Discrepancy in the Magnitude Values of Earthquakes in the Western Canada Sedimentary Basin

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Summary

Earthquake magnitude plays a crucial role in assessing ground shaking severity of significant seismic events. It is widely used in regulatory traffic light protocols to mitigate the seismic risk of induced earthquakes. Conventionally, the local magnitude scale (M_L, also known as the Richter scale, Richter, 1935) is adopted for earthquakes in the Western Canada Sedimentary Basin (WCSB). However, the Richter scale appears to have several limitations, including the amplitude saturation of very large earthquakes, the improper conversion of instrument responses, and the inadequate adjustment for the attenuation with distance. The combined effect from these issues often leads to under- and over-estimation of M_L depending on the epicentral/hypocentral distances at individual stations (Boore, 1989).

In Canada, Natural Resources Canada (NRCan) adopts the adjustment factors proposed by Richter (1958, referred as R1958 hereafter) to calculate M_L for earthquakes in western Canada. Specifically, in the WSCB where injection-induced earthquakes (IIE) have been observed for decades, previous studies have shown that the M_L values reported by NRCan appear to be systematically overestimated with respect to those derived from the local array data established by local operators (Yenier, 2017; Babaie Mahani and Kao, 2019). With an updated dataset, Babaie Mahani and Kao (2020) further revised the distance adjustment factors to better characterize the attenuation of ground motions in WCSB. In this study, we investigate the discrepancy in the magnitude values reported by various agencies/organizations, including a new ground motion dataset that was not available to previous studies, and explain how using inappropriate distance adjustment factors may affect the estimation of M_L that, in turn, can lead to regulatory ambiguities.

We compile a dataset of Wood-Anderson amplitudes from the maximum of the two horizontal components of 1178 earthquakes that occurred between 2021 and 2023 in WCSB. A total of 14,093 amplitude values from 85 seismograph stations are included in our analysis. These events occurred in 10 clusters with the hypocentral distance ranging from 1 to 600 km. All events are shallow, with the majority of focal depths <10 km.

For each event, we calculate the magnitude value at individual stations and the median is taken as the event magnitude. Using the R1958 model, the station magnitude values appear to be systematically smaller and larger than the event magnitudes at near distances (between 10 and 40 km) and beyond ~200 km, respectively. Using the adjustment factors proposed by Yenier (2017, referred to as the Y2017 model), the magnitude difference appears to be stable across all distances with a slight underestimation (i.e., average station magnitude < event magnitude) at distances <10 km. Behaviors of the models proposed by Babaie Mahani and Kao (2019, referred

to as the BK2019 model) and Babaie Mahani and Kao (2020, referred to as the BK2020 model) are similar with best performance in the distance range of 10–200 km.

Figure 1 shows three extreme examples of overestimated M_L values using inadequate distance adjustment factors. It is apparent that the station magnitude values derived with the R1958 model are generally larger than those with the BK2020 model, and the difference increases with distance from <0.3 at 30-150 km to nearly 1 at >300 km. Figure 2 shows the number of events as a function of event M_L in the northern Montney cluster when different sets of distance adjustment factors are applied. Notice that there are 8 M_L4+ events when the R1958 model is used, whereas the more appropriate distance adjustment factors (Y2017, BK2019, and BK2020) do not lead to any red-light event. Overall, the R1958 model results in 33 red-light events across all clusters in our study area, which is more than three times the number of red-light events determined with other models (10 red-light events by Y2017, 10 by BK2019, and 9 by BK2020). These results clearly demonstrate the unnecessary economic consequences when exaggerated M_L values are used in the regulatory process and underscore the importance of adopting properly calibrated adjustment factors in the calculation of M_L for IIE in the WCSB.

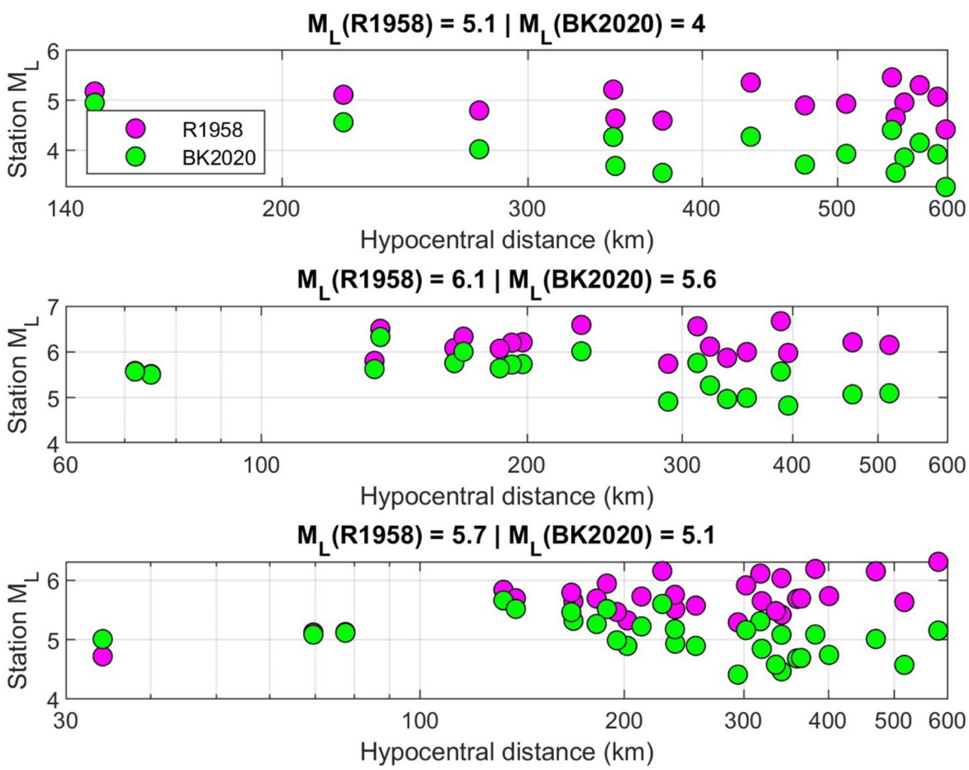

Figure 1. Comparison of M_L values calculated for three events (top: 2021/10/21T03:23:22; middle: 2022/11/30T00:55:56; bottom: 2023/03/16T14:59:10) using the distance adjustment factors proposed by Richter (1958; R1958) and Babaie Mahani and Kao (2020; BK2020). Each circle corresponds to one station M_L value and the difference between the two models increases with distance. The event M_L is shown in bold at the top.

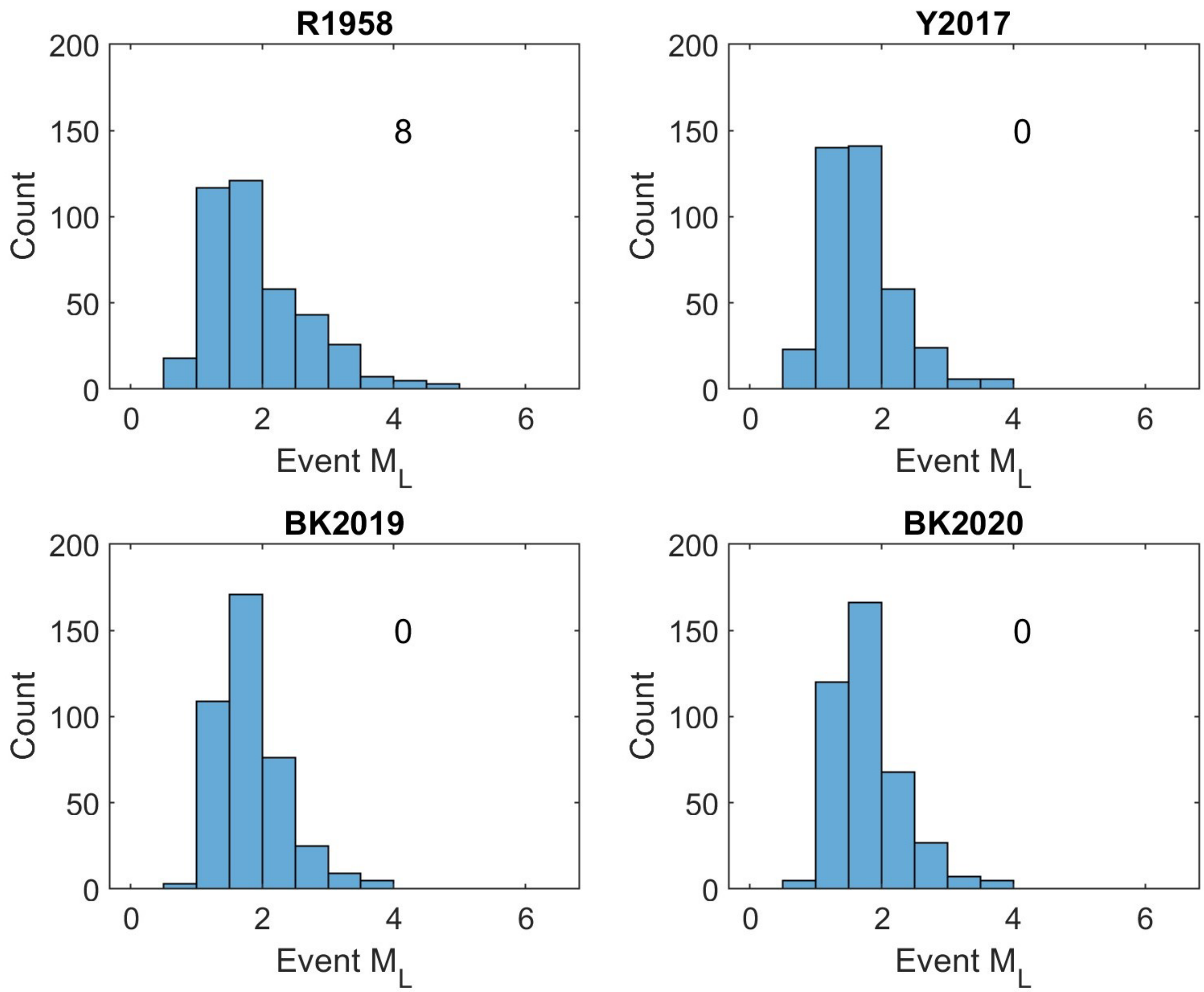

Figure 2. Number of earthquakes as a function of M_L value in the Northern Montney earthquake cluster when four different sets of distance adjustment factors are used (R1958: Richter, 1958; Y2017: Yenier, 2017; BK2019: Babaie Mahani and Kao, 2019; BK2020: Babaie Mahani and Kao, 2020). The integer inside each plot corresponds to the number of red-light events with $M_L \geq 4$.

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