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EXTENSION OF THE ISC-GEM GLOBAL INSTRUMENTAL EARTHQUAKE CATALOGUE

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Abstract

The first version of the ISC-GEM Global Instrumental Earthquakes Catalogue (1900-2009) was released in 2013 (www.isc.ac.uk/iscgem/index.php) following the 27-month project funded by the ISC and GEM Foundation. The catalogue was constructed for use in both global and regional seismic hazard and risk assessment. The main feature of this catalogue is the improved homogeneity and accuracy of the main earthquake parameters (location and magnitude) over a 110-year period of instrumental recordings.

Due to the time and resource limitations of the original project, the ISC-GEM catalogue included only earthquakes greater than or equal to the following time-variable cut-off magnitudes: M_S 7.5 for earthquakes occurring before 1918; M_S 6¼ between 1918 and 1959; and M_S 5.5 from 1960 onwards. With further funding from several commercial and public bodies, we started working on the 4-year Extension project, adding both recent earthquakes as well as those in the early instrumental period that fell below the original cut-off magnitude of 6¼. In this article we present the updated ISC-GEM catalogue, which now includes many thousands of additional large earthquakes that occurred during the 1935-1959 period.

The results of the Extension project will also be helpful for regional cross-border seismic hazard studies. The ISC-GEM catalogue is based primarily on teleseismic station readings and can be used as a reference for cross checking the consistency in location and magnitude of the same earthquakes that are listed in various regional catalogues.

Keywords: homogeneous, global, earthquake, catalogue, magnitude.

1. Introduction

The ISC-GEM Global Instrumental Earthquake Catalogue (ISC-GEM catalogue) was created by the International Seismological Centre (ISC) with the help of several international experts. The original work, covering the 1900-2009 period, was funded by the Member-Institutions of the ISC and a special grant from the Global Earthquake Model Foundation (GEM). As far as the GEM Foundation is concerned, the ISC-GEM catalogue is one of the five GEM global databases, methodologies and tools for use in global seismic hazard area. The other four include the Historical Earthquake Catalogue and Archive (1000-1903), the Active Faults Database and Tool, the Ground Motion Prediction Equations and the Geodetic Strain Rate Model. The ISC perceives the ISC-GEM catalogue as one of its major products and an adaptation and extension of the ISC Bulletin data for use in global and regional seismic hazard and risk analysis.

1.1 The ISC-GEM catalogue: milestones

Following the review and final acceptance of the initial and updated proposals submitted to the GEM Foundation during 2009-2010, the work on the catalogue finally began in April 2010. Within the next 27 months the team of international experts worked together to collect and digitize necessary parametric data, review relevant scientific publications, develop appropriate data processing procedures, and re-compute earthquake hypocentre locations and magnitudes in order to present the results in the form of a publically available catalogue of major earthquake parameters. After several further months spent in final review and reflecting on reviewer comments and suggestions as well as discussing the terms of public release with the GEM Foundation, the first public version of the ISC-GEM catalogue was released in January 2013 [1].

Due to time and resource constraints imposed by the GEM Foundation, we worked towards the following cut-off magnitudes when selecting the earthquakes to be included into the ISC-GEM catalogue [2]:

- 1900-1917: $M_S \geq 7.5$ worldwide plus a selection of smaller shallow events in stable continental areas;
- 1918-1959: $M_S \geq 6¼$;
- 1960-2009: $M_S \geq 5.5$.

Following further work on the catalogue during 2013-2015 two further major versions were released in January 2015 and January 2016 that extended the catalogue in recent years and lowered the magnitude cut-off limits to M_W 5.5 during 1950-1959 and 1935-1949 periods, respectively.

As will be described below, the work on the catalogue continues with the purpose to include further large earthquakes that occurred at the beginning of the 20th century and in recent years.

1.2 Data and methods used in the production of the ISC-GEM catalogue

The full name of the ISC-GEM catalogue implies that unlike the historical GEM catalogue [3], the ISC-GEM catalogue is based on the instrumentally recorded data with the exception of the 1900-1903 period when it relies on the data from [4, 5, 6]. These instrumentally based data include arrival times, amplitudes and periods of body and surface waves. In the early instrumental period (before 1964) these data were collected [7] from historical, mostly paper-based seismic bulletins of individual seismic observatories and networks, as well as global earthquake summaries such as the BAAS [8], ISA [9], ISS [10] and others. From 1964, these data were predominantly sourced from digitally available sources of bulletin information such as the ISC Bulletin [11]. In addition, we used reliable seismic moment and moment magnitude determinations as computed by the Harvard CMT [12] and GCMT [13] projects. We also collected scalar seismic moments and moment magnitudes for individual earthquakes, mostly before 1976, from a multitude of scientific studies that used the original analogue waveform records [14].

The major parameters of earthquake hypocentres and their uncertainties were re-computed based on the collected arrival times of all seismic waves [15, 16] reported by seismic stations and networks worldwide. The hypocentre determination procedure [17] involves a combined use of the EHB [18] and new ISC location procedures [19] based on the *ak135* velocity model [20].

In line with the original requirement, all earthquake magnitudes in the ISC-GEM catalogue are expressed in the M_W scale. Where possible we used the direct determinations. Otherwise, mostly before 1976, we used M_W proxy values based on M_S or m_b magnitudes using our own non-linear regression curves developed during this project [21].

1.3 Format of the ISC-GEM catalogue

The ISC-GEM catalogue is distributed from the dedicated suite of webpages at the ISC website: http://www.isc.ac.uk/iscgem/. The catalogue is protected by the Copyright © 2016 GEM Foundation and the International Seismological Centre with the usage possible under the terms of CC-BY-SA 3.0 (unported) Creative Commons License.

The webpage suite includes a log of updates with a short description of work done for each released version, general overview of the catalogue, as well as the citing, acknowledgement and contact pages.

The distribution package consists of the main and supplementary catalogues along with the visualization kmz-file to be used with the *Google Earth* package.

The ISC-GEM catalogue (both main and supplementary) is a flat comma separated text file that includes the following parameters for each earthquake:

- Date and origin time of the earthquake,
- Latitude and longitude of the epicenter,
- Parameters of error ellipse: length of major and minor semi-axis and the strike angle,
- Quality of epicenter determination (A through D, where A is the highest),
- Hypocentre depth with uncertainty and quality of determination (A through D),
- Moment magnitude with uncertainty and quality (A through D),
- Magnitude source: direct (d) determination or proxy (p) recalculation from other magnitude types,
- Scalar moment and six components of the moment tensor (if available), author (either GCMT or Bibliographical search),
- Unique earthquake identification number.

The ISC-GEM catalogue is a combination of the main and supplementary catalogue. The main catalogue contains those earthquakes where we were able to determine both hypocentre and magnitude parameters with reasonable confidence (quality flags on the epicenter, depth and magnitudes are between A and C). The supplementary catalogue is an essential part that lists those earthquakes for which one of the parameters could not have been determined with reasonable confidence (quality flag D). Usually this is because of poor magnitude determination. Users are advised to use both catalogues in their studies. The cases of poor quality of earthquake parameter determination are a consequence of the sparse recording seismic network and should not be seen as compromising the fact of occurrence of such earthquakes.

2. Benefits to Seismic Hazard Analysis Studies

For those studying global and regional seismic hazard and risk, the ISC-GEM catalogue has obvious advantages over other global comparable sources:

- Unlike other catalogues, the ISC-GEM catalogue covers the entire period of instrumentally recorded seismicity, spanning over approximately 110-year period;
- The earthquake hypocentres are computed using the same global seismic wave velocity model and advanced location technique over almost the entire period of the catalogue coverage;

- The earthquake magnitudes are expressed in the same magnitude scale, M_W, that is appropriate for large earthquakes;
- Both hypocentre parameters and magnitudes are accompanied by comparable estimates of uncertainty and quality of their determination that, in turn, contributes towards more accurate estimation of hazard uncertainties;
- The ISC-GEM catalogue, being a catalogue of large earthquakes, plays an important magnitude calibration role when regional catalogues of seismicity with smaller magnitude cut-offs are complied by researchers from a combination of local, regional and global data;
- The ISC-GEM catalogue, being a product of an operational organization, is constantly updated and extended using newly recovered historical or newly recorded recent earthquake data.

The above reasons have led to a constant demand for the ISC-GEM catalogue from many professionals in the field. The catalogue also gave boost to a number of efforts in improving regional earthquake records with homogeneous magnitude estimates comparable to the ISC-GEM such as EMCA-GEM [22].

3. Extension of the ISC-GEM Catalogue

Having studied the historical summaries of earthquakes in the early instrumental period during the original stage of the ISC-GEM project, we learned that there would be further possibilities to enrich the content of the ISC-GEM catalogue beyond the original requirements of the GEM Foundation.

3.1 Motivation

History shows that several excellent global earthquake catalogues have been discontinued which, as a consequence, has limited their usefulness with time. Examples include the catalogues of Gutenberg-Righter [23] covering the period 1904-1952, Abe [4] covering 1900–1980, Pacheco-Sykes [24] covering 1900-1989 and the Centennial Catalogue [25]. The ISC needed to continue updating the ISC-GEM catalogue to include the recent earthquakes that have had a high impact on the understanding of the earthquake hazard in various regions. Neglecting to update the ISC-GEM catalogue would have also seriously hampered the community efforts of testing and refinement of the earthquake forecasting models.

It is well known that in seismic hazard studies the effect of small to moderate size earthquakes is not negligible. This is especially the case in densely populated and industrialized areas. The L'Aquila earthquake, Italy, occurred on the 6 April 2009 with M_W 6.3 (GCMT) and caused 308 casualties and severe damage in the Abruzzo region. Another recent earthquake of similar size (M_W 6.1-6.3) occurred in New Zealand on 21 February 2011 causing 181 casualties and an evaluated damage of about $15 billion. If similar events occurred in the first half of the 20th century then, due to the uncertainties of magnitude determination and originally applied magnitude cut-off limits, they may or may not be part of the ISC-GEM catalogue. For example, the October 30, 1930 earthquake in Central Italy with an estimated M_W 6.0 is not yet part of the ISC-GEM catalogue, yet it was felt even at large distances and caused collapse and severe damage in Senigallia, Fano, Montemarciano and Ancona in Marche region.

It also has to be noted that there are no magnitude estimates for earthquakes in our main original source of data – the ISS bulletin. Some of these events in the first part of the 20th century could be large enough to have caused damage. The work of including many more earthquakes recorded at teleseismic distances and bringing previously unavailable station amplitude data from historical station bulletins would greatly contribute to more accurate consequent analysis of global earthquake hazard and risk.

3.2 Work plan

Our work plan for years 2013-2017 (Fig. 1) was to continue updating the ISC-GEM catalogue for the years beyond 2009 as well as to incrementally include into the catalogue all known earthquakes in the magnitude range 5.5-6¼ that occurred during the period 1918-1959 and earthquakes in the magnitude range 6¼-7.5 that

occurred during the period 1904-1917. The work for the 1st part of the 20th century is based on existing global earthquake summaries such as ISS [10], complemented with recorded seismic wave amplitude and period data from individual historical observatory bulletins to facilitate the magnitude computation. Finding and digitizing the original amplitude data requires a very large manual effort.

With the support of the sponsors and ISC Member-Institutions, the ISC embarked on the four-year project to gradually, where possible, bring additional earthquakes in the 1st half of the 20th century to approximately the same magnitude level as it was done for the 2nd half.

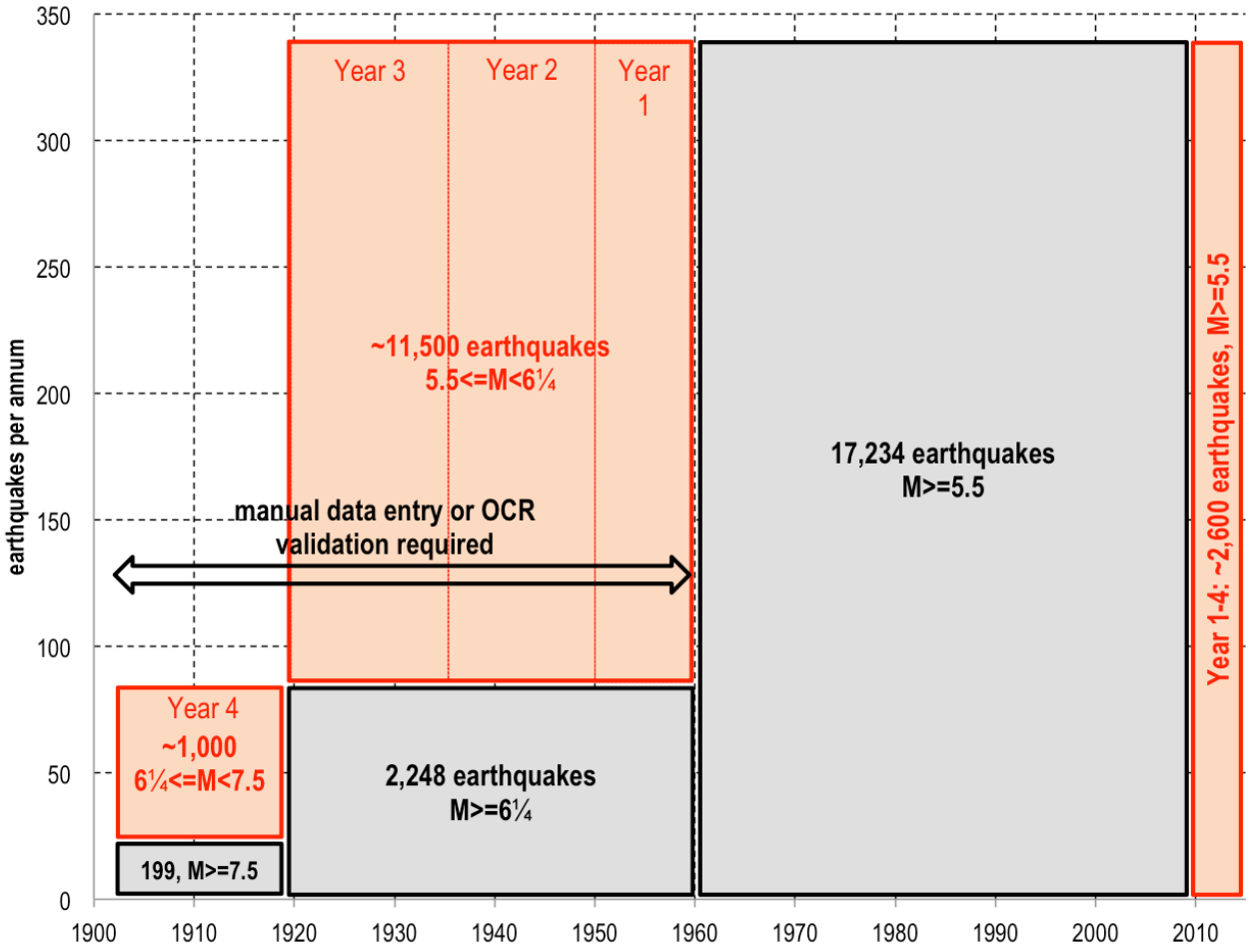

Figure 1. The diagram shows the approximate number of earthquakes for each period of time and magnitude interval in the existing ISC-GEM catalogue (black) and the approximate number of earthquakes to be added to the catalogue (red) during the four-year Extension project. Note that a large manual data entry and/or validation of the results of the optical character recognition process from historical paper-based bulletins are required for data years 1904-1959; the original seismic station data for years 2010-2014 are/will be already available for further work in electronic format.

3.3 Achievements after the first two years of work on the Extension project.

As a result of the two-year effort on the Extension project, 8,559 known earthquakes that occurred during the 1935-1959 period and had magnitude between 5.5 and 6¼ had been re-assessed and added to the ISC-GEM catalogue; 1,590 earthquakes with moment magnitude greater or equal to 5.5 that occurred during 2010-2012 period have also been added to the catalogue (Fig. 2). Overall, the annual number of earthquakes in the ISS (no magnitude estimate available) gives us a good chance to further improve the contents of the ISC-GEM catalogue during the period 1904-1934 in the remaining two years of the Extension project.

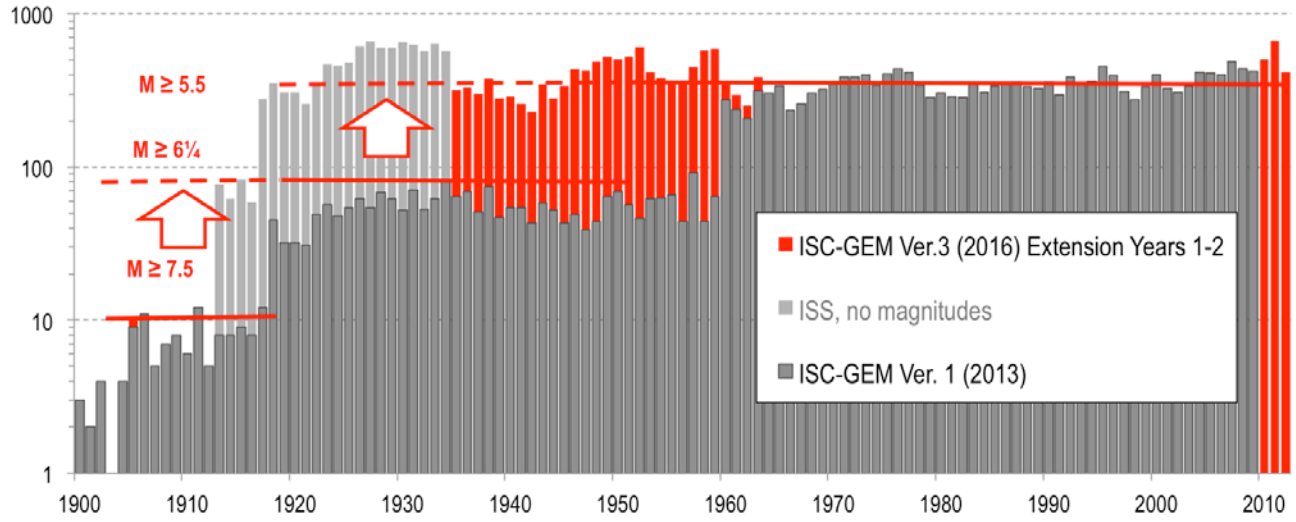

Figure 2. The annual number of earthquakes in the original ISC-GEM catalogue (Version 1, 2013, dark grey) has increased (in red) as a result of the first two years of work on the Extension project (Version 3, 2016) with many smaller yet still potentially damaging earthquakes with M 5.5-6¼ re-assessed and added to the catalogue. Still not processed are the earthquakes in the ISS (light grey); their magnitudes are yet to be re-computed during the final two years of the project.

An example of how the ISC-GEM catalogue was improved in South America is shown on Fig. 3. Many earthquakes in the magnitude range 5.5-6¼ have been added for the 1935-1959 period. Remaining visible lack of small earthquakes during 1935-1965 as compared to the more recent years is likely to be a consequence of the very limited number of seismic observatories in the region during that period, which is more critical for earthquakes in magnitude range 5.5-6.0 as compared to higher magnitude earthquakes reliably recorded and quantified by stations at teleseismic distances alone.

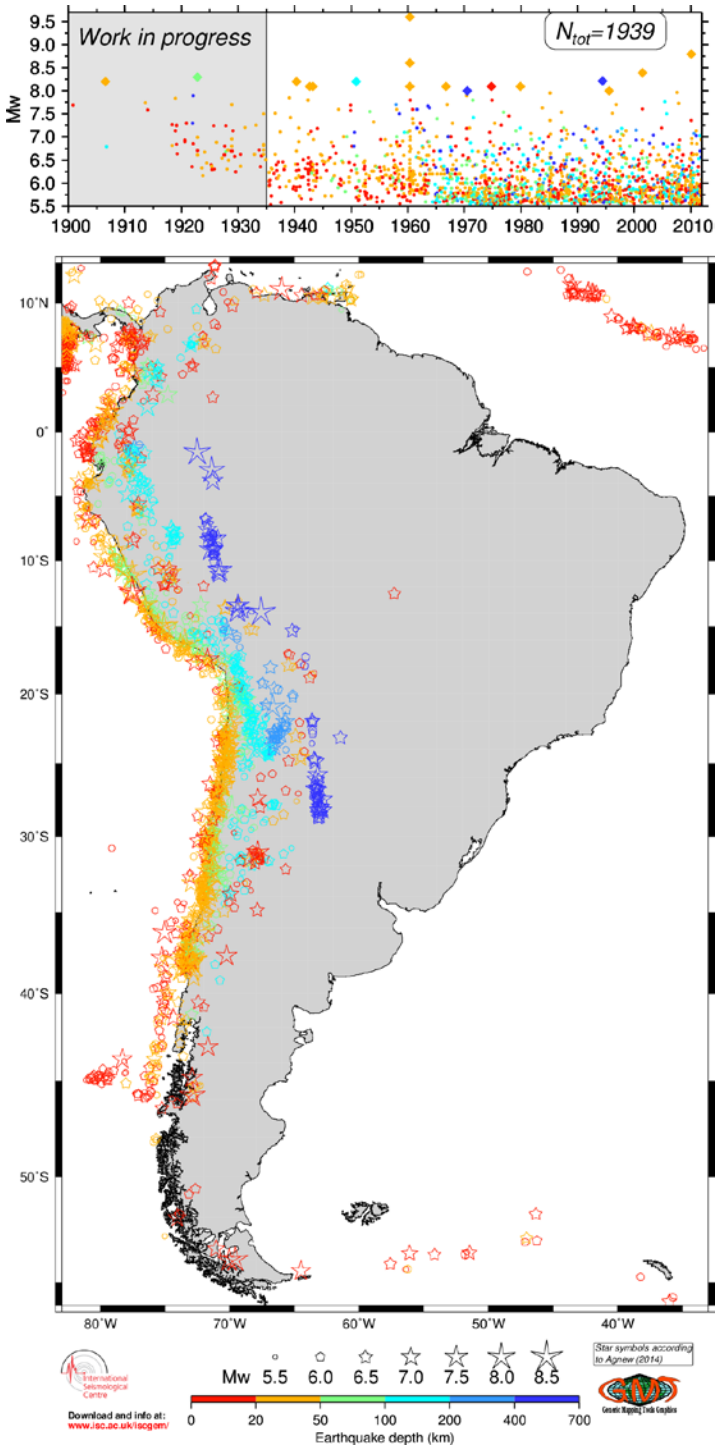

Figure 3. ***Top***: timeline of the ISC-GEM catalogue magnitude distribution of 1,939 earthquakes in South America; in the first two years of the Extension project we included many earthquakes with magnitude 5.5 and above to unify the magnitude cut-off thresholds during 1935-2012; the shaded time period indicates further work to be done to drop the magnitude cut-off thresholds before 1935.

Bottom: the map of the ISC-GEM catalogue in South America; the colours indicate depths of earthquakes and variable star symbols indicate earthquake size as per [26].

As of January 2016, the Version 3 of the catalogue is available for download. Based on the download logs held at the ISC, on average the ISC-GEM catalogue is downloaded ten times a day by professionals in the field. Figure 4 shows a steady stream of downloads during the last twelve months with a distinct peak within 5 days from the new version announcement in January 2016.

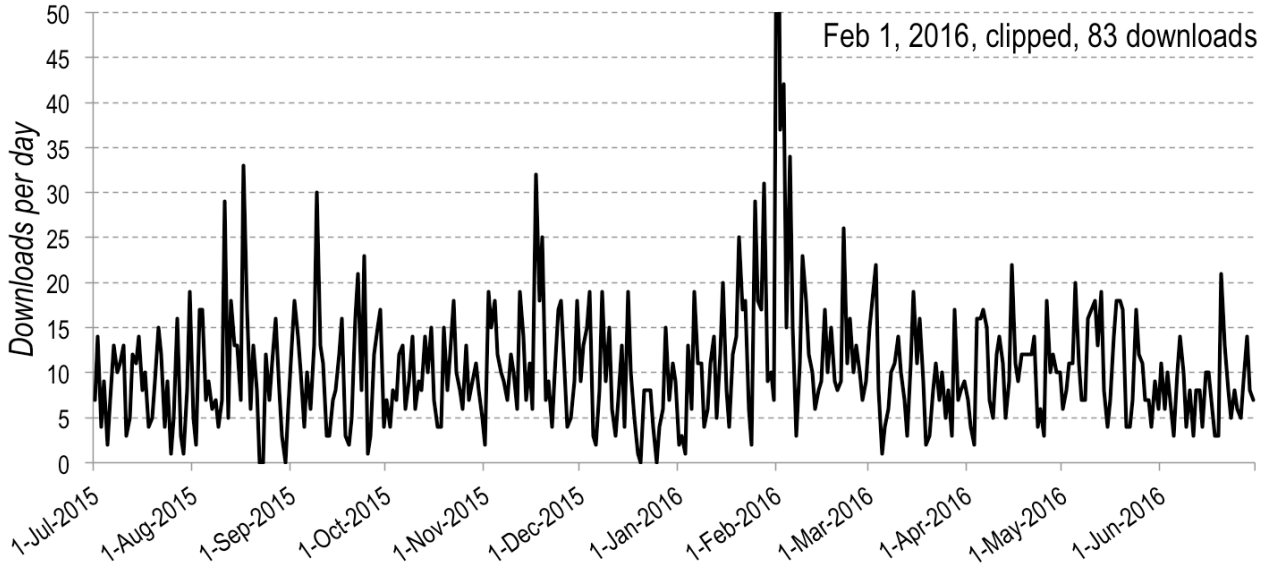

Figure 4. The log of ISC-GEM catalogue downloads held at the ISC shows a steady interest to the catalogue from professionals in the field with distinct peak observed within 5 days from the Version 3 announcement.

4. Conclusions

The ISC-GEM Global Instrumental Earthquake Catalogue remains the most complete and long-term source of large earthquake parameter data for many applications. The homogeneous earthquake locations and magnitudes, with estimates of uncertainty and quality of their determination is a major asset for those working in global and regional seismic hazard modeling.

We continue extending the ISC-GEM catalogue in order to unify the magnitude cut-off thresholds throughout the ~110-year period, where possible. As a result, 8,559 earthquakes during 1935-1959 period and 1,590 earthquakes in 2010-2012 period have been added following a very large data collection effort and consequent re-location and magnitude re-evaluation using the standard ISC-GEM procedures.

Users are encouraged to download both the main and supplementary part of the catalogue freely available from the dedicated ISC-GEM webpages at the ISC website.

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tape, despite the financial difficulties experienced by the ISC at the time. We also acknowledge the effort of Tom Boyd, Colorado School of Mines, for further correction of this data.

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