ELECTRONIC SEISMOLOGIST

Public Release of the ISC–GEM Global Instrumental Earthquake Catalogue (1900–2009)

by Dmitry A. Storchak, Domenico Di Giacomo, István Bondár, E. Robert Engdahl, James Harris, William H. K. Lee, Antonio Villaseñor, and Peter Bormann

INTRODUCTION

The International Seismological Centre–Global Earthquake Model (ISC–GEM) Global Instrumental Earthquake Catalogue (1900–2009) is the result of a special effort to substantially extend and improve currently existing global catalogs to serve the requirements of specific user groups who assess and model seismic hazard and risk. The data from the ISC–GEM Catalogue would be used worldwide yet will prove absolutely essential in those regions where a high seismicity level strongly correlates with a high population density (Fig. 1).

The Catalogue is also expected to have a multidisciplinary use in a wide range of studies such as global seismicity assessment, tectonics, as well as the rapid determination of seismic hazard. Because of the large volume of digitized seismic travel-time and amplitude data generated during this project, we expect the Catalogue to be useful in studies of the inner structure of the Earth as well as in nuclear monitoring research.

This global catalog was also designed to serve as a reference to be used for calibration purposes by those compiling regional seismicity catalogs that contain events of much smaller magnitudes. This will guarantee that the catalogs prepared by other teams for different regions will contain comparable earthquake locations and magnitude parameters, especially in border areas.

The work on the Catalogue was funded by the GEM Foundation as part of the five Global Hazard Components and is a result of a 27-month-long project. This project was led by the ISC and performed by the team of international experts in accordance with the requirements of the Scientific Board of GEM and following recommendations of the International Association of Seismology and Physics of the Earth's Interior (IASPEI) observers. Further, eight IT, administrative, and technical staff at the ISC worked on this project. Details can be found in the Acknowledgments.

OVERVIEW OF THE ISC–GEM CATALOGUE

The following cut-off magnitudes were set prior to the start of the project (Fig. 2) and were dictated predominantly by the delivery times and funding given by the GEM Foundation:

- 1900–1917: $M_S \geq 7.5$ worldwide complemented by a few tens of smaller shallow earthquakes in stable continental areas;
- 1918–1959: $M_S \geq 6\frac{1}{4}$;
- 1960–2009: $M_S \geq 5.5$.

This ISC–GEM Catalogue is unique and presents a major improvement when compared with previously available products (e.g., Engdahl and Villaseñor, 2002) because it contains homogeneous locations and magnitudes with estimates of uncertainty for the entire period 1900–2009 prepared, where possible, using uniform techniques. The Catalogue features:

- 110 years of ~20, 000 earthquake hypocenters and uncertainties, recomputed using the original arrival-time data and the same technique and velocity model throughout;
- where possible, earthquake magnitudes are expressed in M_w scale based on seismic moment;
- proxy M_w is estimated in all other cases based on the newly developed empirical relationship with M_S and m_b;
- uncertainty and quality flag for both earthquake hypocenters and magnitudes are estimated using uniform techniques.

ORIGINAL DATA

We used many hundreds of individual data sources in preparation of the ISC–GEM Catalogue. Several important data sets were available or made available to us in digital form in anticipation of the project:

- The ISC Bulletin that is based on the parametric data of several hundred seismic networks, data centers, and observatories that had been in operation around the world during the period between 1964 and 2009 (ISC, 1964–2009).
- The International Seismological Summary (ISS) Bulletins (1960–1963; ISS, 1918–1963; Villaseñor and Engdahl, 2007);
- Global Centroid Moment Tensor (Global CMT) Catalog (1976–2009; the Global CMT is available at www.globalcmt.org/CMTsearch.html [last accessed December 2011]);
- Catalog of Abe and Noguchi (1983a,b; 1900–1903);

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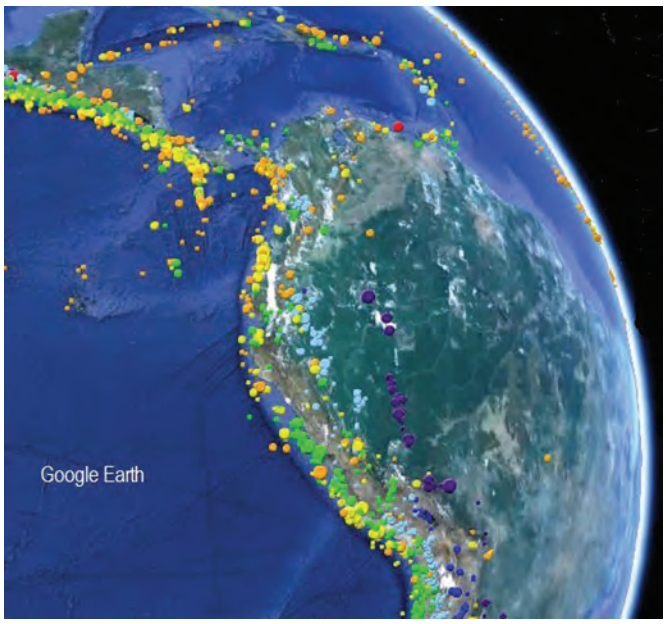
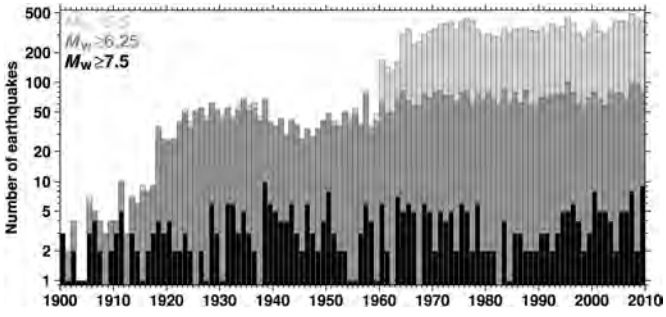


▲ **Figure 1.** Earthquakes from the ISC–GEM Catalogue in Central and South America. Lighter colors indicate shallow earthquakes and darker colors indicate deep earthquakes.

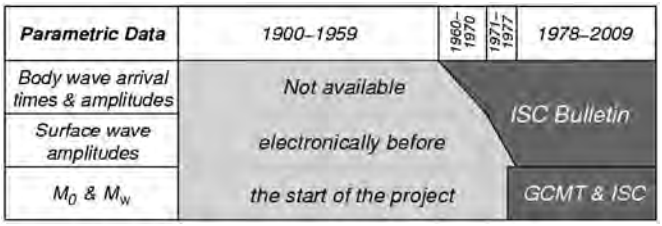
- Historical catalog of Japan Meteorological Agency (JMA; 1923–1970).

Notably, prior to the beginning of the ISC operations in 1964, there was no single source of digitally available global data that contained the station surface- and body-wave amplitude measurements. The most comprehensive source of seismic-wave arrival times, the ISS, did not contain earthquake magnitude determinations or amplitude and period readings at individual stations and was only partly available in digital format, thanks to the work on the Centennial Catalogue (Engdahl and Villaseñor, 2002). Figure 3 summarizes the electronic availability of parametric data before the start of the project.

A massive effort was made to enter into the ISC database those parametric seismic data that existed in paper-based sources and were not electronically available prior to the beginning of this project:



▲ **Figure 2.** Global earthquake number timeline demonstrates the effect of different cut-off magnitudes over the entire 110-year period.



▲ **Figure 3.** Electronic availability of seismic parametric data prior to the start of the project.

- ~270, 000 arrival times, ~110, 000 body- and surface-wave amplitudes and periods from the historical paper-based bulletins of 85 high-quality stations (Fig. 4) available at the ISC and supplemented from the historical collections of a few other agencies (see the Acknowledgments);
- ~620, 000 arrival times from the ISS Bulletins (1918–1959);
- ~1900 arrival times from the Gutenberg Notepads (1904–1912; Goodstein *et al.*, 1980) and the International Seismological Association (ISA) bulletins (1904–1907; Schweitzer and Lee, 2003, and references therein);
- ~3800 arrival times from the Bulletin of the British Association for Advancement of Science (BAAS, 1913–1917);
- M_0 and M_w for 971 earthquakes from 1127 selected reviewed scientific articles.

PROCEDURES, 1: EARTHQUAKE RELOCATION

We relocated every earthquake hypocenter (except a few between 1900 and 1903) using a two-stage process:

Stage 1: Earthquake depths are determined using the EHB technique (Engdahl *et al.*, 1998) that features:

- a comprehensive analysis of near-event surface reflections off the Earth's surface inland and ocean bottom or water surface in the oceans;
- station patch corrections.

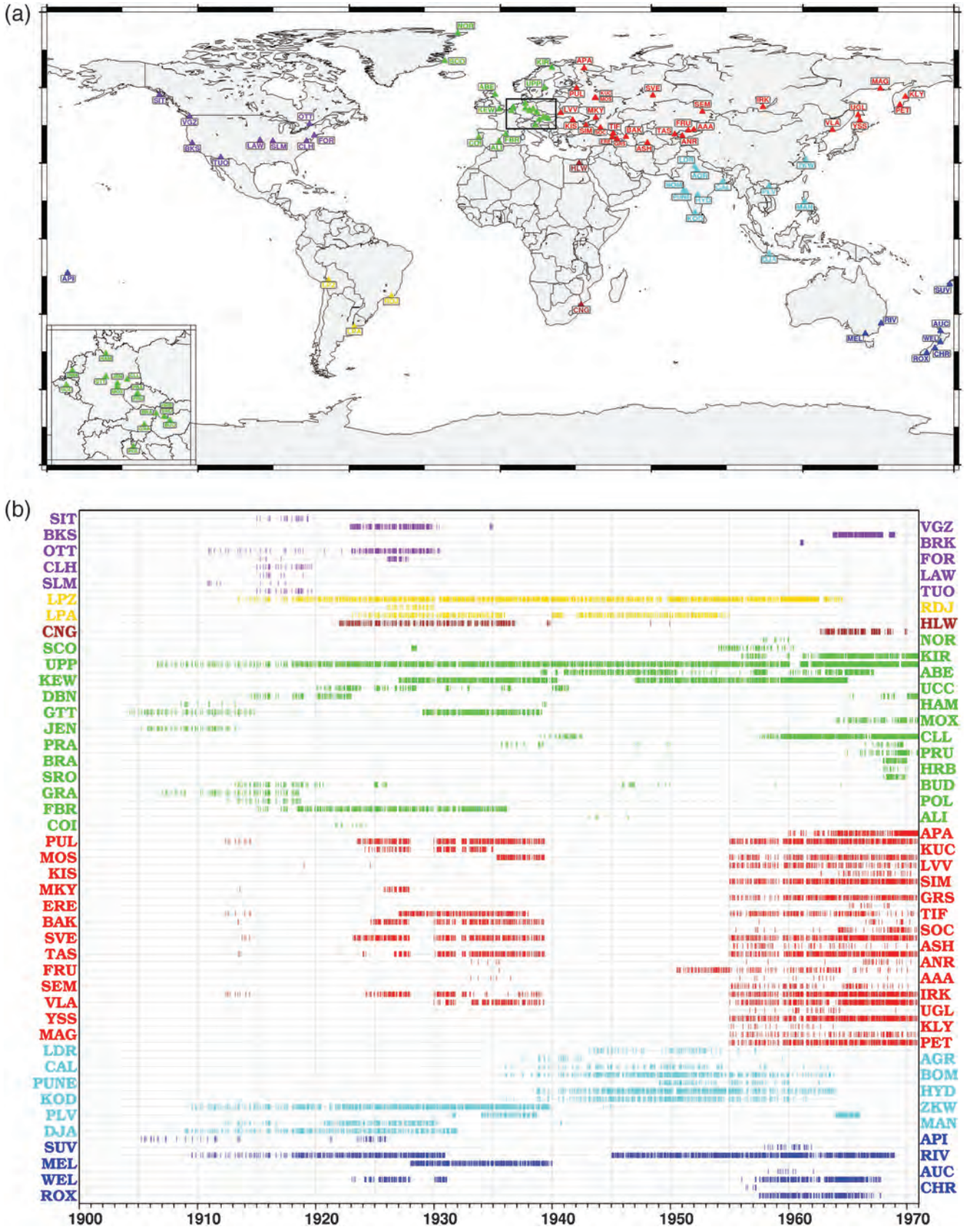
Stage 2: New ISC location algorithm (Bondár and Storchak, 2011) is used with earthquake depths fixed to those from EHB analysis (Fig. 5):

- independent depth confirmation using depth-phase stacking;
- more accurate epicenter locations due to correlated error structure taken into account; thereby removing bias caused by uneven geometrical station configuration;
- all phases predicted by the ak135 velocity model (Kennett *et al.*, 1995) are used to constrain hypocenters.

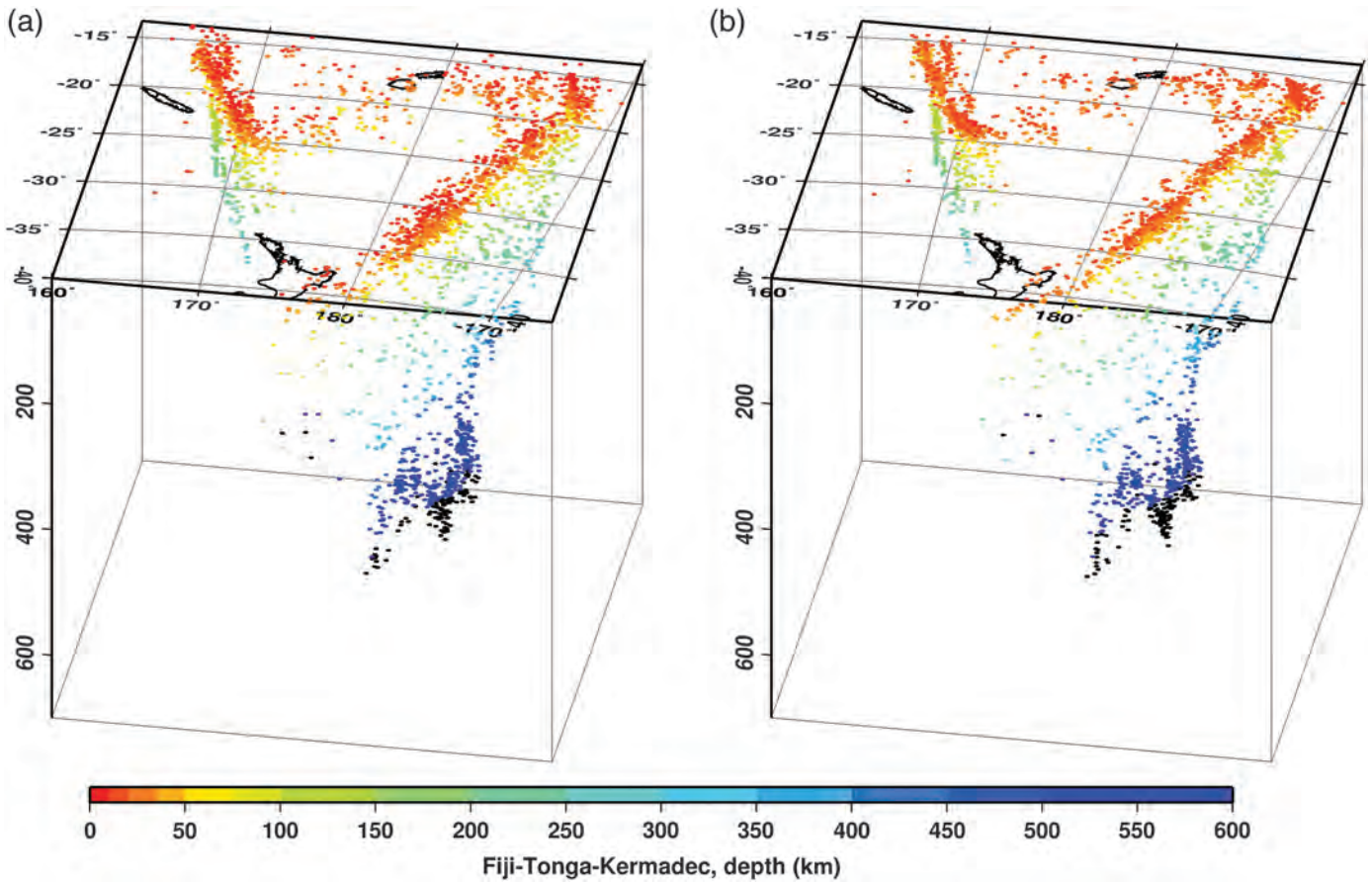
PROCEDURES, 2: EARTHQUAKE MAGNITUDE DETERMINATION

Each event in the Catalogue is characterized by a magnitude expressed in M_w scale with an uncertainty. Where possible we used M_w based on a reliable value of seismic moment obtained from:

- the Global CMT (1976–2009);



▲ **Figure 4.** (a) The map and (b) the timeline of those seismic stations that operated for long periods of time for which previously unavailable in digital format amplitude and period data have been manually entered and used for computation of the M_S and m_b magnitudes. Groups of stations are colored on a regional basis to show corresponding bulletin data availability during different time periods.



▲ **Figure 5.** (a) An example of improvement of previously available event locations in the ISS/ISC database in the Fiji–Tonga–Kermadec region as a result of this project is seen in (b) a much tighter clustering of events illuminating specific tectonic features.

- our own bibliographical search of scientific articles (1900–1979) that feature a reliable direct estimation of M_0 that is not based on any regression relationships with other magnitude types.

Proxy M_w estimates were used in all other cases (the majority prior to 1976), based on the newly developed empirical relationships with M_S and m_b. All M_S and m_b were recomputed as part of this project using the original amplitude and period measurements at individual quality long-term stations (Fig. 6). We preferred M_S if available, yet we had to use m_b for deep earthquakes.

OVERALL GLOBAL MAGNITUDE COMPLETENESS

Because of the comparatively small number of earthquakes in the Catalogue, it is hard to assess magnitude completeness on a regional basis. On a global scale we observe a change of completeness from M_w 5.6 before 1964 to M_w 6.4 after (Fig. 7). This, of course, is a direct result of the change in the cut-off magnitude that, in turn, is related to the start of the ISC operations and the corresponding massive increase in parametric data availability.

Seismicity rates for large ($M_w > 7.5$–7.6) earthquakes are best assessed considering the entire time window. For moderate earthquakes the modern period is a better basis for magnitude–frequency studies.

We suspect that a pronounced dip in the magnitude–frequency curve at large magnitudes reflects the fact that the 110 year period is still not representative enough to account for statistics of very large earthquakes.

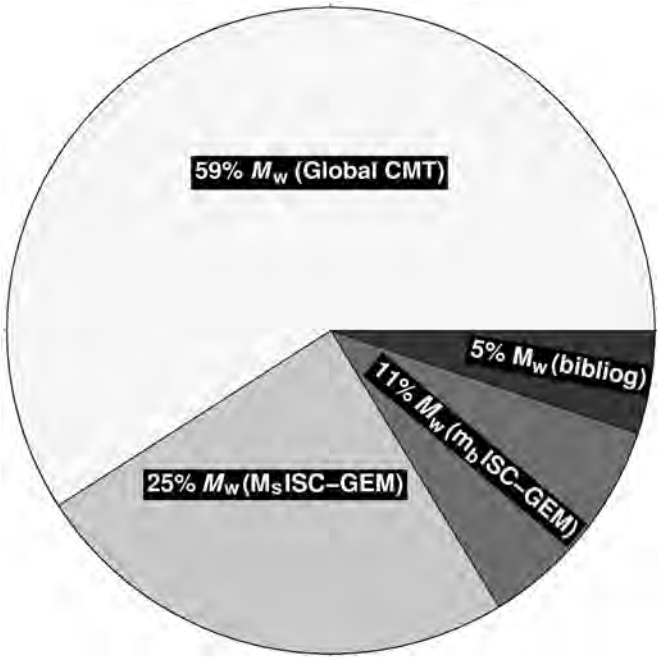
AVAILABILITY OF THE CATALOGUE

From 31 January 2013, the ISC–GEM Catalogue is available from the ISC website on www.isc.ac.uk/iscgem (last accessed July 2013). The Catalogue is protected by the Copyright © 2013 GEM Foundation and the International Seismological Centre. You may use this work under the terms of the CC-BY-NC-SA 3.0 license (unported; http://creativecommons.org/licenses/by-nc-sa/3.0/, last accessed July 2013).

We also aim to maintain the page of updates and version releases as essential changes to the Catalogue are made.

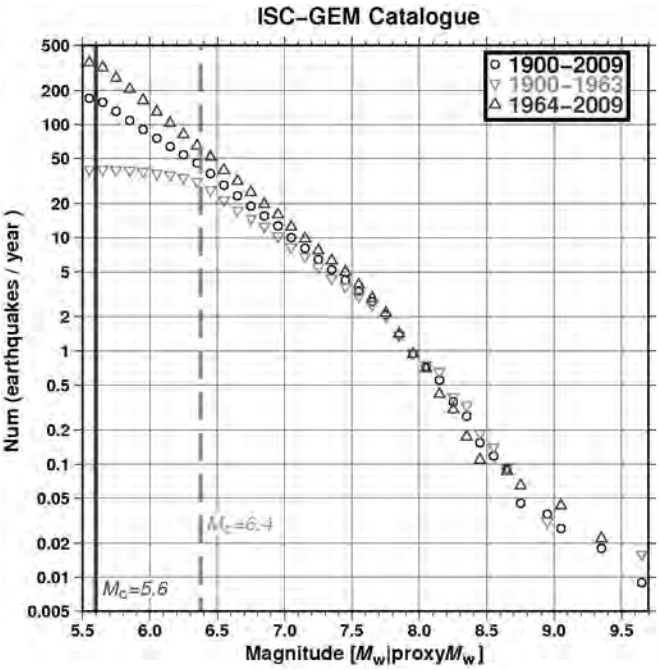
FURTHER PLANS

At this point we have released the Catalogue without the associated seismic-wave arrival times and amplitudes/periods used for this work. It is our plan to make those available to



▲ **Figure 6.** Just four comparable types of M_w determination in the ISC–GEM Catalogue compare favorably against ~20 magnitude types, determination techniques, and sources used in the Centennial Catalogue (Engdahl and Villaseñor, 2002).

all users in 2014 concurrently with the release of the rebuilt ISC Bulletin that will feature the entire collection of all available arrival-time data and ISC hypocenter solutions based on the ak135 velocity model and the new ISC Location algorithm.



▲ **Figure 7.** Magnitude frequency distribution of earthquakes in the ISC–GEM Catalogue within different periods of time.

We are planning to extend the Catalogue into the future as further reviewed ISC Bulletins become available beyond 2009.

We are also aiming to extend the ISC–GEM Catalogue in the first part of the twentieth century by lowering the magnitude cut-off thresholds, entering additional paper-based parametric data, relocating and re-estimating magnitudes, as well as performing further bibliographical searches for direct measurements of seismic moment. This work is beyond the normal ISC operations and therefore is a subject to the success of our current fund raising initiatives.

The paper-based station bulletins from the ISC collection, used in this project, are currently being scanned by the SISMOS project at the National Institute of Geophysics and Volcanology (INGV) in Rome, Italy, under the supervision of Graziano Ferrari. Once this work is finished, these digital scans of bulletin pages will be made electronically available as well.

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We acknowledge several hundred research and operational institutions around the world for providing on a goodwill basis paper-based seismic bulletins to the ISC and its predecessors regularly over the course of the twentieth century. We gratefully acknowledge the financial support given by all ISC Member Institutions to sustain the operations of the ISC and its predecessors.

We acknowledge the advice and guidance received from the group of International Association of Seismology and Physics of the Earth's Interior (IASPEI) observers that included Göran Ekström (Global Centroid Moment Tensor [Global CMT] Project, Columbia University, U.S.A.), Roger Musson (British Geological Survey [BGS], UK), Johannes Schweitzer (Norwegian Seismic Array [NORSAR], Norway), Nobuo Hamada (Japan Meteorological Agency [JMA], emeritus, Japan) and Peter Suhadolc (University of Trieste, Italy).

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Finally, we gratefully acknowledge the use of Google Earth and Generic Mapping Tool (GMT, Wessel and Smith, 1991).

The complete list of acknowledgments can be found at the www.isc.ac.uk/iscgem/acknowledge.php (last accessed July 2013).

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