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Canada

ISSN 2816-7155
ISBN 978-0-660-44749-0
Catalogue No. M183-2/8912E-PDF

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# Comparing felt intensity patterns for crustal earthquakes in the Cascadia and Chilean subduction zones, offshore British Columbia, United States, and Chile

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## 2022



Permanent link: https://doi.org/10.4095/330475

This publication is available for free download through GEOSCAN (https://geoscan.nrcan.gc.ca/).

**Recommended citation**
Rutherford, J. and Cassidy, J.F., 2022. Comparing felt intensity patterns for crustal earthquakes in the Cascadia and Chilean subduction zones, offshore British Columbia, United States, and Chile; Geological Survey of Canada, Open File 8912, 40 p. https://doi.org/10.4095/330475

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## ABSTRACT

In this study, we utilize US Geological Survey citizen science earthquake felt intensity data to investigate whether crustal earthquakes in the Chilean Subduction Zone show similar, "felt intensity" distributions to events of the same magnitude and depths within the Cascadia Subduction Zone (Quitoriano & Wald, 2020; USGS Earthquake Hazards Program, 2020). In a companion article (Rutherford & Cassidy, 2022) we examined intraslab (deep) earthquake intensity patterns for the Chile and Cascadia subduction zones. Building on the intraslab companion article, the goal of this comparison is to determine whether felt intensity information from several recent large (M8-8.8) subduction earthquakes in Chile can be applied to Cascadia, where no subduction earthquakes have been felt since 1700. This will provide a better understanding of shaking intensity patterns for future subduction earthquakes in Cascadia – critical information for scientists, engineers, and emergency management organizations.

For this research, we utilized 20 years of catalogued "Did You Feel It?" (DYFI) citizen science data from the US Geological Survey's (USGS) earthquake online catalogue, the *ANSS Comprehensive Earthquake Catalog (ComCat) Documentation* (USGS Earthquake Hazards Program, 2021). In total, we compared intensity patterns for fourteen magnitudes (M4.5-7.2) from 29 crustal earthquakes in Cascadia, to the intensity patterns from 114 earthquakes in Chile, with the same magnitudes as the Cascadia events.

Our analysis involved plotting and fitting the Chile and Cascadia earthquakes' DYFI responses to compare the intensity patterns for the two subduction zones. All plots show the expected downward trend for intensity with distance, and overall, we find good agreement between felt intensity patterns at all magnitude ranges in Chile and Cascadia. These results provide confidence that Chilean intensity data from recent megathrust earthquakes can act as a proxy for future megathrust earthquakes in Cascadia.


## INTRODUCTION

The world's largest earthquakes occur along subduction interfaces. This is where denser oceanic plates are pushed (subducted) beneath lighter continental plates. Not only do subduction zones produce large (M~9) earthquakes, but they also produce large tsunamis (Di Menna & Flick, 2005; Staisch, Walton, & Witter, 2019). Figure 1 shows the three types of earthquakes that occur in subduction zones: 1) crustal earthquakes in the continental (overriding) plate; 2) deep, intraslab earthquakes within the subducting oceanic plate; and 3) plate interface (megathrust subduction) earthquakes that result from movement along the subduction fault.

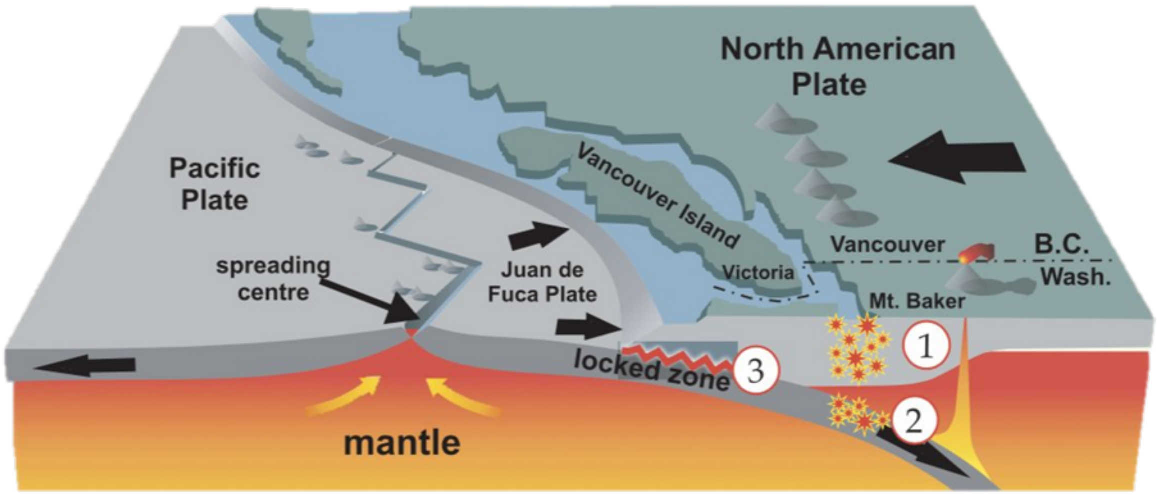



Figure 1: The Cascadia Subduction Zone has three types of earthquakes: Crustal earthquakes occur at a depth less than ~ 35 km (circle 1); Deep intraslab earthquakes occur at depths of ~40 to 60 kilometers below the surface (circle 2), and megathrust earthquakes occur along the boundary between the oceanic and continental plates (circle 3). (Government of Canada, 2011)

This study looked at two similar subduction zone regions, the Cascadia Subduction Zone (CSZ) in the Pacific Northwest (Figure 2) and the Chile Nazca Subduction Zone in South America (Figure 3). Both subduction zones have segments with a very young oceanic crust (< ~5 MY) and subduction rates of 2-8 cm/year (USGS Subduction Zone Science, 2020; Wang & Tréhu, 2016). Both subduction zones experience all three of these types of earthquakes; Cascadia has not experienced a major subduction earthquake since 1700, however, whereas Chile has experienced 3 major subduction earthquakes (M8.2-8.8) since 2010 (Government of Canada, 2021a; Staisch, Walton, & Witter, 2019).

The Cascadia Subduction Zone (Figure 2), is an 1,100 km-long tectonic boundary between the continental North American Plate and the oceanic Explorer, Juan De Fuca and Gorda plates, extending from northern Vancouver Island down to northern California (Government of Canada, 2021b; USGS Pacific Coastal Marine Science Center, 2021; Watt & Brothers, 2020). Here the oceanic plates are subducting beneath North America at approximately 2-5 cm/year (Government of Canada, 2021b). For a detailed description of this subduction zone, see, for example (Government of Canada, 2021b; USGS Pacific Coastal Marine Science Center, 2021; Wang & Tréhu, 2016).

The Chile Subduction Zone (Figure 3) is located along the coastal margin of Chile where the oceanic Nazca Plate is subducting beneath the western edge of the continental South American Plate along a 5,900-kilometer length of South America (Henig, Blackman, & German, 2010; Patton, Ammirati, Stein, & Sevilgen, 2019; Dura, et al., 2017; Cisternas, Garrett, Wesson, Dura, & Ely, 2017). Subduction rates vary from 6.5-8.0 cm/year along this margin. For a detailed description of this subduction, see, for example (IRIS, No date; Henig, Blackman, & German, 2010; Cisternas, Garrett, Wesson, Dura, & Ely, 2017). In this study, we considered earthquakes that occurred along the Chile portion of this margin.

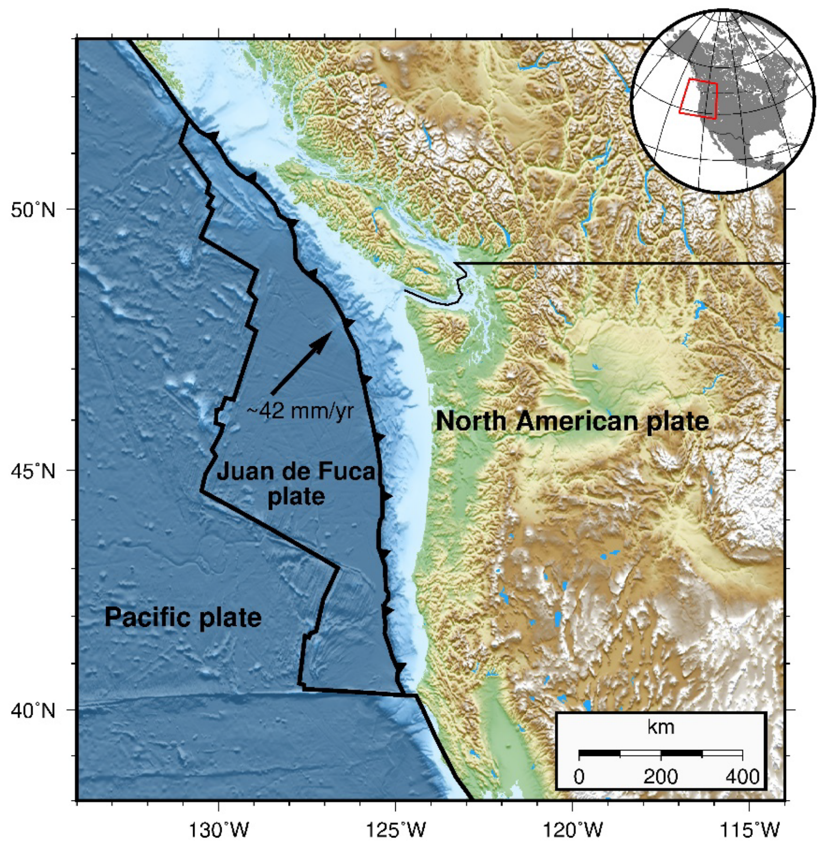



Figure 2: Black variegated line shows the ~1,100 km long Cascadia Subduction Zone, located between the Juan De Fuca and North American Plates, where the Juan de Fuca plate is subducting beneath the North American plate at ~42 mm/year.

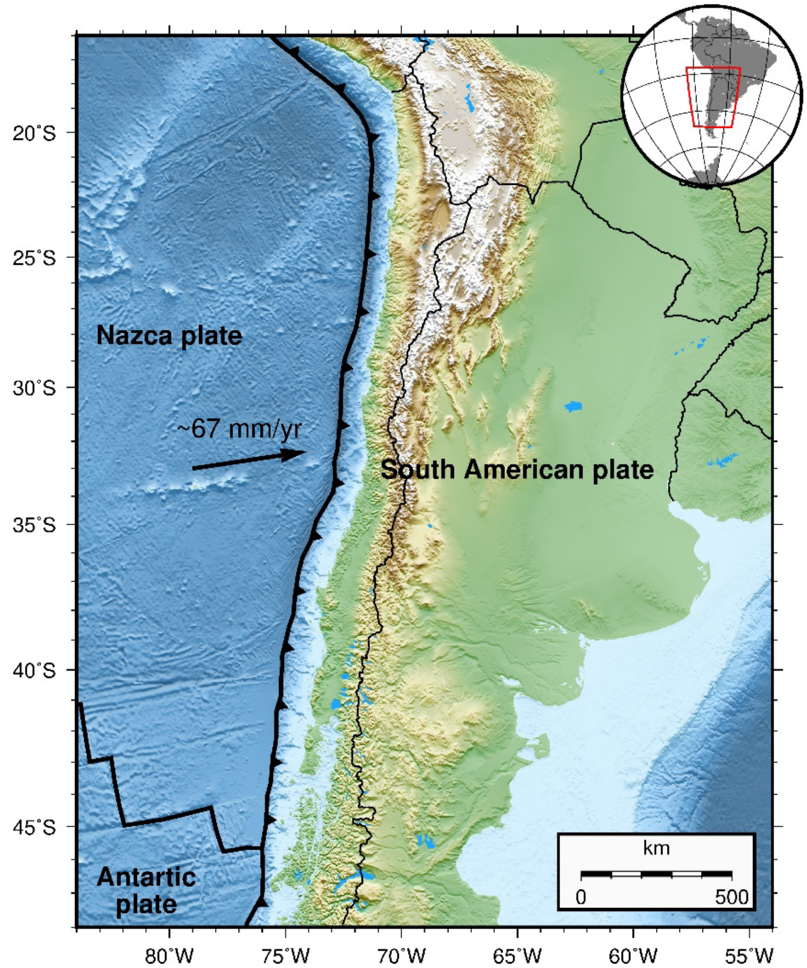



Figure 3: Black variegated line shows the ~5,900 km long Chile Subduction Zone, located between the Nazca and South American Plates, where the Nazca plate is subducting at approximately 67 mm/year beneath the South American plate.

Earthquake intensity is the qualitative measurable severity of ground shaking, controlled by several factors, with earthquake magnitude and distance from the epicenter generally being most dominant/influential; with higher intensities close to the rupture and lower values further from the earthquake (USGS Earthquake Hazards Program, 2020). Earthquake depth, surface geology, distance to a fault, as well as building characteristics are additional factors that influence the intensity people will experience (USGS Earthquake Hazards, 2022).

To gain a greater picture of this ground shaking, macroseismic intensities provide an estimate of the effect and impact of shaking that people experienced. The USGS uses a citizen science platform to capture this information through the "Did You Feel It?" (DYFI) website (USGS Earthquake Hazards Program, 2020). These macroseismic intensities people experience are assigned a numerical value based on, and calibrated to, the Modified Mercalli Intensity (MMI) scale, which is an increasing level of intensity ranging from not felt shaking (MM=1) to catastrophic destruction (MMI=10) (USGS Volcano Hazards, 2021). However, the USGS DYFI data is an intensity calculation based on the weighted sum of the eight various DYFI questionnaire indices aggregated (not the average) and is represented/captured as Community

Decimal Intensity (CDI) rating for either 1-kilometer or 10-kilometer block/grid area (USGS Earthquake Hazards Program, 2020). Details on the CDI rating calculation and additional information can be found on the USGS Earthquake Hazards Program webpage (USGS Earthquake Hazards Program, 2020).

In this article, we look at patterns in the DYFI Intensity vs. Distance data for crustal earthquakes greater than magnitude 4.5. Intensities used in the USGS's Intensity vs. Distance plots use an 'Intensity Prediction Equation' (IPE) that captures intensities from the DYFI questionnaire's responses and compares them against estimated intensities and distances from the reported magnitudes (USGS Earthquake Hazards Program, 2020).

The DYFI data have been collected since 2004, when the online USGS DYFI platform became available to users around the globe (Quitoriano & Wald, 2020). Although there are other earthquake intensity datasets, for example, NRCan in Canada and the Seismological Service of Chile for Chile, (Wald D. J., Quitoriano, Worden, Hopper, & Dewey, 2011), we only consider the USGS intensity data for consistency. The same data collection form is used in both areas, so the resulting intensity values will be directly comparable.

Increasing our understanding of how intensities from specific earthquake events affect people, infrastructure, and the environment contributes to earthquake scenario development, earthquake risk assessment, and community risk and emergency management planning. This research is part of the Canadian Government's Public Safety Geoscience Program; ultimately, our aim of this project is to contribute to better preparedness for future large earthquakes in Canada.

## METHODS

This project uses the same approach conducted in the intraslab companion study (Rutherford & Cassidy, 2022), which involved three main components. First, a literature review of the *USGS DYFI Scientific Background* documents was conducted to determine how best to use the DYFI data (resolution, file format, etc) for this research. Second, felt earthquakes within search criteria were identified, and DYFI data from the *USGS Search Earthquake Catalog* (ComCat) were acquired for crustal (shallow) felt earthquakes that occurred within the overriding continental plates (North American in Cascadia, and South American in Chile) from January 1, 1960, to Jan 1, 2020. Most of the intensity data in this study are from 2004 onward, after the USGS DYFI portal became operational to global contributors (Quitoriano & Wald, 2020). A small number of significant historical events (going back to 1960) were added to the USGS DYFI database and are used in this study. The third component involved running conversion analytics and generating data visualization through plots created in MS Excel. The following provides a brief summary of the methodology, for more details see Rutherford & Cassidy (2022).

### Identifying Earthquakes & Acquiring DYFI Data from ComCat

Identifying crustal earthquakes of interest for this project involved searching the USGS ComCat (USGS Earthquake Hazards Program, 2021) database for earthquakes felt or experienced by people, of magnitude 4.5 and greater, within the North and South American Plates from 1960 to 2020.

The tectonic settings within the regions of interest (Figure 2 and Figure 3) control the earthquake depth (Hayes & Crone, 2021; Duo, McGuire, Liu, & Hardebeck, 2018; Cisternas, Garrett, Wesson, Dura, & Ely, 2017). Crustal events of depths less than 35 km primarily occur within the overriding continental plate, or unsubducted oceanic crust (as seen in Figure 1) (Adams & Halchuk, 2004; Hayes & Crone, 2021; Government of Canada, 2021b). Meanwhile, deeper (depth > 35 km) earthquakes are likely occurring within the subducting slab (Staisch, Walton, & Witter, 2019; USGS Subduction Zone Science, 2020). The mechanics and general effects of earthquakes in these two regimes differ, and therefore, we treated them separately. We therefore set the depth parameters in *ComCat* to separate the Intraslab from the Crustal earthquakes in our search.

## ComCat Search for Crustal Earthquakes

For this project we identified crustal 'felt' earthquakes (at depth less than 35 kilometers) that occurred within the North American Plate in the Cascadia subduction zone (Figure 2 & Figure 4A) and in the South American Plate in the Chilean subduction zone (Figure 3 & Figure 4B). We reviewed the Cascadia crustal results to determine the lowest and highest magnitude earthquakes with 'felt' data for the Cascadia region, and this formed the basis for what Chile earthquakes we included in our comparison. In this case, our Chile search was for events between magnitudes of 4.5 and 7.2, as the Cascadia search results generate no earthquakes with 'felt' data above magnitude 7.2.

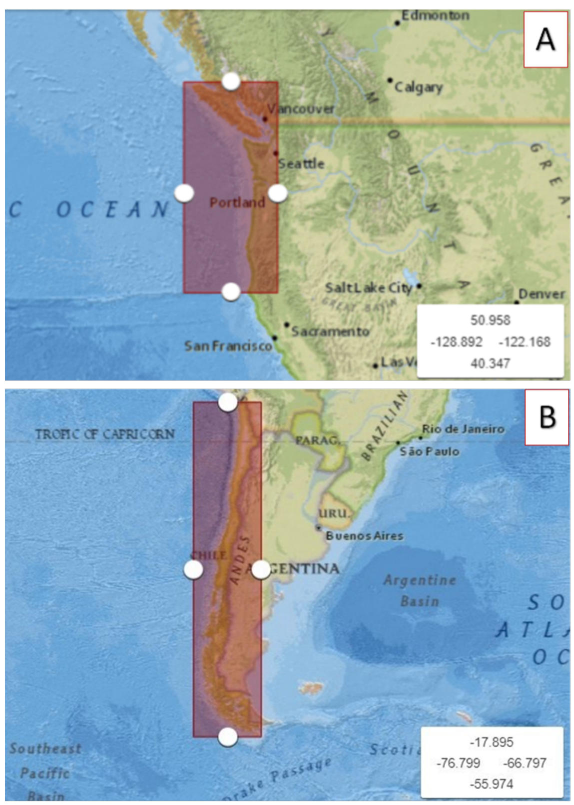



Figure 4: Geographic ComCat search areas capturing the boundaries of the Cascadia Subduction Zone (Image A) and the Chile Subduction Zone (Image B).

The images in Figure 5 show the results of this search for these two zones. Note the ComCat search shows some crustal earthquakes in the oceanic plates. These offshore events were not considered in this analysis.  The results section of this document highlights the total number of events found, omitted, and used for this study.

The ComCat search results are summarized in Appendix A and Appendix B and contain the USGS source information for each earthquake. We include hyperlinks to the USGS webpage for each specific earthquake, based on their USGS earthquake ID. This allowed for quick access to each earthquake's specific webpage and was useful for the retrieval/downloading of the DYFI data associated with each event, and validating specific information associated with each earthquake.

The ComCat search engine provided high-quality felt intensity data. There were, however, some limitations with the ComCat search platform. For example, delineating the geographical search area in ComCat via a rectangular outline for both subduction regions, Cascadia (Figure 4A) and Chile (Figure 4B) caused the search to pick up earthquakes outside the region of interest, e.g., within Juan de Fuca Plate (Cascadia) and the Nazca Plate and bordering countries (Chile) (see Figure 5). We therefore filtered out events that did not occur within the North and South American plates. We then extracted for this study earthquakes based on 14 magnitudes found from the Cascadia search, e.g., magnitudes 4.5-4.9, 5.0, 5.2, 5.4-5.7, 6.4, 6.5 and 7.2. For example, we found ten M5.7 events at depths less than 35km that occurred from 1960 to 2020 within the Chile subduction zone.

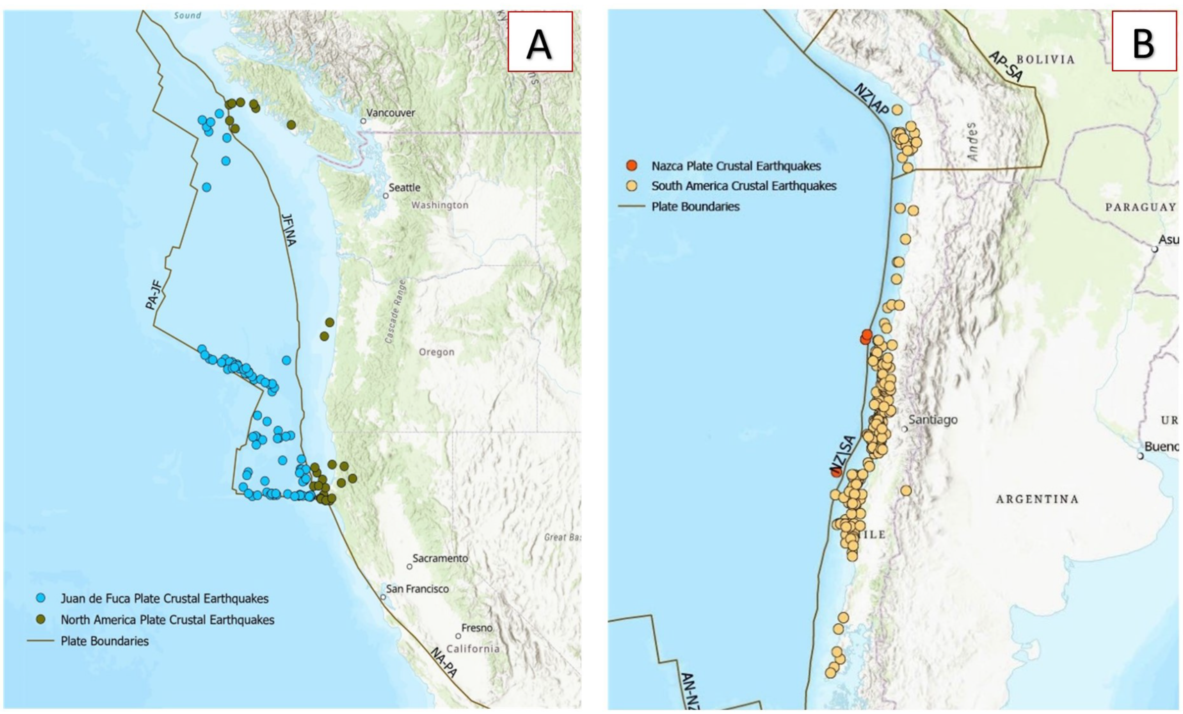



Figure 5: ComCat search results for all M>4.5 crustal (depth <35 km) earthquakes for Cascadia (Image A) and Chile (Image B) for the time period 1960-2020. Note that offshore  earthquakes within the Juan de Fuca plate (Figure A) and the Nazca Plate (Figure B) were filtered out and not considered in this analysis.

### Acquiring Raw Data from the ComCat Catalog

Acquiring raw data associated with each earthquake, based on their USGS ID, required sourcing, downloading, and processing the DYFI data from the USGS ComCat database (USGS Earthquake Hazards Program, 2021). For events which did not have readily downloadable intensity vs distance data, we sent a request to USGS database steward Vince Quitoriano, and he reran the files to produce relevant data, which were then available for download on the USGS website. The data were provided in three main formats, .PNG/.JPG (plots), CSV (raw DYFI), and JSON (intensity vs distance). All downloaded intensity versus distance data for each earthquake event have been archived, as detailed in Appendix D.

### Validation & Quality Control of the ComCat Search Results

The DYFI data included intensity versus distance data, which were aggregated in blocks, binned into 10-km grids cells (USGS Earthquake Hazards Program, 2021; Quitoriano V. , personal communication, June 15, 2021). We reviewed individual events by their USGS catalog and determined if they were suitable for use, by evaluating the quality and quantity of USGS DYFI responses, omitting events with limited or poor-quality (fewer than three DYFI responses) data. We discuss the details of filtering and removal of DYFI in the results section.

## Processing, Analytics & Plotting DYFI Data

The process we used to investigate whether the felt intensity patterns between Cascadia and Chile subduction zones are comparable involved binning data by distance and plotting events of the same magnitude and depth on one graph. The following briefly outlines the procedures used to process, graph, and edit the acquired USGS ComCat DYFI intensity versus distance data. For more details, see Rutherford & Cassidy (2022).

1) **Plotting values by Magnitude:**
   To get a first glance at the intensity versus distance data, we plotted all felt crustal earthquakes of a specific magnitude for events that occurred within Chile and Cascadia subduction zones as separate events, for each of the 14 magnitudes (4.5-4.9, 5.0, 5.2, 5.4-5.7, 6.4, 6.5 and 7.2) together on one plot. As one example, intensity data for each of the crustal M4.7 Chile and Cascadia events were plotted as separate earthquakes as seen in Figure 6.

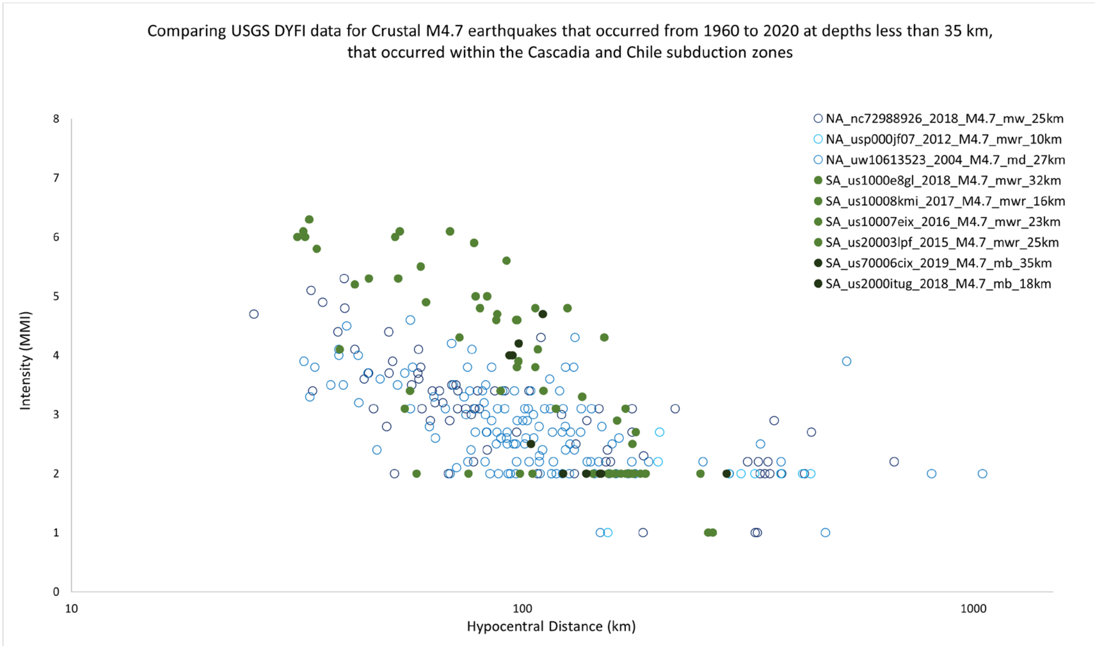
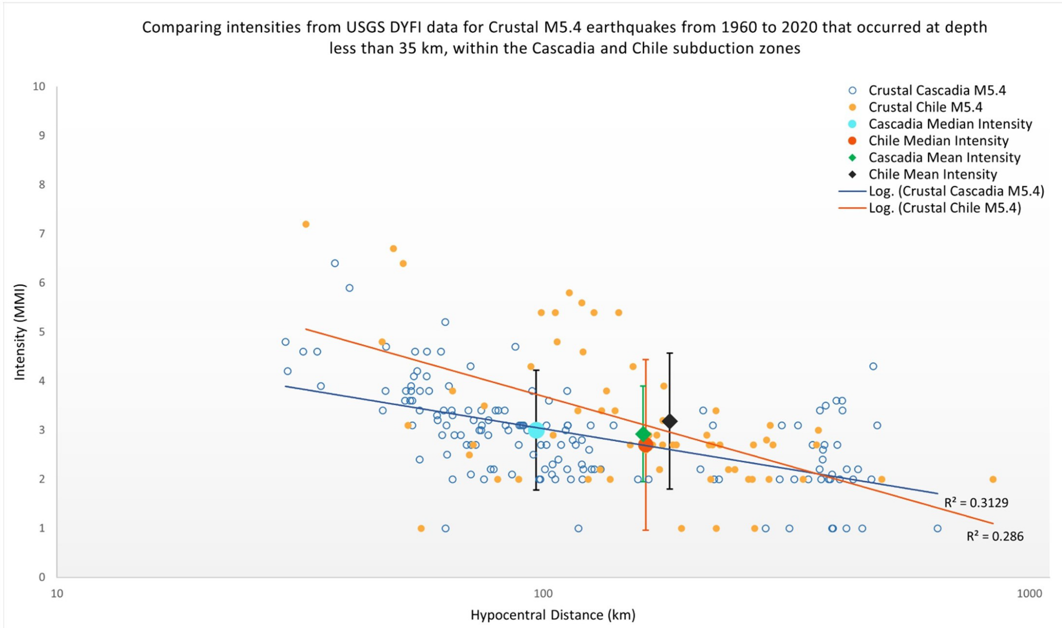



Figure 6: An example of one of the crustal combined plots with associated data, showing the magnitude 4.7 individual Chile & Cascadia earthquakes used in this study.

2) **Combining Chile and Cascadia intensity and distance values by magnitude**: In this next step, we combined the intensity vs distance values for the 14 magnitudes (e.g., 4.5…, 5.0…, 6.4…etc.) from Chile and Cascadia into a combined plot. For example, we plotted the DYFI intensities for M5.4 earthquakes in Chile and Cascadia as two separate series (Figure 7). The same plots also included the mean and median intensities for the entire Cascadia and Chile dataset (all distance values) and the related standard deviations (for details, see Rutherford & Cassidy, 2022). These plots provide a rough view of the felt intensity patterns across each magnitude for Chile and Cascadia subduction zones.




| Crustal Cascadia M5.4 | | | Crustal Chile M5.4 | | | | Chile Median Intensity | Chile Median Distance | Cascadia Median Intensity | Cascadia Median distance |
|---|---|---|---|---|---|---|---|---|---|---|
| Distance | Intensity | | Distance | Intensity | | Value | 2.7 | 162.5 | 3 | 96.75 |
| 55.7 | 2.4 | | 52.7 | 3.1 | | STDEV | 1.737695981 | 153.8882883 | 1.222665166 | 174.4133093 |
| 69.6 | 2.7 | | 140.4 | 3.4 | | | | | | |
| 61.6 | 4.6 | | 184.8 | 2.7 | | | Chile Mean Intensity | Chile Mean Distance | Cascadia Mean Intensity | Cascadia Mean Distance |
| 40 | 5.9 | | 162.5 | 2.6 | | Value | 3.183076923 | 182.0553846 | 2.921527778 | 160.4951389 |
| 127.4 | 2.2 | | 167.7 | 2.7 | | STDEV | 1.386480795 | 122.7850893 | 0.975545659 | 139.1616867 |

Figure 7: An example of a combined plot with associated data, showing all Chile & Cascadia earthquake response values combined on one graph. The table below the plot, shows the calculations use for the mean and median.

3) **Curve fitting mean intensity over binned distance: Generating binned distance plots**
To get an estimate for the mean and median intensities, we binned intensity values into small distance ranges, which captured the average intensity for binned distances and generated a mean of intensities for each binned distance.

We created a combined binned distance plot for each magnitude by taking the values from the combined magnitude plots (Figure 7). Our first step in achieving this was to create a list of bin distance values that captured the range of distances for intensity values of each magnitude for both Cascadia and Chile events (Figure 8).

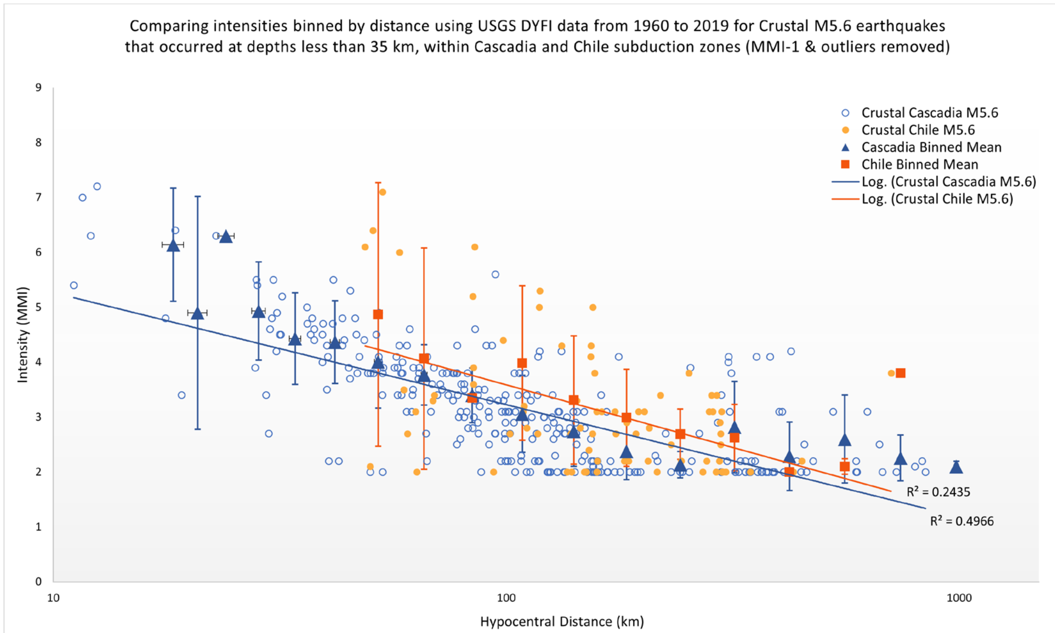



Figure 8: An example of a curve-fitting plot (with MMI and outliers removed), which combined DYFI data from the entire dataset of 9 Chile M5.6 earthquakes and the 2 Cascadia M5.6 earthquakes, where we binned intensity values by distance.

4) **Remove outliers, MMI = 1 values and edit combine plots**:
The final step in this study involved reviewing each plot to infer a comparison in intensities between the crustal earthquakes in the Cascadia and Chile subduction zones, and removing any significant outliers, (i.e., some extremely distal responses that give unrealistic intensity measures > 4 as an MMI = five at 1000 km)

Lastly, further review of the plots showed that MMI one values (not felt) in all plots influenced the overall trend. We noticed that these (not felt) values were more common in Cascadia, and not used as often in Chile. We removed all MMI 1 values, as they served no purpose in our analyses (Figure 8).

# RESULTS

## ComCat Catalog Crustal Earthquake Search Results

The USGS ComCat search provided (Figure 5) felt intensity information for 29 crustal earthquakes of magnitude > 4.5 within the North American Plate (Cascadia subduction zone), and more than 800 earthquakes within the South American Plate (Chile subduction zone).

For earthquakes that occurred within the North American Plate (Cascadia subduction zone), there were 14 different magnitudes, ranging from M4.5 to 7.2. There were five magnitudes for the 4.5-4.9 range, six magnitudes for the M5.0-5.9 range (e.g., 5.0, 5.2, 5.4, 5.5, 5.6, 5.7), two magnitudes (6.4 & 6.5) for the M6.0-6.9 range, and 1 magnitude (7.2) for the 7.0-7.9 range. The Cascadia crustal results formed the parameters of what magnitudes we could include in our comparison. This meant that we only compared earthquakes of the same 14 Cascadia magnitudes.

Earthquakes with fewer than three felt responses and Chile events that did not have a corresponding magnitude with Cascadia earthquakes were omitted from the analysis. We removed 113 of the 142 Cascadia earthquake events and removed 769 of the 883 Chile events found in our ComCat search. Therefore, we used 114 Chile earthquakes and 29 Cascadia earthquakes in our analysis and generating the comparison plots.

The USGS ComCat documents are summarized in Appendix A and B, where Table 1 shows the number of aggregated responses values plotting for each magnitude. Far more earthquakes occurred within the Chilean subduction zone compared to the Cascadia subduction zone (Figure 5). In general, however, there were more felt response values for Cascadia earthquakes than for the Chile events.

## Results of Data Interrogation & Plotting

Here we provide a short discussion on each step of the data analysis and conclusions (following headings in the method section) to help facilitate similar research by others in the future. Overall, three main plots were generated for each of the fourteen magnitudes from 4.5 to 7.2. These plots allowed us to view and interrogate the trends and comparability of felt data for the two-subduction zones. In general, plots show good overall agreements between felt patterns in Chile and Cascadia. The following section shows the three plots generated for each magnitude. Appendix C contains the full suite of the four types of plots generated for the 14 magnitudes compared in this study.

### Combined by Magnitude Plots - Separate Earthquakes by USGS ID

Figure 9, show six magnitudes (e.g., 4.5. 4.8, 5.2, 5.7, 6.5, and 7.2) for Cascadia and Chile earthquakes plotted separately, based on their event ID (USGS ComCat search ID). In these plots, we show the depth and magnitude type of each earthquake in the legends. All six plots in Figure 10 show the expected trend of decreasing intensity with distance. They also show minimal, yet similar clustering patterns that range from ~30 to 600 kilometers. Plots M4.5, M4.8, M5.2, M5.7, and M7.2 responses start around 15 kilometers and range to over 1000 kilometers. There is a slight discrepancy in M6.7 plot, where values cluster around a 300 to 700 kilometers, with responses starting at 60 kilometers and range up 1000 km. All plots show a plateau at intensity MMI-1, and as, ‘not-felt’ response; we removed these values in further analyses.

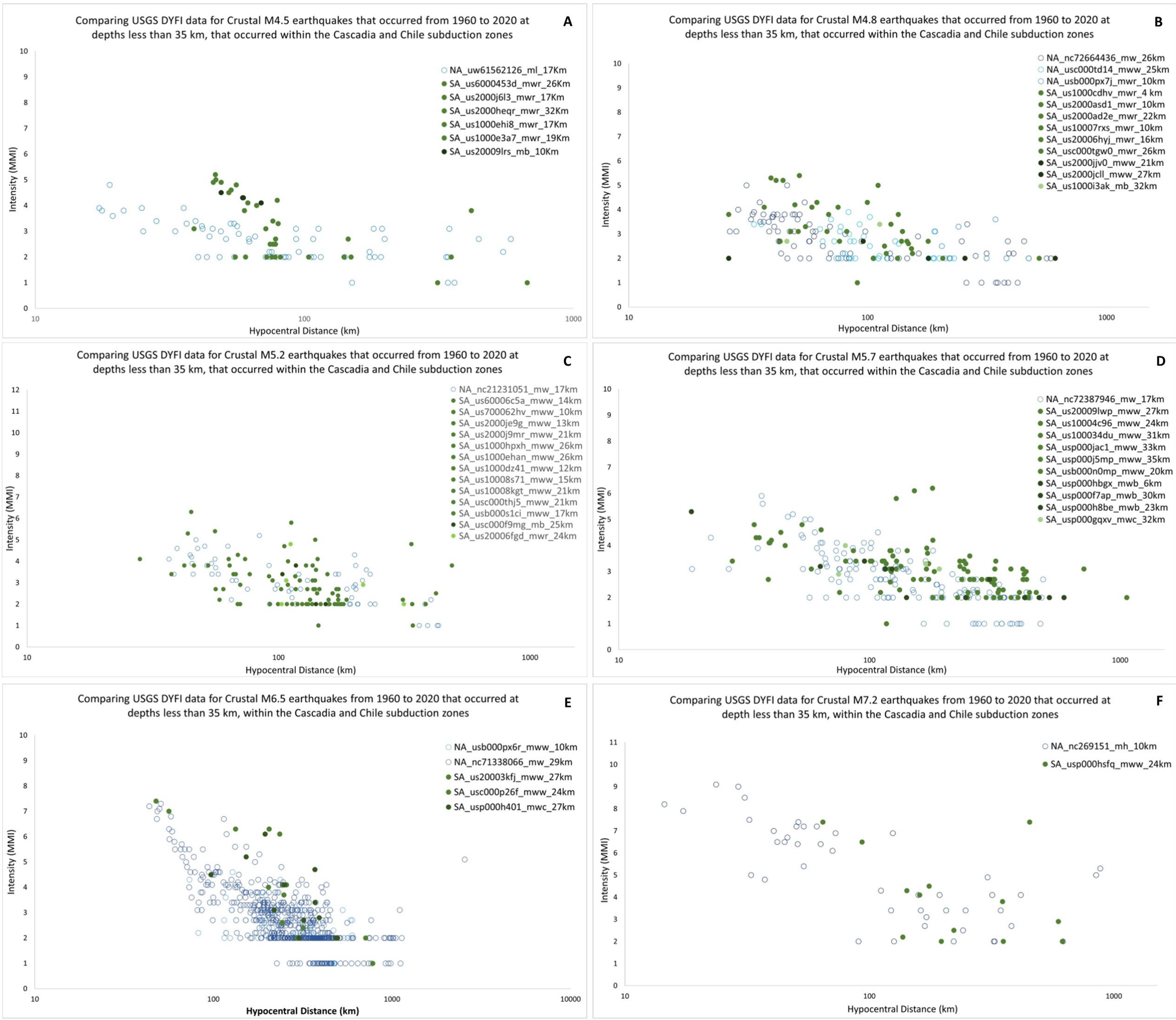



Figure 9: Combined DYFI intensity response data for earthquakes in Chile and Cascadia from 1960 to 2020; showing clustering patterns of the individual events for magnitude 4.5 (image A), 4.8 (image B), 5.2 (image C), 5.7 (image D), 6.5 (image E), and 7.2 (image F) indicating a comparable intensity pattern between the Chile and Cascadia subduction zones. Colour coded dots show the response values based on magnitude type (blue dots represent Cascadia (NA) and the different green coloured dots show Chile (SA) responses.

In Table 1, we can see the number of response values per magnitude earthquake for both Chile and Cascadia. For all magnitudes, there were more Chile earthquakes, yet fewer response values for each earthquake. We see this in all the magnitude plots, apart from magnitude 5.5 with Cascadia having 14 responses and Chile at 123 (Table 1).

Table 1: Highlighting the number of Chile and Cascadia earthquakes and response values plotted for the 14 magnitudes.

| Cascadia | Earthquakes | Plotted Response Values | Chile | Earthquakes | Plotted Response Values |
|---|---|---|---|---|---|
| **M4.5** | 1 | 62 | **M4.5** | 6 | 39 |
| **M4.6** | 5 | 115 | **M4.6** | 7 | 28 |
| **M4.7** | 3 | 205 | **M4.7** | 6 | 76 |
| **M4.8** | 3 | 126 | **M4.8** | 9 | 43 |
| **M4.9** | 3 | 140 | **M4.9** | 9 | 43 |
| **M5.0** | 2 | 123 | **M5.0** | 8 | 72 |
| **M5.2** | 1 | 59 | **M5.2** | 13 | 86 |
| **M5.4** | 2 | 144 | **M5.4** | 9 | 65 |
| **M5.5** | 1 | 14 | **M5.5** | 17 | 123 |
| **M5.6** | 2 | 332 | **M5.6** | 9 | 97 |
| **M5.7** | 1 | 138 | **M5.7** | 10 | 97 |
| **M6.4** | 2 | 158 | **M6.4** | 5 | 78 |
| **M6.5** | 2 | 630 | **M6.5** | 3 | 27 |
| **M7.2** | 1 | 45 | **M7.2** | 1 | 13 |
| Response values are the aggregated 10-kilometer grid values plotted in our graphs | | | | | |

## Combined by Magnitude Plots - Combined Earthquakes

Here, we combine all the response values for the Cascadia earthquakes and the Chile earthquakes for each of 14 magnitudes. We then plotted the combined data as two series, one for all Cascadia events and one for Chile events for each of the fourteen magnitudes. Figure 10 plots show the downward trend, have similar slopes, indicating that the data are comparable. For example, even though the $R^2$ values are low, the sloping trend in Figure 10B indicates consistent responses for both magnitude 4.8 Cascadia and Chile data, with Cascadia $R^2$ value of 0.4075 and Chile is at 0.2792. This slope comparability is evident in most of the fourteen magnitude plots.

Additionally, the mean and median intensity for all responses values was calculated and provided a general view of the distribution of intensities. In general, these distribution values for Chile and Cascadia data are similar. For example, we can see that for magnitude 5.2 earthquakes (Figure 10C), the mean and median values are relatively similar (Cascadia mean: 117 km, 3.1 MMI; Chile mean: 129 km, 2.7, and Cascadia median: 150 km, 3.0 MMI; Chile median: 140 km, 3.0 MMI). There is some variability in the mean and median for the other five magnitudes.

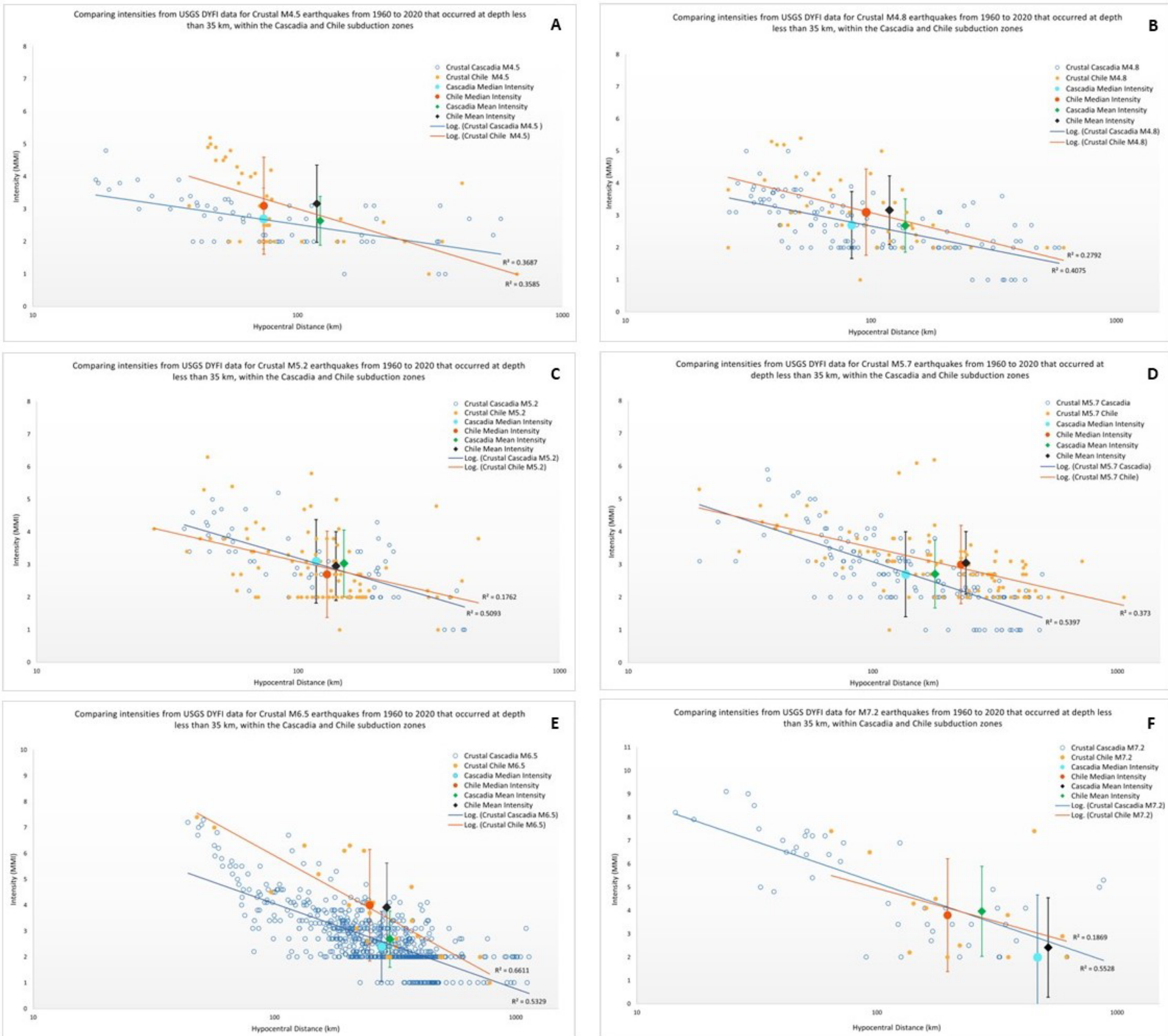



Figure 10: Combined plots for earthquakes in the Chile and Cascadia subduction zones; showing clustering patterns of all response values for events of magnitudes 4.5 (image A), 4.8 (image B), 5.2 (image C), 5.7 (image D), 6.5 (image E), and 7.2 (image F), and the mean and median of all response values, indicating comparable intensity patterns between Chile and Cascadia.

## Combined by Magnitude Plots - Curve Fitting

The curve-fitting plots were generated to provide a best-fit distribution. In these plots, we binned intensity values into smaller distance ranges, which captured the average intensity for binned distances and generated a mean intensity for each binned distance (Figure 11 and Figure 12). We also removed the values of insignificance, the MMI-1 (not-felt) values, and outliers (Table 2). We deemed outliers to be intensity values that appear unrealistic for the earthquake's documented magnitude. For example, in Figure 10D there are three intensities values over MMI 6 at distances greater than 150 km, for a 5.7 magnitude earthquake, and an intensity of MMI 7.4 at approximately 450 km for an M7.2 earthquake (Figure 10F). A complete set of plots without the outliers and MMI-1 values removed can be viewed in Appendix C. Twelve of the plots show good comparison, however, there are two smaller magnitudes, M4.5 and M4.7 (Figure 12) that do not show as good agreement.

Table 2: Showing the number of response values plotted (before MMI=1 and outliers removed) and the number of response values removed (MMI=1 and outliers removed) for all 14 magnitudes.

| Cascadia | Response Values | Values Removed | Chile | Response Values | Values Removed |
|---|---|---|---|---|---|
| **M4.5** | 62 | 3 | **M4.5** | 39 | 3 |
| **M4.6** | 115 | 4 | **M4.6** | 28 | 3 |
| **M4.7** | 205 | 6 | **M4.7** | 76 | 5 |
| **M4.8** | 126 | 7 | **M4.8** | 43 | 1 |
| **M4.9** | 140 | 8 | **M4.9** | 43 | 5 |
| **M5.0** | 123 | 9 | **M5.0** | 72 | 2 |
| **M5.2** | 59 | 4 | **M5.2** | 86 | 21 |
| **M5.4** | 144 | 9 | **M5.4** | 65 | 24 |
| **M5.5** | 14 | 4 | **M5.5** | 123 | 9 |
| **M5.6** | 332 | 36 | **M5.6** | 97 | 20 |
| **M5.7** | 138 | 15 | **M5.7** | 97 | 4 |
| **M6.4** | 158 | 27 | **M6.4** | 78 | 0 |
| **M6.5** | 630 | 52 | **M6.5** | 27 | 1 |
| **M7.2** | 45 | 2 | **M7.2** | 13 | 1 |

Response values are the aggregated 10-kilometer grid values plotted in our graphs

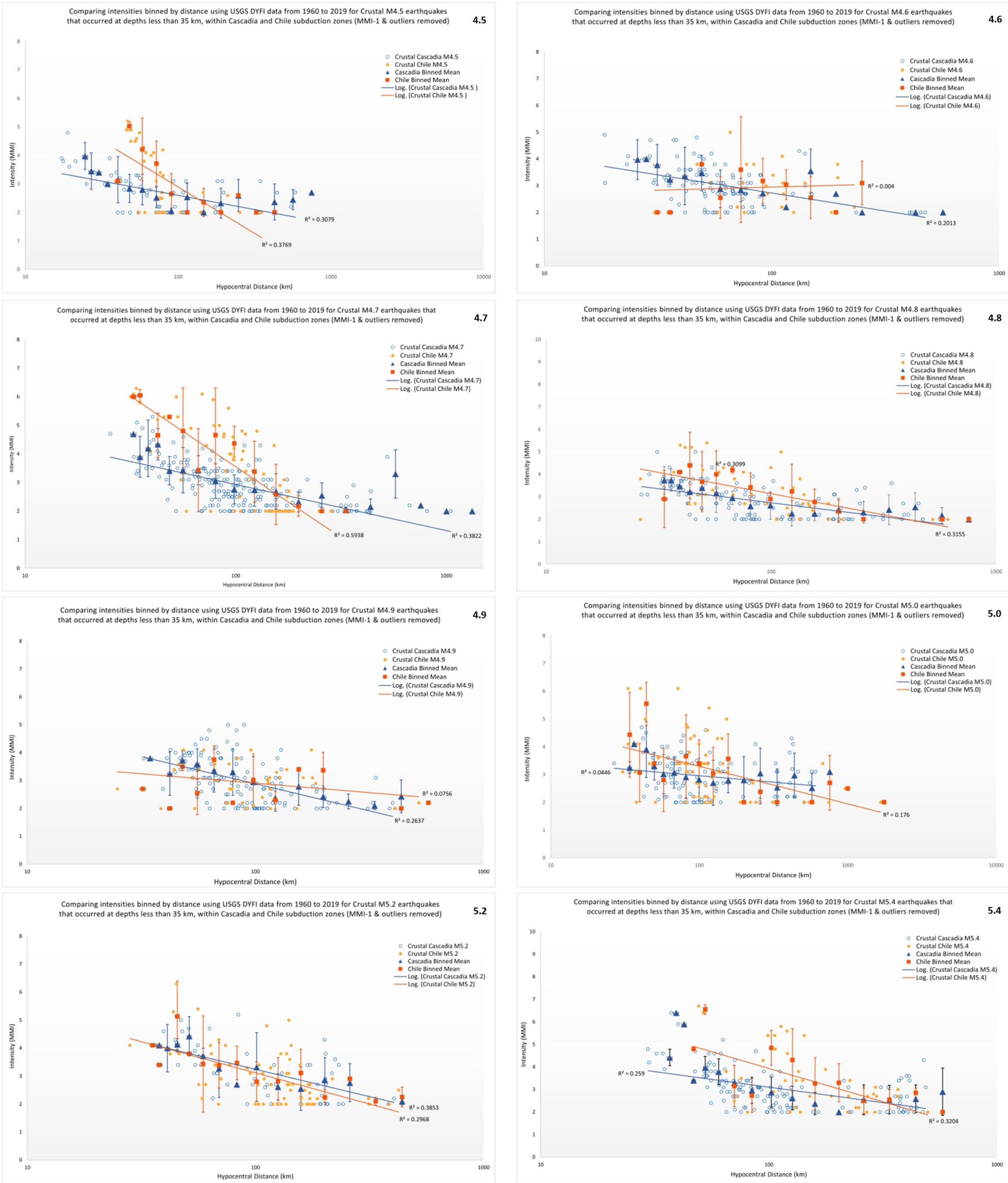



Figure 11: Curve fitting plots for 8 of the 14 magnitude earthquakes in the Chile and Cascadia subduction zones; showing clustering patterns of all response values for magnitudes 4.5 to 4.9, 5.0, 5.2 and 5.4, and the values for mean and median intensities binned by distance.

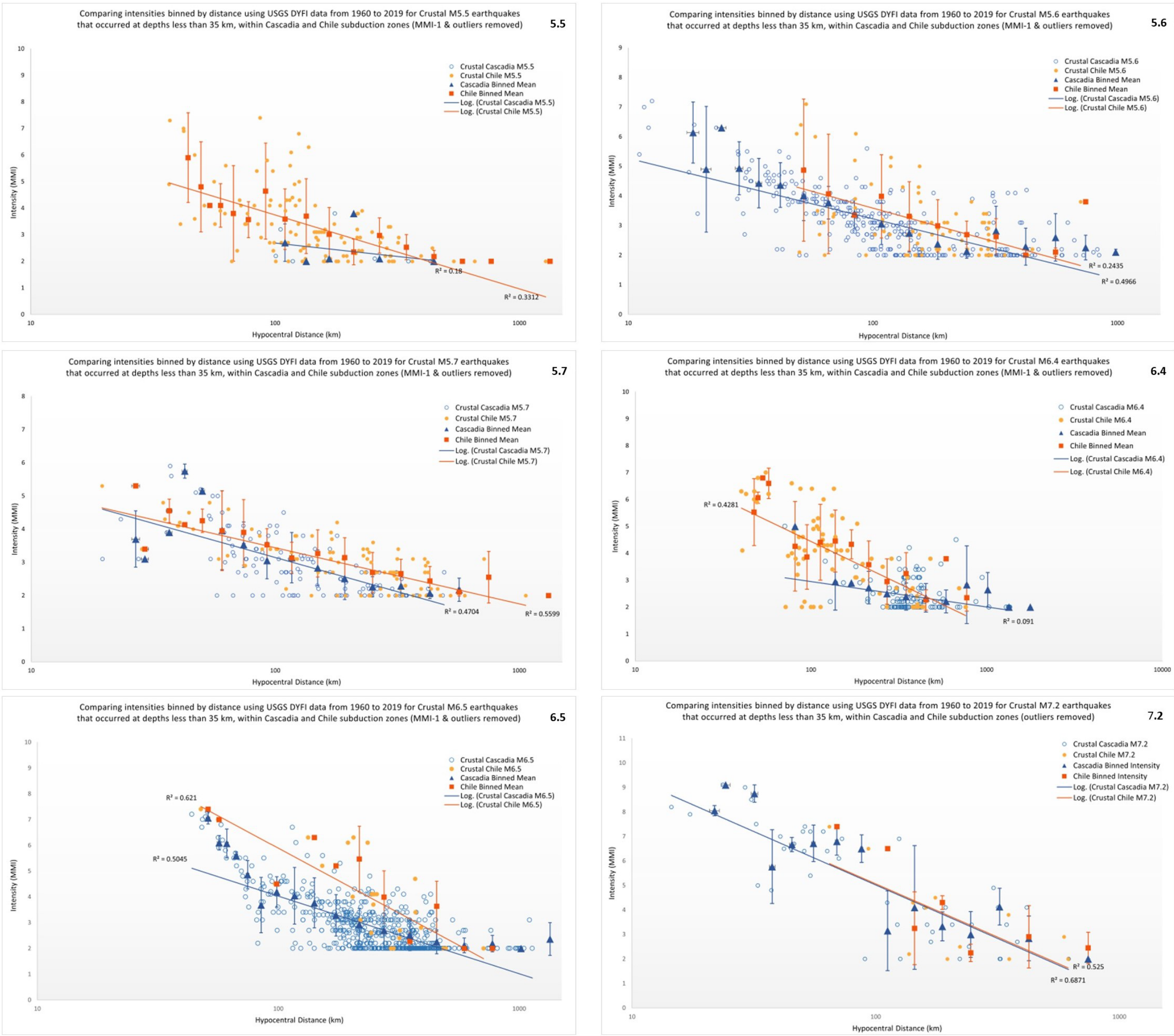



Figure 12: Curve fitting plots for 6 of the 14 magnitude earthquakes in the Chile and Cascadia subduction zones; showing clustering patterns of all response values and the values for mean and median intensities binned by distance, for magnitudes 5.5., 5.6, 5.7, 6.5, 6.6 and 7.2.

## CONCLUSION & FUTURE RESEARCH

This study compared felt intensity information from crustal earthquakes in the Cascadia and Chilean subduction zones. The ultimate goal is to assess whether felt intensity information from large (M8-8.8) subduction earthquakes in Chile can be used as a proxy for similar events in Cascadia. Overall, the result of this study shows good agreement between felt patterns for crustal earthquakes in the two subduction zones, providing confidence that Chilean intensity data for megathrust earthquakes can be representative for those in Cascadia.

There were a few limitations in our study, which included the availability and quantity of comparable data. There were limited earthquakes of the same magnitude, as well as an unequal number of response values between Chile and Cascadia, and these factors contributed to our study's comparability limitations. The differences in the quantity of response data between Cascadia and Chile are seen in all plots. Nearly all magnitudes in this study had more response values per event for the Cascadia earthquakes compared to the Chile events. Having a more even distribution of response values between Chile and Cascadia would provide a more robust view of the intensity pattern. Furthermore, we were unable to compare all magnitudes ranging from 4.5 to 8.0, as there were (at this time) no comparable earthquakes found in the North American plate within the Cascadia zone, for magnitudes 5.1, 5.3, 5.8, 5.9, 6.0-6.3, 6.6-6.9, 7.0, 7.1, 7.3-8.0.

There is an opportunity to expand this research, by incorporating other earthquake intensity databases (e.g., NRCan in Canada and the Seismological Service of Chile for Chile). The data collection form or method for deriving intensity rating may differ between datasets, however, and thus data may not be directly comparable. Furthermore, expanding this study into looking at other subduction zones and global DYFI platforms (e.g., Japan) would be valuable addition to this research.

This project completes the two comparison studies, one on deep intraslab earthquakes (Rutherford & Cassidy, 2022) and this crustal earthquake study. The next step is to expand this research by investigating intensity patterns, using USGS DYFI data for earthquakes in the Japan subduction zone. We will apply the same process to investigate the intraslab and crustal earthquakes in both Cascadia and Japan subduction zones.

In conclusion, the results of this study indicate that ground shaking (felt intensity) patterns for crustal earthquakes in Chile and Cascadia are similar. This is useful information for the scientific, engineering and emergency management communities, and suggests that intensity information from large subduction earthquakes in Chile can be applied to Cascadia.

## ACKNOWLEDGMENTS

Firstly, we would like to thank Vince Quitoriano (United States Geological Survey (USGS)) for assisting us in navigating the ComCat platform and working with us to acquire DFYI data for felt earthquakes used in this study. We also thank Collin Paul (Earthquake Seismologist with Natural Resources Canada) for developing scripts and analytics, as well as editing contributions to the method section of this report. We are grateful for the map images in Figure 2 and Figure 3 which Carlos Herrera (Ph.D. Candidate the University of Victoria) kindly produced all the while preparing for his Ph.D. Defense. Lastly, we thank Alison Bird (Earthquake Seismologist with Natural Resources Canada) for the thorough and thoughtful review of this manuscript.

## REFERENCES


Adams, J., & Halchuk, S. (2004). Fourth-generation seismic hazard maps for the 2005 national building code of Canada. *13th World Conference on Earthquake Engineering* (p. 12). Vancouver, B.C., Canada: Natural Resources Canada. doi:https://doi.org/10.4095/226357

Cisternas, M., Garrett, E., Wesson, R., Dura, T., & Ely, L. L. (2017). Unusual geologic evidence of coeval seismic shaking and tsunamis shows variability in earthquake size and recurrence in the area of the giant 1960 Chile earthquake. *Marine Geology, 385*, 101-113. doi:https://doi.org/10.1016/j.margeo.2016.12.007

Di Menna, J., & Flick, S. (2005). *A'la carte: After shock.* Geological Survey of Canada, Natural Resources Canada. Canadian Geographic A'la carte. Retrieved December 15, 2021, from https://earthquakescanada.nrcan.gc.ca/zones/cascadia/Canadian_Geographic2005_CascadiaSumatra.pdf

Duo, L., McGuire, J., Liu, Y., & Hardebeck, J. (2018). Stress rotation across the Cascadia megathrust requires a weak subduction plate boundary at seismogenic depths. *Earth and Planetary Science Letters, 485*, 55-64. doi:https://doi.org/10.1016/j.epsl.2018.01.002

Dura, T., Horton, B. P., Cisternas, M., Ely, L. L., Hong, I., Nelson, A. R., . . . Nikitina, D. (2017). Subduction zone slip variability during the last millennium, south-central Chile. *Quaternary Science Reviews, 175*, 112-137. doi:https://doi.org/10.1016/j.quascirev.2017.08.023

Government of Canada. (2011). *Natural Resources Canada: Earthquake Canada.* Retrieved from Products, Publications, and Research: Earthquakes in southwestern British Columbia: https://earthquakescanada.nrcan.gc.ca/pprs-pprp/pubs/GF-GI/GEOFACT_earthquakes-SW-BC_e.pdf

Government of Canada. (2021a, April 06). *Important Canadian Earthquakes*. Retrieved from Natural Resources Canada: Earthquakes Canada: https://earthquakescanada.nrcan.gc.ca/historic-historique/map-carte-en.php

Government of Canada. (2021b). *Seismic Zones in Western Canada*. Retrieved January 4, 2022, from Natural Resources Canada, Earthquake Canada: https://earthquakescanada.nrcan.gc.ca/zones/westcan-en.php#Cascadia

Hayes, G., & Crone, T. (2021). *USGS Natural Hazards: At what depth do earthquakes occur? What is the significance of the depth?* Retrieved July 18, 2021, from USGS science for a changing world: https://www.usgs.gov/faqs/what-depth-do-earthquakes-occur-what-significance-depth?qt-news_science_products=0#qt-news_science_products

Henig, A., Blackman, D., & German, C. (2010). *INSPIRE: Chile Margin 2010; Chile Margin and Triple Junction Geology*. Retrieved January 4, 2022, from NOAA Ocean Exploration: https://oceanexplorer.noaa.gov/explorations/10chile/background/geology/geology.html

IRIS. (No date). *Incorporated Research Institutions for Seismology (IRIS): National Science Foundation*. Retrieved January 10, 2022, from Peru-Chile Subduction Zone: Earthquakes & Tectonics: https://www.iris.edu/hq/inclass/animation/peruchile_subduction_zone_earthquakes__tectonics

Patton, J. R., Ammirati, J. B., Stein, R., & Sevilgen, V. (2019). *Strong shaking from central coastal Chile earthquake: What does it reveal about the next megathrust shock?* (Temblor) doi:http://doi.org/10.32858/temblor.012

Quitoriano, V. (personal communication, June 15, 2021). US Geological Society (USGS).

Quitoriano, V., & Wald, D. J. (2020). USGS "Did You Feel It?' - Science and Lessons from 20 Years of Citizen Science-Based Macroseismology. *Frontiers in Earth Science, 8*, 120. doi:https://doi.org/10.3389/feart.2020.00120

Rutherford, J., & Cassidy, J. F. (2022). *Comparing Felt Intensity Patterns for Deep Intraslab Earthquakes in the Cascadia and Chilean Subduction Zones, offshore British Columbia, UNited States, and Chile.* Geological Survey of Canada, Open File Report 8899, 24p. doi:https://doi.org/10.4095/330207

Staisch, L., Walton, M., & Witter, R. (2019). *Addressing Cascadia Subduction Zone Great Earthquake Recurrence*. (Eos Science News by American Geophysical Union) doi:https://doi.org/10.1029/2019EO127531

USGS Earthquake Hazards. (2022). *Earthquake Magnitude, Energy Release, and Shaking Intensity*. Retrieved April 19, 2022, from USGS science for a changing world: https://www.usgs.gov/programs/earthquake-hazards/earthquake-magnitude-energy-release-and-shaking-intensity

USGS Earthquake Hazards Program. (2020). *Earthquake Hazards Program: DYFI Scientific Background*. Retrieved January 21, 2020, from USGS science for a changing world: https://earthquake.usgs.gov/data/dyfi/background.php

USGS Earthquake Hazards Program. (2021). *Earthquake Hazards Program: Search Earthquake Catalog*. Retrieved January 15, 2021, from USGS Science for a changing world: https://earthquake.usgs.gov/earthquakes/search/

USGS Pacific Coastal Marine Science Center. (2021). *Cascadia Subduction Zone Marine Geohazards*. Retrieved January 4, 2022, from USGS Science for a Changing World: Pacific Coastal and Marine Science Cente: https://www.usgs.gov/centers/pcmsc/science/cascadia-subduction-zone-marine-geohazards#overview

USGS Subduction Zone Science. (2020). *Introduction to Subduction Zones: Amazing Events in Subduction Zones*. Retrieved January 6, 2022, from USGS Science for a Changing World: Subduction Zone Science: https://www.usgs.gov/special-topics/subduction-zone-science/science/introduction-subduction-zones-amazing-events

USGS Volcano Hazards. (2021). *The Modified Mercalli Intensity (MMI) assigns intensities as...* Retrieved August 6, 2021, from USGS science for a changing world: https://www.usgs.gov/media/images/modified-mercalli-intensity-mmi-scale-assigns-intensities

Wald, D. J., Quitoriano, V., Worden, C. B., Hopper, M., & Dewey, J. W. (2011). USGS “Did You Feel It?” Internet-based macroseismic intensity maps. (R. Bossu, & P. S. Earle, Eds.) *Annals of Geophysics, 54*(6). doi:https://doi.org/10.4401/ag-5354

Wald, D., Quitoriano, V., Dengler, L., & Dewey, J. (1999). Utilization of the Internet for Rapid Community Intensity Maps. *Seismological Research Letters, No. 6*, pp. 680-697.

Wang, K., & Tréhu, A. M. (2016). Invited review paper: Some outstanding issues in the study of great megathrust earthquakes-The Cascadia exmaple. *Journal of Geodynamics, 98*, 1-18. doi:https://doi.org/10.1016/j.jog.2016.03.010

Watt, J. T., & Brothers, D. S. (2020). Systematic characterization of morphotectonic variability along the Cascadia convergent margin: Implications for shallow megathrust behavior and tsunami hazards. *Geosphere, 17*(1), 95-117. doi:https://doi.org/10.1130/GES02178.1

# APPENDIX A

**Thirty Cascadia earthquakes from 1960 to 2020 used in the Crustal intensity comparison study between Cascadia (North America) and Chile (South America) subduction zones.**

| USGS ID | Event Time | Latitude | Longitude | Depth (km) | Magnitude | Mag-Type | Location | Plate Location | Responses | USGS Link |
|---|---|---|---|---|---|---|---|---|---|---|
| **Magnitude 4.5 Earthquakes** | | | | | | | | | | |
| uw61562126 | 2019-11-30: T01:45:12 | 42.776 | -124.477 | 16.7 | 4.5 | ml | 3km NNE of Port Orford, Oregon | North America | 517 | https://earthquake.usgs.gov/earthquakes/eventpage/uw61562126/executive |
| **Magnitude 4.6 Earthquakes** | | | | | | | | | | |
| usc000ll77 | 2013-12-15: T18:11:47 | 49.263 | -127.811 | 5.0 | 4.6 | mwr | 139km W of Tofino, Canada | North America | 5 | https://earthquake.usgs.gov/earthquakes/eventpage/usc000ll77/executive |
| nc51211307 | 2008-11-16: T05:43:15 | 40.314 | -124.603 | 18.9 | 4.6 | mw | Offshore Northern California | North America | 274 | https://earthquake.usgs.gov/earthquakes/eventpage/nc51211307/executive |
| nc51207076 | 2008-08-17: T05:56:59 | 41.189 | -124.216 | 15.7 | 4.6 | mw | Offshore Northern California | North America | 754 | https://earthquake.usgs.gov/earthquakes/eventpage/nc51207076/executive |
| nc21510606 | 2006-03-26: T01:56:37 | 40.278 | -124.449 | 22.3 | 4.6 | mw | Offshore Northern California | North America | 268 | https://earthquake.usgs.gov/earthquakes/eventpage/nc21510606/executive |
| nc21223451 | 2002-04-29: T00:43:29 | 40.602 | -124.450 | 28.7 | 4.6 | mw | Offshore Northern California | North America | 312 | https://earthquake.usgs.gov/earthquakes/eventpage/nc21223451/executive |
| **Magnitude 4.7 Earthquakes** | | | | | | | | | | |
| nc72988926 | 2018-03-23: T03:09:39 | 40.428 | -124.511 | 25.2 | 4.7 | mw | 22km WNW of Petrolia, CA | North America | 1441 | https://earthquake.usgs.gov/earthquakes/eventpage/nc72988926/executive |
| usp000jf07 | 2012-02-16: T06:37:33 | 49.089 | -127.617 | 10.0 | 4.7 | mwr | Vancouver Island, Canada | North America | 13 | https://earthquake.usgs.gov/earthquakes/eventpage/usp000jf07/executive |
| uw10613523 | 2004-08-19: T06:06:03 | 44.665 | -124.300 | 27.3 | 4.7 | md | Offshore Oregon | North America | 840 | https://earthquake.usgs.gov/earthquakes/eventpage/uw10613523/executive |
| **Magnitude 4.8 Earthquakes** | | | | | | | | | | |
| nc72664436 | 2016-07-21: T23:09:05 | 40.724 | -123.892 | 26.2 | 4.8 | mw | 19km SSE of Blue Lake, CA | North America | 1087 | https://earthquake.usgs.gov/earthquakes/eventpage/nc72664436/executive |
| usc000td14 | 2015-01-08: T02:02:53 | 49.171 | -125.647 | 24.6 | 4.8 | mww | 18km E of Tofino, Canada | North America | 258 | https://earthquake.usgs.gov/earthquakes/eventpage/usc000td14/executive |
| usb000px7j | 2014-04-24: T03:44:17 | 49.610 | -127.826 | 10.0 | 4.8 | mwr | 124km SSW of Port Hardy, Canada | North America | 10 | https://earthquake.usgs.gov/earthquakes/eventpage/usb000px7j/executive |
| **Magnitude 4.9 Earthquakes** | | | | | | | | | | |
| nc72086051 | 2013-10-11: T23:05:37 | 40.984 | -124.750 | 8.6 | 4.9 | mw | 53km WNW of Eureka, California | North America | 717 | https://earthquake.usgs.gov/earthquakes/eventpage/nc72086051/executive |
| nc71011617 | 2008-10-26: T09:27:22 | 40.337 | -124.629 | 20.8 | 4.9 | mw | Offshore Northern California | North America | 141 | https://earthquake.usgs.gov/earthquakes/eventpage/nc71011617/executive |
| uw10609208 | 2004-07-12: T16:45:00 | 44.334 | -124.489 | 28.8 | 4.9 | md | Offshore Oregon | North America | 675 | https://earthquake.usgs.gov/earthquakes/eventpage/uw10609208/executive |
| **Magnitude 5.0 Earthquakes** | | | | | | | | | | |
| nc51183469 | 2007-06-25: T02:32:24 | 41.116 | -124.825 | 2.6 | 5.0 | mw | Offshore Northern California | North America | 1224 | https://earthquake.usgs.gov/earthquakes/eventpage/nc51183469/executive |
| nc21527987 | 2006-07-19: T11:41:43 | 40.281 | -124.433 | 20.1 | 5.0 | mw | Offshore Northern California | North America | 484 | https://earthquake.usgs.gov/earthquakes/eventpage/nc21527987/executive |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Magnitude 5.2 Earthquakes** | | | | | | | | | | |
| nc21231051 | 2002-06-17: T16:55:07 | 40.810 | -124.552 | 17.2 | 5.2 | mw | Offshore Northern California | North America | 951 | https://earthquake.usgs.gov/earthquakes/eventpage/nc21231051/executive |
| **Magnitude 5.4 Earthquakes** | | | | | | | | | | |
| nc40216664 | 2008-04-30: T03:03:06 | 40.836 | -123.497 | 27.8 | 5.4 | mw | Northern California | North America | 1782 | https://earthquake.usgs.gov/earthquakes/eventpage/nc40216664/executive |
| nc40193932 | 2007-02-26: T12:19:54 | 40.643 | -124.863 | -0.5 | 5.4 | mw | Offshore Northern California | North America | 1023 | https://earthquake.usgs.gov/earthquakes/eventpage/nc40193932/executive |
| **Magnitude 5.5 Earthquakes** | | | | | | | | | | |
| usb000iv7t | 2013-08-04: T13:22:27 | 49.661 | -127.429 | 10.0 | 5.5 | mwb | 115km S of Port Hardy, Canada | North America | 33 | https://earthquake.usgs.gov/earthquakes/eventpage/usb000iv7t/executive |
| **Magnitude 5.6 Earthquakes** | | | | | | | | | | |
| nc73201181 | 2019-06-23: T03:53:02 | 40.274 | -124.300 | 9.4 | 5.6 | mw | 6km SSW of Petrolia, CA | North America | 1778 | https://earthquake.usgs.gov/earthquakes/eventpage/nc73201181/executive |
| nc71734741 | 2012-02-13: T21:07:02 | 41.143 | -123.790 | 27.4 | 5.6 | mw | Northern California | North America | 3011 | https://earthquake.usgs.gov/earthquakes/eventpage/nc71734741/executive |
| **Magnitude 5.7 Earthquakes** | | | | | | | | | | |
| nc72387946 | 2015-01-28: T21:08:53 | 40.318 | -124.607 | 16.9 | 5.7 | mw | 40km SW of Ferndale, California | North America | 1007 | https://earthquake.usgs.gov/earthquakes/eventpage/nc72387946/executive |
| **Magnitude 6.4 Earthquakes** | | | | | | | | | | |
| usp000j7ur | 2011-09-09: T19:41:34 | 49.535 | -126.893 | 22 | 6.4 | mww | Vancouver Island, Canada | North America | 3782 | https://earthquake.usgs.gov/earthquakes/eventpage/usp000j7ur/executive |
| usp000d0fx | 2004-07-19: T08:01:49 | 49.623 | -126.967 | 23.7 | 6.4 | mwb | Vancouver Island, Canada | North America | 49 | https://earthquake.usgs.gov/earthquakes/eventpage/usp000d0fx/executive |
| **Magnitude 6.5 Earthquakes** | | | | | | | | | | |
| usb000px6r | 2014-04-24: T03:10:10 | 49.639 | -127.732 | 10 | 6.5 | mww | 120km S of Port Hardy, Canada | North America | 952 | https://earthquake.usgs.gov/earthquakes/eventpage/usb000px6r/executive |
| nc71338066 | 2010-01-10: T00:27:39 | 40.652 | -124.693 | 28.7 | 6.5 | mw | Offshore Northern California | North America | 9027 | https://earthquake.usgs.gov/earthquakes/eventpage/nc71338066/executive |
| **Magnitude 7.2 Earthquakes** | | | | | | | | | | |
| nc269151 | 1992-04-25: T18:06:05 | 40.335 | -124.229 | 9.9 | 7.2 | mh | 20km SSW of Rio Dell, California | North America | 110 | https://earthquake.usgs.gov/earthquakes/eventpage/nc269151/executive |

# APPENDIX B

**One hundred and fourteen Chile earthquakes from 1960 to 2020 used in the Crustal intensity comparison study between Cascadia (North America) and Chile (South America) subduction zones.**

| USGS ID | Event Time | Latitude | Longitude | Depth (km) | Magnitude | Mag-Type | Location | Plate Location | Responses | USGS Link |
|---|---|---|---|---|---|---|---|---|---|---|
| **Magnitude 4.5 Earthquakes** | | | | | | | | | | |
| us6000453d | 2019-06-24: T04:42:41 | -38.635 | -73.377 | 26.5 | 4.5 | mwr | 19km WNW of Carahue, Chile | South America | 6 | https://earthquake.usgs.gov/earthquakes/eventpage/us6000453d/executive |
| us2000j6l3 | 2019-01-20: T09:23:32 | -29.882 | -71.989 | 17.0 | 4.5 | mwr | 62km W of Coquimbo, Chile | South America | 7 | https://earthquake.usgs.gov/earthquakes/eventpage/us2000j6l3/executive |
| us2000heqr | 2018-09-14 T18:15:11 | -32.545 | -71.604 | 32.5 | 4.5 | mwr | 36km WSW of La Ligua, Chile | South America | 6 | https://earthquake.usgs.gov/earthquakes/eventpage/us2000heqr/executive |
| us1000ehi8 | 2018-06-02 T19:58:16 | -20.266 | -70.828 | 17.0 | 4.5 | mwr | 71km W of Iquique, Chile | South America | 4 | https://earthquake.usgs.gov/earthquakes/eventpage/us1000ehi8/executive |
| us1000e3a7 | 2018-05-11 T21:57:40 | -32.757 | -71.957 | 19.1 | 4.5 | mwr | 43km NW of Valparaiso, Chile | South America | 77 | https://earthquake.usgs.gov/earthquakes/eventpage/us1000e3a7/executive |
| us20009lrs | 2017-06-10: T16:09:21 | -33.063 | -72.258 | 10.0 | 4.5 | mb | 58km W of Valparaiso, Chile | South America | 7 | https://earthquake.usgs.gov/earthquakes/eventpage/us20009lrs/executive |
| **Magnitude 4.6 Earthquakes** | | | | | | | | | | |
| us70003ddw | 2019-04-28: T12:03:00. | -32.196 | -72.078 | 22.3 | 4.6 | mwr | 84km WNW of La Ligua, Chile | South America | 7 | https://earthquake.usgs.gov/earthquakes/eventpage/us70003ddw/executive |
| us1000f1ue | 2018-06-26: T02:05:18. | -32.150 | -71.885 | 23.5 | 4.6 | mwr | 70km WNW of La Ligua, Chile | South America | 5 | https://earthquake.usgs.gov/earthquakes/eventpage/us1000f1ue/executive |
| us1000e4fm | 2018-05-14: T02:58:06 | -42.829 | -74.001 | 30.2 | 4.6 | mwr | 28km SSW of Chonchi, Chile | South America | 9 | https://earthquake.usgs.gov/earthquakes/eventpage/us1000e4fm/executive |
| us2000cz50 | 2018-02-08: T21:37:06 | -37.437 | -74.064 | 10.0 | 4.6 | mb | 41km WNW of Lebu, Chile | South America | 6 | https://earthquake.usgs.gov/earthquakes/eventpage/us2000cz50/executive |
| us2000cm4u | 2018-01-21: T14:42:50 | -36.016 | -73.419 | 7.5 | 4.6 | mb | 78km NNW of Tome, Chile | South America | 3 | https://earthquake.usgs.gov/earthquakes/eventpage/us2000cm4u/executive |
| us2000atse | 2017-09-24: T02:30:00 | -27.878 | -71.318 | 31.9 | 4.6 | mwr | 94km NW of Vallenar, Chile | South America | 3 | https://earthquake.usgs.gov/earthquakes/eventpage/us2000atse/executive |
| usc000stvc | 2014-11-04: T11:44:51 | -41.227 | -73.831 | 25.4 | 4.6 | mwr | 65km WSW of Purranque, Chile | South America | 7 | https://earthquake.usgs.gov/earthquakes/eventpage/usc000stvc/executive |
| **Magnitude 4.7 Earthquakes** | | | | | | | | | | |
| us70006cix | 2019-11-24: T21:18:25 | -31.799 | -71.486 | 35.0 | 4.7 | mb | 35km WSW of Illapel, Chile | South America | 22 | https://earthquake.usgs.gov/earthquakes/eventpage/us70006cix/executive |
| us2000itug | 2018-12-15: T12:12:49 | -19.976 | -70.959 | 18.3 | 4.7 | mb | 89km WNW of Iquique, Chile | South America | 19 | https://earthquake.usgs.gov/earthquakes/eventpage/us2000itug/executive |
| us1000e8gl | 2018-05-19: T06:43:40 | -32.183 | -71.486 | 31.6 | 4.7 | mwr | 38km NW of La Ligua, Chile | South America | 110 | https://earthquake.usgs.gov/earthquakes/eventpage/us1000e8gl/executive |
| us10008kmi | 2017-04-25: T12:13:22 | -33.123 | -72.213 | 16.3 | 4.7 | mwr | 55km W of Valparaiso, Chile | South America | 5 | https://earthquake.usgs.gov/earthquakes/eventpage/us10008kmi/executive |

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|---|---|---|---|---|---|---|---|---|---|---|
| us10007eix | 2016-12-03: T04:30:58 | -32.178 | -71.979 | 22.5 | 4.7 | mwr | 76km WNW of La Ligua, Chile | South America | 2 | https://earthquake.usgs.gov/earthquakes/eventpage/us10007eix/executive |
| us20003lpf | 2015-09-19: T02:49:40 | -31.498 | -71.890 | 25.1 | 4.7 | mwr | 70km WNW of Illapel, Chile | South America | 5 | https://earthquake.usgs.gov/earthquakes/eventpage/us20003lpf/executive |
| **Magnitude 4.8 Earthquakes** | | | | | | | | | | |
| us2000jjv0 | 2019-02-19: T05:09:42 | -28.014 | -71.530 | 21.5 | 4.8 | mww | 97km NW of Vallenar, Chile | South America | 4 | https://earthquake.usgs.gov/earthquakes/eventpage/us2000jjv0/executive |
| us2000jcll | 2019-02-03: T02:56:43 | -31.367 | -71.813 | 27.3 | 4.8 | mww | 68km WNW of Illapel, Chile | South America | 2 | https://earthquake.usgs.gov/earthquakes/eventpage/us2000jcll/executive |
| us1000i3ak | 2018-12-06: T05:24:14 | -30.725 | -71.418 | 32.2 | 4.8 | mb | 25km SW of Ovalle, Chile | South America | 2 | https://earthquake.usgs.gov/earthquakes/eventpage/us1000i3ak/executive |
| us1000cdhv | 2018-02-01: T00:12:54 | -37.486 | -74.160 | 4.2 | 4.8 | mwr | 47km WNW of Lebu, Chile | South America | 2 | https://earthquake.usgs.gov/earthquakes/eventpage/us1000i3ak/executive |
| us2000asd1 | 2017-09-21: T07:12:40 | -37.899 | -73.696 | 10.0 | 4.8 | mwr | 28km WSW of Canete, Chile | South America | 2 | https://earthquake.usgs.gov/earthquakes/eventpage/us2000asd1/executive |
| us2000ad2e | 2017-08-30: T03:15:36. | -37.350 | -73.558 | 21.6 | 4.8 | mwr | 22km NW of Curanilahue, Chile | South America | 5 | https://earthquake.usgs.gov/earthquakes/eventpage/us2000ad2e/executive |
| us10007rxs | 2017-01-08: T00:33:48 | -30.150 | -72.187 | 10.0 | 4.8 | mwr | 84km WSW of Coquimbo, Chile | South America | 3 | https://earthquake.usgs.gov/earthquakes/eventpage/us10007rxs/executive |
| us20006hyj | 2016-07-26: T23:00:21 | -32.633 | -71.842 | 16.4 | 4.8 | mwr | 49km NNW of Valparaiso, Chile | South America | 51 | https://earthquake.usgs.gov/earthquakes/eventpage/us20006hyj/executive |
| usc000tgw0 | 2015-01-18: T03:59:59 | -32.703 | -71.703 | 25.8 | 4.8 | mwr | 37km N of Valparaiso, Chile | South America | 20 | https://earthquake.usgs.gov/earthquakes/eventpage/usc000tgw0/executive |
| **Magnitude 4.9 Earthquakes** | | | | | | | | | | |
| us70005966 | 2019-08-28: T15:53:02 | -20.582 | -70.390 | 29.8 | 4.9 | mww | 47km SSW of Iquique, Chile | South America | 2 | https://earthquake.usgs.gov/earthquakes/eventpage/us70005966/executive |
| us60004yrj | 2019-08-01: T19:36:25 | -34.188 | -72.191 | 10.0 | 4.9 | mb | 84km SW of San Antonio, Chile | South America | 2 | https://earthquake.usgs.gov/earthquakes/eventpage/us60004yrj/executive |
| us2000dutq | 2018-04-05: T06:32:40 | -42.555 | -74.171 | 26.7 | 4.9 | mwr | 30km WNW of Chonchi, Chile | South America | 8 | https://earthquake.usgs.gov/earthquakes/eventpage/us2000dutq/executive |
| us2000d71v | 2018-02-23: T18:49:21 | -34.505 | -72.222 | 23.1 | 4.9 | mb | 79km W of Santa Cruz, Chile | South America | 6 | https://earthquake.usgs.gov/earthquakes/eventpage/us2000d71v/executive |
| us1000738c | 2016-10-31: T11:15:47 | -33.760 | -72.511 | 9.4 | 4.9 | mww | 84km WSW of San Antonio, Chile | South America | 5 | https://earthquake.usgs.gov/earthquakes/eventpage/us1000738c/executive |
| us10006qck | 2016-09-17: T03:55:57 | -37.282 | -73.724 | 13.5 | 4.9 | mwr | 36km W of Arauco, Chile | South America | 7 | https://earthquake.usgs.gov/earthquakes/eventpage/us10006qck/executive |
| us10004qzj | 2016-02-19: T05:33:08 | -30.593 | -71.593 | 23.6 | 4.9 | mww | 37km W of Ovalle, Chile | South America | 5 | https://earthquake.usgs.gov/earthquakes/eventpage/us10004qzj/executive |
| us20004150 | 2015-11-01: T01:28:38 | -38.783 | -73.368 | 22.0 | 4.9 | mb | 19km WSW of Carahue, Chile | South America | 23 | https://earthquake.usgs.gov/earthquakes/eventpage/us20004150/executive |
| usb000l7vx | 2013-11-29: T05:21:29 | -33.377 | -72.266 | 8.1 | 4.9 | mb | 64km WNW of San Antonio, Chile | South America | 8 | https://earthquake.usgs.gov/earthquakes/eventpage/usb000l7vx/executive |
| **Magnitude 5.0 Earthquakes** | | | | | | | | | | |
| us70005nkr | 2019-09-29: T20:11:58 | -35.517 | -72.988 | 13.9 | 5 | mww | 55km WSW of Constitucion, Chile | South America | 3 | https://earthquake.usgs.gov/earthquakes/eventpage/us70005nkr/executive |
| us1000j9nk | 2019-03-01: T22:43:26 | -30.588 | -71.634 | 24.0 | 5 | mww | 41km W of Ovalle, Chile | South America | 7 | https://earthquake.usgs.gov/earthquakes/eventpage/us1000j9nk/executive |

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|---|---|---|---|---|---|---|---|---|---|---|
| us1000i2xc | 2018-12-05: T17:12:13 | -33.658 | -71.632 | 34.8 | 5 | mww | 7km S of San Antonio, Chile | South America | 139 | https://earthquake.usgs.gov/earthquakes/eventpage/us1000i2xc/executive |
| us2000cpsu | 2018-01-26: T13:27:06 | -37.447 | -73.981 | 10.0 | 5 | mww | 34km WNW of Lebu, Chile | South America | 11 | https://earthquake.usgs.gov/earthquakes/eventpage/us2000cpsu/executive |
| us10008kcn | 2017-04-24: T21:58:31 | -33.135 | -72.038 | 17.1 | 5 | mb | 39km WSW of Valparaiso, Chile | South America | 4 | https://earthquake.usgs.gov/earthquakes/eventpage/us10008kcn/executive |
| us20008mhp | 2017-02-26: T08:59:16 | -28.960 | -71.588 | 34.7 | 5 | mww | 91km WSW of Vallenar, Chile | South America | 5 | https://earthquake.usgs.gov/earthquakes/eventpage/us20008mhp/executive |
| us20007gk0 | 2016-10-25: T07:18:20 | -26.701 | -71.069 | 10.0 | 5 | mww | 103km NW of Copiapo, Chile | South America | 4 | https://earthquake.usgs.gov/earthquakes/eventpage/us20007gk0/executive |
| us10004db0 | 2016-01-10: T13:33:35 | -31.327 | -71.755 | 26.2 | 5 | mwr | 65km WNW of Illapel, Chile | South America | 2 | https://earthquake.usgs.gov/earthquakes/eventpage/us10004db0/executive |
| us10004c4b | 2016-01-07: T15:40:42 | -41.665 | -74.089 | 22.6 | 5 | mww | 31km NW of Ancud, Chile | South America | 20 | https://earthquake.usgs.gov/earthquakes/eventpage/us10004c4b/executive |
| **Magnitude 5.2 Earthquakes** | | | | | | | | | | |
| us60006c5a | 2019-11-15: T17:16:42 | -34.003 | -72.246 | 13.7 | 5.2 | mww | 73km SW of San Antonio, Chile | South America | 12 | https://earthquake.usgs.gov/earthquakes/eventpage/us60006c5a/executive |
| us700062hv | 2019-11-03: T08:06:10 | -30.643 | -72.117 | 10.0 | 5.2 | mww | 87km W of Ovalle, Chile | South America | 3 | https://earthquake.usgs.gov/earthquakes/eventpage/us700062hv/executive |
| us2000je9g | 2019-02-06: T17:56:49 | -19.891 | -71.044 | 13.0 | 5.2 | mww | 101km WNW of Iquique, Chile | South America | 11 | https://earthquake.usgs.gov/earthquakes/eventpage/us2000je9g/executive |
| us2000j9mr | 2019-01-28: T09:00:47 | -35.589 | -72.960 | 21.0 | 5.2 | mww | 56km WSW of Constitucion, Chile | South America | 10 | https://earthquake.usgs.gov/earthquakes/eventpage/us2000j9mr/executive |
| us1000hpxh | 2018-11-09: T18:54:10 | -30.629 | -71.711 | 25.8 | 5.2 | mww | 49km W of Ovalle, Chile | South America | 5 | https://earthquake.usgs.gov/earthquakes/eventpage/us1000hpxh/executive |
| us1000ehan | 2018-06-02: T06:17:19 | -38.246 | -73.707 | 26.2 | 5.2 | mww | 56km SSW of Canete, Chile | South America | 8 | https://earthquake.usgs.gov/earthquakes/eventpage/us1000ehan/executive |
| us1000dz41 | 2018-05-06: T02:44:20 | -34.269 | -72.268 | 12.1 | 5.2 | mww | 92km WNW of Santa Cruz, Chile | South America | 27 | https://earthquake.usgs.gov/earthquakes/eventpage/us1000dz41/executive |
| us10008s71 | 2017-05-13: T16:54:45 | -32.928 | -72.031 | 15.0 | 5.2 | mww | 39km WNW of Valparaiso, Chile | South America | 12 | https://earthquake.usgs.gov/earthquakes/eventpage/us10008s71/executive |
| us10008kgt | 2017-04-25: T01:43:03 | -33.144 | -72.028 | 21.4 | 5.2 | mww | 39km WSW of Valparaiso, Chile | South America | 22 | https://earthquake.usgs.gov/earthquakes/eventpage/us10008kgt/executive |
| us20006fgd | 2016-07-18: T02:58:50 | -30.754 | -71.794 | 24.0 | 5.2 | mwr | 59km WSW of Ovalle, Chile | South America | 5 | https://earthquake.usgs.gov/earthquakes/eventpage/us20006fgd/executive |
| usc000thj5 | 2015-01-20: T17:34:41 | -23.354 | -70.883 | 20.6 | 5.2 | mww | 59km WNW of Antofagasta, Chile | South America | 14 | https://earthquake.usgs.gov/earthquakes/eventpage/usc000thj5/executive |
| usb000s1ci | 2014-08-08: T04:10:15 | -33.777 | -72.203 | 16.5 | 5.2 | mww | 57km WSW of San Antonio, Chile | South America | 7 | https://earthquake.usgs.gov/earthquakes/eventpage/usb000s1ci/executive |
| usc000f9mg | 2013-02-18: T10:00:11 | -33.954 | -72.051 | 25.4 | 5.2 | mb | 56km SW of San Antonio, Chile | South America | 16 | https://earthquake.usgs.gov/earthquakes/eventpage/usc000f9mg/executive |
| **Magnitude 5.4 Earthquakes** | | | | | | | | | | |
| us60004z17 | 2019-08-02: T00:55:16. | -34.183 | -72.196 | 13.2 | 5.4 | mww | 84km SW of San Antonio, Chile | South America | 19 | https://earthquake.usgs.gov/earthquakes/eventpage/us60004z17/executive |
| us2000hin5 | 2018-09-22: T13:13:59 | -25.900 | -70.938 | 28.4 | 5.4 | mww | 71km SW of Taltal, Chile | South America | 3 | https://earthquake.usgs.gov/earthquakes/eventpage/us2000hin5/executive |
| us20009wav | 2017-07-14: T12:00:29 | -33.723 | -72.518 | 10.0 | 5.4 | mww | 84km W of San Antonio, Chile | South America | 17 | https://earthquake.usgs.gov/earthquakes/eventpage/us20009wav/executive |

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|---|---|---|---|---|---|---|---|---|---|---|
| us10008lm1 | 2017-04-28:T15:58:33 | -33.232 | -72.048 | 22.5 | 5.4 | mww | 44km WSW of Valparaiso, Chile | South America | 2 | https://earthquake.usgs.gov/earthquakes/eventpage/us10008lm1/executive |
| us10008kcr | 2017-04-24:T21:46:24 | -32.931 | -71.984 | 13.2 | 5.4 | mb | 35km WNW of Valparaiso, Chile | South America | 8 | https://earthquake.usgs.gov/earthquakes/eventpage/us10008kcr/executive |
| us20008k59 | 2017-02-16:T07:02:05 | -30.168 | -72.109 | 9.8 | 5.4 | mww | 77km WSW of Coquimbo, Chile | South America | 2 | https://earthquake.usgs.gov/earthquakes/eventpage/us20008k59/executive |
| us20006v8s | 2016-08-30:T08:09:09 | -34.896 | -72.555 | 14.2 | 5.4 | mww | 50km NNW of Constitucion, Chile | South America | 25 | https://earthquake.usgs.gov/earthquakes/eventpage/us20006v8s/executive |
| us20003mgp | 2015-09-21:T15:37:08 | -31.024 | -71.794 | 25.6 | 5.4 | mww | 73km SW of Ovalle, Chile | South America | 29 | https://earthquake.usgs.gov/earthquakes/eventpage/us20003mgp/executive |
| usb000k2e3 | 2013-09-29:T23:23:16 | -37.407 | -73.394 | 15.5 | 5.4 | mwb | 7km NNW of Curanilahue, Chile | South America | 31 | https://earthquake.usgs.gov/earthquakes/eventpage/usb000k2e3/executive |
| **Magnitude 5.5 Earthquakes** | | | | | | | | | | |
| us70003cb3 | 2019-04-26:T06:22:34 | -25.899 | -71.017 | 29.0 | 5.5 | mww | 76km SW of Taltal, Chile | South America | 5 | https://earthquake.usgs.gov/earthquakes/eventpage/us70003cb3/executive |
| us1000j9yt | 2019-03-02:T20:21:52 | -33.677 | -72.595 | 10.4 | 5.5 | mww | 90km W of San Antonio, Chile | South America | 16 | https://earthquake.usgs.gov/earthquakes/eventpage/us1000j9yt/executive |
| us1000i02j | 2018-12-01:T23:55:24 | -33.922 | -72.401 | 10.0 | 5.5 | mww | 80km WSW of San Antonio, Chile | South America | 17 | https://earthquake.usgs.gov/earthquakes/eventpage/us1000i02j/executive |
| us2000c2xt | 2017-12-11:T19:00:56 | -19.708 | -71.059 | 12.0 | 5.5 | mww | 111km WNW of Iquique, Chile | South America | 10 | https://earthquake.usgs.gov/earthquakes/eventpage/us2000c2xt/executive |
| us10007piy | 2017-01-03:T21:19:07 | -43.353 | -74.502 | 10.3 | 5.5 | mww | 76km WSW of Puerto Quellon, Chile | South America | 4 | https://earthquake.usgs.gov/earthquakes/eventpage/us10007piy/executive |
| us20004g1p | 2015-12-10:T00:09:32 | -35.884 | -73.276 | 10.0 | 5.5 | mww | 86km NNW of Tome, Chile | South America | 15 | https://earthquake.usgs.gov/earthquakes/eventpage/us20004g1p/executive |
| us10003mjs | 2015-10-09:T18:27:36 | -31.732 | -71.733 | 35.0 | 5.5 | mww | 54km WSW of Illapel, Chile | South America | 18 | https://earthquake.usgs.gov/earthquakes/eventpage/us10003mjs/executive |
| us20003mis | 2015-09-21:T18:36:53 | -31.046 | -71.820 | 27.0 | 5.5 | mww | 77km SW of Ovalle, Chile | South America | 11 | https://earthquake.usgs.gov/earthquakes/eventpage/us20003mis/executive |
| us100031b7 | 2015-08-12:T00:14:40 | -31.697 | -71.623 | 30.0 | 5.5 | mww | 43km W of Illapel, Chile | South America | 21 | https://earthquake.usgs.gov/earthquakes/eventpage/us100031b7/executive |
| usb000rsnz | 2014-07-13:T20:54:14 | -20.259 | -70.348 | 33.1 | 5.5 | mww | 21km W of Iquique, Chile | South America | 20 | https://earthquake.usgs.gov/earthquakes/eventpage/usb000rsnz/executive |
| usp000j62j | 2011-08-06:T13:22:34 | -35.884 | -73.334 | 31.9 | 5.5 | mwc | offshore Bio-Bio, Chile | South America | 8 | https://earthquake.usgs.gov/earthquakes/eventpage/usp000j62j/executive |
| usp000j3xp | 2011-06-29:T05:36:46 | -33.906 | -72.341 | 19.7 | 5.5 | mwc | offshore Libertador O'Higgins, Chile | South America | 45 | https://earthquake.usgs.gov/earthquakes/eventpage/usp000j3xp/executive |
| usp000hxk6 | 2011-03-16:T22:36:16 | -32.564 | -71.726 | 32.7 | 5.5 | mwc | offshore Valparaiso, Chile | South America | 254 | https://earthquake.usgs.gov/earthquakes/eventpage/usp000hxk6/executive |
| usp000huf9 | 2011-02-13:T13:44:36 | -36.557 | -73.275 | 18.9 | 5.5 | mwb | offshore Bio-Bio, Chile | South America | 8 | https://earthquake.usgs.gov/earthquakes/eventpage/usp000huf9/executive |
| usp000hnek | 2010-10-23:T05:58:27 | -37.743 | -73.362 | 15.0 | 5.5 | mwb | Bio-Bio, Chile | South America | 26 | https://earthquake.usgs.gov/earthquakes/eventpage/usp000hnek/executive |
| usp000hep7 | 2010-06-29:T01:40:00 | -37.836 | -73.278 | 17.0 | 5.5 | mwc | Bio-Bio, Chile | South America | 128 | https://earthquake.usgs.gov/earthquakes/eventpage/usp000hep7/executive |
| usp000fuv0 | 2007-12-20:T03:06:56 | -32.713 | -71.788 | 30.1 | 5.5 | mwc | offshore Valparaiso, Chile | South America | 48 | https://earthquake.usgs.gov/earthquakes/eventpage/usp000fuv0/executive |

**Magnitude 5.6 Earthquakes**

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|---|---|---|---|---|---|---|---|---|---|---|
| us60004ys7 | 2019-08-01: T20:01:28 | -34.281 | -72.373 | 15.4 | 5.6 | mww | 100km WNW of Santa Cruz, Chile | South America | 15 | https://earthquake.usgs.gov/earthquakes/eventpage/us60004ys7/executive |
| us2000kbs5 | 2019-04-07: T10:52:41 | -33.759 | -72.515 | 10.0 | 5.6 | mww | 84km WSW of San Antonio, Chile | South America | 11 | https://earthquake.usgs.gov/earthquakes/eventpage/us2000kbs5/executive |
| us2000cz4c | 2018-02-08: T21:19:24 | -37.439 | -73.979 | 4.3 | 5.6 | mww | 35km NW of Lebu, Chile | South America | 25 | https://earthquake.usgs.gov/earthquakes/eventpage/us2000cz4c/executive |
| us1000991f | 2017-07-12: T09:08:17 | -35.391 | -73.265 | 10.0 | 5.6 | mww | 77km W of Constitucion, Chile | South America | 12 | https://earthquake.usgs.gov/earthquakes/eventpage/us1000991f/executive |
| us10008k2i | 2017-04-23: T19:40:10 | -33.015 | -72.115 | 20.0 | 5.6 | mww | 45km W of Valparaiso, Chile | South America | 60 | https://earthquake.usgs.gov/earthquakes/eventpage/us10008k2i/executive |
| us10003mxa | 2015-10-12: T03:15:19 | -31.185 | -71.823 | 21.0 | 5.6 | mww | 79km NW of Illapel, Chile | South America | 8 | https://earthquake.usgs.gov/earthquakes/eventpage/us10003mxa/executive |
| us20003mjn | 2015-09-21: T19:56:08 | -31.782 | -71.641 | 28.4 | 5.6 | mww | 48km WSW of Illapel, Chile | South America | 43 | https://earthquake.usgs.gov/earthquakes/eventpage/us20003mjn/executive |
| usp000jdmm | 2012-01-17: T23:21:35 | -31.655 | -71.499 | 32.9 | 5.6 | mww | Coquimbo, Chile | South America | 350 | https://earthquake.usgs.gov/earthquakes/eventpage/usp000jdmm/executive |
| usp000ha3f | 2010-03-28: T21:43:13 | -35.406 | -72.897 | 21.5 | 5.6 | mwc | offshore Maule, Chile | South America | 16 | https://earthquake.usgs.gov/earthquakes/eventpage/usp000ha3f/executive |
| **Magnitude 5.7 Earthquakes** | | | | | | | | | | |
| us20009lwp | 2017-06-12: T02:43:26 | -31.500 | -71.760 | 27.0 | 5.7 | mww | 58km WNW of Illapel, Chile | South America | 155 | https://earthquake.usgs.gov/earthquakes/eventpage/us20009lwp/executive |
| us10004c96 | 2016-01-08: T01:12:01 | -30.664 | -71.638 | 24.0 | 5.7 | mww | 42km W of Ovalle, Chile | South America | 28 | https://earthquake.usgs.gov/earthquakes/eventpage/us10004c96/executive |
| us100034du | 2015-08-23: T23:10:04 | -29.719 | -71.296 | 31.1 | 5.7 | mww | 21km N of La Serena, Chile | South America | 49 | https://earthquake.usgs.gov/earthquakes/eventpage/us100034du/executive |
| usb000n0mp | 2014-03-04: T10:51:15 | -33.605 | -71.957 | 20.0 | 5.7 | mww | 31km W of San Antonio, Chile | South America | 80 | https://earthquake.usgs.gov/earthquakes/eventpage/usb000n0mp/executive |
| usp000jac1 | 2011-11-05: T07:13:57 | -23.468 | -70.199 | 33.0 | 5.7 | mww | Antofagasta, Chile | South America | 67 | https://earthquake.usgs.gov/earthquakes/eventpage/usp000jac1/executive |
| usp000j5mp | 2011-07-28: T19:50:20 | -35.770 | -73.116 | 35.0 | 5.7 | mww | offshore Maule, Chile | South America | 18 | https://earthquake.usgs.gov/earthquakes/eventpage/usp000j5mp/executive |
| usp000hbgx | 2010-04-16: T22:41:33 | -37.460 | -73.732 | 6.0 | 5.7 | mwb | offshore Bio-Bio, Chile | South America | 9 | https://earthquake.usgs.gov/earthquakes/eventpage/usp000hbgx/executive |
| usp000h8be | 2010-03-01: T02:44:42 | -35.039 | -72.487 | 22.9 | 5.7 | mwb | offshore Maule, Chile | South America | 11 | https://earthquake.usgs.gov/earthquakes/eventpage/usp000h8be/executive |
| usp000gqxv | 2008-12-19: T09:36:04 | -32.458 | -71.949 | 32.2 | 5.7 | mwc | offshore Valparaiso, Chile | South America | 44 | https://earthquake.usgs.gov/earthquakes/eventpage/usp000gqxv/executive |
| usp000f7ap | 2007-03-24: T19:13:50 | -19.722 | -70.142 | 30.0 | 5.7 | mwb | Tarapaca, Chile | South America | 8 | https://earthquake.usgs.gov/earthquakes/eventpage/usp000f7ap/executive |
| **Magnitude 6.4 Earthquakes** | | | | | | | | | | |
| us600040ja | 2019-06-14: T00:19:12 | -30.056 | -72.082 | 11.0 | 6.4 | mww | 72km W of Coquimbo, Chile | South America | 34 | https://earthquake.usgs.gov/earthquakes/eventpage/us600040ja/executive |
| us10002ke8 | 2015-06-20: T02:10:07 | -36.360 | -73.812 | 11.0 | 6.4 | mww | 73km WNW of Talcahuano, Chile | South America | 54 | https://earthquake.usgs.gov/earthquakes/eventpage/us10002ke8/executive |
| usb000s5rc | 2014-08-23: T22:32:23 | -32.695 | -71.442 | 32.0 | 6.4 | mww | 23km WNW of Hacienda La Calera, Chile | South America | 469 | https://earthquake.usgs.gov/earthquakes/eventpage/usb000s5rc/executive |
| usc000ndw9 | 2014-03-17: T05:11:34 | -20.017 | -70.884 | 21.0 | 6.4 | mww | 80km WNW of Iquique, Chile | South America | 19 | https://earthquake.usgs.gov/earthquakes/eventpage/usc000ndw9/executive |

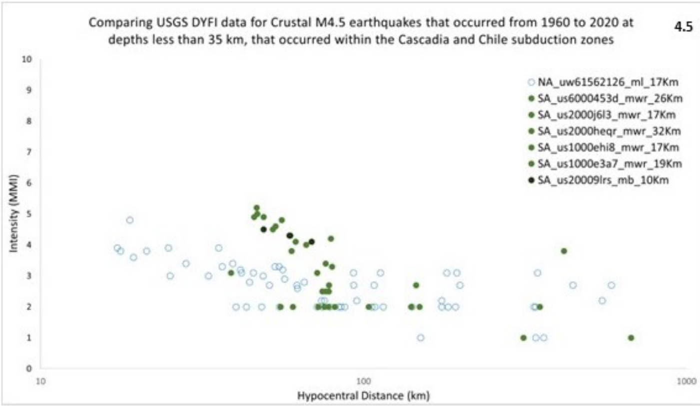
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| usp000ev15 | 2006-10-12: T18:05:56 | -31.256 | -71.368 | 31.0 | 6.4 | mwc | Coquimbo, Chile | South America | 111 | https://earthquake.usgs.gov/earthquakes/eventpage/usp000ev15/executive |
| **Magnitude 6.5 Earthquakes** | | | | | | | | | | |
| us20003kfj | 2015-09-17: T03:55:15 | -31.424 | -71.688 | 27.0 | 6.5 | mww | 54km WNW of Illapel, Chile | South America | 12 | https://earthquake.usgs.gov/earthquakes/eventpage/us20003kfj/executive |
| usc000p26f | 2014-04-03: T01:58:30 | -20.311 | -70.576 | 24.1 | 6.5 | mww | 46km WSW of Iquique, Chile | South America | 30 | https://earthquake.usgs.gov/earthquakes/eventpage/usc000p26f/executive |
| usp000h401 | 2009-11-13: T03:05:57 | -19.394 | -70.321 | 27.0 | 6.5 | mwc | near the coast of Tarapaca, Chile | South America | 77 | https://earthquake.usgs.gov/earthquakes/eventpage/usp000h401/executive |
| **Magnitude 7.1 Earthquakes** | | | | | | | | | | |
| usp000hsfq | 2011-01-02: T20:20:17 | -38.355 | -73.326 | 24.0 | 7.2 | mww | Araucania, Chile | South America | 341 | https://earthquake.usgs.gov/earthquakes/eventpage/usp000hsfq/executive |

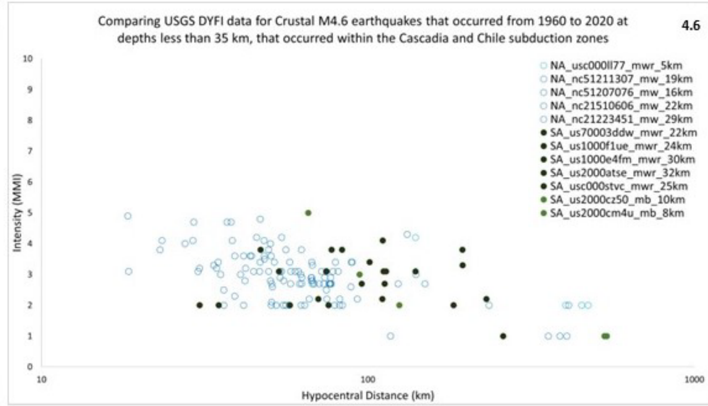
# APPENDIX C

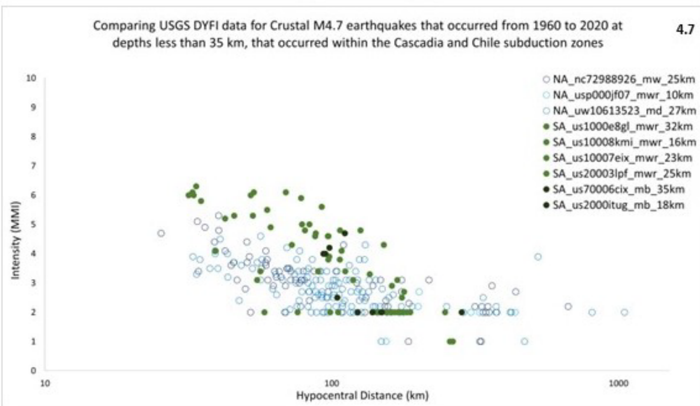
**The 14 magnitude plots for this Crustal earthquake intensity comparison study for events from 1960 to 2020 that occurred within the Cascadia and Chile subduction zones.**

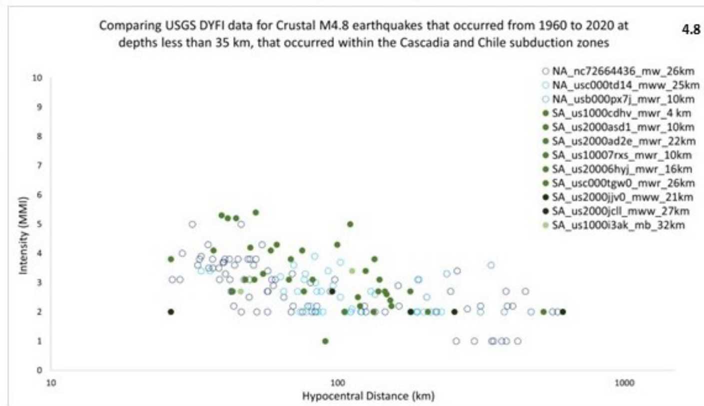
The following is a complete set of all four types of plots generated from the 29 Cascadia and 114 Chile Crustal earthquakes, for the 14 magnitudes used in this study. The sections are structure by the type of plot, e.g., Separate Earthquake Plots, Combined Chile and Cascadia Plots, Binned by Distance Plots and lastly, the curve fitting plots (binned by distance) with MMI 1 values and outliers removed. There are four plots for each of the 14 magnitudes and they are split in two images, with 8 images showing the plots for magnitudes 4.5 to 5.5 and the following six images showing plots for magnitudes 5.6 to 7.2.

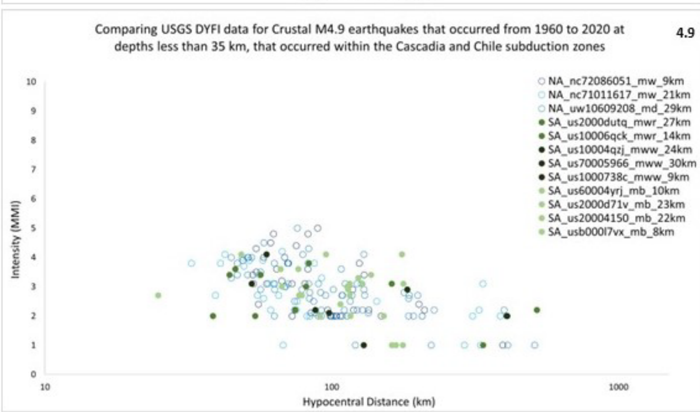
## Separate Earthquake Plots: Magnitude 4.5 to 5.4

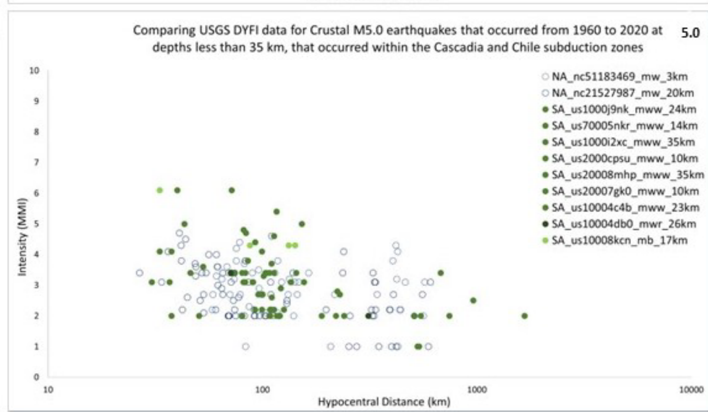


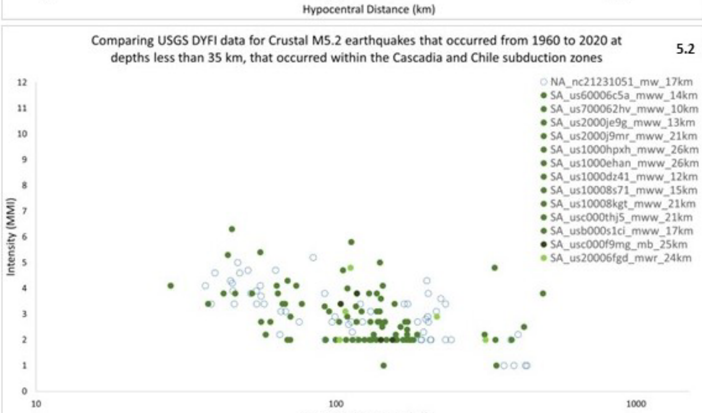



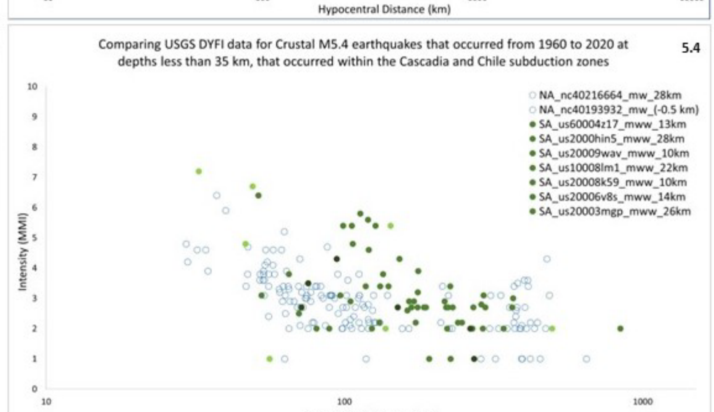



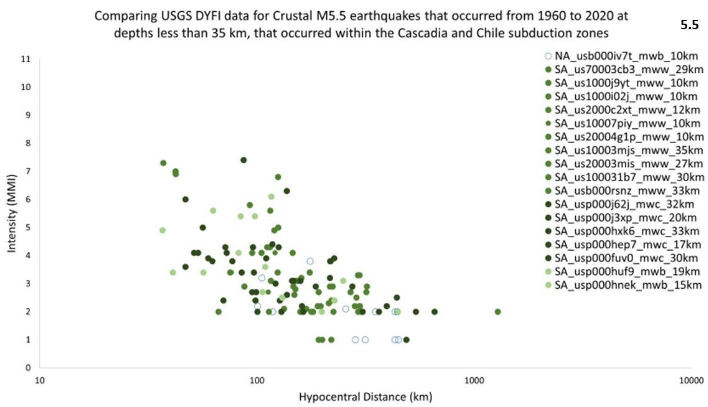



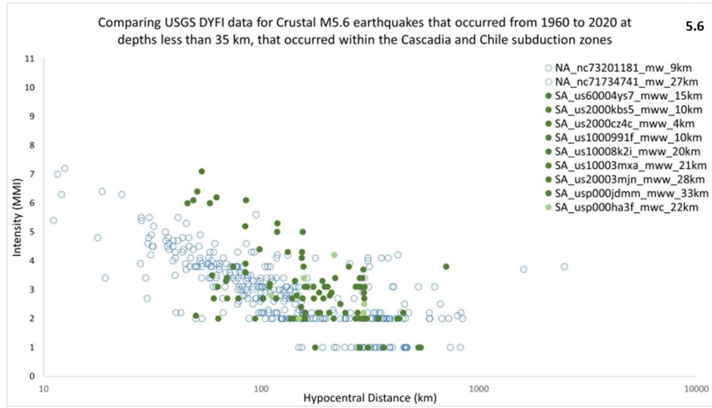



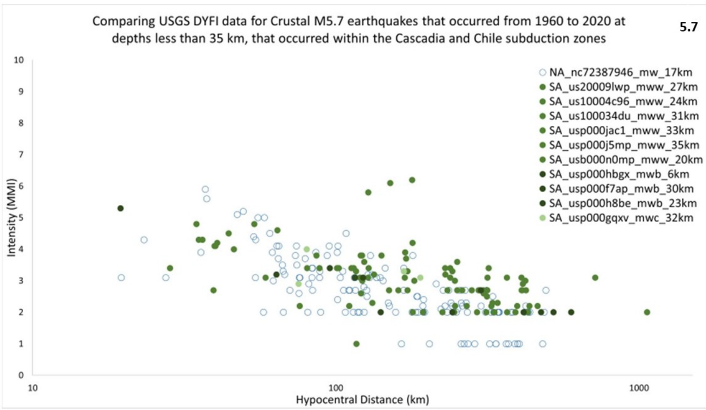



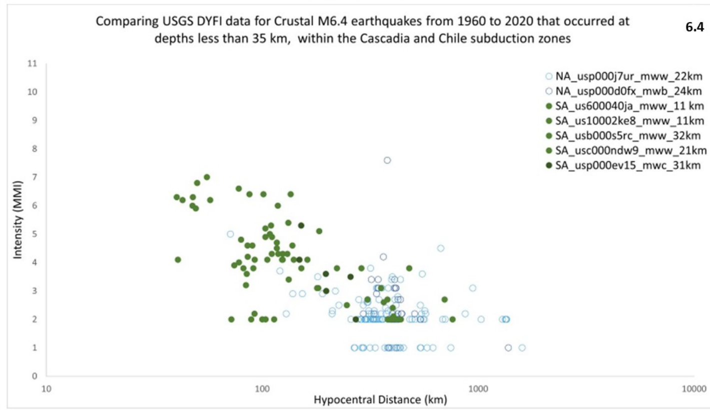



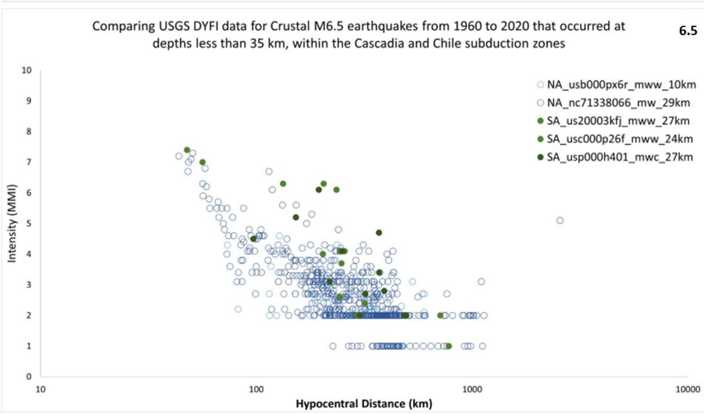
## Separate Earthquake Plots Magnitude 5.5-7.2

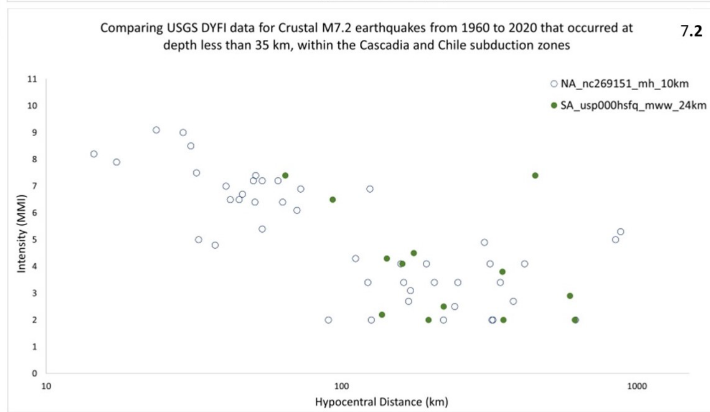


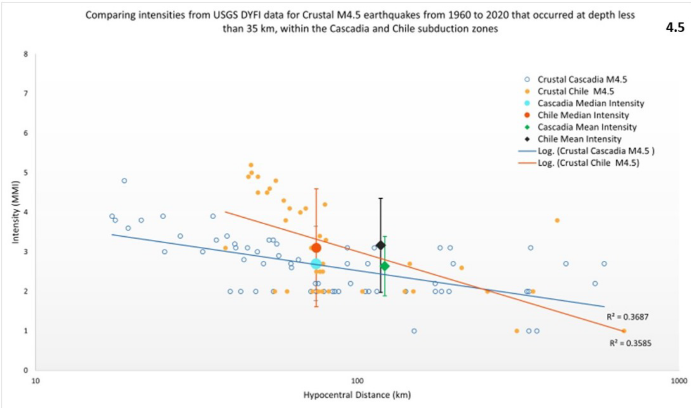



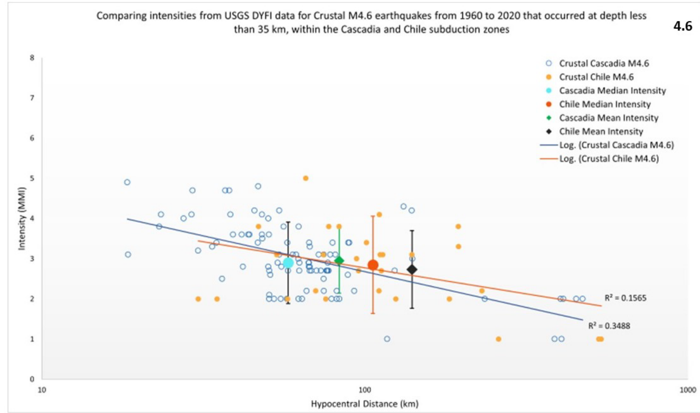



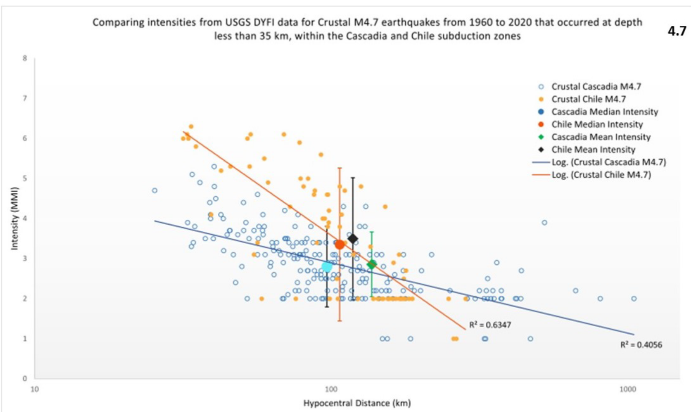



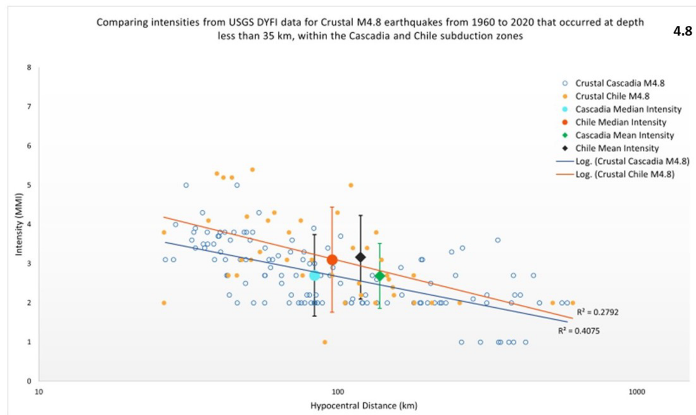



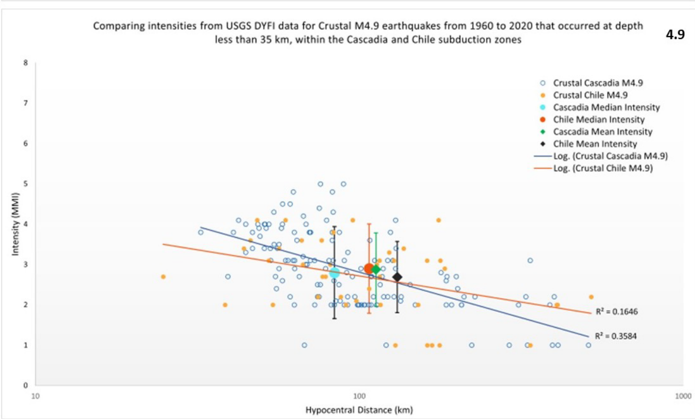
## Combined Plots: Magnitude 4.5 to 5.4

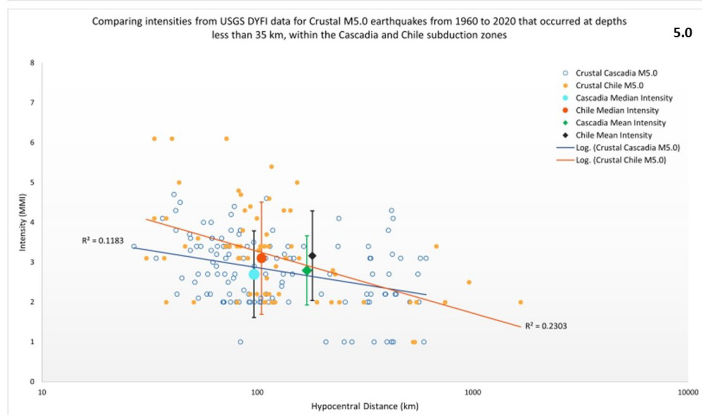


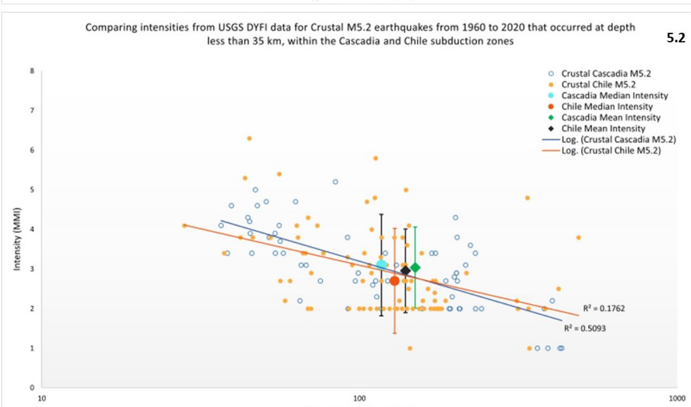



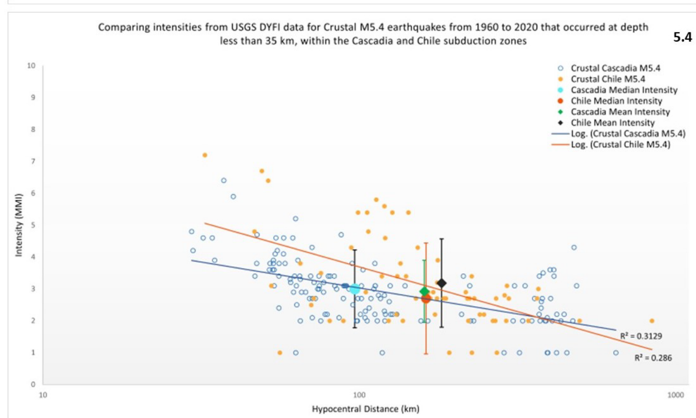



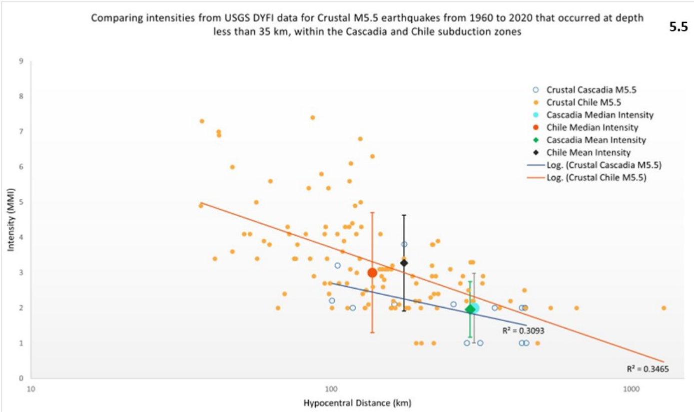



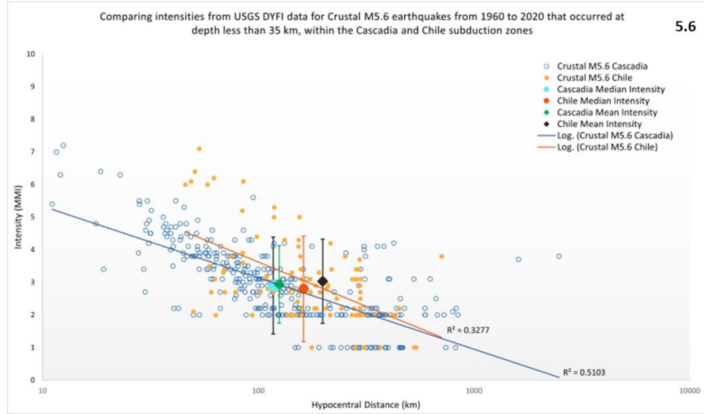



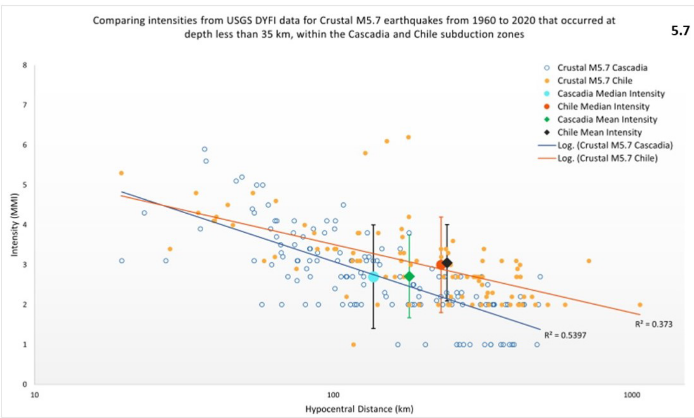



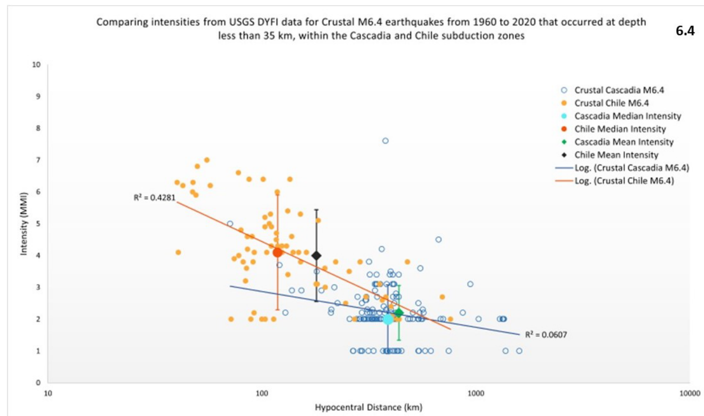



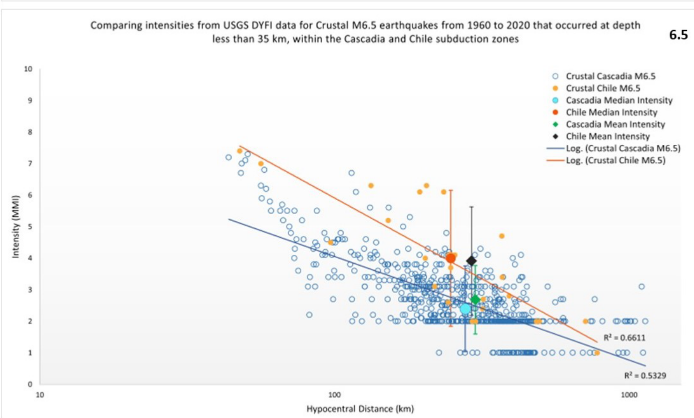
## Combined Plots Magnitude 5.5-7.2

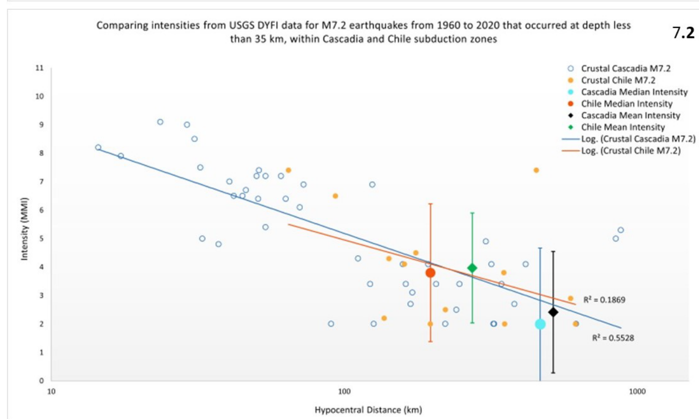


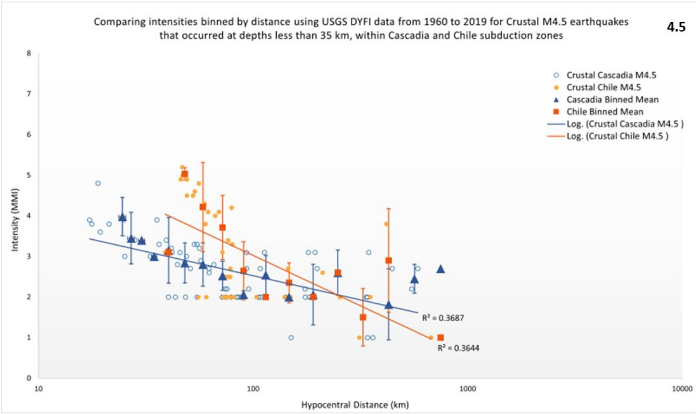



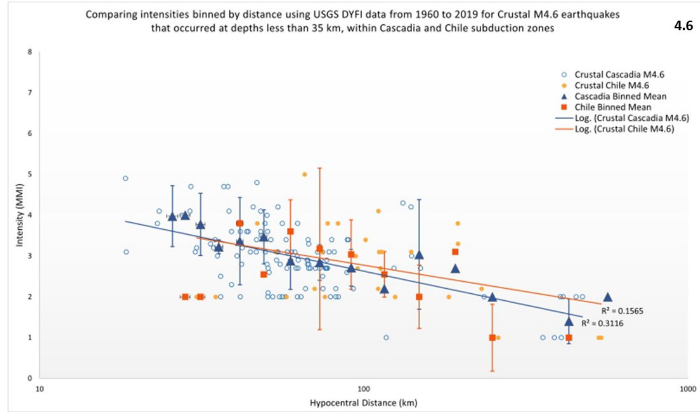



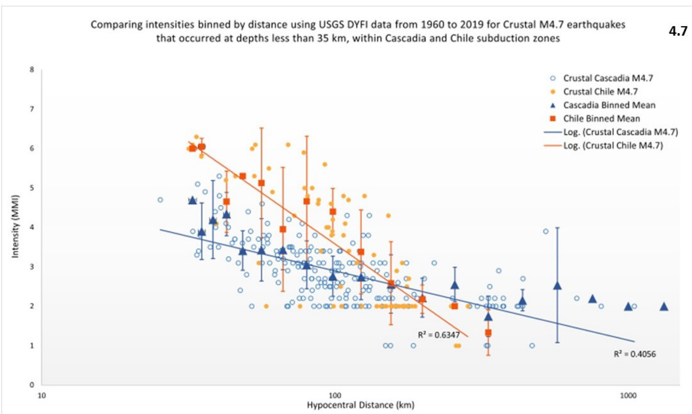



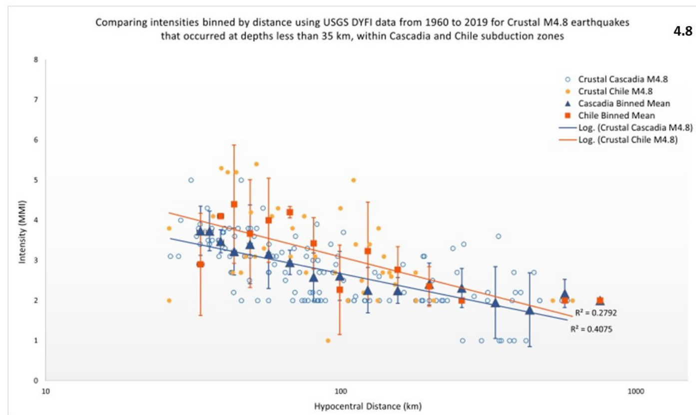



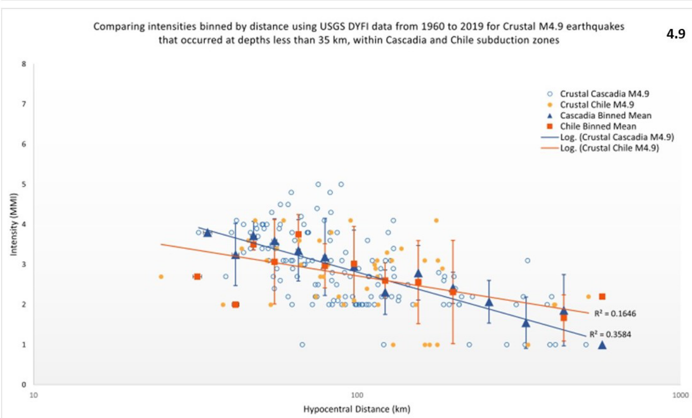
## Binned by Distance Curve Fitting Plots Magnitude 4.5 to 5.4

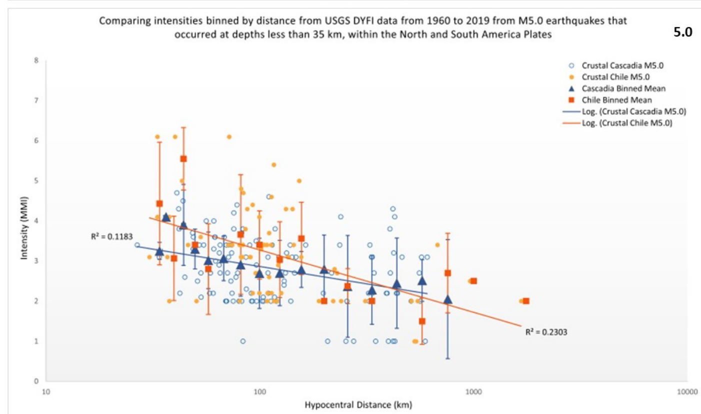


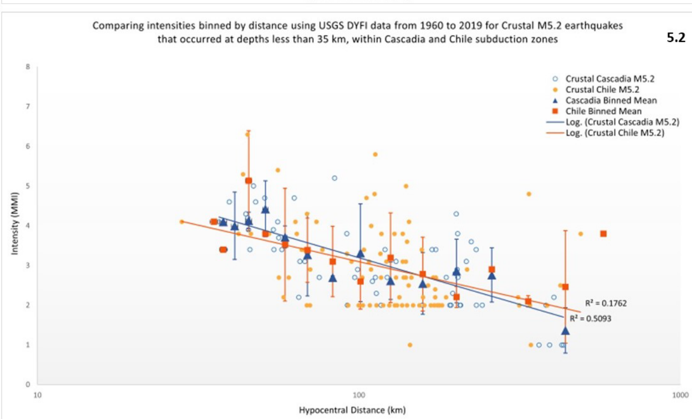



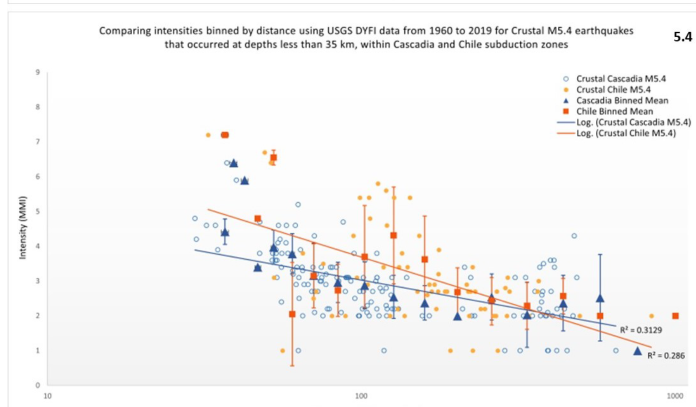



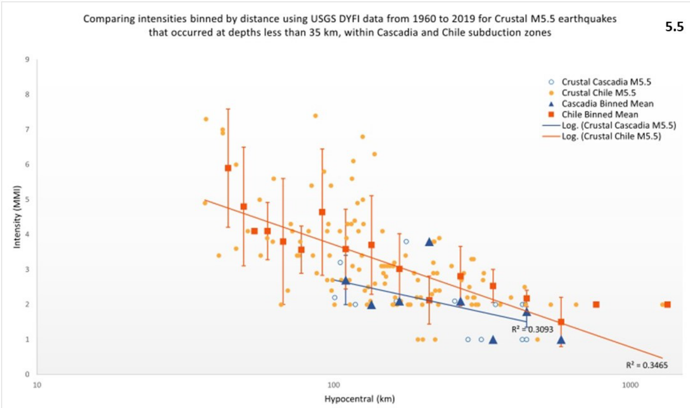



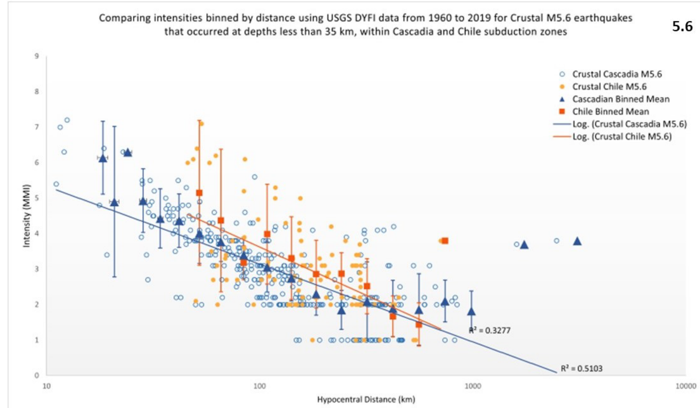



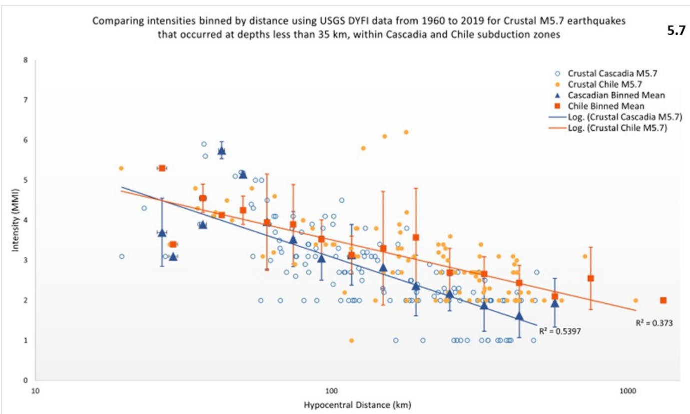



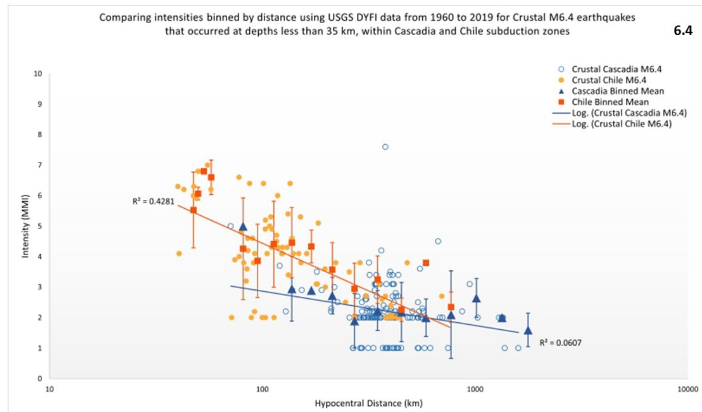



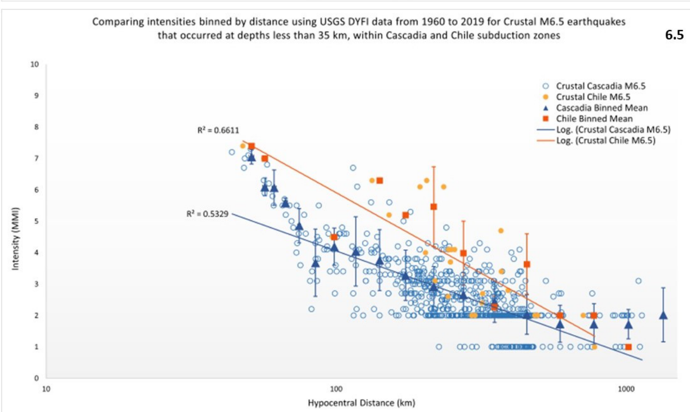
## Binned by Distance Curve Fitting Plots Magnitude 5.5-7.2

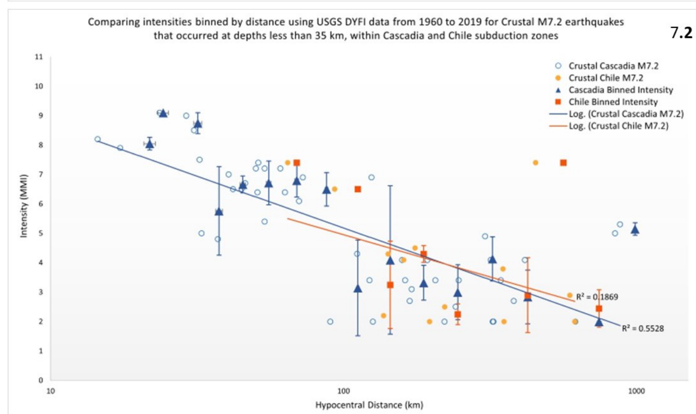


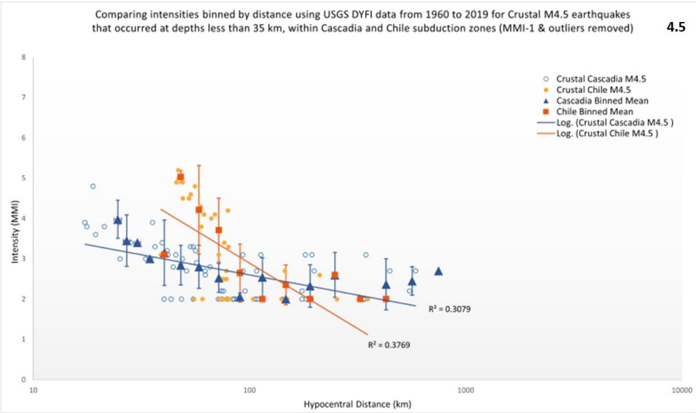



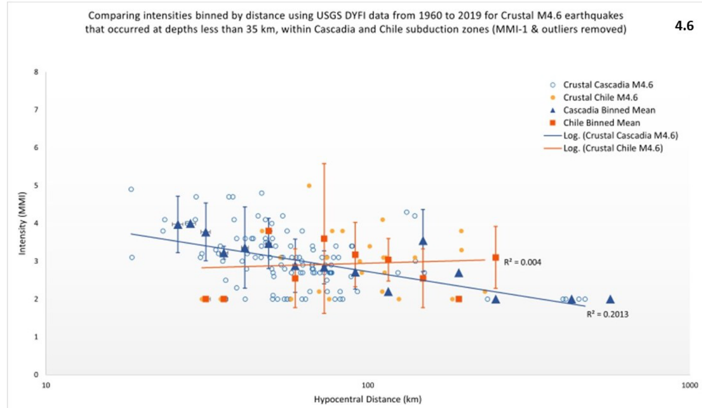



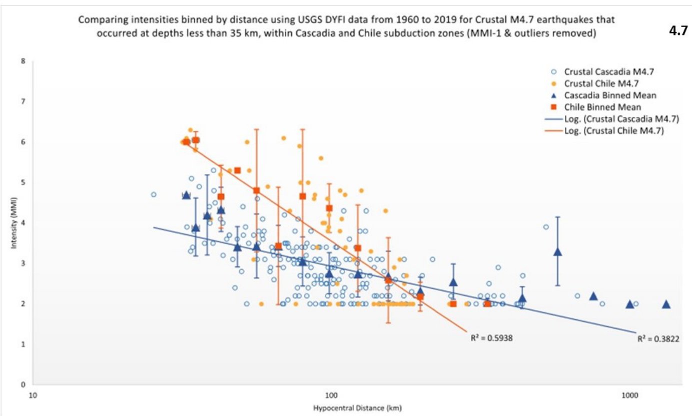



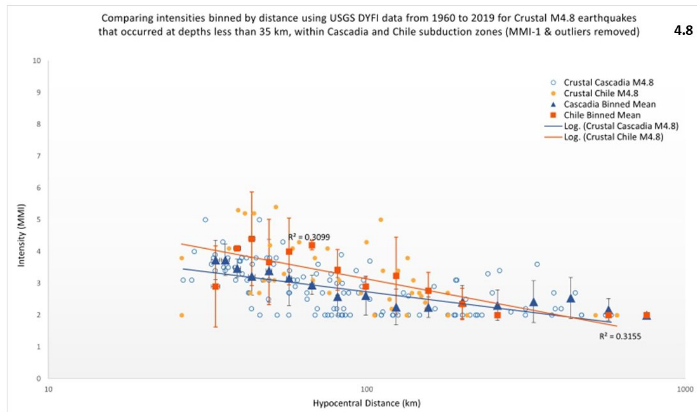



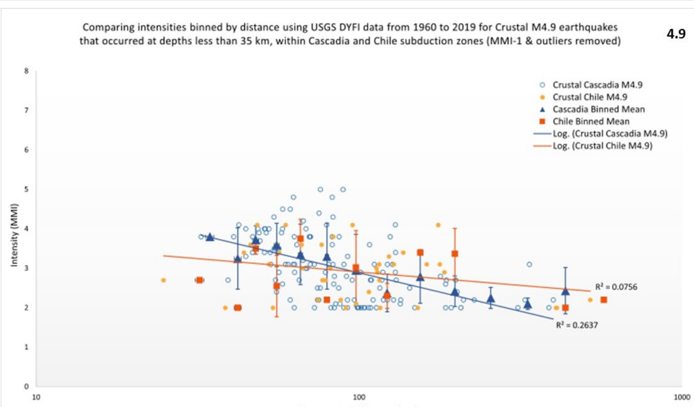
## MMI Intensities & Outliers Removed from Binned by Distance Curve Fitting Plots Magnitude 4.5 to 5.4

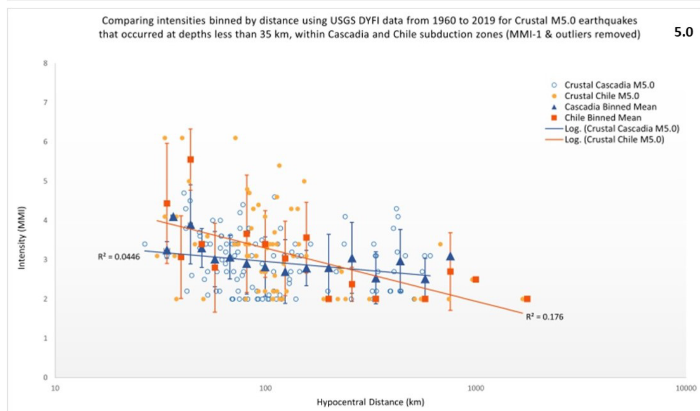


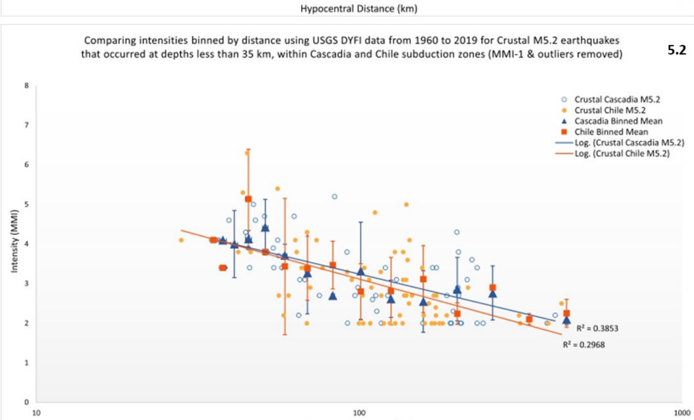



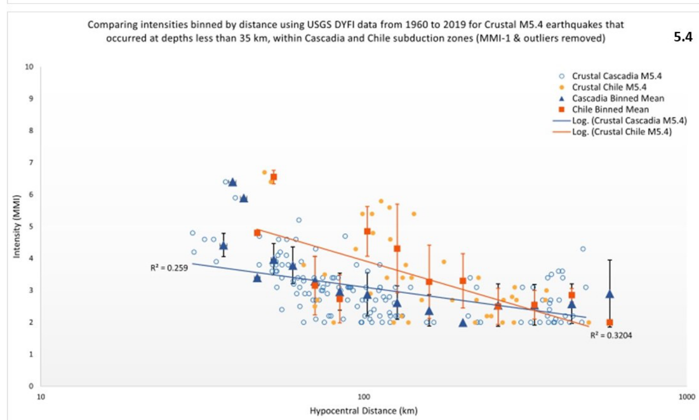



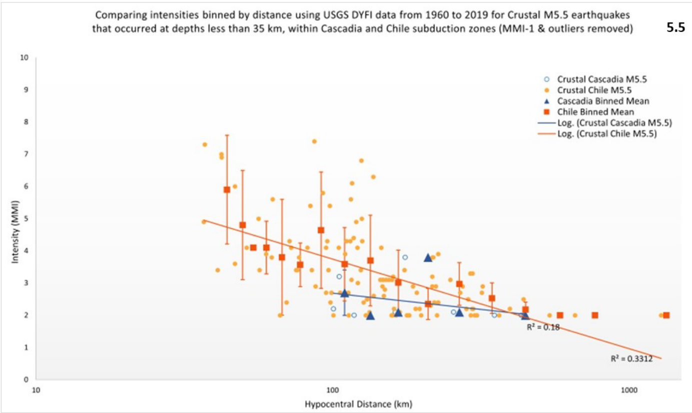



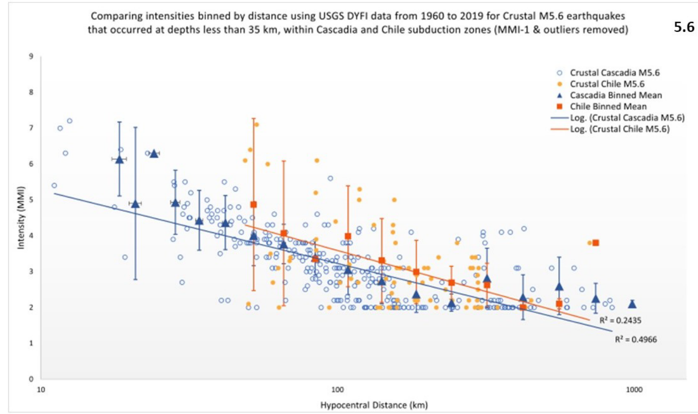



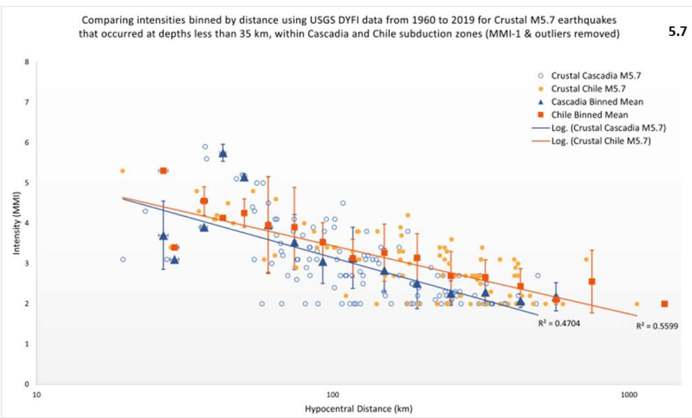



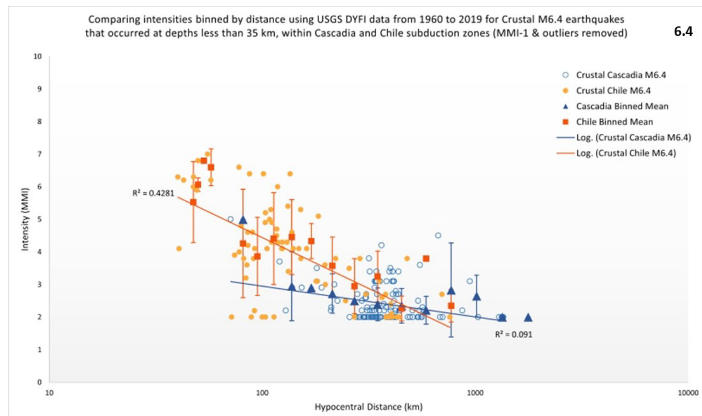



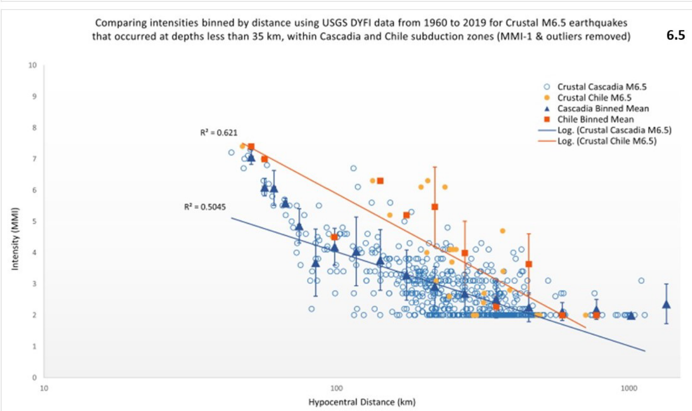
## MMI Intensities & Outliers Removed from Binned by Distance Curve Fitting Plots Magnitude 5.5-7.2

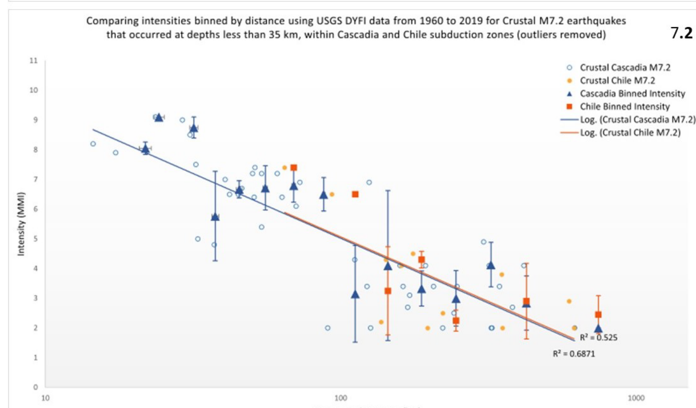


# APPENDIX D

**Folder locations documentation for the - Earthquake Intensity Comparison Study**



Project database compiled by: Jessica Rutherford (Research Scientist Contractor with Gyp-Sea Natural Science Consulting). Email: jmr.rutherford@gmail.com

Data and information on this project have been transferred to the Pacific Geological Centre server.
For specific information contact: Dr. John Cassidy at email address: john.cassidy@nrcan-rncan.gc.ca

| Main Folder | Project Folders | Subfolders/Files | Content |
|---|---|---|---|
| Chile Cascadia Intensity Project (Rutherford & Cassidy, 2022) | Crustal Earthquake Intensity Study (Cascadia Chile) | Final Crustal Combined Plots<br>Old Versions (Crustal Working Analysis Plots)<br>USGS Data Crustal Cascadia Earthquakes<br>USGS Data Crustal Chile Earthquakes<br>Crustal_M4.5Plus_Plot_Images<br>Crustal_M5.0Plus_Plot_Images<br>Crustal_M6.0Plus_Plot_Images<br>Crustal_M7.0Plus_Plot_Images<br>Crustal_M4.5_Combined_SeperatePlots<br>Crustal_M5.0_Combined_SeperatePlots<br>Crustal_M6.0_Combined_SeperatePlots<br>Crustal_M7.2_Combined_SeperatePlots<br>CrustalCombined_Plot_Review (March 20, 2022)<br>Rerun_Combined_M4.5Plus_Crustal<br>Rerun_Combined_M5.0Plus_Crustal<br>Rerun_Combined_M6.0Plus_Crustal<br>Rerun_Combined_M7.2Plus_Crustal<br>Cascadia_M4.5_4.9<br>Cascadia_M5.0_5.9<br>Cascadia_M6.0_6.9<br>Cascadia_M7.0_7.9<br>json_to_csv<br>Crustal_Cascadia<br>EventsUsed_Crustal_Cascadia<br>For methods Section_Cascadia<br>USGS_Crustal_Cascadia<br>Work Progress and Notes_Cascadia<br>Chile_M4.0_4.9<br>Chile_M5.0_5.9<br>Chile_M6.0_6.9<br>Chile_M7.0_7.9<br>Chile_M8.0_8.9<br>json_to_csv<br>Chile_Crustal_searchedResults<br>EventsUsed_Crustal_Chile_new<br>For method section_Chile<br>USGS_Crustal_Chile<br>Work Progress and Notes_Chile | These folders contain all data, documents, and images used in the Crustal earthquake intensity comparison study. Information in these folders includes working and final plots, images, and documents. Raw data downloaded from the USGS COMCAT platform is in the folders (USGS Data Deep Cascadia/Chile Earthquakes). They also contain the raw data, JSON file conversion files, and scripts. 'Old Versions…" folders with old plots and analytics have been left in these folders for future reference. There is also an ArcGIS folder "ArcPro_Project_CrustalMaps" which contains the crustal database used to create figure maps.<br><br>Final Excel documents and images of plots for figures used in this Open File report are in the "NRCan Open File Publication Documents" folder (see below). |
| Chile Cascadia Intensity Project (Rutherford & Cassidy, 2022) | Chile Cascadia Intensity Study - NRCan Open File Documents | Crustal Earthquakes Open File<br>Deep Earthquakes Open File<br>Previous versions of Reports (2021)<br>Reference Source Publications<br>Documents for Appendix<br>Figures for Crustal Open File<br>Final Crustal Open File Reports<br>Previous Section Versions | The "Crustal Earthquakes" folder contains the drafts and final reports, images/figures, and appendix sections for the NRCan Open File report. There are previous drafts of the report sections, which highlight the edited and changes made for the final report. |