INTERNATIONAL SEISMOLOGICAL CENTRE (ISC)

2020

Annual Director's Report

International
Seismological
Centre

Despite the worldwide pandemic, it was a rather productive year for the ISC thanks to the support of 70 Member-Institutions and 12 Project Sponsors.

The ISC was registered as a charitable incorporated organization (CIO) with the Charity Commission for England and Wales, which will ensure its tax efficient operation in future years.

The project of rebuilding the ISC Bulletin has been completed and, as a result, the entire 1964-2018 period is now based on the *ak135* velocity model and currently used location and magnitude computation methods.

The data for seismic events during 2017-2020 have been added to the ISC Bulletin. The ISC continued using openly available waveforms to determine source mechanisms, based on first motion polarities, and to constrain earthquake depths, based on depth phase pickings.

Smaller continental earthquakes during the 1990-1999 period and several hundreds of source mechanisms from literature have been added to the ISC-GEM catalogue. The ISC-EHB dataset and corresponding subduction zone cross-sections have been extended to include the data year 2017.

Both the download statistics and the large number of scientific research articles indicate extensive worldwide use of ISC data.

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1: EXECUTIVE SUMMARY

- The ISC gratefully acknowledges generous support from **70 Member-Institutions in 47 countries** and additional project grants (**25%** of total income) from CTBTO, USGS, BGR, SED/ETH, FM Global, Lighthill Risk Network, US NSF, MS&AD InterRisk as well as sponsorships from REF TEK, GeoSIG, TAIDE and SRC.
- We are especially grateful to US NSF for providing the emergency Covid-19 supplement to the standard NSF award.
- The ISC has acquired a new formal status as a charitable incorporated organization (CIO) by formally registering with the Charity Commission in England and Wales; this status has and will in the future allow the ISC to run in the most tax-efficient manner.
- The 2020 annual income exceeded the ISC's expenditure by £180,499, which is the cumulative result of an unplanned local tax refund, additional assistance from NSF and Royal Society, several staff leaving before the end of their contracts and the cancellation of almost all travel by staff and the Executive Committee; this surplus will help to compensate the losses expected in the coming years.
- The Director and the Administration Officer had to spend a disproportionate amount of time to recover many delayed contributions. Even after this effort £51,138 was still owed to the ISC on the 31st of December 2020; £37,579 was still owed at the time of writing this report. We praise those ISC Members who pay their dues promptly.
- At any one time, 16-18 staff members, two contractors and one member of the Earth Science Department of the University of Oxford worked at the ISC during the year.
- After ~10 years, the **rebuilt** ISC Bulletin for the entire period (1964-2010) has been completed and made available to on-line users. As a result, the entire ISC Bulletin (1964-2018) is now based on *ak135* velocity model and most recent location and magnitude determination methods.
- The 2nd open-source scientific article on the Rebuild project was published in *Geoscience Letters* with the financial support from AOGS.
- 1,228 seismic stations were registered or modified in the **International Seismograph Station Registry**.
- Within a few days after an event occurrence, the ISC collected and grouped preliminary data from 28 networks and made the **Preliminary ISC Bulletin** available to all users.
- The routine process of collecting revised bulletins from various institutions stood at 12 months behind real time; a large number of agencies were not able to comply with this deadline and inadvertently hindered the ISC Bulletin analysis.
- During the year, the analysts fully reviewed 15 months of the **ISC Bulletin** and partially reviewed a further 3 months, bringing the ISC Bulletin availability forward to ~27.5 months behind real time.

- Overall, ~87,000 reviewed events with ~11.6 million associated phases were added to the reviewed part of the Bulletin. The Bulletin (both reviewed and un-reviewed) was enlarged with ~949,000 events and ~29.9 million associated phases.
- 1,149 ISC focal mechanisms for recent events were added to the Bulletin based on reported first motion polarities and those automatically picked by the ISC using waveforms available on-line.
- We also continued waveform picking of depth phases (global) and general seismic phases (Africa) to fill in the gaps in agency reporting.
- The ISC Bulletin remains more complete than the bulletins of either NEIC or IDC.
- We released two further issues of the printed **Summary of the ISC Bulletin,** which included several invited network related articles; each issue and each invited article now has its own DOI registered via the ISC's membership of CrossRef.
- The **ISC-GEM Global Instrumental Earthquake Catalogue** (now 1904-2017) has been advanced to include ~1,900 small continental earthquakes during 1991-1999 and ~450 earthquake mechanisms from scientific literature; it was further extended to include 2017.
- References to ~1,100 scientific articles related to ~4,300 seismic events have been added to the **ISC Event Bibliography.**
- We continued the operation and improvement of the **CTBTO Link to the ISC database** which experienced a steady stream of data requests from NDC and IDC personnel.
- The ISC database and the website mirrors at IRIS DMC in Seattle, ERI in Tokyo, LLNL in Livermore and CEA in Beijing/Xian helped to maintain a reasonable speed of access to ISC data.
- 1,238 GT events have been added to the IASPEI Reference (**GT**) Event List.
- We extended the **ISC-EHB** dataset to include the data year 2017 and published the 2nd scientific article describing this popular ISC service.
- We continued to run the **Seismological Dataset Repository** and the **International Contacts in Seismology**.
- We participated in a number of international scientific conferences, mostly on-line.
- The ISC has contributed to the work of **IASPEI** by maintaining the IASPEI website, leading several working groups and working at the IASPEI ExecCom.
- Impressive ISC data download statistics and a large number of published scientific articles using ISC data indicate a very wide and extensive use of ISC products by researchers worldwide.

Signed, 31st March 2021

Dr. Dmitry A. Storchak
Director

2: STAFF and CONTRACTORS

A total of 18 members of staff (16-18 at any one time), two contractors and one member of staff from the University of Oxford worked at the ISC throughout the year, thanks to the regular Member's support and a number of additional grants given to the ISC by international institutions, public institutions and commercial companies to work on the ISC-GEM Catalogue, CTBTO Link, Station Registry and ISC Event Bibliography. Staff changes through the year are highlighted in red or light blue.

Among the staff, there were 7 Ph.D., 4 M.Sc. or equivalent, and 4 B.Sc. or equivalent degrees. The ISC staff represents 9 different countries from 3 continents. Several members of staff took part in professional meetings, international conferences and professional training programmes, predominantly on-line

ISC staff often organise sessions at scientific conferences. Several ISC staff are members of professional organizations such as IASPEI, EGU, AGU and SSA. ISC staff members are engaged in the IASPEI's Executive Committee, commissions and working groups.

MANAGEMENT and ADMINISTRATION

Dmitry Storchak, Ph.D.
Director/Seismologist
Russia/UK

Lynn Elms
Administration Officer
UK

SYSTEM ADMINISTRATION and WEB DEVELOPMENT

James Harris
Senior Systems & Database Administrator,
UK

Oliver Rea, B.Sc.
Systems Administrator,
UK

BULLETIN DATA COLLECTION and ENTRY

The Data Collection Officer communicates with agencies and manages routine automatic entry of reported data. The Historical and Bibliographical Data Entry Officer helps with entering paper-based data into the ISC database and maintaining the ISC Event Bibliography.

John Eve, B.Sc.
Data Collection Officer
UK, retired in September

Gary Job,
Data Collection Officer,
UK, **joined in July**

Daniela Olaru,
M.Sc.Admin., Historical and Biblio Data Entry Officer, *Romania/UK*

ANALYSIS TEAM: STANDARD and REBUILT BULLETINS

Ten analysts and one contractor were engaged in reviewing the current ISC Bulletin. Each member of this team has an additional task either in development or data collection.

Kathrin Lieser, Ph.D.
Seismologist / Analyst Administrator / Editor of the Summary, *Germany*

Elizabeth Ayres, B.Sc. Geog., Analyst/Historical Data Officer, *UK*

Blessing Shumba, M.Sc.
Seismologist / Senior Analyst, *Zimbabwe/UK*

Gharikleia Gkarlaouni, Ph.D.,Seismologist/Analyst,
Greece, left in December

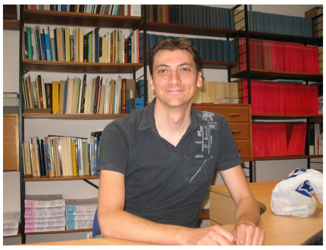
Rebecca Verney, B.Sc., Analyst/Historical Data Officer, 3 days a week, *UK*

Rosemary Hulin,
M.Phys. Geog., 3 days a week, *UK*

Peter Franek, Ph.D.,
Seismologist/Analyst,
Slovakia

Burak Sakarya, M.Sc.,
Seismologist/Analyst,
Turkey

DEVELOPMENT PROJECTS



Domenico Di Giacomo
Ph.D.
Senior Seismologist
Italy/UK

Kostas Lentas
Ph.D.
Seismologist/Developer
Greece, left in November

Thomas Garth, PhD, *UK*
PDRA, Uni. of Oxford, part-funded by ISC;
in October, joined ISC as full time Seismologist/ Senior Developer

CONTRACTORS

During the year, the following persons also contributed as contractors:

- **E.R. Engdahl**, Ph.D., *Boulder*, *USA*: overseeing preparation of the ISC-EHB dataset;
- **Lonn Brown**, M.Sc., University of Alberta, *Edmonton, Canada:* former ISC Analyst, taking part in analysis of the ISC Bulletin remotely.

3: CIO REGISTRATION

Not-for-profit Status of the ISC

For the last ~55 years, the ISC has been run as a not-for-profit, non-governmental, international organization. During those years, the ISC never had to pay corporation tax that would otherwise be applicable in those years when the ISC income exceeded the ISC expenditure. We were able to claim back the VAT that we paid on all purchases, services and building maintenance works, based on the fact that we acted as a book publisher. Finally, we have been in receipt of 80% relief on the local business rates – the tax imposed by the local government in West Berkshire on all entities.

The application of law in the UK has recently changed. The old registration model that the ISC secured in Scotland in the early 1970s – an *unincorporated association* - was no longer an appropriate basis for the authorities to continue recognising the ISC's charitable intentions. Receiving an appropriate modern status within the *Charity Commission for England and Wales* became necessary to continue receiving the relief on local business rates as well as uninterrupted services from banks and insurance companies.

With the agreement of the ISC Executive Committee and the Chair of the ISC Governing Council, and on the advice of our regular auditor, Wilkins Kennedy (now Azets), we instructed Lester Aldridge LLP, a firm specialising in legal advice and law, to assist the ISC in selecting an appropriate charity status, preparation of documentation, and registration with the *Charity Commission*. Lester Aldridge is based in Bournemouth and has a lawyer highly experienced in similar applications to the *Charity Commission*.

Charitable Incorporated Organization (CIO)

Having familiarised himself with the operations of the ISC, Lester Aldridge's lawyer has recommended selecting a relatively new charity model called *Charitable Incorporated Organization (CIO)*. It was created and rolled out by the *Charity Commission for England and Wales* a few years ago to address a number of issues that hindered many charitable organizations similar to the ISC. Effectively, a CIO is a crossbreed between a charity and a company.

CIOs are registered with the *Charity Commission* as opposed to the UK *Companies House.* They have to conform to the *Charity Act*, register their Trustees formally, run regular meetings of the governors and submit annual statements of accounts. Both the UK *Revenue and Customs office* and the local government in West Berkshire formally recognise the *CIO* model.

Moreover, the *CIO* model will better protect current and future members of the Executive Committee – the *Trustees* - from unexpected legal and financial liabilities. The *CIO* model will also allow for the ISC building and land to be transferred directly into the name of the

ISC and the currently unavoidable personal engagement of a few named scientists will no longer be necessary.

Registration of the new CIO and its Constitution

The *Constitution* is the legal instrument by which the ISC becomes a charity registered with the *Charity Commission*. In close cooperation with the lawyer, we worked on the document of the new *Constitution* that had to be as close to the current ISC *Working Statutes* in spirit as possible, but at the same time conform to the standards and charity law as required by the *Charity Commission*. Because any future change in the *Constitution* will have to be reported to the *Charity Commission*, the *Constitution* includes only the general setup of the ISC, the membership, governing bodies and procedural items. The rest of the items currently described (or not) in the *Working Statutes* will be accommodated in the *Bye-laws* that will be prepared for and debated at the 2021 GC Meeting in Hyderabad. The *Bye-laws* will have to complement the *Constitution* without contradicting the *Charities Act*. The *Bye-laws* will be changeable by the GC without any recourse to the *Charity Commission*.

The *Constitution* draft, as worked out with Lester Aldridge LLP, has been reviewed by the Chairs of the ISC Governing Council and Executive Committee as well as by the IASPEI Representative. The draft was offered for consultation at the extraordinary meeting of the Governing Council.

The lengthy process of CIO registration was completed on April 8, 2020. The CIO has received a registered charity number 1188971, signed by the Chair of the Charity Commission for England and Wales, Rt Hon Baroness Stowell of Beeston.

At that point, the CIO had no assets. It had the Constitution and four Trustees, all of whom were current Executive Committee Members.

Extraordinary Meeting of the Governing Council

The Extraordinary meeting of the ISC Governing Council took place on May 12, 2020, on-line. The formal representatives of the ISC Members have:

- discussed and approved registration of a new *CIO* with the Constitution as drafted;
- amended the existing *ISC Working Statutes* to allow winding up the old ISC and empower the Executive Committee to oversee the asset transfer to a newly registered CIO as and when all legal requirements had been satisfied.

Transfer of Assets and Liabilities to new ISC (CIO) and Closure of old ISC

During its regular annual meeting on June 14-15 and July 3 (on-line), the ISC Executive Committee reviewed and signed the transfer agreement with the new CIO and authorised the ISC Director to transfer all current assets and liabilities of the old ISC (unincorporated association) to the newly registered ISC (charitable incorporated organization - CIO, registered charity number 1188971) when he was satisfied that all necessary administrative arrangements were in place. Further to that, the members of the ExecCom debated the draft of the new CIO Bye-laws that will be offered to the ISC Governing Council for further discussion and approval.

Following the ExecCom meeting, the ISC building and land on Pipers Lane in Thatcham (Berkshire, UK) were transferred to the ISC (CIO) and registered with HM Land Registry on July 23, 2020 (title number BK243550). Some minor details of this registration were corrected by the Land Registry by November 6, 2020.

Following the above, on December 31, 2020, all other ISC assets and liabilities, such as bank accounts, grant awards and contracts, staff contracts and various other obligations were transferred to the new ISC (CIO) and accepted by its Trustees. The old ISC has been wound up on the same day.

The traditional annual ISC Accounts for 2020 therefore reflect the full financial activities of the old ISC. The 2020 Accounts of the CIO, prepared in parallel, will reflect no financial activities with the exception to the transfer of assets and liabilities on the last day of the year.

Although the whole process seemed a complicated legal and bureaucratic procedure, in reality, neither users of the ISC data, nor the ISC staff or visitors have noticed any changes. The building and computers still stay where they are. Bank accounts, insurance policies, grant awards and sponsorship agreements have not changed. The building and land are still registered under the name of the International Seismological Centre, albeit as a charitable incorporated organization.

Most importantly, the financial contributions that the Members make to the ISC every year are used by the ISC wisely and tax efficiently. The first recognition of success came when West Berkshire Council refunded 80% of the local business rates overpaid by the ISC in the last two years – a hefty sum of £21,247 that was well in excess of the £16,725 fees paid to Lester Aldridge LLP for their legal advice, work and assistance. In the future, the CIO status is expected to save ISC and its Members at least £13,000 each year that would have been additionally spent on local business rates if this registration has not taken place. Other benefits are also expected to be received over the coming years.

4: OPERATIONS

INTERNATIONAL SEISMOGRAPH STATION REGISTRY (IR) as part of the ADSL DATABASE

The International Seismograph Station Registry (IR) allocates globally unique codes to seismic stations worldwide.

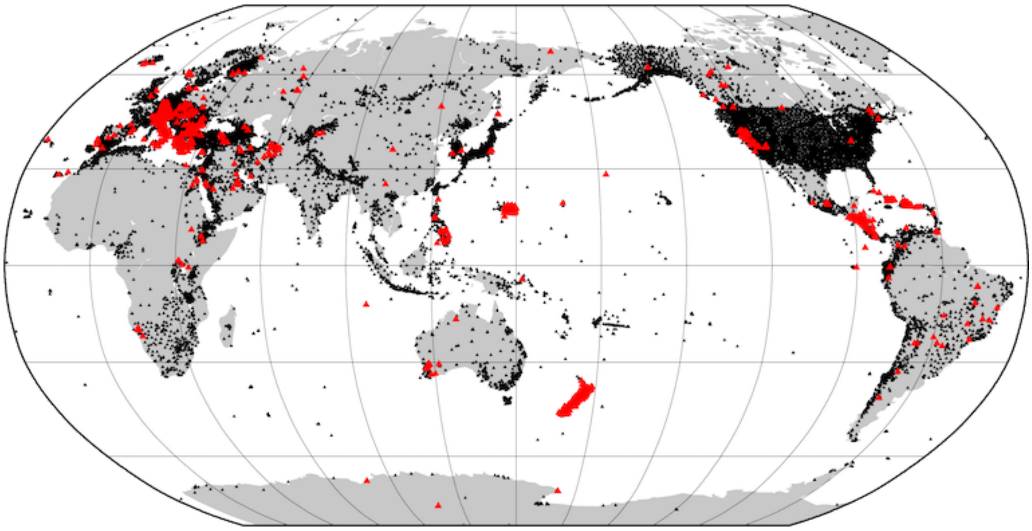


***Figure 1**. 28,477 stations, open or closed, were fully registered in the International Seismographic Station Registry at the end of 2020; parameters of 1,228 of those (in red) were either registered or modified during 2020.*

During 2020, the IR has been particularly improved and extended in Europe, the Mediterranean, New Zealand, Central America and the Caribbean region (Fig. 1) as part of:

- regular ISC Bulletin work,
- inclusion of additional or missing datasets into the ISC Rebuilt Bulletin,
- update of the IASPEI Reference Event (GT) List and
- participation in the CTBTO initiative on Regional Seismic Travel Times (RSTT).

The ISC runs a popular web page giving an account of already registered stations as well as inviting the submission of parameters required to register a new station. Figure 2 gives an account of the IR related web searches, per country.

In fact, the IR has become part of the ADSL database (Agency.Deployment.Station.Location) which we designed and continue maintaining jointly with NEIC. The ISC maintains the agency.deployment "ISC.IR" as a subset of ADSL. In order to use all waveform data available on-line, NEIC routinely updates the ADSL database with stations under the deployment codes equal to corresponding FDSN two-character network codes, based on dataless mini-SEED files available at IRIS DMC. NEIC no longer needs the IR in day-to-day operations since they use waveforms of stations available on-line, usually with FDSN codes.

Now and in the future, the globally unique ISC.IR station codes will remain an exclusive source of station position information for the historical period of time. Also, the ISC.IR will continue to cover a large number of stations whose waveform data are not available to the international waveform data centres.

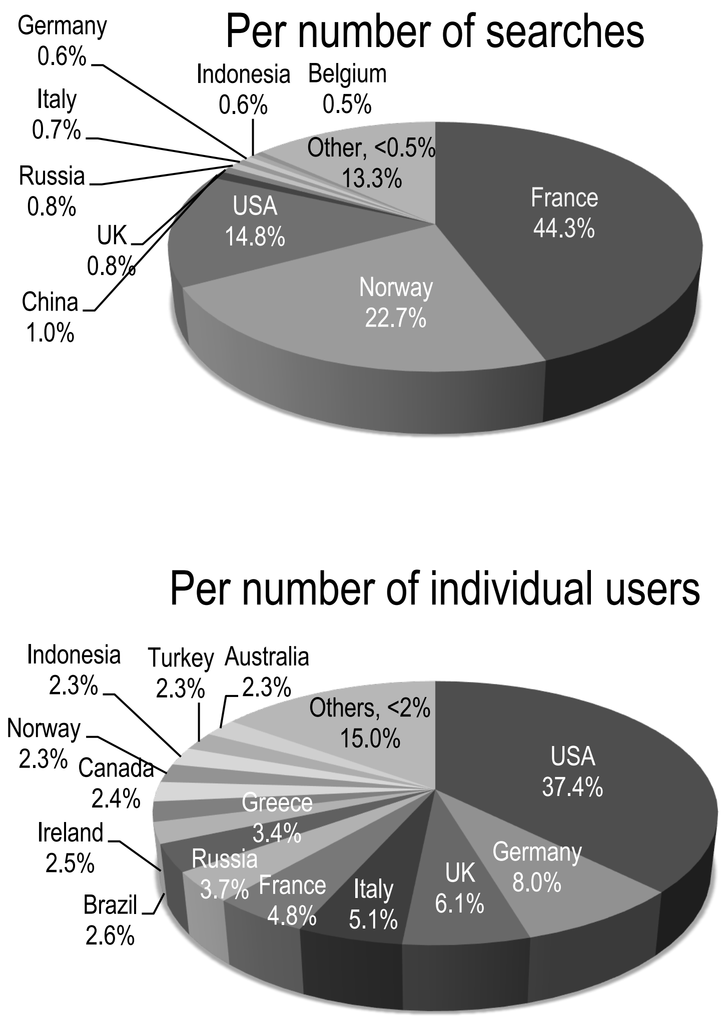


Figure 2. *Per country statistics of IR web-searches; some countries may be shown here due to them housing a VPN-server through which some user-searches are made; NEIC/USGS now searches directly through the ADSL database and is not shown here.*

At present, for the majority of its standard operational activities, the ISC uses just the IR (almost equivalent to ISC.IR element of the ADSL database). In order to be able to deal with a multitude of additional stations becoming available largerly from NEIC, the ISC plans to switch to working with the entire ADSL. To make this happen, a very large effort is required to update, test and validate almost the entire operational and web distribution computer code at the ISC. This work was begun in 2019 but progressed slowly due to a major conflict with the Bulletin Rebuild project that required us to run two main ISC databases at the same time.

During 2020, after the completeinon of the Rebuild project, we have been:

- preparing for the ISC Bulletin distribution using the ISF2.1 format that implements ADSL station coding;
- studying the code of the ISC location program to see how to use it with the ADSL; it was found to be ADSL-compliant as far the hypocentre location process is concerned; potential difficulties related to ISC magnitude computation have been identified; we are therefore building plans to safeguard the ISC magnitude values from being skewed by data of the same station reported with different network codes or stations positioned very closely to each other;
- amending the event station map program that will be used as part of the VBAS software used by ISC analysts;
- planning measures to be able to use the ISC-EHB software with ADSL; in particular, we worked on the FFB-output format used in ISC-EHB production and distribution.

Overall, the work on ADSL will continue throughout 2021-2022.

ISC BULLETIN

Collecting Preliminary Network Bulletins

The ISC continues to collect preliminary bulletin data from a large number of networks and data centres. These data are expected to have undergone at least a minimal review by local analysts. Typically, the incoming data include a preliminary hypocentre location, magnitude estimates, moment tensor solution and station arrival data, though there are large variations from agency to agency. Agencies that reported preliminary data during year 2020 are shown in Table 1.

***Table 1**. 28 agencies reported **preliminary** hypocentre determinations and corresponding arrival time data to the ISC in 2020.*

Country	Reporting Agency
Armenia	National Survey of Seismic Protection
Australia	Geoscience Australia
Austria	Zentralanstalt fur Meteorologie und Geodynamik (ZAMG)
Canada	Canadian Hazards Information Service, Natural Resources Canada
Cyprus	Cyprus Geological Survey Department
Czech Republic	Geophysical Institute, Academy of Sciences of the Czech Republic
Denmark	Geological Survey of Denmark and Greenland
Finland	Institute of Seismology, University of Helsinki
France	Centre Sismologique Euro-Mediterranean (CSEM/EMSC)
Germany	Helmholtz Centre Potsdam, GFZ Research Centre for Geosciences
Germany	Landeserdbebendienst Baden-Wurttemberg
Hungary	Geodetic and Geophysical Research Institute
India	National Geophysical Research Institute

Israel	Geophysical Institute of Israel
Italy	Istituto Nazionale di Geofisica e Vulcanologia
Japan	Japan Meteorological Agency
Kyrgyzstan	Institute of Seismology, Academy of Sciences of Kyrgyz Republic
Norway	University of Bergen
Norway	Stiftelsen NORSAR
Romania	National Institute for Earth Physics
Russia	Geophysical Survey of Russian Academy of Sciences (GS RAS)
Russia	Baykal Regional Seismological Centre, GS RAS
Russia	Kamchatka Branch, GS RAS
Slovenia	Slovenian Environment Agency
Spain	Instituto Geografico Nacional
UK	British Geological Survey
USA	NEIC, USGS
USA	Pacific Tsunami Warning Center

There are 19 agencies that produce bulletins soon after an event occurrence and never return to event re-analysis unless there is a special need (Table 2). These agencies can be considered as reporting both preliminary and final bulletins at the same time.

***Table 2**. Agencies reporting final analysis results within a month of event occurrence*

Australia	Geoscience Australia
Austria	International Data Centre, CTBTO
Chinese Taipei	Institute of Earth Sciences, Academia Sinica
France	Institut de Physique du Globe de Paris
France	Laboratoire de Detection et de Geophysique/CEA
French Polynesia	Laboratoire de Geophysique/CEA
Germany	Alfred Wegener Institute for Polar and Marine Research
Germany	GFZ Potsdam
Greece	National Observatory of Athens
Greece	University of Patras, Department of Geology
Ireland	Dublin Institute for Advanced Studies
Kyrgyzstan	Kyrgyz Seismic Network
New Zealand	Institute of Geological and Nuclear Sciences
Norway	Stiftelsen NORSAR
Poland	Institute of Geophysics, Polish Academy of Sciences
Portugal	Instituto Geofisico do Infante Dom Luiz
Romania	National Institute for Earth Physics
Spain	Real Instituto y Observatorio de la Armada
Switzerland	Swiss Seismological Service

Notably, the availability of data from the IDC/CTBTO bulletin (REB) stayed as agreed with CTBTO – seven days after formal release of each REB data day. This is essential since the ISC is the only channel through which academic research scientists can get regular uninterrupted access to the REB event and station recording parameters (not original bulletins) except for the most recent 10-14 days. In line with CTBTO's formal conditions of release, the ISC is not allowed to make the original REB bulletins openly available.

Building the Preliminary ISC Bulletin

Preliminary hypocentre solutions and station arrivals are grouped in the ISC database with corresponding solutions from other agencies and made available through the standard ISC Bulletin search procedure within a few hours of receipt. For each event an output includes several hypocentre solutions reported by various agencies, all reported source mechanisms and magnitude estimates as well as corresponding station arrival data. Event headers include logo images of each reporting agency and, by clicking on the logo, Preliminary ISC Bulletin users can get further information from each agency directly.

Almost all events with magnitude 5 and above and many of smaller magnitudes are reported within the first week. Further reports beyond one week add information to already reported large and moderate events and also inform about smaller events.

This process is there to fill the gap between the event occurrence and the time when the final Reviewed ISC Bulletin becomes available. It presents an attempt to consolidate the effort of many data centres and networks to make their data available internationally in good time. At this stage the ISC does not compute or publish its own event solutions. This service is not intended for use by the media or civil protection agencies. It is designed to be used by seismologists to receive as much information as possible in one single format from one single source and then to get access to details using the links provided to the original data reporters.

No later than one year after each seismic event occurrence, the preliminary data from agencies are substituted with their final, revised versions; this is well before the ISC analysts make their final review of the ISC Bulletin. The ISC hypocentre solutions are still based only on the revised set of bulletin parametric data given by each reporting institution.

Collecting Revised Network Bulletins

The standard ISC data collection pulls together revised bulletins from agencies (network data centres and single observatories) around the world up to 12 months behind real time. This delay gives the majority of data contributors enough time for reviewing and finalising their bulletin data before submission to the ISC. There is though still a considerable number of agencies that delay their reports to over 24 months behind real time, giving the ISC little time to apprehend the data before the analysis begins. The global pandemic has obviously made the ISC data collection harder as many agency's staff, based at home, were unable to analyse and send their data to the ISC on time.

Appendix 1 lists 151 agencies in 95 countries that contributed revised seismic bulletins to the ISC during the calendar year 2020. It is important to note that among them there are two regional data concentrators: the NEIC/USGS, which in fact represents a number of US-based networks, and the East and South Africa Regional Seismological Working Group

(ESARSWG) that contributes a coordinated collection of local bulletins from 9 countries (*Ethiopia, Eritrea, Kenya, Malawi, Mozambique, Tanzania, Uganda, Zambia and Zimbabwe)*.

Notably, one of the data contributors is the ISC itself, with depth phase arrival time picks for earthquakes worldwide and arrival time picks from African stations for earthquakes in Africa.

Figure 3 shows countries and agencies that contributed revised bulletins for various months and years, directly or indirectly (via other agencies), during 2020. Figure 4 shows those agencies that reported data for the data months that the ISC reviewed during 2020. This collection is generally more complete (see the improvement in Cote D'Ivoire, Madagascar, Namibia, Pakistan, Peru and Sudan) due to the effort of the Data Collection Officer and the Director to obtain missing agency data before the analysis at the ISC begins.

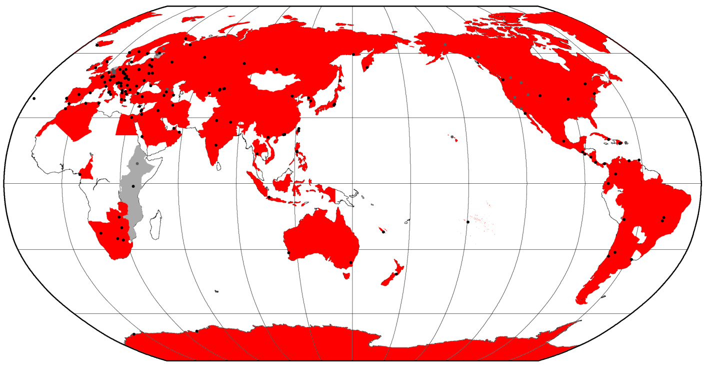


***Figure 3**. Agencies (black dots) and corresponding countries (in colour) that reported revised bulletins during 2020; red/grey colours indicate direct/indirect contributions.*

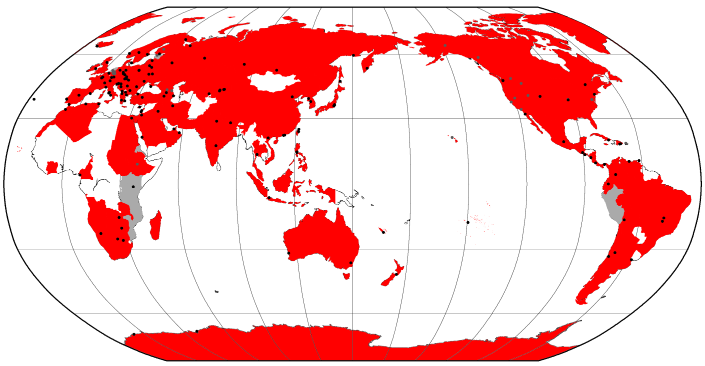


***Figure 4**. Agencies and corresponding countries that reported revised bulletins for the data months reviewed by the ISC in 2020: April 2017 – September 2018.*

During 2020, we sadly lost the regular phase picks from Malaysia due to *Malaysian Met Office* unexpectedly requesting a payment for their data. This request has been rejected by the ISC as inappropriate. Also, the contribution from Pakistan's *MSSP* has been lost with little hope of recovering it soon. In both cases, further negotiations are planned for the after-pandemic period.

Among the new data received during 2020, we should mention the seismic bulletins from:

- *Universidad Autonoma de Santo Domingo* in Dominican Republic,
- *Thai Meteorological Department* in Bangkok, Thailand (after a long break),
- *Seismological Observatory of the University of Brasilia* in Brazil,

- *Central American Tsunami Advisory Center (CATAC),* based in Nicaragua, replacing and expanding on the former data from Instituto Nicaraguense de Estudios Territoriales (INETER)
- private *Seismological Observatory of Dr. Pawel Wiejacz* in Warsaw, Poland.

The ISC Bulletin is progressively updated with each network report coming in. Preliminary network contributions are substituted with final reviews. New events are built, merged or split with every new report coming to the ISC by e-mail and processed either automatically or manually by the ISC Data Collection Officer.

This year included the overlap period between the outgoing Data Collection Officer (for the last few years worked from home in Scotland, retired in September) and a newly appointed Data Collection Officer (hired in July to work at the ISC office). Associated training had to continue for three months since it had to be done remotely, by Zoom.

The Analyst Administrator and the Data Collection Officer regularly review the status of data collection and contact various agencies to avoid reporting gaps. The Director helps to address urgent and difficult cases.

First Motion Based Focal Mechanisms Computed in House

In 2020, we continued with the production of the focal mechanisms, calculated in house at the ISC and based on first motion polarities. Focal mechanisms of recent earthquakes are calculated automatically, combining first motion polarities reported to the ISC with auto-picked first motions from waveforms available at IRIS, EIDA, and other openly accessible waveform archives. We look at all earthquakes in the reviewed ISC bulletin with a magnitude $mb_{ISC} \geq 4.5$ and focus especially on earthquakes with no previously reported source mechanisms. In this work we use the HASH algorithm to compute focal mechanisms (Hardebeck and Shearer, 2002) and FilterPicker source code to automatically determine the polarities of first motions (Lomax *et al*., 2012). The entire procedure is described in scientific papers published by Lentas (2018) and Lentas and Harris (2019).

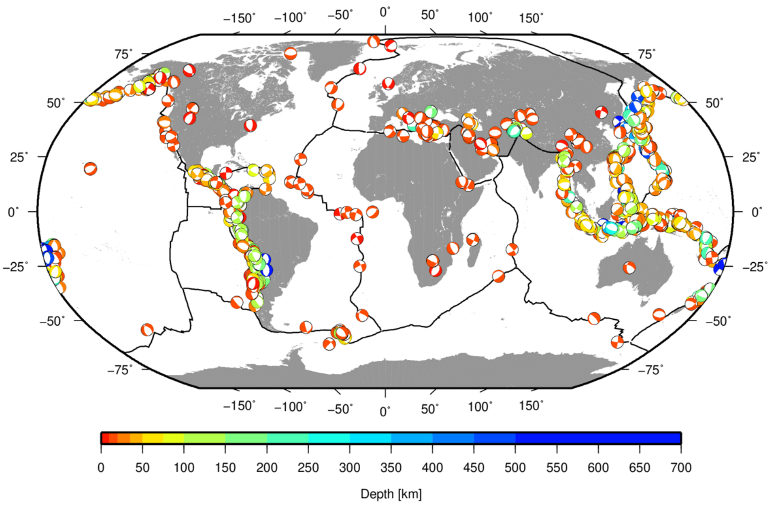


Figure 5*. Map of 1,149 earthquakes for which the source mechanisms were computed by the ISC during 2020 and made available through the on-line bulletin.*

During 2020, the ISC on-line Bulletin was updated with 1,149 ISC focal mechanisms covering the period from April 2017 to June 2018 (Fig. 5). In November 2020, Dr. Kostas Lentas left the ISC and the maintenance of ISC-FM was passed to Dr Tom Garth, with the assistance of James Harris.

In House Waveform Picking of Depth Phases

From 1964, the ISC's mission has been based on re-using the seismogram (waveform) arrival time measurements (picks) made by many tens of observatories and data centres. In recent years, the ISC used reported arrival times of ~8.5 thousand stations worldwide. The ISC does not have sufficient staff capacity to obtain those picks from waveforms, even if these waveforms were always available. We nevertheless feel that the value and quality of the ISC Bulletin would have been compromised if we didn't act in two particular areas.

Depth phases such as pP, sP, pPKP, sPKP etc. are crucial for constraining the hypocentre depth of many moderate earthquakes in the ISC Bulletin that occur away from close monitoring stations. During the last 10-14 years though, we have observed a steady decline in the number of depth phase reports.

Since 2018, we set aside a small fraction of analyst resources to deal with the problem. Three ISC analysts have been picking the depth phases on waveforms available from IRIS DMC for earthquakes with mb^{NEIC} ≥4.8, using the SEISAN software (Havskov *et al.*, 1999, 2010, 2020). We time this activity so that the results can be used during the routine production of the ISC Bulletin.

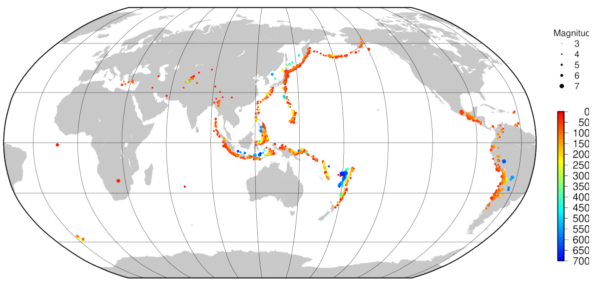


Fig. 6. *The map of 1,143 events where additional ISC pP/sP picks were critical to constrain the ISC event depths.*

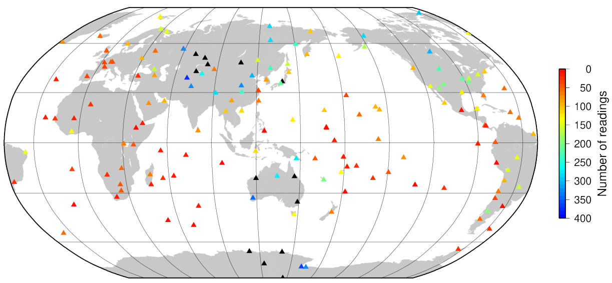


Fig. *7. Waveforms of 162 stations were used by the ISC to deliver the missing pP/sP picks; relative contributions are shown by colour.*

Depth phases for 1,697 earthquakes were added to the ISC Bulletin during 2020. Figure 6 shows 1,143 events for which this information was crucial, i.e., the depth would have otherwise had to be fixed to the area's default. Figure 7 shows the worldwide distribution of 162 stations used and their comparative input. As expected, stations in quiet regions of Asia, Australia, Antarctica and North America provided the largest input.

We also continued picking waveforms of the Africa Array to compensate for the unfortunate lack of permanent observations on large parts of this continent. We include these picks in the routine production of the ISC Bulletin.

Bulletin Review

When the time comes, one month's worth of data is pulled into a separate database and a set of automatic procedures are run to produce automatic ISC event locations and magnitude determinations for those events that are large enough to be reviewed by the ISC seismologists. The threshold criteria are complex yet almost all events of magnitude 3.5 and larger are reviewed.

The ISC seismologists/analysts currently review ~10% of all events formed in the ISC database by the automatic procedures. Although this review misses smaller events, it makes the most used part of the ISC Bulletin accurate and trustworthy. The accuracy of *ak135*-based ISC solutions and magnitude estimates, and proper grouping of reported information between the events in the Bulletin is under constant scrutiny. The ISC analysts also review the correctness of automatic association of reported station arrivals to events, reported arrival's phase identification and travel-time residuals.

All analysis work is done using the Visual Bulletin Analysis System (VBAS). At the beginning of the Covid-19 pandemic in UK (end of March 2020) all ISC analysts and their computer equipment were transferred to working from private homes at short notice. To make that happen, two ISC system administrators worked for almost two weeks to ensure that VBAS can be operated remotely from the central database server. Some reduction of the analysis speed was unavoidable and the analyst's time was also lost in the actual move.

The US National Science Foundation (NSF) has been generous and promptly awarded an emergency covid-related supplement to the existing ISC grant. These extra funds have been used to pay for the additional hardware required for the staff working from home, additional system administrator's time as well as additional time required to analyse the Bulletin.

Throughout 2020, the Analysis Team varied between 6.2 (at the start of the year) and 7.2 members (end of the year). This variability was caused by maternity leave. The Team was also assisted by an outside contractor (former member of the Team) as well as some members of the Team working additional hours during weekends.

During last year (2019), the Team was conducting the review of the standard current ISC Bulletin as well as the Rebuilt ISC Bulletin. In fact, in the second half of 2019, the priority and most resources were directed at the Rebuild project, with just two analysts performing the analysis of the standard ISC Bulletin. As a result, the lag in the reviewed ISC Bulletin availability behind real time increased by four months at the end of 2019. The analysis under the Rebuild project was finished in the early weeks of 2020 and the whole Team has been busy recovering the delay in standard analysis (Fig.8).

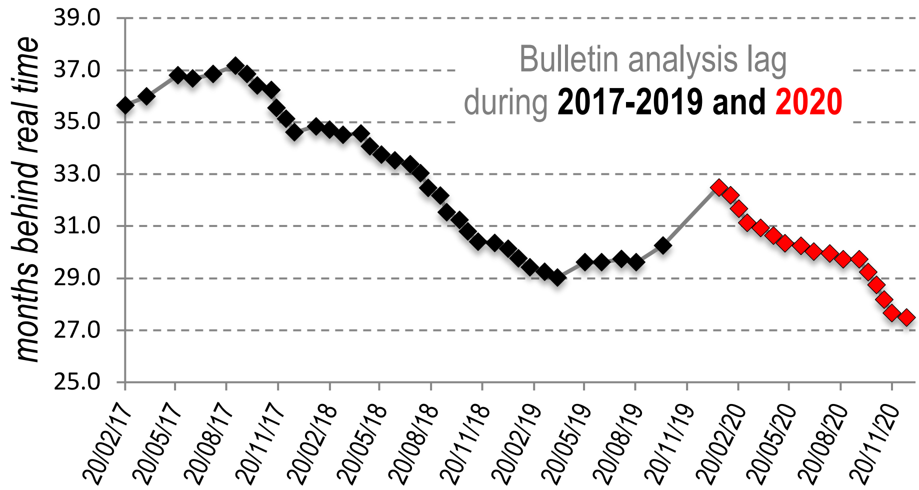


Figure 8*. further lag reduction in availability of the Reviewed ISC Bulletin during 2020.*

In addition, members of the team were involved in other projects such as the ISC-EHB bulletin, Event Bibliography, ISC-GEM catalogue, depth phase picking from waveforms and production of the printed/electronic Summary of the ISC Bulletin.

As a result, during 2020, the Analysis Team fully reviewed **15** complete data months of the recent ISC Bulletin with **3** data months receiving partial review. Overall, this covered data from April 2017 - September 2018. The analysts were working with approximately the same number of seismic events as during the previous five years (Fig. 9). Nevertheless, the number of associated phases reviewed by analysts was on the increase as new stations and networks were set up and corresponding data reported to the ISC. By design, VBAS helped to alleviate this problem.

During the calendar year 2020 (*2019*), ~87,000 (*~60,000*) reviewed events with ~11.6 (*~7.7*) million associated phases were added to the reviewed part of the Bulletin by the ISC analysts. Overall, the Bulletin (both reviewed and un-reviewed) was enlarged with ~949,000 (~683,000) events and ~29.9 (~24.3) million associated phases.

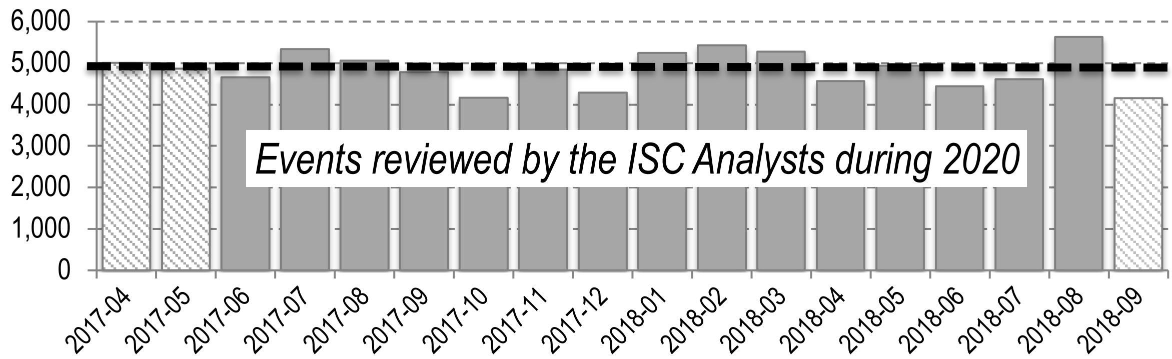


Figure 9*. Monthly number of seismic events in the Reviewed ISC Bulletin analysed during 2020; the solid colour represents those data months that were fully completed during the year; the dashed line shows the average monthly number during the preceding 5 years.*

The result of the ISC work can be seen when comparing Figures 10 and 11. A fuzzy picture of the originally reported seismicity sharpened by the Reviewed ISC Bulletin.

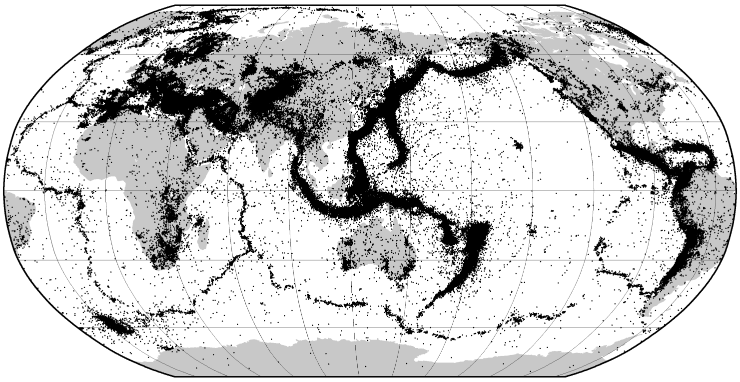


***Figure 10**. All hypocentres reported by individual networks (April 2017 – September 2018).*

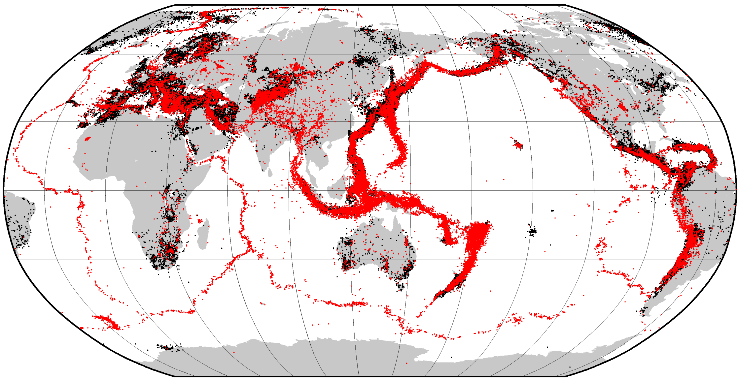


***Figure 11**. Primary hypocentres in the ISC Bulletin (black) in the period (April 2017 – September 2018); in red are the reviewed events.*

Figure 12 demonstrates the diversity of seismic phases included in the ISC Bulletin.

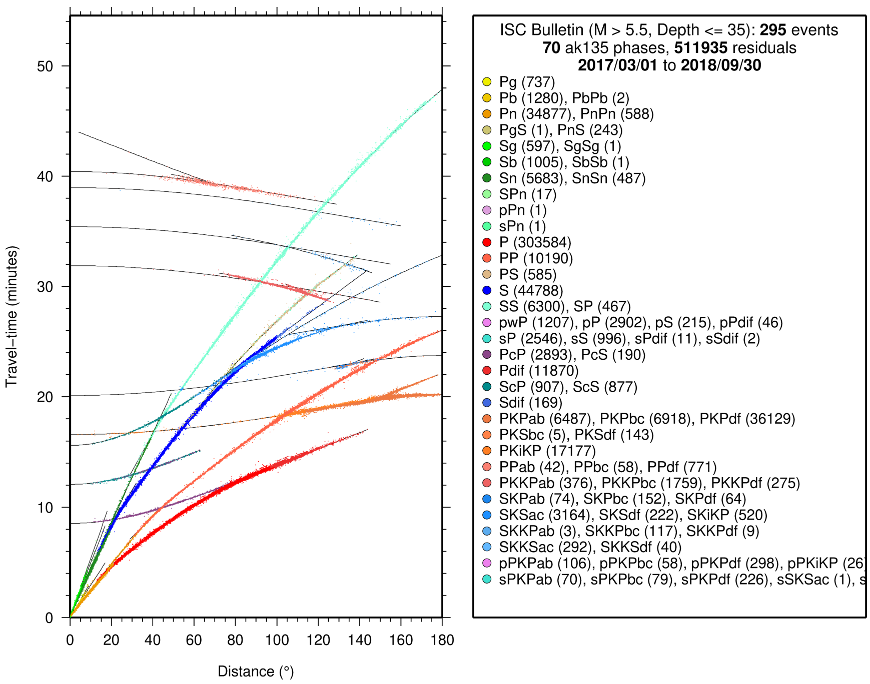


***Figure 12**. The travel-time graph and associated table show the statistics of various seismic phases generated by large shallow events reviewed by the ISC analysts during 2020; depth <=35 km and magnitude above 5.5 are shown.*

General Statistics of the ISC Bulletin

The ISC Bulletin and the ISC database grow by the day in both seismic event (earthquake or explosion) numbers (Fig. 13) and reported seismic wave arrival times and amplitudes of seismic waves recorded at stations registered in the IR (Fig. 14). Please note that the numbers on these graphs were taken after the ISC Bulletin has been fully rebuilt for the period 1964 to 2010.

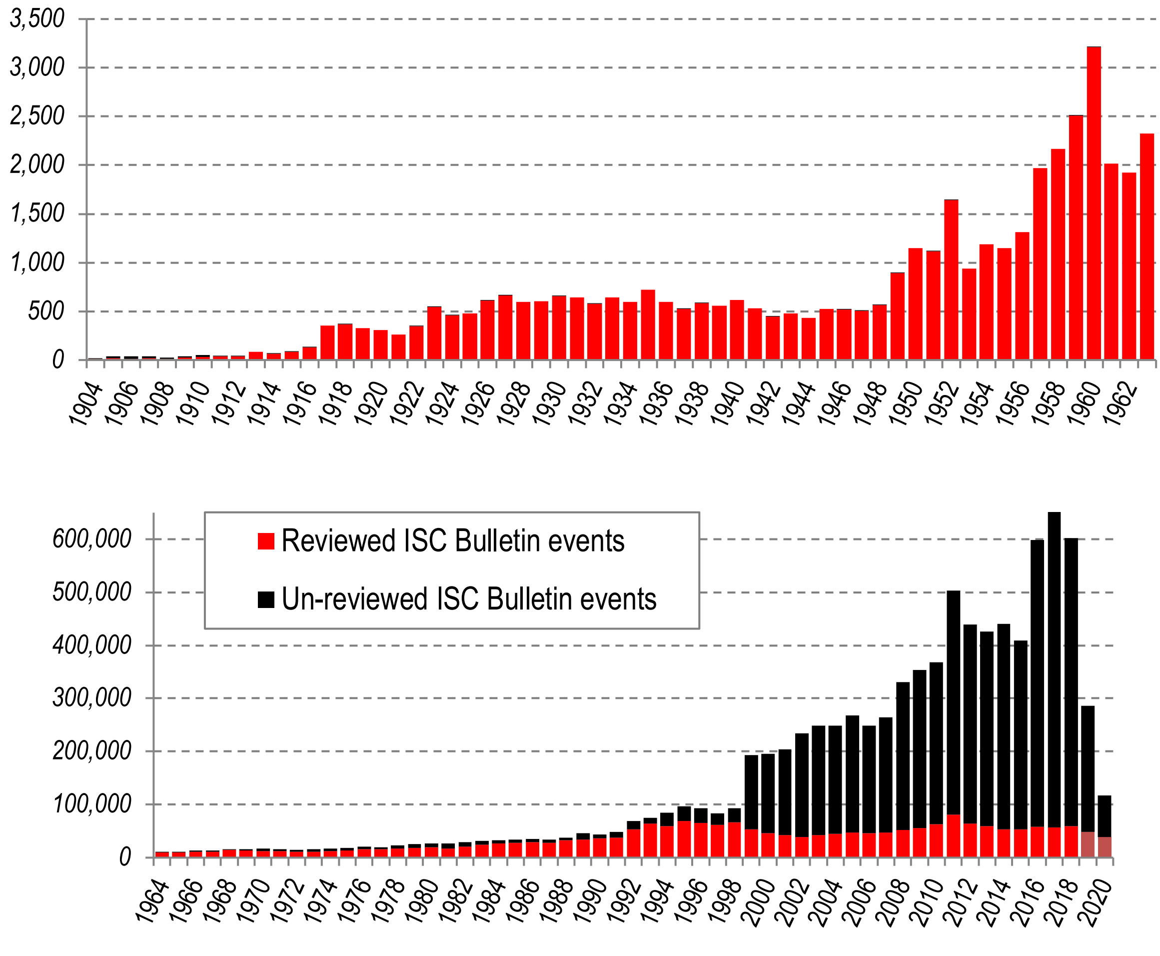


***Figure 13**. Timeline of the annual number of reviewed and un-reviewed (small) events in the ISC Bulletin; the total height of each column represents the annual number of all seismic events in the ISC Bulletin; note different scale used for events before and after 1964; "Reviewed" events beyond September 2018 are those intended for review.* Numbers as of Jan 19, 2021

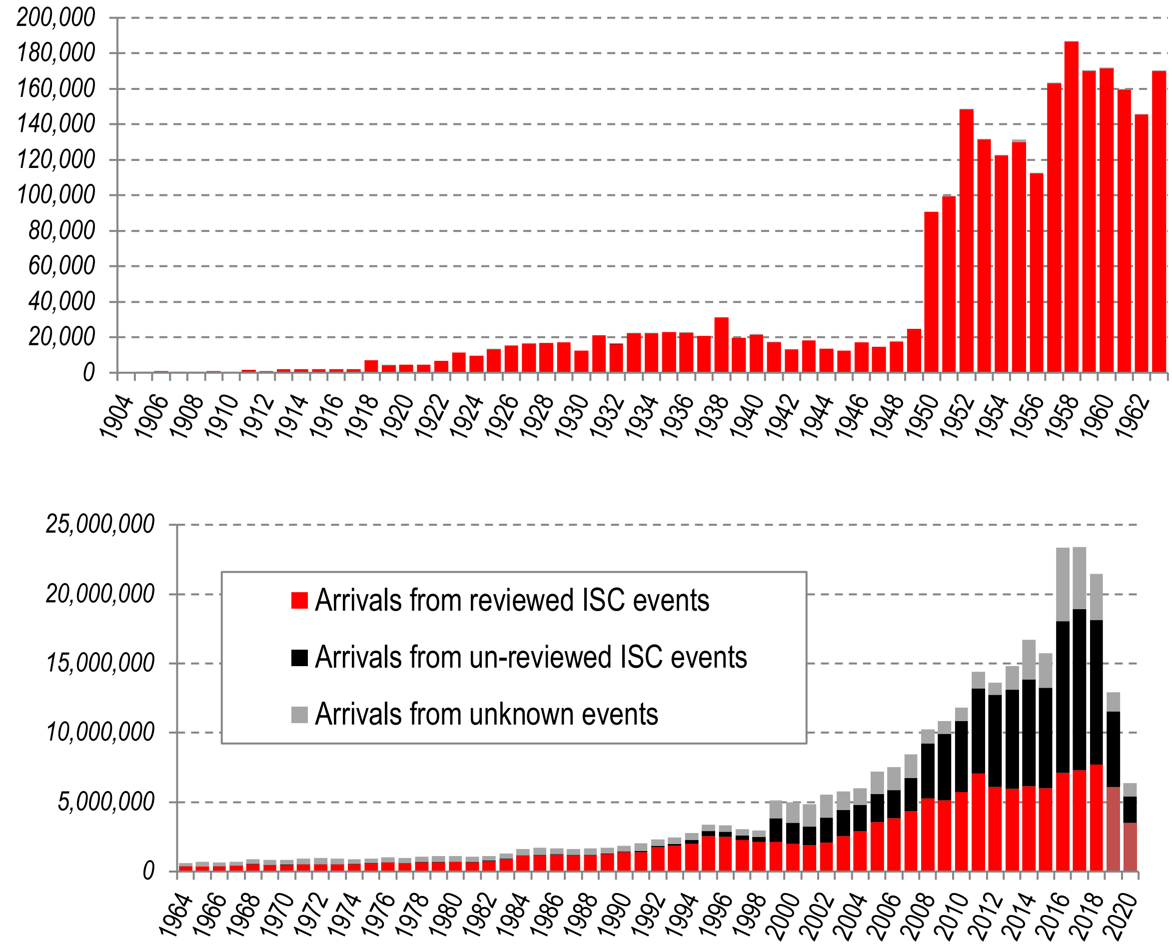


***Figure 14**. Timeline of the annual number of seismic arrivals associated with both reviewed (red) and un-reviewed (black) events in the ISC Bulletin, as well as those arrivals in the ISC database that are not associated to any known event (grey); the total height of each column represents the annual number of all seismic arrivals in the ISC database; note different scales used for events before and after 1964; "reviewed" events beyond September 2018 are those intended for review.*

Numbers as of January 19, 2021

Figure 15 demonstrates the comparative magnitude completeness of the ISC Bulletin and bulletins of NEIC/USGS and IDC/CTBTO. The ISC Bulletin appears to be more complete globally than NEIC or IDC by at least half a unit of magnitude. The NEIC's current global operational magnitude cut-off threshold is 4.5. Smaller events are routinely included only for US territories. Thus, the ISC Bulletin is more complete by definition. The IDC is unlikely to use many more seismic sites/arrays than they use at present because the exact IMS network station positions are a fixed part of the Comprehensive Test Ban Treaty. Hence, the Bulletin of the ISC is likely to stay more complete than that of either NEIC or IDC.

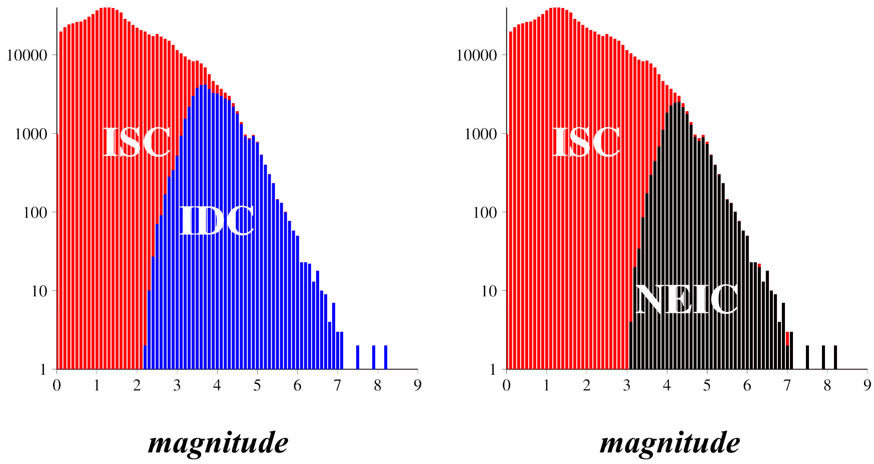


***Figure 15**. Number of seismic events of different magnitude in the ISC, IDC/CTBTO (left) and NEIC/USGS (right) bulletins during the period from March 2017 to September 2018.*

The ISC Bulletin is used by a large number of researchers worldwide. The number of bulletin web searches in 2020 increased 2.5 times compared to the previous year (Fig. 16a,b). Notably, ~78% of Bulletin searches are done through the fdsn-webservice and ~22% - through the ISC website. The above number doesn't even include searches through the ISC mirror databases at ERI, CTBTO, LLNL or CEA. Nor does it include individual user searches based on flat bulletin files downloaded by some users from the ftp-site.

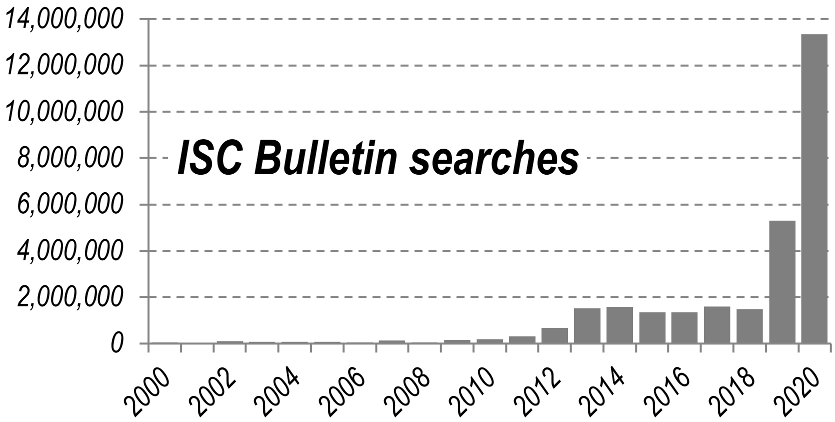


***Figure 16** (a). The annual number of ISC Bulletin searches made by users; during 2020, the search numbers averaged **26 per minute**.*

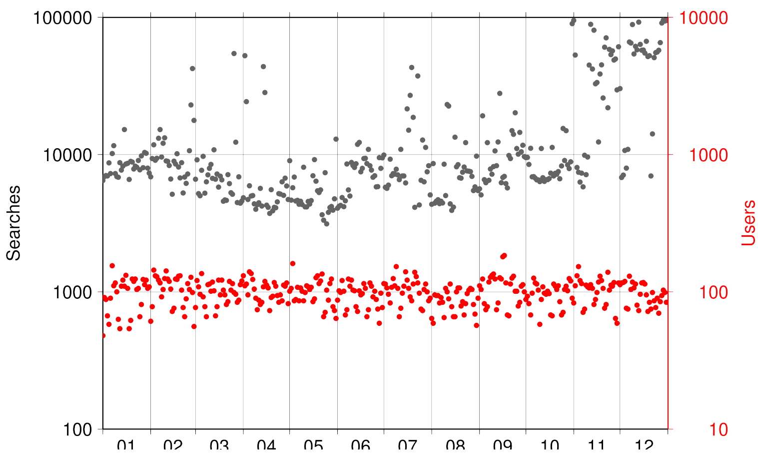
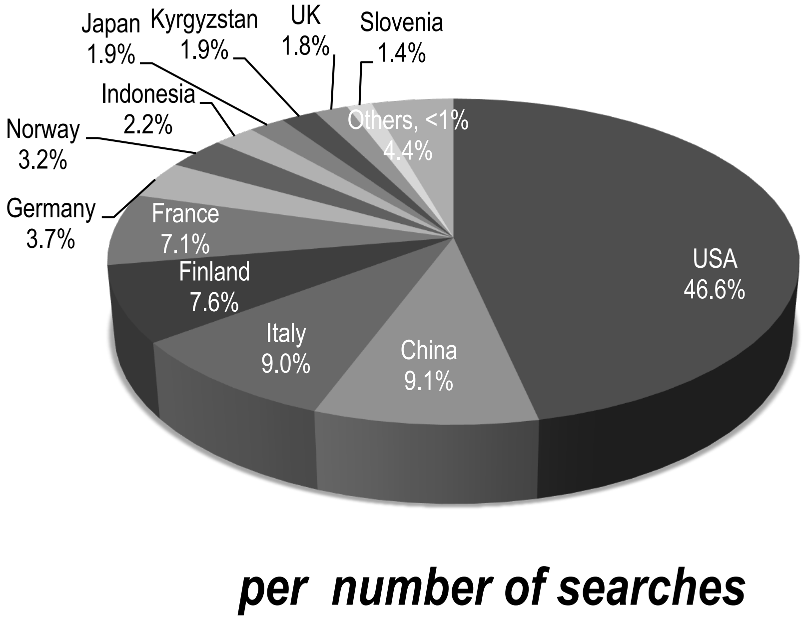


***Figure 16** (b). Daily distribution of ~13.3 million Bulletin searches and individual users during 2020*

Figure 17 shows the multinational character of the ISC Bulletin search users.



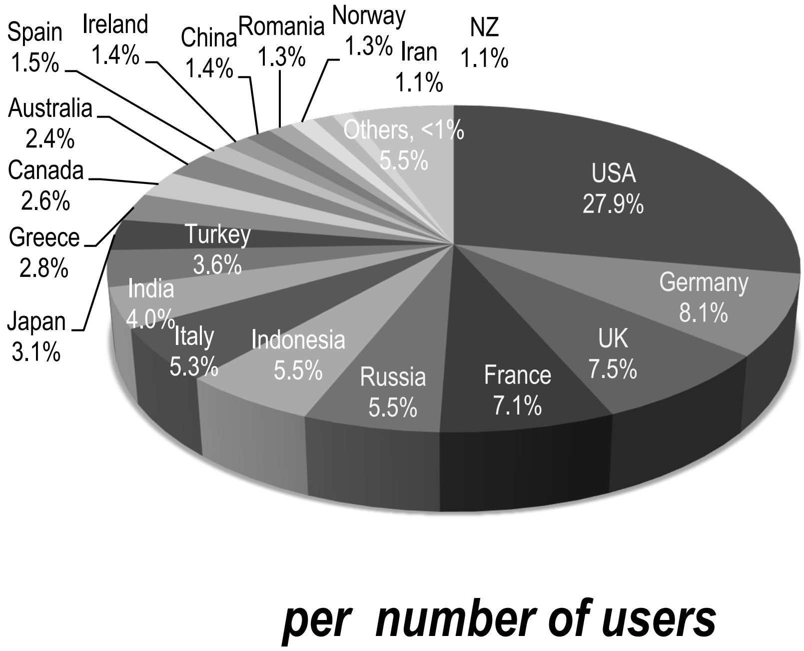


Figure 17*. International usage of the ISC Bulletin in 2020: per number of searches (top) and per number of individual users (bottom).*

The above statistics include the use of the ISC mirror website at IRIS DMC, but not bulletin searches made from mirror-sites at ERI in Tokyo and LLNL in Livermore. Where reliably known, we have removed the numbers related to web crawlers.

Currently, the website searches give output in three major formats: ISF1.0 (International Seismic Format), QML (QuakeML) and CSV (comma separated variables). Figure 18 shows that the total number of searches in QML exceeds those of ISF and CSV combined. The

QuakeML searches though, are performed by fewer users who tend to run automated queries that request larger volumes of data. It therefore appears that all three formats are popular and need to be maintained in the future.

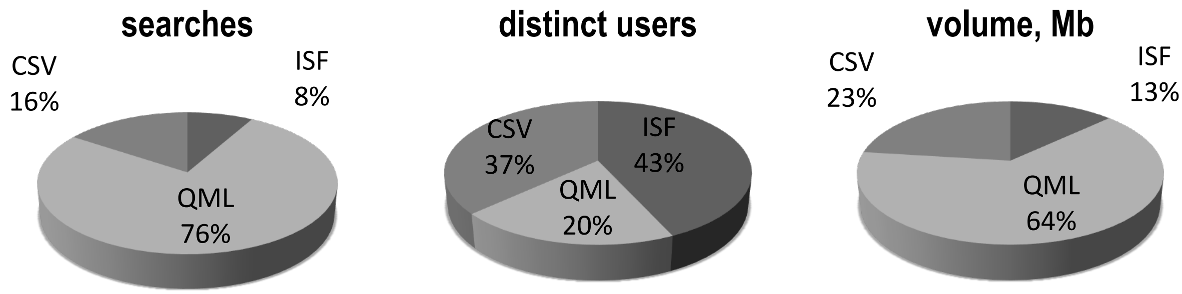


***Figure 18**. Distributions of the number of ISC Bulletin searches, distinct users and overall volume of data taken per output format.*

Printed Summary of the ISC Bulletin

Each issue of the *Summary of the Bulletin of the ISC* covers six months of data. The Summary is prepared at the ISC, printed by *Cambrian Printers* in Wales and posted to ISC Members and paying customers within approximately two months after the relevant period of ISC data becomes available to users. Within a few months the Summary becomes openly available on the web.

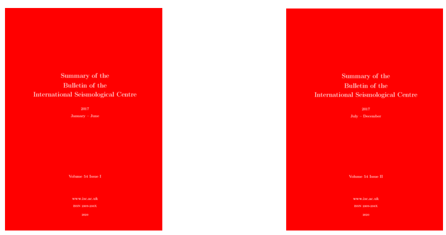


***Figure 19**. The first and second issues of the printed Summary of the Bulletin of the ISC for data year 2017 were published during 2020.*

During 2020, we published two issues covering the period from January-December 2017 (Fig. 19). The following topics were covered:

- The ISC (Mandate, History, Evolution of the Bulletin, Member Institutions, Sponsors, Data Contributors, Staff)
- Operational Procedures (data collection, grouping, association, thresholds, location, magnitude determination, review, history of operational changes)
- IASPEI Standards
- Summary of Seismicity (for every 6 months)
- Invited articles on the history, status and procedures used at:
    a. ***Aristotle University of Thessaloniki*** in Greece
    b. ***Latvian Environment, Geology and Meteorology Center*** in Latvia

c. ***China Earthquake Administration*** in China

- Statistics of Collected Data
- Overview of the *ISC Bulletin*
- Leading Data Contributors
- Advertisements for instrument producers – Sponsors of the ISC

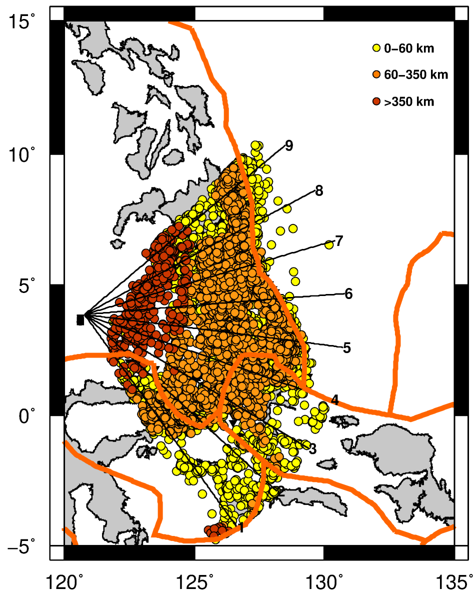
The invited network description articles become associated with general information available for each agency contributing to the *ISC Bulletin*.

As a book publisher, the ISC charges zero VAT (Value Added Tax) on its printed products yet VAT on all goods and services that it buys from other suppliers can be reclaimed.

ISC-EHB

The ISC-EHB dataset (Weston *et al*., 2018) is a groomed subset of the ISC Bulletin that includes well-recorded events and uses the advantages of both the ISC (Bondar and Storchak, 2011) and EHB (Engdahl *et al*., 1998) location techniques. Teleseismically well-constrained events are selected from the ISC Bulletin and are relocated using the EHB location algorithms to minimise errors in location (particularly depth) due to assumed 3D Earth structure. The EHB algorithm incorporates a specific phase identification algorithm for teleseismic depth phases (pP, pwP, sP, PcP) and uses PKiKP, PKPdf, PKPbc and PKPab.

During 2020, together with E.R. Engdahl of University of Colorado Boulder, we applied the ISC-EHB approach to events in the year 2017. The ISC-EHB greatly benefitted from the additional depth phase picks made by the ISC analysts using waveforms available at IRIS.



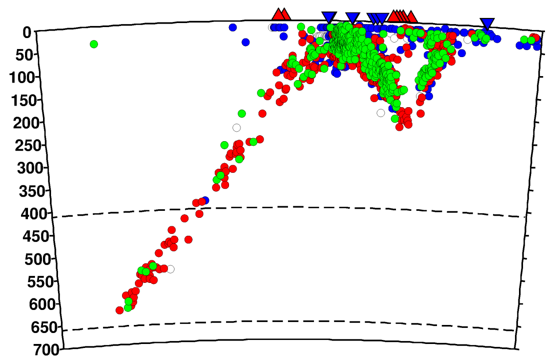


Figure 20. *An example of a cross-section through the Celebes Sea region (number 4 on the map; the upright triangles are volcanos; the inverted triangles are trench points.*

The ISC-EHB dataset has great potential to reveal complicated structures (Fig. 20). It is available from the ISC website along with **cross-section plots** for a large number of seismic regions. The entire dataset (1964-2017) now contains 177,416 seismic events. It is a valuable tool for global and regional seismicity studies and tomographic inversions.The second scientific article on ISC-EHB was published in early 2020 (Engdahl *et al.*, 2020).

IASPEI REFERENCE EVENT LIST (GT)

The International Seismological Centre maintains the IASPEI database of Reference Events (earthquakes and explosions, including nuclear) for which epicentre information is known with high confidence (to 5km or better, GT5) with seismic signals recorded at regional and/or teleseismic distances (Fig.21a,b). It should be noted that the depth of these events is not known to the same level of accuracy as the epicentre.

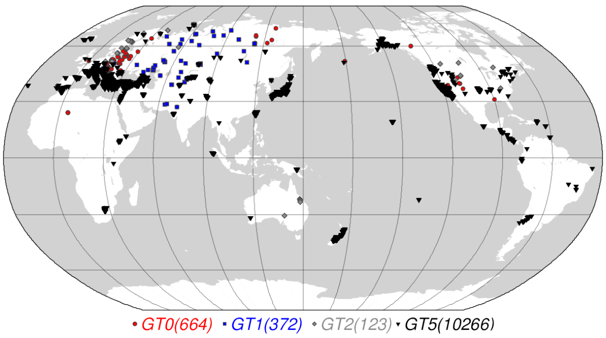


Figure 21a. *The IASPEI List contains seismic events during 1959-2018 for which epicentre information is known with high confidence (to Xkm or better (GTX))*

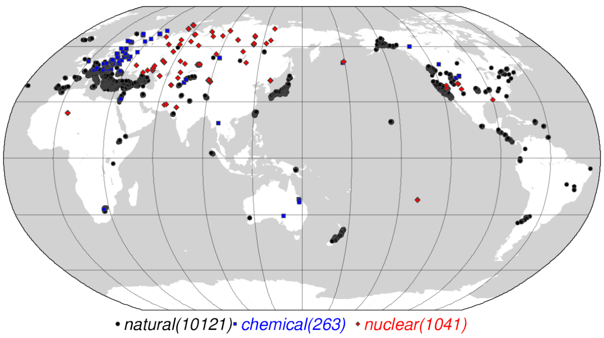


Figure 21b. *The IASPEI List contains natural earthquakes as well as chemical and nuclear explosions.*

The global effort of collecting and validating GT events is coordinated by the CoSOI/IASPEI working group on Reference Events for Improved Location which in 2020 included Bob Engdahl, Eric Bergman, István Bondár, Keith McLaughlin and Kostas Lentas.

The GT database of 11,425 reference events (1959-2018) and 1,563,465 station arrival times facilitates better visualization of the Earth's structure, better modelling of velocities of seismic waves, more accurate travel time determinations and increased accuracy of event locations.

The ISC users are able to search this database at the ISC website and receive GT locations and corresponding ISC locations along with station arrival data available for each event. A cross-link to the ISC Bulletin is provided for users to go between ISC and GT databases.

At the end of the analysis of each ISC Bulletin data year, we add new events to the Reference Event List. During 2020, 1238 events were added or updated (Fig. 22).

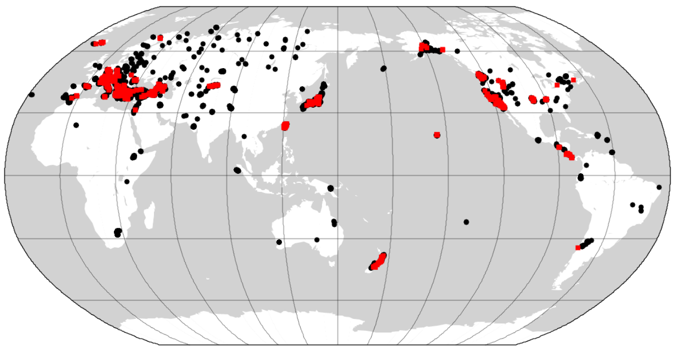


Figure 22. Events (in red) updated or added to the IASPEI Reference Event List during 2020

ISC EVENT BIBLIOGRAPHY

The ISC Event Bibliography (Di Giacomo *et al.*, 2014) facilitates an interactive web search for references to scientific publications linked to both natural and anthropogenic events that have occurred in the geographical region of their choice based on earthquake (location, time, etc.) and/or publication parameters (author, journal, year of publication, etc.). The output is presented in a format accepted by major scientific journals. For most recent publications the results include the DOI that allows direct access to scientific articles from corresponding journal websites.

References are collected and linked to events in the ISC database based on the titles and abstracts of scientific publications found in the electronic indexes provided by scientific journals as well as references collected during work on the ISC-GEM catalogue.

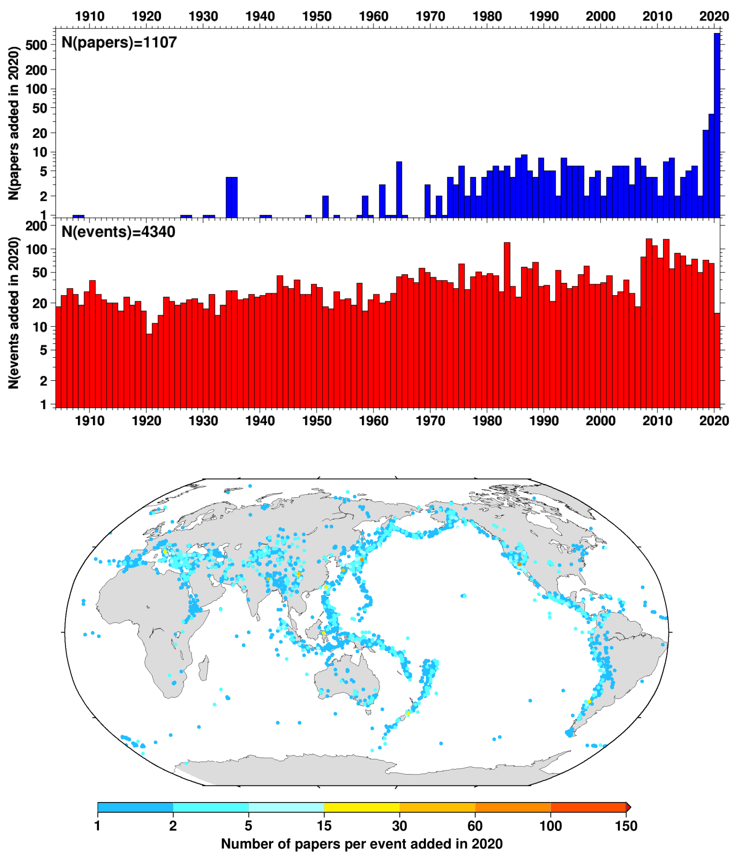


Figure 23. Annual numbers and the map of 4,340 seismic events related to 1,107 scientific articles added to the ISC Event Bibliography during 2020.

Figure 23 illustrates 1,107 articles related to 4,340 events that were added to the Event Bibliography during 2020. A large proportion of this work for the 20^{th} century benefitted from the bibliographical efforts of the ISC staff bringing reliable earthquake source mechanisms and moment tensors into the ISC-GEM catalogue.

ISC SEISMOLOGICAL DATASET REPOSITORY

Just before the 2019 IUGG Assembly in Montreal, we released a new supplementary ISC service that allows individual researchers or groups to submit seismological datasets that they wish to be openly available to the scientific community for a long period of time.

This service (International Seismological Centre, 2020) will assist a positive trend in scientific publishing to require article authors to make the original research data openly available so that their conclusions can be both tested and used by other researchers.

Examples of acceptable datasets include but are not limited to:

- Event catalogues/bulletins
- Results of earthquake source studies
- Results of structure studies
- Velocity models
- Notable earthquake observations
- Seismological computer code

We do not envisage storing raw waveforms as this role falls within the mission of other data centres.

This long-term secure repository of seismic datasets includes all necessary metadata such as a DOI, author contact information, affiliation, relevant scientific publication and date of submission as well as associated information such as comments, formats, positions of relevant seismic stations etc.

The ISC shall obtain the DOI for each submitted dataset via CrossRef.

The ISC Repository is an open facility that has good potential to serve geophysicists for a very long time. This facility is likely to be recognised by scientific journal editors as one of the legitimate independently maintained places for depositing author processed datasets to satisfy editorial board requirements on open access to data.

The Repository received 15 eligible submissions by the end of 2020. George Choy was the first registered author with the USGS source parameters catalogue (1987-2013), listing broadband depths, focal mechanisms, radiated energy and energy magnitudes (Choy, 2019).

SEISMOLOGICAL CONTACTS

The objective of this project is to maintain up-to-date information on the network of scientific institutions, seismologists and geophysicists, especially in developing countries (Fig. 24), willing to serve as scientific points of contact for:

- Seismologists and Geophysicists in other countries,
- Governments,
- Charitable, Response and Relief organizations,
- Media.

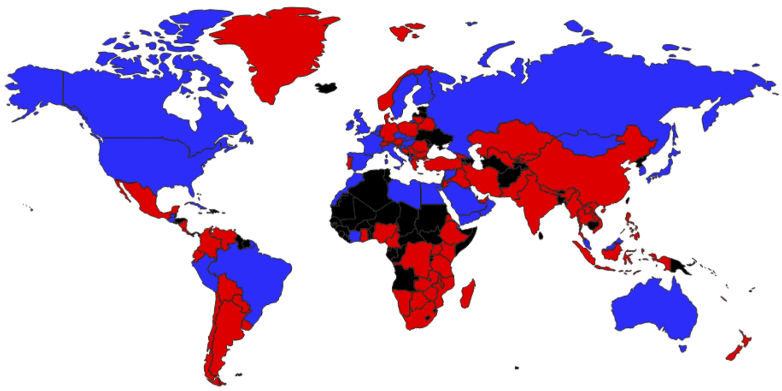
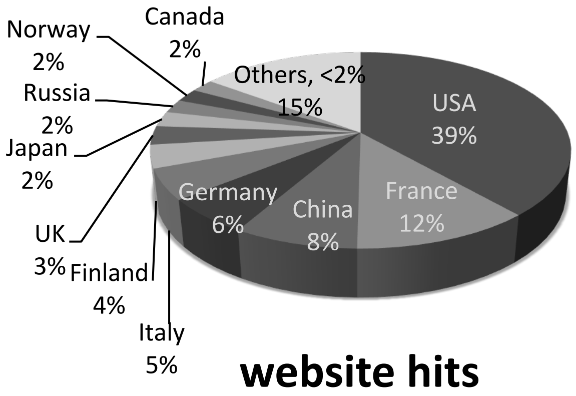


Figure 24. *Seismological Contacts webpage; in* ***red*** *are countries in which institutes and individual staff members are willing to share information and serve as a local point of contact; in* ***blue*** *are countries for which we have information about operating geophysical organisation(s); in* ***black*** *are countries for which we do not hold any information.*

ISC WEB and FTP SITES

In 2020, the ISC website experienced ~31.3 million hits which is 250% of that in 2019. The majority of the ISC web data are distributed through the main ISC website and the mirror at IRIS DMC in Seattle. The load balancer automatically directs user queries to the least busy server.

The use of the ISC ftp site in 2020 increased by 50% compared to the previous year. The ftp-site is used for downloading pdf copies of the printed ISC Bulletins and Summaries, the ISC Bulletin in FFB and ISF formats, the ISC-EHB bulletins and the text version of the IR station list. Figure 25 demonstrates worldwide interest in ISC data.



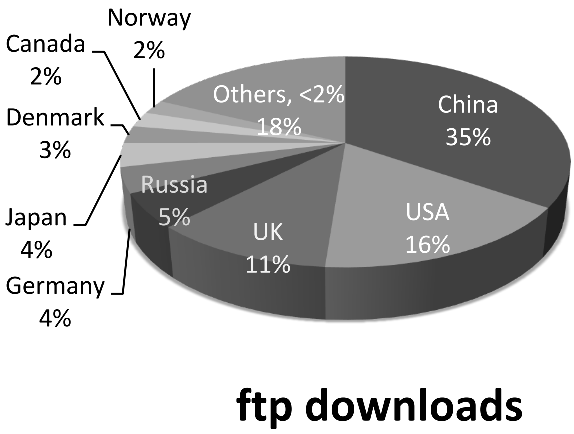


Figure 25**. Per country statistics of **downloads from the ISC website and ftp-site

ISC DATABASE, WEBSITE BACKUP and MIRRORS

The ISC continued maintaining a virtual server at the IRIS DMC in Seattle in order to hold a mirror of the ISC database and the ISC website. This was done with assistance from DMC and US NSF in order to achieve a general ISC data back-up and fall-over facility in case of a breakdown of services at the ISC itself as well as to spread the load on the ISC internet line and give ISC users faster access to data.

The mirror has been operational since 2011. The database in Seattle is updated with approximately an hour time lag. The load balancer evenly distributes the load on the ISC website, including the user searches, between the server at the ISC in Thatcham and the server at DMC in Seattle. Users no longer need to know the exact web address in Seattle and are generally no longer aware which server is addressing their request.

In addition, the IRIS DMC is able to use the database, when required, to serve DMC archive users with event-based selection of waveform data.

Other mirrors of the ISC database are maintained by the Earthquake Research Institution (ERI) of University of Tokyo to serve the research community in Japanese universities, by the Lawrence Livermore National Laboratory (LLNL) to serve users from nuclear test monitoring laboratories in the US and a database mirror and website installed in Beijing and Xian by the China Earthquake Administration (CEA) to help numerous Mandarin speaking seismologists to obtain more intuitive access to the ISC data.

5: DEVELOPMENT PROJECTS

ISC BULLETIN REBUILD

The value of the ISC Bulletin is subject to adhering to uniform procedures over a long period of time. Nevertheless, essential changes in the ISC procedures have occurred (Fig. 26):

- The *ak135* velocity model (Kennett *et al*., 1995) has been used since 2006 superseding the *JB* travel times (Jeffreys and Bullen, 1940).
- A new event Locator based on a different approach was introduced from data year 2009 (Bondar and Storchak, 2011).
- Throughout ISC history different sets of seismic phases were used for location: P and (from 2001) S with other *ak135* phases from 2009.
- Latitude and longitude error estimates were computed before Oct 2002, followed by full error ellipses later on.
- Procedures that determine which reported events require relocation by the ISC were also changed in 1999, 2005 and 2006.

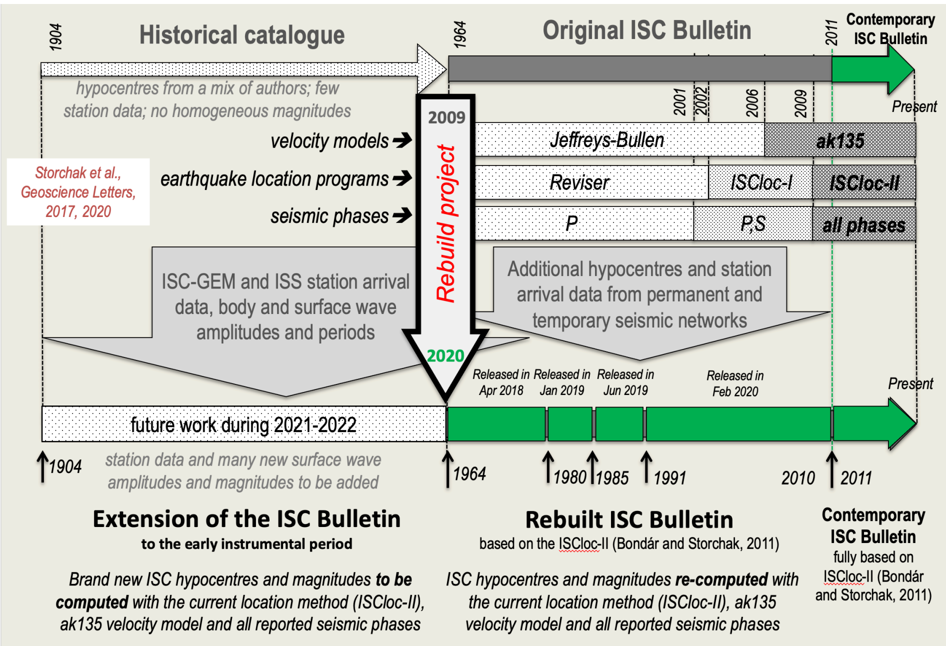


Figure 26. *The overall plan and current status of the ISC Bulletin Rebuild project (updated figure from Storchak et al., 2017, 2020)*

Over the last ~10 years, we have been rebuilding the ISC Bulletin using current ISC procedures to guarantee homogeneity throughout its entire period by:

- Renaming the ISC phase identifications in line with the IASPEI standard (Storchak *et al.* 2003, 2011; Schweitzer *et al.,* 2019);
- re-computing all ISC hypocentres and event magnitudes with uncertainties;

- soliciting, obtaining and integrating essential additional datasets that were not available at the time of the original ISC Bulletin production;
- performing essential integrity and consistency checks, quality control and correction.

The ISC analysts reviewed events with considerable departures of main hypocentre parameters from the original ISC solutions as well as events with unacceptable travel time residuals at individual stations. They also reviewed those events where the only hypocentre is that of the ISC and events where there was no ISC hypocentre in the past.

During the first weeks of 2020, we completed the review of the last remaining seismic events, substituted the old data in the main ISC database with those rebuilt and released to users, as part of general bulletin search, in February 2020. Again, with financial help from AOGS, we prepared and published the 2nd open-source scientific article on the Rebuild project in *Geoscience Letters* (Storchak *et al,* 2020). Here we show figures for the entire rebuilt period (1964-2010), similar to those in Storchak *et al.* (2020).

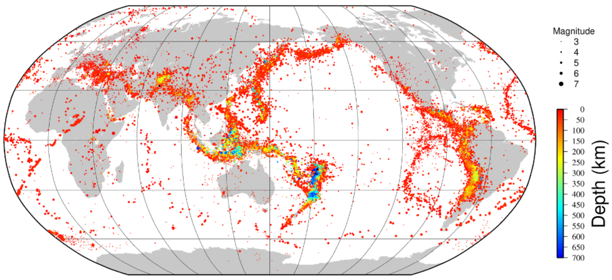


***Figure 27**. Poorly located or phantom events discarded from the ISC Bulletin (1964-2010) (updated figure from Storchak et al (2020)).*

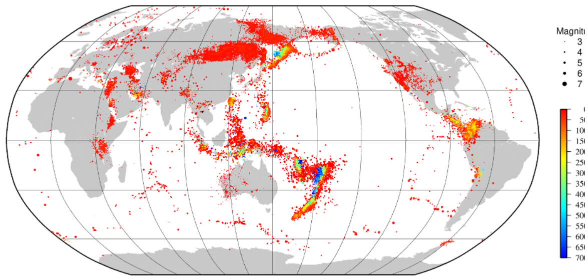


***Figure 28**. New events added to the ISC Bulletin (1964-2010) (updated figure from Storchak et al (2020)).*

We performed the overall review of events in the Bulletin by removing poorly constrained and phantom events (Fig. 27) as well as adding new events from ~90 previously unavailable datasets from temporary and permanent seismic networks (Fig.28). As a result, the rebuilt ISC Bulletin now contains 17% more seismic arrivals and 21% more stations as compared to the original (Fig. 29).

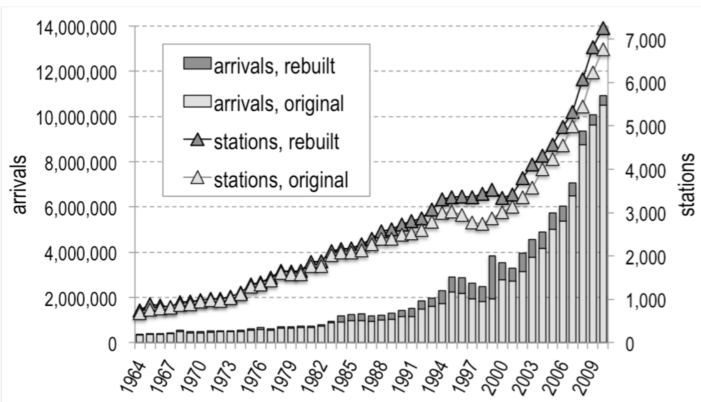


***Figure 29**. Timeline of the number of arrivals and stations in the original (white) and rebuilt (grey) ISC Bulletins during 1964-2010 period (updated figure from Storchak et al (2020)).*

Considerable changes have taken place in the magnitude area (Fig. 30). Many one or two station based ISC *mb* and *MS* magnitudes have been deleted whilst the rest of the magnitudes were recomputed using a much more robust technique that is used by the ISC today.

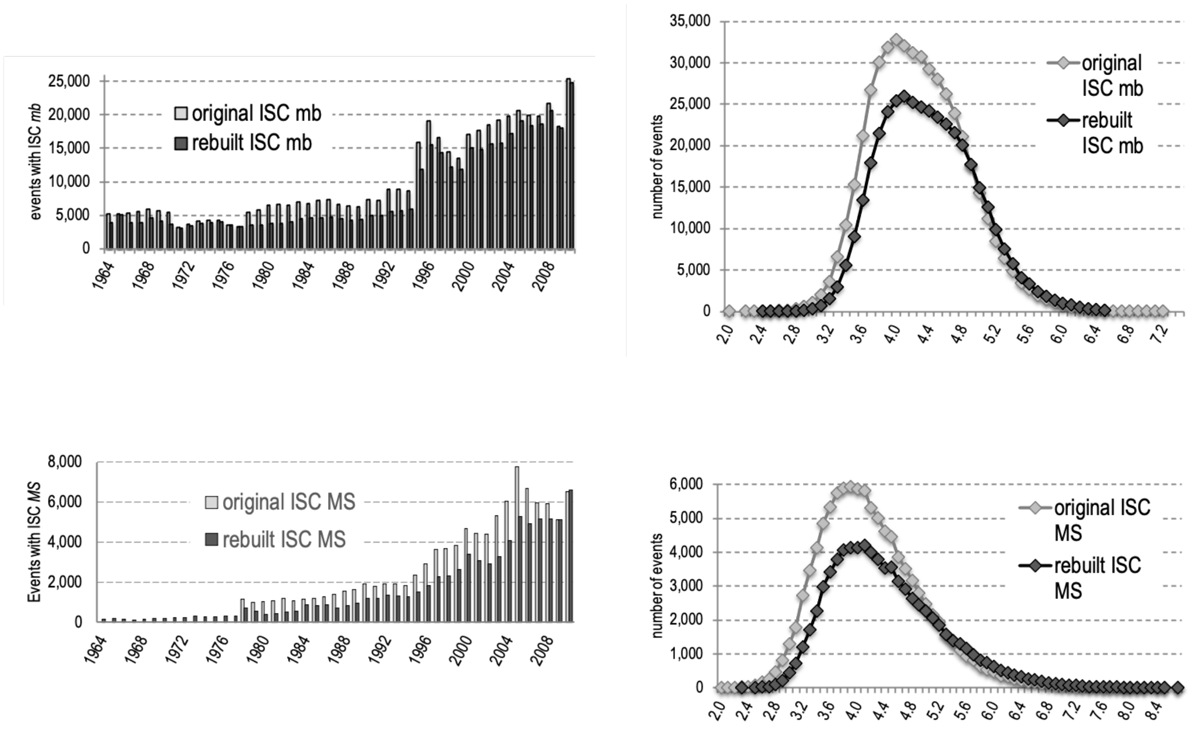


Figure 30*. Comparison of the annual number (left) and the magnitude frequency distribution (right) of the ISC mb (top) and ISC MS (bottom) in the original and the rebuilt ISC bulletins during 1964-20109 (updated figure from Storchak et al (2020)).*

Figure 31 shows the statistical differences between the original and rebuilt ISC magnitudes. It appears, that the rebuilt *mb* is 0.05 larger, on average, than the original *mb*. The rebuilt *MS* is 0.01 larger than the original *MS*. There are now ~18% fewer mb and ~25% fewer MS in the ISC Bulletin, but their estimates and confidence limits are more robust and reliable.

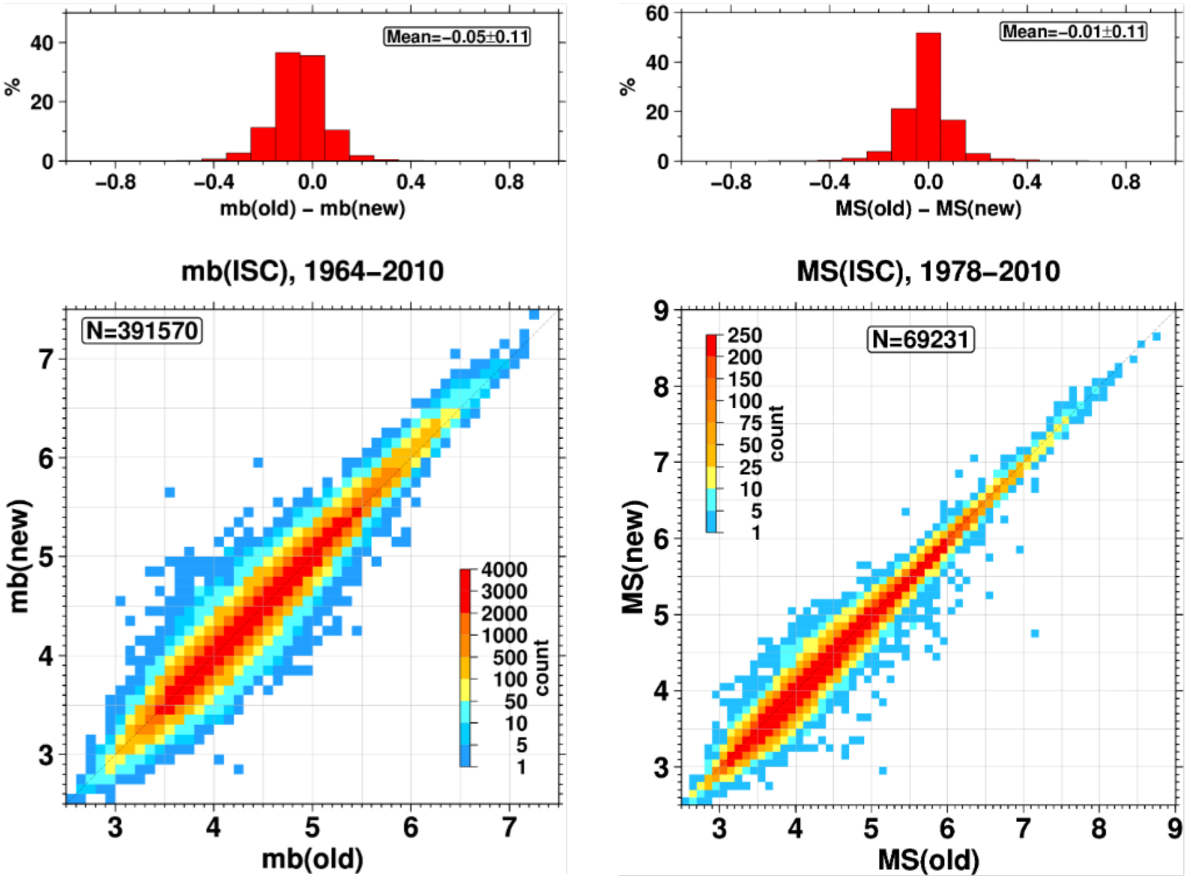
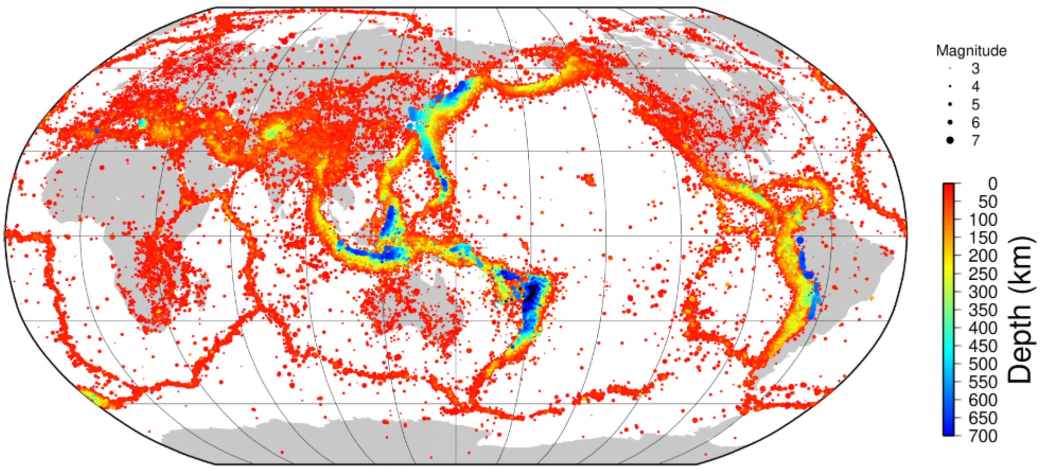


Figure 31. *Statistical differences between the original and rebuilt ISC mb (left) and MS (right) (updated figure from Storchak et al (2020)).*

Figure 32 shows the changes in location of seismic events that have taken place with the introduction of the rebuilt ISC Bulletin.



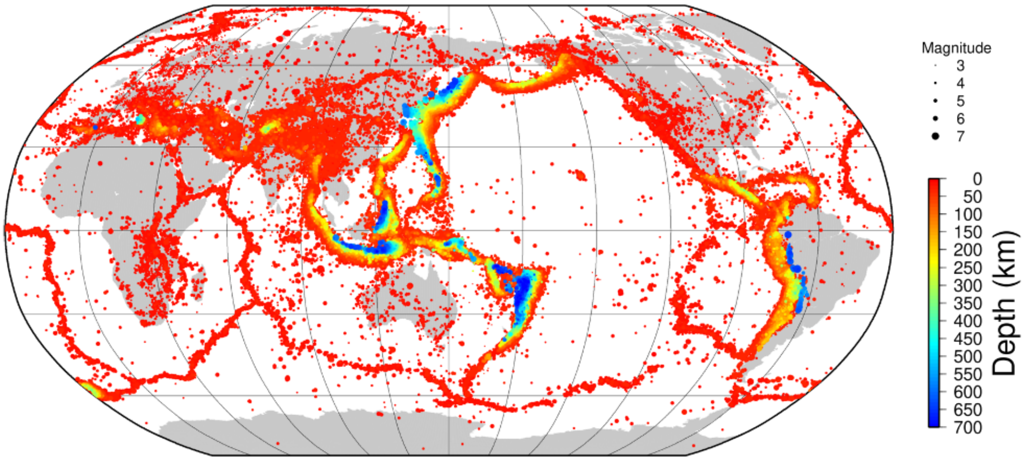


Figure 32*. Before / after maps that demonstrate the changes in the Rebuilt ISC Bulletin during the 1964-2010 period (updated figure from Storchak et al (2020)).*

Our plan for 2021-2022 is to extend the ISC Bulletin for the 1904-1963 period, based on the data available in the ISC-GEM database account.

As a result, the entire extended ISC Bulletin (1904-present) will be relocated based on the same location procedure, *ak135* velocity model and magnitude computation techniques that are used in the ISC Bulletin production today.

ADVANCEMENT of the ISC-GEM CATALOGUE

The ISC-GEM Global Instrumental Catalogue was originally requested and funded by the GEM Foundation. The catalogue is widely used for modelling seismic hazard on a regional and global scale. In addition, the catalogue is used as an authoritative reference and a starting point in regional studies in South America, Africa and Asia. The catalogue also has a multidisciplinary use in a wide range of other areas such as studies of global seismicity, tectonics, earthquake hazard forecasting, rapid determination of hazard etc (Storchak *et al*., 2015). Moreover, during the ISC-GEM project, we digitised a large volume of basic station observation data which can now be used by individual researchers for historical earthquake studies.

Notably, the ISC-GEM catalogue forms the basis of the USGS's ComCat Catalog (ANSS Catalog) before 1970.

The popularity of ISC-GEM has grown over the years. An average of ~15.6 downloads per day were recorded in the last 5.5 years and an average of ~19.2 - during 2020 alone (Fig. 33).

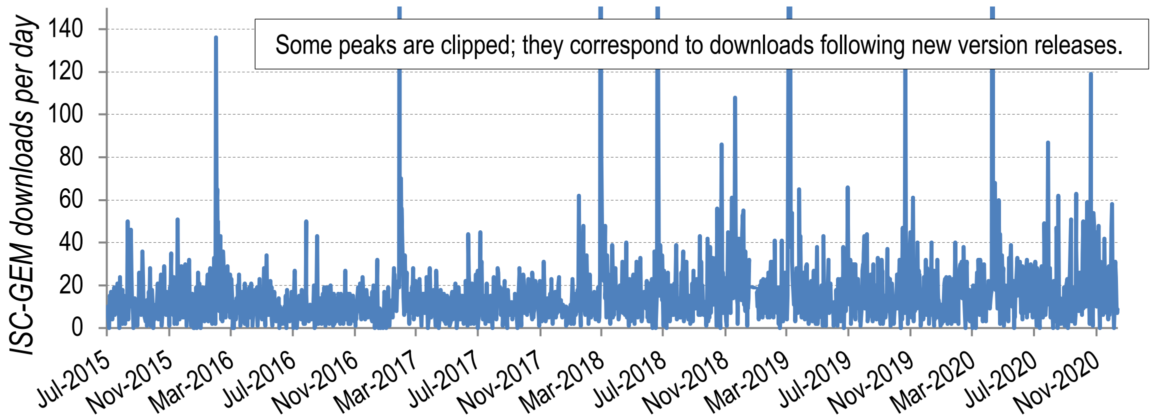


***Figure 33**. During the last 5.5 years, the ISC-GEM catalogue has, on average, been downloaded ~16 times per day.*

The ISC-GEM catalogue was first released in January 2013 (Storchak *et al.*, 2013). Unlike the ISC Bulletin, the ISC-GEM catalogue was built for use in seismic hazard and risk assessment. The catalogue covers ~110 years of global seismicity and includes:

- hypocentres computed (Bondar *et al.,* 2015) using *ak135* velocity model (Kennett *et al.*, 1995), using a combination of the EHB technique (Engdahl *et al.*, 1998) and the new ISC locator (Bondár and Storchak, 2011), based on the original station arrival time reports (Di Giacomo *et al.*, 2015a);
- magnitudes expressed in M_W scale (Di Giacomo *et al.*, 2015b, Lee and Engdahl, 2015;
- formal uncertainties and quality given for both hypocentre and magnitude determinations.

The original ISC-GEM catalogue covered the period 1900-2009 with the magnitude cut-off thresholds dictated by the size of the original funding available at the time and the need to finish the original project in just over two years:

- 1900-1917: M≥7.5
- 1918-1959: M≥6¼
- 1960-2009: M≥5.5

As a result of work under the *Extension* project (Di Giacomo *et al.*, 2018), the improved cut-off thresholds were as follows:

- 1904-1917: M≥6¼
- 1918-2015: M≥5.5

Year 2020 was the 3rd year of the *Advancement* project. We further dropped the cut-off magnitude to M_W 5.0 in the continental areas by adding ~1,900 earthquakes during 1991-1999. We also extended the catalogue to the end of 2017 by adding 543 earthquakes (Fig. 34).

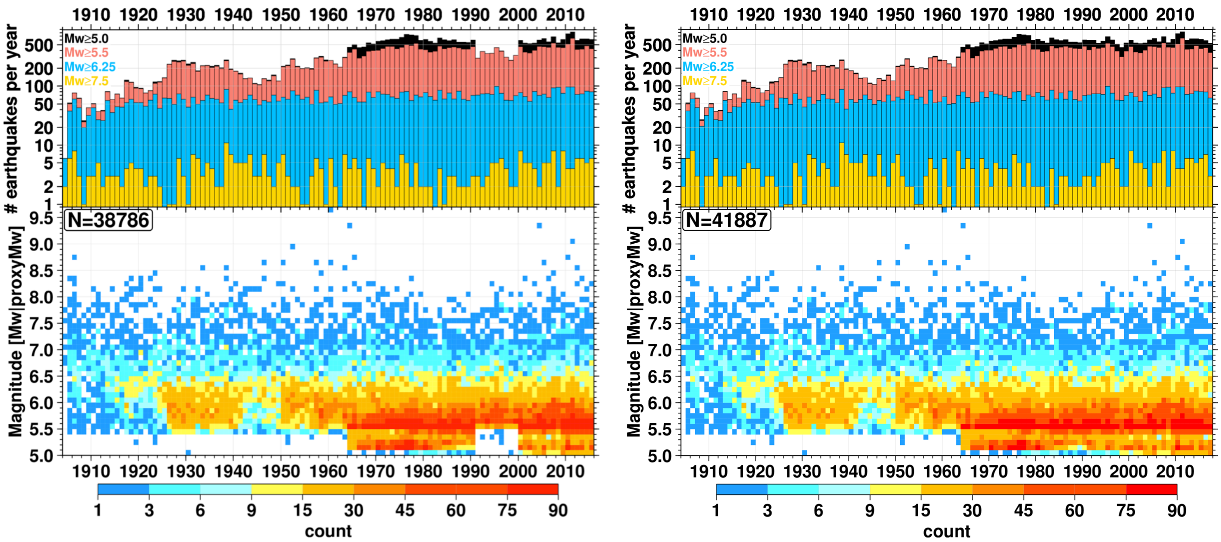


Figure 34. *Annual number (top) and magnitude distribution (bottom) of earthquakes above a certain magnitude in ISC-GEM Ver.7 (at the end of Year 2 of the Advancement project, left) versus Ver.8b at the end of Year 3 of the Advancement project (right).*

We also continued with the large task of searching through the scientific literature for studies of fault mechanisms of past earthquakes before 1976 when the Global CMT project (Ekström *et al*., 2012) began. The results are shown in Figure 35.

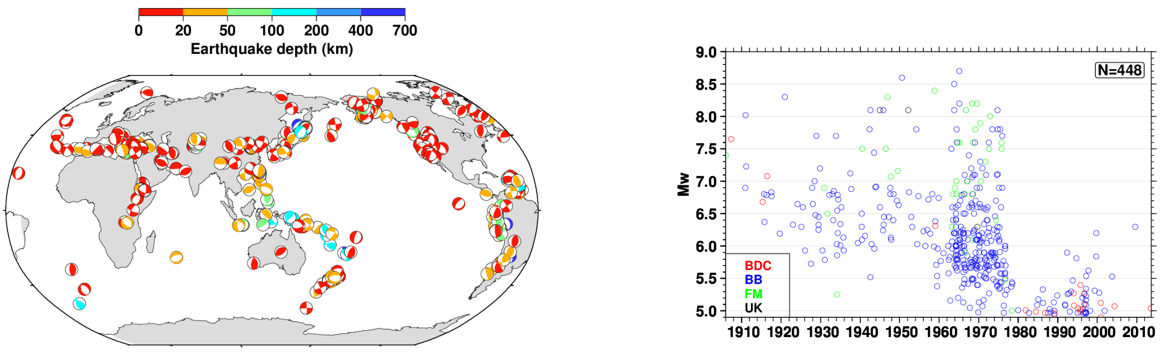


Figure 35: *Left: 448 earthquakes with source mechanisms added from literature, colour-coded by depth; right: timeline colour-coded by type of source mechanism: best double couple (BDC), broadband (BB), first motion polarities (FM), unknown (UK).*

In addition, we made further improvements to ~400 earthquakes already listed in the catalogue by updating the magnitude and/or location.

We also made an impressive effort in digitising additional important bulletins. The major source of phase data for the ISC-GEM catalogue before the beginning of the ISC Bulletin started in 1964 is the International Seismological Summary (ISS 1918-1963). The ISS has been entirely digitized and the earthquakes with ISS data have been assessed for the ISC-GEM catalogue. Another source of phase data pre-ISC Bulletin is the Bureau Central International de Seismologie (BCIS, 1933-1968) that was produced in France in parallel to the production of the ISS in the United Kingdom. The BCIS lists absolute arrival times of large and small earthquakes around the globe and in some years appears to list station data for more earthquakes than the ISS. Hence, in this project year we started digitizing the BCIS content for earthquakes that occurred in the 1950s that are not listed in the ISS or have no data in the ISS. Such a task, although time consuming, has the potential to add quite a few earthquakes that had no data before (hence not processed for the ISC-GEM catalogue) and improve the composition of the ISC-GEM catalogue in years where the ISS censored several earthquakes from its listing, particularly between 1953 and 1959.

By the end of this project year, we digitized station data for over 7,500 earthquakes in the 1950s, as shown in Figure 36.

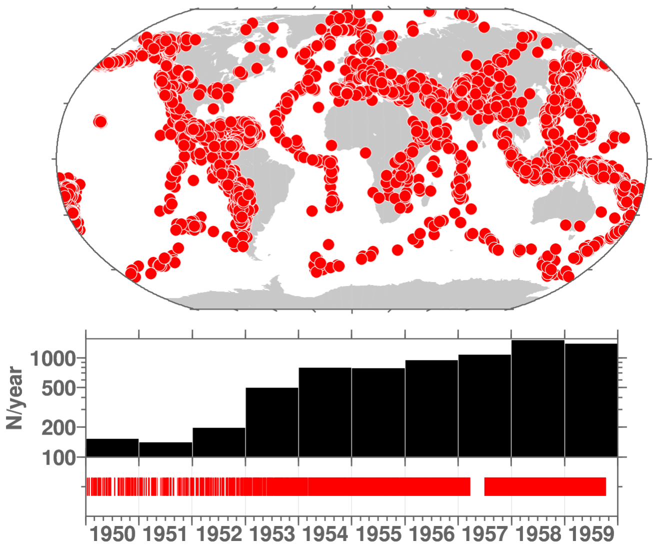


Figure 36. *Top: locations of 7,517 BCIS earthquakes for which we digitized phase data in the 1950s; Bottom: timeline and number of earthquakes per year.*

PROBABILISTIC STF, MT and DEPTH INVERTIONS

In October, Dr. Tom Garth joined the ISC full-time, on completion of his previous post held jointly between the ISC and the seismology group in the Department of Earth Sciences at the University of Oxford. The Oxford seismology group has invited Tom to remain as a visiting researcher, in order to maintain links with both this group and the earthquake mechanics and tectonics research groups, as well as maintaining access to the University publication subscriptions and certain high performance computing facilities.

During 2020, Tom has continued developing the new ISC source time function (STF) product, which will be referred to as ISC-PPSM (where PPSM stands for Probabilistic Point Source Model). This new ISC product will provide probabilistic constraints on the earthquake moment tensor (MT), source time function (STF) and depth for moderate magnitude earthquakes (M_W 5.8 – 7.2) globally, along with a full assessment of the inherent uncertainty in each of these parameters (Fig. 39). In this work, Tom has been building on the work of the project partner Prof. Karin Sigloch (University of Oxford) (Sigloch and Nolet, 2006; Stahler and Sigloch, 2014; 2016). The work has involved:

- finalising the data workflow around the code that has been developed during this project, with the aim of making the process as automated and reliable as possible;
- continued testing of the methodology and workflow on a broader set of example earthquakes, fixing the bugs that were exposed;
- developing the code written to deal with as broad as possible spectrum of global earthquakes, with minimized human supervision;
- designing and implementing procedures to integrate the depth resolution of the STF inversion into the main ISC relocation procedure and bulletin;
- updating the forward modelling methods using the cutting edge *Instaseis* tool (van Driel *et al*., 2018).

The new depth resolution of this method, particularly for remote shallow earthquakes, will be used to set earthquake depths in the ISC Bulletin, where the depth would otherwise be uncertain and fixed to a default depth. The ISC-PPSM earthquake depths, source time functions and probabilistic moment tensors will also be available as a separate product.

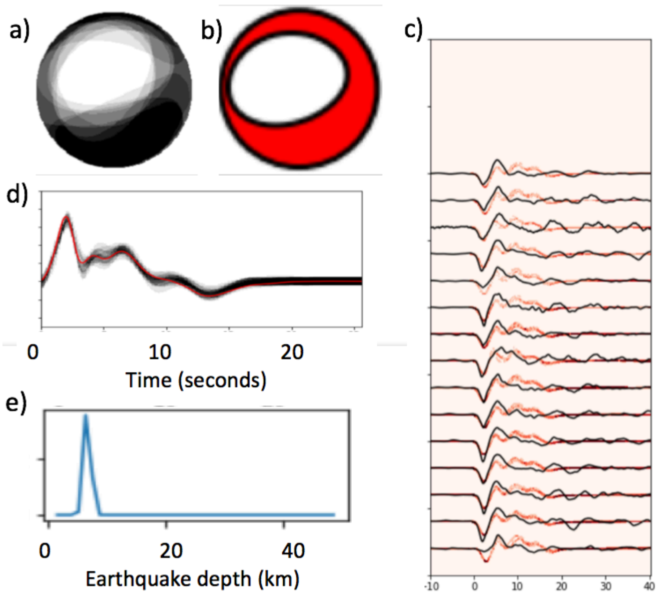


***Figure 39**: Example of the probabilistic STF and moment tensor inversion; **a)** Bayesian beach ball **b)** Best fitting beach ball **c)** Observed seismograms (black) along with ensemble of fitted seismograms (reds) **d)** Probabilistic STF in grey, with best fitting STF in red **e)** Depth probability density function.*

In addition, an outline of the methodology along with a number of illustrative examples was presented at the online AGU Fall 2020 meeting, and at an invited departmental online seminar Dublin (iCRAG lecture series hosted by the Department of Earth Sciences, University College Dublin, September 2020).

CTBTO LINK to the ISC DATABASE

In 2008, the UK Foreign and Commonwealth Office (FCO) awarded the ISC with a three-year grant to set up a dedicated and secure link to the ISC database for the CTBTO Provisional Technical Secretariat (PTS) and National Data Centres (NDC). The FCO provided 90% of the total funding with GEUS (Denmark), NORSAR (Norway), FOI (Sweden) and University of Helsinki (Finland) complementing it with 2.5% each. From April

2011, the funding of the project was taken over by CTBTO. The previous contract ran from April 2015 until March 2020. A new annual contract has been signed and started in April 2020. It provides a possibility of four annual extensions.

During 2020, we maintained a dedicated server at the ISC that held a mirror version of the ISC database. The dedicated web-based software package designed, maintained and upgraded by the ISC for this service allowed users from the PTS and NDCs at CTBTO to query the ISC database in ways specific to the nuclear test monitoring community. The software package includes four types of bulletin searches: area based, REB event based, GT event based and IMS station based through the wealth of parametric information in the ISC database.

The objective is to provide the capability for NDCs to perform various analysis such as:

- assessing historical seismicity in a specific region;
- putting an event of interest into context with the seismicity of the surrounding region;
- examination of observations reported by non-IMS stations;
- comparison of hypocentre solutions provided by various agencies;
- relocating an REB event based on user selected arrival times available in the ISC database using the *ak135* 1-D model with optional RSTT regional velocity model;
- investigation of station histories and residual patterns of IMS or IMS surrogate stations.

We developed an interface for selecting waveforms of non-IMS stations for REB events from the IRIS DMC, EIDA and GeoNet archives. For recent REB and GT events, this interface:

- allows selection of stations by distance / azimuth to the REB epicentre;
- shows the number of stations, for which waveforms are available at all three archives;
- exhibits pre-prepared images of selected waveforms, filtered and un-filtered with theoretical first arrivals indicated on top of the waveform images;
- offers a form to request part of a waveform, based on absolute or relative theoretical arrival times of required seismic phases or on group velocity of surface waves;
- triggers a request to waveform archives; as a result, users receive required waveforms by e-mail in the SEED format.

Figure 40 shows user activity on the Link by both PTS/CTBTO and NDCs.

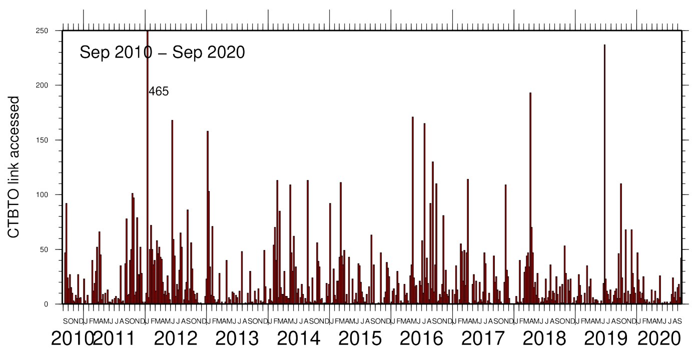


***Figure 40**. The Link to the ISC database mirror is provided to the NDCs through the IDC secure website. The figure shows the healthy stream of user activity.*

This project also benefits the ISC and the ISC users.

- The ISC development staff acquired relevant skills and experience during this project. The advances made under this project are gradually implemented to improve the open ISC web services. For example, the station histories now form an essential part of the International Seismograph Station Registry, available from the ISC website.
- In particular, experience of downloading, quality checking and processing waveforms on an industrial scale helps the ISC's efforts towards making its own automatic waveform measurements to further improve the quality of the ISC Bulletin.
- The ISC and its Bulletin users have speedy access to the REB Bulletin which is now available in **daily batches within 7-22 days after an event occurrence** as opposed to 6-12 months in the past (Fig. 41).
- Many NDCs are run by institutions that are either Members or Reporters of data to the ISC.
- Several NDC's either became ISC Members or increased their financial contributions, based on the added value of the ISC services.

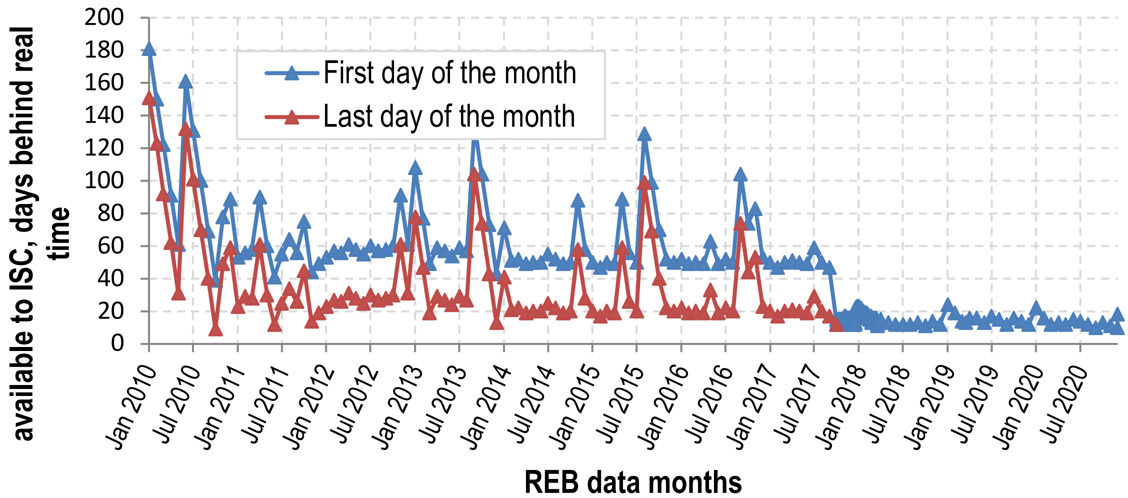


Figure 41. *The availability of data from the ISC REB bulletins (not REB itself) to general ISC Bulletin users (days behind real time) has considerably improved as an indirect result of routine operation of the CTBTO Link; reporting of daily instead of monthly batches made any day of a data month available at the ISC much sooner.*

It also has to be noted that although the use of software created under this project is open only to the monitoring community, the actual data used by them are exactly the same as used by all ISC users: the *ISC Bulletin*, *GT List*, the *ISC-EHB* bulletin and the *International Seismograph Station Registry*.

6: FINANCE

The detailed financial statements of the ISC for 2020 were audited by Azets Audit Services (Newbury, UK) who took over from Wilkins Kennedy Chartered Accountants, used by the ISC in the past. (Newbury, UK). These statements present the state of the ISC's financial affairs as at 31st December 2020.

In line with the decision of the Extraordinary Meeting of the ISC Governing Council on the 12th of May 2020, all assets and liabilities of the ISC (unincorporated association) have been transferred to the ISC (charitable incorporated organization) on the last day of 2020.

Income

In 2020, the ISC had a total income of £1,011,552.

The ISC was expecting to receive £756,501 of contributions from 70 Member Institutions in 47 countries. It took an unprecedented amount of time from the Director and Administration Officer to collect all delayed membership and grant payments this year. Even after that effort, £51,138 (~7%) of the total amount was still delayed on 31st Dec 2020, and £37,579 (~5%) still delayed at the time of producing this report and the annual 2020 Accounts. We praise those Members who make an effort to pay membership invoices promptly.

During 2020, we experienced the loss of membership support from:

- Royal Scientific Society (RSS), Amman, *Jordan*;
- Institute of Earth Sciences Jaume Almera (ICTJA), Barcelona, *Spain;*
- Seismic Research Unit, University of West Indies, St. Augustine, *Trinidad.*

During 2020, we welcomed the following new Members:

- Institute of Radiological and Nuclear Safety (IRSN), Ministries of Defence, the Environment, Industry, Research and Health, Fontenay-aux-Roses, *France*;
- National Geophysical Research Institute (NGRI) of the Council of Scientific and Industrial Research (CSIR), Hyderabad, *India;*
- Geological Survey of Israel, Jerusalem, *Israel* (superseded GII);
- The Centre for Earth Evolution and Dynamics (CEED), University of Oslo, *Norway*;
- Alaska Earthquake Center (AEC), University of Alaska Fairbanks, *USA*;

We are grateful to the US National Science Foundation for providing the supplementary Covid-19 related grant to help the ISC alleviate additional costs caused by the need to organize the staff working from their private homes as well as the need for additional analyst's time to compensate for the reduction in the speed of remote Bulletin analysis.

Grants for special projects and general sponsorship totalled £255,051, which is ~25% of the total income.

Traditionally, the income also includes the revenue from sales of the Bulletin Summary book, reduced by the cost of the book and DVD-ROM production and postage, which in 2020 amounted to a loss of £4,539.

We received a rather mediocre £751 in interest on our bank accounts.

Expenditure

As much as 87% of ISC expenditure was committed to personnel costs. The staff costs include salaries, pension contributions, and recruitment of new staff. The ISC salaries continue to follow the scales adopted in 2015 and approved by the Executive Committee. Each January, with the approval from the Chairs of the Governing Council and the Executive Committee, we increase the staff salaries in line with the annual inflation index (CPI), published by the UK Office of National Statistics. Thus, salaries of all ISC staff were raised by 1.3% from January 2020. We also sustain the continuing rise in pension costs as the experienced staff earns an increase in ISC contribution to their pension pots in line with their length of service. Although this measure is costly, it does help to retain good staff.

This year, the staff costs also include additional hours spent by analysts keeping the Bulletin production going whilst working from home. They were also helped by one of the two contractors, L. Brown, working odd hours from his home in Canada. The costs of the second Contractor, R.E. Engdahl, are accounted for in ISC-EHB project costs.

Notably, staff travel dropped to a very minimal level due to Covid-19. The building maintenance costs in 2020 stayed level with those in 2019. Computer costs almost doubled due to the need to purchase additional equipment for staff working at home and also to arrange for better and more protected servers in the office.

The cost of the PDRA position at the University of Oxford, supported by the ISC (66.66%), was £30,262, which this year was charged by the University in three quarterly invoices. Since Tom Garth left the University and joined ISC, the associated expense moved under general staff costs.

A total of £2,205 has been treated as bad debt. This corresponds to one unit of unrecovered membership subscription for one year from Institute of Earth Sciences Jaume Almera (Barcelona, Spain) who informed the ISC of their unfortunate decision to withdraw during 2020. The other two former Members, mentioned above, made the ISC aware of their decision to withdraw before the start of the year.

The exchange rate between UK £ and US $ / Euro changed throughout the year. Taking into account the timings of individual incoming and outgoing transactions, the ISC made a gain of £8,442 on foreign currency exchange in 2020.

In 2020, in pursuit of the charity (CIO) status, the ISC paid £14,000 for the services and advice to Lester Aldridge LLP. In total, taking 2019 payments into account, these services costed £16,725.

Following its registration as a CIO, the ISC received a refund from the West Berkshire Council (local authority) of 80% of business rates (£21,247) paid by the ISC during 2018 and 2019.

Reserves

In understanding that all missing contributions will be paid, the ISC's income during 2020 exceeded its expenditure by £180,499, which will help to alleviate the expected austerity period in the post-covid years. As a result, the total reserves, comprising cash in the bank, value of building and land, money owed to the ISC (debtors) minus money the ISC owes (creditors) have increased to £1,026,754.

As described in Chapter 3 of this report, these reserves have been transferred to the ISC (CIO) on the 31st of December 2020.

Cash Flow

The cash flow in Fig. 42 shows receipts and expenditure using dates when transactions were recorded at the bank and the bank balances where US Dollars and Euros are converted to Sterling using the exchange rate at the end of each month.

Due to the size of its General Reserve serving as a safety cushion, the ISC was fortunate not to experience problems with its cash flow in 2020. This may change in the future if Members and Sponsors do not provide funds in time. We would like to thank once again those Member-Institutions that make their annual fee payment promptly and accurately when invoices are sent at the beginning of each year.

As described in Chapter 3 of this report, on the 31st of December, all cash has been transferred to the ISC (CIO).

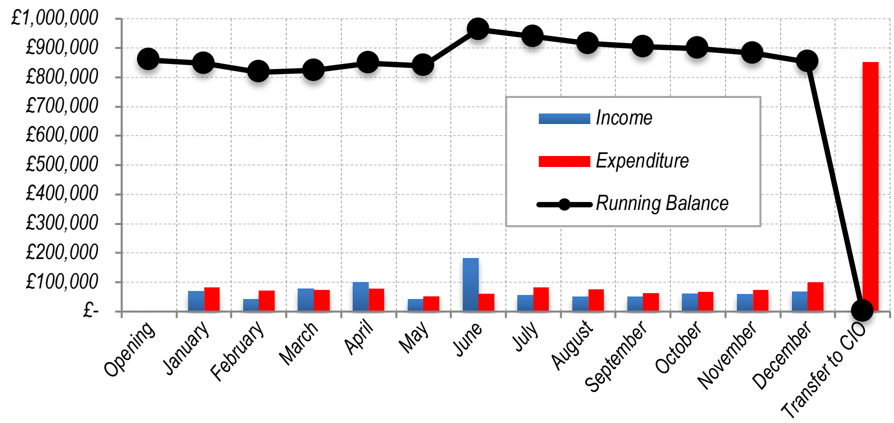


Figure 42. Income, expenditure and running cash balance at the end of each calendar month during 2020.

7: SCIENTIFIC COMMUNITY AWARENESS

Visitors to the ISC

On average, two dozen colleagues visit the ISC each year, meet with the staff and make presentations of their work. Sadly, due to global pandemic, the ISC has not received a single visitor this year.

Conferences, Meetings, Workshops, Training Courses

Members of the ISC staff presented at the following conferences, meetings and workshops that have been run predominantly on-line:

- 11th Gulf Seismic Forum, Doha, ***Qatar***
- CTBTO WGB-54 meeting, Vienna, ***Austria***
- iCRAG lecture series, University College Dublin, virtual, ***Ireland***
- Nordic Seismology Seminar, virtual, ***Denmark***
- GS RAS Scientific Council, virtual, ***Russia***
- AGU Meeting, virtual, ***USA***

ISC Staff Visiting Other Institutions

Often with the help of the hosting institution, members of the ISC staff visit and, where appropriate, give a presentation to the staff. Due to the start of global pandemic, all visits have been cancelled except for the one that happened early in the year:

- IDC/CTBTO, Vienna, ***Austria***

ISC Prizes: University of Oxford

Several years ago, the ISC established a small annual Prize in Mathematics and Geophysics (£200 and traditional ISC coffee mug) for the best first year student at the Earth Science Department of its home institution – the University of Oxford.

In 2020, the prize was given to Mr Hiroki Nagao, the student with the best exam results in Mathematics and Geophysics. By awarding this prize the ISC hopes to attract University of Oxford students to take note of the ISC services right from their first year, support the ISC in the future and perhaps even help the ISC in fulfilling its mission.

Scientific Publications by ISC Staff

The ISC staff published several scientific articles during 2020 to fulfil a general strategy of making the ISC standards, procedures and services transparent to users. This also helps to keep an improved historical record of how the ISC data were put together at different times.

Di Giacomo, D. and Dewey, J. (2020). The (Mythical) M 8.2 Off Coast of Peru Earthquake of 12 December 1908, Seism. Res. Lett., 91(1), 488-498,https://doi.org/10.1785/0220190232

Engdahl, E. R., Di Giacomo, D., Sakarya, B., Gkarlaouni, C. G., Harris, J., Storchak, D. A. (2020). ISC-EHB 1964–2016, an improved data set for studies of Earth structure and global seismicity. Earth and Space Science, 7, e2019EA000897. https://doi.org/10.1029/2019EA000897

Lentas, K. (2020) Indications of seismic station phase reversals detected from parametric data in the ISC bulletin. *J Seismol,* https://doi.org/10.1007/s10950-020-09960-1

Shumba, B.T., Midzi, V., Manzunzu, B., Ottemöller, L., Marimira, K.T. (2020). Source parameters of the moderate Mozambique – Zimbabwe border earthquake on 22 December 2018. Journal of African Earth Sciences,103829, ISSN 1464-343X, https://doi.org/10.1016/j.jafrearsci.2020.103829

Storchak, D.A., Harris, J., Brown, L., Lieser, K., Shumba, B., Di Giacomo, D. (2020) Rebuild of the Bulletin of the International Seismological Centre (ISC)—part 2: 1980–2010. Geosci. Lett. 7: 18, https://doi.org/10.1186/s40562-020-00164-6

Ziolkowski, A., Bell, A., Browitt, C., Curtis, A., Macdonald, C., Main, I., Peacock, S., Rawlinson, N., Storchak, D.A., Walker A. (2020). Frontiers of seismology. Astronomy and Geophysics, 61, 4, 4.29–4.35, https://doi.org/10.1093/astrogeo/ataa057

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APPENDIX 1: STANDARD BULLETIN REPORTERS

151 institutions in 95 countries reported reviewed seismic bulletin data to the ISC during 2020. This number also includes the ISC itself, which now produces depth phase arrival times, polarities of first motions and event source mechanisms in addition to the traditional set of hypocentre solutions and magnitudes.

Albania	The Institute of Seismology, Academy of Sciences of Albania
Algeria	Centre de Recherche en Astronomie, Astrophysique et Geophysique
Argentina	Universidad Nacional de La Plata
Argentina	Instituto Nacional de Prevencion Sismica
Armenia	National Survey of Seismic Protection
Australia	Geoscience Australia
Australia	Primary Industries and Resources SA
Australia	Curtin University
Austria	International Data Centre, CTBTO
Austria	Zentralanstalt fur Meteorologie und Geodynamik (ZAMG)
Azerbaijan	Republican Seismic Survey Center of Azerbaijan National Academy of Sciences
Belgium	Royal Observatory of Belgium
Bolivia	Observatorio San Calixto
Bosnia and Herzegovina	Republic Hydrometeorological Service, Seismological Observatory, Banja Luka
Botswana	Botswana Geoscience Institute
Brazil	Instituto Astronomico e Geofisico, USP
Brazil	Observatory Seismological of the University of Brasilia
Bulgaria	Geophysical Institute, Bulgarian Academy of Sciences
Cameroon	Seismological Observatory of Mount Cameroon
Canada	Canadian Hazards Information Service, Natural Resources Canada
Chile	Centro Sismologico Nacional, Universidad de Chile
China	China Earthquake Networks Center
Chinese Taipei	Institute of Earth Sciences, Academia Sinica
Chinese Taipei	CWB
Colombia	Red Sismologica Nacional de Colombia
Costa Rica	Seccion de Sismologia, Vulcanologia y Exploracion Geofisica
Croatia	Seismological Survey of the Republic of Croatia
Cuba	Servicio Sismologico Nacional Cubano
Cyprus	Cyprus Geological Survey Department
Czech Republic	The Institute of Physics of the Earth (IPEC)
Czech Republic	Geophysical Institute, Czech Academy of Sciences
Czech Republic	WBNET, Geophysical Institute, Czech Academy of Sciences
Denmark	Geological Survey of Denmark and Greenland
Dominican Republic	Observatorio Sismologico Politecnico Loyola
Dominican Republic	Universidad Autonoma de Santo Domingo
DPRK	Korea Earthquake Administration

Ecuador	Servcio Nacional de Sismologia y Vulcanologia
Egypt	National Research Institute of Astronomy and Geophysics
El Salvador	Servicio Nacional de Estudios Territoriales
Finland	Institute of Seismology, University of Helsinki
France	Centre Sismologique Euro-Mediterranen (CSEM/EMSC)
France	Institut de Physique du Globe de Paris
France	Laboratoire de Detection et de Geophysique / CEA
France	EOST / RENaSS
French Polynesia	Laboratoire de Geophysique/CEA
Georgia	Institute of Earth Sciences/ National Seismic Monitoring Center
Germany	Alfred Wegener Institute for Polar and Marine Research
Germany	Bundesanstalt fur Geowissenschaften und Rohstoffe
Germany	Seismological Observatory Berggiesshubel, TU Bergakademie Freiberg
Germany	Geophysikalisches Observatorium Collm
Germany	Helmholtz Centre Potsdam GFZ German Research Centre For Geosciences
Germany	Landeserdbebendienst Baden-Wurttemberg
Greece	National Observatory of Athens
Greece	Department of Geophysics, Aristotle University of Thessaloniki
Greece	University of Patras, Department of Geology
Guatemala	INSIVUMEH
Hong Kong	Hong Kong Observatory
Hungary	KRSZO, Geodetic and Geophysical Research Institute
Iceland	Icelandic Meteorological Office
India	National Geophysical Research Institute
India	National Centre for Seismology of the Ministry of Earth Sciences of India
Indonesia	Badan Meteorologi, Klimatologi dan Geofisika
Iran	Tehran University
Iraq	Iraqi Meteorological and Seismology Organisation
Ireland	Dublin Institute for Advanced Studies
Israel	The Geophysical Institute of Israel / Geological Survey of Israel
Italy	MedNet Regional Centroid - Moment Tensors
Italy	Istituto Nazionale di Geofisica e Vulcanologia
Italy	Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS)
Italy	Laboratory of Research on Experimental and Computational Seismology
Japan	Japan Meteorological Agency
Japan	National Research Institute for Earth Science and Disaster Prevention
Japan	National Institute of Polar Research
Jordan	Jordan Seismological Observatory
Kazakhstan	National Nuclear Center
Kazakhstan	Seismological Experimental Methodological Expedition
Kyrgyzstan	Kyrgyz Seismic Network
Kyrgyzstan	Institute of Seismology, Academy of Sciences of Kyrgyz Republic
Latvia	Latvian Seismic Network
Lebanon	National Council for Scientific Research
Lithuania	Geological Survey of Lithuania

Macao	Macao Meteorological and Geophysical Bureau
Mexico	Centro de Investigacion Cientifica y de Educacion Superior de Ensenada
Mexico	Instituto de Geofisica de la UNAM
Moldova	Institute of Geophysics and Geology
Montenegro	Seismological Institute of Montenegro
Morocco	National Centre for Scientific and Technical Research
Namibia	The Geological Survey of Namibia
Nepal	National Seismological Centre, Nepal
New Caledonia	IRD Centre de Noumea
New Zealand	Institute of Geological and Nuclear Sciences
Nicaragua	Central American Tsunami Advisory Center
North Macedonia	Seismological Observatory Skopje
Norway	University of Bergen
Norway	Stiftelsen NORSAR
Oman	Sultan Qaboos University
Panama	Universidad de Panama
Philippines	Philippine Institute of Volcanology and Seismology
Philippines	Manila Observatory
Poland	Institute of Geophysics, Polish Academy of Sciences
Poland	Private Observatory of Pawel Jacek Wiejacz, D.Sc.
Portugal	Instituto Dom Luiz, University of Lisbon
Portugal	Instituto Portuges do Mar e da Atmosfera, I.P.
Portugal	Sistema de Vigilancia Sismologica dos Azores
Republic of Belarus	Centre of Geophysical Monitoring of the National Academy of Sciences of Belarus
Republic of Crimea	Inst. of Seismology and Geodynamics, V.I. Vernadsky Crimean Federal University
Republic of Korea	Korea Meteorological Administration
Romania	National Institute for Earth Physics
Russia	Altai-Sayan Seismological Centre, GS SB RAS
Russia	Baykal Regional Seismological Centre, GS SB RAS
Russia	Federal Center for Integrated Arctic Research
Russia	Kola Regional Seismic Centre, GS RAS
Russia	Kamchatkan Experimental and Methodical Seismological Department, GS RAS
Russia	Mining Institute of the Ural Branch of the Russian Academy of Sciences
Russia	Geophysical Survey of Russian Academy of Sciences, Obninsk
Russia	North Eastern Regional Seismological Centre, GS RAS
Russia	Sakhalin Experimental and Methodological Seismological Expedition, GS RAS
Saudi Arabia	Saudi Geological Survey
Serbia	Seismological Survey of Serbia
Slovakia	Geophysical Institute, Slovak Academy of Sciences
Slovenia	Slovenian Environment Agency
South Africa	Council for Geoscience
Spain	Instituto Geografico Nacional
Spain	Institut Cartografic i Geologic de Catalunya
Spain	Real Instituto y Observatorio de la Armada
Switzerland	Swiss Seismological Service (SED)

Thailand	Thai Meteorological Department
Trinidad and Tobago	Seismic Research Centre
Tunisia	Institut National de la Meteorologie
Turkey	Disaster and Emergency Management Presidency
Turkey	Kandilli Observatory and Research Institute
U.S.A.	Experimental (GSETT-2) International Data Center
U.S.A.	The Global CMT Project
U.S.A.	IRIS Data Management Center
U.S.A.	National Earthquake Information Center, USGS
U.S.A.	Pacific Northwest Seismic Network
U.S.A.	Pacific Tsunami Warning Center
U.S.A.	Washington University Earth and Planentary Sciences
Ukraine	Main Centre for Special Monitoring
Ukraine	Subbotin Institute of Geophysics, National Academy of Sciences
United Arab Emirates	Dubai Seismic Network
United Kingdom	British Geological Survey
United Kingdom	International Seismological Centre
Uzbekistan	Institute of Seismology, Academy of Sciences
Venezuela	Fundacion Venezolana de Investigaciones Sismologicas
Vietnam	National Center for Scientific Research
Zambia	Geological Survey Department of Zambia
Zimbabwe	Goetz Observatory
Zimbabwe	Eastern and Southern Africa Regional Seismological Working Group (ESARSWG)

APPENDIX 2: ISC DATA in RESEARCH PUBLICATIONS

This list is a result of a special effort to put together a collection of scientific papers published during 2020 that used ISC data. The list is by no means exhaustive. The ISC has become such a familiar name that many researchers sadly fail to reference their use of the ISC data.

To track publications that use one or more of the ISC dataset and services, we set up automatic alerts with Google Scholar for scientific papers that refer to ISC. The Google Scholar alerts return matches with different ways to refer to the ISC as normally done by authors, such as "International Seismological Centre", "International Seismological Center", "ISC-GEM", "ISC-EHB" and "EHB" + "seismic". No doubt many more references can be found by using different search phrases. Below are the bibliographic references to the 304 works in year 2020 as gathered by Google Scholar. The references to articles published in journals are listed first, followed by the references to other types of publications (e.g., chapters in books, reports, thesis, websites). The references are sorted by journal name. The vast majority of the references below belong to journal articles.

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