INTERNATIONAL SEISMOLOGICAL CENTRE (ISC)

# 2018

# Annual Director's Report


The year 2018 was another productive year for the ISC thanks to the support of 65 Member-Institutions and 11 Project Sponsors and despite the loss of support from the local government in West Berkshire which, being under financial pressure from the central UK Government, subjected the ISC to annual taxes at the standard business rate.

The data for earthquakes and other seismic events during 2015-2018 have been added to the ISC Bulletin. The timeliness of the ISC Bulletin has been improved from 35 to 30 months behind real time. The ISC Bulletin has been further rebuilt for the period 1980-1984. For the first time in ISC history, over 5,000 source mechanisms (1938-1979, 2011-2016) have been computed by the ISC, based on first onset polarities, both reported to the ISC and determined by the ISC. The ISC-GEM catalogue was advanced for 1964-1979 and 2000-2015 periods.

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

# EXECUTIVE SUMMARY

- The ISC gratefully acknowledges generous support received from 65 Member-Institutions in 48 countries and additional project grants (28% of the total income) from CTBTO, USGS, BGR, FM Global, Lighthill Risk Network, US NSF, WRN as well as sponsorships from Reftek, GeoSIG, Guralp and SRC.
- Even assuming that all unpaid membership contributions will be paid, the 2018 annual expenditure has exceeded the ISC income by approximately £44,454.
- A total of £117,683 was owed to the ISC at the end of 2018; we strongly encourage the ISC membership fees to be paid promptly when invoiced.
- 18-20 staff members, one contractor and one member of the Earth Science Department of University of Oxford worked at the ISC during the year.
- 1,418 seismic stations were registered or modified in the **International Seismograph Station Registry**.
- Within hours and days after an event occurrence, the ISC collected and grouped preliminary data from 30 networks and made the **Preliminary ISC Bulletin** available to all users.
- The routine process of collecting revised bulletins from ~150 institutions stood at 12 months behind real time; a number of agencies were not able to comply with this deadline and inadvertently hindered the ISC Bulletin analysis.
- More than 16 full data months were added to the Reviewed **ISC Bulletin** with ~76,000 events and ~8.8 million seismic arrivals; one further data month was at an advanced stage of review at the year's end; the entire Bulletin was enlarged by ~613,000 seismic events and ~20.3 million associated seismic arrivals.
- Reviewed Bulletin availability was improved from 35 to 30 months behind real time.
- For the first time in its history, the ISC computed and released as part of its Bulletin 5,219 earthquake source mechanisms for the periods 1938-1979 and 2011-March 2016. These solutions are based on our analysis of P-wave polarities, both reported to the ISC and those determined by the ISC using digital waveforms available on-line.
- We began depth phase waveform picking (global) and Africa Array picking to fill in the gap in agency reporting.
- The ISC Bulletin remains more complete than the bulletins of either NEIC or IDC.
- We completed the ISC Bulletin **Rebuild** for 1980-1984.

- We released three further issues of the printed **Summary of the ISC Bulletin,** which included several invited network and notable earthquake related articles; each issue and each invited article now has it own DOI registered via ISC membership of CrossRef.
- The **ISC-GEM Global Instrumental Earthquake Catalogue** has been advanced to include many earthquakes during 1964-1979 and 2000-2015.
- References to ~1,400 scientific articles related to ~4,000 seismic events have been added to the **ISC Event Bibliography.**
- We continued operating and improving the **CTBTO Link to the ISC database** which experienced a steady stream of data requests from NDC and IDC personnel; the IDC REB is now sent to the ISC on a daily basis with an appropriate delay.
- The ISC database and the website mirrors at IRIS DMC in Seattle, ERI in Tokyo and LLNL in Livermore guaranteed improved speed of access to ISC data; another set of mirrors in Beijing and Xian have been built by the China Earthquake Administration.
- We continued updating and distributing the IASPEI Reference (**GT**) Event List and the List of **International Contacts in Seismology**.
- We worked to extend the **ISC-EHB** dataset to 2015 complete with a collection of regional seismicity cross-sections; two new ISC-EHB analysts have been trained.
- The ISC staff published several scientific articles on ISC-GEM Extension, ISC source mechanisms, ISC-EHB datasets and BSM2017.
- We attended a number of international and regional scientific and industry conferences.
- 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 the ISC products by many researchers worldwide.

Signed, 15th June 2019

Dr. Dmitry A. Storchak
Director

# STAFF and CONTRACTORS

A total of 21 members of staff, one contractor and one member of staff from 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 light blue.

Among the ISC staff members, there were 9 Ph.D., 7 M.Sc. or equivalent, and 3 B.Sc. or equivalent degrees. The ISC staff represents 12 different countries from 4 continents. Several members of staff took part in professional meetings, travelled to international conferences and participated in professional training programmes.

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 System & Database Administrator, UK*

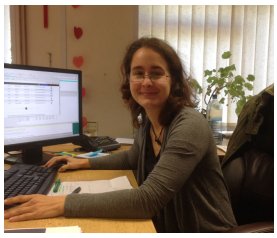
**Alfie Barber**
*Systems Administrator, UK*

**Gergely Csontos**
*Web Developer, Hungary*

## BULLETIN DATA COLLECTION and ENTRY

The Data Collection Officer communicates with agencies and manages routine automatic entry of reported data. The Data Collection Seismologist initiates collection from newly established permanent networks as well as past and present temporary seismic deployments. The Historical Data Entry Officer helps with entering paper-based data into the ISC database.

**John Eve**, B.Sc.
Data Collection Officer
*UK*



**Edith Korger**, Ph.D.
Data Collection Seismologist, left in July, *Austria*

**Daniela Olaru**
M.Sc.Admin., Historical Data Entry Officer, *Romania*

## ANALYSIS TEAM: STANDARD and REBUILT BULLETINS

Ten analysts were engaged in reviewing the current ISC Bulletin. Each member of this team has an additional task either in development projects or in data collection. Four of them take part in the Rebuild of the historical ISC Bulletin.

**Rosemary Hulin**, M.Phys. Geog., no longer team Admin, now 3 days a week, *UK*

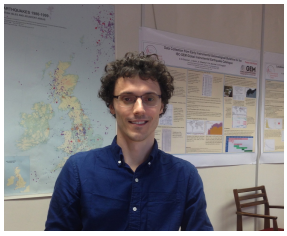
**Blessing Shumba**, M.Sc. Seismologist / Senior Analyst, *Zimbabwe*

**Rebecca Verney**, B.Sc., Analyst, returned from leave for 3 days a week, *UK*

**Elizabeth Entwistle**, Ph.D. Seismologist / Analyst, *left in March, UK*

**Jennifer Weston**, Ph.D. Seismologist / Analyst, left in April, *UK*

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

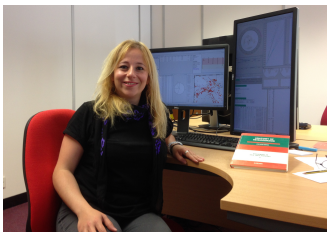


**Lonn Brown, M.Sc.**
Seismologist/ Analyst
Administrator,
*Canada*

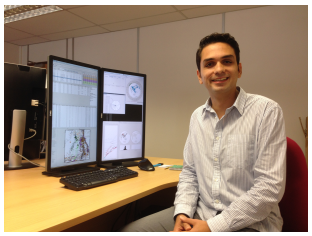
**Kathrin Lieser, Ph.D.**
Seismologist / Analyst,
Editor of the Summary
*Germany*

**Gharikleia Gkarlaouni, M.Sc.**,Seismologist/Analyst,
*joined in February*,
*Greece*

**Peter Franek, M.Sc.**,
Seismologist/Analyst,
*joined in February*,
*Slovakia*



**Angeliki Adamaki, PhD**,Seismologist/Analyst,
*joined in May*,
*Greece,*



**Burak Sakarya**, **M.Sc**.,
Seismologist/Analyst,
*joined in May*,
*Turkey*

## DEVELOPMENT PROJECTS

**Domenico Di Giacomo**
Ph.D.
Senior Seismologist
*Italy*

**Kostas Lentas**
Ph.D.
Seismologist/Developer
*Greece*

**Thomas Garth**
PDRA, Department of Earth Sciences, University of Oxford, part-funded by the ISC, *UK*

## CONTRACTORS

During the year, the following person also contributed to the ISC as contractor:

- **E.R. Engdahl**, Ph.D., *Boulder*, *USA*; taking part in the advancing of the ISC-GEM catalogue and preparing the ISC-EHB bulletin;

# 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.

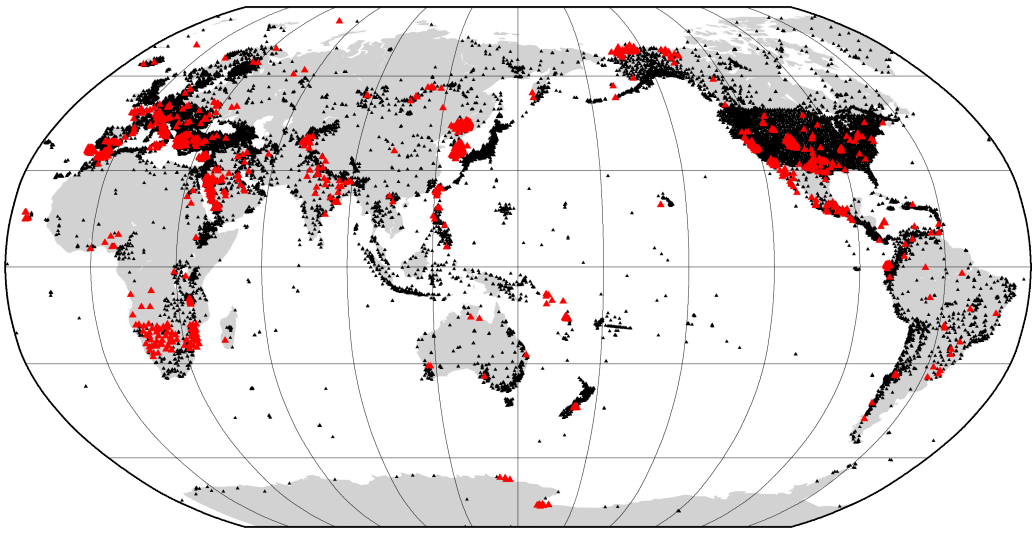


***Figure 1***. *26,307 stations, open or closed, were fully registered in the International Seismographic Station Registry at the end of 2018; parameters of 1,418 of those (in red) were either registered or modified during 2018.*

During 2018, the IR has been particularly improved and extended in Europe, the Mediterranean, South of Africa, Arabian Peninsula, India, Korean Peninsula, North and Central America (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 the 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.

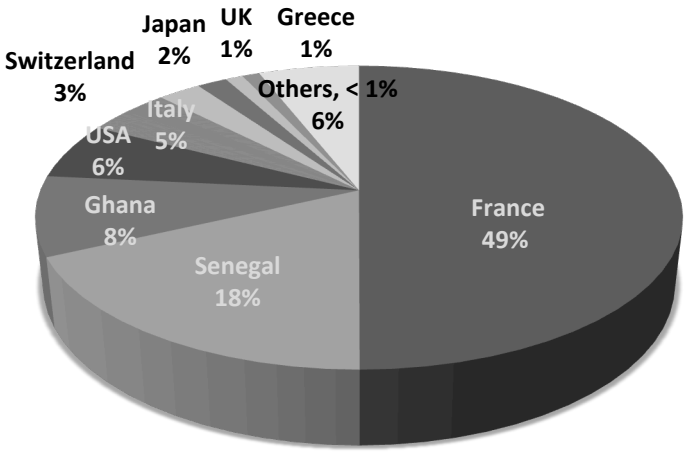



***Figure 2.*** *Per country statistics of the user web-searches directly from the IR; some countries may be shown here due to them housing a VPN-server through which some user-searches are made; NEIC now searches directly through the ADSL database and is not shown here.*

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 will need 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 has been started and will continue into 2019.

## 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 undergo 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 variations are large from agency to agency. Agencies that reported preliminary data during year 2018 are shown in Table 1.

***Table 1****. 31 agencies reported* ***preliminary*** *hypocentre determinations and corresponding arrival time data to the ISC in 2018.*

| 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 |
| Egypt | National Research Institute of Astronomy and Geophysics |
| Finland | Institute of Seismology, University of Helsinki |
| France | Institut de Physique du Globe de Paris |
| 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 |
| India | National Centre for Seismology, Ministry of Earth Sciences |
| Indonesia | Badan Meteorologi, Klimatologi dan Geofisika |
| 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 | Baykal Regional Seismological Centre, GS RAS |
| Russia | Geophysical Survey of Russian Academy of Sciences (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 24 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 |
| Cape Verde | Instituto Nacional de Meteorologia e Geofisica |
| Chinese Taipei | Institute of Earth Sciences, Academia Sinica |
| France | Laboratoire de Detection et de Geophysique/CEA |
| French Polynesia | Laboratoire de Geophysique/CEA |
| Germany | Alfred Wegener Institute for Polar and Marine Research |
| Germany | Seismological Observatory Berggiehühubel, TU Bergakademie Freiberg |
| Greece | National Observatory of Athens |
| Greece | University of Patras, Department of Geology |

| | |
|---|---|
| Iran | International Institute of Earthquake Engineering and Seismology |
| Ireland | Dublin Institute for Advanced Studies |
| Ivory Coast | Station Geophysique de Lamto |
| Kyrgyzstan | Kyrgyz Seismic Network |
| Mexico | Centro de Investigacion Cientifica y de Educacion Superior de Ensenada |
| Moldova | Institute of Geophysics and Geology |
| New Caledonia | IRD Centre de Noumea |
| 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 |
| Russia | Sakhalin Branch, Geophysical Survey, RAS |
| Switzerland | Swiss Seismological Service |
| U.S.A. | Red Sismica de Puerto Rico |

Notably, the timeliness of the IDC bulletin (REB) availability at the ISC has improved a great deal. 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 place and then to get access to details using provided links 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.

*Appendix 1* lists 151 agencies that contributed revised seismic bulletins to the ISC during the calendar year 2018. It is important to note here that among them are **two regional data concentrators** that in fact represent a number of networks. The East and South Africa Regional Seismological Working Group (**ESARSWG**) contributes a coordinated collection of local bulletins from 9 countries: *Ethiopia, Eritrea, Kenya, Malawi, Mozambique, Tanzania, Uganda, Zambia and Zimbabwe*. The US National Earthquake Information Center (**NEIC**) also covers a multitude of regional seismic networks in the US.

The ISC no longer receives seismic bulletins from the European-Mediterranean Seismological Centre (EMSC). All available bulletin contributions from this region arrive at the ISC directly from individual institutions.

Figure 3 shows countries and agencies that contributed revised bulletins for various months and years, directly or indirectly (via other agencies), during 2018. There is currently ~18 months gap between the data collection deadline and the Bulletin availability. Figure 4 shows those agencies that reported data for the data months that the ISC reviewed during 2018. This collection is generally more complete (see East Africa, Pakistan, Thailand) due to the effort made by the Data Collection Officer and the Director to bring missing agency data before the analysis begins.

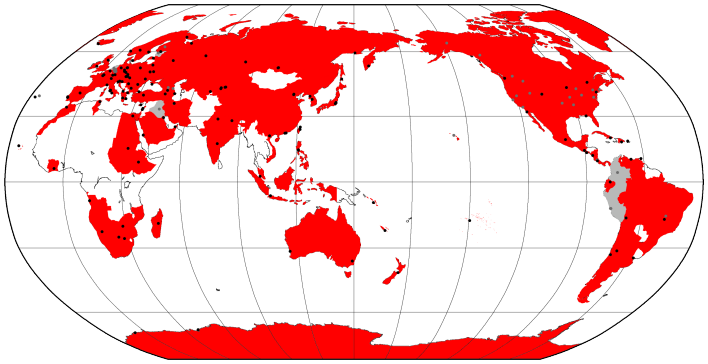


***Figure 3**. Agencies (black dots) and corresponding countries (in colour) that reported revised bulletins during 2018; red/grey colours indicate direct/indirect contributions.*

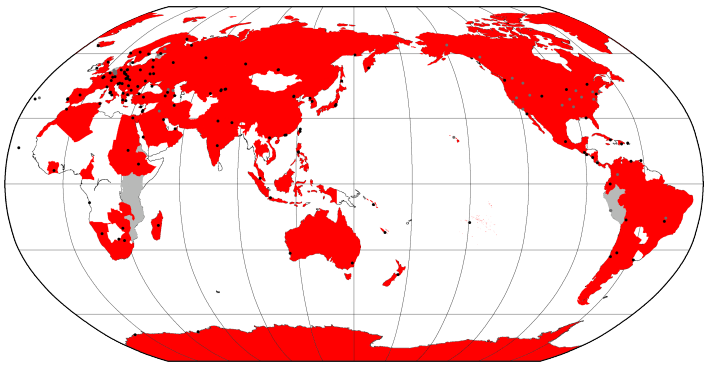


***Figure 4**. Agencies and corresponding countries that reported revised bulletins for the data months reviewed by the ISC in 2018: February 2015 – June 2016.*

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, who is working remotely from his home office in Scotland. 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.

## VBAS-based 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 review approximately 10-20% 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 1st version of the Visual Bulletin Analysis System (VBAS). Improving this version is not currently seen as a major priority.

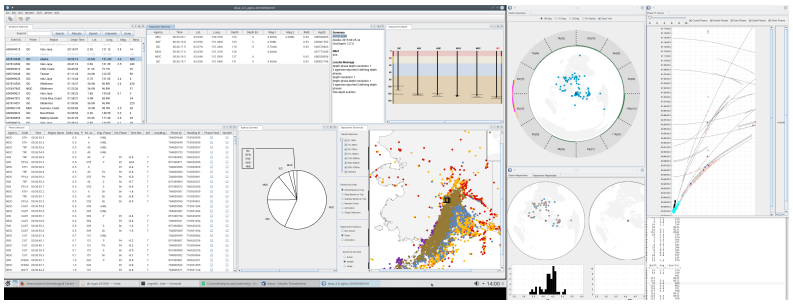


***Figure 5**. Graphical windows of the Visual Bulletin Analysis System (VBAS) can be arranged in line with the individual analyst's convenience.*

Throughout 2018, the Analysis Team varied between 7 (at start of the year) and 9.2 members (second half of the year) members, temporarily dropping to 4.6 for a few months in spring. This variability was caused by a return from maternity leave, two resignations for personal reasons and two members of staff moving to a shorter working week and four new analysts arriving. Early in the year, the two parts of the analyst group (standard and rebuild) were merged and administration of the entire group was reassigned to Mr Lonn Brown, who led just the rebuild part of the team in the past.

In addition to the standard Bulletin analysis, members of the team were involved in other projects such as the ISC-EHB bulletin, Event Bibliography, ISC-GEM catalogue, automatic amplitude measurements from waveforms and production of the printed/electronic Summary of the ISC Bulletin, including its statistical analysis.

During 2018, the Analysis Team fully reviewed 16 new data months of the ISC Bulletin (February 2015 - June 2016). A fair amount of work for February 2015 was done in 2017. The analysts were working with a lower number of seismic events compared to the average number during the previous 6 years (Fig. 6). Nevertheless the number of associated phases reviewed by analysts was on the increase (see numbers below) as new stations and networks were set up and corresponding data reported to the ISC. By design, VBAS helped to alleviate this problem.

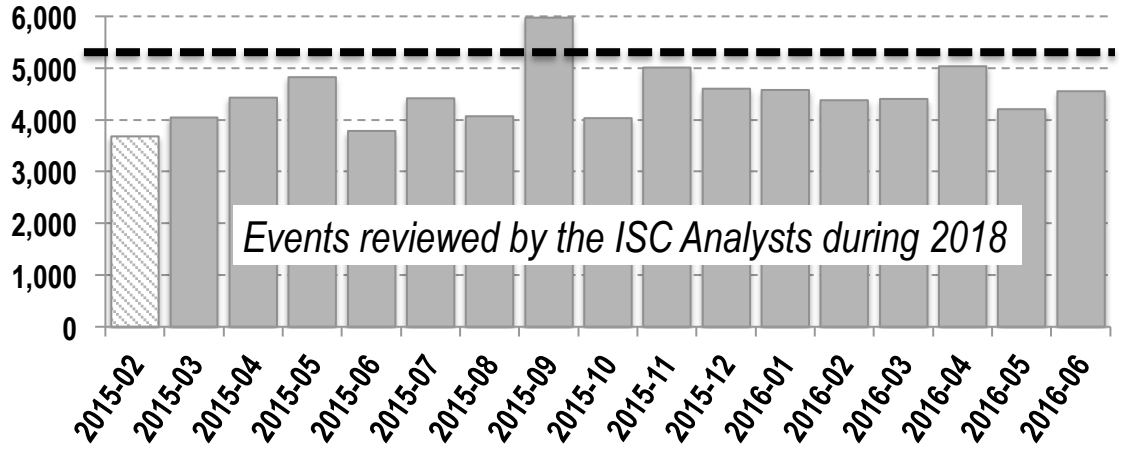



***Figure 6**. Monthly number of seismic events in the Reviewed ISC Bulletin analysed during 2018; the solid colour represents those data months that were fully completed; the dashed line shows the average monthly number during the preceding 6 years.*

The result of the ISC work can be seen when comparing Figures 7 and 8. A fuzzy picture of the originally reported seismicity sharpened by the Reviewed ISC Bulletin.

During the calendar year 2018 (*2017*), ~76,000 *(~53,000)* reviewed events with ~8.8 *(~6.1)* 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 ~613,000 (~434,000) events and ~20.3 (~13.7) million associated phases.

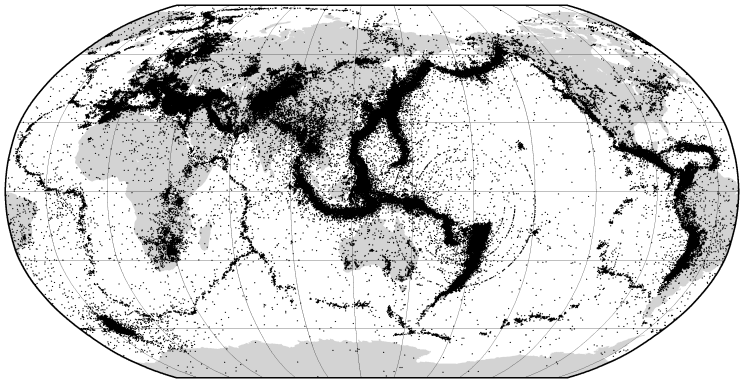


***Figure 7**. All hypocentres reported by individual networks (February 2015 – June 2016).*

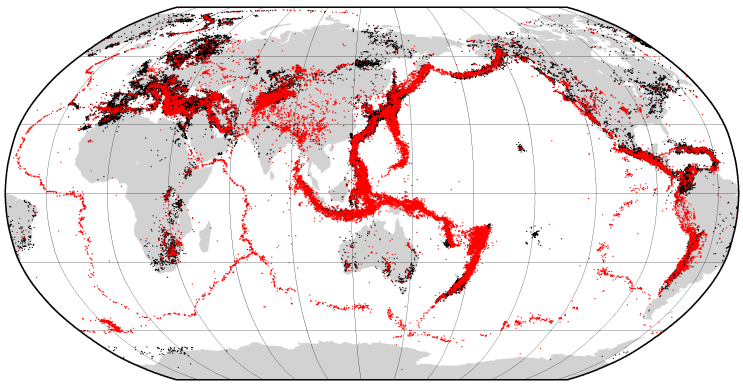


***Figure 8**. Primary hypocentres in the ISC Bulletin (black) in the period (Feb 2015 – June 2016); in red are the reviewed events.*

Figure 9 demonstrates the diversity of seismic phases included in the ISC Bulletin.

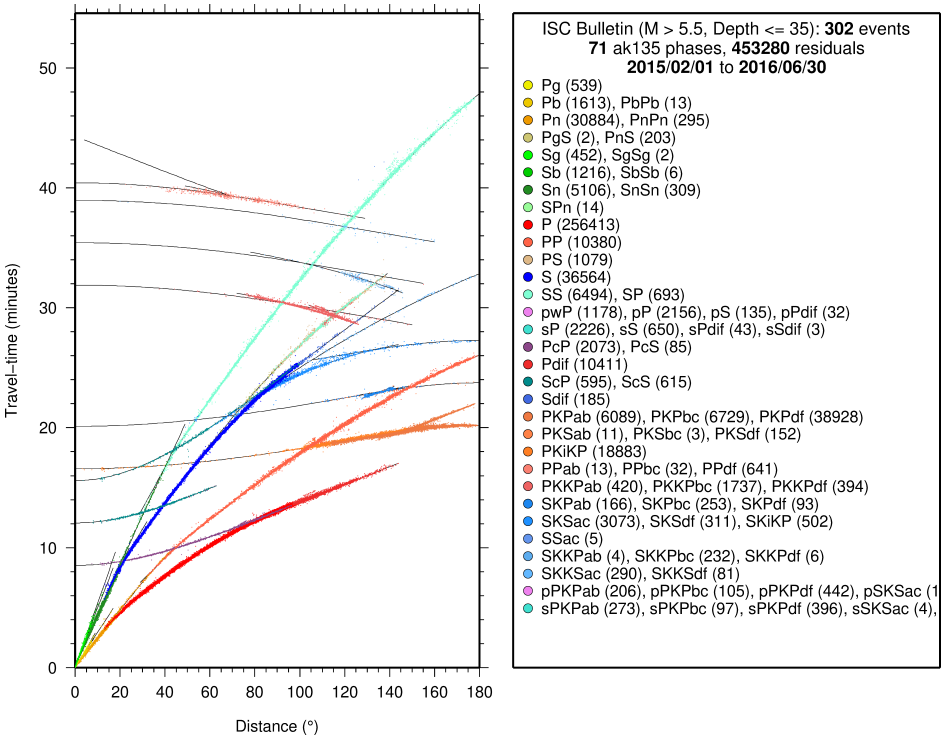



***Figure 9**. The travel-time graph and associated table show the statistics of various seismic phases generated by large shallow events reviewed by the ISC analysts during 2018; depth <=35 km and magnitude above 5.5 are shown.*

## 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. 10) and reported seismic wave arrival times and amplitudes of seismic waves recorded at stations registered in IR (Fig. 11).

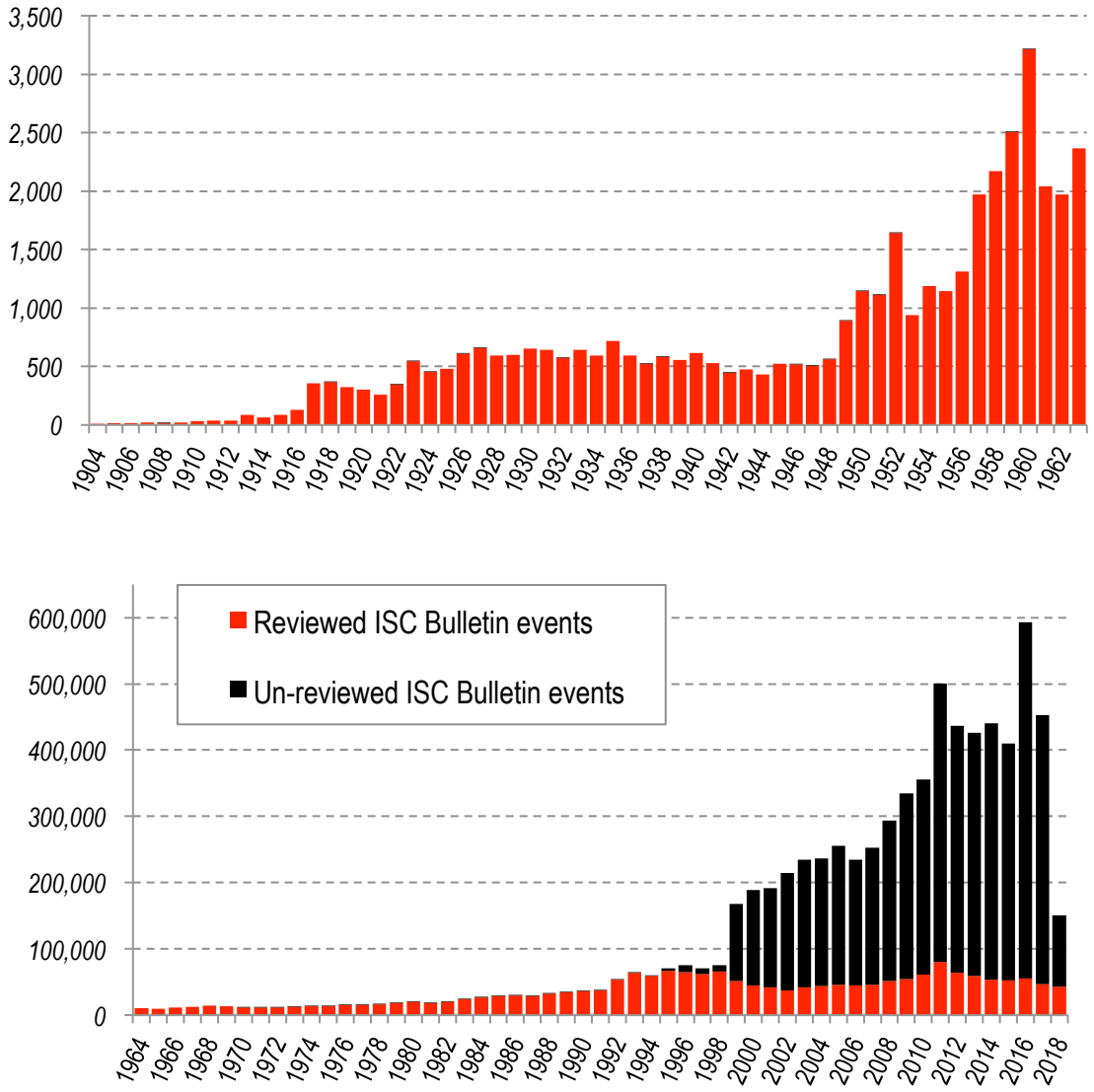



***Figure 10***. *Timeline of the annual number of reviewed and un-reviewed (small) events in the ISC Bulletin; the total height of each column represents the annual number of all seismic events in the ISC Bulletin; note different scale used for events before and after 1964; "Reviewed" events beyond June 2016 are those intended for review.* Numbers as of March 19, 2019

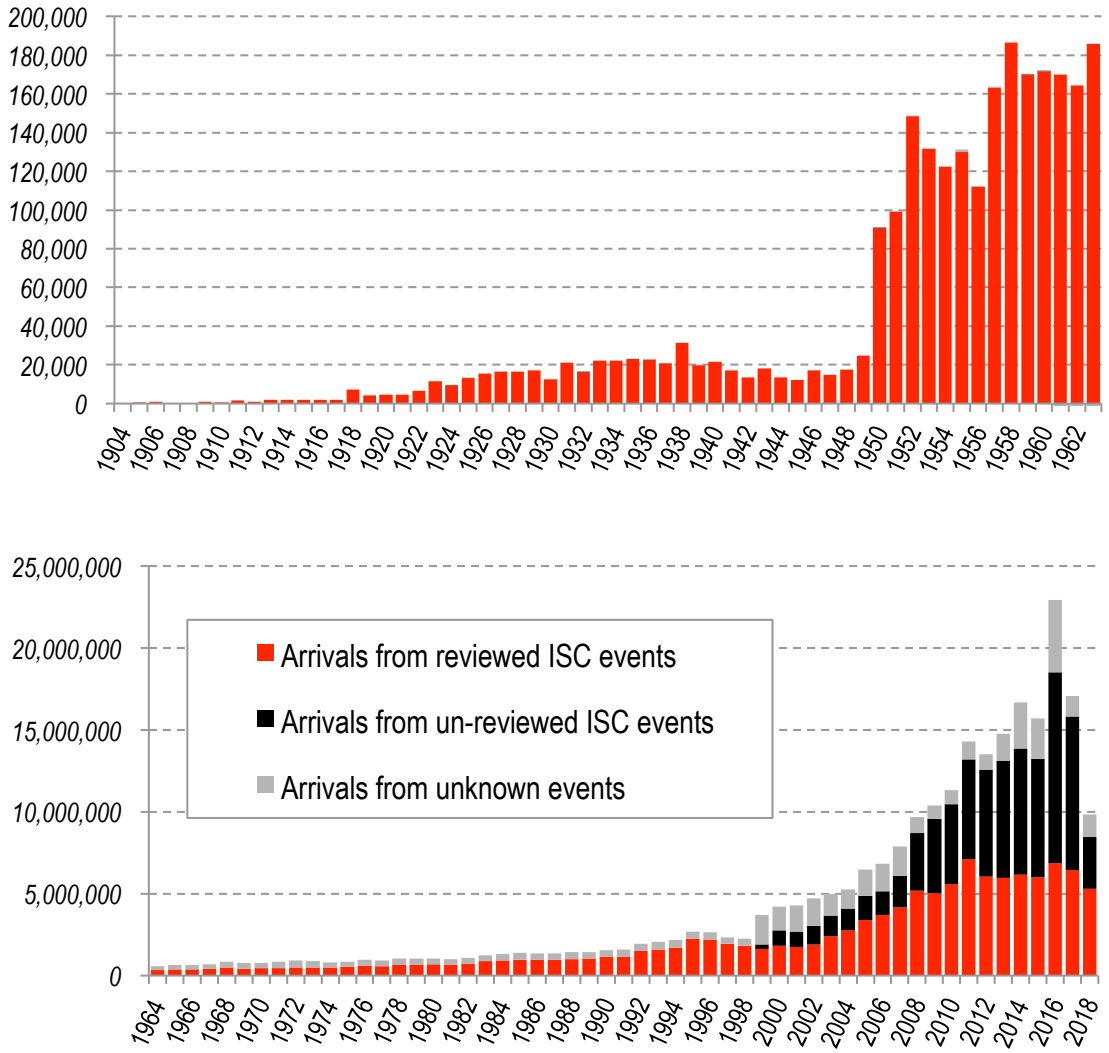



***Figure 11***. *Timeline of the annual number of seismic arrivals associated with both reviewed (red) and un-reviewed (black) events in the ISC Bulletin, as well as those arrivals in the ISC database that are not associated to any known event (grey); the total height of each column represents the annual number of all seismic arrivals in the ISC database; note different scales used for events before and after 1964; "Reviewed" events beyond June 2016 are those intended for review.* Numbers as of March 19, 2019

Figure 12 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.

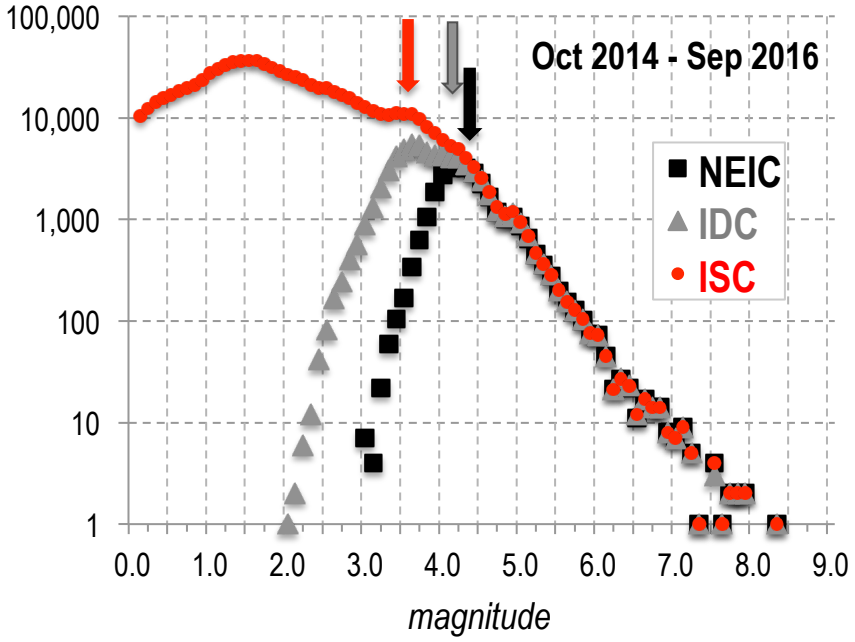



***Figure 12**. Number of seismic events in the ISC, NEIC/USGS and IDC/CTBTO bulletins during the Oct 2014 - Sep 2016 period; vertical arrows indicate an approximate magnitude of completeness.*

The ISC Bulletin is used by a large number of researchers worldwide. The number of bulletin web searches in 2018 decreased by 5.8% compared to 2017; it is in the order of 3 searches per minute (Fig. 13). The above number doesn't even include searches through the ISC mirror databases at ERI, CTBTO, LLNL or CEA. Neither does it include individual user searches based on flat bulletin files downloaded by some users from the ftp-site.

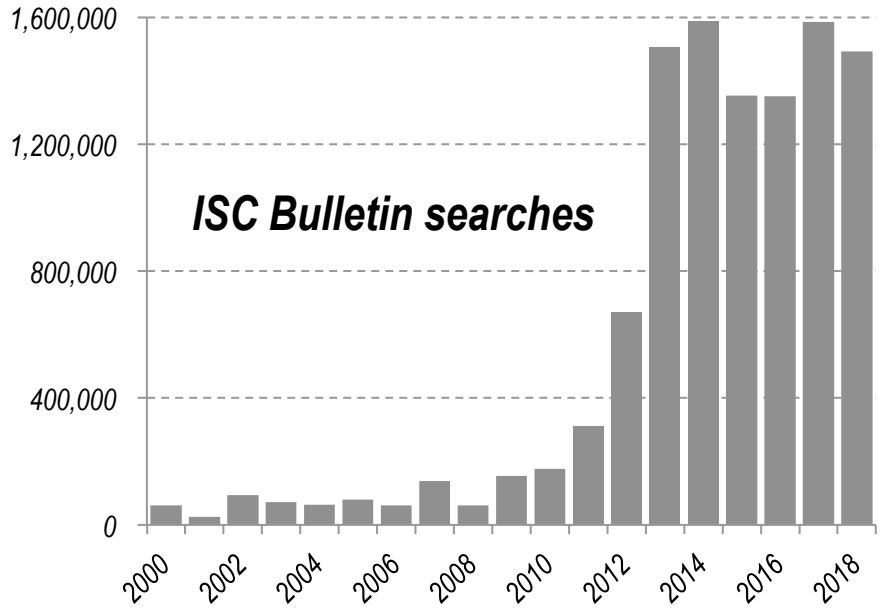



***Figure 13**. The annual number of ISC Bulletin searches made by website users; during 2018, the search numbers averaged **three per minute**.*

Figure 14 shows the multinational character of the ISC Bulletin search users.

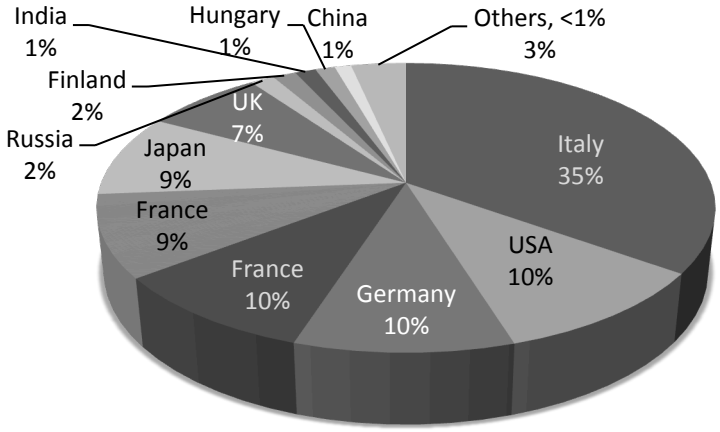



***Figure 14**. Distribution of the ISC Bulletin searches, per country, made by ISC website users during 2018.*

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 15 shows that the total number of searches in QML exceeds those of ISF or CSV. The QuakeML searches though, are performed by fewer users who tend to run automated queries that request larger volumes of data. Nevertheless, it appears that all three formats are popular and need to be maintained in the future.

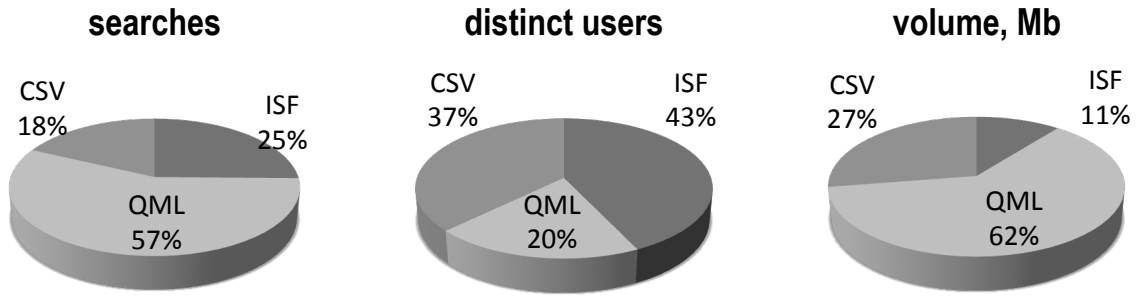



***Figure 15**. Distributions of the number of ISC Bulletin searches, distinct users and overall volume of data taken per output format.*

## PRINTED SUMMARY of the BULLETIN of the ISC

Each volume 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.

During 2018, we signed up for membership of CrossRef that now allows us to issue and register digital object identifiers (DOI) for each issue of the book and each invited article inside the book. We made considerable efforts to build dedicated webpages for this publication that will greatly improve its visibility on the web.

This year, we published three issues covering the period from July 2014 to December 2015 (Fig. 16). 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 (6 months)
- Invited articles on the history, status and procedures used at:
    a. ***AWI*** in Germany
    b. ***Bergen University*** in Norway
    c. ***University of Helsinki*** in Finland
    d. ***BGR*** in Germany
- Invited articles on notable events:
    a. October 2015 earthquake in the ***Central Ural Mountains***, Russia
- Statistics of Collected Data
- Overview of the *ISC Bulletin*
- Leading Data Contributors
- Advertisements of instrument producers – Sponsors of the ISC

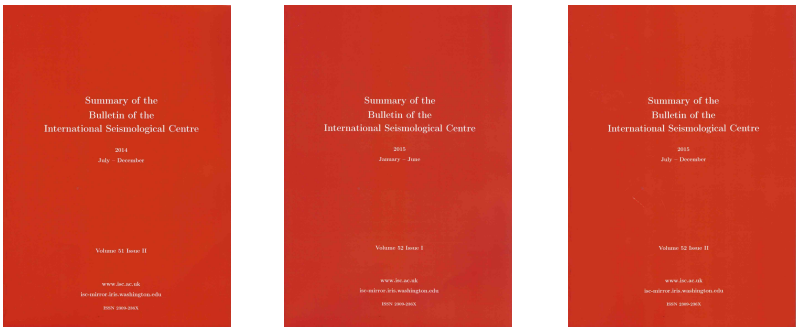



***Figure 16****. Three issues of the printed Summary of the Bulletin of the ISC were published during 2018: second issue for the data year 2014 and both issues for the data year 2015.*

The invited articles on notable events contribute to the *ISC Event Bibliography*. 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 no Value Added Tax (VAT) on its printed products yet VAT on all goods and services that it buys from other suppliers can be reclaimed.

## 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.17a,b). It should be noted that the depth of these events is not known to the same level of accuracy as the epicentre.

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

The GT database of 9,698 reference events (1959-2017) and approximately 1,130,000 station arrival times facilitates better visualization of the Earth 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.

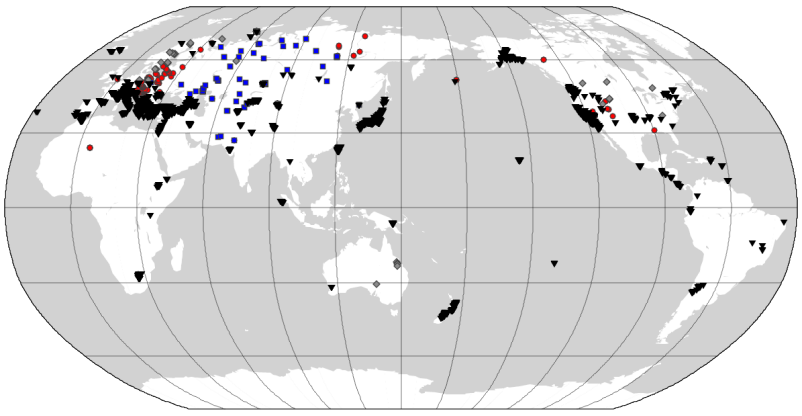



***Figure 17a.*** *The IASPEI List contains seismic events during 1959-2017 for which epicentre information is known with high confidence (to Xkm or better (GTX))*

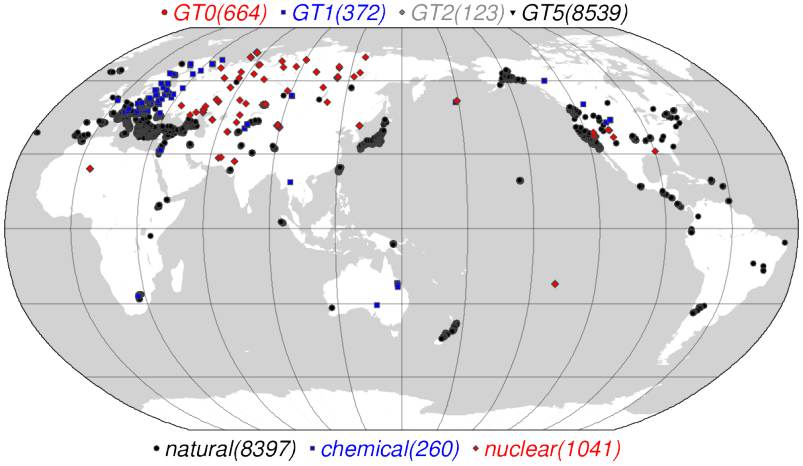



***Figure 17b.*** *The IASPEI List contains natural earthquakes as well as chemical and nuclear explosions.*

At the end of analysis of each ISC Bulletin data year, we add new events to the Reference Event List. During 2018, 426 events were added or updated (Fig. 18).

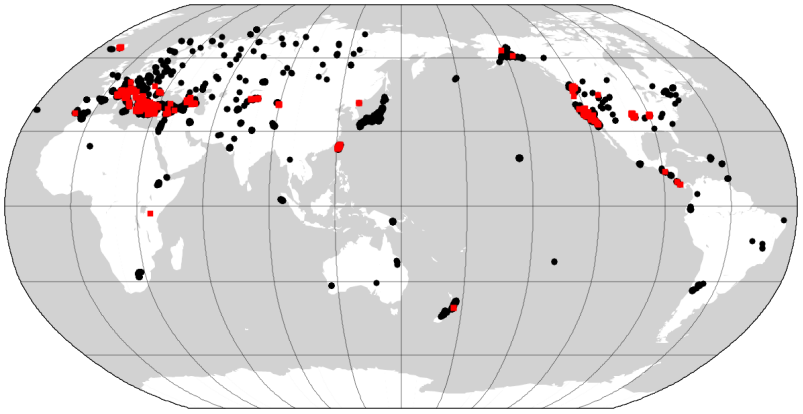


***Figure 18.*** *Events (red) updated or added to the IASPEI Reference Event List during 2018*

## ISC EVENT BIBLIOGRAPHY

The ISC Event Bibliography (first released in April 2013) 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, magnitude, etc.) and/or publication parameters (author name, 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 ISC Bibliography of Seismology, electronic indexes provided by scientific journals as well as references collected during work on the ISC-GEM Catalogue.

References to publications are not limited to Seismology. They cover a broad range of disciplines including, but not limited to, earthquake engineering, tectonics, structural geology, geodesy, remote sensing, nuclear test monitoring, tsunami, landslides, environmental studies, coastal science, natural disasters, hydrology, geochemistry, atmospheric sciences and geomagnetism. This feature makes the Event Bibliography an attractive tool for multidisciplinary studies and useful for researchers and students from different fields.

At the end of 2018, the Event Bibliography included ~21,000 articles from ~500 journal titles related to ~18,500 seismic events. Seismic events cover the period from 1904 till present; publications covered the period from 1904 till present. Figure 19 illustrates 1,418 articles related to 3,990 events that were added to the Event Bibliography during 2018. A large proportion of this work for the 20$^{th}$ century benefitted from the bibliographical efforts bringing reliable earthquake source mechanisms and moment tensors into the ISC-GEM catalogue.

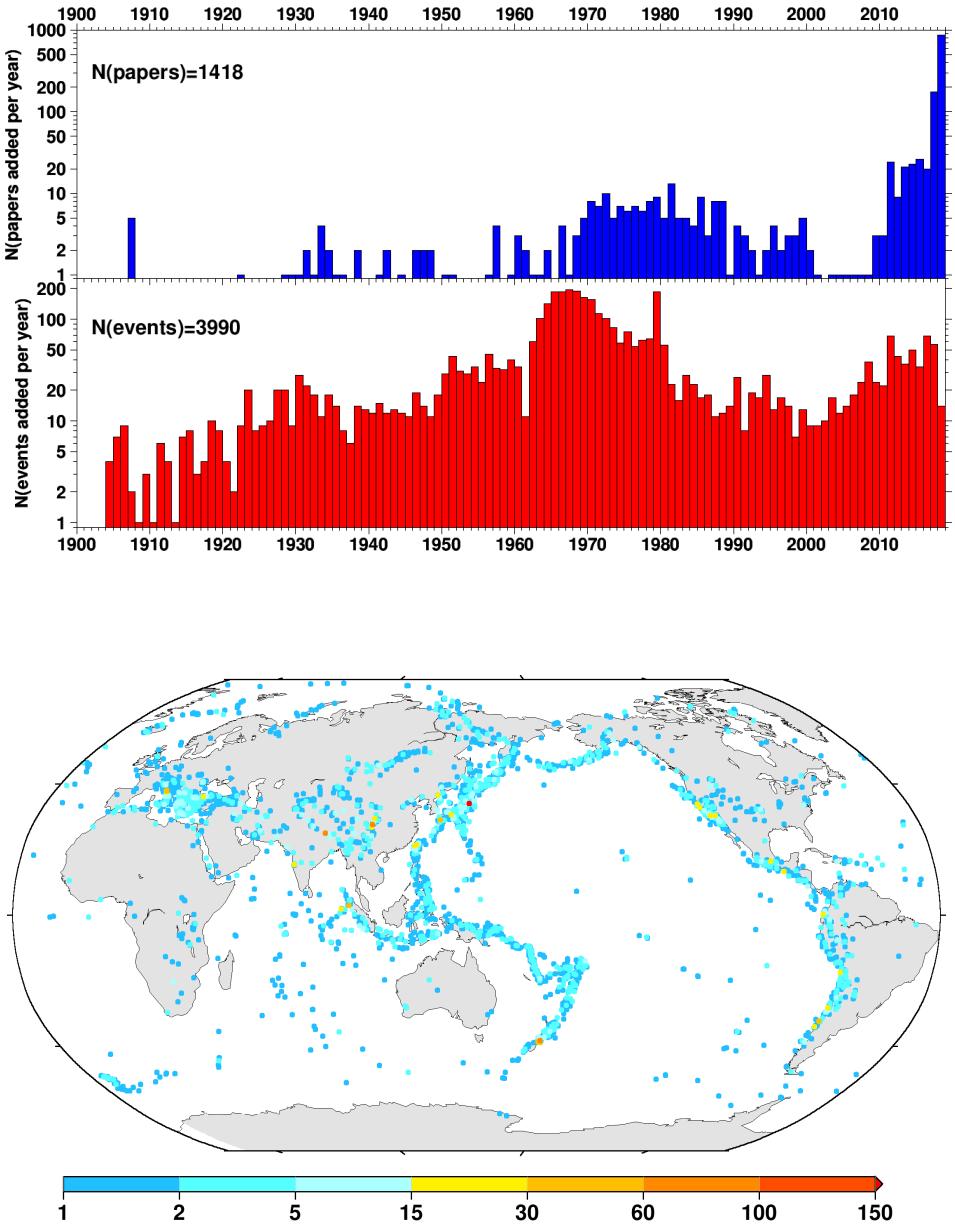



***Figure 19**. Annual numbers and the map of 3,990 seismic events related to 1,418 scientific articles added to the ISC Event Bibliography during 2018; added information on events during the 20th century originated from bibliographical work on the ISC-GEM catalogue*

## 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 the developing countries (Fig. 20), willing to serve as scientific points of contact for:

- Seismologists and Geophysicists in other countries,

- Governments,
- Charitable, Response and Relief organizations,
- Media.

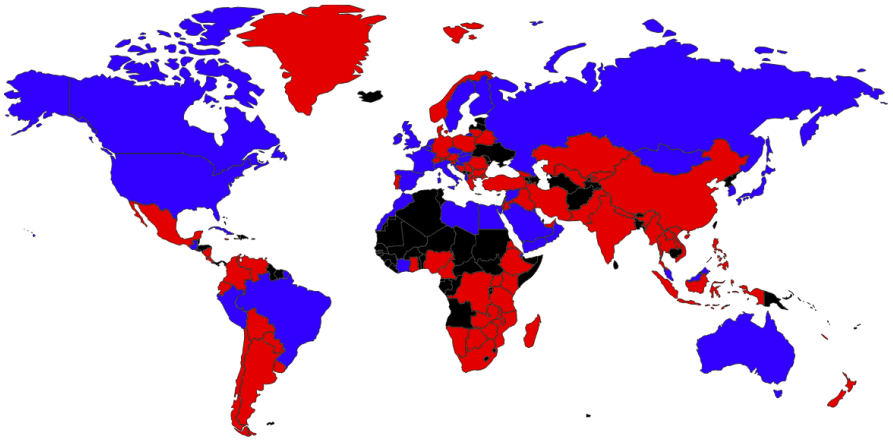


***Figure 20**. Seismological Contacts webpage; in **red** are countries in which institutes and individual staff members are willing to share information and serve as a local point of contact; in **blue** are countries for which we have information about operating geophysical organisation(s); in **black** are countries for which we do not hold any information.*

## ISC WEB and FTP SITES

In 2018, the ISC website experienced ~9.1 million hits which is marginally higher than in year 2017. The majority of the ISC web data are distributed through the main ISC website and the mirror at IRIS DMC in Seattle. In the past, users could choose the IRIS website to get the most quick and efficient service. In early 2015 we installed the load balancer that automatically directs users queries to the least busy server. It substantially improved ISC user web experience, efficiency and speed of queries. At the same time, due to the new enhanced software now used to track robots, web crawlers and other non-human interaction, we are not able to compare meaningfully the numbers of the ISC website hits before 2015 and now.

The use of the ISC ftp site in 2018 doubled again compared to the previous year. The ftp-site is used for downloading the pdf copies of the printed ISC Bulletins and Summaries, the ISC Bulletin in FFB and ISF formats, the EHB bulletins and the text version of the IR station list.

Per country usage of the ISC web and ftp services (Fig. 21) demonstrates worldwide interest in ISC data.

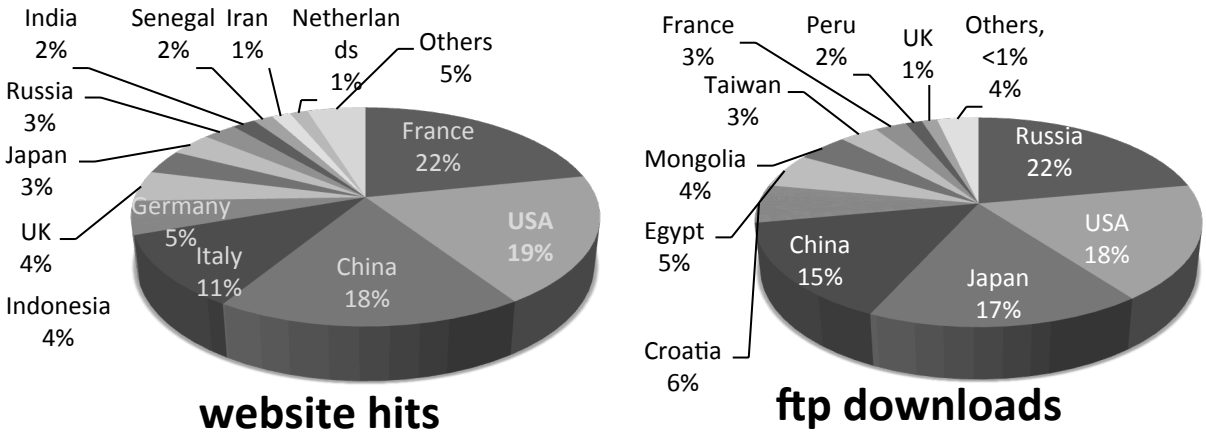



***Figure 21**. Per country statistics of **downloads from the ISC website and ftp-site***

## ISC DATABASE, WEBSITE BACKUP and MIRRORS

The ISC continued maintaining one of it's servers 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 and by the Lawrence Livermore National Laboratory (LLNL) to serve users from nuclear test monitoring laboratories in the US.

A new database mirror has been installed in Beijing and Xian by the China Earthquake Administration. This ISC website will help numerous Mandarin speaking seismologists to obtain more intuitive access to the ISC data. We are currently discussing ways of keeping the main ISC and Chinese mirror website as concurrent as possible.

# 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. 22):

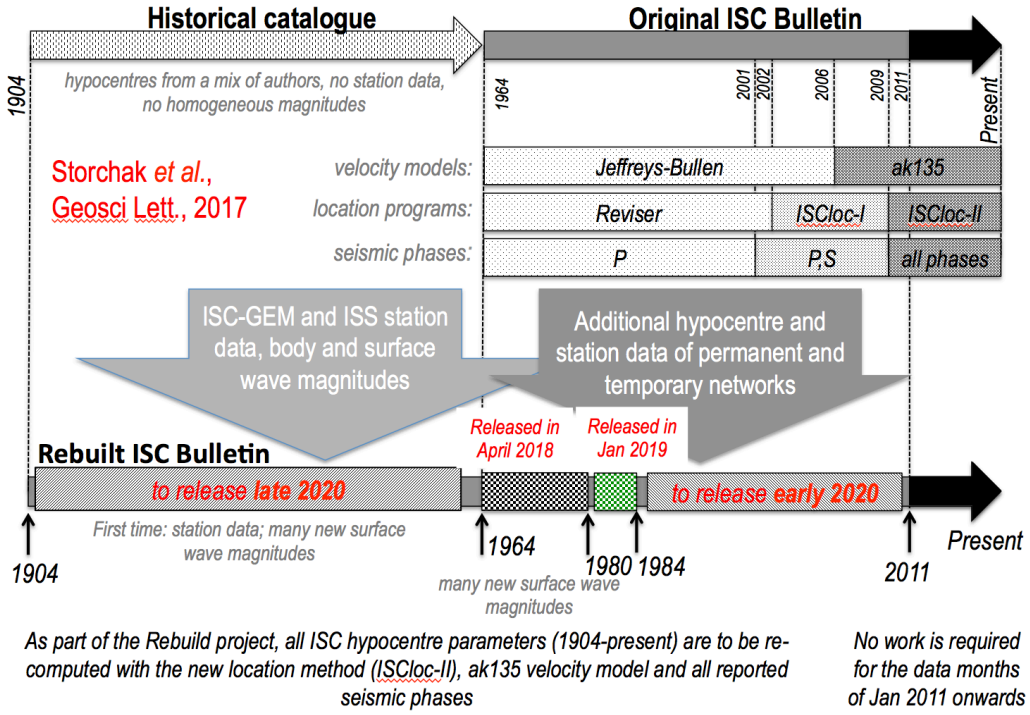



***Figure 22**. The overall plan and current status of the ISC Bulletin Rebuild project (updated figure from Storchak et al., 2017)*

- 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 the ISC history different sets of seismic phases were used for location: P & (from 2001) S with other *ak135* phases from 2009.
- Latitude & 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.

We are currently 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, 2013);

- 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 early 2018, we completed the review of seismic events within the period 1964-1979, substituted the old data in the main ISC database with those rebuilt and released to users as part of general search on April 16, 2018. We then continued the review of the 1980-1984 period which was largely complete by the end of 2018 and released to users in a similar manner on the 21st of January 2019. The outcomes of the Bulletin Rebuild of 1964-1979 were discussed in Storchak *et al.* (2017). Here we show similar figures for the 1980-1984 period.

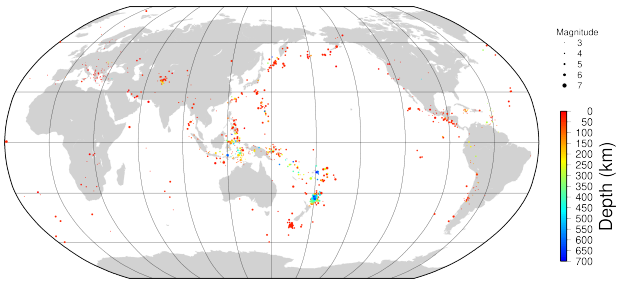



***Figure 23**. Poorly located or phantom events discarded from the ISC Bulletin (1980-1984).*

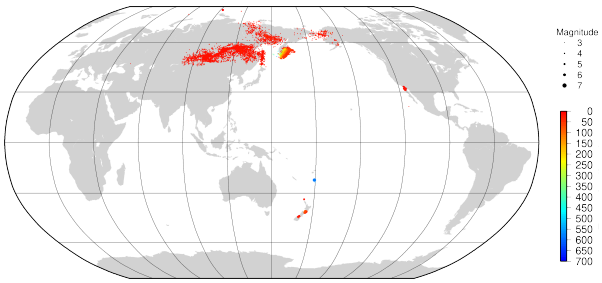



***Figure 24**. New events added to the ISC Bulletin (1980-1984).*

We performed the overall review of events in the Bulletin by removing poorly constrained and phantom events (Fig. 23) as well as adding new events from previously unavailable datasets (Fig.24). New stations are shown on Figure 25. A large number of seismic arrival times have been added to the Bulletin (Fig. 26).

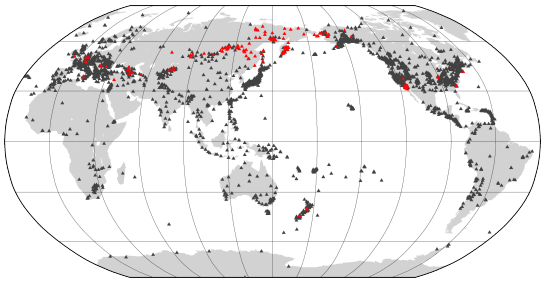


***Figure 25**. The existing and new (red) stations in the Rebuilt Bulletin during 1980-1984 period.*

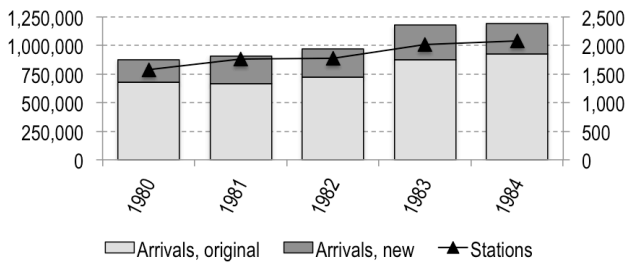



***Figure 26**. Comparative numbers of original and new seismic arrivals and the growth in station numbers through the 1980-1984 period.*

Considerable changes have taken place in the magnitude area (Fig. 27). 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.

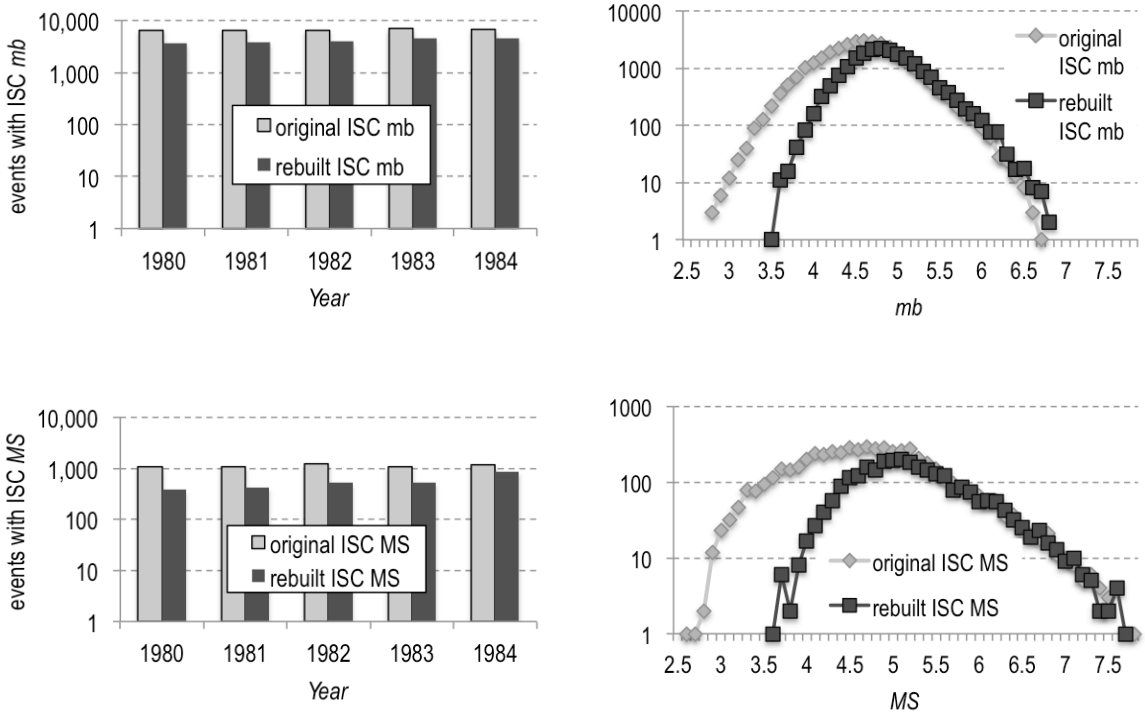
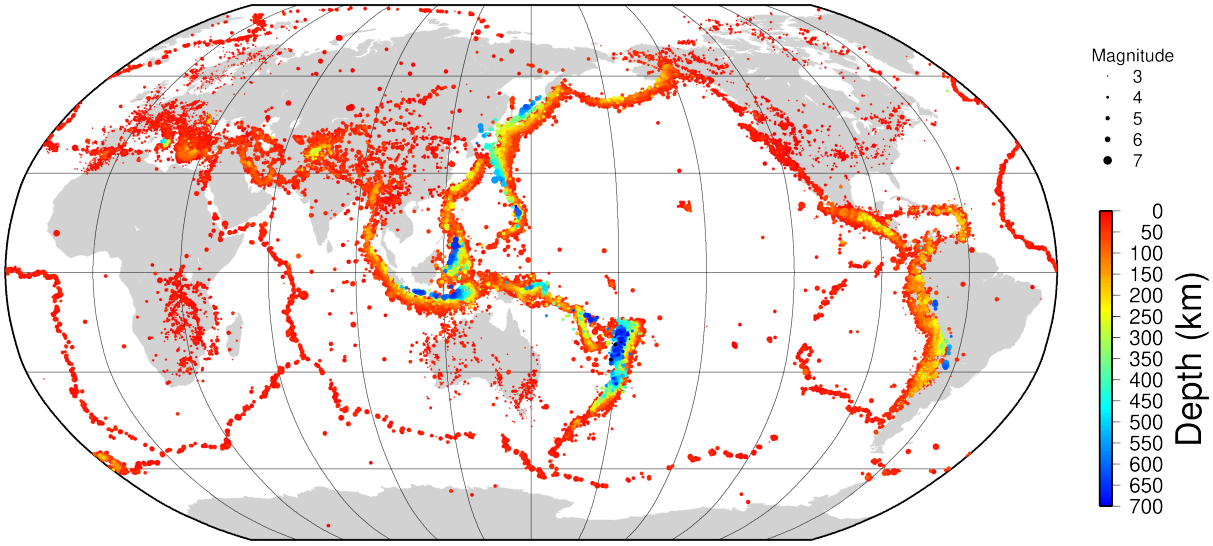



***Figure 27****. Comparison of the annual number (left) and the magnitude frequency distribution (right) of the ISC mb (top) and ISC MS (bottom) in the original and the rebuilt ISC bulletins during 1980-1984.*

Figure 28 shows the changes in location of seismic events that have taken place with the introduction of the Rebuilt ISC Bulletin.



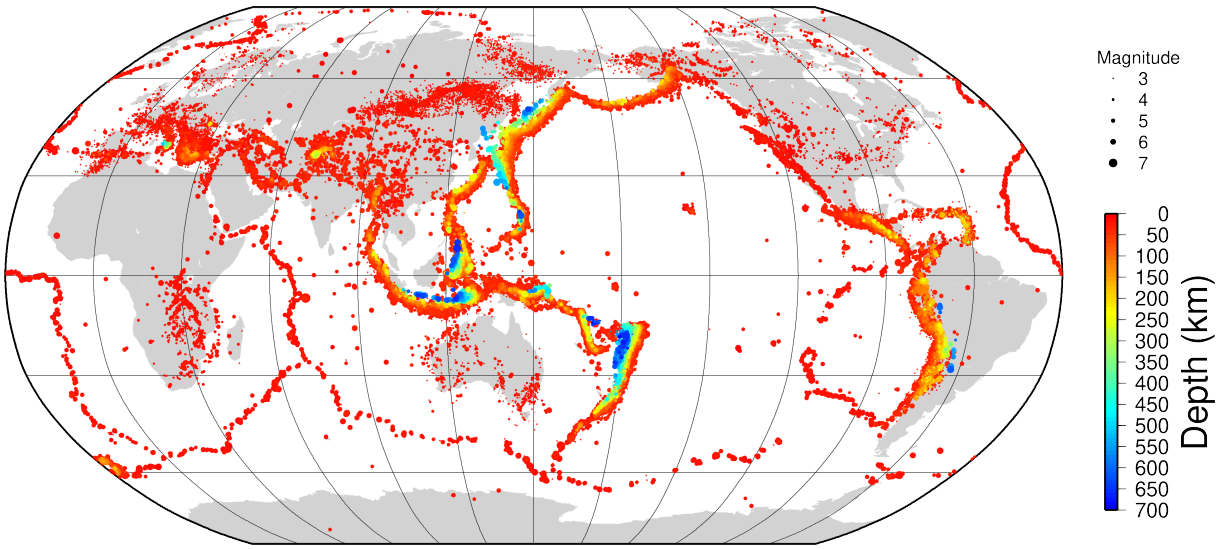



***Figure 28**. Before / after maps that demonstrate the changes in the Rebuilt ISC Bulletin during the 1980-1984 period.*

The speed of the analyst's review was highly variable for different data months, which makes estimates of the likely end of the project highly uncertain. We are trying to speed up the review aiming to complete the project during 2019 whilst we have the analyst resources available.

Our plan for early 2020 is to release the entire 1964-2010 period and, by the end of 2020, to reinvent 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.

## COMPUTING EARTHQUAKE FOCAL MECHANISMS at the ISC

We are now computing fully automatic focal mechanisms of recent earthquakes, combining directions of first motions reported to the ISC with auto-picked first motions from waveforms available at IRIS, EIDA, etc. We focus on moderate to large earthquakes ($mb^{ISC} \geq 4.5$) in the reviewed ISC bulletin and especially on earthquakes with no previously reported source mechanisms. For the historical period, we placed no magnitude restriction and computed mechanisms for all events where adequate collection of station polarity reports was available. For this work we took advantage of the HASH algorithm to compute focal mechanisms (Hardebeck & Shearer, 2002) and FilterPicker source code to automatically determine the polarities of first motions (Lomax *et al*., 2002). The entire procedure is described in scientific paper published by Lentas (2018).

At the end of 2018, the ISC on-line Bulletin contained (Fig. 29):

- **4,236** earthquakes with ISC solutions during the period (Jan 2011 - Mar 2016), based on measured and reported polarities of first motions;
- **813** earthquakes during 1964-1979 based on reported polarities;
- **170** earthquakes during 1938-1963 based on reported polarities.

This work was timed to coincide with the release of the portions of the Rebuilt ISC Bulletin and will continue in both historical and current time periods.

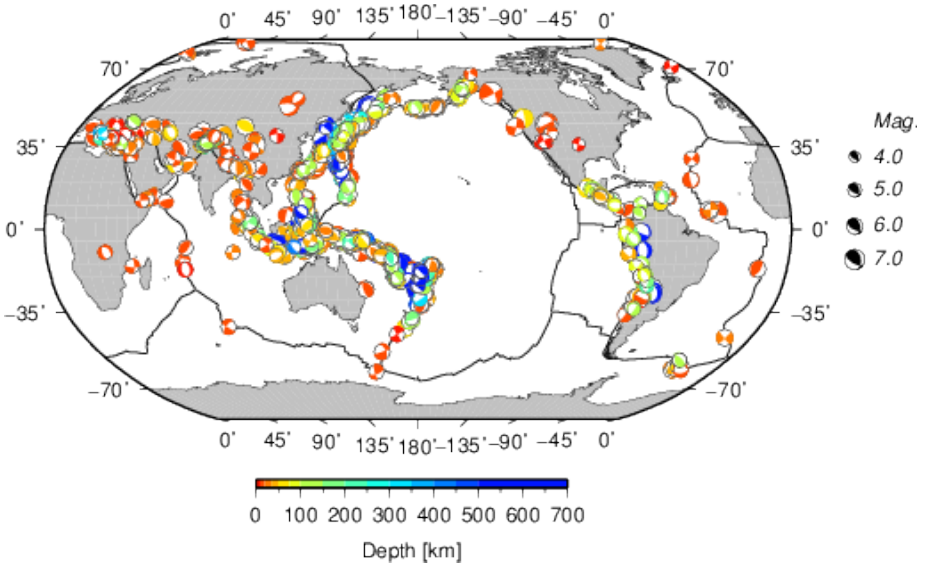



***Figure 29**. Map of earthquakes for which the source mechanisms were computed by the ISC and made available through on-line bulletin.*

## IN-HOUSE WAVEFORM PICKING for USE in the ISC BULLETIN

From the outset in 1964, the ISC's mission was based on re-using the seismogram (waveform) arrival time measurements (picks) made by many tens (~150 at present) of observatories and network data centres. In recent years, the ISC uses reported arrival times of 8.5 thousands of stations worldwide. The ISC does not have a staff capacity to obtain those picks from waveforms, even if these waveforms were always available. We nevertheless felt 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. Fig. 30 shows the monthly statistics of these reports for the three largest reporters of depth phases: National Earthquake Information Center (NEIC/USGS), International Data Centre (IDC of CTBTO) and Geophysical Survey of Russian Academy of Sciences (GS RAS). Consultation with the three agencies have shown that we can't expect the numbers to improve in the short term.

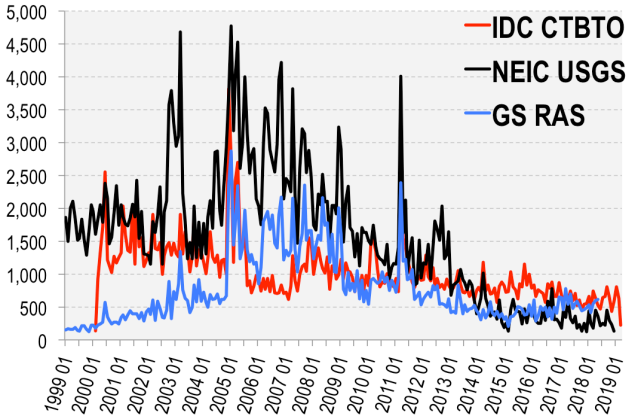



***Fig. 30.*** *Steady decline in the monthly number of depth phase (pP, sP, pPKP, ...) arrival time reports by the three largest reporters of this information to the ISC.*

We therefore set aside a small fraction of analyst resources to deal with the problem. We ran a pilot project where two analysts were spending one day per week picking the depth phases on waveforms available from IRIS DMC for earthquakes with $mb^{NEIC}$ ≥4.8. We timed this activity so that the results could be used during the routine production of the ISC Bulletin and reviewed by the ISC analysts. An example of such work is shown on Fig. 31.

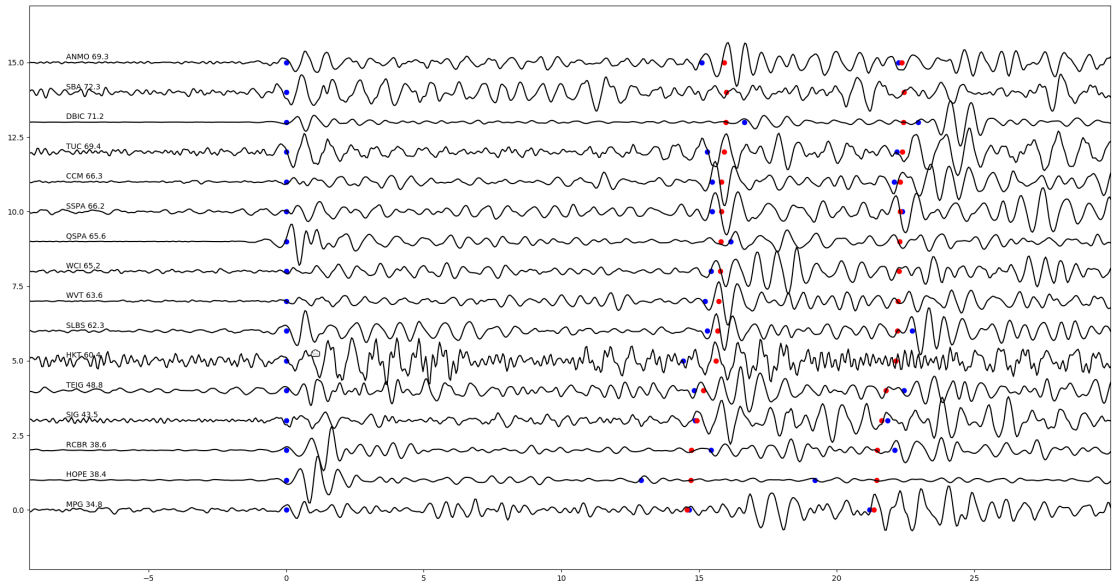



***Fig. 31****. An example of picking of depth phases by the ISC analysts using SEISAN package for mb 5.2 earthquake in Northern Chile; blue/red dots indicate measured/theoretical arrivals of depth phases for the ak135 model against ISC solution.*

Depth phases for ~700 earthquakes during 8 data months were added to the ISC Bulletin. Figure 32 shows ~500 events for which this information was crucial, i.e. the depth would have otherwise had to be fixed to the area's default. Figure 33 shows the worldwide distribution of these stations and their comparative input. As expected, stations in quiet regions of Australia, Antarctica and Kazakhstan provided the largest input.

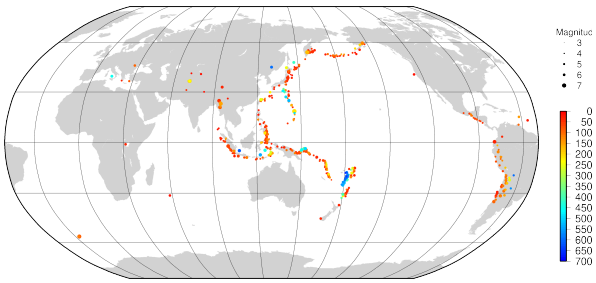



***Fig. 32**. The map of ~500 events where additional ISC pP/sP picks were critical to constrain the ISC event depths.*

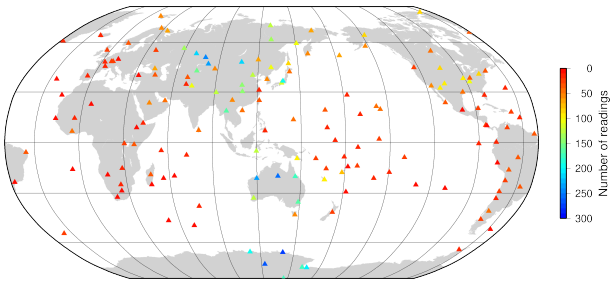



***Fig. 33**. Waveforms of 160 stations were used by the ISC to deliver the missing pP/sP picks; relative contributions are shown by colour.*

We expect to continue with this effort throughout 2019 and beyond.

We also began picking waveforms of Africa Array to compensate for the unfortunate lack of permanent observations on large parts of this continent. The aim was to include these picks in the routine production of the ISC Bulletin. As the availability of the ISC Bulletin was improving from 35 to 30 months behind real time, we soon ran into the problem that the 3-year freeze on the availability of Africa Array waveforms prevented us from timely picking. We are now engaged in consultations with Africa Array into lifting/adjusting this restriction for the ISC.

## ISC-EHB: RECONSTRUCTING the EHB

The EHB dataset is a groomed version of the ISC Bulletin. It is a valuable tool for global and regional seismicity studies and tomographic inversions. Teleseismically well-constrained events are selected from the ISC Bulletin and are relocated using the EHB location algorithms (Engdahl *et al*., 1998) 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) as well as using PKiKP, PKPdf, PKPbc and PKPab.

The original **EHB** stopped in 2008, and since then the volume and quality of bulletin data at the ISC has significantly improved. We have used these enlarged and improved data, updated the event selection, data preparation and processing, and relocation procedures to produce a cleaner and more robust **ISC-EHB** dataset, using the advantages of both the ISC (Bondar & Storchak, 2011) and EHB location techniques.

During 2016-2017, together with E.R. Engdahl of University of Colorado Boulder, we applied the ISC-EHB approach to events in the 2000-2014 period. This dataset has replaced the equivalent years in EHB (Fig. 34). For now, the 1960-1999 period follows the old EHB approach.

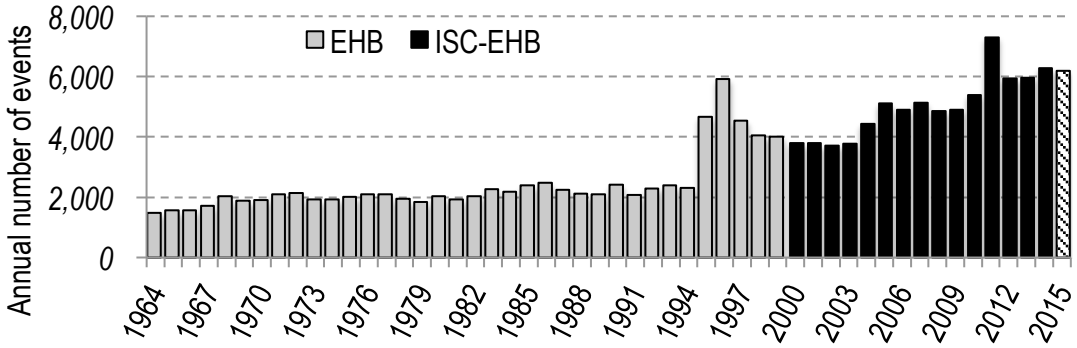



***Figure 34**. The annual number of events in the original EHB and reconstructed ISC-EHB; there is a total of 88,964 events during 1960-1999 and 81,497 during the 2000-2015 period; the data year 2015 (striped black) is to be released in early 2019.*

During 2018, we published an article describing the preparation of the ISC-EHB dataset and techniques used (Weston *et al*., 2018), trained two other analysts able to work on the dataset with the help of E.R. Engdahl and extended the data to 2015, ready for public release early next year.

The entire EHB/ISC-EHB dataset contains 168,146 seismic events from 1960 to 2015. During 2019, we shall replace the EHB with ISC-EHB for years 1964-1999. This will considerably increase the total number of events, improve visualization of seismicity in each geographical area and give enough data for studies of the inner structure of the Earth. The regional cross-section plots, available from the ISC website, will be updated accordingly.

We shall then incrementally extend this dataset forward in time as part of routine operations, based on the progress in production of its original source of data - the Reviewed ISC Bulletin.

The ISC-EHB dataset has great potential to reveal complicated structures (Fig. 35). It is available from the ISC website along with **cross-section plots** for a large number of seismic regions.

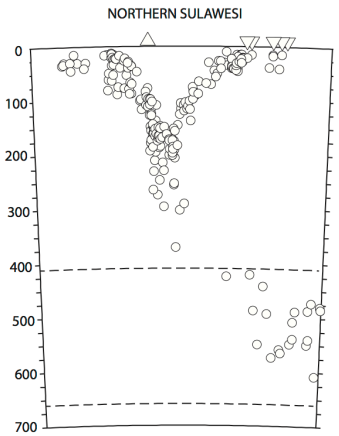



**Figure 35.** *333 km wide North-South cross-section of the Northern Sulawesi region shows the intersection of two slabs; the upright triangle is a volcano; the inverted triangles are trench points.*

## ADVANCEMENT of the ISC-GEM CATALOGUE

The ISC-GEM Global Instrumental Catalogue was originally requested and funded by the GEM Foundation. Unfortunately, this support was taken away a few years ago, but the catalogue still carries the name of the foundation, it's copyright and license terms. It continues to give good publicity to the GEM Foundation as well as to the ISC.

The catalogue is widely used for modelling seismic hazard on a regional and global scale. In addition, the catalogue is also 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. Moreover, the basic station observation data, digitised by the ISC for use in the catalogue's production, 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 catalogue continues to grow in popularity with an average of ~14 downloads per day recorded in the last 30 months and an average of ~19 during 2018 alone (Fig. 36).

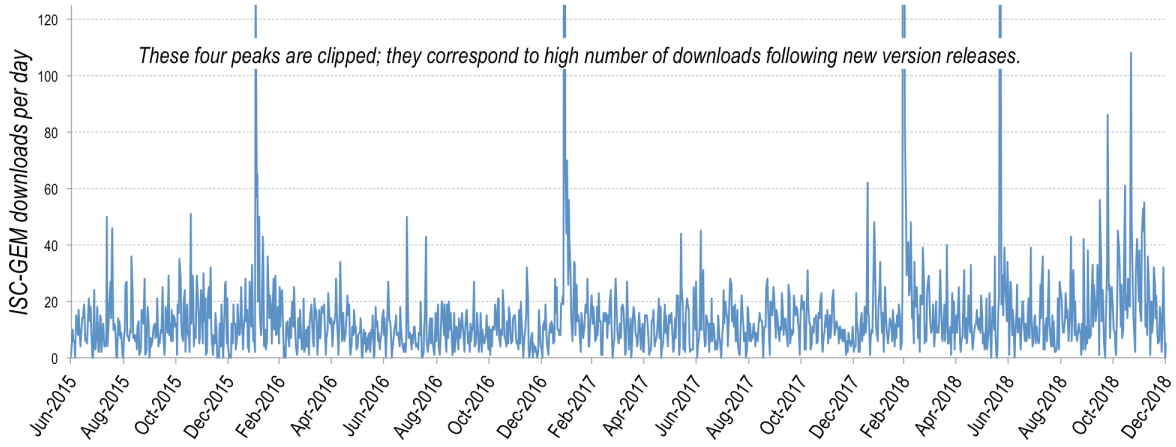



***Figure 36**. During the last 30 months, the ISC-GEM catalogue has, on average, been downloaded 15 times per day.*

The ISC-GEM catalogue was first released in January 2013 (Storchak *et al.*, 2013). It was created by ISC personnel and a team of international experts in global earthquake location and magnitude estimation (Bormann, Engdahl, Lee, Villaseñor) and overseen by a group of advisers (Ekström, Hamada, Musson, Schweitzer).

Unlike the ISC Bulletin that is designed to serve multiple groups of users and applications, 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 with the same advanced technique and velocity model;
- magnitudes expressed in $M_W$ scale;
- formal uncertainties and quality given for both hypocentre and magnitude determinations.

We recomputed all earthquake hypocentres from 1904 (Bondar *et al.,* 2015) based on the original station arrival time reports (Di Giacomo *et al*., 2015a) and *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).

In the ISC-GEM catalogue, the earthquake magnitudes have all been expressed in a single scale ($M_W$) and originated from four sources: the Global CMT (Ekström *et al.,* 2012), bibliographical search of scientific articles devoted to specific earthquakes (Lee and Engdahl, 2015), regression from our recomputed $M_S$ and *mb*, performed using our own non-linear relationships (Di Giacomo *et al.*, 2015b).

The original ISC-GEM catalogue, as released in 2013, covered the period 1900-2009 with the magnitude cut-off thresholds dictated by the size of 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.*, 2018a), the improved cut-off thresholds were as follows:

- 1904-1917: M≥6¼
- 1918-2015: M≥5.5

During 2018, we began with the 1st year of the *Advancement* project. We further dropped the cut-off magnitude to $M_W$ 5.0 in the continental areas during 1964-1979 and 2000-2015 as shown on Figure 37.

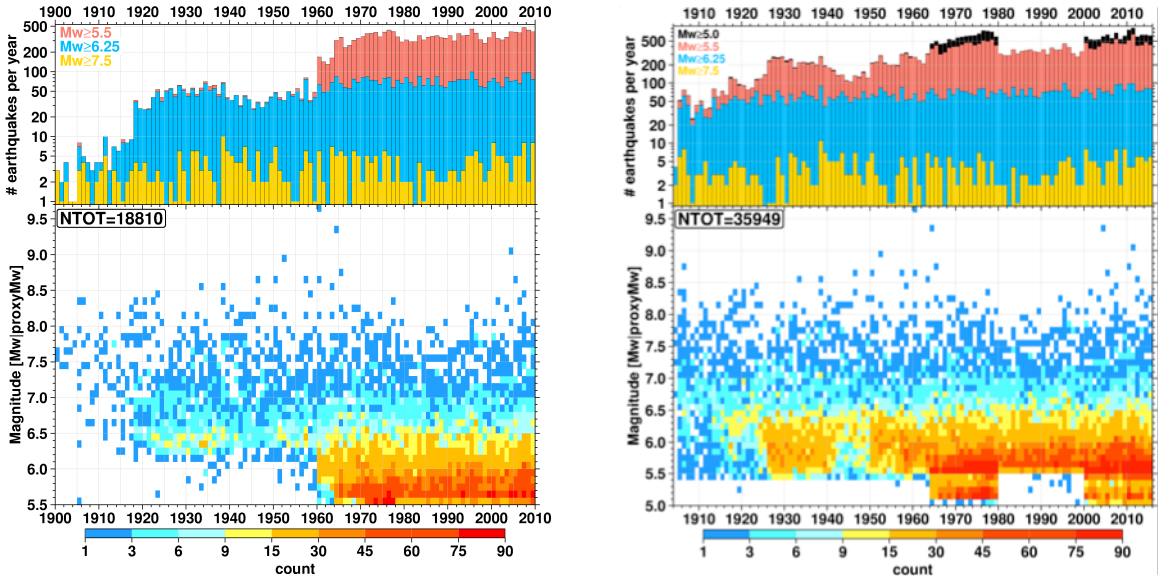



***Figure 37**. Annual number (top) and magnitude distribution (bottom) of earthquakes above a certain magnitude in the original Ver. 1 of the main ISC-GEM catalogue (left) versus Ver.6 at the end of Year 1 of the Advancement project (right).*

The current state of the ISC-GEM catalogue is represented in Figure 38. The completeness of the catalogue is not uniform over the 112 year period, yet a good effort is made to include the majority of known moderate to large earthquakes, subject to the deficiencies of seismic monitoring in the early instrumental period (Storchak *et al.*, 2015).

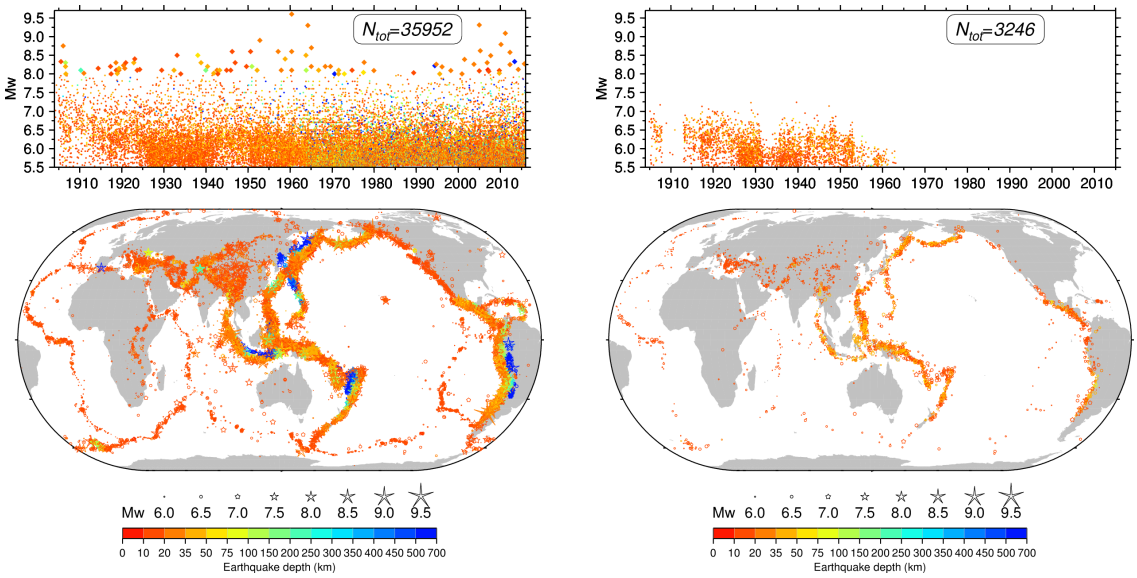



***Figure 38**. Left: magnitude timeline and a map of all earthquakes in the ISC-GEM catalogue (with re-assessed locations and magnitudes at the end of the Year 1 of the Advancement project); the diamonds show earthquakes with $M_W \geq 8$. Right: the ISC-GEM historical earthquakes that didn't have a well-constrained magnitude estimate before this work; symbols by Agnew (2014).*

During Year 1, we also began the large task of searching through the scientific literature for studies of fault mechanisms of past earthquakes before 1976 when the Global CMT project began. The first results are shown in Figure 39.

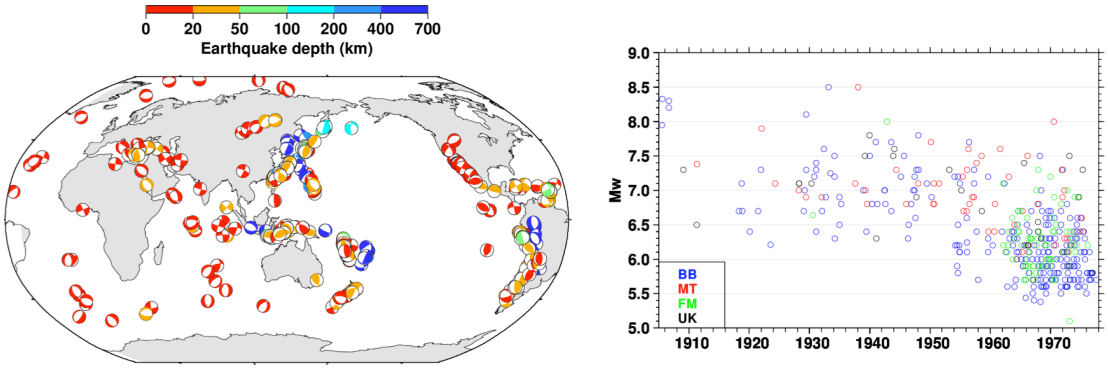



***Figure 39**: Left: global map showing the distribution of the 385 earthquakes with source mechanisms from the literature. The source mechanisms are colour-coded by depth. Right: timeline colour-coded by source mechanism type: red= moment tensors (MT), blue = broadband analysis (BB); green = first motion polarities (FM); black= unknown (UK).*

During 2019-2021, we plan to continue the Advancement of the ISC-GEM catalogue further. The objective is to continue including new continental earthquakes that were large enough to be potentially damaging. We shall improve parameters of existing earthquakes and include credible fault plane solutions or moment tensor determinations from scientific literature. We shall update the catalogue for recent earthquakes and review information from newly published scientific articles devoted to individual earthquakes. This work will provide improved data for more adequate representation of seismicity and associated hazard in many regions of moderate seismicity.

## SOURCE TIME FUNCTIONS and DEPTHS

In September 2017, Dr Tom Garth joined the ISC and Department of Earth Sciences in University of Oxford of which he is a formal employee (PDRA). His appointment is jointly funded by the ISC (⅔) and Prof. Karin Sigloch's ERC grant (⅓). He has a desk at both the ISC and University of Oxford.

With this project, we are exploring additional resolution to earthquake depths that can be gained by using openly available seismic waveforms. Based on established techniques, we intend to develop automatic procedures to build source time functions for moderate to large earthquakes in the ISC Bulletin.

During 2018, Garth has been working on a set of methods to utilise the increasingly broadly available waveform data sets to further improve the ISC data set. He was developing a code to automate the calculation of earthquake source time functions (STFs), building on the work of the project partner Prof. Karin Sigloch (University of Oxford) (Sigloch & Nolet, 2006; Stahler & Sigloch, 2014;2016).

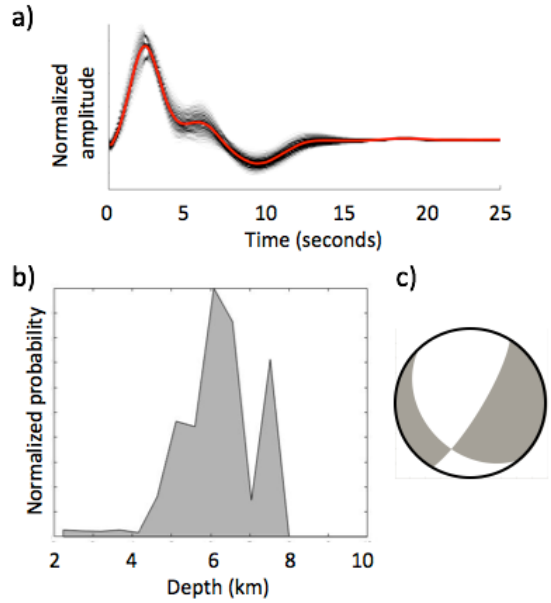



***Figure 40:*** *Preliminary output from the ISC-STF code.* ***a)*** *optimum STF (red) along with other possible STFs.* ***b)*** *PDF of potential earthquake depths compared to depths from the NEIC-PDE catalogue, inversion following Sigloch & Nolet (2006) and optimum depth from this code* ***c)*** *optimum source.*

The STFs and earthquake mechanisms are determined from teleseismic body waves, and the suite of likely solutions are produced and appraised using the neighbourhood algorithm of Sambridge (1999a, b). As the inversion is highly sensitive to the arrival of depth phases, the technique has the potential to give new depth constraints on moderate magnitude events, a constraint that is particularly missing for shallow earthquakes (0 – 40 km) in current global catalogues.

Garth is building, testing and integrating the code with current ISC procedures, with the aim that initial production will start in 2019. As well as creating a new ISC product, giving constraints and full uncertainty estimates of earthquake mechanisms and STFs, it is anticipated that these new constraints on earthquake depths will help to improve the accuracy of parameters in the ISC bulletin.

In December 2018, the principles of the proposed methodology and the initial preliminary results gained from the code developed for the ISC were presented at the AGU fall meeting (Garth *et al*., 2018) (Fig.40).

It is expected that at the end of the 3-year PDRA post, he will be able to join the ISC as a full member of staff responsible for earthquake location and other developments.

## 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 PTS and National Data Centres. 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. From April 2015, a new annual contract was signed with four possible annual extensions. The contract has now been extended to run until the end of March 2020.

During 2018, 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 Provisional Technical Secretariat and National Data Centres for 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 capacity for NDCs to perform various analysis such as:

- assessing the 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.

During 2018, we made a substantial effort to re-write the entire website software based on a modern platform, making it internally consistent and fast. Many database queries have been reviewed and updated. To the user, the website looks almost exactly the same, but it is much easier for the ISC development staff to operate and make further developments.

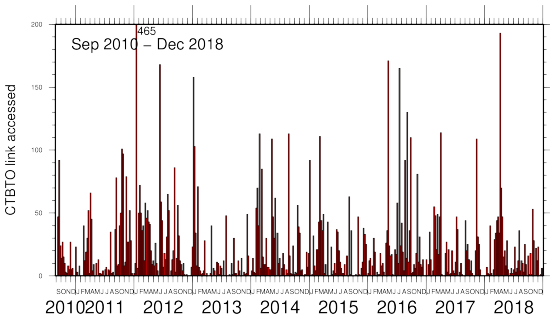



***Figure 41**. The Link to the ISC database mirror is provided to the NDCs through the IDC secure website. The figure shows the healthy stream of user activity.*

Figure 41 shows user activity on the Link by both PTS/CTBTO and NDCs.

This project also benefits the ISC and the ISC users.

- The ISC development staff acquired important skills and experience during this project. The advances made under this project are gradually implemented to improve the traditional open ISC web services.
- In particular, experience of downloading, checking quality 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.
- During 2018, the ISC and its Bulletin users gained much speedier access to the REB Bulletin which is now available in **daily batches within 7-14 days after an event occurrence** as opposed to half a year in the past (Fig. 42).
- Many National Data Centres for CTBTO are run by institutions that are either Members of the ISC 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 service.

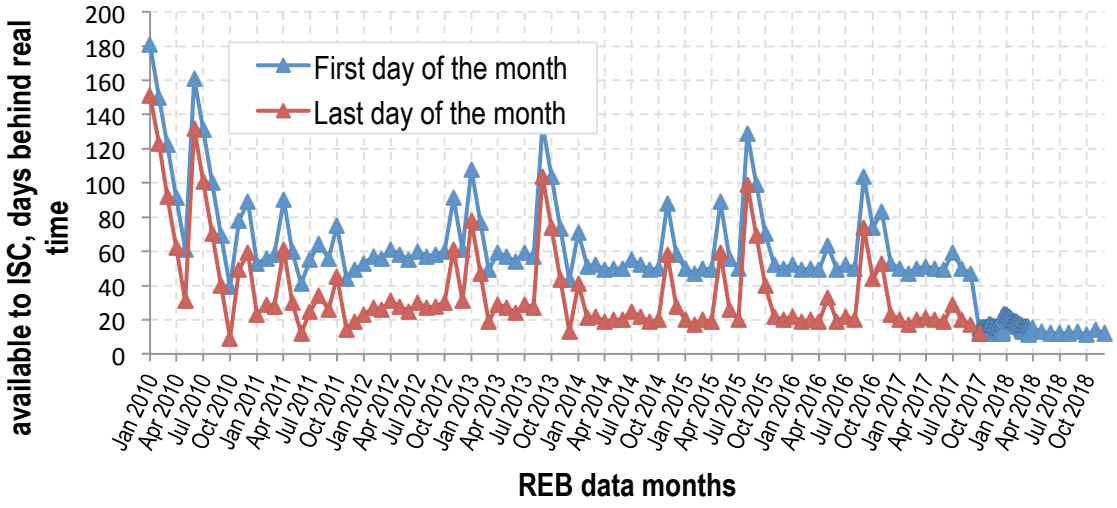



***Figure 42**. The availability of data from the ISC REB bulletins (not REB bulletins themselves) to general ISC Bulletin users (days behind real time) has considerably improved as an indirect result of routine operation of the CTBTO Link; reporting of daily instead of monthly batches made any day of 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*.

# FINANCE

The detailed financial statements of the ISC for 2018 were audited by Wilkins Kennedy Chartered Accountants (Newbury, UK) and approved by Prof. Karin Sigloch of the ISC Executive Committee. These statements present the state of the ISC's financial affairs as at 31st December 2018.

## INCOME

In 2018, the ISC had a total income of £865,620 from 65 Membership contributions, grants for special projects and general sponsorship. The grants and sponsorships amounted to ~28% of the total income, which helped to ease the burden on Members. The ISC also received £1,808 of interest on its bank accounts.

The exchange rate between UK £ and US $ changed throughout the year with £1=$1.34 at the beginning of January and £1=$1.28 at the end of December. The exchange rate between the UK £ and € varied throughout the year starting at £1=€1.13 at the beginning of January and finishing at £1=€1.12 at the end of December. Taking into account the timings of individual incoming and outgoing transactions, the ISC gained £5,922 on foreign exchange in 2018, having lost £20,612 in 2017.

The total of £2,420 has been treated as bad debt. This corresponds to old invoices (still on the books) for Bulletin Summaries, which will not be paid. All Bulletin Summaries are now paid via pro-forma invoice prior to despatch. No membership bad debts.

At the end of the year 2018, £117,683 had yet to be paid by Members. At the time of writing this report £63,436 had been received, leaving £54,247 outstanding, with almost £50,000 of that being due from INSU/CNRS in France.

Most unfortunately, there occurred another 2-months gap between the two consequent 4-year awards from the United States National Science Foundation which adversely affected the ISC income this year.

## EXPENDITURE

82.4% of ISC expenditure was committed to personnel costs, an increase from 81.5% in 2017, predominantly due to one additional member of staff and continuing rise in pension costs. During the year we saw the departure of three and arrival of four new members of staff. Two members of staff asked for reduction of their working week to just three days due to personal reasons. 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.

Building maintenance costs increased by approximately 28% as compared to 2017. Staff travel and computer costs decreased. As in previous years, staff travelled to several countries to attend meetings and increase the profile of the ISC, take part in project meetings and also to seek new data and future funding.

The cost of the PDRA position at University of Oxford, supported by the ISC (66.66%), was higher as five instead of four quarterly invoices were presented to the ISC by the accounting department of University of Oxford. One of those invoices should have been given at the end of 2017 but was delayed.

Additionally, the increased expenditure reflected an unexpected loss of the 80% relief granted by the West-Berkshire Council (local authority) granted to the ISC as the non-profit making organization in the past. Having lost grants from central Government, the Council has reviewed its relief policy at a short notice. As a result, from April 1, 2018, the ISC is charged ~£15,000 per annum instead of ~£3,000 formerly charged. Negotiations with the local Council and HMRC to reinstate the discount have proven lengthy and frustrating, despite the support from our accountant's charity specialists.

## RESERVES

In understanding that all missing contributions will be repaid, the ISC's expenditure during 2018 exceeded its income by £44,454. 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 reduced to £806,387; this includes money ear-marked for on-going projects. The Contingency Fund still stands at £30,000 in accordance with the wish of the ISC Governing Council. The ISC General Reserve stands at £776,387.

## CASH FLOW

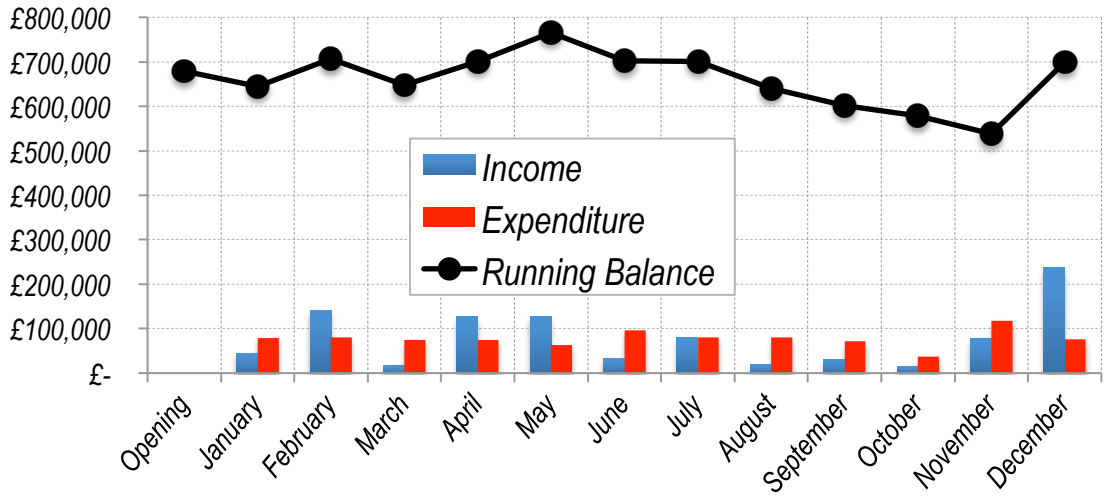



**Figure 43.** Income/Expenditure and running cash balance during 2018

The cash flow in Fig. 43 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.

In 2018, 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 but this may change in the future if Members and Sponsors do not provide funds in time. In particular, the General Reserve is subject to £117,683 still owed to the ISC at the end of 2018.

Here 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.

# SCIENTIFIC COMMUNITY AWARENESS

## VISITORS to the ISC

The following geophysicists visited ISC premises in Thatcham during the year:

- Michelle Salmon, ANU, ***Australia***
- Aaron Velasco, University of Texas, ***USA***
- Marianne Karplus, University of Texas, ***USA***
- Stephanie Framkle, LANL, ***USA***
- Bruce Warner, LLNL, ***USA***
- Alan Ross, LLNL, ***USA***
- Doug Berning, LANL, ***USA***
- Jim Koster, LANL, ***USA***
- Brad Wallin, LLNL, ***USA***
- Eiji Kuwabara, ERI/University of Tokyo, ***Japan***
- Natalia Poiata, NIEP, ***Romania*** / IPGP, ***France***
- Bertrand Delouis, CNRS, ***France***
- Goran Ekstrom, NSF, ***USA***
- Johannes Schweitzer, IASPEI, ***Norway***
- John Adams, GSC, ***Canada***
- John Woodhouse, Royal Society, ***UK***
- Karin Sigloch, University of Oxford, ***UK***
- Kenji Satake, ERI/University of Tokyo, ***Japan***
- Marcelo Assumpcao, IAG-USP, ***Brazil***
- Inho Kim, KIGAM, ***South Korea***
- Sung-Tae Nam, KIGAM, ***South Korea***
- Robert Engdahl, University of Colorado, ***USA***
- Steve Kirby, USGS, Menlo Park, ***USA***

## CONFERENCES, MEETINGS, WORKSHOPS, TRAINING COURSES

We published a scientific paper (Lieser *et al*., 2018), summarizing the British Seismology Meeting (BSM2017) that the ISC staff have organised in Reading last year.

Members of the ISC staff presented at the following conferences, meetings and workshops:

- CTBTO WGB-50 meeting, Vienna, ***Austria***
- CTBTO WGB-51 meeting, Vienna, ***Austria***
- ASC & Decade Memory of Wenchuan Earthquake, Chengdu, ***China***
- Nordic Seismology Seminar, Kjeller, ***Norway***
- 6th Arab Conference on Astronomy and Geophysics, Helwan, ***Egypt***
- AG Seismology, Pirna, ***Germany***
- JpGU-AGU, Makuhari, ***Japan***
- International Workshop on Data Science, ROIS, Mishima, **Japan**
- Monitoring of Nuclear Test and their Consequences, Almaty, ***Kazakhstan***
- ESC, Valetta, ***Malta***
- AfSC, Al-Hoceima, ***Morocco***
- 10th Gulf Seismic Forum, Muscat, ***Oman***
- Complex studies of 2003 Altay Earthquake, Moscow, ***Russia***
- International Seismology School, GS RAS, Dushanbe, ***Tajikistan***
- Impact Forecasting Revealed, Aon Benfield, London, ***UK***
- Future of Passive Seismic Acquisition, Edinburgh, **UK**

## ISC STAFF VISITING OTHER INSTITUTIONS

Often with the help of the hosting institution, members of the ISC staff visited and, where appropriate, gave a presentation to the staff of:

- IDC/CTBTO, Vienna, *Austria*
- China Earthquake Networks Center, Beijing, *China*
- National Research Institute for Astronomy and Geophysics (NRIAG), Helwan, *Egypt*
- Seismological Observatory Berggieshubel, TU Bergakademie Freiberg, *Germany*
- National Institute of Genetics, ROIS, Mishima, *Japan*
- InterRisk Research & Consulting, MS&AD Ins Group, Tokyo, *Japan*
- Kazakhstan National Data Centre (KNDC), Almaty, *Kazakhstan*
- Seismological Experimental and Methodological Expedition, Almaty, *Kazakhstan*
- Medeo Observatory, Almaty, *Kazakhstan*
- NORSAR, Kjeller, *Norway*
- Muscat University, Muscat, *Oman*
- Institute of Physics of the Earth, RAS, Moscow, *Russia*
- Geophysical Survey, Russian Academy of Sciences, Obninsk, *Russia*
- WDC-B, Geophysical Centre, Russian Academy of Sciences, Moscow, *Russia*

- Institute of Geology, Earthquake Engineering and Seismology, Dushanbe, *Tajikistan*
- Geophysical Survey, Dushanbe, *Tajikistan*
- Academy of Sciences, Dushanbe, *Tajikistan*
- Thai Meteorological Department, Bangkok, *Thailand*
- Lighthill Risk Network, London, *UK*
- University of Oxford, Earth Science Department, Oxford, *UK*

## 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 2018, the prize was given to Mr William Eaton, 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 2018 to fulfill a general strategy of making the ISC 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., Engdahl, E. R. and Storchak, D.A. (2018a). The ISC-GEM Earthquake Catalogue (1904–2014): status after the Extension Project, Earth Syst. Sci. Data, 10, 1877-1899, doi: 10.5194/essd-10-1877-2018

Di Giacomo, D., Engdahl, E. R. and Storchak, D.A. (2018b). Comment on "Historical and recent large megathrust earthquakes in Chile" by Ruiz and Madariaga, 2018, Tectonophysics, 745, 453-456, doi: 10.1016/j.tecto.2018.05.016

Weston, J., Engdahl, E.R., Harris, J., Di Giacomo, D. and Storchak, D.A. (2018). ISC-EHB: Reconstruction of a robust earthquake dataset, Geophys. J. Int., 24, 1, 474-484, doi: 10.1093/gji/ggy155

Lentas, K. (2018). Towards routine determination of focal mechanisms obtained from first motion P-wave arrivals, Geophys. J. Int., 212(3), 1665–1686. doi: 10.1093/gji/ggx503

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# APPENDIX 1: STANDARD BULLETIN REPORTERS

As many as 151 institutions and projects in 95 countries reported reviewed seismic bulletin data to the ISC during 2018.

| Country/Region | Institution/Project |
|---|---|
| Albania | The Institute of Seismology, Academy of Sciences of Albania |
| Argentina | Instituto Nacional de Prevencion Sismica (INPRES) |
| Argentina | Universidad Nacional de La Plata |
| Armenia | National Survey of Seismic Protection |
| Australia | Curtin University |
| Australia | Geoscience Australia |
| Austria | International Data Centre, CTBTO |
| Austria | Zentralanstalt fur Meteorologie und Geodynamik (ZAMG) |
| Azerbaijan | Republican Seismic Survey Center, National Academy of Sciences |
| Belgium | Royal Observatory of Belgium |
| Bolivia | Observatorio San Calixto |
| Botswana | Botswana Geoscience Institute |
| Brazil | Instituto Astronomico e Geofisico |
| Bulgaria | Geophysical Institute, Bulgarian Academy of Sciences |
| Canada | Canadian Hazards Information Service, Natural Resources Canada |
| Cape Verde | Instituto Nacional de Meteorologia e Geofisica |
| Chile | Centro Sismologico Nacional, Universidad de Chile |
| China | China Earthquake Networks Center |
| China | Institute of Geology & Geophysics, Chinese Academy of Sciences |
| Chinese Taipei | Institute of Earth Sciences, Academia Sinica |
| Chinese Taipei | C Weather Bureau (CWB) |
| 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 | Geophysical Institute, Czech Academy of Sciences |
| Czech Republic | WBNET, Geophysical Institute, Czech Academy of Sciences |
| Czech Republic | The Institute of Physics of the Earth (IPEC) |
| Denmark | Geological Survey of Denmark and Greenland |
| Dominican Republic | Observatorio Sismologico Politecnico Loyola |
| DPR of Korea | Korea Earthquake Administration |
| Eastern and Southern Africa | Eastern and Southern Africa Regional Seismological Working Group |
| Ecuador | Servicio Nacional de Sismologia y Vulcanologia |
| Egypt | National Research Institute of Astronomy and Geophysics |
| El Salvador | Servicio Nacional de Estudios Territoriales |

| | |
|---|---|
| Ethiopia | University of Addis Ababa |
| Finland | Institute of Seismology, University of Helsinki |
| France | EOST / ReNaSS |
| France | Institut de Physique du Globe de Paris |
| France | Laboratoire de Detection et de Geophysique/CEA |
| France | UMR Geoazur |
| 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 | Earth Science Dept., Geophysics Section |
| Germany | GEOMAR |
| Germany | Geophysikalisches Observatorium Collm |
| Germany | Helmholtz Centre Potsdam GFZ German Research Centre For Geosciences |
| Germany | Landeserdbebendienst Baden-Wurttemberg |
| Germany | Seismological Observatory Berggieshubel, TU Bergakademie Freiberg |
| Greece | Department of Geophysics, Aristotle University of Thessaloniki |
| Greece | National Observatory of Athens |
| Greece | University of Patras, Department of Geology |
| Guatemala | INSIVUMEH |
| Hong Kong | Hong Kong Observatory |
| Hungary | Geodetic and Geophysical Research Institute |
| Iceland | Icelandic Meteorological Office |
| India | National Centre for Seismology of the Ministry of Earth Sciences of India |
| India | National Geophysical Research Institute |
| Indonesia | Badan Meteorologi, Klimatologi dan Geofisika |
| Iran | International Institute of Earthquake Engineering and Seismology (IIEES) |
| Ireland | Dublin Institute for Advanced Studies |
| Israel | The Geophysical Institute of Israel |
| Italy | Dipartimento per lo Studio del Territorio e delle sue Risorse (RSNI) |
| 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 Seimology |
| Italy | MedNet Regional Centroid Moment Tensors |
| Ivory Coast | Station Geophysique de Lamto |
| Japan | Japan Meteorological Agency |
| Japan | National Institute of Polar Research |
| Japan | National Research Institute for Earth Science and Disaster Prevention |
| Kazakhstan | National Data Center |
| Kazakhstan | Seismological Experimental Methodological Expedition |
| Kuwait | Kuwait Institute for Scientific Research |
| Kyrgyzstan | Institute of Seismology, Academy of Sciences of Kyrgyz Republic |
| Kyrgyzstan | Kyrgyz Seismic Network |
| Latvia | Latvian Seismic Network |

| | |
|---|---|
| Lebanon | National Council for Scientific Research |
| Macao, China | Macao Meteorological and Geophysical Bureau |
| Madagascar | Institut et Observatoire Geophysique de Antananarivo |
| Malaysia | Malaysian Meteorological Service |
| Mexico | Centro de Investigacion Cientifica y de Educacion Superior de Ensenada |
| Mexico | Instituto de Geofisica de la UNAM |
| Moldova | Institute of Geophysics and Geology |
| Morocco | Centre National de Recherche |
| Mozambique | Mozambique Rift Tomography Project |
| Namibia | Geological Survey of Namibia |
| Nepal | National Seismological Centre |
| New Caledonia | IRD Centre de Noumea |
| New Zealand | Institute of Geological and Nuclear Sciences |
| Nicaragua | Instituto Nicaraguense de Estudios Territoriales - INETER |
| Norway | Stiftelsen NORSAR |
| Norway | University of Bergen |
| Panama | Universidad de Panama |
| Philippines | Manila Observatory |
| Philippines | Philippine Institute of Volcanology and Seismology |
| Poland | Institute of Geophysics, Polish Academy of Sciences |
| Portugal | Instituto Geofisico do Infante Dom Luiz |
| Portugal | Instituto Portugues do Mar e da Atmosfera, I.P. |
| Portugal | Sistema de Vigiliancia Sismologica dos Azores |
| Republic of Belarus | Centre of Geophysical Monitoring of the National Academy of Sciences |
| 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 | Geophysical Survey of Russian Academy of Sciences |
| Russia | Institute of Environmental Problems of the North, Russian Academy of Sciences |
| Russia | Institute of the Earth Crust, SB RAS |
| Russia | Kamchatkan Experimental and Methodical Seismological Department, GS RAS |
| Russia | Kola Regional Seismic Centre, GS RAS |
| Russia | Mining Institute of the Ural Branch of the Russian Academy of Sciences |
| 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 |
| Solomon Islands | Ministry of Mines, Energy and Rural Electrification |
| South Africa | Council for Geoscience |
| Spain | Instituto Geografico Nacional |
| Sudan | Sudan Seismic Network |
| Sweden | University of Uppsala |
| Switzerland | Swiss Seismological Service (SED) |
| Syria | National Syrian Seismological Center |
| Trinidad and Tobago | Seismic Research Centre |
| Tunisia | Institut National de la Meteorologie |
| Turkey | Disaster and Emergency Management Presidency |
| Turkey | Faculty of Mines, Department of Geophysical Engineering |
| Turkey | Kandilli Observatory and Research Institute |
| Ukraine | Main Centre for Special Monitoring |
| Ukraine | Subbotin Institute of Geophysics, National Academy of Sciences |
| UAE | Dubai Seismic Network |
| UK | British Geological Survey |
| UK | International Seismological Centre |
| USA | Center for Earthquake Research and Information |
| USA | IRIS Data Management Center |
| USA | National Earthquake Information Center, USGS |
| USA | Pacific Tsunami Warning Center |
| USA | Red Seismica de Puerto Rico |
| USA | Scripps Institution of Oceanography |
| USA | The Global CMT Project |
| USA | The University of Arizona, Department of Geosciences |
| USA | University of Colorado, Boulder |
| USA | University of Wisconsin-Madison, Department of Geoscience |
| Uzbekistan | Institute of Seismology, Academy of Sciences |
| Venezuela | Fundacion Venezolana de Investigaciones Sismologicas |
| Vietnam | National Center for Scientific Research |
| Zimbabwe | Goetz Observatory |

# APPENDIX 2: ISC DATA in RESEARCH PUBLICATIONS

This list is a result of a special effort to put together a collection of scientific papers that used ISC data and published in 2018, The list is by no means exhaustive. The ISC has become such a familiar name that many researchers unfortunately fail to reference the ISC when using the ISC data.

To track publications using one or more of the ISC dataset and services, we have 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 of the ~250 publications for year 2018 as gathered with Google Scholar alerts. The references of articles published in journals are listed first, followed by the references for 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 belongs to articles in journals.


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