Modified Mercalli Intensities for Lane County, Oregon based on a Potential Earthquake in the Cascadia Subduction Zone

Abstract:

The purpose of this project was to determine possible earthquake intensities for Lane County, Oregon based off a large predicted event in the Cascadia subduction zone. Positions of past earthquakes were inputted into statistically derived equations relating the length of fault rupture and potential magnitude. This produced a distance and magnitude for the proposed event. The magnitude was then inputted into a separate equation that relates distance from the epicenter to intensity. Data produced from the equations were combined with a map indicating political boundaries, creating a surface showing possible intensities for Lane County caused by a large earthquake occurring off the Oregon-Washington coast.

Introduction:

Over the past ten years the northwestern United States has been flooded with articles and reports detailing an earthquake that would utterly decimate the area. The purpose of the project was to determine how this
proposed “mega earthquake” would affect Lane County, Oregon. Lane County’s western border is situated on the central Oregon coast and extends inland approximately two hundred and twenty kilometers to the Pacific Crest. The first focus of the project is to see how effectively possible intensities in Lane County can be modeled. This is turn will answer the question of how concerned Lane County residents should be about the magnitude of the predicted earthquake. The second focus was to see if the literature values of magnitudes predicted for the earthquake could be repeated with the magnitude calculated from the length of fault lines.

To investigate the predicted earthquake one had to make several decisions. First, where will this earthquake occur? Secondly, how strong will it be? Thirdly, how will this affect the areas surrounding it? The investigation was set up to theoretically answer all three of the questions above. Exact location and strength can only be estimated given the parameters of the area, however the strength relative to distance can be modeled with an equation. On the Mercalli scale an intensity of six is where the effects jump from only being felt to causing structural and property damage. Once the effect is modeled relative to the Modified Mercalli Scale, an intensity of six will be used to determine significance.

Data used to answer the questions came from three sources. Earthquake data came from the Harvard Centroid Moment Tensor project, which provides dates, locations, focal mechanisms and strengths for earthquakes in the region since 1976. The second source of information was the intensities for a series test points spread on a one-degree gird over the northwest. This information was in the form of a spreadsheet that detailed the point’s location, the distance from the proposed epicenter, and the estimated intensity. The last information source were shapefiles made by ESRI Inc. The shapefiles are polygons representing political boundaries for the region. The maps included boundaries for United States counties, states, and neighboring countries.

Figure 2: shows the boundary of the Juan de Fuca plate. The subducting thrust and locked interface on the margin are also indicated. Figure from the Pacific Northwest Seismograph Network
To investigate the difference between measured and predicted intensities, two intensity maps were made. To compare them, the values were subtracted from each other ideally equaling zero.

**Background:**

The northwestern United States sits on a very active plate margin known as the Cascadia subduction zone. In this zone the Juan de Fuca Plate is colliding with and being subducted under the North American Plate. This subduction zone is responsible for the volcanics that produced the Cascade Mountain Range. A recent example of the areas active margin can be seen with the 1980 eruption of Mount Saint Helens and the 1949 earthquake in Olympia, Washington (CascadiaEQs).

The Cascadia Subduction Zone has long been known for large earthquakes. Approximately every four to six hundred years a massive earthquake hits the region. The largest recognized in the geologic record has been a 9.0 on the Richter scale, although it has been hypothesized that the fault zone is capable of creating a 9+ event. These large events occur on shallow (less than 20 miles deep) dipping faults that run from Vancouver Island all the way down to Northern California (CascadiaEQs). In all, the fault zone is 900 kilometers. These earthquakes result from the release of a locked interface (see figure 2) in the fault zone (Hyndman and Wang 1995).

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**Figure 3: example of data acquired from the Harvard CMT Catalog.**

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<th>Date</th>
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<th>Scalar Moment</th>
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**Equations for calculating intensity and magnitude**

1.) \( M = 0.85 \log L + 5.7 \)

2.) \( I = 3.42 + 1.369 \times M - (0.0044 \times R) - (3.037 - \log R) \)

\( I = \) Intensity of the Modified Mercalli scale
\( M = \) Magnitude on Richter scale
\( R = \) Distance from epicenter in kilometers
\( L = \) Length of the fault rupture in kilometers

**Figure 4: Equations used to determine intensity of the earthquake given a certain distance from the epicenter and to determine the magnitude of an earthquake given the length of the fault rupture. Provided by Dr. Richard Norris from the University of Otago. GEOL 271/371 lab.**
Data:

The first data gathered was on past earthquakes in the region. The reason for doing this was to establish faults surrounding the Juan de Fuca plate that had not broken in recent history. The information was obtained from the Harvard CMT catalog. By constraining the results to only those earthquakes located between 40 and 50 degrees north latitude and 120 to 135 degrees west longitude a list of 79 earthquakes was produced. An example of the information provided by the CMT catalog can be seen in Figure 3. The information provided by CMT was functional, however it has some major down falls. It only accounted for earthquakes since 1976. Another problem is that is doesn’t count small earthquakes. Anything smaller than a five on the Richter scale doesn’t appear in the catalog.

Two equations were used to make the final intensity map. The first equation, labeled one in Figure 4, equates the magnitude of an earthquake to the length of the fault that ruptured. The second equation, labeled two in Figure 4, is used to determine intensity given a certain magnitude and distance from the epicenter. Both equations were statistically derived by looking at thousands of past earthquakes. There is some error associated with the equations. It is most noticeable in equation two at very small distances. Distances within twenty kilometers, had values higher than the source earthquake. However past this 20 kilometer buffer the values appear accurate.

The last pieces of acquired data were base maps (see Figure 5) used to build the surface that modeled intensity. The base maps were shapefiles representing the following polygons: neighboring countries, US boundary, US states, and US counties.

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<th>Figure 5</th>
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Data Preprocessing:

Data processing took on two forms for the project. One was the procedure necessary for getting the data into a useable format, and the other was the actual processing in the ArcGIS program.

Earthquakes:

With the data gathered from the Harvard CMT catalog, an Excel spreadsheet was built. This table featured the position in latitude and longitude, magnitude, focal mechanism, and CMT identification number. Once the table was constructed, it was highlighted and saved a Dbase 4 table. After the table was saved it was imported into ArcMap. The reason for including this data was to
gain a better understanding of where the predicted event will occur. The end result of this table can be seen in Figure 6.

![Image](image.png)

**Figure 6: Purple dots represent earthquakes in the region from 1976 to Present.**

**Predicted Event:**

Positioning the event was done by looking at past earthquakes and by consulting literature. According to the USGS the so called “mega earthquake” will occur in the subduction zone. The next step was to look at earthquakes in this region. As seen in Figure 6, no earthquakes have occurred between Vancouver Island and Northern California. This leaves a 900-kilometer section of unbroken fault lines. By inputting 900 kilometers into equation 1 in Figure 4 a magnitude for the event was calculated to be 8.0037. Positioning this event required some hypothesizing. It was eventually placed in the subduction zone halfway between Vancouver and Northern California. For future calculations this point was defined as 46.5 degrees north and 125.5 degrees west.

**Waypoints:**

To build a surface representing intensity, a series of locations in the desired area that could be given Z values were defined. To cover the area, a point grid with one degree spacing was constructed. This grid was bounded on the top by the line 49 degrees north and the bottom by the line 41 degrees north. The east-west borders were 115 degrees west and 128 degrees west respectively. The waypoints came be seen in Figure 7. Once the waypoints were established, their distances from the proposed epicenter had to be measured. Using the length tool in ArcMap, the measurements were taken. An excel spreadsheet was made with columns representing positions of the waypoints and their distance to the epicenter. All of the waypoints were given z values which represented intensities at their given locations. This had to be done twice. One for predicted values and once for the measured values. These calculations were done with equation 2 in Figure 4. The distances and possible magnitudes (9.0 and 8.037) were placed into the equation using Excel and Mercalli intensities for
both the predicted and measured events were calculated for each waypoint and added to separate columns in the spreadsheet.

To prepare the table for ArcMap several steps needed to be followed. First, all of the cells were formatted with the correct number of decimal places. The longitude and latitude were given with no decimals places. The distances were formatted as general, and the intensities were formatted to have two decimal places. The next step was cut all of the cells and paste then as only values. This step eliminates the equations that represented the individual cells from the intensity calculations. Next, the data needs to be transferred to a new spreadsheet. This step is essential otherwise ArcMap will not recognize all of the columns in the spreadsheet. The final step is to turn the document into a Dbase 4 (.dbf) file. Highlighting the desired region and going to save as Dbase 4 will do this. This enables the file to be imported into Arc Map.

ArcGIS Processing:

The following are the steps and procedures necessary for converting the raw data into the final maps used for interpretation and analysis. These steps were used to make both the predicted and measured intensity maps. All of files worked with, have the geographic coordinate system North American 1983. The resulting positions are in latitude and longitude.

Importing X, Y:

The first step was to import the intensity data into a base map consisting of the US states and counties. Using the Add X, Y data under the tools tab, the locations and corresponding intensities were brought into the ArcMap. At this point a window pops up asking for X, Y values. For these latitude and longitude
were selected as the X, Y coordinates. This process left the series of points with full attribute information as seen in Figure 7.

Inverse Distance Weighting:

Once the points with Z information were inputted, a surface can be made using the inverse distance weighting function in the geostatistical wizard. Inverse distance weighting creates a surface by taking the inverse distance to known Z values and using those as powers to weight the values from surrounding waypoints. The specifications for the inverse distance weighting can be seen in Figure 8. Inverse distance weighting seemed like the most appropriate method given distance versus intensity has a relatively linear relationship. This process was done for both the predicted and measured intensities. Both of the intensities originated from the waypoints.

Exporting As Raster:

After a surface depicting intensity was in existence, it needed to be classified. This was accomplished was by choosing export to raster in the TOC of the layer. The resulting figure is a gray scale raster of showing intensity. This was done for both the predicted and measured rasters.

Reclassifying Raster:

Once the rasters were created, they needed to be classified in a way that showed the data meaningfully. While a continuous scale of Mercalli Intensities are useful, the most common way of viewing them is in terms of whole numbers going from zero to twelve. To accomplish this, the classify tool in geospatial analyst was used. By hitting the classify button in this window, the division values can be manually set. These values were set at one number increments starting at the nearest half division after the minimum value (e.g. min =1.32, then breaks at 1.5, 2.5, etc.). After the divisions were set their values were classified according to the corresponding whole number (e.g. 1.5 to 2.5 = 2). By doing this, the raster becomes contoured with whole number bands representing different intensity levels. Both rasters were reclassified.

Calculating Difference:

Because the project involved comparing predicted versus measured intensities, a way to compare them had to be developed. Using raster calculator
in the geospatial analyst extension, the measured raster was subtracted from the predicted raster. The resulting raster showed the difference in intensities of the proposed earthquakes.

Shapefiles:

Many of the original shape files had to be digitized or otherwise modified to suit the purposes of the investigation. The first step was to digitize the outline of both Lane County and Oregon. This was accomplished by using the existing shape files as a guide with the editor extension. In the editor extension, create new feature was used to make a new polygon shapefile that represented the boundaries of Oregon and Lane County. The new shapefiles have the same geographic coordinate system as their mother files.

The second modification of the existing shapefiles was in the form of clipping them. Once boundaries had been digitized, they could be used to clip data to. Using the clip to feature in the geoprocessing wizard, counties of the USA were clipped to just show the ones in Oregon. The same tool was also used to clip the raster to show only the values represented in Lane County.

The last modification of shape files was symbolizing certain features in them. This was done in the symbology tab under properties in the TOC. This allowed Lane County to be defined relative to the rest of the counties in Oregon.

Analysis, Interpretation, and Discussion:

The resulting maps from the project show bands of intensity correlating with the Modified Mercalli Index. Two maps were produced (see Figure 9). One of them shows the intensities resulting from an earthquake with a magnitude of 8.037. This earthquake is referred to as the measured earthquake because it is the one resulting from measurements made of unbroken fault lengths. The
The results above show that Oregon is at risk given a major earthquake off of its coast. Predicted results show a range of Mercalli values from nine in the second map is based off an earthquake with a magnitude of 9+. This magnitude is from USGS literature that gives the possible size of the predicted event. In either case, a large devastating quake is predicted.

The raster values in the maps are based off the Modified Mercalli Index. This index reflects the felt intensities at any given spot. The scale spans from one to twelve. One being a quake that most people will not know occurred and a twelve being total annihilation of all structures. The entire index can be viewed in Figure 10.
northwest corner to three in the southeast. A Mercalli value of nine correlates with cracked ground and significant damage to large buildings and foundations. The values for the measured equation are slightly less ranging from two to eight. Lane County fits right into the middle of each of the spectrums, ranging from five to six on the measured and six to seven on the predicted. These values border or exceed the previously stated cutoff. It would be fair to conclude that no matter which earthquake occurs, Lane County has reason to be worried. While devastating destruction is unlikely, the resulting damage would be enough to cause disturbances in everyday life.

Intensities resulting from the measured event indicate that there is risk of earthquake damage in Lane County. The contours representing a Mercalli intensity of five and six bisect the county (see Figure 11). Figure 11 clearly shows that in the case of the measured event only the western half of the county exceeds the cutoff intensity.

In the event of the predicted earthquake, Lane County would experience intensities of six and seven. Figure 11 shows where these contours cross through the county's eastern half. An intensity of seven, that most of Lane County would experience, equates to structural damage depending on the quality of construction.

**Figure 11: On the left are the measured intensities for Lane County. The map on the right shows predicted intensities. Just to note, while the color scheme is the same for both maps they represent different values.**

**Conclusions:**

In terms of predicting potential intensities for Lane County the project was a success. The other part of the project was somewhat less successful. The earthquake that was calculated based off of the fault lines does not correlate with the ones described in the literature. The average difference between the two was 1.37 Mercalli units. Figure 12 shows the differences between the intensity maps. The surface showing the difference is partially transparent and layered over the predicted surface. This was done to show how the error correlated to the different intensity contours. Where the dark blue bands are, the difference is two and where the color comes through, the difference is one.
There are several pitfalls involved in this project. The first is there are an infinite number of real life variables that the project did not take into account. Some of these include rock type and soil saturation. Both of these factors could influence the strength and damage done in the event of an earthquake. In terms of concern for the residence of Lane County there is also a list of other related events that could wreak havoc. These include but are not limited to tsunamis and landslides.

Figure 12: Shows the difference between the predicted and measured layers. To show how the difference correlates to the intensity contours, the difference layer is shown partially transparent and overlaid on the predicted layer.

There is also inherent error in the equations and calculations used. The equations are designed to model earthquake intensities based off of past events. It has to be remembered that it is just a model. To date there is no way to exactly predict the strength of earthquakes. Another potential error in the calculations is with the original positioning of the event. While a general area can be hypothesized, exact positioning can only happen after the event occurs.

There were also some problems in the calculations. The biggest one occurred when trying to input Dbase 4 tables into ArcMap. The program was only reading the position data and missed the attribute data occupying the rest of the table. To remedy this, the table had to be pasted into a new spreadsheet as values only. This removed all associated equations and formats, and allowed the file to be resaved as a Dbase table and inputted into ArcMap.

To improve the study, two things should happen. First, find a way to include more variables to represent the intensity figure. By using rock types and surficial units, intensities would be more accurate. The second improvement would be to use a smaller grid size. This would create smoother contours and would show the intensities surrounding the epicenter with a better precision.

References:

Harvard Centroid Moment Tensor Catalog: <http://www.seismology.harvard.edu/CMTsearch.html>

Pacific Northwest Seismograph Network:
<http://www.pnsn.org/HAZARDS/CASCADIA/cascadia_zone.html>

USGS PDF “CascadiaEQs”:
<www.pnsn.org/CascadiaEQs.pdf>