Bias in the BC Energy Regulator's Earthquake Monitoring

Allan Chapman
Victoria BC
February 3, 2025
Email: allan.chapman@telus.net

Introduction

Earthquakes in northeast BC (NEBC) induced through unconventional petroleum development became evident in the Geological Survey of Canada's (GSC) earthquake monitoring by about 2008. For the 2010s, the GSC monitoring was considered the de facto standard for earthquake monitoring in Canada. In the late 2010s, as induced earthquakes became a more significantly-recognized issue, the BC Oil and Gas Commission (now the BC Energy Regulator) created a regulatory requirement for the suspension of fluid injection with a reported M≥4.0 earthquake occurring near an injection well, and the BCER created a requirement under Order for a suspension of hydraulic fracturing with a reported M≥3.0 earthquake occurring near a well in the Kiskatinaw Seismic Area (which comprises about 9 percent of the area of the Montney Trend in BC). Precision in earthquake magnitude and accuracy in earthquake epicentre location measurement became important, to apply the suspension triggers. The BCER, with industry and other partners, developed an earthquake monitoring system with a larger number of seismometers and different analytical methods from the GSC system. In particular, the BCER methods uses different distance calibration functions from the GSC. This results in the BCER estimating substantially lower earthquake magnitudes than the GSC methods for matched events (Babaie Mahani et. al., 2024). Babaie Mahani et. al. (2024) refers to a goal of not unduly burdening industry with unnecessary hydraulic fracturing suspensions. At the same time, researchers should keep in mind that the objective of regulatory hydraulic fracturing suspensions is to attempt to mitigate the occurrence of large, potentially damaging earthquakes (e.g., M≤4.0). In NEBC there is the perplexing situation of two separate earthquake monitoring systems operating in the same geographic space at the same time but generating different results. The BCER uses only its own earthquake data for regulatory applications, ignoring the GSC data. A review of the GSC's earthquake catalogue has 19 earthquakes during 2018-2023 that exceeded the suspension threshold. Under the BCER's system, however, only six resulted in injection suspensions. An examination of these events suggested that the differences in earthquake magnitude between the GSC and BCER in the North Montney were greater than the differences in the South Montney. That observation led to this brief study, which looks at differences in earthquake magnitude North and South of the Peace River in relation to the location of the seismometers used to estimate the median value for the event magnitude, and implications for applying regulatory fluid injection suspensions.

Data and Methods

In addition to the GSC and BCER earthquake catalogues, other catalogues that have been compiled over the past few years, the most recent by Goerzen et. al. (2024), encompassing 2021 and 2022 for the Montney Trend. The Goerzen catalogue is derived from a network of 58 seismometers operated by a variety of entities (Appendix 1). Of these 58 seismometers, 36 are used in the BCER's earthquake monitoring and used for their regulatory oversight. For the analysis reported here, the seismometers were divided into two groups based on their location either North or South of the Peace River[1].

From the Goerzen catalogue, all earthquakes of M≥2.5 were extracted (n=60), as this is approaching a threshold where a regulatory suspension can come into play. The earthquakes were divided into two groups based on the location of their epicentres either North or South of the Peace River. Data for the various seismometers selected by Goerzen's picks for each earthquake were extracted. From this array, the data from just the BCER's subset of seismometers were used for further analysis, to match as closely as possible to the BCER's catalogue[2]. This creates four categories of earthquakes, based on the earthquake location and the seismometer location: North-North, North-South, South-North, South-South. For each earthquake, the magnitude measured at each picked seismometer was extracted, and the distance from each seismometer to the earthquake epicentre was calculated.

The magnitude of the earthquake event is reported by Goerzen and the BCER as the median value for the various seismometers that were picked. For the median to be valid, the data must meet a number of assumptions, including that the underlying members be unbiased and not displaying systematic error. To test this assumption, a variable M_{diff} was calculated as:

$$M_{diff} = M_{seis} - M_{median}$$

where: M_{diff} is the difference between earthquake magnitude measured at a seismometer from the event median

M_{seis} is the earthquake magnitude at the seismometer

M_{median} is the median value of all the picked seismometers for the earthquake event

The M_{diff} data were examined using a Student's T-Test to determine if there were statistically significant differences in the patterns of deviance amongst the pairs of data (N-N vs. N-S, and S-N vs. S-S). Secondly, within the two earthquake location groups (North, South), linear regression was used to determine if there was variance with M_{diff} related to the distance of the seismometer from the earthquake epicentre. Thirdly, linear regression was used to evaluate the earthquake measurements in relation to the distance of the seismometers from the earthquake epicentres, for individual earthquake events.

Results – T-Test

The T-Test analysis indicates there are statistically significant differences among the four groups of earthquake data (Table 1):

[1] All geospatial analysis was done with QGIS.

[2] I do not know what specific seismometers were used in the BCER's picks, and so there could be some differences between the BCER and Goerzen datasets. That said, the differences would be minor. For the 60 M≤2.5 earthquakes analyzed here, both BCER and Goerzen have identical mean values of M=2.90.

N-N 0.084	S-N -0.023
N-S -0.033	S-S 0.001

Table 1. T-Test results for the variable M_{diff}, in four groups: North-North, North-South, South-North, and South-South (the 1st value is the location of the earthquake, and the 2nd value is the location of the seismometer). M_{diff} is the difference between the earthquake magnitude measured at a seismometer and the median earthquake value for the event. The values in groups N-N and N-S are statistically different (p<0.01); S-S and S-N are not different.

- For earthquakes that occur North of the Peace River, seismometers located North of the Peace River measure earthquake magnitudes significantly larger than seismometers located South of the Peace River (p<0.01). The mean difference between North and South is M=0.117.
- For earthquakes that occur South of the Peace River, there is no statistically significant difference in earthquake measurements related to the North or South grouping of the seismometers

Since the earthquake magnitude reported for the event by the BCER is the median value of the readings from all picked seismometers, this indicates that the BCER's system will, on average, significantly under-estimate earthquake magnitude for events located North of the Peace River. As a hypothesis, I was interested in the question of whether the physical, geological discontinuity of the Peace River valley might affect seismometer readings on opposite sides of the valley for shallow induced earthquakes[3]. The T-Test supports that hypothesis. Alternatively, however, it is possible that the distance between the seismometer and the earthquake epicentre is an explanatory variable, that there is a decay in earthquake magnitude with distance possibly resulting from the distance calibration functions used by Goerzen and the BCER. This is tested using linear regression.

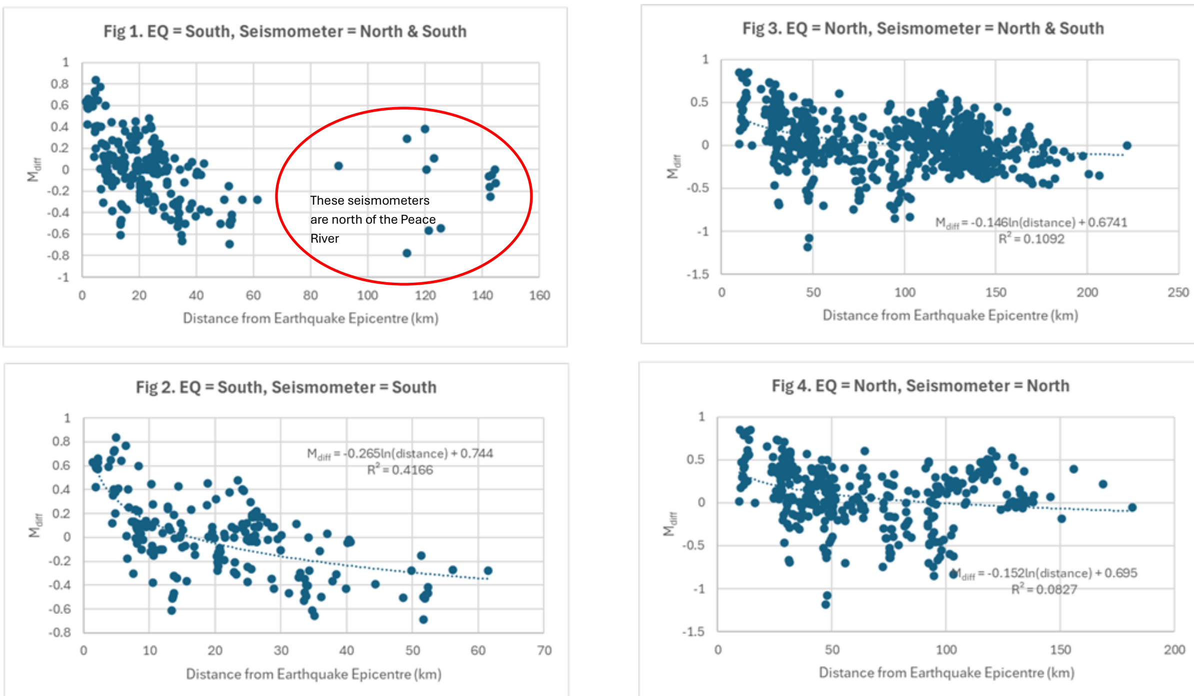
Results – Regressions

The variable M_{diff} (the difference between magnitude at the seismometer and the median magnitude for the event) was regressed against the distance between the seismometer and the earthquake (km). The results are shown in Figures 1-4.

The results indicate that there is a statistically significant effect of distance from the earthquake epicentre on the earthquake magnitude at the seismometers (p<0.05). Seismometers closer to the epicentre are reading higher magnitudes relative to the median value while seismometers further from the epicentre are reading lower magnitudes relative to the median. Figure 1 depicts earthquakes South of the Peace River against seismometers both North and South of the river. The readings from the seismometers in the North are anomalous relative to the rest of the data and so Figure 2 shows earthquakes in the South as measured only by seismometers in the South. The M_{diff} vs. distance data appear to be nonlinear, and so the best-fit line depicted in Figures 2-4 are based on log-transformed distance. Further investigation could be done on this. For these results, aggregated in the two zones for all M≤2.5 earthquakes in 2021 and 2022, the statistical intercept value is a better estimate of the event

[3] Earthquakes in the Goerzen catalogue have a reported mean depth of 2.2 km (SD = 0.9 km).

magnitude than the median value. This suggests the BCER's reported event magnitudes are biased and 0.3-0.7 too low (depending on whether a linear or log-linear fit is applied).



Figures 1-4. Relationship between M_{diff} (the difference in earthquake magnitude measured at a seismometer and the median magnitude for the earthquake event) and the distance of the seismometer from the earthquake epicentre.

To dig into this more deeply, I completed linear regressions of earthquake magnitude versus distance for all individual earthquakes (n=60). For these regressions, I tested earthquakes in the North against seismometer readings in both the North and South, and I tested earthquakes in the South against only the seismometers in the South, because of the anomalies reflected in Figure 1, above. Of the 60 earthquake events, 16 (27%) have statistically significant relationships between magnitude and distance ($p<0.05$), with magnitude decreasing with increased distance from the earthquake epicentre. These 16 earthquakes are equally divided between the North and South zones. A further 17 earthquake events also show the relationship of declining magnitude with distance from the epicentre, but the results are not statistically significant because of the small degrees of freedom for the analyses. Plots for the 16 statistically significant earthquake events are shown in Figures 5 and 6.

For these earthquakes with statistically significant relationship of magnitude declining with distance from the epicentre, it should be clear that the median earthquake magnitudes of the picked seismometers <u>is not appropriate</u> to represent the event magnitude. Instead, where there is a clear relationship with distance from the epicentre, the statistical intercept more accurately represents the magnitude of the earthquake at its epicentre. To examine the implications of this analysis, a comparison of the GSC, BCER, Goerzen and "Corrected"-Goerzen magnitudes for the 2021-2022 M≤2.5 earthquakes is presented in

Table 2. The “Corrected” Goerzen data reflect the intercept value where there is a statistically significant linear regression, and they reflect the median value for seismometers in the same location zone (North or South) as the earthquake.

For 2021-2022, the BCER reports two (2) earthquakes M≤4.0, whereas the corrected data show four (4). For earthquakes of M≤3.0, the BCER reports 22 earthquakes in the two years, whereas the corrected data show 33 such earthquakes. The record number of M≤3.0 earthquakes in 2024 from the GSC catalogue was reported by Chapman (2025). The under-reporting of magnitude for 15 earthquakes had potential regulatory implications, including four (4) earthquakes south of the Peace River (in the Kiskatinaw Seismic Area) where hydraulic fracturing suspensions should have occurred but weren’t.

Conclusions

This brief investigation of the detail in the Goerzen et. al. (2024) earthquake catalogue indicates there is a statistically significant magnitude-distance relationship for many earthquake events in NEBC, with magnitude declining with distance from the earthquake epicentre. For these earthquake events, the use of the statistical median of the picked seismometers as the event magnitude is inappropriate, as it biases the reported event magnitude to be significantly lower than the actual magnitude. Where the BCER’s earthquake data are used for regulatory oversight, this favours petroleum industry, as it reduces the number of earthquake events where a regulatory fluid injection suspension threshold is reached. Conversely, it increases risk for the population living near hydraulic fracturing or fluid injection operations, if the earthquake-causing activity is not suspended when it should have been. It is possible that the bias is resulting from the distance calibration functions used by the BCER (Babaie Mahani et. al., 2023). This bias and possible calibration error may also be related to the shallow nature of most induced earthquakes in NEBC, and effects associated with near-surface geologic characteristics, including differences in near-surface geologic characteristics North and South of the Peace River.

It is important for the various agencies and associates involved with induced seismicity monitoring in western Canada to investigate and resolve this issue in a timely manner, to hopefully result in a single earthquake monitoring system that is accurate, timely and defensible, and not subject to errors of omission or commission.

It is hoped that the BC Energy Regulator resolves and corrects the real-time earthquake reporting on their website, and corrects the historic data contained their on-line catalogue.

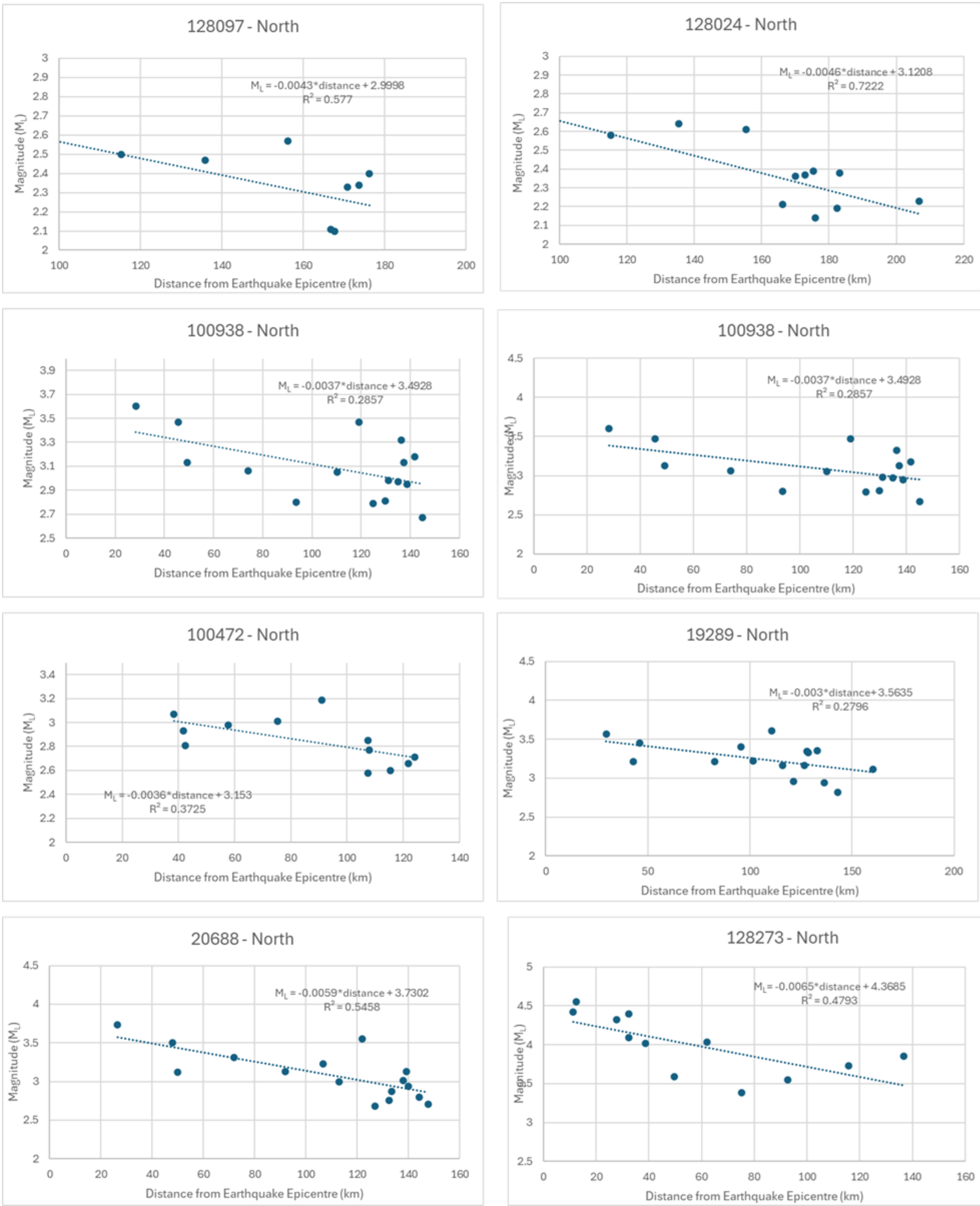


Figure 5. Earthquake magnitude in relation to the distance between the seismometer and the earthquake epicentre, for earthquakes located **North** of the Peace River. The seismometers are located both north and south of the Peace River. All relationships are statistically significant (*P*<0.05). The number in the title of each plot refers to the “event ID” from Goerzen et. al. (2024)

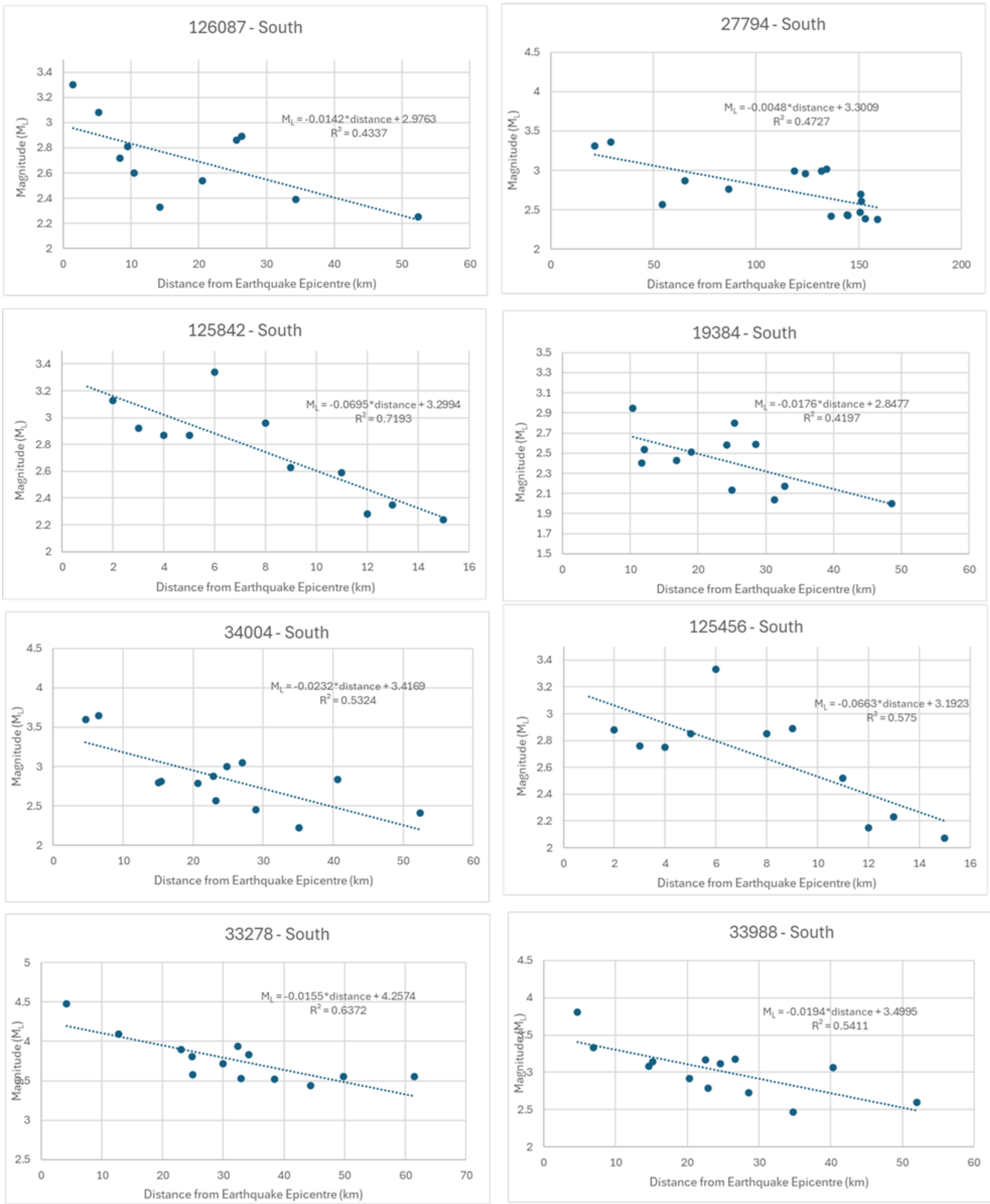


Figure 6. Earthquake magnitude in relation to the distance between the seismometer and the earthquake epicentre, for earthquakes located **South** of the Peace River. The seismometers are located south of the Peace River. All relationships are statistically significant (*P*<0.05). The number in the title of each plot refers to the "event ID" from Goerzen et. al. (2024).

Event	Date-Time	Location	GSC	BCER	Goerzen	Goerzen "corrected"	Regulatory Implications?
9195	08-Jan-21 02:02	NORTH	missing	2.9	2.9	3.0	yes
18886	27-Apr-21 10:20	NORTH	2.8	2.7	2.8	2.8	
18939	29-Apr-21 20:11	NORTH	missing	2.6	2.6	2.8	
19005	30-Apr-21 00:11	NORTH	2.5	2.6	2.6	2.7	
19139	25-Jan-21 06:07	SOUTH	2.7	3.0	3.0	3.0	
19289	09-May-21 14:21	NORTH	3.3	3.2	3.2	3.6	
19384	02-Feb-21 00:18	SOUTH	missing	2.5	2.5	2.8	
20484	04-Jun-21 01:30	NORTH	missing	2.5	2.6	2.6	
20531	04-Jun-21 04:59	NORTH	3.3	3.1	3.1	3.2	
20537	04-Jun-21 05:05	NORTH	missing	2.8	2.8	3.1	yes
20558	04-Jun-21 07:06	NORTH	3.0	3.0	3.0	3.2	
20603	04-Jun-21 09:51	NORTH	2.8	2.6	2.7	3.0	yes
20688	04-Jun-21 22:00	NORTH	3.3	3.0	3.0	3.3	
20697	05-Jun-21 00:19	NORTH	2.9	2.8	2.9	3.0	yes
20721	05-Jun-21 01:31	NORTH	2.9	2.6	2.6	2.7	
22803	12-Jun-21 19:54	NORTH	3.1	3.1	3.2	3.3	
27794	21-Aug-21 16:13	NORTH	3.3	2.6	2.7	2.9	
33278	26-Jul-21 09:32	SOUTH	3.5	3.9	3.9	4.3	yes
33440	11-Nov-21 17:29	NORTH	2.5	2.5	2.5	2.6	
33952	27-Nov-21 07:37	NORTH	3.4	2.7	2.7	2.9	
33988	21-Aug-21 14:48	SOUTH	3.2	3.1	3.1	3.5	
34004	21-Aug-21 22:19	SOUTH	3.0	2.9	2.9	3.7	yes
100472	28-Nov-21 22:30	NORTH	3.0	2.8	2.8	3.0	yes
100668	03-Dec-21 08:08	NORTH	3.6	3.2	3.2	3.4	
100671	06-Dec-21 13:45	NORTH	3.8	3.8	3.8	4.1	yes
100938	01-Jun-21 19:29	NORTH	3.2	3.0	3.0	3.5	
100941	01-Jun-21 20:24	NORTH	3.5	3.4	3.4	3.4	
100943	04-Jun-21 00:59	NORTH	2.7	2.9	2.9	3.0	yes
100952	04-Jun-21 23:15	NORTH	missing	2.8	2.8	3.2	yes
106439	27-Dec-21 21:18	NORTH	3.1	3.0	3.0	3.0	
107549	17-Sep-21 18:11	SOUTH	2.6	2.7	2.7	2.7	
107861	11-Jan-22 14:50	NORTH	3.5	3.0	3.0	3.2	
107897	12-Jan-22 22:51	NORTH	4.2	3.5	3.6	3.6	
108474	08-Feb-22 22:20	NORTH	3.4	2.7	2.7	2.6	
108963	10-Mar-22 20:21	NORTH	4.3	3.4	3.4	3.6	
108967	10-Mar-22 20:22	NORTH	2.7	2.8	2.8	2.8	
116518	19-Dec-21 17:41	SOUTH	2.6	2.6	2.7	2.7	
116521	19-Dec-21 17:42	SOUTH	2.6	2.5	2.5	2.5	
120547	08-Jun-22 04:39	NORTH	3.8	3.0	3.1	3.0	
122920	17-Apr-22 08:19	SOUTH	2.9	2.7	2.7	2.8	
122974	08-Aug-22 08:55	NORTH	3.3	2.8	2.8	2.7	
124404	30-Apr-22 03:48	SOUTH	2.6	2.6	2.5	2.6	
125456	03-Sep-22 23:39	SOUTH	missing	2.8	2.8	3.0	yes
125677	04-Sep-22 23:17	SOUTH	missing	2.7	2.6	2.6	
125788	05-Sep-22 20:24	SOUTH	missing	2.5	2.5	2.5	
125842	06-Sep-22 02:35	SOUTH	missing	2.8	2.8	3.0	yes
126049	07-Sep-22 21:47	SOUTH	missing	2.8	2.8	2.8	
126087	08-Sep-22 02:56	SOUTH	2.6	2.8	2.7	3.0	yes
126608	19-Sep-22 14:22	NORTH	3.3	2.5	2.6	2.5	
128024	10-Nov-22 14:56	NORTH	3.2	2.6	2.6	3.0	yes
128089	11-Nov-22 09:22	NORTH	3.0	2.5	2.5	2.6	
128097	11-Nov-22 09:29	NORTH	3.2	2.5	2.5	2.8	
128199	12-Nov-22 23:18	NORTH	4.2	3.4	3.5	3.6	
128271	11-Nov-22 16:10	NORTH	4.5	4.0	3.8	4.1	yes
128273	16-Nov-22 02:40	NORTH	4.0	4.0	4.0	4.4	
128391	17-Nov-22 14:05	NORTH	3.5	2.8	2.8	2.7	
128562	21-Nov-22 18:14	NORTH	2.7	2.5	2.5	2.6	
128668	24-Nov-22 20:26	NORTH	3.1	3.1	3.1	3.2	
128686	25-Nov-22 19:25	NORTH	missing	3.5	3.6	3.5	
128716	28-Nov-22 05:44	NORTH	3.1	2.5	2.5	2.6	

Mean GSC =	3.2
Mean BCER =	2.9
Mean Goerzen =	2.9
Mean "corrected" =	3.1

Table 2. Comparison of earthquake magnitude calculations from the GSC, BCER, Goerzen et. al., and Goerzen "corrected". For Goerzen "corrected", the records shown in colour are based on the statistical intercept value of the linear regression.

Station	Network	Catalogue	Elevation	Lat	Long	UTM-E	UTM-N	UTM-Z	Location
BCH1A	1E	BCER	689	55.8324	-120.2590	671665	6190825	10	South
BCH2A	1E	BCER	761	55.9461	-120.3561	665102	6203238	10	South
MONT1	1E	BCER	697	55.9102	-120.5865	650857	6198717	10	South
MONT2	1E	BCER	642	56.0197	-120.0470	684048	6212207	10	South
MONT3	1E	BCER	783	56.0058	-120.4539	658751	6209650	10	South
MONT4	1E	BCER	1110	57.3184	-122.7057	517725	6352868	10	North
MONT5	1E	BCER	1097	57.0269	-122.3360	540307	6320576	10	North
MONT7	1E	BCER	797	56.3079	-122.0316	559915	6240770	10	North
MONT8	1E	BCER	695	56.0673	-120.7774	638365	6215797	10	South
MONT9	1E	BCER	832	55.8039	-120.5388	654259	6186996	10	South
MONTA	1E	BCER	651	56.1043	-121.0700	620037	6219366	10	South
MONTB	1E	BCER	959	57.4026	-122.1302	552265	6362532	10	North
MONTC	1E	BCER	1181	57.1338	-122.7622	514393	6332303	10	North
MONTD	1E	BCER	737	56.7848	-122.1778	550236	6293730	10	North
MONTE	1E	BCER	1024	57.2138	-122.1745	549861	6341493	10	North
BMTB	CN	BCER	1099	56.0451	-122.1332	553997	6211438	10	Peace
FNSB	CN	BCER	440	58.8061	-122.7328	515437	6518492	10	North
FSJ1	EO	Goerzen	685	56.3467	-120.6663	644226	6247108	10	North
FSJ2	EO	Goerzen	766	56.4082	-121.0773	618637	6253168	10	North
KSM01	EO	Goerzen	773	56.0210	-120.5537	652472	6211117	10	South
KSM02	EO	Goerzen	730	55.8866	-120.4407	660065	6196419	10	South
KSM03	EO	Goerzen	652	55.8400	-120.1380	679205	6191974	10	South
KSM04	EO	Goerzen	705	55.7739	-120.6443	647760	6183431	10	South
KSM05	EO	Goerzen	759	55.7927	-120.2098	674923	6186537	10	South
KSM06	EO	Goerzen	752	55.9501	-120.7129	642814	6202887	10	South
KSM07	EO	Goerzen	803	56.0020	-120.9209	629649	6208253	10	South
KSM08	EO	Goerzen	718	56.0204	-120.1306	678835	6212062	10	South
KSM09	EO	Goerzen	644	56.1673	-120.2796	668906	6228036	10	North
KSM10	EO	Goerzen	715	56.0824	-120.7844	637872	6217468	10	South
KSM11	EO	Goerzen	677	55.9501	-120.4513	659144	6203461	10	South
KSM12	EO	Goerzen	706	55.8727	-120.6678	645914	6194366	10	South
KSM13	EO	Goerzen	683	55.9787	-120.3187	667296	6206951	10	South
NAB1	PQ	BCER	754	56.7663	-121.2587	606438	6292724	10	North
NAB2	PQ	BCER	646	58.5950	-119.1656	374138	6496990	11	North
NBC1	PQ	BCER	421	59.6559	-123.8237	453580	6613383	10	North
NBC2	PQ	BCER	486	59.7735	-122.4878	528766	6626293	10	North
NBC3	PQ	BCER	452	59.6372	-120.6688	631435	6613311	10	North
NBC4	PQ	BCER	815	55.6873	-120.6602	647089	6173759	10	South
NBC5	PQ	BCER	1161	57.5231	-122.6776	519308	6375664	10	North
NBC6	PQ	BCER	445	58.5839	-121.3339	596866	6494921	10	North
NBC7	PQ	BCER	821	57.0139	-121.4974	591239	6319935	10	North
NBC8	PQ	BCER	709	56.5731	-122.4044	536594	6270024	10	North
WTMTA	RV	Goerzen	1030	55.6942	-119.2398	359224	6174321	11	South
MG01	XL	BCER	721	56.0548	-120.6380	647089	6214694	10	South
MG03	XL	BCER	697	55.9122	-120.4414	659916	6199266	10	South
MG04	XL	BCER	682	55.9914	-120.3380	666038	6208321	10	South
MG05	XL	BCER	795	55.8951	-120.3019	668707	6197695	10	South
MG07	XL	BCER	749	55.7836	-120.4024	662890	6185050	10	South
MG08	XL	BCER	722	55.8381	-120.8997	631527	6190056	10	South
MG09	XL	BCER	795	56.1591	-121.6081	586450	6224659	10	Peace
MG10	XL	BCER	798	55.7229	-120.0633	684434	6179147	10	South
MG11	XL	BCER	657	55.9222	-120.1423	678559	6201110	10	South
RU01	XL	Goerzen	612	56.1451	-120.4800	656556	6225085	10	North
RU02	XL	Goerzen	611	56.1320	-120.1882	674742	6224331	10	North
RU03	XL	Goerzen	795	55.8074	-121.1345	616917	6186223	10	South
RU04	XL	Goerzen	892	55.9614	-121.0388	622430	6203517	10	South
RU05	XL	Goerzen	606	56.1806	-120.7334	640690	6228494	10	North
RU06	XL	Goerzen	773	55.9896	-120.5269	654265	6207681	10	South

Appendix 1. Earthquake monitoring network used by the BCER and Goerzen et. al. (2024).