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Evolution of the Guatemalan Earthquake Catalog †

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Abstract: This paper describes all the characteristics of the Guatemalan earthquake catalog and how it has evolved. Over 64,483 earthquakes are included in this paper distributed in some areas of El Salvador, Mexico, Honduras, and Belize, but mainly in Guatemala. Regularly, the earthquake catalogs improve their characteristics over time, however, this is not the case for the catalog of Guatemala. Although earthquake detection improved with the establishment of the national seismic network operated by the National Institute of Seismology, Vulcanology, Meteorology and Hydrology (INSIVUMEH) in 1977, the catalog has not kept a favorable evolution over time. This has led to problems with earthquake detection, large location errors, increasing magnitude of completeness, and others that are going to be discussed later in this paper.

Keywords: magnitude; magnitude of completeness; seismic network

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1. Introduction

The ability to detect and describe earthquakes depends on a variety of factors, such as changes in technology, detection methods, or the number of seismic stations available for earthquake detection. Those factors are always changing over time. Hence, seismic catalogs can have inconsistencies and variations that could lead to wrong conclusions during any analyses of seismic data. As such, the present paper aims to unveil and decipher any temporal and spatial heterogeneities present in the earthquake catalog of Guatemala. Figure 1 shows the events of the catalog used for this paper.

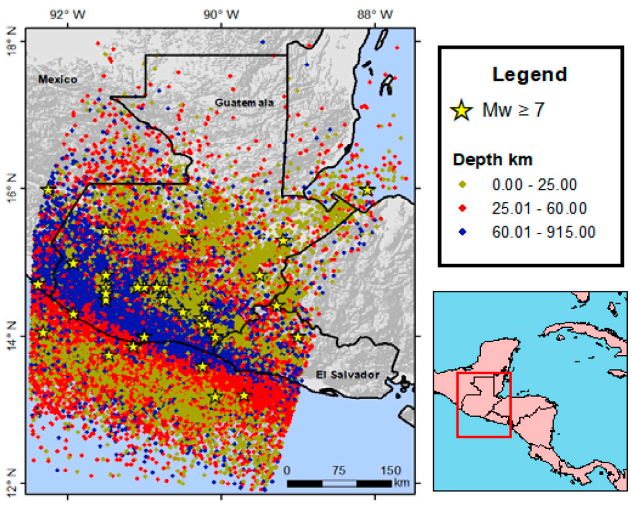


Figure 1. Epicenters in the Guatemalan earthquake catalog from 1500 to the end of 2022 according to different depths. The stars represent the events with a magnitude greater or equal to 7 Mw. The catalog is divided according to different depths.

2. Evolution of the Catalog

The catalog used in this study can be categorized into three distinct parts: historical earthquakes from 1500 to 1900 [1], seismic events from 1900 to 1984 compiled by the International Seismological Centre (ISC) [2], and earthquakes from 1977 to 2023 compiled by National Institute of Seismology, Vulcanology, Meteorology and Hydrology of Guatemala (INSIVUMEH) [3]. The INSIVUMEH and ISC catalogs overlapped from 1977 to 1984. The catalog has been homogenized to moment magnitude (Mw). Figure 2 shows the cumulative number of earthquakes per year in the catalog.

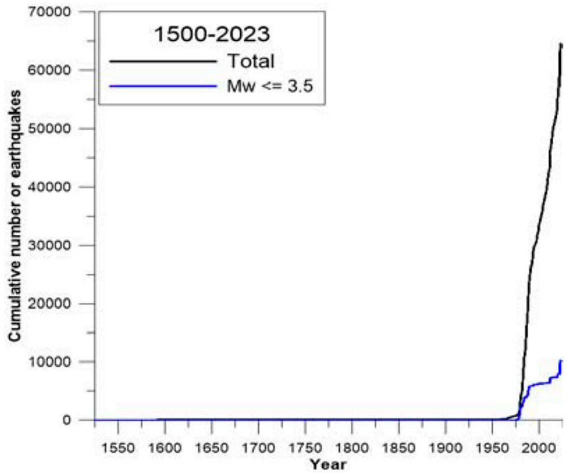


Figure 2. Cumulative number of earthquakes from 1500 to 2023. The blue line represents the cumulative number of earthquakes with a magnitude lower or equal to 3.5 Mw.

Figure 2 shows a low earthquake rate until 1965, followed by a drastic increase after 1976 when the INSIVUMEH was established. Low-magnitude earthquakes were recorded starting in 1977. Nevertheless, the proportion of low-magnitude events in relation to the total number suggests a deficiency in monitoring these low-magnitude events. Next, a comprehensive overview of the seismic network history of Guatemala is provided including the evolution of the catalog concerning its diverse sources.

Historical period (until 1900): This portion of the catalog is based on historical records that describe the effects of earthquakes. Some of these historical records are listed in [4]. Although earthquake-recording instruments existed in the early 1900s, Guatemala lacked a seismological network.

First instruments (1900–1977): The first instrumental records in Guatemala began in 1925 with the installation of the first mechanical seismographs [5]. Nevertheless, despite the presence of these instruments, there was no monitoring network in Guatemala at the time, so records of the events that occurred during this period are only available through international institutions.

Establishment of the national network (1976): In 1976, the Guatemalan government decided to create the INSIVUMEH. This institution was tasked with seismic monitoring. As a result, the national seismic network of Guatemala was created [6].

First operations of the national network (1977–1990): The national seismic network in Guatemala started operations in 1977 with only 6 stations. At the end of this period, 14 stations were operating [6]. The record was kept on paper until 1990.

Analog period (1990–2013): In 1991, the SEISAN software [7] was introduced to record earthquakes. Even though there was already equipment for digital processing, seismic records were taken exclusively analogically until 2013. During this period an average of 10 stations were operating.

Analog–digital period (2013–2019): In 2013, INSIVUMEH joined the International Federation of Digital Seismographic Networks (FDSN). However, during the period from 2013 to 2019, the records were kept in a mixed format, with some analog and other digital [8].

Additionally, during this period the SeisComP3 software [9] began to be used in parallel to SEISAN. During this period an average of 7 stations were operating.

Digital period (2019–2023): In 2019, the Guatemalan authorities strengthened the national seismic network. Permanent monitoring and new quality control protocols were implemented. As of 2019, the records were kept completely digitally through the SeisComP3 software (GFZ, Potsdam, Germany). In addition, 32 stations were operating during this period [8].

3. Precision of Earthquake Locations

For all earthquakes since 1984, the INSIVUMEH seismic catalog indicates the precision of the focal locations using the errors in the three coordinates of the focus (north, east, and depth). These errors and other factors related to the seismic network, define the quality of the focal locations. It was decided to perform an analysis of the quality of focal locations reported by INSIVUMEH. This analysis is presented below.

3.1. Quality of Focal Locations

Based on the errors, statistical factors, and factors related to the seismic network, Ottemoller et al. [10] proposed a classification of the general quality of the location (Q). Figure 3 shows the spatial distribution of location quality for the Guatemalan catalog from 1984 to the end of 2022.

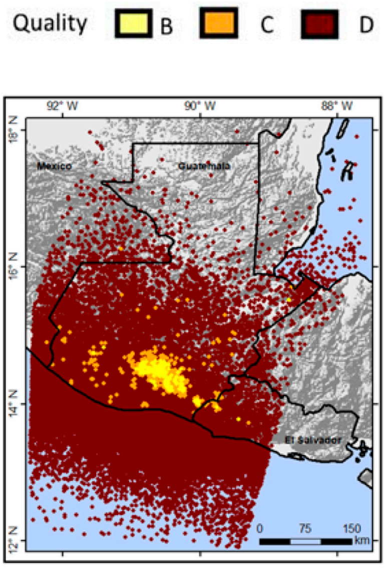


Figure 3. Spatial distribution of location quality from 1984 to the end of 2022.

Analyzing Figure 3, it is clear that most of the earthquakes have a D location quality with poor epicentral location and poor depth location. In numbers, 94% of the total earthquakes from 1984 to the end of 2022 have a D quality. 5% have a C with a fair epicentral location and poor depth location and only 1% B quality with a good epicentral location and fair depth location. The locations with quality C and B are grouped in the department of Guatemala and its surroundings.

3.2. Focal Depth

The analysis of the focal depth of the catalog was made only for the period between 1900 and the end of 2022. As previously mentioned, the ISC and INSIVUMEH catalogs were combined, overlapping the events from 1977 to 1984. To do this overlapping between catalogs and avoiding repeated events, the ZMAP software [11] was used. During this analysis, it was observed that ISC-affiliated networks detected earthquakes with depths deeper than 100 km since 1933. After 1980, the INSIVUMEH network detected earthquakes with depths greater than 300 km, and some with depths deeper than 500 km, however, according to the INSIVUMEH geophysics director they may be outliers [12].

4. Magnitude Determination

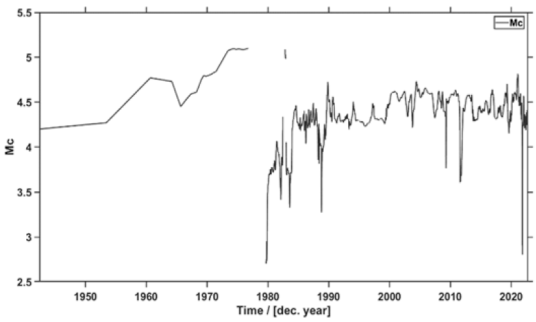
The events reported in the ISC and INSIVUMEH catalogs have been reported using different magnitudes and formulas over time. In the case of this catalog, there were three different magnitudes for the ISC part and two for the INSIVUMEH part. From 1900 to 1964, the ISC catalog reported some events using the magnitude of surface waves (Ms), from 1964 to 1984, some others using the magnitude of body waves (Mb), and for most of the events from 1900 to 2023, the ISC has used moment magnitude (Mw). On the other hand, INSIVUMEH has used a magnitude coda (Mc) to report earthquakes since its establishment. Additionally, in some cases from 1984 INSIVUMEH has reported using local magnitude (Ml).

Catalog Homogenization

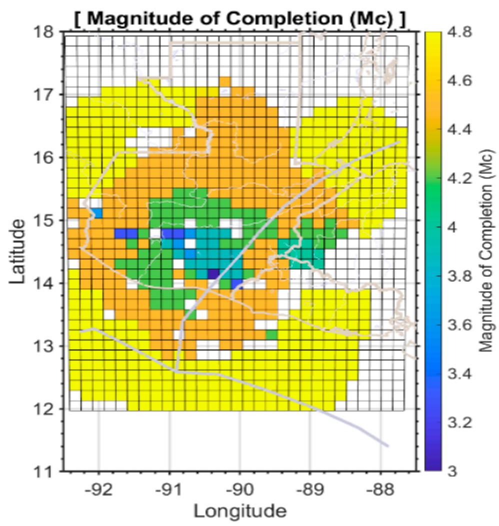
For this work, it was sought to obtain a catalog homogenized to a single magnitude. To carry out this procedure, the moment magnitude (Mw) was selected to represent all the events in the catalog. Therefore, to convert all the magnitudes present in the catalog to moment magnitude, the relationships used were the ones proposed in [13,14].

5. Magnitude of Completeness

The magnitude of completeness or magnitude of completion (Mc) is the lowest magnitude at which all earthquakes in space and time are detected and reported in the catalog [15]. A solid earthquake catalog would have a low Mc [16]. To analyze the variation of Mc in Guatemala, two types of analysis were made. The first was the yearly analysis of the variation of Mc. The second was the spatial distribution of the Mc. Figure 4 shows the annual change of Mc for Guatemala including all depths from 1940 to the end of 2022 and the spatial distribution of Mc for Guatemala.



(**a**)



(**b**)

Figure 4. Mc analysis. (**a**) annual change of Mc, (**b**) Spatial distribution of Mc for Guatemala including all depths from 1977 to the end of 2022.

Figure 4a shows that the Mc value oscillates with an increasing trend over time. However, Figure 4a also shows a recent decline in Mc since 2020, suggesting an improvement in the detection network. Figure 4b indicates that the lowest Mc values are found in the area surrounding Guatemala City, this area corresponds to quality locations B and C. The Mc value increases radially as the distance from this area increases.

6. Conclusions

This paper provides a comprehensive analysis of the earthquake catalog in Guatemala with a particular focus on the period since the establishment of the Guatemalan seismic network in 1977. This analysis includes earthquake detection, seismic network development, earthquake location precision, magnitude determination, and catalog completeness. It was found that, although earthquake detection improved after 1976, the number of low-magnitude earthquakes has not increased proportionally, suggesting deficiencies in detection. Regarding earthquake locations, it was found that earthquakes with acceptable location quality are clustered around Guatemala City. Furthermore, magnitude determination procedures have varied over time. Finally, it can be concluded that the magnitude of completeness varies significantly over time and space, with a radial pattern of increase, with the lowest values around Guatemala City.

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References

1. Guzmán-Speziale, M.; Molina, E. Seismicity and seismically active faulting of Guatemala: A review. *J. South Am. Earth Sci.* **2022**, *115*, 103740. [CrossRef]
2. *ISC Bulletin*; The International Seismological Centre (ISC): Berkshire, UK, 2018. [CrossRef]
3. *GI: Red Sismologica Nacional*; Instituto Nacional de Sismologia, Vulcanologia, Meteorologia e Hidrologia (INSIVUMEH): Guatemala City, Guatemala, 1976.
4. White, R.A. *Catalog of Historic Seismicity in the Vicinity of the Chixoy-Polochic and Motagua Faults, Guatemala*; Open-File Report 84–88; U.S. Geological Survey: Reston, VA, USA, 1984. [CrossRef]
5. Instituto Nacional de Sismología VM e H (INSIVUMEH). Boletín Sismológico 2019. 2020. Available online: https://insivumeh.gob.gt/?p=6863 (accessed on 2 September 2021).
6. Instituto Nacional de Sismología VM e H (INSIVUMEH). Sismología en Guatemala. 2022. Available online: https://insivumeh.gob.gt/?p=6863 (accessed on 10 October 2021).
7. Havskov, J.; Ottemoller, L. SeisAn Earthquake Analysis Software. *Seism. Res. Lett.* **1999**, *70*, 532–534. [CrossRef]
8. Robin, Y. Instrumentación sísmica de la red sismológica nacional. In Proceedings of the CESEM Symposium Guatemala, Guatemala City, Guatemala, 23 September 2021.
9. Helmholtz-Centre Potsdam GFZ German Research Centre for Geosciences; GEMPA GmbH. *The SeisComP Seismological Software Package*; GFZ Data Services: Potsdam, Germany, 2008. [CrossRef]
10. Ottemoller, L.; Voss, P.; Havskov, J. *SEISAN Earthquake Analysis Software for Windows, Solaris, Linux and MacOsX*, Version 11.0 2017; Apple Inc.: Cupertino, CA, USA; 2017.
11. Wiemer, S. A Software Package to Analyze Seismicity: ZMAP. *Seism. Res. Lett.* **2001**, *72*, 373–382. [CrossRef]
12. Yani, R.; Instituto Nacional de Sismologia, Vulcanologia, Meteorologia e Hidrologia (INSIVUMEH), Guatemala City, Guate-mala. Personal communication, 2022.
13. Benito, B.; Lindholm, C.; Camacho, E.; Climent, Á.; Marroquín, G.; Molina., E.; Rojas, W.; Talavera, E.; Escobar, J.; Alvarado, G. *Amenaza sísmica en América Central*; Entimema: Madrid, Spain, 2010; ISBN 978-84-8319-474-4.
14. Rojas, W.; Bungum, H.; Lindholm, C. Historical and recent earthquakes in Central America. *Rev. Geológica De América Cent.* **2011**, *16*, 5–22. [CrossRef]

15. González, Á. The Spanish National Earthquake Catalogue: Evolution, precision and completeness. *J. Seism.* **2016**, *21*, 435–471. [CrossRef]
16. Gardine, L. What Is Magnitude of Completeness? 2020. Available online: https://earthquake.alaska.edu/what-magnitude-completeness (accessed on 9 April 2023).