OKLAHOMA EARTHQUAKE FREQUENCY, INTENSTY & SPATIAL VARIABILITY ANALYSIS

GEO 386G FINAL PROJECT

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INTRODUCTION

Seismologists and emergency management professionals are responsible for assessing risks and identifying potential earthquake hazards. The purpose of this project is to identify areas in the state of Oklahoma that have been at risk for earthquakes. By using data from the Oklahoma Geological Survey (OGS), the density, frequency and spatial variability of earthquakes are analyzed from the years 1980-2017. Data that is gathered from the OGS is implemented within ArcGIS and is used to preform hotspot analysis. This will be used to create maps that dictate areas that historically have the highest concentration of earthquakes with large magnitudes.

The question: Historically, how has the frequency, intensity and spatial variability changed for earthquakes in Oklahoma recorded in 1980 to 2017?

The hypothesis: There will be an observable increase in frequency, intensity and shift in spatial variability from earthquakes along major fault lines.

DATA COLLECTION

Border:

The data downloaded for the Oklahoma state border was sourced from the United States Census Bureau website. The download will contain a shapefile of the United States. In order to have Oklahoma as its own shapefile, we have to select Oklahoma in the attribute table under "Name" and export the selected data.

Faults:

The fault data was from the Oklahoma Geological Survey Fault Database website. Open-File Report name: OF2-2016 from the *Comprehensive Fault Database and Interpretive Fault Map of Oklahoma*, by Stephen Marsh and Austin Holland. From the Open-File report we can download the shapefile of the faults. The faults shown here in Figure 1 represent one interpretation of all the faults in the Oklahoma Fault Database being compiled by the OGS.

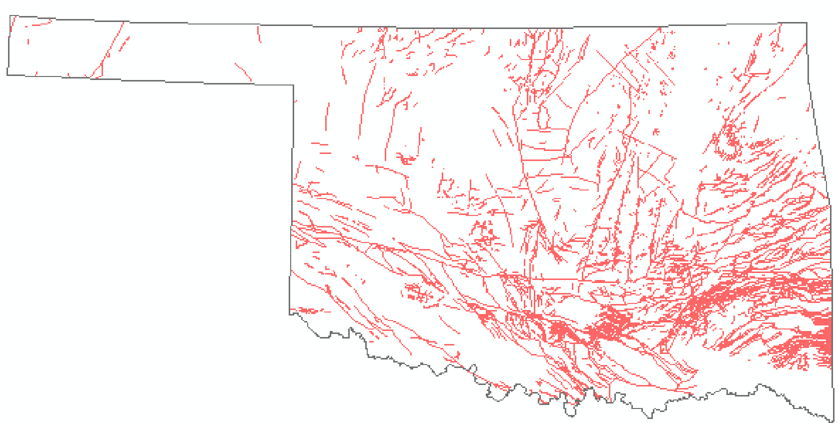

Figure 1. Oklahoma Border with Faults

Earthquakes:

The earthquake data was from the Oklahoma Geological Survey Earthquake Catalogs website. Each earthquake is accompanied by detailed information regarding its location and size indicated by the Catalog Header Descriptions. (See table 1 for data used)

Category	Description
origintime	Estimated date and time of the earthquake
latitude	Estimated latitudinal coordinate of the earthquake epicenter
longitude	Estimated Longitudinal coordinate of the earthquake epicenter
prefmag	Preferred magnitude

Table 1. Catalog Header Descriptions

Projection and Datum consistently used for all data files.

Projected Coordinate system: NAD 1983 2011 StatePlane Oklahoma North FIPS 3501 (meters)

Datum: D_North_American_1983

ARCGIS PROCESSING

The main focus for this project is to observe the concentration of high magnitude earthquakes within Oklahoma. Thus, utilizing the "Optimized Hot Spot Analysis" tool in ArcToolbox will provide the proper analysis for this. A Hot spot analysis is a way of finding the hot and cold spots in the data using the Getis-Ord Gi* statistic (i.e. a positive z-score means a clustering of high values where as a negative z-score means a clustering of low values). The input data needs to be points or polygons. There is also the choice of using the Hot Spot Analysis (Getis-Ord Gi*). Here we will use the Optimized Hot Spot Analysis, because it pre-sets some parameters based on your data. This tool needs a minimum of 30 data points and works best with large sets of data. So I ran the Hot Spot Analyst for merged datasets: 1980-1989, 1990-1999, 2000-2009, 2010-2017. In order to analyze the data by decade, the data from each year needs to be merged.

Steps for merging datasets:

1. Open ArcToolbox and go to Data Management Tools>General>Merge
2. **Input Datasets:** Select the datasets to merge (ex. 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017)
3. See figure 2 for visual description
4. **Output Dataset:** Indicate where you want to save your new file

5. Click OK
6. Repeat 1-5 for 1980-1989, 1990-1999, 2000-2009

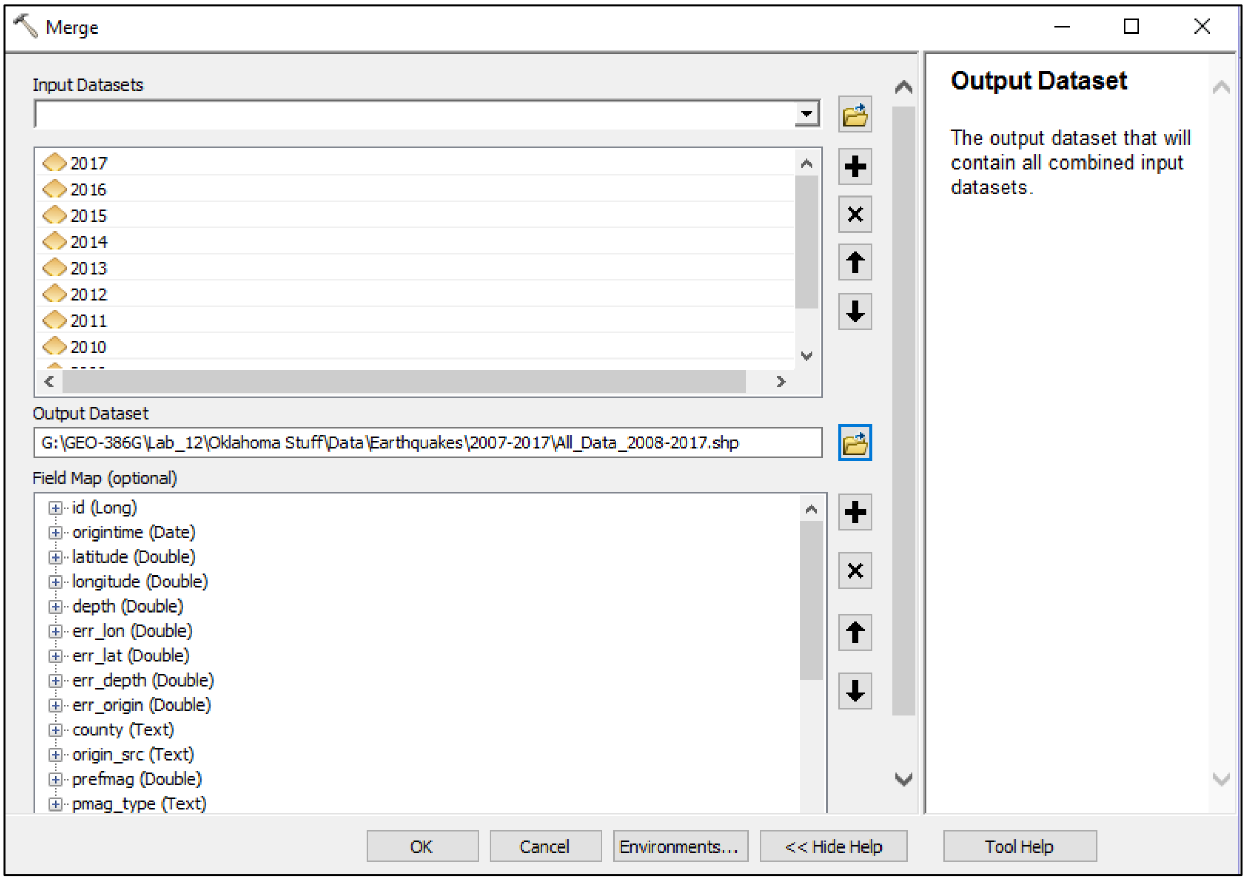

Figure 2. Screen Capture of Merge inputs

Steps for using the Hot Spot Analyst tool:

1. Open the tool by going to Spatial Statistic tool set>Mapping Clusters>Optimized Hot Spot Analysis
2. **Input feature:** Point data for the earthquakes from a specified year (ex. 2017)
3. **Output feature:** Indicate where you want to save your new file
4. **Analysis field:** Some measurement that happens at those points (ex. prefmag)
5. **Incident Data Aggregation Method:**
    - We don't need to specify an aggregation method since we've chosen an analysis field
6. See figure 3 for visual description
7. Click OK to run the tool
8. For the purpose of this project repeat 1-7 for the datasets 1980-1989, 1990-1999, 2000-2009, 2010-2017

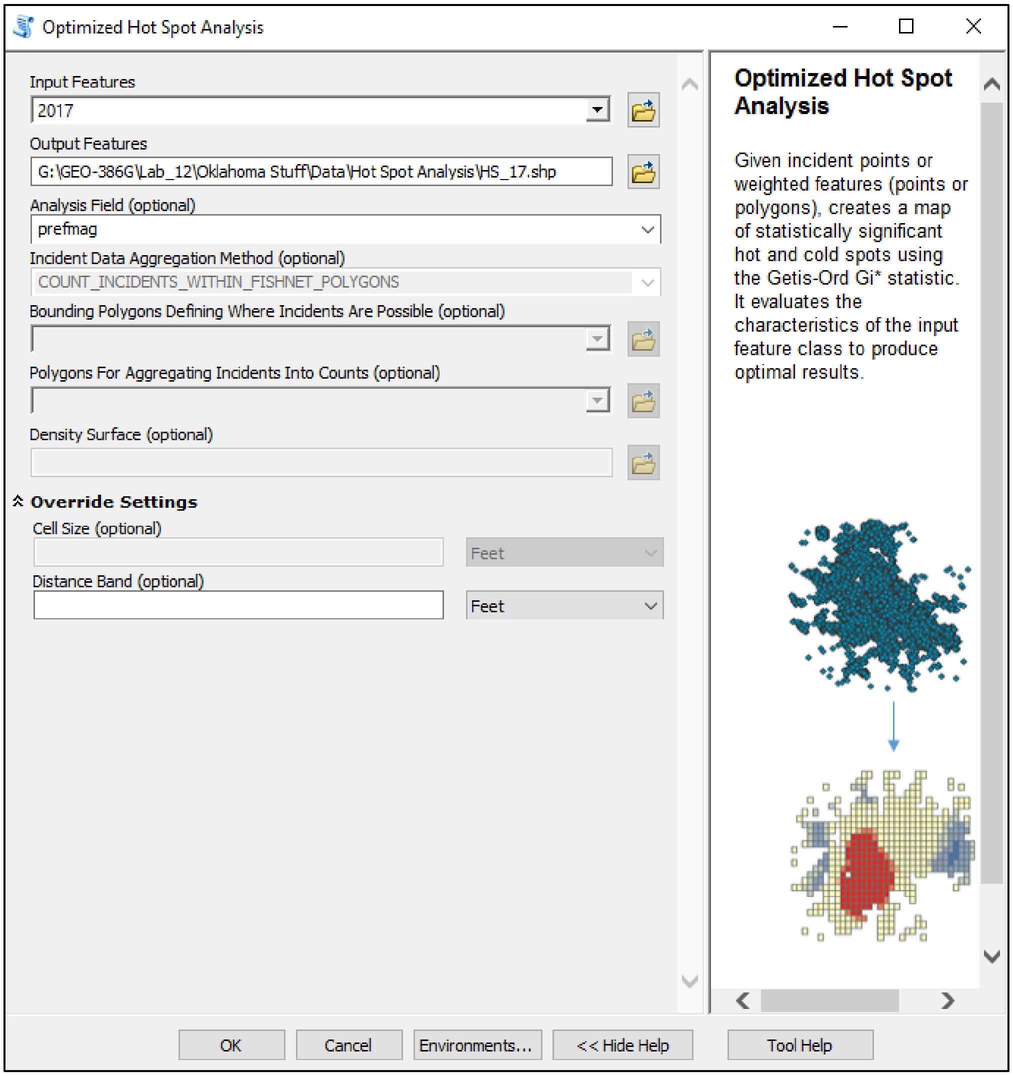

Figure 3. Screen Capture of Optimized Hot Spot Analysis tool inputs

When you expand the results for the layer that gets added automatically from the Hot Spot Analysis (HSA) it comes already symbolized (see figure 3.1).

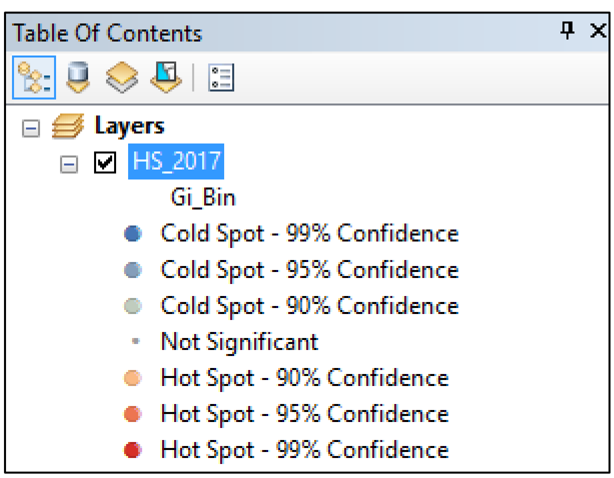

Figure 3.1. Expanded layer results from HSA

The data includes a new attribute field called **Gi_Bin** which shows the statistical significance/confidence interval of the data. It ranges from red for a hot spot down to blue for a cold spot and yellow points are not significant. Specifically, features in the +/-3 bins reflect statistical significance with a 99 percent confidence level; features in the +/-2 bins reflect a 95 percent confidence level; features in the +/-1 bins reflect a 90 percent confidence level; and the clustering for features in bin 0 is not statistically significant. The results show the hot spots for the most intense earthquakes in Oklahoma from 2017 (see figure 4).

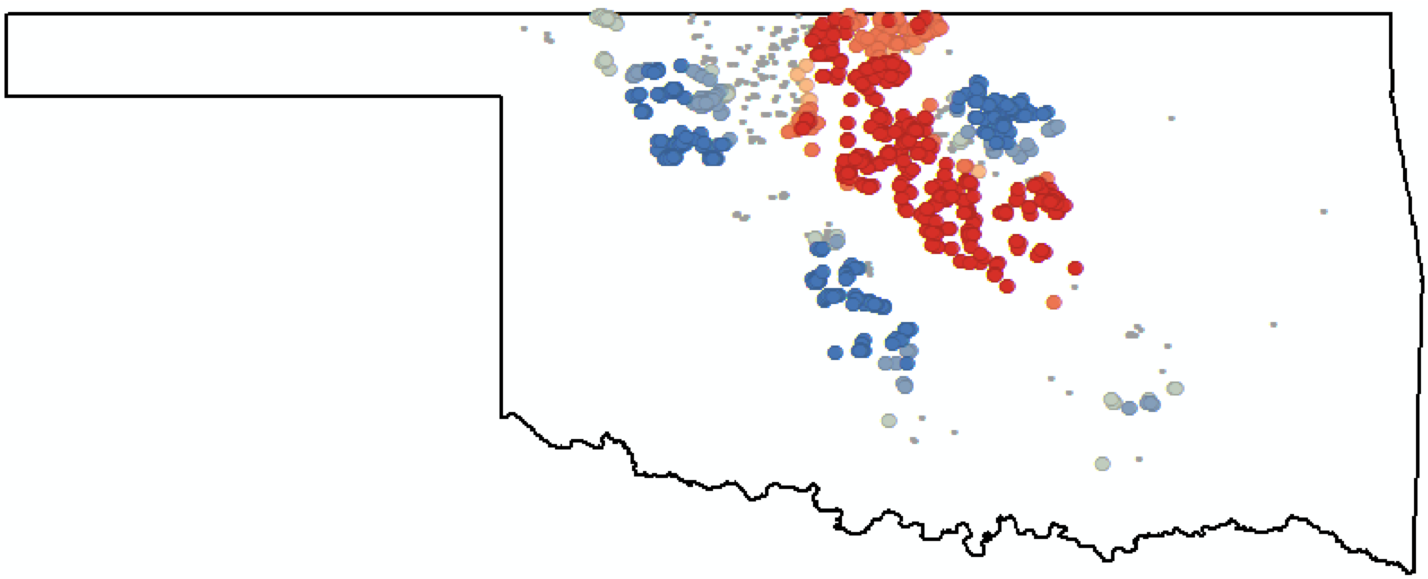

Figure 4. Hot Spot Analysis results from 2017

The results show points were these points seen in figure 4 and we don't get a continuous surface. To get a full picture we need to now run an IDW to interpolate a raster surface from the Hot Spot analysis points using an inverse distance weighted (IDW) technique.

Steps for using the IDW tool:

1. Open ArcToolbox go to Spatial Analyst Tools>Interpolation>IDW
   - Don't forget to turn on the Spatial Analyst extension
2. **Input point features:** Hot Spot Analysis results (ex. HS_80_89)
3. **Z value field:** Gi_Bin
4. Accept all the defaults (see figure 5 for visual description)
5. Click OK to run the tool
9. Repeat for Hot Spot Analysis from 1990-1999, 2000-2009, 2010-2017

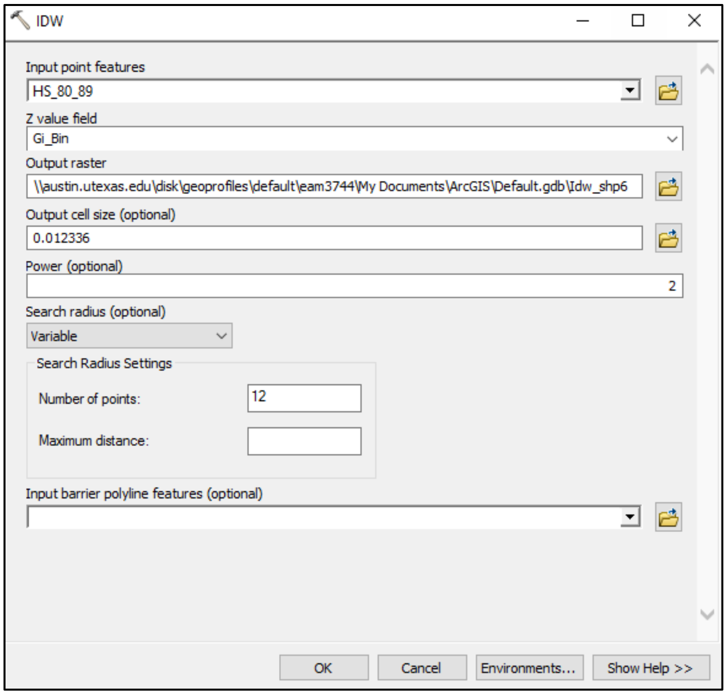

Figure 5. Screen Capture of IDW tool inputs

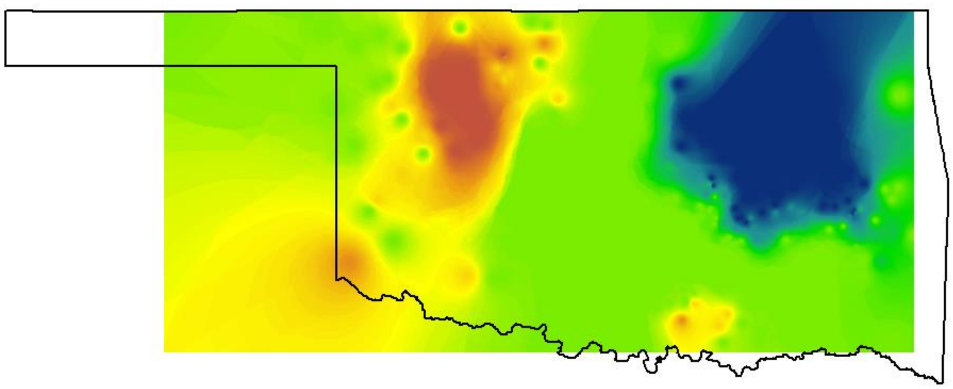

Figure 6. IDW Results for 1980-1989

The results, figure 6, show extraneous interpolation beyond the border that is not needed. In order to focus on information within the state the clip tool is used.

Steps for using the Clip tool:

10. Open ArcTool box and go to Data Management tools>Raster>Raster Processing>Clip
11. **Input raster:** Raster you want to clip (ex. IDW_80_90)
12. **Output Extent:** Raster dataset to use as extent (ex. Border)
13. **Output Raster Dataset:** Indicate where you want to save your new file
14. Check **Use Input Features for Clipping Geometry**
15. Accept all the defaults (see figure for visual description)
16. Click OK
17. Repeat for IDW technique from1990-1999, 2000-2009, 2010-2017

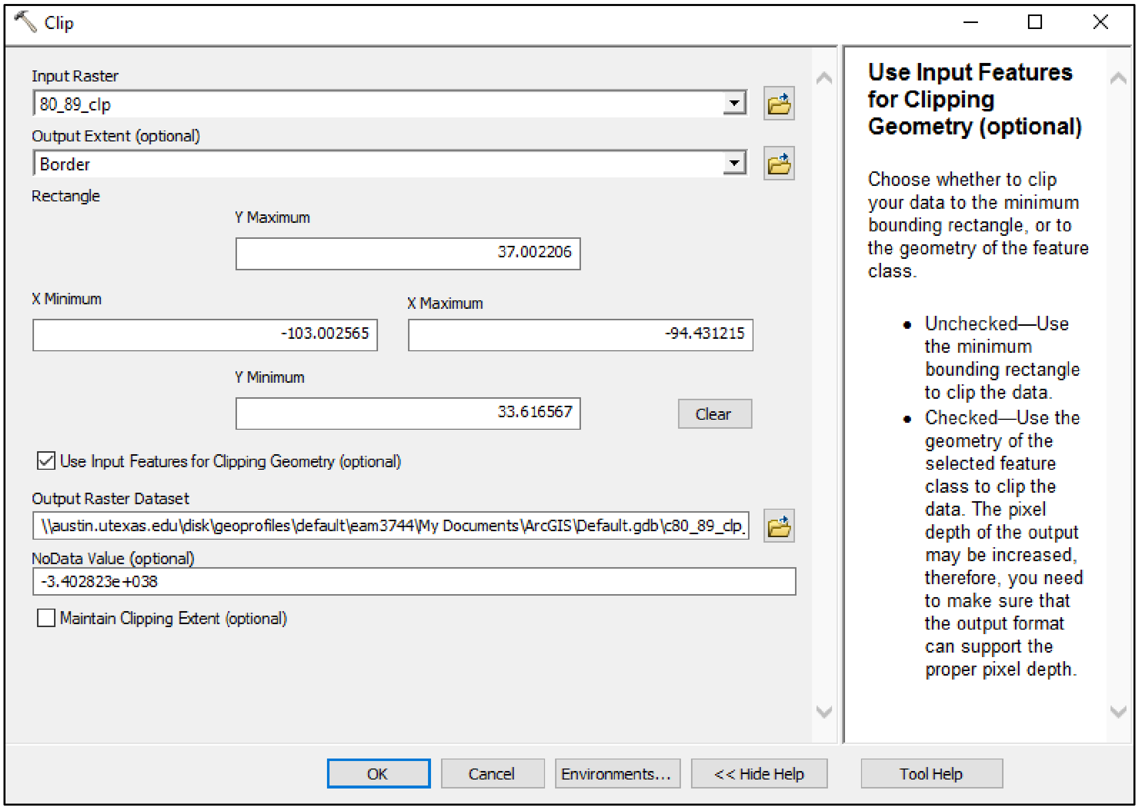

Figure 7. Screen Capture of Clip tool inputs

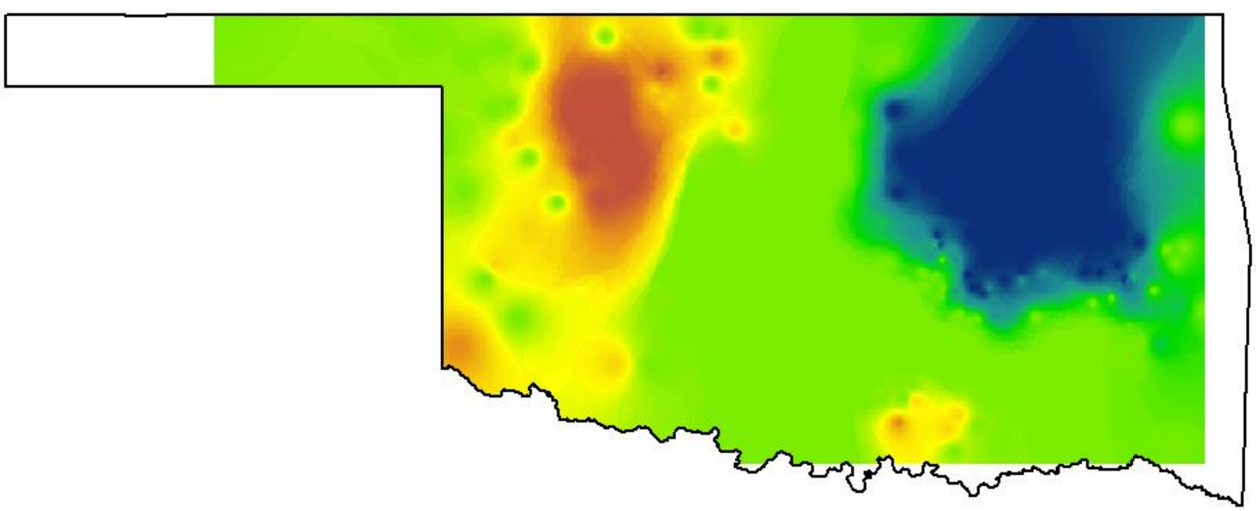

Figure 8. Screen Capture of Clip tool Results for 1980-1989

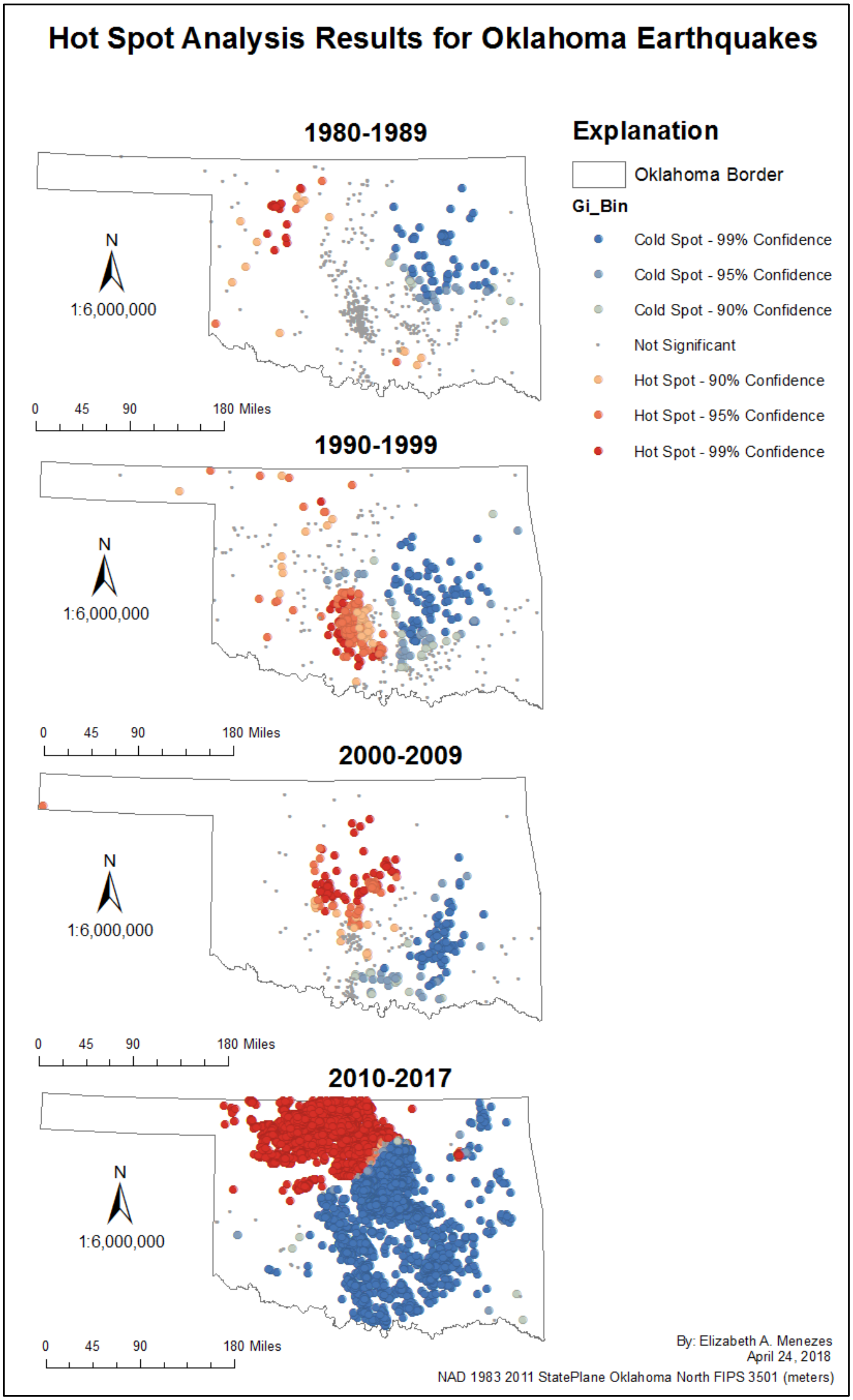

Figure 9. Hot Spot Analysis Results for Oklahoma Earthquakes

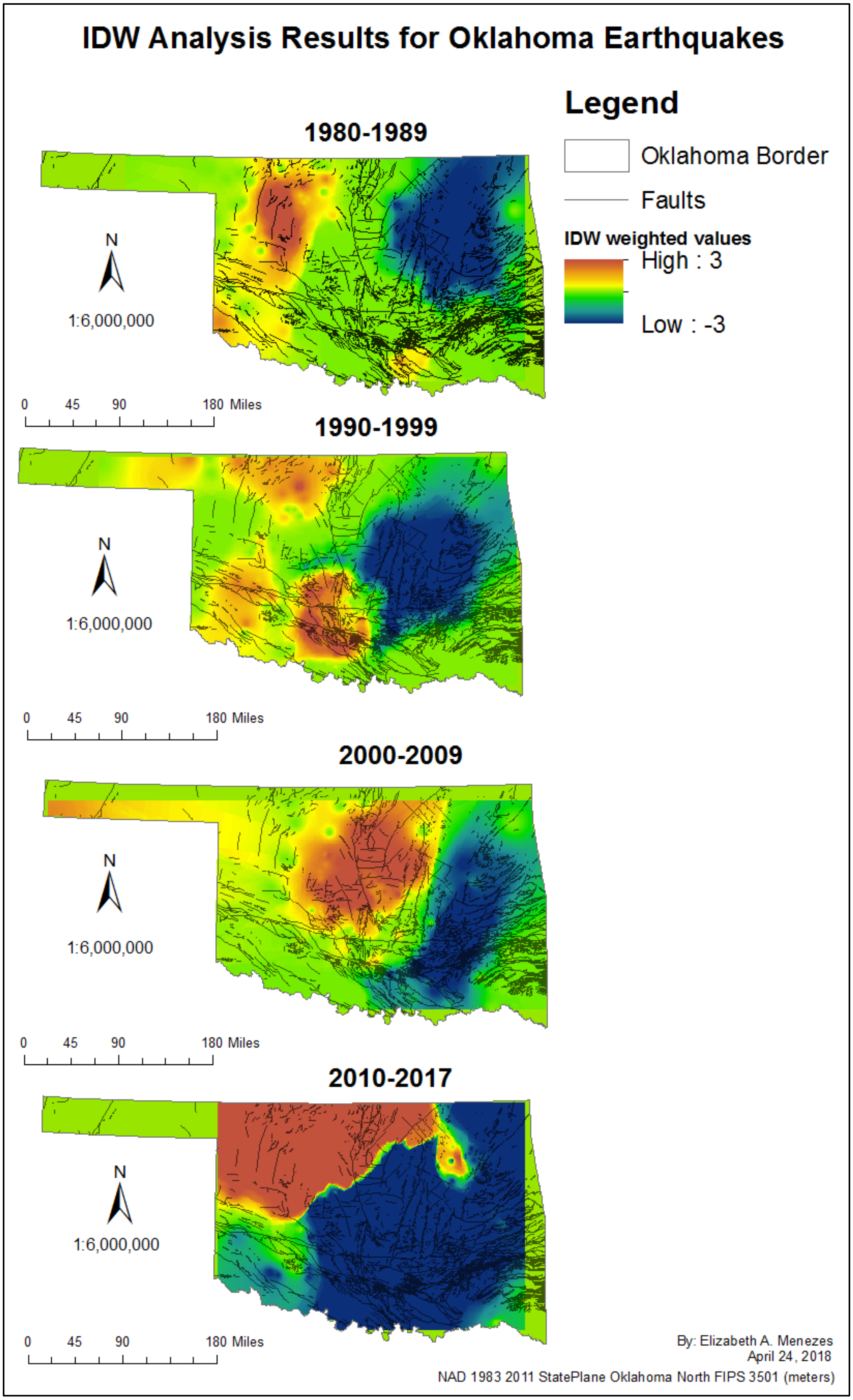

Figure 10. IDW Analysis Results for Oklahoma Earthquakes

Definitions to help understand the results and conclusions

Gi_Bin – calculated confidence interval producing statistically significant intervals from the data. The features in the +/-3 bins reflect statistical significance with a 99 percent confidence level; features in the +/-2 bins reflect a 95 percent confidence level; features in the +/-1 bins reflect a 90 percent confidence level; and the clustering for features in bin 0 is not statistically significant.

Hot Spot Analysis (HSA) – calculates the frequency of the top and bottom 10% and of the earthquakes in the dataset by their magnitudes and marks those points accordingly.

Inverse Distance Weighted technique (IDW) – An interpolation technique that estimates cell values in the Hot Spot Analysis raster from a set of sample points (the Gi_Bin) that have been weighted so that the farther a sampled point is from the cell being evaluated, the less weight it has in the calculation of the cell's value.

Moment magnitude (Mw) – a new scale that characterizes the size of earthquakes similar to the Richter Scale. This scale retains a continuum of magnitude values similar to that defined by the Richter scale.

Negative magnitude – Magnitude calculations are based on a logarithmic scale, so a ten-fold drop in amplitude decreases the magnitude by 1. An earthquake of negative magnitude is a very small earthquake that is not felt by humans.

Richter Scale Magnitude (ML) – "Local Magnitude Scale" a number that characterizes the relative size of an earthquake based on measurement of the maximum motion recorded by a seismograph based on a logarithmic scale.

Quantitative results from the Hot Spot Analysis and IDW tools for each time interval

1980-1989: Using the statistics Frequency Distribution graph of the Gi_Bin in figure 11, the highest frequency earthquakes are between magnitude -0.5 and 0.3. The highest positive magnitude earthquakes are 2.8 and a count of less than 100 earthquakes.

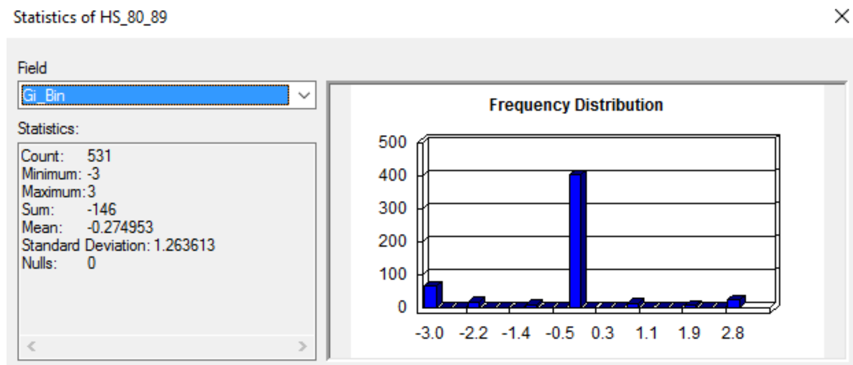

Figure 11. Statistics of the HSA for 1980-1989

1990-1999: Using the statistics Frequency Distribution graph of the Gi_Bin in figure 12, the highest frequency earthquakes are between magnitude 1.7 and 2.4. The count is about 300 earthquakes.

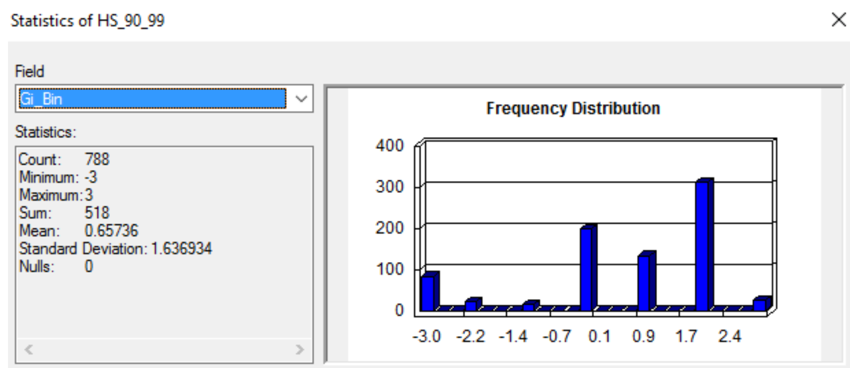

Figure 12. Statistics of the HSA for 1990-1999

2000-2009: Using the statistics Frequency Distribution graph of the Gi_Bin in figure 13, the highest frequency earthquakes are between magnitude -0.4 and 0.5 at a count of about 125 earthquakes. The highest positive magnitude earthquakes are greater than 2.3 and a count of about 50 earthquakes.

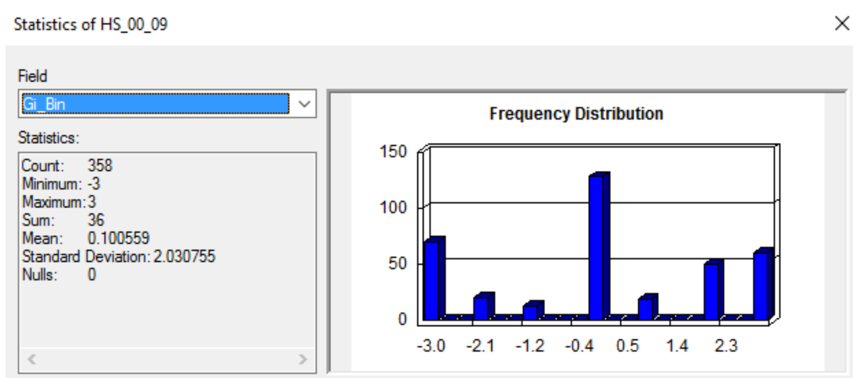

Figure 13. Statistics of the HSA for 2000-2009

2010-2017: Using the statistics Frequency Distribution graph of the Gi_Bin in figure 14, the highest frequency earthquakes tie between around 13,500 earthquakes at either magnitude -3.0 or greater than magnitude 2.7.

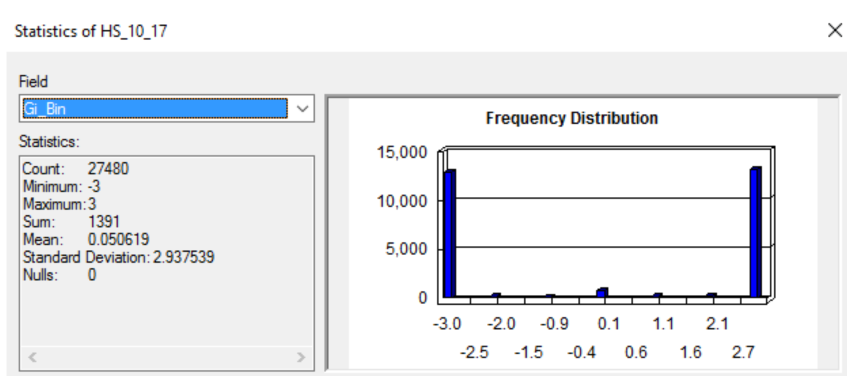

Figure 14. Statistics of the HSA for 2010-2017

Conclusions

The purpose of this project is to determine how the frequency, intensity and spatial variability changed historically for earthquakes located in Oklahoma from 1980 to 2017. In order to quantify the frequency and intensity through the decades a Hot Spot Analysis was performed to a dataset within each decade. Then an IDW technique interpolated the data from the Hot Spot Analysis to produce a smooth surface to visually display the highest and lowest concentration of high and low magnitude earthquakes as well as their spatial variability from decade to decade. The results from the statistics graphs in figures 11-14 indicate that there is an increase in the frequency of high magnitude (greater than 2) earthquakes from 1980 to 2017. There also an increase in the number of negative and low magnitude earthquakes as well. From the IDW Interpolation map in figure 10, the spatial variability of the region with the highest concentration of high magnitude earthquakes shifted north.

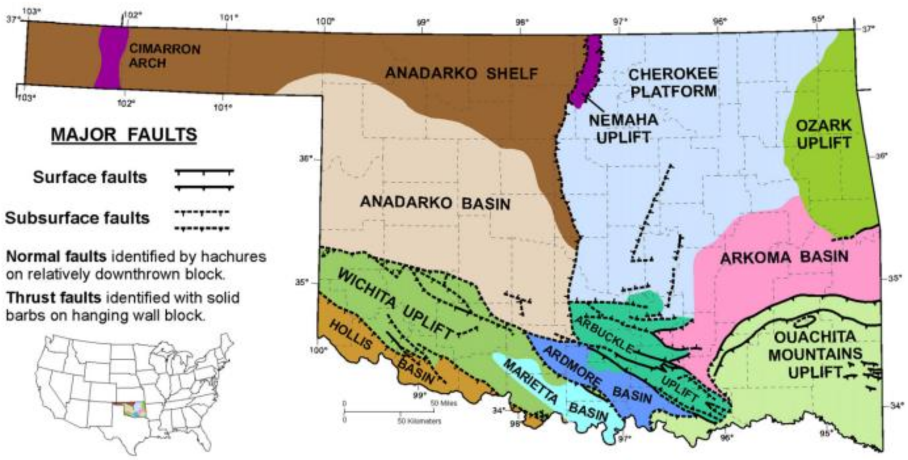

Figure 15. Geologic Provinces of Oklahoma (modified from Northcutt and Campbell, 1998)

Initially, it was assumed that the major earthquakes in Oklahoma would be located along major fault lines such as the Wichita, Arbuckle and Ouachita Mountains Uplift. However, results from this project indicate that the highest activity of high magnitude earthquakes occur within the Anadarko basin, figure 15. In the IDW map for 2010-2017, figure 10, we see a widely spread hotspot of earthquakes in the region of the Anadarko basin. Between 2010 and the end of 2012, the industry "added 169,000 jobs nationwide, growing at a rate about ten times that of overall U.S. employment" (Brown, 2013). It is interesting to see how the development of hydraulic fracturing and industry operations have affected this region in Oklahoma.

Issues and Further Studies

The data used from the Oklahoma Geological Survey indicated that the earthquakes were recorded on a mix between moment magnitude and Richter magnitude scales. In further studies, I would standardize the data so that the earthquakes are all on the same scale to get a more accurate representation of. Also, the earthquake data included in this project contain negative magnitudes. Negative magnitudes cannot be felt by people. So, in future studies I would remove these values form the attribute table in order to narrow the scope of magnitudes to only positive intensities.

RESOURCES

Internet Links

- Oklahoma Border: https://www.census.gov/geo/maps-data/data/cbf/cbf_state.html
- Fault Data: http://www.ou.edu/ogs/data/fault
- Earthquake Data: http://www.ou.edu/ogs/research/earthquakes/catalogs
- USGS FAQ: https://www.usgs.gov/faqs/how-can-earthquake-have-a-negative-magnitude?qt-news_science_products=7#qt-news_science_products

Article

Brown, S., and Yucel, M., 2013, US Shale Gas and Tight Oil Boom - The Opportunities and Risks for America: SPE Asia Pacific Oil and Gas Conference and Exhibition, doi: 10.2118/165770-ms.

Journal

Cardott, B.J., 2012, Thermal maturity of Woodford Shale gas and oil plays, Oklahoma, USA: International Journal of Coal Geology, v. 103, p. 109–119, doi: 10.1016/j.coal.2012.06.004.