Boletín Geológico

SERVICIO GEOLÓGICO COLOMBIANO

Boletín Geológico, 50(1), 2023

https://doi.org/10.32685/0120-1425/bol.geol.50.1.2023.665

Received: June 10, 2022

Revision received: October 27, 2022

Accepted: October 31, 2022

Data article

Integrated Seismic Catalog for Colombia

Catálogo Sísmico Integrado para Colombia

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ABSTRACT

This article presents the Integrated Seismic Catalog (CSI), which is an earthquake dataset for Colombia and neighboring territories (i.e., the borders of Costa Rica, Ecuador, Nicaragua, Panama, Peru and Venezuela). The CSI contains preferred solutions that were derived from global and regional seismic catalogs. Each preferred solution includes the best available solution for event magnitude and location, which were selected from among the multiple candidates from the different catalogs and compiled following prioritization matrices. The seismic events that make up the CSI are located in a quadrant that ranges from −84° to −66° longitude and 5° to 16° latitude (referenced to the WGS84 datum) and encompasses the period from 1610 (supported by catalogs of historical earthquakes with magnitudes estimated from macroseismic intensities) to December 31, 2020. The magnitude values of all preferred solutions included in the CSI have been standardized to moment magnitude (M_w), using transformations in instances where this value was not estimated from the original source and a different type of magnitude was calculated instead. The CSI is expected to serve as a reference or input used to generate hazard models and characterize seismogenic sources since it integrates different location and magnitude solutions, which have been standardized to the parameters most used today.

Keywords: seismology, regional seismicity, historical seismicity, South America, Central America, Caribbean, seismic hazard.

RESUMEN

Este artículo presenta el conjunto de datos de terremotos denominado Catálogo Sísmico Integrado (CSI) para Colombia y territorios limítrofes (fronteras con Costa Rica, Ecuador, Nicaragua, Panamá, Perú y Venezuela). El CSI contiene soluciones denominadas preferidas, construidas con base en catálogos sísmicos globales y regionales. Cada solución preferida incluye las mejores alternativas disponibles para magnitud y localización, seleccionadas de entre las candidatas provenientes de los diferentes catálogos recopilados siguiendo matrices de priorización. Los eventos sísmicos que componen el CSI se encuentran en un cuadrante entre los −84° y −66° de longitud y −5° y 16° de latitud, en el sistema geográfico WGS84, y cubre el periodo desde 1610 (apoyado en catálogos de sismos históricos con magnitudes estimadas a partir de intensidades macrosísmicas) hasta el 31 de diciembre de

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Citation: Montejo, J., Arcila, M., & Zornosa, D. (2023). Integrated Seismic Catalog for Colombia. *Boletín Geológico, 50*(1). https://doi.org/10.32685/0120-1425/bol.geol.50.1.2023.665

2020. Las soluciones preferidas incluidas en el CSI tienen valores de magnitud homogeneizados a magnitud de momento (Mw), utilizando transformaciones en los casos en donde este valor no se estimó por su fuente original, y en su lugar se calculó un tipo de magnitud diferente. Se espera que el CSI sirva como insumo o referencia para generar modelos de amenaza y caracterizar fuentes sismogénicas, puesto que busca integrar diferentes soluciones de localización y magnitud, estandarizadas a los parámetros más utilizados en la actualidad.

Palabras clave: sismología, sismicidad regional, sismicidad histórica, Suramérica, Centroamérica, Caribe, peligro sísmico.

1. INTRODUCTION

Colombia is a seismically active country with four well defined tectonic environments namely i) shallow earthquakes of crustal origin, with depths up to 60 km; ii) Pacific interplate subduction earthquakes, with depths up to 60 km; iii) subduction earthquakes, in the western Andes region, ocurring at intermediate depths below 60 km; and iv) earthquakes associated with the Bucaramanga seismic nest, which occur at depths greater than 100 km (Arcila et al., 2020; Ojeda and Havskov, 2001; Pedraza et al., 2007; Syracuse et al., 2016; Yarce et al., 2014). Since 1993 the seismicity in Colombia is monitored by the national seismic network (RSNC, from its abbreviation in Spanish), a permanent array of seismic stations located mainly on the Andes mountain range, includying several of the major cities, such as Bogotá, Cali, Medellín, Bucaramanga, Pasto and Pereira. Due to the complex tectonic environments in the country and the spatial and temporal limitations of the RSNC, it is pertinent to consult international seismic sources, which may have more accurate solutions regarding the magnitude and location of earthquakes. This is true for regions where the existing RSNC contains large uncertainties or with insufficient coverage. Furthermore, data from external sources is needed to assess seismic activity during periods when the network was not yet operational.

Since the publication of the *National Seismic Hazard Model* (MNAS, for its abbreviation in Spanish) of Colombia (Arcila et al., 2020) by the Servicio Geológico Colombiano (SGC) and the GEM foundation, the SGC continues to perform improvements for the model that yield results with fewer uncertainties and that better describe the national territory. These improvements include the development of new models for ground motion prediction, such as the one published by Arteta et al. (2021) for subduction earthquakes in the Colombian-Ecuadorian Pacific domain, the model published for crustal earthquakes by Arteta et al. (2023) and the site effects estimation model proposed by Mercado et al. (2023); and a new Integrated Seismic Catalog (CSI), presented in this work, built from the experience of the MNAS to select the best quality data sources that contribute the most to the study of the seismicity within the region.

For the construction of this CSI, a quadrant between −84° and −66° longitude and −5° and 16° latitude was chosen to include the seismicity that contributes most to the seismic hazard for the continental and insular regions of Colombia. Due to the area selected for the CSI, it was possible to consult different global and national catalogs that use different data sources and techniques for calculating the magnitudes and locations of earthquakes, including for example, regional catalogs developed for Ecuador and Central America.

Therefore, and as presented in this article, to compile the CSI the data from the different sources needed to be converted into the moment magnitude (M_W) scale. This was because many of the sources utilize other types of scales and units to discuss seismic events such as body wave magnitude (m_b), surface wave magnitude (M_s), earthquake duration magnitude (M_d), or local magnitude scales (M_L). The standardization and the compilation of regional studies, including those of relocation and historical seismicity carried out by the SGC, allow the CSI to be more complete and have less uncertainty than other international catalogs such as the one presented by the International Seismological Centre (2022a).

This article summarizes the CSI generated for Colombia and presents an overview of the data as well as the methodology and techniques necessary to consolidate the datasets, the web repository where they can be consulted and includes recommendations for their use.

2. DESCRIPTION OF THE DATA

The new version of the seismic catalog contains more than 16 000 seismic events, including aftershocks, each one characterized by the following attributes: i) time of origin (UTC time format), ii) location (latitude and longitude), iii) depth and uncertainty, iv) moment magnitude (M_w), and v) source cata-

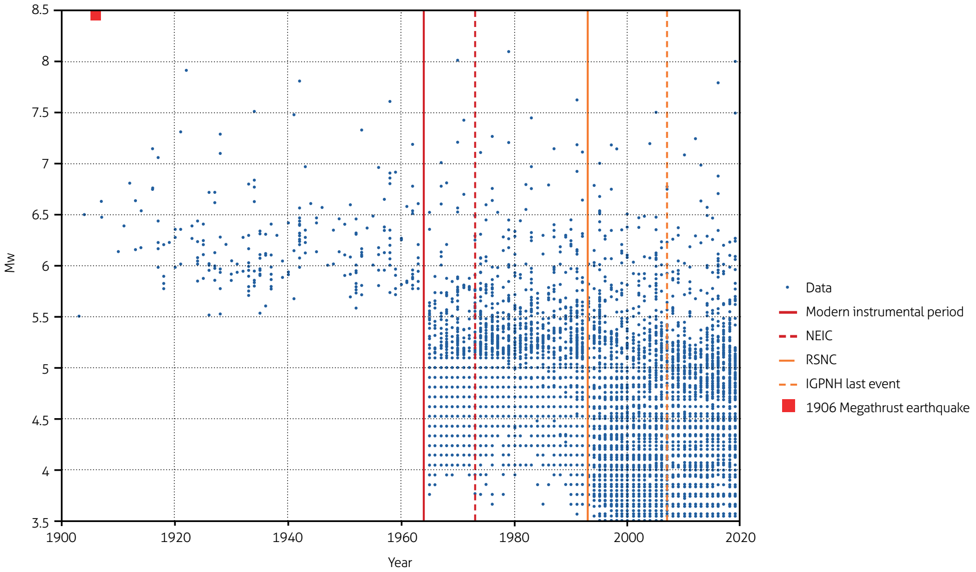


Figure1. Temporal distribution of Mw since 1900

log from which the information of location and magnitude are taken. The distribution of the *Mw* values over time is shown in Figure 1, where important changes in the nature of the CSI are highlighted, such as the beginning of the modern instrumental period in 1964, the founding of the National Earthquake Information Center (NEIC) by the United States Geological Survey (USGS) in 1973, the implementation of the RSNC in 1993, and the last year (2007) presented by the homogenized catalogue developed by the Instituto Geofísico of the Escuela Politécnica Nacional of Ecuador (IGEPN), which magnitude is provided by Font et al. (2013). The earthquake with the largest event in the catalog is the 1906 Colombia-Ecuador earthquake with an estimated magnitude of M_w 8.45 (International Seismological Centre (ISC-GEM), 2022). This event is also identified in Figure 1.

The binned and cumulative distributions of earthquakes per year are shown in Figures 2a y 2b respectively. In these figures, reference lines are drawn at the same corner periods as for Figure 1 (i.e, 1964, 1973, 1993 and 2007). As expected, changes in the recorded seismicity appear to coincide with the reference years as evidenced by the change in slope in the cumulative distribution curve (Figure 2b). These figures are based on previous studies, such as those presented by Hutton et al. (2010), Gónzalez (2017) and Öztürk (2017).

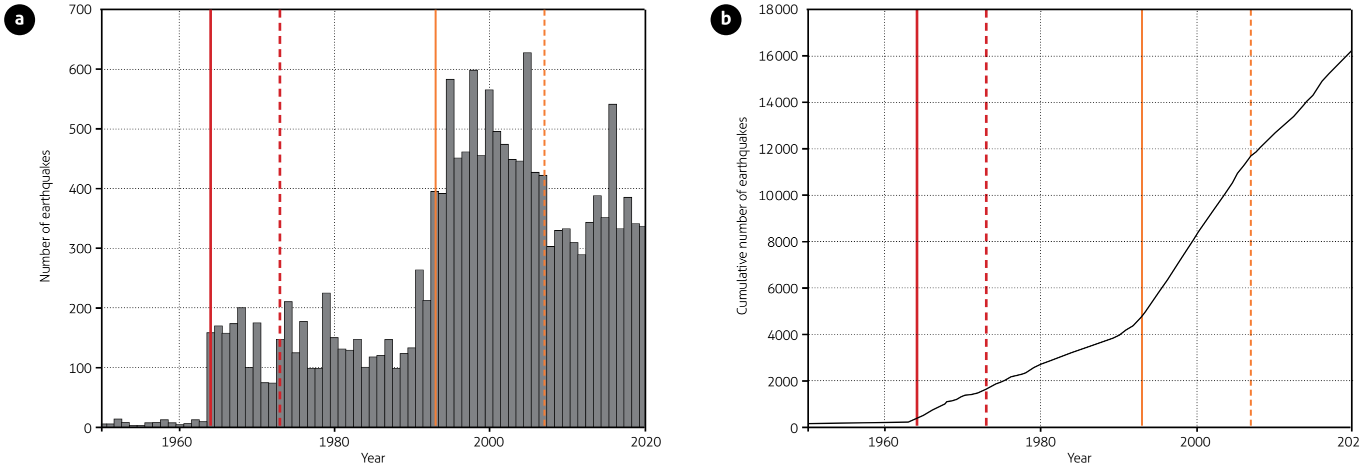


Figure 2. a) Histogram of the number of events per year; b) number of accumulated events over time per year

Finally, the spatial distribution of the data within the catalog is presented in Figure 3. The summary of the general statistics for the different periods, including the first cataloged event in 1610, is shown in Table 1. Although the statistics indicate a higher median magnitude in the pre-instrumental period (M_w 6.2), it is necessary to point out that earthquakes with M_w less than 5.5 were difficult to record before 1963. Thus, the average value decreased as monitoring improved over time.

Additionally, Table 2 presents the depths for shallow (depth ≤ 60 km) and intermediate earthquakes (depth > 60 km). Due to the improvements in monitoring discussed above, it was determined that, when considering the complete catalog, the average depth of shallow earthquakes was approximately 20 km, with a median value of 15 km. For the intermediate seismic events included in the complete catalog, the average depth was approximately 147 km, with a median of approximately 154 km.

The CSI contains a list of earthquakes with their preferred solution, in terms of magnitude and location, which are selected from what we called *candidate solutions* for the purpose of this work. The preferred solutions were determined by ranking the candidate solutions from regional and international earthquake catalogs using the methodology and criteria presented in Section 4. The inputs and detailed methodology for the construction of these candidates are presented in the following sections. The data of the CSI is arranged in a table format in Microsoft Excel. The attributes of the catalog are described in table 3.

Table 1. General statistics of the CSI in terms of magnitudes

Period		Number of events	Mw			
Initial year	Final year		Min.	Max.	Median	Mode
1610	1963	268	5.5	8.5	6.2	6.1
1610	1973	1683	3.8	8.5	4.7	4.4
1610	1993	4862	3.5	8.5	4.8	4.7
1610	2007	11713	3.5	8.5	4.3	3.5
1610	2020	16291	35	8.5	4.3	3.5

Table 2. General statistics of CSI depths for shallow earthquakes and intermediate depths

Period		Shallow earthquakes			Intermediate seismicity		
Initial year	Final year	Number of events	Median	Mode	Number of events	Median	Mode
1610	1963	262	15	15	6	131	N/A
1610	1973	1129	20	35	554	160	166
1610	1993	3200	20	35	1662	158	166
1610	2007	6834	16	35	4879	154	166
1610	2022	9619	15	35	6672	154	166

Table 3. Description of attributes of the data presented

Field	Description:	Format	Units	Example
Date and time in UTC, [dd/mm/yyyy, hh:mm:ss]	Date and time of origin of the event in the UTC reference system	Date type text	dd/mm/yyyy hh:mm:ss	07/03/2004 21:36:17
Longitude, [degrees]	Epicentral longitude	Numerical	Decimal degrees in WGS84	-74.25
Latitude, [degrees]	Epicentral latitude	Numerical	Decimal degrees in WGS84	6.2
Location error	Error in the estimation of the epicentral location, reported by the original source	Text	Component error, in km *	errorLat = 12.6, errorLon = 62.1
			Error ellipsoid**	smajax = 9.8, sminax = 7.2, strike = 67.7
		Numerical	Estimated error distance, in km***	5.4
Depth, [km]	Hypocentral depth	Numerical	km	30
Depth error, [km]	Error in the estimation of hypocentral depth, reported by the original source	Numerical	km****	4.5
Author location	Regional or global catalog from which the localization solution was taken	Text	N/A	ISC-GEM
Magnitude [M_w]	Magnitude of the event	Numerical	Mw	5.2
Error	Magnitude error, which corresponds to the error of the transformation used to standardize the magnitudes in terms of Mw	Numerical	Mw	0.1
Source magnitude	Regional or global catalog from which the magnitude solution was taken	Text	N/A	ISC-EHB

* Sources such as the SGC express the error as the possible uncertainty in km of latitude and longitude. ** Sources such as ISC express the epicentral location error in terms of azimuth and principal axes of the error ellipse. In the case of the sources reported by the revised ISC (ISC, IDC, CASC) and the ISC-EHB, the ellipse has a confidence level of 90%. *** Sources such as the USGS ANSS catalog express the epicentral location error only with a distance in km. **** Due to its calculation method and source of information, the sources ISC-GEM, ISC-EHB, CASC, IDC and ISC, the depth error corresponds to the error associated with the 90% range. In the case of NEIC, this value is defined as the largest projection of the three main errors on the vertical axis.

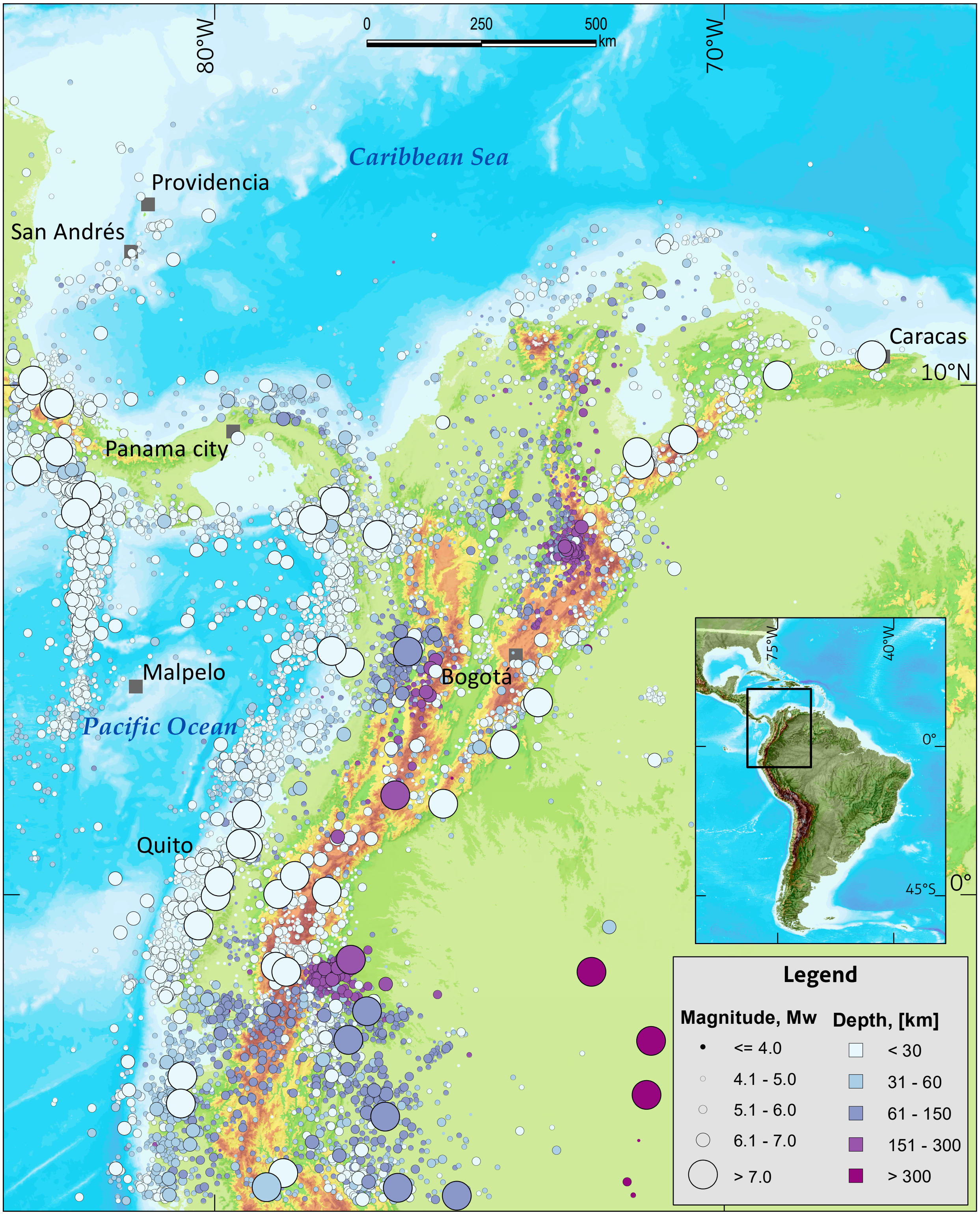


Figure 3. Location of preferred soluction of the CSI

3. The importance of the CSI for the assessment of the seismic hazard in Colombia

The CSI is expected to be a fundamental input for the seismic hazard assessment in the Colombian territory. The different available seismic catalogs that cover the region were integrated into the CSI where the information can be presented in a homogeneous way and using the moment magnitude (M_w) scale, which is currently the most accepted parameter to evaluate the seismic hazard.

There are a large number of scientists, specialists and institutions dedicated to locating earthquakes and estimating their magnitude according to different methodologies, calculation methodologies and data source. The CSI was created from the necessity of capturing the best magnitude and location estimations, after evaluating and prioritizing the available information from the best sources based on its methodologies, criteria, rigor and geographic coverage over the study area.

4. Inputs and methodology for the compilation, homogenization, and processing of the CSI

As mentioned before, regional and international earthquake catalogs were examined as an initial step for the creation of the CSI. The earthquake catalogs considered and the methodology for their integration are described in sections 4.1 and 4.2, respectively.

4.1. Inputs

Tables 3 and 4 summarize the catalogs used to collect the data for the CSI and the data retrieved from each. The attributes considered from each catalog, namely the number of solutions examined, magnitude, location range (long, lat), period range and online source, are shown in Table 4. Although each catalog has a generic author, a specific abbreviated name was used for each catalog included in the CSI, which identifies each data subset from that author that has been considered separately in the processing and prioritization of the candidate solutions.

Table 4. General description of the regional catalogs consulted

Author	Abbreviated name	Number of solutions	Magnitude Scale	Period	Long. range	Lat. range	Remarks	Download page
Instituto Geofísico of the Escuela Politécnica Nacional of Ecuador (IGEPN)	IGEPNH	3545	M_w	1994 to 2007	-81.21 to -77.09	-2.87 to 1.45	- The standardized catalog built by the IGEPN was included. - Only the solutions whose referred author was 'FONT' were included. - Data published by Beauval et al. (2013).	https://www.igepn.edu.ec/catalogos-seismicos/formulario-catalogos-seismicos
Servicio Geológico Colombiano (SGC)*	SGC I	8125	M_L, M_w, M	1993 to 2020	-79.32 to -71.908	0.71 to 10.39	- Events located by the SGC were included, identified within the reliability polygon defined by Arcila et al. (2020). - Only events with magnitudes greater than 3.5 were accepted into the SGC database.	http://bdrsnc.sgc.gov.co/paginas1/catalogo/index.php
	SGC O	904	M_L, M_w, M, m_b, *M	1993 to 2020	-84.12 to -69.02	-2.17 to 13.67	- Events located by the SGC identified outside the polygon of reliability defined by Arcila et al. (2020). -Only events with magnitudes greater than 3.5 were included in the SGC database.	
	SGC_ReLoc	895	N/A	1993 to 2020	-82.79 to -70.35	0.01 to 9.99	- Relocated events were included using the information recorded by the SGC.	This dataset is in the process of being published
	SGC_SISH	81	M_w, M_S, M	1644 to 2016	-71.08 to -81.52	0.53 to 12.61	- The SGC Catalog of historical earthquakes. - These events were used mainly to cover the preinstrumental period (prior to 1964).	http://sish.sgc.gov.co/visor/
Central American Seismic Center (CASC)	CASC	177	M_w, m_b, M_d	1998 to 2010	-84.99 to -77.93	10.00 to 15.59	- For the search of this regional catalog, the preferred solutions were consulted (*prime*, see definition in Di Giacomo and Storchack, 2016) of the revised catalog of the ISC whose author is CASC (Alvarenga et al., 1998). - This catalog was filtered using a smaller polygon to complement the catalog in the area near San Andrés archipielago.	http://www.isc.ac.uk/iscbulletin/search/bulletin/

* M corresponds to types of unknown magnitude types.

Table 5. General description of the global catalogs consulted

Author	Abbreviated name	Number of solutions	Magnitude Scale	Period	Long. range	Lat. range	Remarks	Download page
Global Centroid Moment Tensor Catalog	GCMT	1133	M_w	1976 to 2020	-85 to -67.01	-5.95 16.42	- The GCMT catalog (Ekström et al., 2012; Dziewonski et al., 1981) was consulted only to use the reported magnitudes.	https://ds.iris.edu/spud/momenttensor It can also be consulted directly at: https://www.globalcmt.org/CMTsearch.html
International Seismological Centre (ISC)	IDC	57	M_S, m_b	2020 to 2020	-84.99 to -67.55	-5.84 to 11.29	- For the search of this global catalog, the *prime* solutions of the ISC catalog that have the International Data Center (IDC) as author were consulted. The events from May 2020 were used to cover the time not yet covered by the revised ISC catalog.	http://www.isc.ac.uk/iscbulletin/search/bulletin/
ISC and the Global Earthquake Model (GEM) Foundation	ISC-GEM	1556	M_w	1904 to 2018	-68.60 to -84.95	-5.99 to 16.76	- The latest available version of this catalog was used, this is version 9 and it was released on March 15, 2022. (ISC, 2022b; Storchak et al., 2013; Storchak et al., 2015).	http://www.isc.ac.uk/iscgem/download.php
ISC-EHB Bulletin	ISC-EHB	3503	M_w, m_b, M_S	1964 to 2018	-84.97 to -66.47	-4.99 to 14.7	- The latest available version of this catalog was used for the start date of the CSI, with solutions up to December 2018. (ISC, 2022c; Weston et al., 2018; Engdahl et al., 2020; Engdahl et al., 1998).	http://www.isc.ac.uk/isc-ehb/
International Seismological Centre	ISC	19568	M_b, M_S	1964 to 2020	-84.99 to -5.053	-5.9967 to 16.9984	- The latest available version of the revised ISC catalog was used. Only the *prime* solutions authored by the ISC were consulted.	http://www.isc.ac.uk/iscbulletin/search/bulletin/
ANSS Catalog of the National Earthquake Information Center (NEIC) of the U.S. Geological Survey (USGS)	NEIC	9313	M_w, M_b, M_S, M*	1973 to 2022	-85 to -65.01	-5.99 to 16.99	- The revised solutions with magnitudes greater than 2.5 were downloaded, as a default parameter on the download page. - Only solutions with author 'us' were taken into account (USGS, 2017).	https://earthquake.usgs.gov/earthquakes/search/
GEM Foundation (Albini et al., 2013)	GEM_H	14	M_w	1610 to 1894	-83.15 to -67.1	-1.73 to 10.6	- Catalog of historical earthquakes of the GEM Foundation. - Some solutions were discarded based on the historical catalog of the SGC.	https://storage.globalquakemodel.org/what/seismic hazard/historical catalog/

* M corresponds to types of unknown magnitude types.

4.2. Methodology

The methodology followed is based on that described in Arcila et al. (2020), which consists of four main steps:

- *Preprocessing*. Duplicated solutions presented by the same catalog were revised and collapsed into a single solution per catalog. This yielded few duplicate solutions within the same catalog and allowed us to debug and update the version of the event catalog presented on the SGC web portal.
- *Grouping*. The candidate solutions are grouped in time and space with defined spans based on observations made from the collected data to identify the different locations and magnitude solutions for the same earthquake. This process included the identification and review of the best solution under two specific cases: when a candidate solution can be grouped with two different preferred solutions (that is, two different earthquakes) based on the grouping thresholds and when two candidate solutions from the same source could be grouped within the same preferred solution (the same earthquake).
- *Prioritization*. For each seismic event, the best magnitude and location solution is selected using priority matrices defined in accordance with the criteria presented in Arcila et al. (2020).
- *Conversion of magnitudes*. The magnitudes reported by each of the regional and global catalogs consulted homogenized to moment magnitude (M_w).

The methodology described here, for the update of the CSI, is similar to that presented in Arcila et al. (2020). Nonetheless, the following relevant improvements were introduced with respect to the latter:

- Identification of different events from the same source that can fall into the same group, as detailed in the groupping.
- Prioritization of sources by catalog and not by author. With this, the priority matrices were simplified, and sources with large uncertainties were discarded. Additionally, for reducing the uncertinties only subsets of data from completes catalogs such as NEIC and IGEPN were used after discarding data with different criterions described in Tables 3 and 4.
- *The minimum magnitude value in the catalog was limited to* M_w *3.5*. In the first version of the CSI, the cut-off magnitude was set at M_w 3.0. However, those events are not normally considered for hazard assessment and may include greater uncertainties in terms of magnitude estimates.

4.2.1. Grouping

The grouping process starts by setting six analysis periods delimited by the corner periods of 1964, 1973, 1993, 2000 and 2007 that were previously defined in Section 2. The reasoning behind the analysis periods is to recognize the increasing precision in the earthquake solutions in more recent times.

In each analysis period the differences in epicentral distances (D_s) and ocurrence times (D_t) between the candidate solutions are computed. The calculation of D_s was performed radially, for which it was assumed that the dimension of the degrees in longitude and latitude remained constant within the study area due to its near-equatorial location. Assuming that, in each analysis period, the calculated differences/ errors residuals follow a statistical distribution, the percentiles of such distribution can be computed as shown in Figure 4a (for epicentral distances) and 4b (for ocurrence times). Outliers are visually identified and removed from the data.

From the final CSI we can define thresholds of relative distance (D_s) and relative time (D_t) setting the 99th percentile as a target. The thresholds estimated for each analysis period are summarized in Table 6. In turn, these thresholds can be used to identify the likely solutions that correspond to same event (i,e. earthquake solutions with relative differences below the defined thresholds), and to group and prioritize the resulting location and magnitude solutions.

The thresholds chosen will always be subject of debate because of increased uncertainty and dispersions for offshore earthquakes or events recorded in the older periods. However, the maximum values chosen represented less than 1% of the combined solutions. Considering the above and as an example, Figure 4 shows the percentiles that exceed 85% of the maximum D_s and D_t values obtained for each cluster. This analysis of percentiles, demonstrates how a threshold close to 0.2° allows for 85% of the solutions to be grouped correctly and how a threshold of 0.1 minutes allows for the temporal grouping of more than 99% of the preferred solutions.

Table 6. Grouping thresholds

Up to	D_t, [minutes]	D_s, [°]
1964	0.2	0.1
1973	0.07	0.33
1993	0.12	0.77
2000	0.16	0.82
2007	0.13	0.66
>2007	0.1	0.42

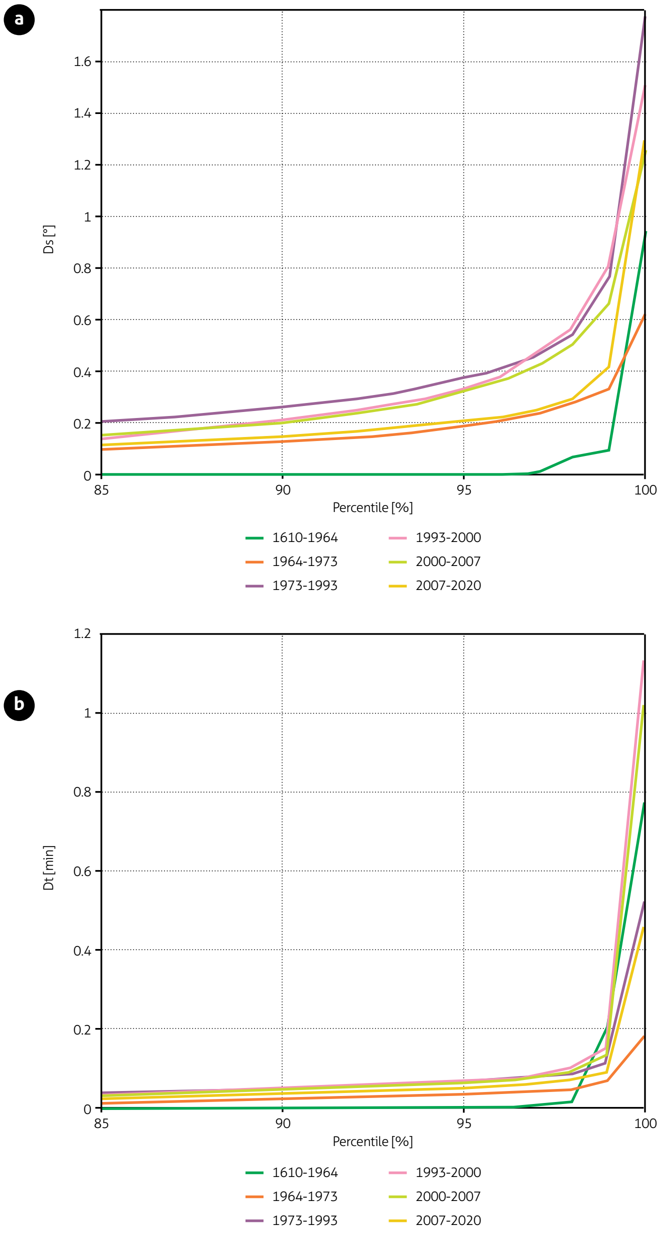


Figure 4. Distribution of percentiles of clusters *Ds* and *Dt* product of the final clustering

4.2.2. Prioritization

The location and magnitude considered were prioritized based on the information and methodologies used to build each of the consulted catalogs. Consistent with the methodology discussed above, a magnitude prioritization matrix, as described in Table 7, and a location prioritization matrix, as summarized in Table 8, were defined to select the best option for each of these variables within the candidate solutions.

The order by which magnitudes from the same source were prioritized, was: M_w, M_s, m_b, M_L and, finally, M_d. This ranking is consistent with the system used in the ISC Bulletin (Di Giacomo and Storchack, 2016). The type of prioritization, in terms of sources, corresponds to the comparison of the methodologies used and the uncertainties associated with each. An example of this is that the source with the highest priority is the GCMT, which performed moment tensor inversions to obtain a stable value of M_w. The lowest priority sources were those that included information on macroseismic intensities when estimating magnitudes during the preinstrumental period, this was the case for events within the GEM_H and SGC_SISH catalogs. Finally, for the prioritization of magnitudes, some sources, or types of magnitude (depending on the source), were discarded. This included those catalogues provided by the ISC-EHB and the SGC_ReLoc, which neither calculated nor reviewed the magnitudes associated with the events. Therefore, not all the magnitudes summarized in Tables 3 and 4 were among those prioritized.

In terms of location prioritization, the process was similar and resulted in the highest prioritization of sources that used algorithms to review locations and depths, such as the ISC-EHB and SGC_ReLoc. Sources with the lowest prioritization correspond to those with larger uncertainties stemming from inadequate network coverage, such as the SGC_O and CASC.

Consistent with the above methodologies, a preferred solution was constructed for each group of candidate solutions with the best information available for each earthquake.

Table 7. Priority matrix for magnitudes

Priority	Type of magnitude	Source catalog
1	M_w	GCMT
2	M_w	NEIC
3	M_w	ISC-GEM
4	M_w	IGEPNH
5	M_w	SGC_SISH
6	M_w	GEM_H
7	M_s	ISC
8	M_s	ANSS
9	M_s	IDC
10	m_b	ISC
11	m_b	ANSS
12	m_b	IDC
13	M_L	SGC_I
14	M_L	SGC_O
15	m_b	CASC
16	M_d	CASC

Table 8. Priority matrix for localization

Priority	Source catalog
1	SGC_ReLoc
2	ISC-EHB
3	ISC
4	ISC-GEM
5	SGC_I
6	NEIC
7	IGEPNH
8	IDC
9	CASC
10	SGC_O
11	SGC_SISH
12	GEM_H

4.2.3. Conversion of Magnitudes

For the homogenization/standardization of magnitudes to moment magnitude (M_w), we use the relationships proposed by Arcila et al. (2020) for M_L, m_b and Ms and the relationship proposed by Salazar et al. (2013) for M_d from the CASC catalog. For this particular case, only solutions with a standardized M_w value greater than or equal to 3.5 were considered.

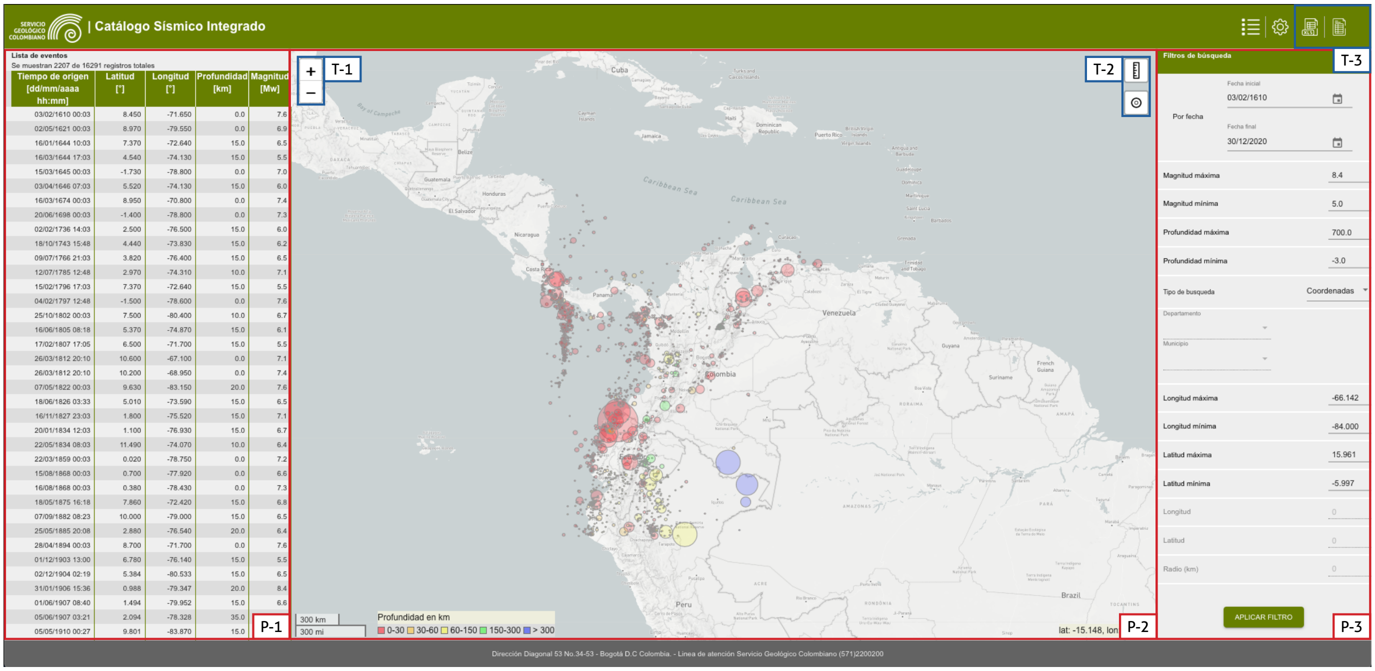
5. PUBLICATION OF CSI DATA

The updated version of the CSI catalog can be accesed online at https://catalogosismico.sgc.gov.co/visor/index.html. The data can be visualized in a map viewer or can be directly downloaded from the link provided.

5.1. Data access

The data viewer is divided into three main panels (Figure 5). Panel P-1 shows a sample of the query as a table, with the time of origin (UTC), the location and the value of M_w for each preferred solution. Panel P-2 presents the results of the query as a map. Panel P-3 displays a series of options to perform the queries (including ranges of depth, magnitude, date and location). Queries can be conducted by radial searches, by latitude-longitude quadrants, or by location in terms of municipality and department.

For the use and extraction of data, the viewer has some additional tools, such as the zoom controls (T-1), which can increase or decrease magnification of the map view; the ruler to measure distances within the map and the reset view button (T-2); and the export data controls (T-3), which allows for either the complete CSI or the results of a specific query to be exported in Excel format.



Lista de eventos
Se muestran 2207 de 16291 registros totales

Tiempo de origen [dd/mm/aaaa hh:mm]	Latitud [°]	Longitud [°]	Profundidad [km]	Magnitud [Mw]
03/02/1610 00:03	8.450	-71.650	0.0	7.6
02/05/1621 00:03	8.970	-79.550	0.0	6.9
16/01/1644 10:03	7.370	-72.640	15.0	6.5
16/03/1644 17:03	4.540	-74.130	15.0	5.5
15/03/1645 00:03	-1.730	-78.800	0.0	7.0
03/04/1646 07:03	5.520	-74.130	15.0	6.0
16/03/1674 00:03	8.950	-70.800	0.0	7.4
20/06/1698 00:03	-1.400	-78.800	0.0	7.3
02/02/1736 14:03	2.500	-76.500	15.0	6.0
18/10/1743 15:48	4.440	-73.830	15.0	6.2
09/07/1766 21:03	3.820	-76.400	15.0	6.5
12/07/1785 12:48	2.970	-74.310	10.0	7.1
15/02/1796 17:03	7.370	-72.640	15.0	5.5
04/02/1797 12:48	-1.500	-78.600	0.0	7.6
25/10/1802 00:03	7.500	-80.400	10.0	6.7
16/06/1805 08:18	5.370	-74.870	15.0	6.1
17/02/1807 17:05	6.500	-71.700	15.0	5.5
26/03/1812 20:10	10.600	-67.100	0.0	7.1
26/03/1812 20:10	10.200	-68.950	0.0	7.4
07/05/1822 00:03	9.630	-83.150	20.0	7.6
18/06/1826 03:33	5.010	-73.590	15.0	6.5
16/11/1827 23:03	1.800	-75.520	15.0	7.1
20/01/1834 12:03	1.100	-76.930	15.0	6.7
22/05/1834 08:03	11.490	-74.070	10.0	6.4
22/03/1859 00:03	0.020	-78.750	0.0	7.2
15/08/1868 00:03	0.700	-77.920	0.0	6.6
16/08/1868 00:03	0.380	-78.430	0.0	7.3
18/05/1875 16:18	7.860	-72.420	15.0	6.8
07/09/1882 08:23	10.000	-79.000	15.0	6.5
25/05/1885 20:08	2.880	-76.540	20.0	6.4
28/04/1894 00:03	8.700	-71.700	0.0	7.6
01/12/1903 13:00	6.780	-76.140	15.0	5.5
02/12/1904 02:19	5.384	-80.533	15.0	6.5
31/01/1906 15:36	0.988	-79.347	20.0	8.4
01/06/1907 08:40	1.494	-79.952	15.0	6.6
05/06/1907 03:21	2.094	-78.328	35.0	
05/05/1910 00:27	9.801	-83.870	15.0	

Profundidad en km
🟥 0-30 🟧 30-60 🟨 60-150 🟩 150-300 🟦 > 300

Filtros de búsqueda

Por fecha	Fecha inicial 03/02/1610 Fecha final 30/12/2020
Magnitud máxima	8.4
Magnitud mínima	5.0
Profundidad máxima	700.0
Profundidad mínima	-3.0
Tipo de busqueda	Coordenadas
Departamento	
Municipio	
Longitud máxima	-66.142
Longitud mínima	-84.000
Latitud máxima	15.961
Latitud mínima	-5.997
Longitud	0
Latitud	0
Radio (km)	0

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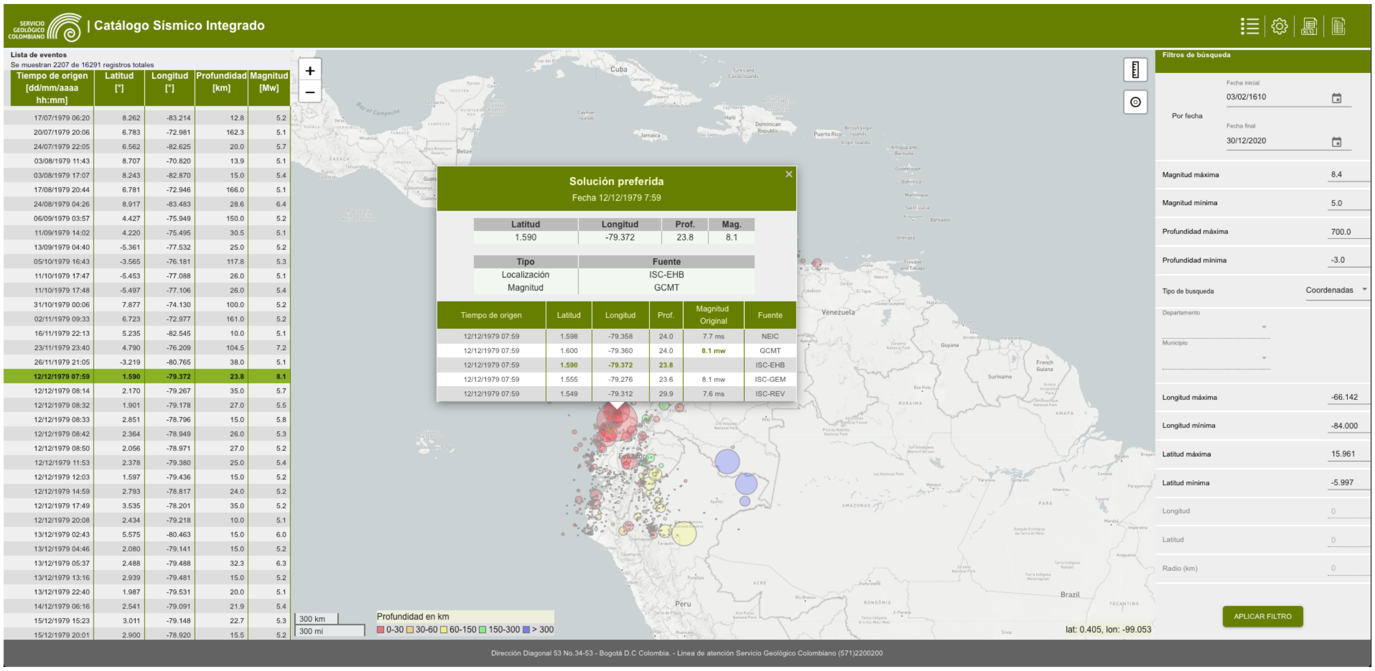
Figure 5. Structure of the viewer

In terms of navigation, there is a dynamic relationship between panels P-1 and P-2. When selecting an event in either of the two panels, the information regarding the candidate solutions evaluated in P-2 is displayed, and the preferred solution is highlighted in the table in panel P-1 (Figure 6).



Lista de eventos
Se muestran 2207 de 16291 registros totales

Tiempo de origen [dd/mm/aaaa hh:mm]	Latitud [°]	Longitud [°]	Profundidad [km]	Magnitud [Mw]
17/07/1979 06:20	8.262	-83.214	12.8	5.2
20/07/1979 20:06	6.783	-72.981	162.3	5.1
24/07/1979 22:05	6.562	-82.625	20.0	5.7
03/08/1979 11:43	8.707	-70.820	13.9	5.1
03/08/1979 17:07	8.243	-82.870	15.0	5.4
17/08/1979 20:44	6.781	-72.946	166.0	5.1
24/08/1979 04:26	8.917	-83.483	28.6	6.4
06/09/1979 03:57	4.427	-75.949	150.0	5.2
11/09/1979 14:02	4.220	-75.495	30.5	5.1
13/09/1979 04:40	-5.361	-77.532	25.0	5.2
05/10/1979 16:43	-3.565	-76.181	117.8	5.3
11/10/1979 17:47	-5.453	-77.088	26.0	5.1
11/10/1979 17:48	-5.497	-77.106	26.0	5.4
31/10/1979 00:06	7.877	-74.130	100.0	5.2
02/11/1979 09:33	6.723	-72.977	161.0	5.2
16/11/1979 22:13	5.235	-82.545	10.0	5.1
23/11/1979 23:40	4.790	-76.209	104.5	7.2
26/11/1979 21:05	-3.219	-80.765	38.0	5.1
12/12/1979 07:59	**1.590**	**-79.372**	**23.8**	**8.1**
12/12/1979 08:14	2.170	-79.267	35.0	5.7
12/12/1979 08:32	1.901	-79.178	27.0	5.5
12/12/1979 08:33	2.851	-78.796	15.0	5.8
12/12/1979 08:42	2.364	-78.949	26.0	5.3
12/12/1979 08:50	2.056	-78.971	27.0	5.2
12/12/1979 11:53	2.378	-79.380	25.0	5.4
12/12/1979 12:03	1.597	-79.436	15.0	5.2
12/12/1979 14:59	2.793	-78.817	24.0	5.2
12/12/1979 17:49	3.535	-78.201	35.0	5.2
12/12/1979 20:08	2.434	-79.218	10.0	5.1
13/12/1979 02:43	5.575	-80.463	15.0	6.0
13/12/1979 04:46	2.080	-79.141	15.0	5.2
13/12/1979 05:37	2.488	-79.488	32.3	6.3
13/12/1979 13:16	2.939	-79.481	15.0	5.2
13/12/1979 22:40	1.987	-79.531	20.0	5.1
14/12/1979 06:16	2.541	-79.091	21.9	5.4
15/12/1979 15:23	3.011	-79.148	22.7	5.3
15/12/1979 20:01	2.900	-78.920	15.5	5.2

Solución preferida
Fecha 12/12/1979 7:59

Latitud	Longitud	Prof.	Mag.
1.590	-79.372	23.8	8.1

Tipo	Fuente
Localización	ISC-EHB
Magnitud	GCMT

Tiempo de origen	Latitud	Longitud	Prof.	Magnitud Original	Fuente
12/12/1979 07:59	1.598	-79.358	24.0	7.7 ms	NEIC
12/12/1979 07:59	1.600	-79.360	24.0	**8.1 mw**	GCMT
12/12/1979 07:59	**1.590**	**-79.372**	**23.8**		ISC-EHB
12/12/1979 07:59	1.555	-79.276	23.6	8.1 mw	ISC-GEM
12/12/1979 07:59	1.549	-79.312	29.9	7.6 ms	ISC-REV

Profundidad en km
🟥 0-30 🟧 30-60 🟨 60-150 🟩 150-300 🟦 > 300

Filtros de búsqueda

Por fecha	Fecha inicial 03/02/1610 Fecha final 30/12/2020
Magnitud máxima	8.4
Magnitud mínima	5.0
Profundidad máxima	700.0
Profundidad mínima	-3.0
Tipo de busqueda	Coordenadas
Departamento	
Municipio	
Longitud máxima	-66.142
Longitud mínima	-84.000
Latitud máxima	15.961
Latitud mínima	-5.997
Longitud	0
Latitud	0
Radio (km)	0

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Figure 6. Detailed information of each preferred solution

5.2. Summary of data specifications

Table 9 presents a summary of the general specifications of the datasets that comprise the CSI.

Table 9. General specification of CSI data

Subject	Earth Sciences (Geophysics)
Specific subject area	Seismic hazard, Location of seismic events, Integrated seismic catalog.
Data type	Table/Viewer.
How the data was acquired	The most recent versions of the international and regional catalogs were downloaded. The candidate solutions for each event from the different catalogs were grouped, using spatiotemporal thresholds that vary with respect to the year of occurrence. Finally, priority matrices were built to identify the best solution, or preferred solution, for both the location and the magnitude.
Data format	Processed, analyzed (Microsoft® Excel® table, * xlsx) [An alternative to consider would be the * csv format, which is free, instead of the * xlsx, which is a proprietary Microsoft format].
Parameters for data collection	The data can be queries by parameter, such as magnitude, time of origin, and location.
Description of data collection	The catalogs used as inputs were downloaded from the official *websites* of each of the different data providers.
Data source location	Northwest of South America, in a polygon between -66° and -85° of longitude and -5° and 16° of latitude.
Data accessibility	The data is free at the following link: https://catalogosismico.sgc.gov.co/visor/index.html

6. Usefulness and application of the CSI

It is expected that the main use of the CSI will be to characterize seismic sources based on the seismic recurrence curves from a specific seismogenic source or within a specified study area, which has been a fundamental tool for probabilistic seismic hazard assessment since the first studies carried out in California by Gutenberg and Richter (1944). Additionally, the results are generalized and presented in terms of the annual estimation of the number of seismic events with a magnitude equal to or greater than a reference value for the various observation periods (Dutfoy, 2021). However, it is recommended that the end user should disaggregate (i.e., *declustering*) the events and consider the completeness of the CSI, in accordance with the particular use and final objective of the study.

A second potential use of this dataset is to calculate the magnitude values according to the seismogenic sources (Manchuel et al., 2018) because this dataset limits the maximum probable seismic event due to the properties of the crust (Kijko and Graham, 1998).

A third use of the CSI is the application and development of new ground motion models (i.e., *ground motion prediction equations* [GMPE]), since the new generation of these models requires that the magnitude values of the seismic events are expressed in terms of M_w.

A fourth use of the CSI is to define scenarios to evaluate the potential seismic hazard and risk in a given territory. This is because the *National Plan for Disaster Risk Management 2015-2025* (UNGRD, 2016) emphasizes the probabilistic assessment of seismic risk on major cities, which may be accompanied by the assessment of deterministic scenarios of interest for disaster risk management.

Outside of the direct calculation of the seismic hazard assessment, this catalog provides an input for analyses of, among others, regional seismotectonics, the spatiotemporal distributions of earthquakes within the country, and seismic sequences. This is in addition to studies of hazard and risks posed by the secondary disasters triggered by earthquakes, such as mass movement events or landslides.

7. Limitation and use of data

The CSI, being a compilation of other international and regional catalogs, is a product that is undergoing continuous revisions. As such, the CSI will be updated by the SGC to include new information and the grouping thresholds and priority matrices will be revised. Because of this, it is proposed to include a change log to track the changes and subsequent CSI versions within the application.

The CSI was designed using expert criteria to select a single solution of magnitude and location for each seismic event from among the many possible solutions. Users of this information are invited to share their findings and suggestions to improve upon the proposed solutions based on their own criteria for particular studies. This is because the development of the CSI was undertaken with a national scale envisioned.

Due to the characteristics of the data and the heterogeneity of the sources used, analyses such as completeness should be conducted with the understanding that there are periods in which the CSI was standardized according to different occurrences or events that cause its behavior to change over time. Consistent with the description of the data acquisition methods above, it is suggested to consider the years 1964, 1973, 1993 and 2007 as important. Furthermore, some additional years or events can be included, such as 1920, which is when the *classic* period of seismology began, and advances were made, such as the development of the Wood Anderson-type seismograph (Agnew, 1989).

ACKNOWLEDGMENTS

The CSI was sponsored by the Servicio Geológico Colombiano (SGC) with the objective of assessing seismic hazard. Therefore, the authors thank the Seismic Hazard and Risk Assessment and Seismic Activity Assessment and Monitoring working groups. Special thanks is given to Ana Milena Sarabia and Diana Barbosa for their support identifying historical earthquakes and interpreting macroseismic information to ensure the correct development of this product. We are also grateful to David Riobamba and Andrés Camilo Romero for their support in the design and deployment of the CSI web viewer. Special acknowledgments are given to Jaime Eraso and Martha Tovar, former collaborators of the SGC, who developed the first versions of the CSI, which was very useful for the current seismic hazard model developed by the SGC and the GEM foundation. Finally, remarkable greetings to Héctor Pérez, who actively helped to review the spelling of this paper.

CONFLICT OF INTEREST

The authors declare that they have no competing financial interests or personal relationships that could have influenced the work reported in this document.

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