Composite Alberta Seismicity Catalog: CASC2014-x

By

Azadeh Fereidoni and Luqi Cui

November 2015

INTRODUCTION

The **Composite Alberta Seismicity Catalog (CASC)** is a compilation of the earthquake catalogs from different agencies with different formats. The aim is to provide a comprehensive list of seismic events reported by different agencies, and to identify duplicates and retain all available information on each event (e.g. origin times, hypocenters, magnitudes, event types, preferred conversions to moment magnitude) . It is patterned after the ideas in the Canadian Composite Seismicity Catalog (CCSC; Fereidoni et al., 2012, in Seism. Res. L.). The CASC is unified with respect to moment magnitude (**M**). The compilation is done semi-automatically, and a matlab script is available so that the catalog can be updated on a monthly basis (AlbertaCompCat2014-10, AlbertaCompCat2014-11, etc).

COORDINATES OF THE STUDY REGION

The CASC covers Alberta and northeastern British Columbia. The geographical coordinates of the coverage polygon are:

Latitude, Longitude

- 48° N, 110° W
- 60° N, 110° W
- 60° N, 124° W
- 53° N, 124° W
- 53° N, 121° W
- 48° N, 121° W

Figure 1 shows the area covered, and plots all of the events in the catalog as of Dec. 1, 2015.

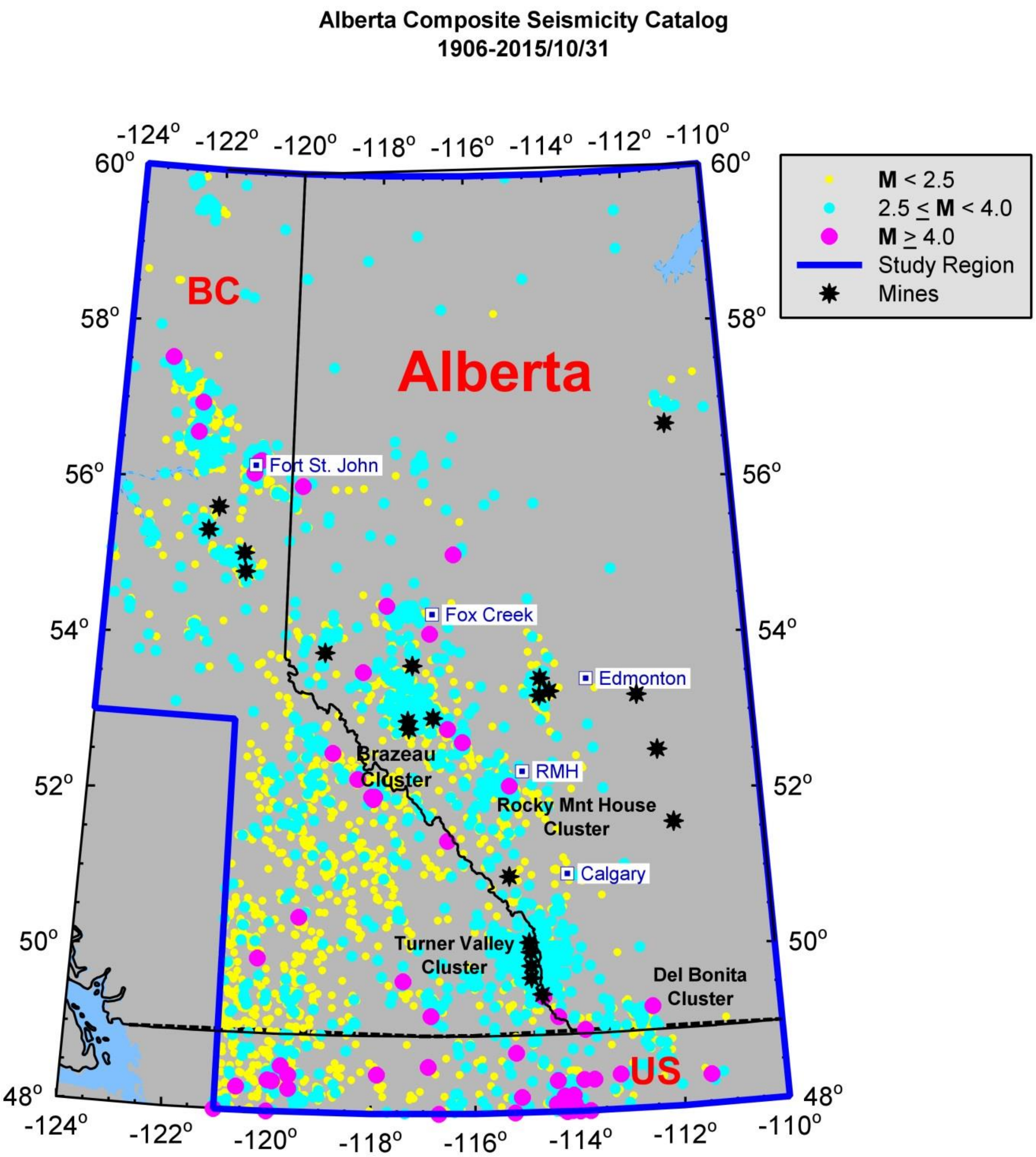

Figure 1- Events in Composite Alberta Seismicity Catalog as of December 2015.

TIME PERIOD OF THE COMPOSITE CATALOG

CASC contains the seismicity information in the study region from the earliest documented events in 1906 until to the present time. The catalog will be updated on a monthly basis, to include new events and revise information from older events where applicable.

EARTHQUAKE DATA SOURCES

Nanometrics catalog (NMX): The TransAlta/ Nanometrics network in western Alberta commenced operation in the fall of 2013. The network comprises 27 three component broadband seismograph stations which act in cooperation with other real-time seismograph stations in the region.

- Source: Nanometrics
- Data availability in the composite catalog: from fall 2013 to present
- Magnitudes include a combination of local magnitude (*ML*) calibrated for the region, and estimated moment magnitude (**M**), based on Atkinson et al., 2014.
- Types of events included: earthquakes and blasts; no special designation available for blasts

Geological Survey of Canada's online catalog (GSC): The GSC's online earthquake database is available from 1985 to the present time. It is compiled by analysts using stations of the Canadian National Seismograph Network (CNSN). The GSC catalog includes earthquake date, time (to nearest second), location, magnitude, depth, a depth designation (whether determined or fixed) and comments.

- Source: Earthquakes Canada
  http://www.earthquakescanada.nrcan.gc.ca/stndon/NEDB-BNDS/bull-eng.php
- Data availability in the composite catalog: from 1985 to present
- Magnitudes are mostly local magnitude (*ML)* or Nuttli magnitude (*MN)*; a few of the larger events have moment magnitude (***M***) and/or body wave magnitude (*MB*) types.
- Types of events included:
  - Quakes
  - Mining events
  - Blast
  - Induced

Alberta Geologic Survey Catalog (AGS): The AGS catalog (Stern et al, 2013) lists the earthquakes in the province of Alberta (or within 10 km of its borders) from September 2006 through December 2010. It differs from the GSC catalog because they included, in addition to the CNSN stations, real-time data from the AGS RAVEN network, and data from campaign-mode stations, in particular the stations of the Canadian Rockies and Alberta Network (CRANE), which includes several semi-permanent non-telemetered seismic stations operated by the University of Alberta (Gu et al., 2009). The additional RAVEN and CRANE data enable the detection of more events and improve location accuracy.

- Source: Table A.2 in AER/AGS Open File Report 2013-15; http://www.ags.gov.ab.ca/publications/abstracts/OFR_2013_15.html
- Data availability in composite catalog: 2006-2010
- Magnitudes are mostly *ML*
- Type of events included:
    - Earthquakes (Quarry blasts and mining-related events have been screened out by AGS)

Canadian Composite Seismicity Catalog (CCSC): CCSC (Fereidoni et al., 2012) is a composite catalog containing earthquake parameters in east and west of Canada. It is compiled using eight local and international earthquake catalogs and is homogenized in terms of moment magnitude. Using CCSC_west, we obtain all relevant seismicity data before 1985 in the study region.

- Source: http://www.seismotoolbox.ca/Catalogs.html
- Data availability in the composite catalog: from 1906 to 1984-12-31
- All reported magnitudes are included. For *MB* and *MN*, a conversion to moment magnitude **M** is made as described in Fereidoni et al., 2012. For *ML,* the conversion to moment magnitude is as described in Appendix D.
- Types of events included: no information available

ANSS Comprehensive Catalog (ANSS): The ANSS Comprehensive Catalog is maintained by US Geological Survey. The catalog contains earthquake source parameters and other products produced by contributing seismic networks. We use the catalog as our US data source commencing 2014.

- Source: USGS http://earthquake.usgs.gov/earthquakes/search/
- Data availability in the composite catalog: 2014-01-01 to present

- Magnitudes in our study region are mostly Duration magnitude (*MD*) and Coda magnitude (*MC*). A few of the events have *ML* or **M** magnitude types.
- Types of events included:
  - Earthquakes
  - Non-Earthquakes (Explosion, Mining Explosion, Quarry, Quarry Blast)

Novakovic and Atkinson's moment magnitude catalog (NA15): Novakovic and Atkinson (2015) provide a moment magnitude catalog for the events recorded by TransAlta/ Nanometrics network. They use the ground-motion based algorithm of Atkinson, Greig and Yenier (2014) to calculate the moment magnitudes, but have updated the algorithm to be calibrated for the study region of the CASC, as described in Novakovic and Atkinson (2015; manuscript in preparation for BSSA). New and updated moment magnitudes are added to the catalog dynamically.

COMPILATION PROCESS

The fundamental idea in the development of the CASC is to preserve the primary datasets and to enhance and extend it through the inclusion of data from the alternative data sources. For events common to more than one catalog, we added additional locations and magnitudes to the primary solution based on the availability and quality of data, and for non-common events we added all the information. The procedure applied to integrate the information is slightly different for the time periods of 1906 to 2013 and 2014 to the present time. Both procedures are fully described in Appendix A, and B. Initially, the CASC was provided in two separate files (CASC13 and AlbertaCompCat-x.txt) containing seismicity information in the above mentioned time periods. These two files are now merged together into one single file representing the entire length of the catalog.

IDENTIFYING DUPLICATES

The integration of the information from several data sources resulted in multiple entries for a single event. The identification of duplicates is done semi-automatically by considering the following maximum intervals to be diagnostic of a duplicated event (which should be merged to a single event entry):

- Time window (in second) = 2 sec

- Space window (in km) = 30 km
- Magnitude window (in magnitude unit, regardless of mag type) = 1 magnitude unit

These intervals were determined based on the evaluation of the histograms shown in Appendix C. The events with time difference of 2 sec or less are flagged as potential duplicates. When the differences in locations and magnitudes of potential duplicates are both smaller than the designated legitimate intervals listed above, the events are automatically considered as duplicates. In the case of a duplicate, the time, location and magnitude are assigned from the highest-priority source (discussed later), and the alternative sources are used to provide additional information on alternative magnitudes and locations. If there is some ambiguity (i.e. event close in time, but the space or magnitude criteria are not met), it is subjectively decided whether they should be considered as duplicates or separate events by a manual review of the information.

When multiple events pass the duplicate criteria, the analyst subjectively decides which one should be kept in the composite catalog. Supplementary information from secondary sources (i.e. alternative location and magnitude information) is retained in the composite catalog.

The following priority of input catalogs is considered:

1. NMX
2. GSC
3. AGS
4. CCSC
5. ANSS

MOMENT MAGNITUDE ASSIGNMENT

Current approaches in seismic hazard and seismicity studies require the input catalog of seismicity to be unified and homogenized in terms of magnitude, with moment magnitude (**M**) being the preferred magnitude scale. To homogenize the Composite Alberta Seismicity Catalog, we adopt the actual **M** values from the reporting agencies or special studies if available. If an actual **M** is not available, we apply empirical relations to convert the preferred instrumental magnitude scale (Mpf) to moment magnitude. The applied empirical relations are discussed in Appendix D.

The assigned **M** values are expressed in the "*MwAsg*" column of the catalog file to the nearest 0.1. Column "*mf*" of the catalog reports the conversion factors between the assigned **M** and the preferred alternative magnitude measure according to the equation below:

$$\mathbf{M}\ \text{assigned} = \text{Mpf} + mf$$

For the events with an actual **M** in the "*MwAsg*" column (and also in the Mpf column), the conversion factors are simply zero. As the conversion factor in some of our empirical relations is also zero, note that a zero in "*mf*" column does not necessarily imply that an actual **M** has been adopted. The assigned moment magnitude is rounded to the nearest 0.1 units. However, the conversion factors are reported to two decimal places. This enables the user to retrieve the converted moment magnitude up to the nearest 0.01, if desired.

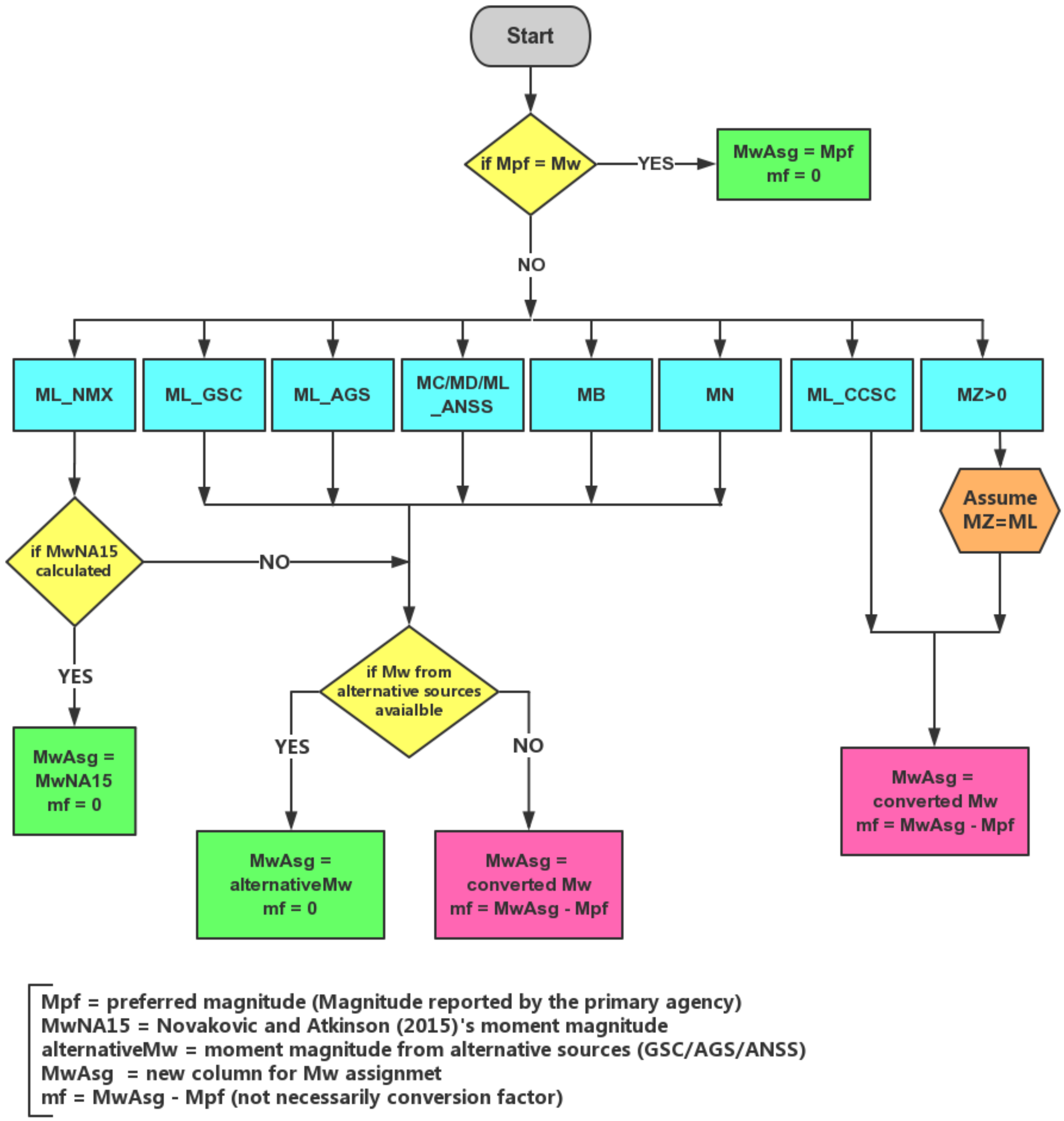

Figure 2-Schematic representation of the process used to assign moment magnitude

MAGNITUDE COLUMNS IN THE COMPOSITE CATALOG

The aim in the development of the composite catalog is to retain all the magnitude scales produced for each particular event and provide a preferred conversion to moment in order to have a unified and homogenized magnitude column for the entire catalog. This section briefly describes all the magnitude columns available in the catalog file.

ML MN MB MW MS MC MD MZ (column 9-16 in the catalog file)

These columns contain all the magnitude scales (instrumental or moment magnitude) reported for each event entry in the catalog. The values could be the magnitude reported in the primary data source or any alternative source when there is more than one solution for a single event. The magnitude values in these columns are expressed to the nearest 0.01.

Mpf Tmpf (column 17, 18)

Our preferred magnitude scale for each entry from the above set is reported in these two columns with "*Mpf"* being the value and "*Tmpf"* being the magnitude type. If an actual moment magnitude is produced for the event, then that is our preferred magnitude scale in these two columns, otherwise the magnitude scale reported by the primary agency is considered as the preferred magnitude and reported here. Thus the magnitude values in "*Mpf"* are a mixture of different magnitude scales. "MWR" in magnitude type column denotes that moment magnitude is computed from regional moment tensor solution and is specified in the source agency's catalog. The preferred magnitude is expressed to the nearest 0.01.

MwAsg (column 25)

For each event our preferred value of moment magnitude is provided in "*MwAsg*" column to the nearest 0.1. We advise the users to apply their magnitude search criteria to this column. The process of moment magnitude assignment is thoroughly described in Appendix D.

MwNMX MwNA15 MwGSC MwAGS MwANSS (column 39 to 43)

As moment magnitude has special importance in the composite catalog, all available moment magnitude values, as produced by NMX, NA15, GSC, AGS, and ANSS for each entry is retained in these columns (where available) to two decimal points.

BLAST EVENTS

Our blast discrimination is preliminary. For the older events, the event type designation is as provided in the primary or alternative data source. For more recent event, we label events that occur at a location of known blasting during daytime hours as blasts. Our procedure may erroneously label some of the local earthquakes as blast; and vice versa. We are working on an algorithm to identify blasts across the region more accurately.

FINAL COMPOSITE CATALOG FORMAT

The final CASC has 43 columns.

Table 1- List of Columns in Output Catalog File

Column No.	Header	Comment
1	yr	Occurrence year in primary source catalog
2	mo	Month
3	dy	Day
4	hh	Hour
5	mm	Minute
6	ss	Second
7	lat	Latitude in primary source catalog
8	lon	Longitude in primary source catalog
9	ML	Local magnitude, -9.99 if not available
10	MN	Nuttli magnitude,-9.99 if not available
11	MB	Body wave magnitude, -9.99 if not available
12	MW	Catalog moment magnitude, -9.99 if not available
13	MS	Surface wave magnitude, -9.99 if not available
14	MC	Coda wave magnitude, -9.99 if not available
15	MD	Duration magnitude, -9.99 if not available
16	MZ	Unknown magnitude type, -9.99 if not available
17	Mpf	Preferred magnitude (our preferred magnitude scale from columns 9-16)
18	Tmpf	Preferred magnitude type*
19	Dep	Event depth in km. A value of 0 denotes very shallow. In NMX catalog a 0 depth is a suspected blast.
20	Dep_err	Depth Error: Not available in GSC catalog (for consistency in composite catalog, reported as -9.99 for GSC events)
21	DD	Depth Designation (Indication on how the depth is determined or assigned): *: Calculated hypocenter , G:Value assigned by a geophysicist, Z: No information for depth designation
22	flag	Primary data source flag: 1: NMX 2: GSC 3:AGS 4:CCSC 5: ANSS
23	zf	Seismic source zone , Not specified at this time
24	mf	MW conversion factor
25	MwAsg	Assigned moment magnitude after calibration
26	EveventType	1= earthquake 2= Suspected Blast 3=No information available

Column No.	Header	Comment
27, 28	latGSC,lonGSC	Location from GSC, if available.
29, 30	mGSC,mtGSC	Alternative Magnitude and Magnitude type from GSC, if available.
31,32	latANSS,lonANSS	Location from ANSS, if available.
33,34	mANSS,mtANSS	Alternative Magnitude and Magnitude type from ANSS, if available.
35,36	latAGS,lonAGS	Location from AGS, if available.
37,38	mAGS,mtAGS	Alternative Magnitude and Magnitude type from AGS, if available.
39	MwNMX	Moment magnitude produced by NMX
40	MwNA15	Moment magnitude produced in Novakovic and Atkinson (2015), if available.
41	MwGSC	Moment magnitude produced by GSC, if available.
42	MwAGS	Moment magnitude produced by AGS, if available.
43	MwANSS	Moment magnitude produced by ANSS, if available.

APPENDIX A- THE COMPILATION PROCESS FOR THE TIME PERIOD FROM 1906 TO 2013-12-31 (PERFORMED BY LUQI CUI)

The earthquakes from 1906 to the end of 1984 are from CCSC_west catalog; earthquakes from 1985 to 2013 are mostly from the GSC catalog. Between September 2006 and December 2010, AGS catalog contains some additional events not in the GSC catalog. The following steps describe the process followed to generate the CASC for the time period from 1906 to 2013-12-31, which is implemented using a MATLAB script.

Step1. Prepare excel-type comma-delimited files for the three input catalogs (AGS, GSC and CCSC-west) and put all these files into the same folder. Add one column in the GSC catalog to show the types of events included: 1=quakes, 2=blasts, 3=unknown. (This is implemented by searching the GSC catalog once for quakes, once for blasts, and combining these files.)

Step2. Perform the script **“**Alberta_2013catalogfinal_processing.m” and it will generate the CASC13.csv catalog. The catalog is sorted from oldest to newest. Add a unique number for all events.

Step3. Perform the script “duplicate.m” to calculate the time-space-magnitude differences and to compare with the above conditions for a duplicate. Find the duplicates and remove them from CASC13.

Step4. Output the compiled CASC13

The NMX catalog for the time period of fall 2013 to the end of 2013 has been added to the CASC13 catalog later.

APPENDIX B - THE COMPILATION PROCESS FOR THE TIME PERIOD FROM 2014-01-01 TO PRESENT TIME (PERFORMED BY AZADEH FEREIDONI)

The matlab script "alberta_comp_cat_exe.m" performs the following process to combine the input catalogs and creates the Alberta composite catalog:

First, the computer program gets the time period and region of the composite catalog from inputparameters.txt file. Note that the default region in the file is the same as the study region defined above. Additionally, in the text file, the user has the option for automatic or manual download of input catalogs. If the automatic option (1) is selected, the computer program builds a custom URL with the user's search parameters and sends requests to the agencies' servers (GSC and ANSS websites), and it automatically downloads the catalog information in csv format. If the manual option (0) is selected, the user should manually download the catalogs from the corresponding websites in csv format. Then he/she locates the downloaded files on the drive.

For the GSC input catalog, the user should download and generate two separate files for earthquake and non-earthquake events. This is because GSC does not list the event types in the catalog. However, its database can be searched for variety of event types. The user should search the GSC database and download the data with only Quakes and Induced types of event included. One more time, he/she should submit the search with Mining events and Blasts selected in the event type. The user should be very careful to first locate the earthquake events file, and second the non-earthquake events file. It is important to locate the file in proper order as the computer program flags the events based on this order. If the automatic download option for GSC is selected, the computer program will do all these steps automatically. Therefore, the automatic download is recommended for the GSC catalog to avoid the possible mistakes in downloading and locating the proper files.

In the next step, the computer program imports the events information from the input catalogs (NMX, GSC, ANSS) into matlab, using the embedded "readAthena.m", "readGSC.m", and "readANSS.m" functions. Next, it uses the "Comb_Cat_f.m "function to combine the NMX and GSC catalogs. The NMX catalog is the preferred source, in case of duplicates.

Finally, it adds the US data source (ANSS) to the composite catalog, removes duplicates and generates the final catalog file in .txt format (AlbertaCompCat-x.txt, where x is the date in year-mo format), retaining supplementary information for duplicates. The process is summarized in the flow chart below.

New and updated Novakovic and Atkinson's moment magnitudes (MwNA15) are added to the dataset dynamically as they update their catalog. The new MwNA15 replaces the MW, Mpf (preferred magnitude scale), and MwAsg (assigned moment magnitude) in the catalog file.

Note:

- The input catalogs must be downloaded in *.csv format from the agencies' websites.
- In the case of manual download, all input catalogs and the matlab files must be in the same folder.
- The automatic download option is not available for Nanometrics (NMX) catalog, as the earthquake data is password protected. The user should download the catalog manually and leave the download option in the text file as 0.

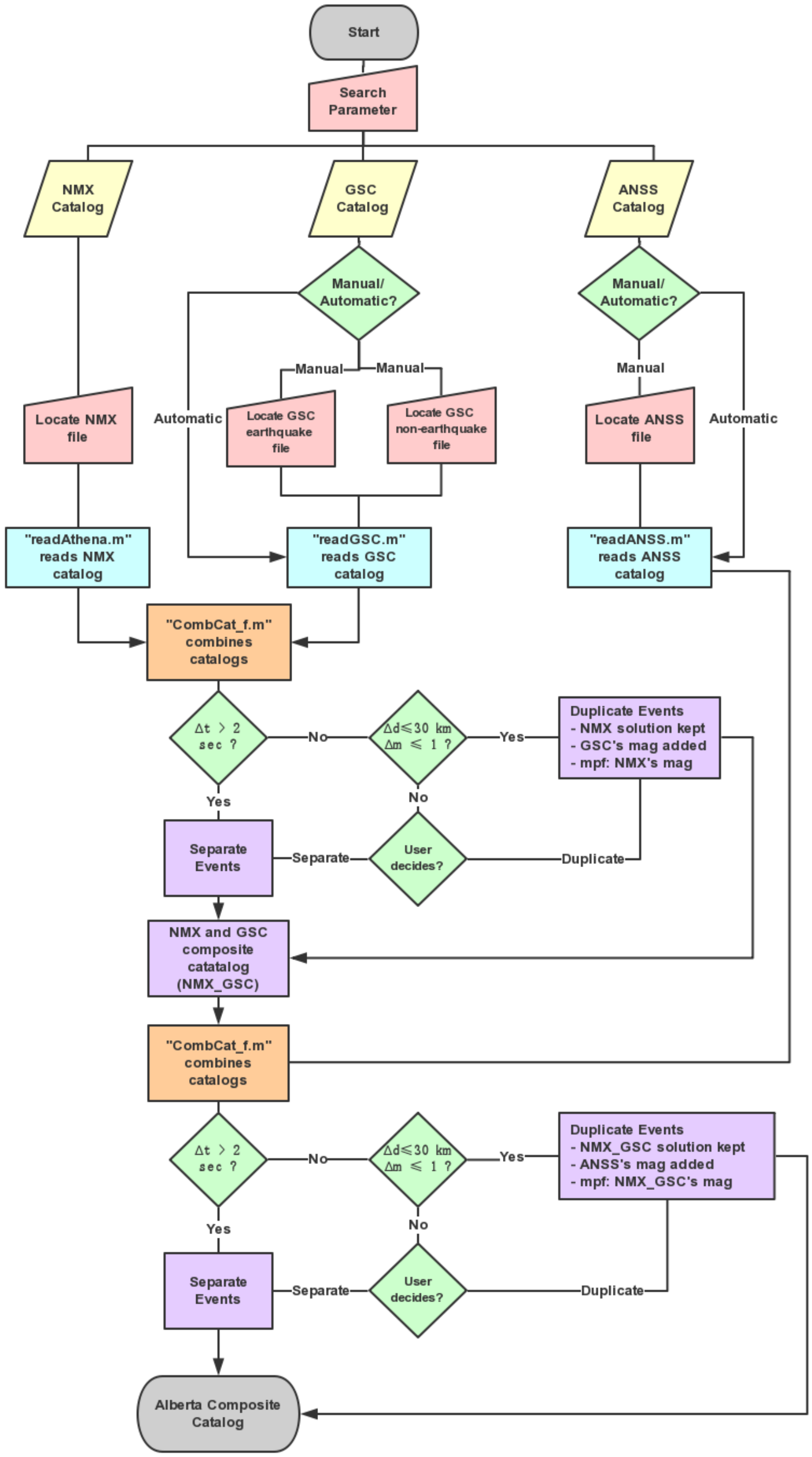

Figure 3- Schematic representation of development process of CASC from time period 2014-01-01 to present time

APPENDIX C- HISTOGRAMS SHOWING TIME, MAGNITUDE, SPACE INTERVALS BETWEEN POTENTIAL DUPLICATES

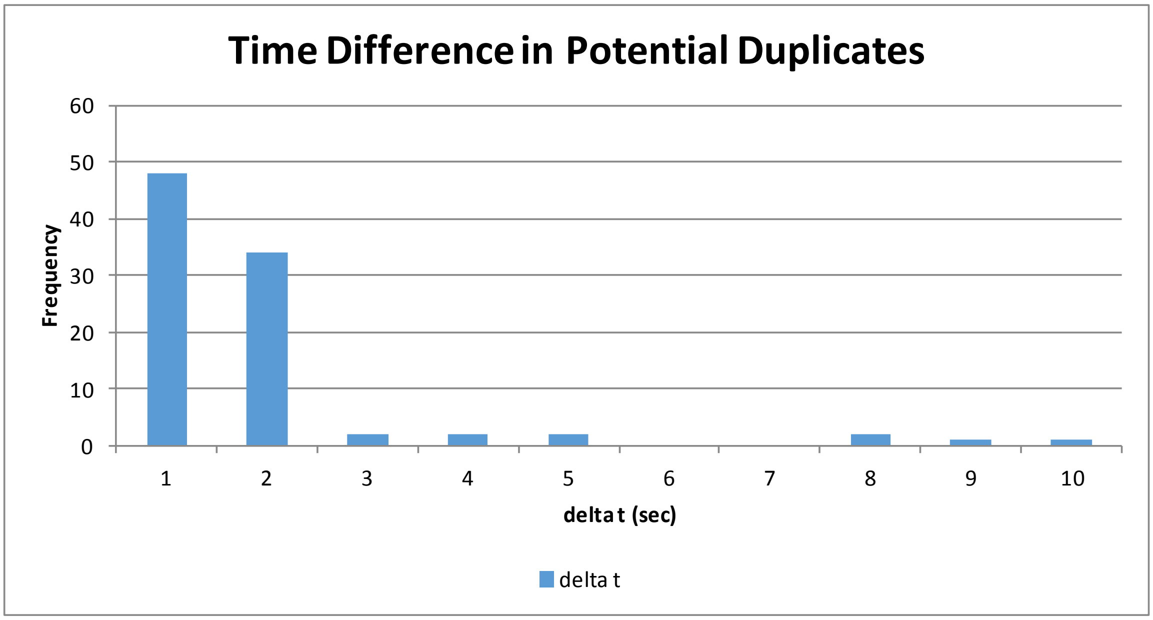

Figure 4-Time difference between potential duplicate pairs (data from 2013 Alberta Composite Catalog)

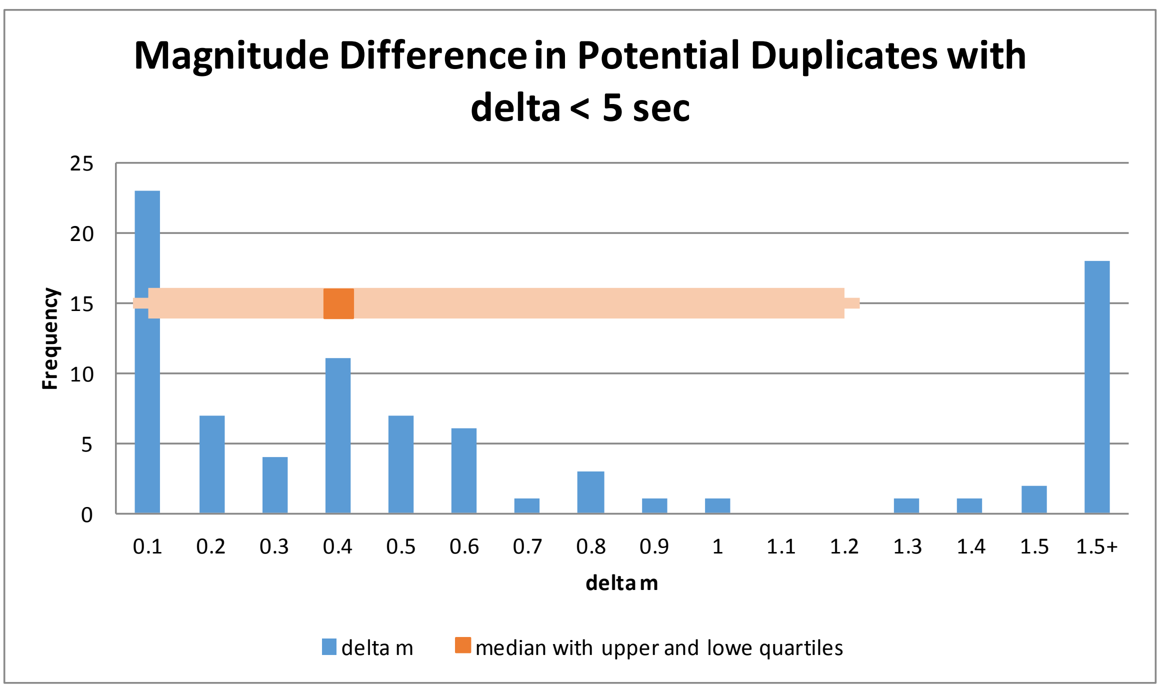

Figure 5- Magnitude difference between potential duplicate pairs, with time separation less than 5 seconds (data from 2013 Alberta Composite Catalog).

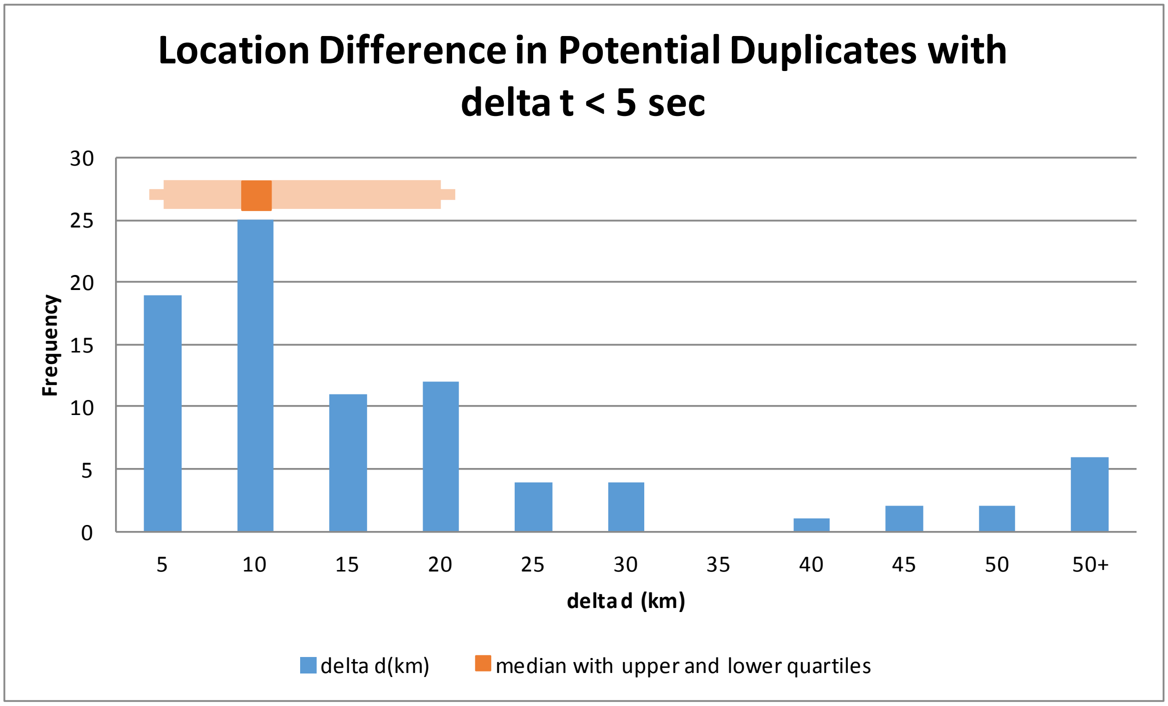

Figure 6- Spatial difference between potential duplicate pairs, with time separation less than 5 seconds (data from 2013 Alberta Composite Catalog).

APPENDIX D- DEVELOPMENT OF EMPIRICAL CONVERSION EQUATIONS

Moment magnitude assignment for events in NMX catalog:

For events in the NMX catalog, we adopt **M** values from the special study by Novakovic and Atkinson (SRL, 2015) which uses the ground-motion based algorithm of Atkinson, Greig and Yenier (2014), as updated by Novakovic and Atkinson (2015). The moment magnitude from this database is called *MwNA15* in the catalog file. For all NMX events for which *MwNA15* is calculated, we have changed the preferred magnitude type to *Mw* and used *MwNA15* as the preferred magnitude in column "*Mpf*" and directly as assigned moment magnitude in column "*MwAsg*". *MwNA15* values also appear in the "*Mw*" column.

Moment magnitude assignment for remaining events:

For the remaining events, if an actual **M** is available from the primary or alternative reporting agencies, that value has been adopted as preferred magnitude in the catalog and has been used directly as the assigned **M** value in "*MwAsg*" column. Otherwise, we apply the appropriate empirical relationships to convert the instrumental magnitude scales to moment magnitude.

Empirical relations for moment magnitude assignment:

ML_NMX (local magnitude calculated by NMX): In Novakovic and Atkinson (2015), the moment magnitude is intentionally tied to local magnitude determined by NMX (*ML_NMX*). Thus we assume that the *ML_NMX* is equivalent to *MwNA15* and apply ***M*** = *ML_NMX* equation to convert the *ML_NMX* to moment magnitude. This conversion is generally required only for the most recent events for which the update of Novakovic and Atkinson's moment magnitude catalog is lagging the update of the composite catalog. As *MwNA15* becomes available, it will replace the converted value.

ML_GSC (local magnitude calculated by GSC): We have derived an empirical relation to convert *ML_GSC* to moment magnitude. For this purpose, we have compared *ML_NMX* versus *ML_GSC* for 228 events in Alberta and adjacent region in the magnitude range of 1.5 to 4.9 and time period of fall 2013 and June 2015. We have obtained a best-fit line assuming slope of 1. The offset for the best-fit line is calculated by taking the average of the residuals between *ML_NMX* and the 1:1 line, and the standard error of the residuals is used as the error. The discrepancy between local magnitude derived by NMX and GSC is 0.06±0.03. Using the empirical relation between *ML_NMX* and *ML_GSC*, as well as assumption of ***M*** = *ML_NMX*, we derived a model for estimating moment magnitude from *ML_GSC* values:

$$\boldsymbol{M} = ML\_GSC - 0.06.$$

The use of the above empirical relation for the entire length of the catalog is justified by the fact that GSC has calculated *ML* in the same manner since 1955 (Ristau et al, 2005).

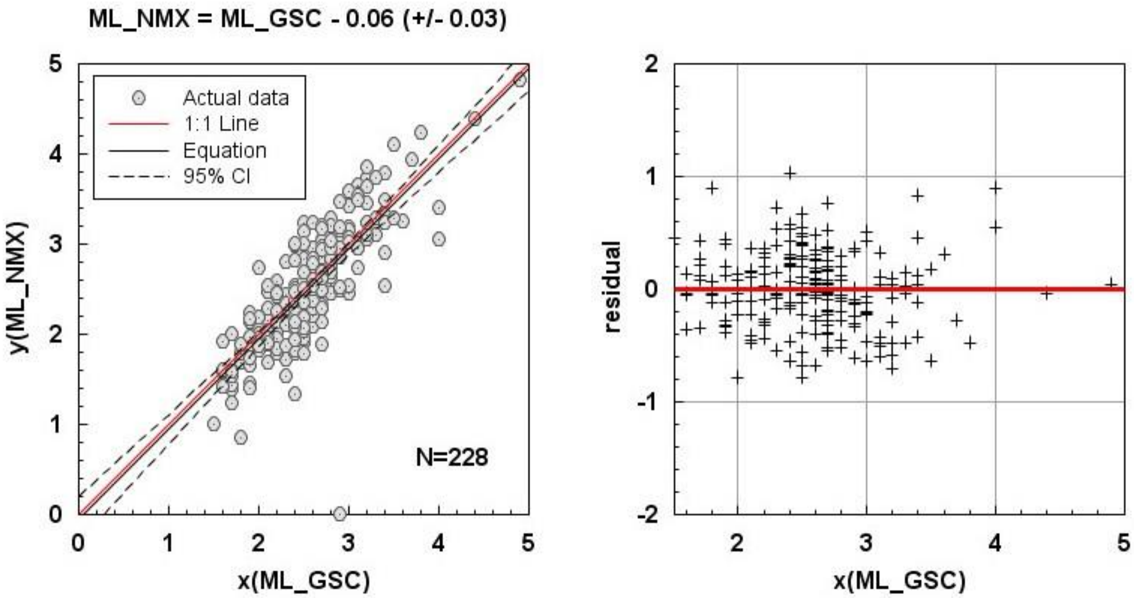

Figure 7 – Comparison of NMX's Local magnitude and GSC's Local Magnitude for 228 earthquakes in Alberta and adjacent region. The left panel shows the data pairs available for the conversion, 1:1 relationship (red line), and the best-fit line assuming slope of 1 (black solid line). Dashed lines show 95% confidence intervals. Right panels show the residuals.

ML_AGS (local magnitude calculated by AGS): We have derived a simple empirical relationship to convert *ML_AGS* to moment magnitude. For this purpose, we have compared *ML_AGS* versus *ML_GSC* for 61 earthquakes in Alberta and adjacent region in the magnitude range of 0.4 to 3.8. We have obtained a best-fit line assuming slope of 1. The discrepancy between local magnitude derived by GSC and AGS is 0.08±0.05.

Using same ***M***-*ML_GSC* relation derived above, we obtain a model to convert AGS's *ML* to ***M*** (e.g. we add the two conversion factors):

$$\boldsymbol{M} = ML\_AGS - 0.14.$$

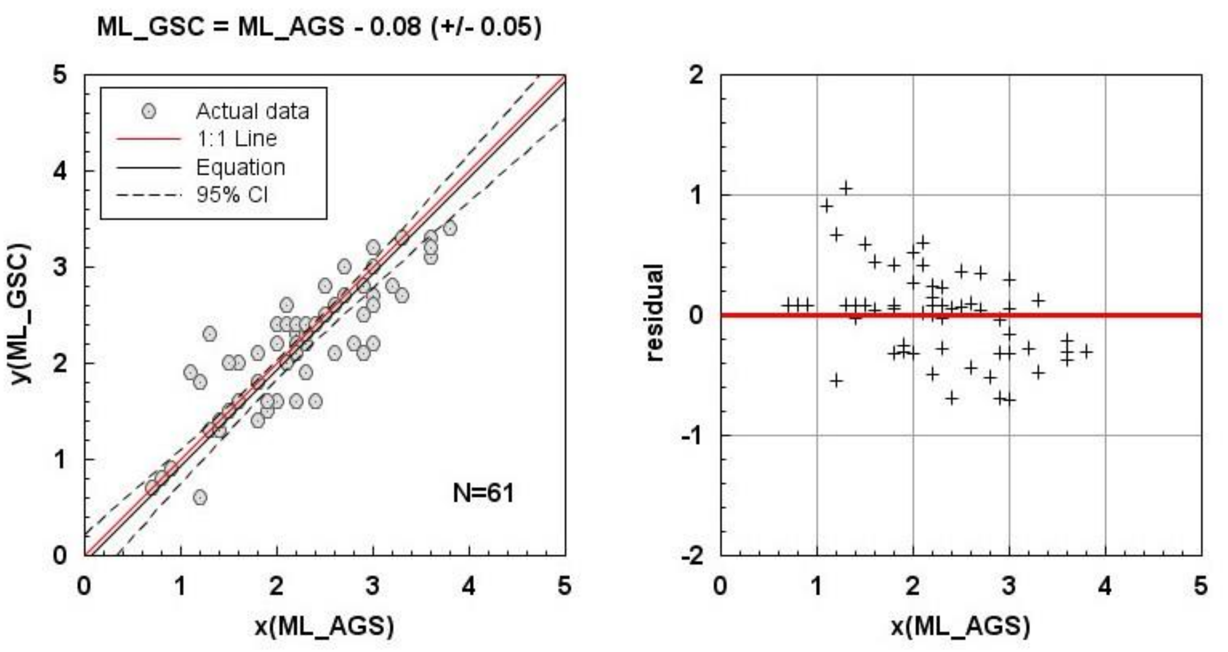

Figure 8-Comparison of GSC's Local magnitude and AGS's local magnitude for 61 earthquakes in Alberta and adjacent region. The left panel shows the data pairs available for the conversion, 1:1 relationship (red line), and the best-fit line assuming slope of 1 (black solid line). Dashed lines show 95% confidence intervals. Right panel shows the residuals.

ML/MC/MD_ANSS (local, coda, and duration magnitude calculated by ANSS): The panel below shows the comparison of ANSS' Duration magnitude (*MD_ANSS*) and *ML_GSC* for 35 earthquakes in our dataset. The comparison does not look good at all but *MD_ANSS* can only be calibrated in this manner with the data available [*ML_GSC = MD_ANSS – 0.37 (+/-0.04)*]. The conversion equation is derived as described above. Using the empirical relation between *ML_GSC* and *MD_ANSS*, as well as above equation between ***M***-*ML_GSC*, we derived a model for estimating moment magnitude from *MD_ANSS* values:

$$\boldsymbol{M} = MD\_ANSS - 0.43.$$

The earthquake source parameters in our study region are mostly contributed by MSRN (Montana Regional Seismic Network) and UW (University of Washington) seismic networks to the ANSS composite catalog. In MSRN, Coda duration magnitudes are intentionally tied to *ML* as a known parameter. Thus we assume *MC_ANSS = MD_ANSS=ML_ANSS*. We consider these to be very poor conversions, but they do not impact many events of interest in the study region.

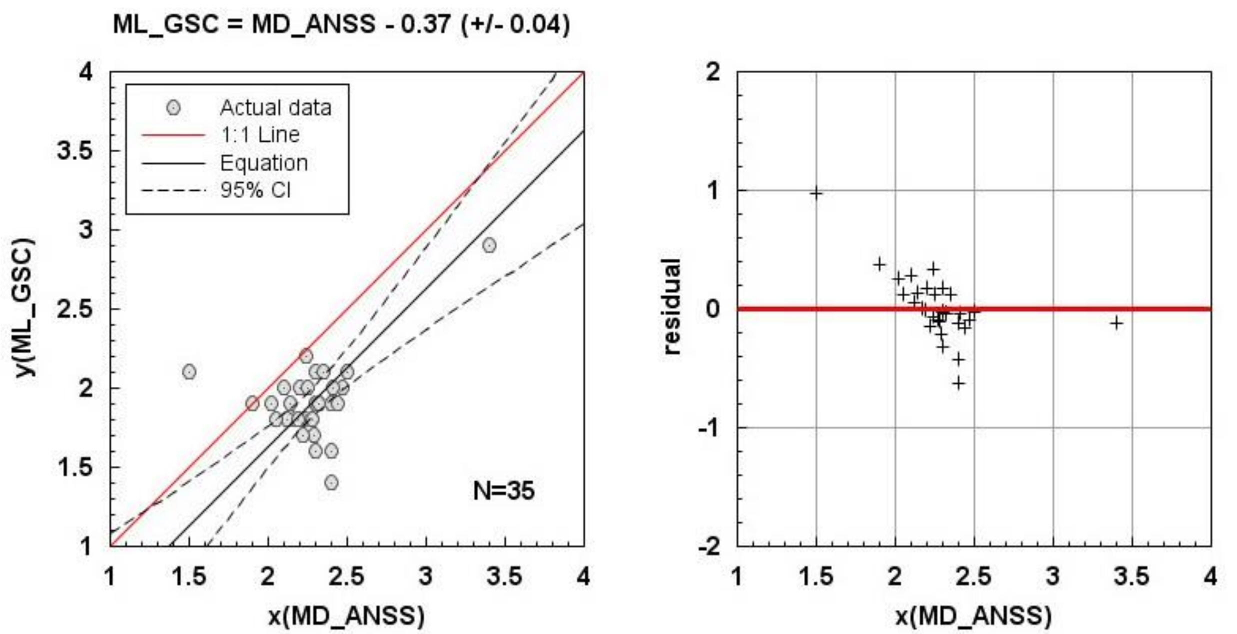

Figure 9- Comparison of GSC's Local magnitude and ANSS's Duration Magnitude for 35 earthquakes in Alberta and adjacent region. The left panel shows the data pairs available for the conversion, 1:1 relationship (red line), and the best-fit line assuming slope of 1 (black solid line). Dashed lines show 95% confidence intervals. Right panel shows the residuals.