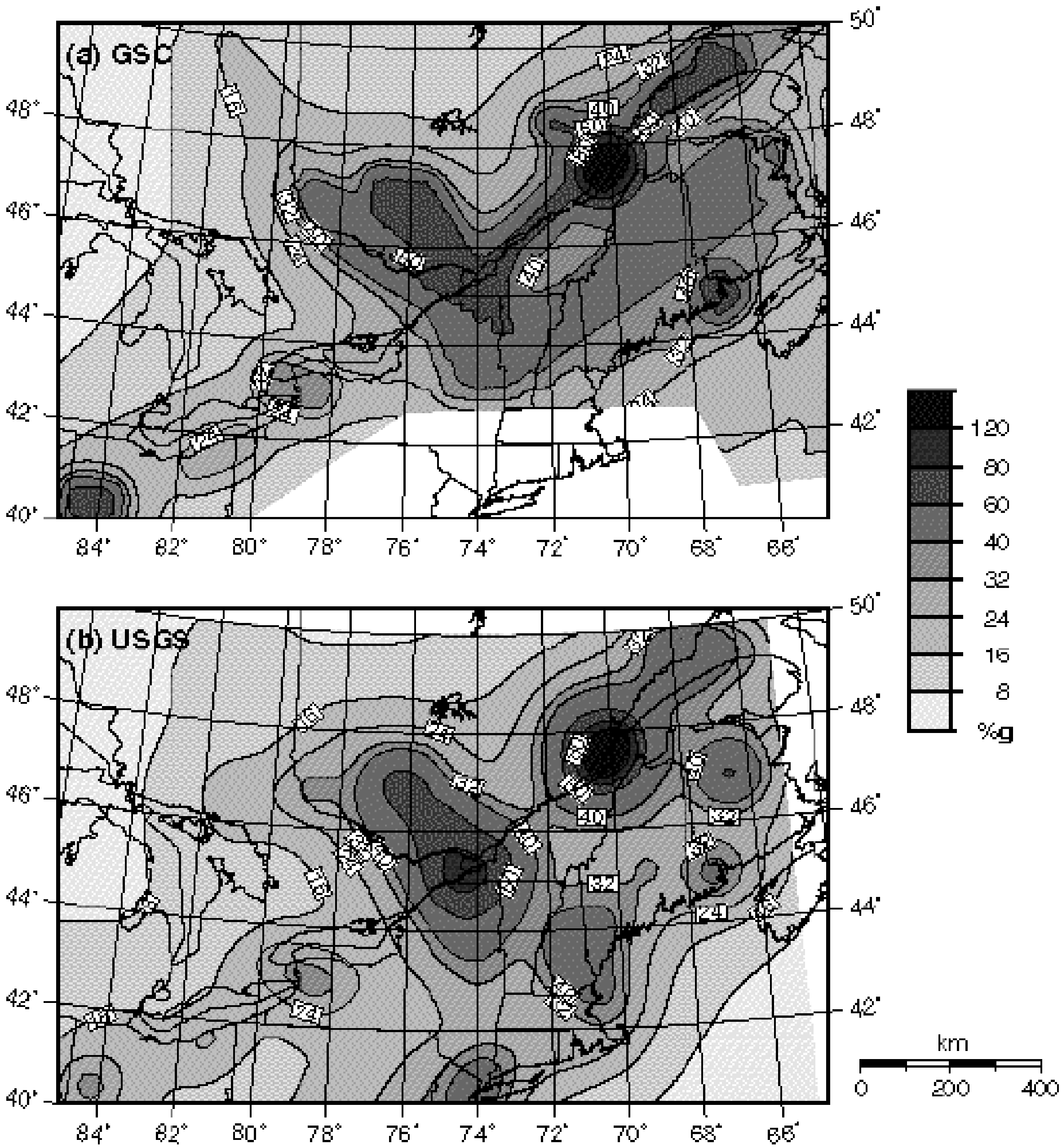

Figure 1. Comparison of PSA0.2 (2%/50 year probability) hazard generated by GSC (a) and USGS (b) models along the eastern border (USGS values have been increased by 10% to match GSC site conditions). Despite differences in the definition of source zones and choice of attenuation relations, the overall similarity in contour level and pattern is high. The USGS values used in this paper were taken from the USGS National Seismic Hazard Mapping Project web pages at http://geohazards.cr.usgs.gov/eq. All figures in this paper were created with the GMT package (Wessel and Smith, 1995).

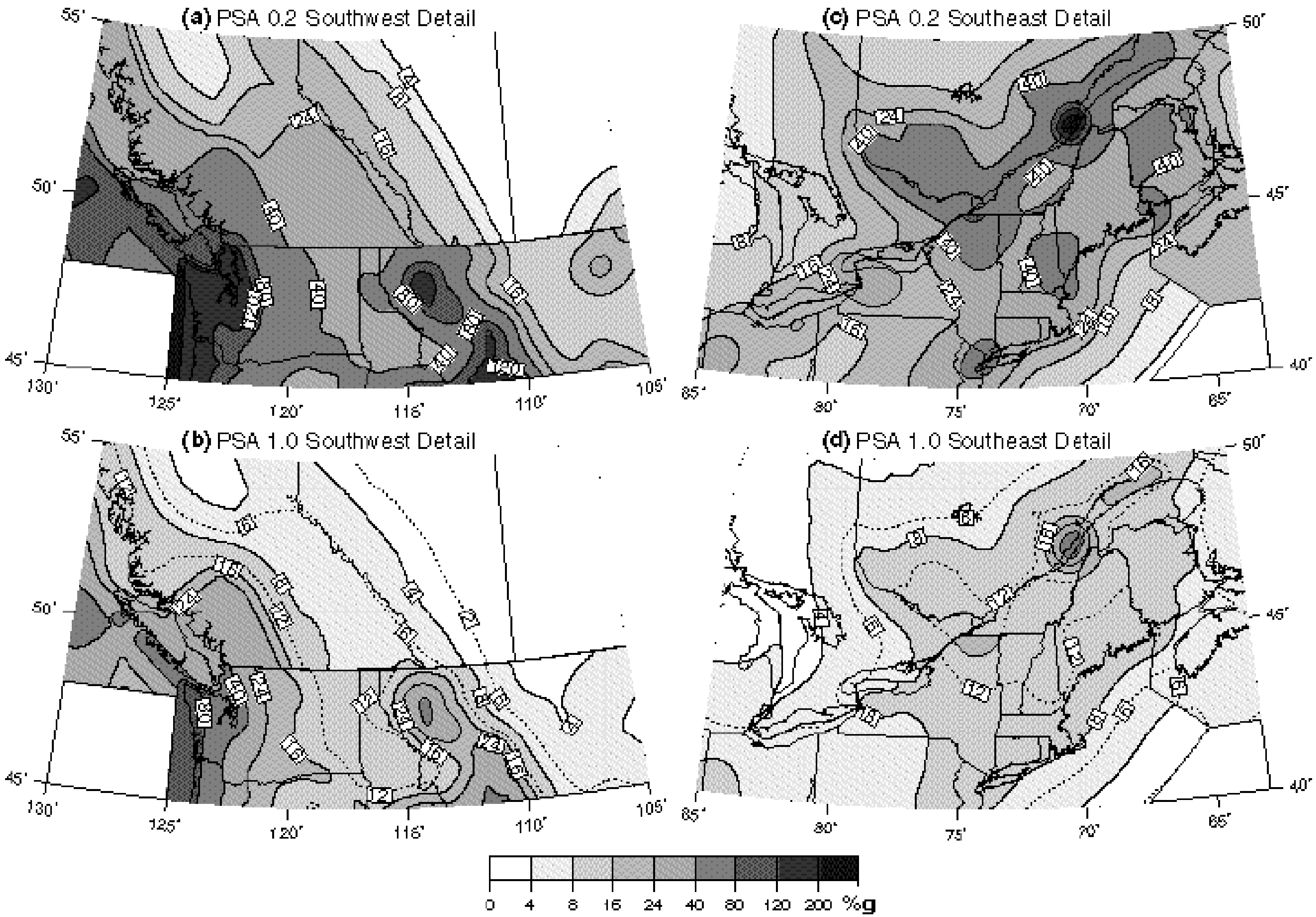

Figure 2. Comparison of PSA0.2 and PSA1.0 (2%/50 year probability) hazard estimates in western and eastern Canada-United States border regions. USGS PSA 0.2 and 1.0 values have been increased by 10% and 15% respectively to match GSC site conditions.

Table 1. Comparison of spectral accelerations (5% damped, 0.000404 p.a.) at selected Canadian and US cities for firm ground. USGS values have been corrected to match Canadian site conditions.

			PSA0.2 (%g)		PSA1.0 (%g)	
City	**Lat**	**Long**	**GSC**	**USGS**	**GSC**	**USGS**
Fredericton	45.9	66.6	39	30	8.6	10
Portland, Me	43.7	70.3	32	41	7.2	12
Montreal	45.5	73.6	69	70	14	17
Ottawa	45.4	75.7	67	60	14	15
New York	40.8	74.0	--	47	--	11
Boston	42.3	71.1	--	34	--	10
Toronto	43.7	79.4	28	22	5.4	6.7
Buffalo	42.9	78.9	39	35	6.8	7.9
Cleveland	41.5	81.7	28	23	5.0	6.7
Calgary	51.0	114.0	15	--	4.1	--
Denver	39.7	105.0	--	22	--	6.7
Kelowna	49.9	119.4	27	31	8.9	11
Spokane	47.7	117.4	--	35	--	11
Vancouver	49.2	123.2	100	120	34	46
Victoria	48.5	123.3	120	132	38	53
Seattle	47.6	122.3	120	177	37	64
San Francisco	37.8	122.5	--	264	--	167

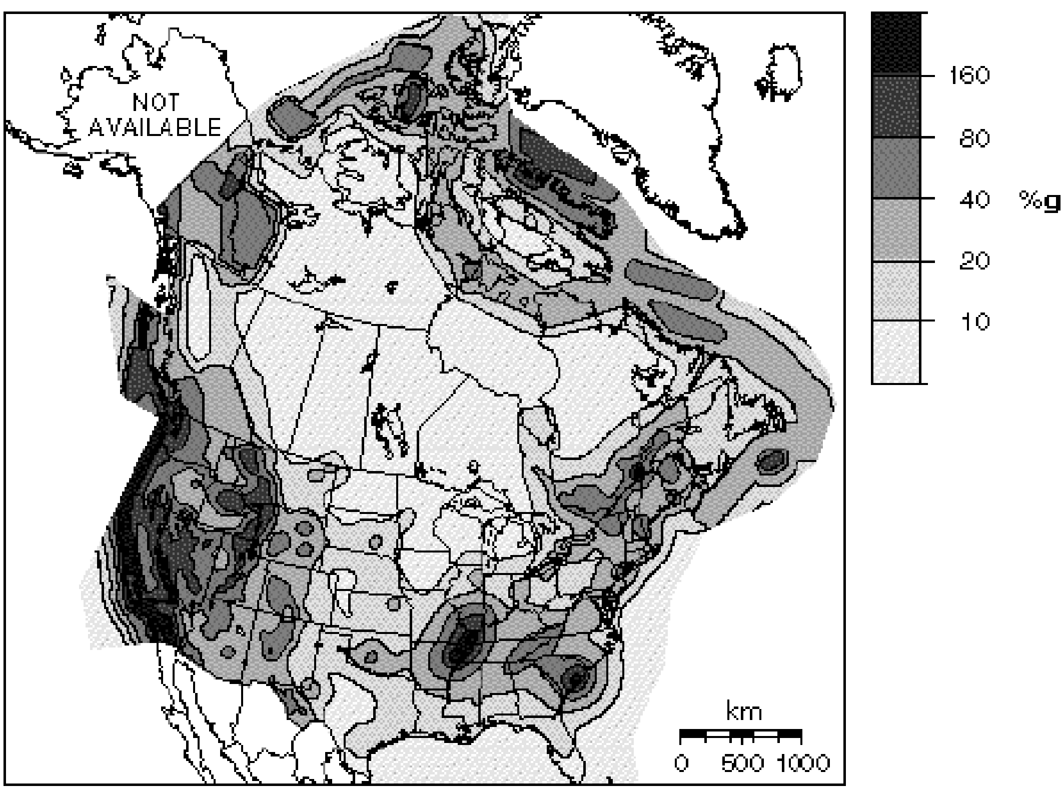

Figure 3. North American smoothed PSA 0.2 second hazard map. Differences at the border (which are generally less than 50%) are smoothed after correcting the USGS values to match Canadian site conditions and then applying a simple ramp function to a common set of points within 100 km of the border (the USGS Alaska results are not yet available).