Analysis and experimental forecasting of earthquakes in the US

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Abstract : The project covers an in-depth analysis of earthquake patterns in the United States, spanning area, year, and the top five earthquakes recorded in the country from 2000 to Feb 2023. The study involves collecting and analysing historical data, as well as employing experimental approaches to forecast future earthquakes. For time series forecasting of earthquake data, this study makes use of ARIMA, Exponential Smoothing, and LSTM models. The goal is to get a better knowledge of the origins and effects of seismic activity, as well as to develop forecasting tools to assist in mitigating the effects of earthquakes on infrastructure and communities. The study's findings will help to improve understanding of earthquake trends in the United States, as well as support the creation of effective disaster mitigation and management policies and methods.

Keywords - *Earthquakes, time series analysis, clustering, forecasting, Machine Learning.*

1. Introduction

The natural disasters that regularly occur on our planet include floods, tornadoes, tsunamis, volcanic eruptions, earthquakes, and storms, among others. It seriously harms both nature and all living things. It is irregular and unpredictable. The Earthquake, usually called a quake or a tremor, is one of the perilous calamities. If there is a dense population, there is tremendous harm.

An earthquake is a natural occurrence that happens when the earth's crust suddenly moves or shakes. The energy that has accumulated over time as a result of the movement of tectonic plates is released during this shaking. Large plates that are part of the earth's crust sit on top of the mantle below, which is molten. Over time, these plates move very slowly, and when they collide, pressure builds up along the fault lines where the plates meet. Other factors, such as landslides, volcanic activity, and human activities like underground mining or the building of major dams, can also produce earthquakes.

To better understand their causes and foretell when they might happen, seismologists research earthquakes. This information is crucial for enhancing earthquake preparedness and reducing the damage and casualties brought on by earthquakes. The US has suffered several earthquakes of varied magnitude since 2000, some resulting in severe damage and fatalities. In this capstone report, we will examine the frequency, magnitude, location, and other pertinent factors of the earthquakes that have occurred in the US throughout this time period. We intend to learn more about the trends and patterns of earthquakes in the US.

To help with a more in-depth analysis of the data and draw insightful conclusions, a variety of fundamental visual representations, including bar charts, line charts, and tables, among others, were created. In order to fully understand historical trends, studies of time series and geographic data were also performed. Furthermore, we also conducted experimental forecasting. Currently, earthquake prediction with a high degree of accuracy and precision is not possible. and is an intricate problem, experimental earthquake forecasting is currently a subject of research in seismology.

Earthquakes occur due to complex and unpredictable geological processes, and there is no known method to predict when and where they will occur with certainty. However, scientists are continuing to conduct research and develop new methods to improve our understanding of earthquake occurrence and potentially predict them in the future. Additionally, it is important to focus on earthquake preparedness, such as building resilient infrastructure and emergency response plans, rather than relying solely on prediction.

2. Motivation and Literature Review

Natural disasters like earthquakes have the potential to seriously harm infrastructure, harm people, and severely damage communities. Because of the numerous active fault lines that are spread throughout the country, the United States is particularly vulnerable to earthquakes. The study aims to uncover patterns and trends in seismic activity by analysing earthquake data gathered from 2000 through 2023. By examining these patterns, scientists can better understand the causes of earthquakes and create forecasting models that are more precise in predicting future seismic events.

Also, the project seeks to raise earthquake safety knowledge among the general public. Researchers can identify regions that are more vulnerable to seismic activity and alert the public to possible dangers through the study of earthquake data. This is necessary because after effects of earthquakes can lead to landslide, tsunami, surface faulting and ground failure as given in [1].

The research paper [2] emphasizes the significance of taking ground motion's non-uniformity into account when evaluating earthquake risks and hazards. Moreover, it highlights the requirement for improved modelling and monitoring of earthquake sources and their impacts on ground motion. The results of this study can assist Alaska and other areas with comparable geological circumstances estimate earthquake risk and take mitigation measures.

The source features and seismotectonic background of the Ridgecrest earthquake sequence are well-explained in [3]. The findings have important implication for estimating earthquake risks and reducing them in California and other places with comparable geological characteristics.

The research paper [4] provides important information about several regions susceptible to earthquakes of the United States. The authors define the seismically active locations and discuss the different kinds of earthquakes that are usually observed in these places. They additionally explore how earthquakes affect various sorts of infrastructure, such as dams, bridges and buildings.

Lastly, the initiative is driven by the chance to further ongoing seismic research. Even though there has been a lot of progress in our knowledge of the seismic activity, there are still a lot of open concerns regarding how earthquakes behave. The initiative aims to further our understanding of earthquakes and strengthen our capacity to anticipate and lessen their effects.

3. Data

3.1. Dataset Description

This data is obtained from the United States Geological Survey (USGS) website https://earthquake.usgs.gov/earthquakes/search/, one of the top experts on seismic activity in the country. The USGS keeps an extensive database of US earthquakes that is frequently updated with the most recent data. All US earthquakes between 2000 and 2023 (till February) having a magnitude of 2.5 or higher are included in our dataset. This covers both naturally occurring earthquakes and those brought on by human activities, like fracking or mining. The location, magnitude, and date of each earthquake that happened in the United States during this time are all included in this dataset.

In order to better understand the patterns and trends of earthquakes in the US, including their frequency, magnitude, location, and other important characteristics, we are undertaking this investigation.

In addition to earthquake source characteristics, the ANSS[2] Comprehensive Earthquake Catalog (ComCat) also contains various products produced by contributing seismic networks (such as moment tensor solutions, macro seismic data, tectonic summaries, and maps) (such as hypocentres, magnitudes, phase picks, and amplitudes). Mechanisms The focal mechanism picture provides a visual depiction of the faulting style (a focal mechanism) based on the calculated moment tensor.

The CSV file for the dataset has 22 attributes and 100892 records. The following are relevant attribute[2] fields used for this project:

Attribute	Description
time	When event has occurred
longitude	Decimal degrees longitude.
latitude	Decimal degrees latitude.
depth	Depth of the event in kilometres.
mag	The magnitude of event
magType	The method or algorithm used to calculate the preferred magnitude for the event
nst	The total number of seismic stations used to determine earthquake location.
gap	The stations that have the greatest azimuthal separation (in degrees)
dmin	Horizontal distance between the closest station and the epicentre (in degrees)
rms	The RMS travel time residual with all weights, expressed in seconds.
net	a data contributor's ID
id	A unique identifier for the event
updated	Date of the most recent update to the event
place	area of geography close to the incident
type	seismic event type
horizontalError	Uncertainty regarding the event's reported position in kilometres
depthError	Uncertainty over the event's claimed depth in kilometres.
magError	Uncertainty over the event's claimed magnitude in kilometres.
magNst	the total number of seismic stations utilized to determine this earthquake's magnitude.
status	shows if a person has examined the incident.
locationSource	the station first reported the scene of this incident.
magSource	initially recorded magnitude for this event by the network.

The agencies, teams, and individuals whose information or materials were used in the creation of the report are included under contributors in USGS earthquake reports. The magnitude of an earthquake occurrence is often calculated using many approaches or algorithms that take into consideration various earthquake criteria such as seismic wave amplitude, distance from the epicentre to the recording station, and earthquake type.

3.2. Data Pre-processing

This is the vital initial phase in both data analysis and machine learning. In this phase, we have the following data cleaning steps:

***Data Merging**:* Downloaded three separate data files for conterminous USA, Alaska, and Hawaii. Merged these files into one data file (complete data of all states in the USA)

***Converting and Extracting attributes**:* We extracted the region name from the entire address in the "place" attribute and converted the "datetime" format of the time attribute into "time" and "date" separately.

***Data filtration**:* For this project, we have taken a dataset that is reviewed by humans i.e., "status" value is set to "reviewed".

***Handling "NA" and "Null" values**:* Missing or null values in an earthquake dataset can be particularly troublesome since they could correspond to crucial seismic measures like the earthquake's magnitude or epicentre. The dataset is made full and correct by removing NA and null values, which can produce analytical and modelling outputs that are more trustworthy and insightful.

***Removing irrelevant attributes**:* Here irrelevant means the features that don't offer any meaningful information or have little bearing on how the analysis or model turns out are considered irrelevant. The dataset may be made simpler and the complexity of the analysis or model can be decreased by removing unnecessary features. The below figure shows the dataset before and after pre-processing. Removed

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attributes are: “id”, “status”, “rms”, “updated”, “net”, ”horizontalError”, “magError”, and “depthError”.

Renaming the attributes: At last, we modified the attribute names for easier understanding after completing the procedures above.

The figures 3.1 and 3.2 shows the data before cleaning and data after cleaning and pre-processing. At this stage, our dataset is ready for analysis with 12 significant attributes.

time	latitude	longitude	depth	mag	mag Type	nst	gap	dmin	rms	net	id	updated	place	type	horizontal Error	depth Error	mag Error	mag Nst	status	location Source	mag Source
2003-12-31 T22:01:47.590Z	35.56133	-120.806	7.45	2.59	md	49.0	56.0	0.08649	0.06	nc	nc21328106	2017-01-04 T23:39:23.080Z	9 km W of Templeton, California	earthquake	0.15	0.88	0.1	50.0	reviewed	nc	nc
2003-12-31 T20:17:47.380Z	35.698	-121.1415	5.94	2.92	md	50.0	118.0	0.1045	0.07	nc	nc21328075	2017-01-04 T23:38:57.270Z	7 km NE of San Simeon, California	earthquake	0.15	0.58	0.07	71.0	reviewed	nc	nc
2003-12-31 T20:14:26.600Z	35.69983	-121.1393	5.25	2.89	md	50.0	116.0	0.1063	0.06	nc	nc30500600	2017-01-04 T23:38:46.650Z	7 km NE of San Simeon, California	earthquake	0.13	0.51	0.09	71.0	reviewed	nc	nc
2003-12-31 T16:20:49.550Z	35.586	-120.9825	5.763	2.82	md	14.0	183.0	0.08108	0.13	nc	nc68007512	2017-01-04 T23:37:40.393Z	9 km ENE of Cambria, California	earthquake	0.7	0.63	0.07	13.0	reviewed	nc	nc
2003-12-31 T15:08:06.590Z	33.66216	-91.76866	1.13	2.8	mlg	11.0	235.0	1.208	0.43	nm	nm605328	2016-04-11 T14:26:52.060Z	4 km NNE of Monticello, Arkansas	earthquake	3.8	7.3	0.351	2.0	reviewed	nm	nm
2003-12-31 T10:27:33.590Z	35.5695	-120.8078	3.685	2.99	md	15.0	201.0	0.08829	0.19	nc	nc68007505	2017-01-04 T23:37:01.057Z	9 km WNW of Templeton, California	earthquake	0.7	1.52	0.09	9.0	reviewed	nc	nc
2003-12-31 T09:46:17.690Z	35.53683	-120.8535	6.45	3.33	ml	57.0	49.0	0.04324	0.06	nc	nc21327818	2017-01-04 T23:36:47.340Z	11 km NNE of Cayucos, California	earthquake	0.15	0.48		2.0	reviewed	nc	nc

Figure 3.1. Raw data in excel format.

Latitude	Longitude	Depth	Magnitude	Magnitude_Method	NST	Azimuthal_Gap	D_min	Type	Magnitude_Nst	Location_Source	Magnitude_Source	Region	Date	Time
19.255	-155.437666666667	1.15	2.53	ml	42.0	111.0		earthquake	23.0	HV	HV	Hawaii	2023-02-27	22:58:07
19.4515	-155.2365	28.35	2.74	ml	45.0	71.0		earthquake	22.0	HV	HV	Hawaii	2023-02-27	17:11:05
20.076	-156.165	42.37	3.17	md	43.0	309.0		earthquake	18.0	HV	HV	Hawaii	2023-02-27	10:34:10
19.1763333333333	-155.5115	31.48	2.78	ml	45.0	104.0		earthquake	23.0	HV	HV	Hawaii	2023-02-26	07:23:43
19.185	-155.621166666667	-0.53	2.95	ml	42.0	92.0		earthquake	26.0	HV	HV	Hawaii	2023-02-25	19:36:35
19.2195	-155.387	29.81	2.76	ml	45.0	155.0		earthquake	14.0	HV	HV	Hawaii	2023-02-24	12:53:24
19.2181666666667	-155.387	30.03	3.33	ml	46.0	155.0		earthquake	28.0	HV	HV	Hawaii	2023-02-24	12:51:14
19.239	-155.3815	33.2	2.56	md	40.0	145.0		earthquake	15.0	HV	HV	Hawaii	2023-02-23	22:32:40
19.9041666666667	-155.158333333333	43.59	3.24	ml	45.0	256.0		earthquake	25.0	HV	HV	Hawaii	2023-02-22	14:11:28

Figure 3.2. Transformed data for analysis.

4. Methodology

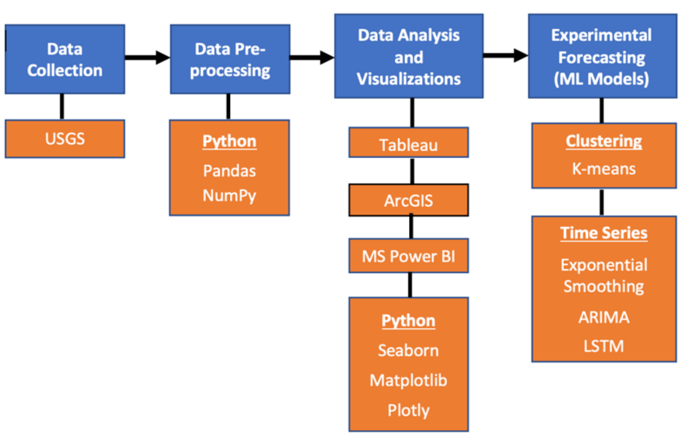

Figure 4. Project phases.

4.1. Analysis and Visualizations

Understanding and predicting seismic events requires a rigorous analysis and visualization of earthquake data. Scientists can build models for earthquake forecasting by analysing seismic data to find trends and patterns in seismic activity. Scientists can better comprehend the intricate connections among earthquakes and geological causes by using visualization tools to convey the data in a comprehensible way.

4.1.1. Overall Trends

The analysis of disaster occurrences that occurred in the USA between 2000 and 2023 is shown in figure 4.1. We can see with clarity that the majority of our data has a high percentage of natural earthquakes roughly 94%. The remaining ones include rock bursts, explosions in mines, and so on. Our examination of the different types of explosives led us to the conclusion that Wyoming exhibits about 34% of explosions and 24% of mining explosion activity. The third graph displays the top 6 geographic areas with the largest explosions, with Wyoming having the largest explosions with a magnitude of 4.8. The highest explosion magnitude as a function of time is depicted in our last graph. 2003 saw a 4.8M explosion, and 2012 saw a 4.5M explosion.

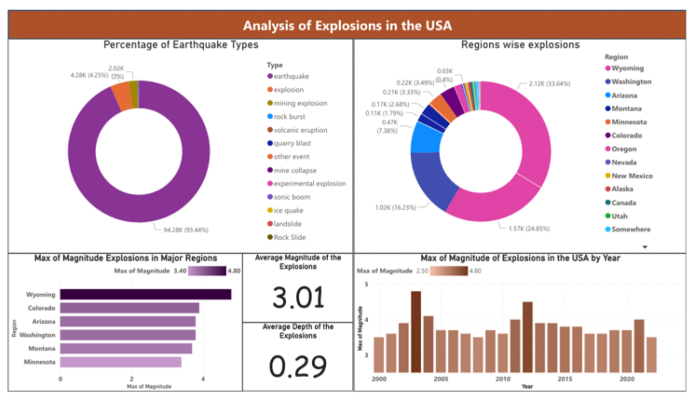

Figure 4.1. Analysis of earthquake types and explosions.

The highest magnitude of each region for each year between 2000 and 2023 is displayed in the figure 4.2. According to this data, Alaska, California, and Mexico are the countries that have experienced big earthquakes with magnitudes of 7.9, 7.1, 7.1, 7.2, and 7.0 in 2002, 2018, 2019, 2010, and 2016, respectively. In the following section, a detailed study of these earthquakes is shown.

Region	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Alabama	3.000	3.900	3.000	4.600	4.300	3.300	2.800	3.000	3.100	3.400	3.200	3.500	2.900	2.900	3.800	3.500	3.000
Alaska	5.800	5.500	7.900	5.400	5.500	5.400	5.400	5.200	5.200	5.900	5.400	5.300	5.800	5.100	6.200	6.400	7.100
Arizona	3.500	3.400	3.500	3.800	2.800	5.100	2.900	3.400	3.700	3.100	3.600	3.800	3.200	3.500	5.300	4.000	3.500
Arkansas	3.900	4.300	2.800	4.000	2.900	4.200	2.800	3.100	2.800	3.000	4.100	4.700	3.900	3.700	3.800	2.980	2.760
Arkansas-O..																	2.700
Bering Strait									3.200	3.300							
Bermuda												4.600					
California	4.900	5.200	5.200	6.500	5.970	5.200	5.000	5.450	5.440	5.190	6.500	4.730	6.300	5.690	6.020	5.720	5.190
California-..	3.130	3.170	3.330		3.610		3.800	3.300	3.730	3.320	4.400	3.500		2.650	2.730	3.400	2.930
California-..										2.900							
Canada	4.700	3.900	4.500	4.200	3.100	4.900	4.200	4.100	3.800	3.600	5.350	3.870	4.500	5.060	3.800	4.790	3.900
Colorado	4.400	4.500	4.300	3.800	4.400	5.000	3.800	4.400	3.400	3.900	3.800	5.300	3.500	3.600	3.800	3.900	4.000
Connecticut															2.660	3.300	
Delaware																	
East Coast			5.400					4.600						4.400			
Florida		3.300															3.800
Georgia	3.500	3.200		3.600	2.500	2.600	2.900	2.600	3.100	3.200	2.600	2.700	2.700	2.800	2.500	2.600	2.510
Gulf of Alas..																2.800	
Gulf of Calif..			4.400	3.500				4.300		4.400		4.300		4.200		5.200	
Gulf of Mex..				3.200			5.900										
Hawaii	5.000	4.900	4.100	5.000	4.500	5.300	6.700	5.400	4.300	4.910	4.700	4.570	4.880	5.300	4.470	5.200	4.720

Figure 4.2. Region-wise maximum earthquakes in each year.

The map shown figure 4.3 displays earthquake points from 2000 to 2023 mapped on top of a USGS earthquake faults layer. The base layer comprises locations and details on faults and related folds that are thought to have caused large earthquakes (those with magnitudes of 6 or higher) over the past 1.6 million years in the United States. An earthquake is the consequence of a movement along a fault, which is a crack or region of cracks in the Earth's mantle along which the crustal blocks have shifted in relation to one another.

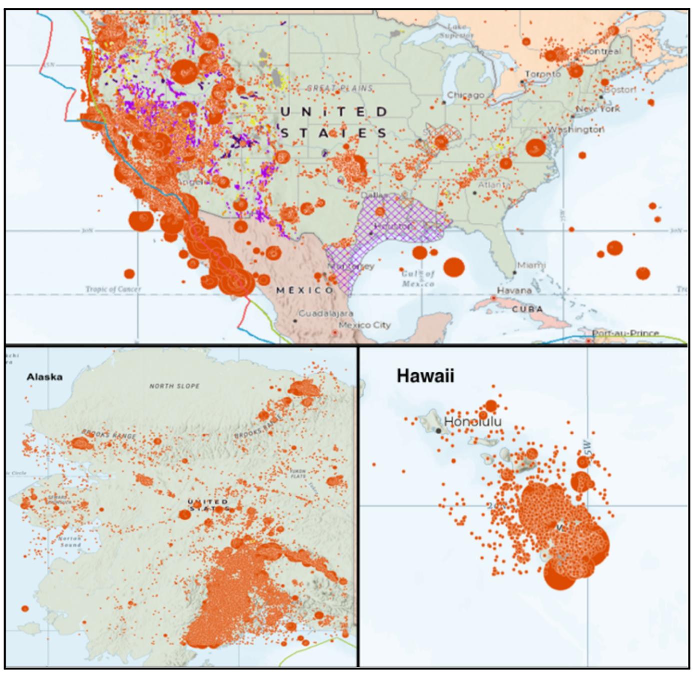

Figure 4.3. USA map showing details of all the earthquakes.

The map shown in the figure 4.4 displays earthquakes of a magnitude greater than 4 on top of a layer that is susceptible to landslides. Earthquakes are one of the main causes of landslides. As a result, the base map highlights regions in the contiguous United States where numerous landslides have occurred, and it also includes regions that are prone to landslides.

Nevertheless it is noted that earthquake sites are less visible in the red areas where landslides are more likely to occur.

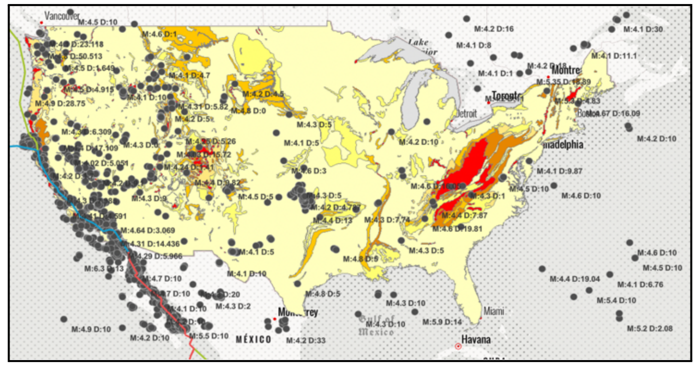

Figure 4.4. The Map of Earthquakes on the layer of Landslide Susceptibility (UCSG).

The number of earthquakes in the top 20 regions from 2000 to 2023 is depicted in the animated graph shown in figure 4.5. One of the states with the most number of earthquakes is California, which recorded 1119, 1170, and 3546 in the years 2000, 2001, and 2019, respectively. Alaska and Hawaii recorded 2985 and 3206 earthquakes, respectively, between the years 2002 and 2018. Moreover, Oklahoma reports 2760 earthquakes in 2015. Mexico, which is a country bordering the United States, recorded 3397 earthquakes in 2010. As a result, Alaska and California are covered in more detail in the following section.

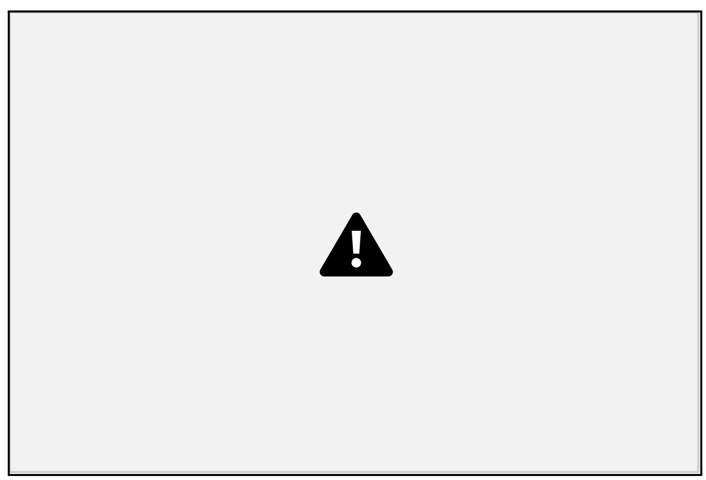

Figure 4.5. Total number of earthquakes in the top 20 regions of the USA.

Figure 4.6 shows a bar graph that displays the annual total number of earthquakes. According to this graph, the year 2018 had the most earthquakes (8,224),

Website: https://arcg.is/nCj8b followed by the years 2010, 2019, and 2020 having 6679, 6501, 6149, and 6111 earthquakes, respectively. As a result, these years are covered in more detail in the following study.

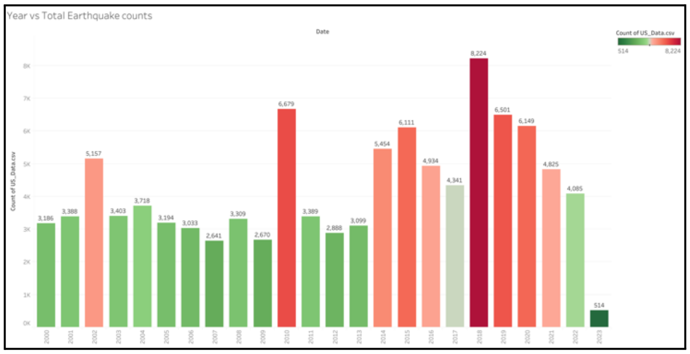

Figure 4.6. Number of earthquakes that occurred each year.

The graph in the figure 4.7 describes the magnitude method, which is used to determine the year's highest magnitude. The years 2002, 2010, 2015, 2018, 2019 and 2020 are taken into consideration for the analysis because they have notable earthquakes. It can be seen that large earthquakes of magnitudes of 7.9, 7.2, 6.4, 7.1, and 5.8 are reliably measured using the "mw" (Moment W-phase) method. Since 2002, the approaches "mb" and "ml" have been applied regularly. Moreover, the "mww" approach appears to have been introduced in 2015 and has been used ever since to calculate the magnitude of big earthquakes.

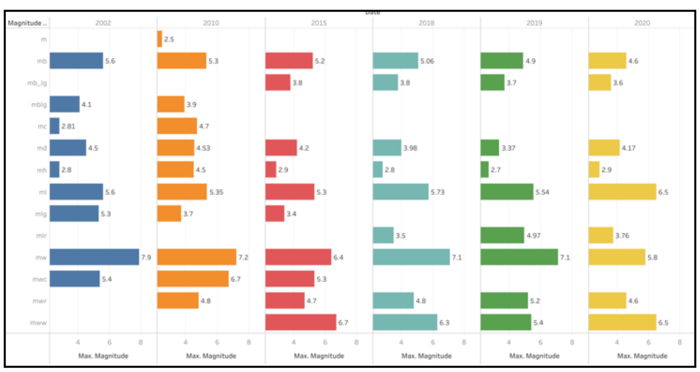

Figure 4.7. Magnitude method vs maximum magnitude graph

The line graph in figure 4.8 display the highest magnitude and corresponding depth for each year, as well as the highest depth and corresponding magnitude. We can see from the graph of highest magnitude that the depth of the earthquake with 7.9M is only 4.2km. Moreover, the 7.2M earthquake only goes below 10km. The earthquake at a depth of 300 km has 2.7M, as can be seen sequentially in the highest depth graph. The earthquake with a depth of 213.5 km also had 2.8M.

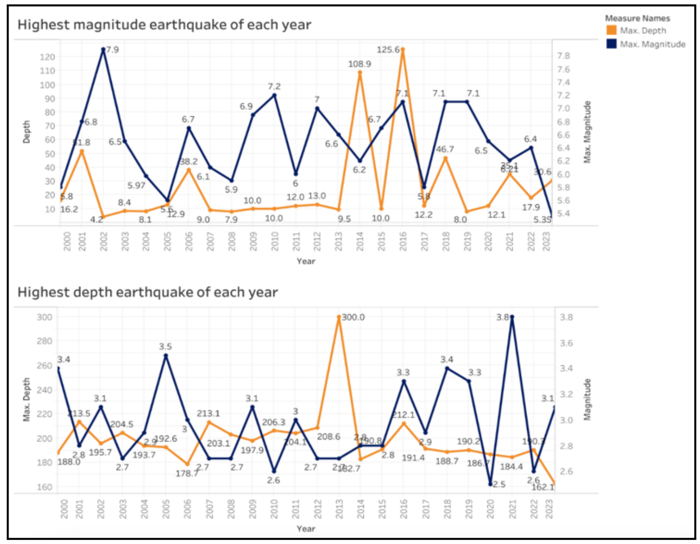

Figure 4.8. Highest magnitude and depth earthquake of each year

Hence, we can draw the conclusion that the relationship between magnitude and depth is not always obvious. Slightly deeper earthquakes of the same size can cause greater damage than deeper earthquakes of the same magnitude because the energy produced by the earthquake is transmitted more directly to the surface. The local rock formations and soil type may have an impact on the earthquake's effects, among other factors.

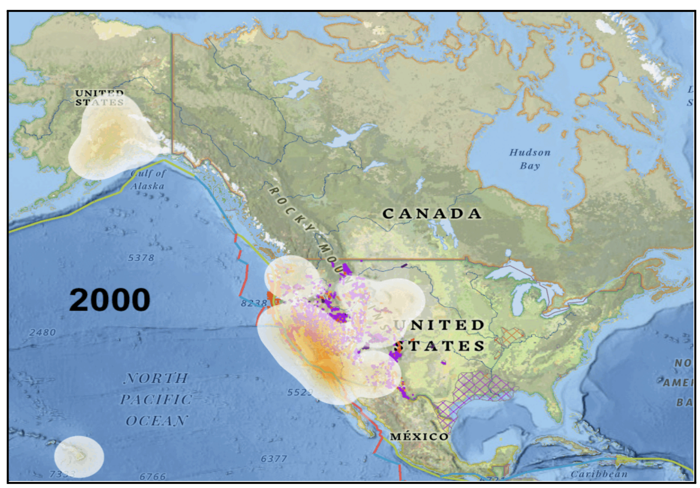

Figure 4.9. Magnitude method vs maximum magnitude graph

The hear map in the figure 4.9 displays the earthquake intensity over time in relation to magnitude. The USGS Earthquake Fault base map has been added. It can be seen that Hawaii, Alaska

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and California are in the darker shade i.e., the most affected regions.

4.1.2. Major Earthquakes

Denali earthquake – 2002

At its epicentre 66 kilometres (41 miles) east of Denali National Park in Alaska, the United States, the 2002 Denali earthquake struck on November 3 at 22:12:41 UTC (1:12 PM local time). The United States has not seen a 7.9 Mw earthquake since 1973. (after the 1965 Rat Islands earthquake). The shock was the most powerful ever recorded in the interior of Alaska. Because to the distant location, there was just one injury and no fatalities. It might be felt all the way in Seattle because to the shallow depth.

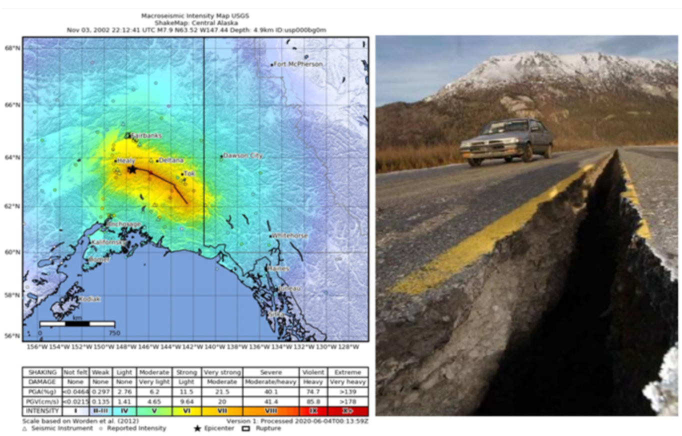

Figure 4.10. Pictures of Denali earthquake - 2002

Old Iliamna earthquake - 2016

The 2016 Old Iliamna earthquake struck the Cook Inlet region of Alaska close to Iliamna on January 24, 2016, about 1:30 AM AKST. About 65 miles (105 km) from Homer and 162 miles (261 km) from Anchorage were the epicentres of the earthquake. [6] The 7.1 on the Richter scale earthquake was felt throughout much of Southcentral Alaska and as far away as Juneau, which is around 700 miles (1,100 km) southeast of the epicentre. Homes, roads, and commercial buildings sustained moderate to severe damage over a wide area.

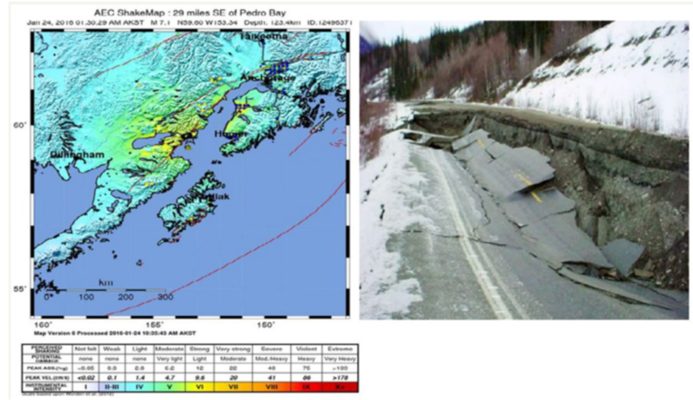

Figure 4.11. Pictures of Old Iliamna earthquake - 2016

Anchorage earthquake – 2018

On November 30, 2018, at 8:29 AKST, a magnitude 7.1 earthquake struck South Central Alaska (17:29 GMT). The earthquake's epicentre was located in Point Mackenzie at a depth of 29 miles, roughly 10 miles (16 km) north of Anchorage (47 km). Six minutes after the initial aftershock, a magnitude 5.7 tremor with a centre 4.0 kilometres (2.5 miles) to the northwest of the municipality was felt. The earthquake could be heard all the way in Fairbanks. The National Tsunami Warning Centre, located 42 miles (68 km) northeast of Anchorage in Palmer, Alaska, inside the earthquake zone, issued tsunami warnings for nearby coastal areas, including Cook Inlet and the Kenai Peninsula. The cautions were immediately lifted, though.

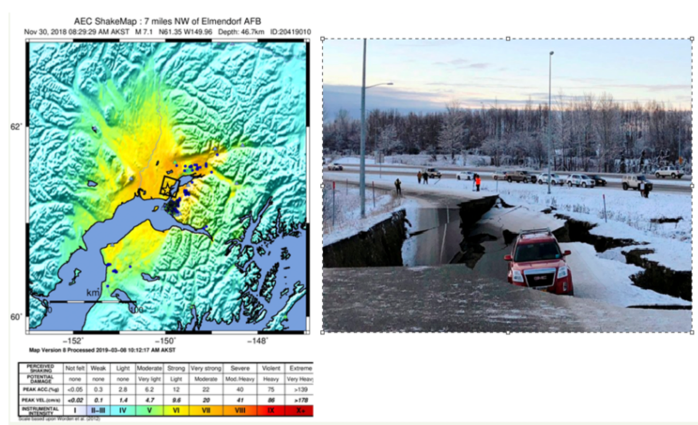

Figure 4.12. Pictures of Anchorage earthquake – 2018

Ridgecrest earthquakes – 2019

The strongest earthquakes to hit California in more than 20 years were the Ridgecrest Earthquakes in July 2019. A magnitude 6.4 earthquake occurred on

July 4 at 10:33 AM PST, roughly 12 km (10.5 miles) southwest of Searles Valley. Following several aftershocks, another earthquake with a magnitude of 7.1 struck on Friday, July 5. On July 5, 2019, an earthquake with a magnitude of 7.1 ripped the earth in the Mojave Desert, unleashing the equivalent of 45 nuclear bombs. The earthquake's strength was comparable to that of the atomic bomb that was dropped on Hiroshima.

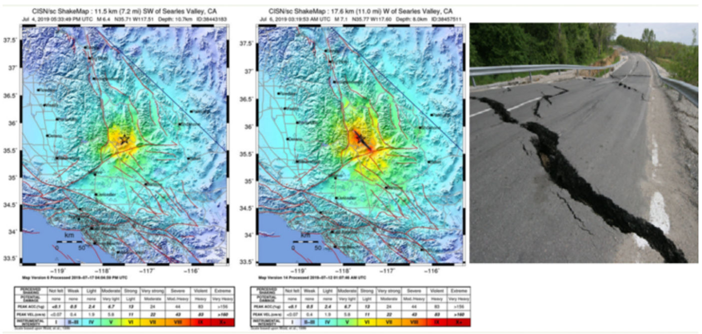

Figure 4.13. Pictures of Ridgecrest earthquakes – 2019

Easter earthquake – 2010

In addition to being known as 2010 Easter, 2010 Sierra El Mayor, or 2010 El Mayor - Cucapah, the 2010 Baja California earthquake struck on April 4 (Easter Sunday), registering 7.2 magnitude at its epicentre and achieving a maximum Mercalli intensity of VII (Very strong). The shock started at 15:40:41 local time south of Guadalupe Victoria, Baja California, Mexico (3:40:41 PM PDT). Southwest Mexico and southern California both saw significant aftershocks from the 89-second earthquake. 58 years have passed since the next most recent equivalent earthquake, the 1952 Kern County earthquake (M 7.3). Moreover, it was the most powerful earthquake to hit southern California in at least 18 years, if not more (since the M 7.3 1992 Landers earthquake). These earthquakes all had similar magnitudes and were felt widely.

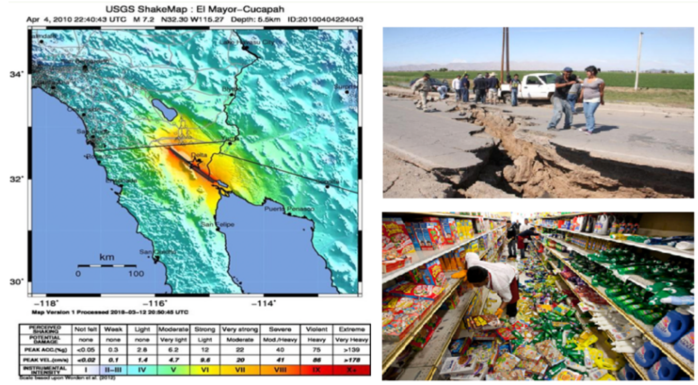

Figure 4.14. Pictures of Easter earthquake – 2010

4.1.3. Year-wise Analysis

Year-wise analysis is a valuable technique for understanding seismic activity and observing trends and patterns over time. The significant earthquakes that happened across the US in the years 2002, 2010, 2015, 2018, and 2019 were the focus of this section. These years saw a number of significant earthquakes that resulted in significant destruction and fatalities, underlining the importance of continued research and readiness initiatives in the field of seismology.

Year - 2002

The map shown figure 4.15 shows the total earthquakes in 2002 with magnitude above 3. We can observe that density of earthquakes is more seen in Alaska and California regions.

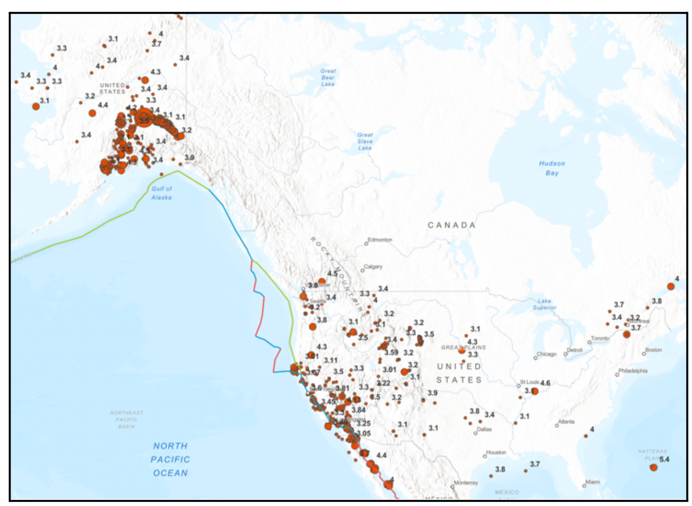

Figure 4.15. Map of the US showing all earthquakes in 2002 with magnitude above 3.

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The graph shown in 4.16 depicts the earthquake with the highest magnitude and depth that occurred on each day of the year 2002. It also displays how many earthquakes occurred each day in 2002. It is clear that on November 4th, there were 535 earthquakes. As previously reported, an M7.9 earthquake was occurred in the same month. In addition, on July 8 there was a 195.7-kilometer-deep earthquake.

The Denali fault was the site of an earthquake of a magnitude of 6.7 on October 23, 2002. The Denali fault ruptured 45 km (28 mi) in length as a result of the earthquake, but aerial observation failed to find a surface rupture. The epicentre of the mainshock is 10 km (6.2 mi) west of the location of this rupture. As a result, there were numerous small rockfalls and snow avalanches in the area.

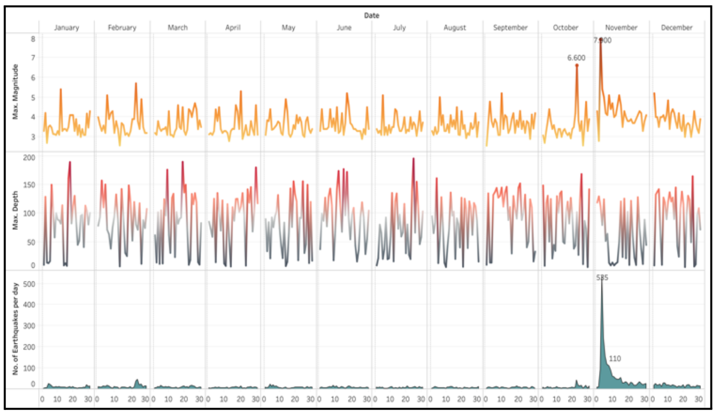

Figure 4.16. Time Series Analysis of the year 2002.

Figure 4.17 shows the earthquake patterns in November 2002, a month with a lot of quakes. On November 3, 2002, an earthquake with a maximum magnitude of 7.9 occurred in Alaska. Each earthquake that happened in Alaska during the month of November 2002 is shown on the map. Many of the aftershocks occurred on nearby faults that aren't believed to have ruptured and could only be allowing for stress changes. On the Denali fault itself, the largest aftershock was only a Mw 5.8 event, and there were fewer and smaller ones than expected.

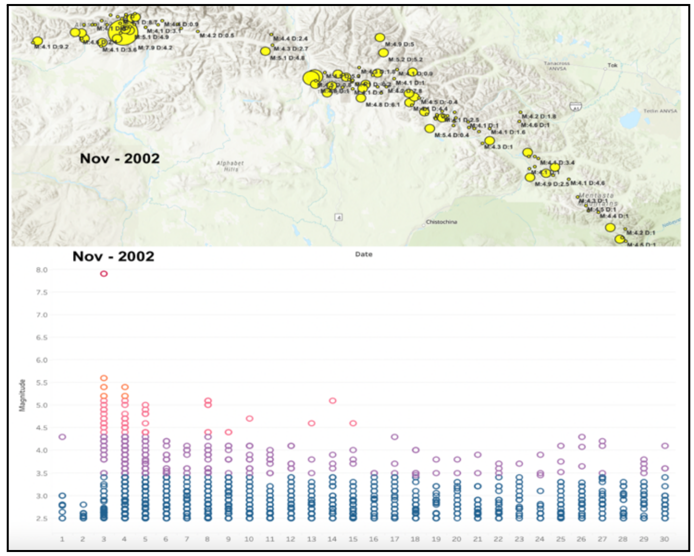

Figure 4.17. Earthquake trends in Nov-2002.

Year – 2010

The figure 4.18 is a map that shows the locations of all earthquakes with a magnitude greater than 3 in 2010. On tectonic plates, it can be seen that the California region experienced more earthquakes than other regions. In the vicinity of Mexico, a major earthquake measuring M7.2 occurred.

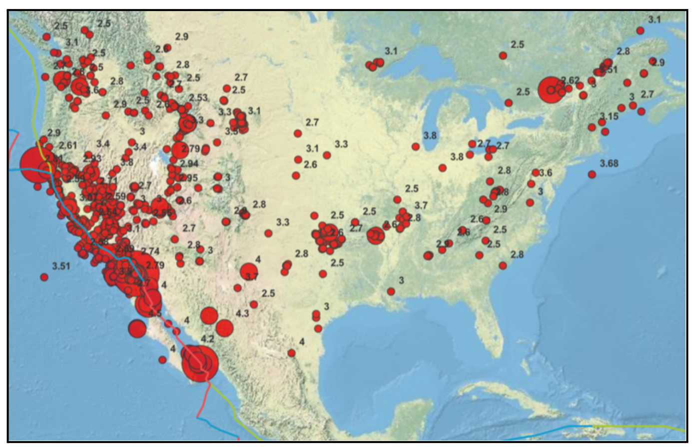

Figure 4.18. Map of the US showing all earthquakes in 2010 with magnitude above 3.

The graph in figure 4.19 displays the day's largest and deepest earthquakes for the entire year of 2010. It also displays how many earthquakes there were each day in 2010. It is evident that three significant earthquakes with magnitudes of 6.5, 7.2, and 6.7 occurred on January 10, April 4, and October 21, respectively. These earthquakes' depths weren't all that noteworthy, though. Although the strongest magnitude earthquake that day was just 3.3M, the 206 km deep earthquake was recorded as the deepest earthquake of the year. It should be mentioned that in April, a month with significant earthquake, there were 664 aftershocks.

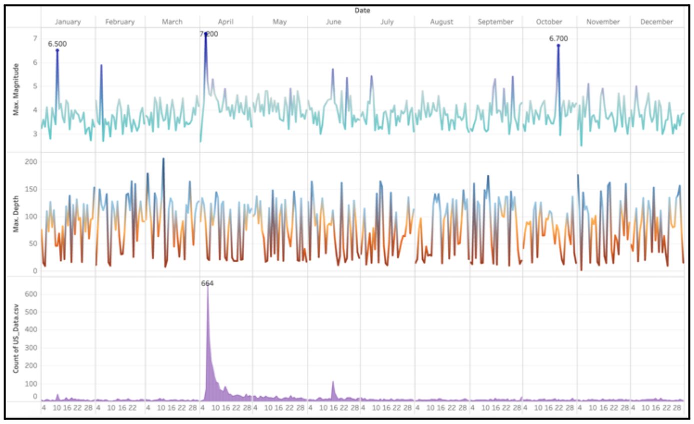

Figure 4.19. Time Series Analysis of the year 2010.

The figure 4.20 the earthquake patterns in April 2010, a month with a lot of earthquakes. The map displays all earthquakes that occurred in April of 2010 in Baja California region. Magnitude of 5.2, 5.4, 5.1, and magnitude of 5.7, all four within an hour, have been reported as aftershocks with a magnitude of at least 5 after 7.2 magnitude earthquake on April 4. On April 8, at around 9:44 AM local time, a 5.3 aftershock struck the area very near the mainshock epicentre. In total, there have been at least nine major aftershocks. More than 90 aftershocks or induced earthquakes from magnitude 3.0 and 5.1 were reported in northern Baja California and Southern California six hours following the initial earthquake.

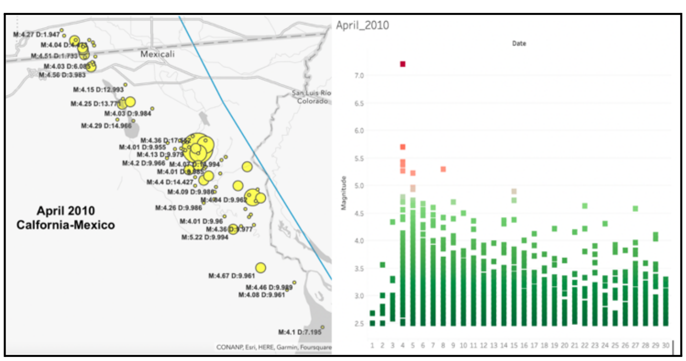

Figure 4.20. Earthquake trends in April-2010.

Year - 2015

All US earthquakes in 2010 with a magnitude greater than 3 are displayed on the map shown in figure 4.21. It was evident that there were many little earthquakes close to Oklahoma State. Significant amount earthquakes were also felt in Alaska and California.

Figure 4.21. Map of the US showing all earthquakes in 2015 with magnitude above 3.

The figure 4.22 displays the day's largest and deepest earthquakes for the entire year of 2015. It also displays how many earthquakes there were each day in 2010. It was noted that there were approximately 35 earthquakes each day. On July 29, at a depth of 119.3 kilometres, a magnitude 6.4 earthquake struck Alaska, United States, 52 km (32 mi) east northeast of Pedro Bay (74.1 mi) and on September 13, at a depth of 10.0 km, a magnitude 6.7 earthquake occurred off the coast of Mexico 95 kilometres (59 miles) southwest of Topolobampo (6.2 mi). Many earthquakes of depth over 150 kms were occurred in the month of July.

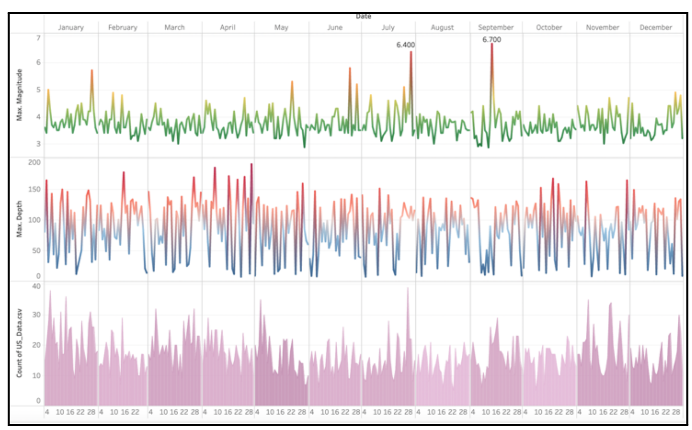

Figure 4.22. Time Series Analysis of the year 2015.

Year - 2018

All earthquakes of a magnitude greater than 3 that occurred in significant locations in 2018 are depicted on the map shown in figure 4.23. Significant amount of earthquakes can be seen in California, Alaska and Oklahoma regions.

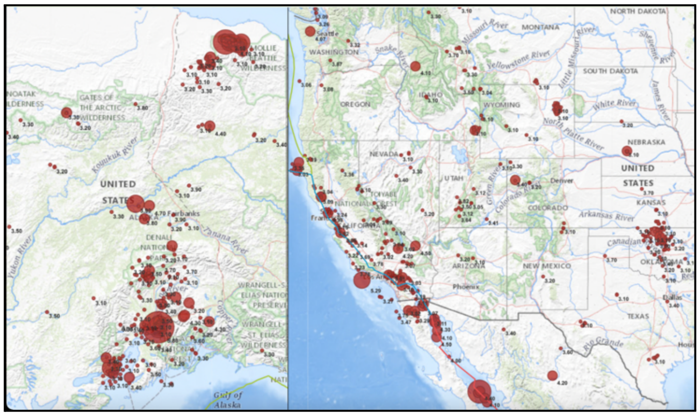

Figure 4.23. Map of the US showing all earthquakes in 2018 with magnitude above 3.

The figure 4.24 displays the day's largest and deepest earthquakes for the entire year of 2018. Moreover, it displays the daily earthquake total. It can be seen that there were more than 200 earthquakes on the 13th of August and the 30th of November. The island of Hawaii was shaken on May 4, 2018, by a strong magnitude-6.9 earthquake on the south flank of Kilauea Volcano. It was Hawaii's biggest earthquake in 43 years. Smaller-magnitude earthquakes are still happening in the same region more than five months later.

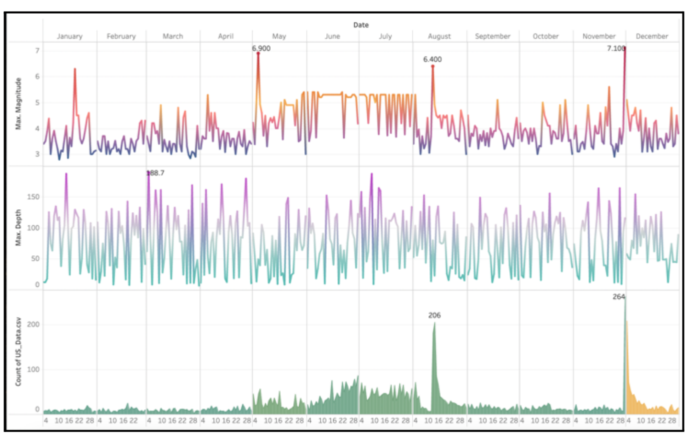

Figure 4.24. Time Series Analysis of the year 2018.

Year- 2019

Every earthquake in 2019 with a magnitude greater than 3 is depicted on the map in figure 4.25. Two significant earthquakes struck California this year, the state endured widespread power outages due to dry weather and wildfires, and homelessness in Los Angeles became a major problem.

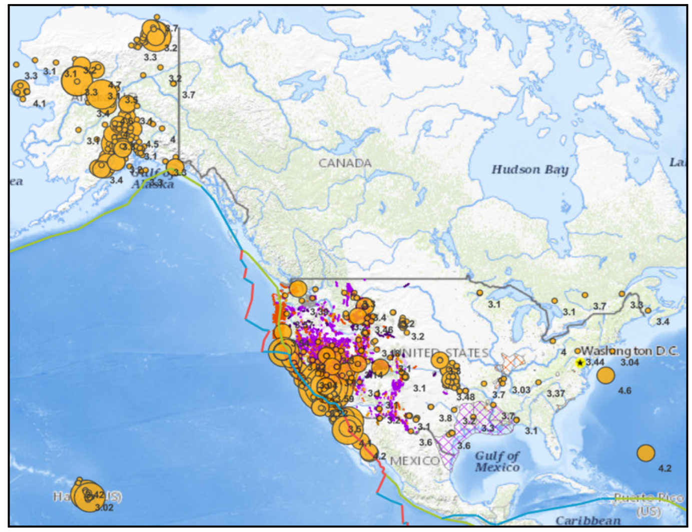

Figure 4.25. Map of the US showing all earthquakes in 2019 with magnitude above 3.

The figure 4.26 displays the day's largest and deepest earthquakes for the entire year of 2019. Additionally, it displays the daily earthquake total. It can be seen that when the M7.1 earthquakes happened on July 6th, there were approximately 1250 earthquakes overall. Moreover, there are about 15 earthquakes with a depth of more than 150 km. Learn more about major earthquakes in this year in region-wise analysis.

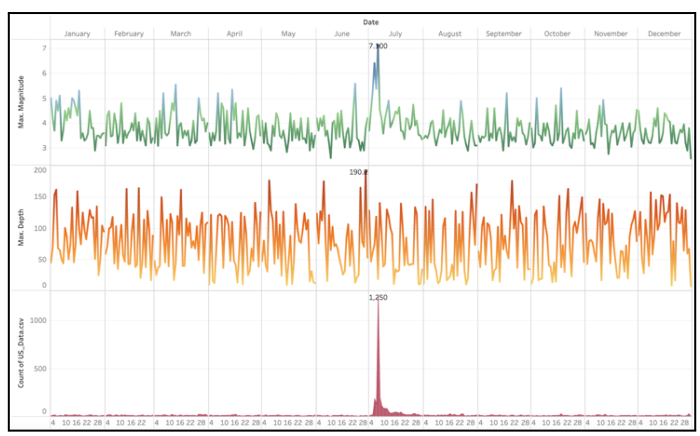

Figure 4.26. Time Series Analysis of the year 2019.

Due to the significant number of earthquakes that occurred in July 2019, as previously mentioned the figure 4.26 reflect the patterns in earthquake activity during that month. A major earthquake of M6.4 and M7.1 were struck on 4th and 6th of July in California near Ridgecrest. It is also noticed that number earthquakes on 4th, 5th, 6th and 7th of July were high. However, USGS claimed that "*A temporary increase or decrease in seismicity is part of the normal fluctuation of earthquake rates. Neither an increase nor decrease worldwide is a positive indication that a large earthquake is imminent.*"

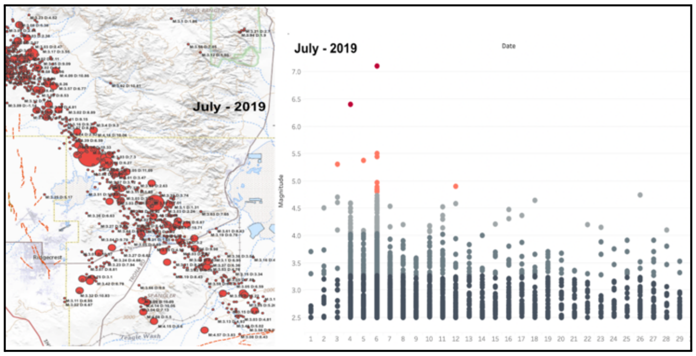

Figure 4.27. Earthquake trends in July-2019.

4.1.4. Region-wise Analysis

California Regional Analysis

In this analysis, we are going to analyse the areas which were impacted by earthquakes, shake intensity, and after effect of earthquakes, and lastly will analyse the highest magnitude earthquake in California from 2000 to 2023 in detail. The map in figure 4.28 shows all earthquakes with a magnitude greater than 4 in California from 2000 to 2023.

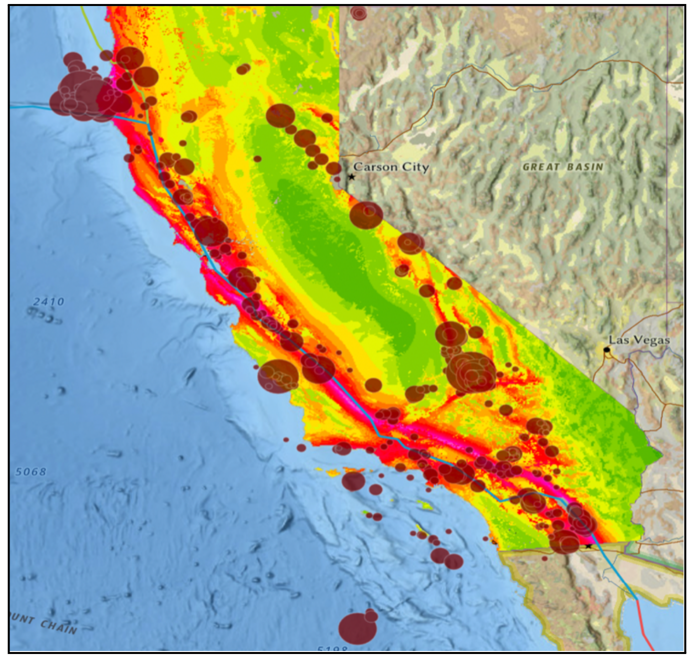

Figure 4.28. Map of the California showing all earthquakes from 2000 to 2023 with magnitude above 4.

The density of earthquakes of various magnitudes across California would be displayed on a density map of earthquake magnitudes in figure 4.29. With multiple faults running through the state, including the well-known San Andreas Fault, California is one of the seismically active regions in the world. The density map would reveal that California has a lot of earthquakes with magnitudes under 2.0 that are rarely felt by people. The frequency of earthquakes declines as the magnitude rises. The map would demonstrate that earthquakes with a magnitude of 2.0 to 3.0 are more frequent than earthquakes with a magnitude of 3.0 to 4.0, and so on. The mean line in green color is represented as a straight line on the density map, with areas above the line showing a higher density of data points, while areas below the line indicate a lower density.

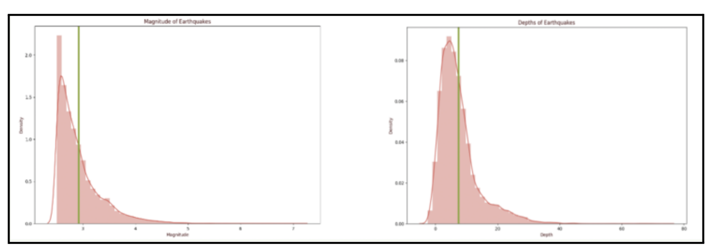

Figure 4.29. Density map of earthquake magnitude and depth.

The density map would demonstrate the range of depths at which earthquakes occur in California. The

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San Andreas Fault and other active faults in the state are frequently linked to the shallowest earthquakes (less than 10 km deep). Compared to earthquakes that happen at deeper depths, this depth's earthquake density is typically higher. The density map of earthquake depths in California would show the seismic activity in the state and the regions that are most vulnerable to earthquakes at various depths. It can be a helpful tool for figuring out how earthquakes occur in California and for locating places that might be more vulnerable to seismic hazards. In a density map of earthquake depths in California, the mean line in green color represents the average depth of earthquakes across the entire region.

This map in figure 4.30 shows the earthquakes that occurred in July 2019 in California.

CA Data: This layer shows the size of magnitude of earthquakes.

Surface_Rupture_Ridgecrest_Prov_rel_1: Documentation of Surface Fault Rupture and Ground-Deformation Features Produced by the 4 and 5 July 2019 Mw 6.4 and Mw 7.1 Ridgecrest Earthquake Sequence.

Shelly_stations: A High-Resolution Seismic Catalog for the Initial 2019 Ridgecrest Earthquake Sequence: Foreshocks, Aftershocks, and Faulting Complexity.

lidar_012020 & lidar_102019: Airborne Lidar and Electro-Optical Imagery along Surface Ruptures of the 2019 Ridgecrest Earthquake Sequence, Southern California.

USGS_ESC_Stations & USGS_ASL_Stations: The U.S. Geological Survey's Rapid Seismic Array Deployment for the 2019 Ridgecrest Earthquake Sequence.

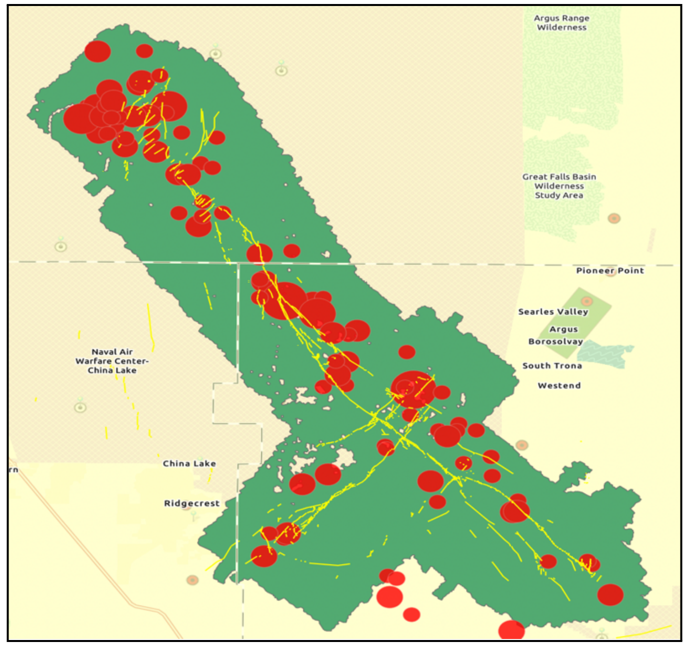

Figure 4.30. A map of California Ridgecrest earthquakes

In figure 4.31 shows the M6.4 earthquake with a focal point 18.2 km (11.3 mi) west-southwest of Ridgecrest, California, shook more than 47,000 individuals in southern California at 10:34am local time on July 4, 2019 as well as those in northern California and Phoenix, Arizona. A series of extremely minor earthquakes (foreshocks) lasting over an hour, including an M4.0 event that occurred approximately 30 minutes earlier, preceded the M6.4. But nobody realized that these smaller occurrences were foreshocks until the M6.4 struck.

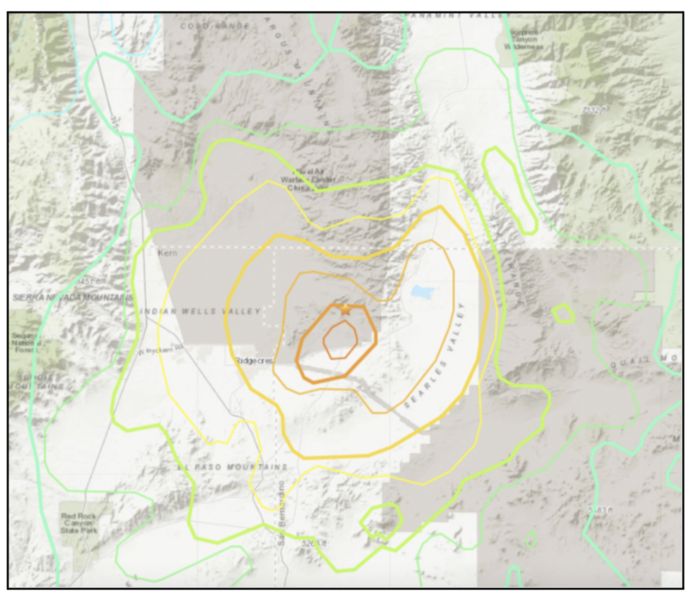

Figure 4.31. Intensity map of 6.4M

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According to figure 4.32, the early information suggested that the earthquake occurred on a shallow strike slip fault, and later aftershocks revealed a fault zone that extended from the southwest to the northeast. Following the M6.4, there were around 250 M2.5 or bigger aftershocks, but it wasn't until 34 hours later, at 8:19 pm local time, and 11 kilometres (6.8 miles) to the northwest of the M6.4 event, that another, more significant earthquake struck. This M7.1 earthquake was a shallow strike-slip event that occurred on a fault that was orthogonal to the strike of the M6.4 (rotated 90 degrees).

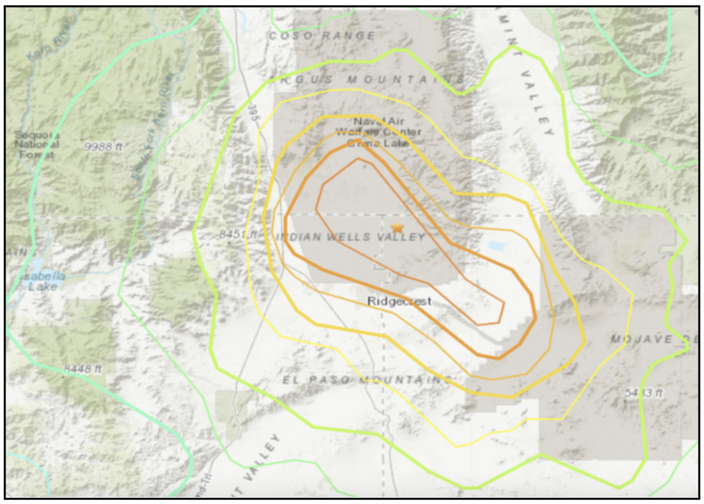

Figure 4.32. Intensity map of 7.1M

The figure 4.33 describes earthquakes that were recorded during the first three days of the July 2019 Ridgecrest earthquake sequence. A circle is used to depict every earthquake, with a blue circle used to indicate earthquakes larger than M4.0. The horizontal and vertical axes, respectively, show the magnitude and time of each earthquake. There is a gap at low magnitudes following the M6.4 and M7.1 earthquakes because there are too many aftershocks happening for them all to be detected.

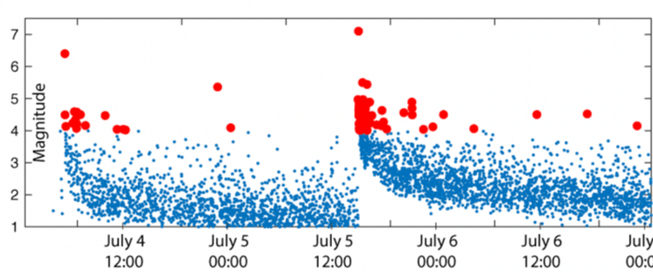

Figure 4.33. The earthquake sequence that occurred in Ridgecrest in July 2019.

Geologists quickly began gathering their tools to investigate any potential earth characteristics left over from the rupture and shaking as the second mainshock was starting. To capture the features' finer nuances when they were still new, this was done. Seismologists were keen to place temporary equipment close to the epicentres of the M6.4 and M7.1 earthquakes in order to get information on the ensuing aftershock sequences due to the comparatively large distance of about 20km (12.4mi) between permanent seismic stations in that area.

San Andreas Fault Line

A significant geological fault can be found in California, USA, called the San Andreas Fault. It is a transform fault, which means that the Pacific Plate and the North American Plate are separated by it. The fault runs through California for approximately 800 miles (1,300 km), from the Salton Sea in the south to Cape Mendocino in the north. The tectonic plate movement that results in the regular earthquakes along the San Andreas Fault is well known. The city of San Francisco was completely destroyed by a magnitude 7.8 earthquake in 1906, which was the fault's most recent significant earthquake. Since then, there have been numerous smaller earthquakes along the fault, and scientists and researchers believe there is a substantial likelihood that a significant earthquake will happen soon.

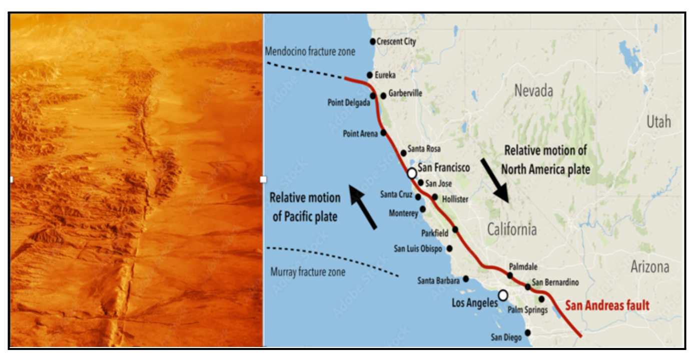

Figure 4.34. Details about San Andreas fault line.

Alaska Regional Analysis

In this section, we are analysing the density maps of depth and magnitude, date-wise analysis of max. magnitude & number of earthquakes that occurred on a particular date, and lastly discuss the region and

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after-effects of the highest magnitude in Alaska from 2000 to 2023.

The density of earthquakes at various magnitudes over Alaska would be displayed in figure 4.35. Because to its location at the meeting point of the Pacific and North American plates, Alaska is one of the seismically active areas in the globe. The purple mean line on an earthquake density map for Alaska reflects the average magnitude of earthquakes throughout the region.

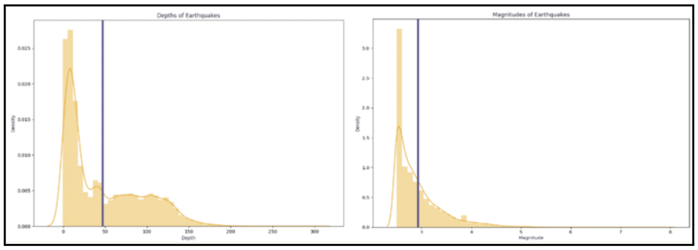

Figure 4.35. Density map of earthquake magnitude and depth of Alaska.

The density map of earthquake depths in Alaska would provide a visual representation of the state's seismic activity and the areas that are most prone to earthquakes at different depths. It can be a useful tool for understanding the distribution of earthquakes in Alaska and for identifying areas that may be at higher risk of seismic hazards. In a density map of earthquake depths shown in figure 4.35 in Alaska, the mean line in purple color represents the average depth of earthquakes across the entire region.

The line graph in figure 4.36 shows the maximum magnitude and total earthquakes that occurred on a specific date. Also, it has a filter by which we can filter out the specific range of earthquakes for better analysis.

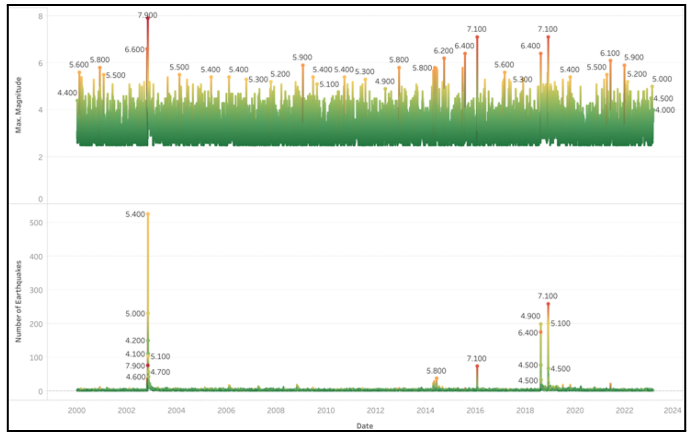

Figure 4.36. Magnitude Peaks of Earthquakes, by Date.

The table in figure 4.37 displays the highest magnitude earthquakes and the total number of earthquakes in Alaska by year. The darker color indicates the earthquakes with the highest magnitudes. If you wish to investigate the data for a specific year, such as 2002, which had the highest magnitude earthquake, you can click on it to access a month-wise analysis. Additionally, you can examine the day of the month on which the earthquake with the highest magnitude occurred.

On November 3rd, 2002, a 7.9 magnitude earthquake occurred, which was the strongest in the past 23 years. If you would like to learn more about the impact and aftermath of the earthquake, you can click on the block corresponding to November 3rd. This will take you to a webpage with additional information about the Denali Fault earthquake.

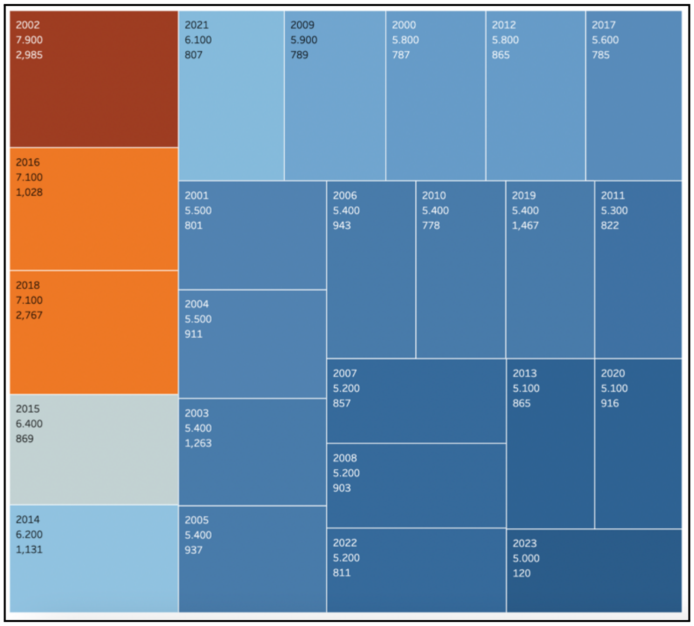

Figure 4.37. Alaska Earthquake Data by Years, Months, and Days.

The inferred rupture area (white dashed line) of the May 4, 2018, magnitude-6.9 earthquake is shown in figure 4.38. An isolated area of Alaska's North Slope, southeast of Prudhoe Bay, was shaken by an earthquake of magnitude 6.4 on Sunday morning

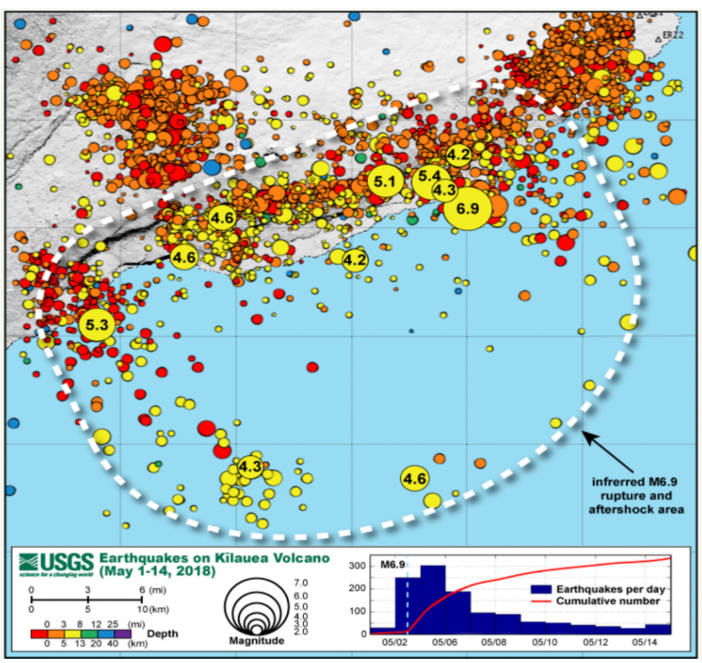

Figure 4.38. The inferred rupture area (white dashed line) of the May 4, 2018, magnitude-6.9 earthquake.

4.2. Experimental Forecasting

Website: https://arcg.is/nCj8b

5. Discussion And Conclusion

5.1. SWOT Analysis

A SWOT analysis may assist you in identifying project strengths and weaknesses, aligning project goals and objectives, evaluating project alternatives, and making educated project decisions. It contributes to the project's success and allows it to adjust to changes in the environment. The image 5.1 describes the SWOT analysis of our project.

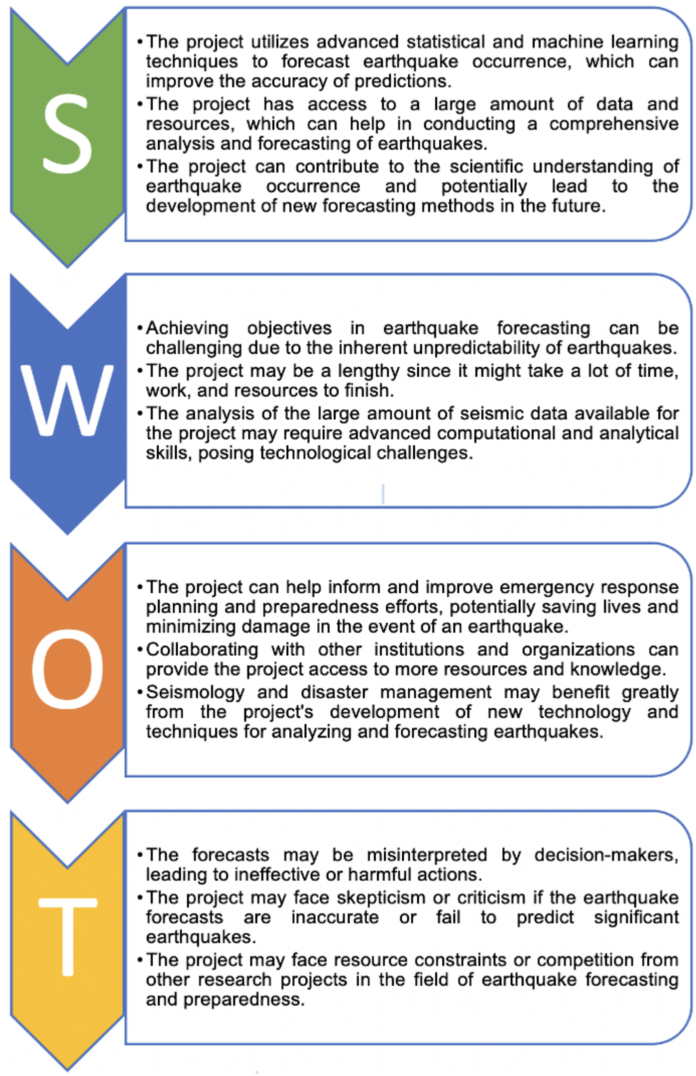

Figure 5.1. SWOT Analysis

5.2. Conclusions

5.3. Future Work

For further research and development of this project, we could aim to study in depth the location specific carbon footprint. For example, a user would know how much emissions are present in the locality of his workplace or home, with features such as real time emission detection.

6. References

[1] https://www.usgs.gov/programs/earthquake-hazards/what-are-effects-earthquakes

[2] https://par.nsf.gov/servlets/purl/10202260

[3] https://earthquake.usgs.gov/storymap/index-ridgecrest.html

[4] https://pubs.usgs.gov/pp/1527/report.pdf

https://earthquake.usgs.gov/data/comcat/#event-terms

https://earthquake.usgs.gov/data/comcat/contributor/

https://earthquake.usgs.gov/data/comcat/catalog/