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GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8027

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2016

Canada

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doi:10.4095/297965

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Recommended citation
Bent, A.L., 2016. Moment Magnitude (M_W) Conversion Relations for Use in Hazard Assessment in Offshore Eastern Canada; Geological Survey of Canada, Open File 8027, 12 p. doi:10.4095/297965

Publications in this series have not been edited; they are released as submitted by the author.

Abstract

Seismic hazard assessments based heavily on earthquake recurrence rates require that the same magnitude scale be used for all earthquakes evaluated to ensure that the assessment is unbiased and uniform across the area of interest no matter how large. Moment magnitude, M_W, is generally seen as the magnitude of preference in current practice. However, it was not routinely calculated in the past for earthquakes in Canada, necessitating the conversion from other magnitude types in common use. This paper focuses on the offshore regions of eastern Canada, including the eastern Arctic, where M_L is the day-to-day magnitude scale. Conversions to M_W are established and evaluated. Until very recently there were few M_W values determined for offshore earthquakes. In recent years, however, regional centroid moment tensor inversions have been run on a routine basis for earthquakes in this region allowing us to build up a database of moment magnitudes for the offshore. While the dataset is still smaller than for the adjacent onshore regions and somewhat restricted in magnitude range, it has enabled the development of an M_L-M_W conversion relation for offshore eastern Canada, which shows that, on average, M_L is 0.21 magnitude units greater than M_W. Statistical tests show no advantage to using a linear relation over a straight constant conversion.

Introduction

Magnitude recurrence rates are a primary data source for seismic hazard assessment in Canada and elsewhere. The Canadian National Earthquake Database (CNED, 2016) hereafter referred to as the CNED, routinely reports several earthquake magnitude scales for Canadian earthquakes with M_N and M_L being the most commonly used for eastern Canada. The use of the latter usually means the former could not be calculated.

The use of a mixed data set in the evaluation of recurrence rates for use in hazard assessment may lead to non-uniform or even erroneous results. Thus, it is crucial to use the same magnitude scale for all earthquakes in the dataset. Moment magnitude or M_W has become the preferred magnitude scale as it can be related to the physical properties of the earthquake rupture and does not saturate at high magnitudes. However, moment magnitude was not routinely calculated in the past in Canada and using it for hazard assessment requires the determination of reliable M_W's for all earthquakes used in the hazard calculations. This paper focuses on offshore eastern Canada including the eastern Arctic. Similar studies have been undertaken to derive M_W conversions for mainland eastern Canada (Bent, 2011; Bent and Greene, 2014) and for western Canada (Ristau et al, 2003, 2005). In this paper I consider a conversion equation for offshore events with M_L. For these, M_N is not appropriate because their S-wavetrain lacks Lg energy or their Lg energy is clearly attenuated. For reference, M_N is the Nuttli (1973) magnitude scale with the modifications suggested by Wetmiller and Drysdale (1982).

There are at least two other types of M_L used in eastern Canada: pre-1980 onshore earthquakes for which magnitudes were computed before M_N was defined (M_N's for most of these back to about 1940 have subsequently been determined from amplitude data but some events remain as M_L's) and small earthquakes up to the present for which there is no amplitude data at a station beyond 50 km; these small earthquakes are not crucial for seismic hazard but Bent and Vadnais (2016) have developed an M_L-M_N magnitude conversion relation for close distances.

Moment magnitude has been determined for most of the largest earthquakes in eastern Canada and for many of the moderate ones. Bent (2009) evaluated data for the 150 largest earthquakes that met the completeness criteria for use in hazard assessment in eastern and northern Canada and determined M_W's for each of them. Furthermore, with the routine use of region centroid moment tensor (RCMT) inversions in Canada (Kao et al., 2012) it is now almost always possible to determine M_W for eastern and northern Canadian earthquakes of magnitude 5.0 or greater and also possible for many of the magnitude 4 to 5 earthquakes. Therefore, in developing a conversion scale, the emphasis is on the smaller (less than magnitude 5.0) earthquakes.

The approach used in this study is similar to that of Bent (2011) in the development of an M_N-M_W conversion relation. A database of offshore eastern Canadian earthquakes for which an instrumentally determined M_L and M_W are available was established and used to develop a conversion relation. Almost all of the M_W's were determined by regional centroid moment tensor inversion but there are a small number of events with instrumental M_W's calculated by other methods.

M_L to M_W

As previously noted, in eastern Canada the M_L scale is normally used only in cases where the M_N scale is inappropriate for the distance or path and the earthquake is too small for a teleseismic magnitude (e.g. M_S, m_b) to be a viable alternative. In practice, this means that it is used primarily for small and moderate offshore events. Thus an M_L-M_W conversion should be based on earthquakes occurring in the offshore regions and not those occurring on the southeastern mainland. M_L is the Richter (1935) scale with no alterations for eastern North American attenuation.

Until recently, there were very few independent, instrumental M_W values for offshore eastern Canadian earthquakes. By independent, I mean that M_W was determined directly from the waveforms, usually by modeling, and not converted from another magnitude type. In recent years, RCMT inversions have become more or less routine in eastern Canada and the number of M_W determinations for this region, while small compared to some others, has increased significantly allowing for the development on magnitude conversion relations.

Based on the complete data set of 29 earthquakes (Table 1) and assuming that the conversion relation is a constant

$$M_W = M_L - 0.21 \pm 0.27 \text{ (S.D.)}$$

If a linear relation is assumed the best fit in a least squares sense is

$$M_W = 0.44 + 0.86M_L \pm 0.25 \text{ (S.E.)}$$

These relations are shown with the data in Figure 2. Given the relatively small size of the data set, more complex conversion relations were not explored. Residuals, the difference between M_W obtained by conversion and the instrumentally obtained M_W, were calculated using the above conversion relations and compared. In both cases, the mean residual is orders of magnitude smaller than the precision to which magnitude is calculated. The mean residual for the constant conversion is 0.0003 ± 0.27 and for the linear conversion, it is -0.006 ± 0.25. The statistical f-test shows that the difference is not statistically significant ($p = 0.927$). Thus, the simpler constant conversion relation is preferred.

Discussion

The earthquakes used in the analysis span a wide geographic range although they would all or mostly be considered passive margin events. To determine whether there are regional differences in the conversion relation, the dataset was divided into three groups based on geographical location: south (Laurentian Channel/Slope and vicinity), central (primarily Labrador Sea), and north (primarily Baffin Bay). These groups were not further subdivided by any other parameter due to the small number of events in each region. Three events east of the southern coast of Newfoundland did not clearly fit into either the southern or central group and the calculations for both groups were done with and without them. They were ultimately included in the central group as their M_L-M_W differences seemed more appropriate for that group. There do seem to be some regional differences as summarized in the equations below:

Southern (5 events): $M_W = M_L - 0.20 \pm 0.25$ (close to overall average)
Central (11 events): $M_W = M_L - 0.07 \pm 0.19$
Northern (13 events): $M_W = M_L - 0.33 \pm 0.30$

Despite the small numbers of earthquakes and the large standard deviations the statistical F-test shows that the differences are significant at approximately the 94% level. Therefore, it would be worth re-examining these regional differences at some point in the future with a larger dataset.

Three of the northern events (20120902, 20140207 and 20140518), while occurring beneath water, are not truly offshore and perhaps should not be included in this dataset. These are the three events that occur on the northwest margin of Figure 1. The calculations were redone with these events excluded. For the full data set there is very little difference; the constant conversion becomes 0.22. For the northern group of events the effect is somewhat greater with the constant increasing from 0.33 to 0.40.

Bent (2011) found a time-dependence in the M_N-M_W relation with the change of 0.12 magnitude units occurring in approximately 1995. It could not be determined whether the time dependence observed for m_N also applies to M_L as the number of events in the dataset used for the present study occurring prior to the 21st century is negligible. Subsequent research into the causes of the time dependence for M_N-M_W (Bent and Greene, 2014) showed that much of it could be attributed to the change in instrumentation and sampling rate when the network was upgraded in the 1990s. This change led to magnitudes being calculated at higher frequencies than they had in the past. M_L is also being calculated at higher frequencies (Figure 3) and thus a similar time-dependence is a possibility. If only the four 20th century events from the data set used in this study are considered, the conversion constant changes by 0.04 magnitude units to 0.25, suggesting that there is little or no time dependence. If only the CMT-derived M_W's are considered, the constant is 0.20. The historical dataset is too small for any conclusion one way or the other to be validated.

There are many m_b magnitudes for historical offshore earthquakes and it might be possible to establish whether the M_L-m_b relation changes with time. An alternative would be to include M_W values for historical earthquakes converted from other magnitude types in the analysis. A drawback to this approach is that the uncertainty for converted magnitudes is inherently greater than for calculated magnitudes, which would translate to an even higher uncertainty in any conversion relations determined.

Conclusions

A relation for converting from M_L to M_W for offshore eastern Canada has been established. On average, M_W is 0.21 magnitude units less than M_L. There is some evidence that the relation may vary with region. Because a large majority of the earthquakes used in the analysis occurred within the last 10 years, it could not be determined whether a time dependence as in the M_N-M_W relation for eastern Canada, which shows a change in 1995, applies to M_L-M_W as well. Extending the offshore M_W dataset back in time requires either the use of converted M_W values or a two-step process such as establishing an M_L-m_b conversion and then converting m_b to M_w. Both approaches would increase the uncertainty in any results obtained. The instrumental M_W dataset for the offshore eastern Canada region is small relative to the adjacent onshore regions, but is increasing as M_W values derived from RCMT analysis are becoming more readily available. It is therefore recommended that this conversion relation and possible regional variations be revisited in a few years time.

Data and Resources

The statistical f-tests were performed using the online ANOVA calculator http://www.danielsoper.com/statcalc3/calc.aspx?id=43 (last accessed 20 January 2016).

Epicentral, origin time and M_L values were obtained from the CNED (2016), noted in the reference section. M_W values came from the sources noted in Table 1.

Maps and figures were generated using GMT software.

Wessel, P. and W. H. F. Smith (1991). Free software helps map and display data, *EOS Transactions of the American Geophysical Union*, **72**, 445-446

Acknowledgments

I thank John Adams for his constructive review.

References

Bent, A. L. (1995). A Complex Double-Couple Source Mechanism for the M_S 7.2 1929 Grand Banks Earthquake, *Bulletin of the Seismological Society of America*, **85**, 1003-1020.

Bent, A. L. (2009). A Moment Magnitude Catalog for the 150 Largest Eastern Canadian Earthquakes, *Geol. Surv. Canada Open File 6080*, 23pp.

Bent, A. L. (2011). Moment Magnitude (M_W) Conversion Relations for Use in Hazard Assessment in Eastern Canada, *Seismological Research Letters*, **82**, 984-990. doi:10.1785/gssrl.82.6.984.

.

Bent, A. L. (2015a). Centroid Moment Tensor Solutions for Eastern Canadian Earthquakes: 2011-2013, *Geol. Surv. Canada Open File 7726*, 71 pp., doi:10.4095/296795.

.

Bent, A. L. (2015b). Centroid Moment Tensor Solutions for Eastern Canadian Earthquakes: 2014, *Geol. Surv. Canada Open File 7834*, 35 pp., doi:10.4095/296822.

Bent, A. L. and H. S. Hasegawa (1992). Earthquakes along the northwestern boundary of the Labrador Sea, *Seismological Research Letters*, **63**, 587-602.

Bent, A. L. and H. Greene (2014). Toward an Improved Understanding of the m_N-M_W Time Dependence in Eastern Canada, *Bulletin of the Seismological Society of America*, **104**, doi:10.1785/0120140031.

Bent, A. L. and F. Vadnais (2016). Magnitude Conversion Relations for Very Short Distances: The Charlevoix, Quebec Seismic Zone, *Geological Survey of Canada Open File 7945*, 16 p., in review.

Canadian National Earthquake Database (2016). Digital database, http://www.seismo.nrcan.gc.ca, Geological Survey of Canada, Ottawa, Ontario (last accessed 15 January 2016).

Hasegawa, H. S. and R. B. Herrmann (1989). A comparison of the source mechanisms of the 1975 Laurentian Channel earthquake and the tsunamigenic 1929 Grand Banks event, in S. Gregersen and P. W. Basham (editors), *Earthquakes at North Atlantic Passive Margins: Neotectonics and Postglacial Rebound*, Kluwer Academic Publishers, Dordrecht, Netherlands, 547-562.

Hashizume, M. (1977). Surface wave study of the Labrador Sea earthquake- 1971 December, *Geophysical Journal of the Royal Astronomical Society*, **51**, 149-168.

Kao, H., S.-J. Shan, A. Bent, C. Woodgold, G. Rogers, J. F. Cassidy and J. Ristau (2012). Regional Centroid-Moment Tensor analysis for Earthquakes in Canada and Adjacent Regions: An Update, *Seism. Res. Lett.*, **83**, 505-515, doi:10.1785/gssrl.83.3.505.

Nuttli, O. W. (1973). Seismic wave attenuation and magnitude relations for eastern North America, *Journal of Geophysical Research*, **78**, 876-885.

Richter. C. F. (1935). An instrumental magnitude scale, *Bulletin of the Seismological Society of America*, **25**, 1-32.

Ristau, J., G. Rogers and J. Cassidy (2003). Moment magnitude calibration for earthquakes off Canada's west coast, *Bulletin of the Seismological Society of America*, **93**, 2296-2300.

Ristau, J., G. C. Rogers and J. F. Cassidy (2005). Moment magniutude-local magnitude calibration for earthquakes in western Canada, *Bulletin of the Seismological Society of America*, **95**, 1994-2000, doi: 10.1785/0120050028.

Wetmiller, R. J. and J. A. Drysdale, 1982. Local magnitude of eastern Canadian earthquakes by an extended m_b(Lg) scale, *Earthquake Notes*, **53-3**, 40.

Table 1
Earthquakes for M_L-M_W Conversion

Date	Location	M_{L*}	M_W	M_W source
19291118	“Grand Banks”	7.2	7.1	Bent (1995)
19711207	Labrador Sea	5.6	5.6	Hashizume (1977)
19751006	Laurentian Channel	5.7	5.1	Hasegawa and Herrmann (1989)
19890314	Labrador Sea	5.2	4.9	Bent and Hasegawa (1992)
20081226	Davis Strait	5.4	5.2	Kao et al. (2012)
20090707	Baffin Bay	6.6	5.9	Kao et al. (2012)
20100415	Baffin Bay	5.1	4.7	Kao et al. (2012)
20100428	Baffin Bay	5.1	4.4	Kao et al. (2012)
20110415	Atlantic Ocean	4.0	4.1	Bent (2015a)
20110510	Labrador Sea	4.2	4.1	Bent (2015a)
20110603	Baffin Bay	4.9	4.3	Bent (2015a)
20111116	Labrador Sea	4.0	4.0	Bent (2015a)
20120412a	Gulf of Maine	4.4	4.2	Bent (2015a)
20120412b	Gulf of Maine	4.1	3.9	Bent (2015a)
20120902	Northern Baffin Bay	4.2	4.5	Bent (2015a)
20130329	Offshore Newfoundland	4.3	4.5	Bent (2015a)
20130829a	Offshore Newfoundland	4.3	4.4	Bent (2015a)
20130829b	Offshore Newfoundland	4.5	4.5	Bent (2015a)
20131030	Baffin Bay	4.7	4.2	Bent (2015a)
20140103	Labrador Sea	4.2	3.8	Bent (2015b)
20140207	Northern Baffin Bay	4.1	4.0	Bent (2015b)
20140303	Labrador Sea	4.5	4.2	Bent (2015b)
20140305	Labrador Sea	4.0	4.1	Bent (2015b)
20140311	Baffin Bay	4.9	4.6	Bent (2015b)
20140518	Lancaster Strait	4.1	3.6	Bent (2015b)
20140902	Baffin Bay	4.0	4.0	Bent (2015b)
20141111	Northern Labrador Sea	4.1	4.0	Bent (2015b)
20150502	Baffin Bay	4.2	4.1	Bent (unpublished RCMT)
20151118	Baffin Bay	4.4	3.9	Bent (unpublished RCMT)

*from CNED (2016)

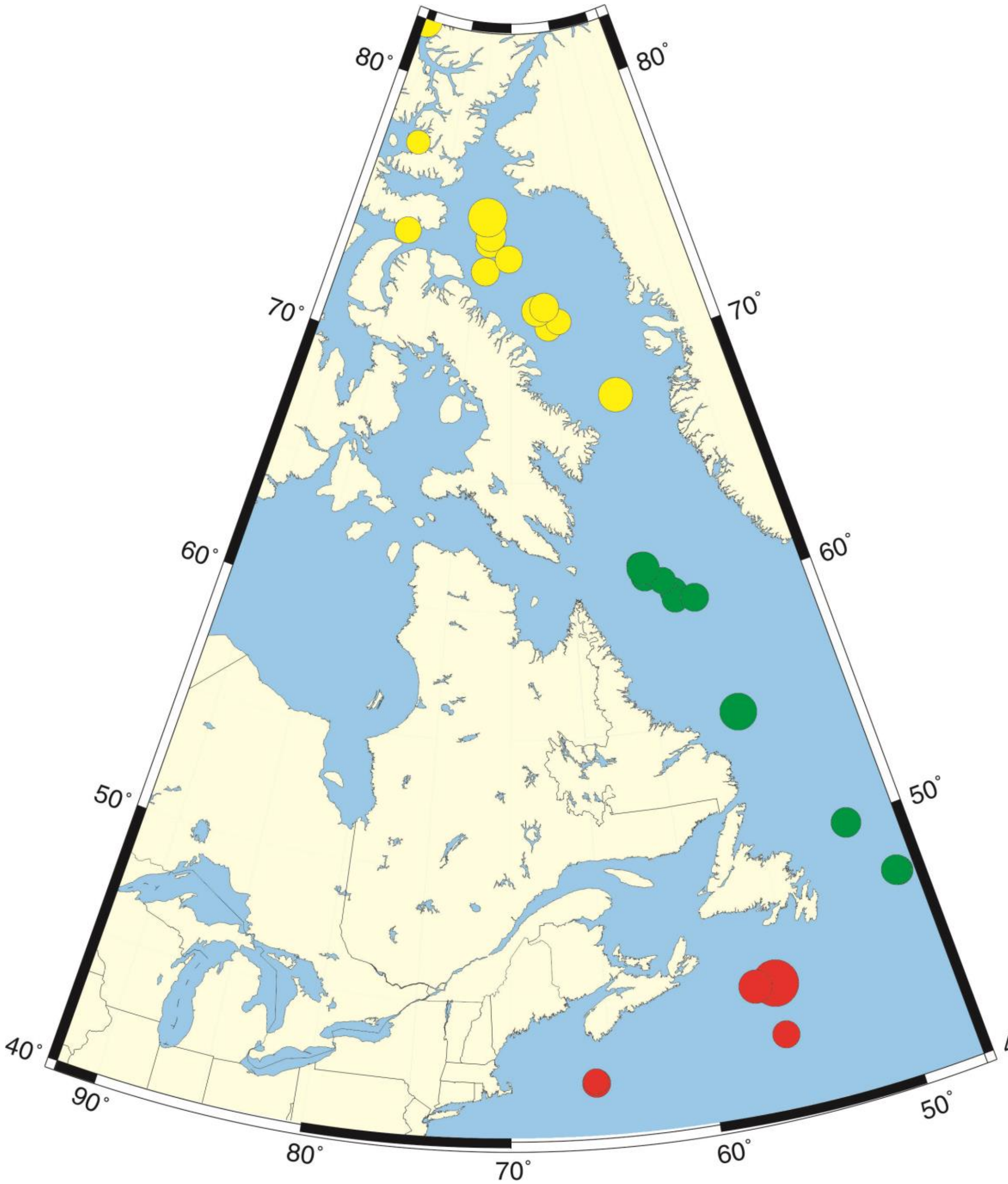

Figure 1: Map showing locations of events used to determine the M_L-W_W conversion relation. Colors indicate the regions discussed in the text: south (red), central (green) and north (yellow). Note that at this scale some closely located events may appear as a single event.

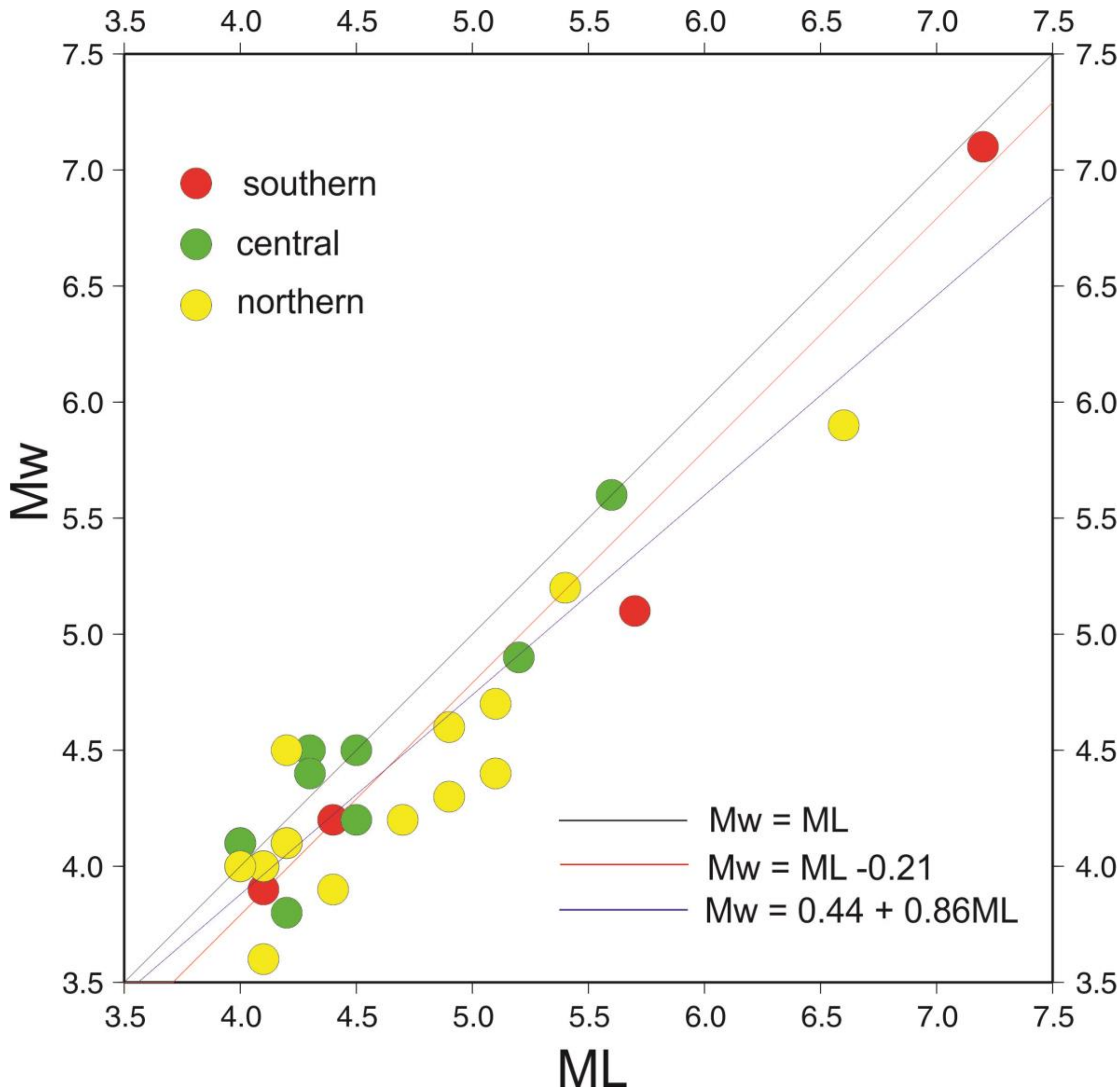

Figure 2: M_W vs. M_L for earthquakes used in this study. The points are color coded by region as discussed in the text and use the same colors shown in Figure 1. Note that some points plot on top of each other. Three M_L-M_W relations are shown by the solid lines: a one-to-one correspondence (black), the best constant relation obtained from this study (red) and the best linear relation obtained from this study (blue). The best fit relations shown are those derived from the complete data set.

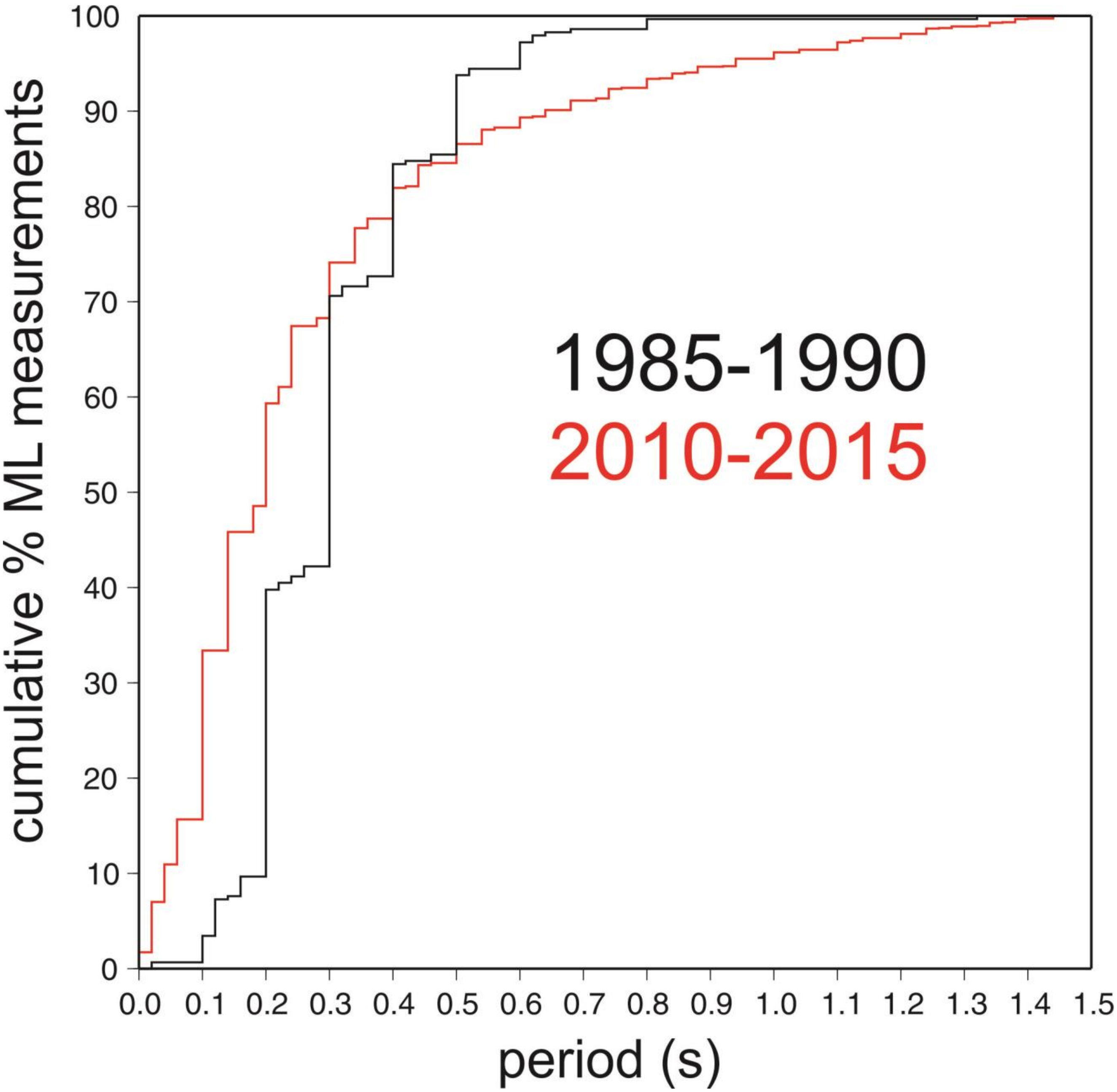

Figure 3. Plot showing the shift toward higher frequencies in M_L measurements in recent years. Data are binned in 0.02 second windows. Only earthquakes occurring in the offshore regions of northern and eastern Canada for which M_L is considered the primary magnitude in the CNED (2016) are considered. To normalize the data sets, the y-axis shows the cumulative percentage of magnitude readings made at a certain period rather than the cumulative number of readings.