INTERNATIONAL SEISMOLOGICAL CENTRE (ISC)

2022

Annual Director's Report



Despite certain irregularities with the membership subscriptions and grants, it was another productive year thanks to the support of 72 Member-Institutions and 7 Project Sponsors.

Publication of the Reviewed Bulletin continued at 24 months behind real time. The data for seismic events during 2020-2022 have been added to the ISC Bulletin, thanks to contributions from 154 agencies worldwide. In addition, the ISC continued using openly available waveforms to constrain earthquake depths based on in-house depth phase picking and probabilistic point source model determinations. Smaller continental earthquakes during the 1976-2018 period and earthquakes in 2019 have been added to the ISC-GEM catalogue. The ISC-EHB dataset and corresponding subduction zone cross-sections as well as the IASPEI GT List have all been extended to include the 2019 data year. We continued publication of scientific articles explaining the nature of the ISC data.

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

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<u>1: EXECUTIVE SUMMARY</u>

- □ This was the second year the ISC operated as a charitable incorporated organization (CIO); this status allows the ISC to be run in the most tax-efficient manner.
- □ The ISC gratefully acknowledges generous support (or an intention to support) from 72 **Member-Institutions in 47 countries (79%** of total income) and additional project grants from CTBTO, FM Global, Lighthill Risk Network, and AXA XL as well as sponsorships from GeoSIG, SARA, and MS&AD (21% of total income).
- □ For the last two months of the year, the ISC worked without support of the US National Science Foundation (NSF) who didn't manage to finalise the next regular 4-year award.
- 7 Members hadn't paid their annual subscription fees by the year end. The Russian and Belarusian Academies of Sciences were ready to pay but could not fulfil their obligations because the banks in their countries were sanctioned by the UK Government. Three other Members paid their subscriptions by the time of writing this report. Polish Academy of Sciences and Spain's ICM still owe their annual dues.
- □ Technically, the 2022 annual income exceeded the ISC's expenditure by \pounds 55,110, yet, taking the unpaid contributions into account, the ISC in fact made a loss of \pounds 3,650.
- □ At any one time, 15-18 staff members and 2 contractors worked for the ISC this year.
- □ 720 seismic stations were registered or modified in the International Seismograph Station Registry.
- □ Within a few days of an event occurrence, the ISC collected and grouped preliminary data from 23 networks and made the **Preliminary ISC Bulletin** available to all users.
- □ The routine process of collecting revised bulletins from **154** institutions in **94** countries stood at 12 months behind real time; many agencies were not able to comply with this deadline and inadvertently hindered the ISC Bulletin analysis.
- □ During the year, the analysts fully reviewed 11 months of the **ISC Bulletin** and partially reviewed two further months, keeping the ISC Bulletin availability at the publication target of 24 months behind real time (b.r.t.).
- □ Overall, ~60,000 reviewed events with ~8.0 million associated phases were added to the reviewed part of the Bulletin. The Bulletin (both reviewed and un-reviewed) was enlarged with ~674,000 events and ~21.0 million associated phases.
- □ We continued waveform picking of depth phases using waveforms of 160 globally distributed stations to fill the gaps in agency reporting. The depth phase picking helped to constrain the depth of 834 events where there was otherwise insufficient information.
- □ 418 PPSM (probabilistic point source model) solutions were added to the ISC Bulletin based on the analysis of waveforms at the ISC; 22 of those solutions were directly used as the ISC hypocentre depths.
- □ We also picked teleseismic phase arrivals from 260 M>=5 globally distributed earthquakes using waveforms of 35 African stations.
- □ The ISC Bulletin remains more complete than the bulletins of either NEIC or IDC.

- □ We worked on two further issues of the printed **Summary of the ISC Bulletin**, which included invited articles; each issue and each invited article has its own DOI registered via the ISC's membership of CrossRef.
- □ The **ISC-GEM Global Instrumental Earthquake Catalogue** has been advanced to include ~18,600 small continental shallow earthquakes during 1976-2018; it was further extended to include the year 2019.
- □ References to ~2,500 scientific articles relating to ~4,400 seismic events have been added to the **ISC Event Bibliography.**
- □ We worked to improve a new ISC service the Electronic Archive of Printed Station/Network Bulletins that was put into operation last year.
- □ We continued the operation and further enhancement of the **CTBTO Link to the ISC database** which experienced a steady stream of data requests from the National Data Centres and Provisional Technical Secretariat of CTBTO.
- □ The ISC database and the website mirrors at IRIS DMC in Seattle, ERI in Tokyo, LLNL in Livermore and CEA in Beijing/Xian helped to maintain a reasonable speed of access to ISC data.
- □ 513 GT events have been added to the IASPEI Reference (GT) Event List.
- U We extended the **ISC-EHB** dataset to include 7,249 events for the data year 2019.
- □ Seven contributions have been added to the ISC Seismological Dataset Repository.
- □ We continued to run the **International Contacts in Seismology** service.
- □ We participated in several international scientific conferences and made working visits to local institutions that monitor seismicity and send data to the ISC.
- □ The ISC contributed to the work of **IASPEI** and **ESC** by maintaining the IASPEI website, leading several working groups and working at the IASPEI and ESC ExecComs.
- □ Impressive ISC data download statistics and a large number of published scientific articles using ISC data indicate very wide and extensive use of ISC products by researchers worldwide.

Signed, 26th June 2023 Dr. Dmitry A. Storchak Director

2: STAFF and CONTRACTORS

A total of 19 members of staff (15-18 at any one time, 18 most of the time) and two contractors worked for the ISC throughout the year, thanks to the regular Member's support and a number of additional grants given to the ISC by international organizations, public institutions and commercial companies to work on the ISC-GEM catalogue, CTBTO Link and the Station Registry. Staff changes through the year are highlighted in red or light blue.

Among the staff, there were 7 Ph.D., 4 M.Sc. or equivalent, and 5 B.Sc. or equivalent degrees. The ISC staff represents 9 different countries from 3 continents. Several members of staff took part in professional meetings, international conferences, and professional training programmes, both in person and on-line.

ISC staff often organise sessions at scientific conferences. Several ISC staff are members of professional organizations such as IASPEI, EGU, AGU and SSA. ISC staff members are engaged in IASPEI Executive Committees, commissions and working groups. The ISC Director has been elected as the President of the European Seismological Commission (ESC).

MANAGEMENT and ADMINISTRATION



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



Lynn Elms Administration Officer UK

SYSTEM ADMINISTRATION, SOFTWARE and WEB DEVELOPMENT



James Harris Senior Systems & Database Administrator, UK



Oliver Rea, B.Sc. Systems Administrator, UK



Adrian Armstrong, B.Comp.Sc., Software Engineer, *UK*

DATA COLLECTION and ENTRY

The Data Collection Officer communicates with agencies, manages routine automatic entry of reported data and corrects the data that failed to be parsed to the ISC database automatically. The Historical Data Entry Officers help with entering and validation of paper-based data into the ISC database.



Gary Job, Data Collection Officer, UK, *left in January*



Rian Harris, MSc Ecology, Historical Data Entry Officer, *UK*, joined in February



Calum Clague, BA (Hons) GIS, Data Collection Officer, *South Africa/UK*, joined in February



Susana Carvalho, Ph.D. N.D., Historical Data Entry Officer, *Portugal*, joined in April

BULLETIN ANALYSIS TEAM

Up to 7 analysts (two part-time) and one contractor reviewed the ISC Bulletin and performed limited waveform analysis. Each analyst has an additional task either in development or data collection.



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



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



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



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



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



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

DEVELOPMENT PROJECTS



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



Ryan Gallacher, PhD, Seismologist/Developer, UK



Thomas Garth, PhD Seismologist/ Senior Developer, UK



Natalia Poiata, PhD, Seismologist/Developer, Moldova/Romania

CONTRACTORS

During the year, the following persons and small companies also contributed as contractors:

- E.R. Engdahl, Ph.D., Boulder, USA: overseeing preparation of the ISC-EHB dataset;
- **PFSAC** a private consultancy company registered in Norway: assistance with depth phase picking using waveforms openly available on-line.

3: OPERATIONS

STATION REGISTRY AS PART OF ADSL DATABASE

The International Seismograph Station Registry (IR) allocates globally unique codes to seismic stations worldwide. During 2022, the IR has been particularly improved and extended in Europe, South-West Asia, Central and South America and the Caribbean region (Fig. 1) as part of the regular ISC Bulletin work.



Figure 1. 29,855 stations, open or closed, were fully registered in the International Seismographic Station Registry at the end of 2022; parameters of 720 of those (in red) were either registered or modified during this year.

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.

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

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

Until the end of data year 2020, for the majority of its standard operational activities, the ISC used 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 has switched to working with the entire ADSL from data year 2021. This will be covered in the 2023 Director's Report.

ISC BULLETIN

Collecting Preliminary Network Bulletins

The ISC continues to collect preliminary bulletin data from a number of networks and data centres before they report their reviewed data. These data are expected to have undergone at least a minimal review by local analysts. Typically, the incoming data include a preliminary hypocentre location, magnitude estimates, moment tensor solution and station arrival data, though there are large variations from agency to agency. 23 agencies reported preliminary data during year 2022 (Table 1). Armenia's National Survey of Seismic Protection, India's National Geophysical Research Institute and Japan Meteorological Agency temporarily stopped reporting their preliminary solutions to the ISC during 2022.

Country	Reporting Agency
Australia	Geoscience Australia
Austria	Zentralanstalt fur Meteorologie und Geodynamik (ZAMG)
Canada	Canadian Hazards Information Service, Natural Resources Canada
Cyprus	Cyprus Geological Survey Department
Czech Republic	Geophysical Institute, Academy of Sciences of the Czech Republic
Denmark	Geological Survey of Denmark and Greenland
Finland	Institute of Seismology, University of Helsinki
France	Centre Sismologique Euro-Mediterranean (CSEM/EMSC)
Germany	Helmholtz Centre Potsdam, GFZ Research Centre for Geosciences
Germany	Landeserdbebendienst Baden-Wurttemberg
Hungary	Geodetic and Geophysical Research Institute
Italy	Istituto Nazionale di Geofisica e Vulcanologia
Kyrgyzstan	Institute of Seismology, Academy of Sciences of Kyrgyz Republic
Norway	University of Bergen
Norway	Stiftelsen NORSAR
Romania	National Institute for Earth Physics
Russia	Geophysical Survey of Russian Academy of Sciences (GS RAS)
Russia	Baykal Regional Seismological Centre, GS RAS
Russia	Kamchatka Branch, GS RAS
Slovenia	Slovenian Environment Agency
Spain	Instituto Geografico Nacional
UK	British Geological Survey
USA	NEIC, USGS

Table 1. 23 agencies that reported preliminary hypocentre determinations and corresponding arrival time data to the ISC in 2022.

There are 19 agencies that produce bulletins soon after an event occurrence and never perform 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.

Country	Reporting Agency
Australia	Geoscience Australia
Austria	International Data Centre, CTBTO
Chinese Taipei	Institute of Earth Sciences, Academia Sinica
France	Institut de Physique du Globe de Paris
France	Laboratoire de Detection et de Geophysique/CEA
French Polynesia	Laboratoire de Geophysique/CEA
Germany	Alfred Wegener Institute for Polar and Marine Research
Germany	GFZ Potsdam
Greece	University of Patras, Department of Geology
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
Puerto Rico, USA	Red Sismica de Puerto Rico
Romania	National Institute for Earth Physics
Spain	Real Instituto y Observatorio de la Armada
Switzerland	Swiss Seismological Service
Turkey	Kandilli Observatory and Earthquake Research Institute
USA	Pacific Tsunami Warning Center

Table 2. Agencies that reported final analysis results within a month of event occurrence

Notably, the availability of data from the IDC/CTBTO bulletin (REB) stayed as agreed with CTBTO – seven days after formal release of each REB data day. This is essential since the ISC is the only channel through which academic research scientists can get regular uninterrupted access to the REB event and station recording parameters (not original bulletins) except for the most recent 10-14 days. In line with CTBTO's formal conditions of release, the ISC is not permitted 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 magnitude are reported within the first week. Further reports beyond one week add information to already reported large and moderate events and also inform about smaller events.

This process is there to fill the gap between the event occurrence and the time when the final Reviewed ISC Bulletin becomes available. It presents an attempt to consolidate the effort of many data centres and networks to make their data available internationally in good time. At this stage the ISC does not compute or publish its own event solutions. This service is not intended for use by the media or civil protection agencies. It is designed to be used by

seismologists to receive as much information as possible in one single format from one single source and then to get access to details using the links provided to the original data reporters.

Approximately one year after each seismic event occurrence, the preliminary data from agencies are substituted with their final, revised versions; this is well before the ISC analysts make their final review of the ISC Bulletin. The ISC hypocentre solutions are still based only on the revised set of bulletin parametric data given by each reporting institution.

Collecting Revised Network Bulletins

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

Appendix 1 lists 154 agencies in 94 countries that contributed revised seismic bulletins to the ISC during the calendar year 2022. Among them there is one regional data concentrator - the NEIC/USGS, which in fact represents a number of US-based networks.

Notably, one of the data contributors is the ISC itself, with depth phase arrival time picks for earthquakes worldwide, arrival time picks from African stations for distant earthquakes as well as ISC-PPSM and ISC-FM solutions.

Figure 2 shows countries and agencies that contributed revised bulletins for various months and years, directly or indirectly (via other agencies), during 2022. Figure 3 shows those agencies that reported data for the data months that the ISC reviewed during 2022. This collection is usually (not this year) more complete due to the efforts of the Data Collection Officer and the Director to obtain missing agency data before the analysis at the ISC began.



Figure 2. Agencies (black dots) and corresponding countries (in colour) that reported revised bulletins during 2022; red/grey colours indicate direct/indirect contributions.

Figure 3. Agencies and corresponding countries that reported revised bulletins for the data months reviewed by the ISC in 2022: Jan 2020 – Feb 2021. During 2022, we still experienced irregular data deliveries from several countries caused by the consequences of the global pandemic and a large backlog of data to be processed. Among agencies who <u>stopped reporting</u>:

- Seismological Observatory of Mount Cameroon, Cameroon
- Institute of Geophysics and Geology, Moldova

Among the new data received during 2022, we should list:

- *SARA Electronic Instrument*, **Italy** (an unusual combination of an ISC commercial sponsor and seismic monitoring data reporter)
- *Institute of Dynamics of Geosphere, RAS,* **Russia** (historical station arrival times, a one-off contribution)

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.

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.

In House Waveform Picking of Depth Phases



Fig. 4. The map of 834 events where additional ISC pP/sP picks were critical to constrain the ISC event depths.





Since 1964, the ISC's mission has been based on re-using the seismogram (waveform) arrival time measurements (picks) made by many tens of observatories and data centres. In recent years, the ISC used reported arrival times of ~10.5 thousand stations worldwide. The ISC does not have sufficient staff capacity to obtain those picks from waveforms, even if these waveforms were always available. We nevertheless feel that the value and quality of the ISC Bulletin would have been compromised if we didn't act in two particular areas.

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

Since 2018, we have set aside a small fraction of analyst resources to deal with the problem. Two ISC analysts and a private contractor (PFSAC) have been picking the depth phases on waveforms available from IRIS DMC for earthquakes with $mb^{NEIC} \ge 4.8$, using the SEISAN software (Havskov *et al.*, 1999, 2010, 2020).

Depth phases for 1,170 earthquakes were added to the ISC Bulletin during this year. Figure 4 shows 834 events for which this information was crucial, i.e., the depth would otherwise have had to be fixed to the area's default. Figure 5 shows the worldwide distribution of 160 stations used and their comparative input. As expected, stations in quiet regions of Asia, Australia, Antarctica and North America provided the largest input.

In House Waveform Picking of distant events at African Stations

We also continued picking teleseismic event waveforms from the Africa Array to compensate for the unfortunate lack of teleseismic observations over large parts of this continent. We include these picks in the routine production of the ISC Bulletin. Figure 6 shows the map of 260 events with M>= 5 picked by one of the ISC analysts using 35 stations in Botswana, Kenya, Madagascar, Mauritus, Namibia, South Africa and Zimbabwe.



Figure 6. 260 M >= 5 earthquakes (left) for which the ISC analysts picked seismic arrival times using openly available waveforms of 35 stations in Africa from IRIS DMC (right).

Bulletin Review (staying at 24 months b.r.t.)

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 analysts. The threshold criteria are complex yet almost all events of magnitude 3.5 and larger are reviewed.

The ISC seismologists/analysts currently review ~10% of all events formed in the ISC database by the automatic procedures. Although this review misses smaller events, it makes the most used part of the ISC Bulletin accurate and trustworthy. The accuracy of *ak135*-based (Kennett *et al.*, 1995) ISC solutions and magnitude estimates, and proper grouping of reported information between the events in the Bulletin is under constant scrutiny. The ISC analysts also review the correctness of automatic association of reported station arrivals to events, reported arrival's phase identification and travel-time residuals.

All analysis work is done using the Visual Bulletin Analysis System (VBAS) that throughout the year allowed the analysts to work both in the office and at their private homes.

Throughout 2022, the Analyst Team varied between 5.2 at the start of the year and 4 members in the second half of the year due to maternity leave taken by two part-time members of staff. The Team was also assisted in depth phase picking by an outside contractor (former member of the Team).

During 2022, the Team conducted the review of the standard current ISC Bulletin, successfully maintaining the target delay of 24 months b.r.t. (Fig.7). In addition, members of the Team were involved in other projects such as the ISC-EHB bulletin, Event Bibliography, ISC-GEM catalogue, depth phase picking from waveforms and production of the printed/electronic Summary of the ISC Bulletin.



Figure 7. Having reached the target of 24 months b.r.t. during 2021, the Analyst Team successfully maintained production of the Reviewed ISC Bulletin at a steady pace during 2022.

As a result, during 2022, the Analysis Team fully reviewed **11** complete data months of the recent ISC Bulletin with **2** data months receiving partial review. The analysis covered data from January 2020 till January 2021. The analysts were working with approximately the same monthly number of events as during the previous five years (Fig. 8). Nevertheless, the number of associated phases reviewed by analysts remained on the increase as new stations and networks were installed. By design, VBAS helped to alleviate this problem. Further improvement of the VBAS software was conducted throughout the year by the ISC Software Engineer who followed requests and advice from the Analyst Administrator.



Figure 8. Monthly number of seismic events in the Reviewed ISC Bulletin analysed during 2022; the solid colour represents those data months that were fully completed during the year; the dashed line shows the average monthly number during the preceding 5 data years.

During the calendar year 2022 (2021), ~60,000 (~86,000) reviewed events with ~8.0 (~10.6) 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 ~674,000 (~815,000) events and ~21.0 (~25.4) million associated phases. During the calendar year 2022 the analysts stayed at the 24 months b.r.t. mark, hence the production of the Bulletin was steady with just one data month released in each calendar month. Thus, fewer events and associated phases have been reviewed during 2022 compared to 2021. This allowed the

Analysis Team to cope with a couple of maternity leaves and be engaged in a number of new developments, including further modification of the VBAS.

The result of the ISC work can be seen when comparing Figures 9 and 10. A fuzzy picture of the originally reported seismicity is sharpened in the Reviewed ISC Bulletin.



Figure 9. All hypocentres reported by individual networks (Jan 2020 – Jan 2021).

Figure 10. Primary hypocentres in the ISC Bulletin (black) in the period (Jan 2020 – Jan 2021); in red are the reviewed events.

Figure 11 demonstrates the diversity of seismic phases included in the ISC Bulletin.



Figure 11. The travel-time graph and associated table show the statistics of various seismic phases (Storchak et al., 2003, 2011; Schweitzer et al., 2019) generated by large shallow events reviewed by the ISC analysts during 2022; 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 seismic event (earthquake or explosion) numbers (Fig. 12), reported seismic wave arrival times and amplitudes of seismic waves recorded at stations registered in the IR (Fig. 13).



Figure 12. 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 January 2021 (amber) are those intended for review.

Numbers as of Jan 26, 2023





Figure 14 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.



The ISC Bulletin is used by many researchers worldwide. The number of bulletin web searches in 2022 was somewhat smaller than in the previous two years (Figures 15 and 16). Notably, ~34% of Bulletin searches are done through the fdsn-webservice and ~66% - through the ISC website. This number doesn't include searches through the ISC mirror at ERI, CTBTO, LLNL or CEA, nor does it include individual user searches based on flat bulletin files downloaded by some users from the ftp-site.



Figure 15. The annual number of ISC Bulletin searches made by users; during 2022, the number of searches was smaller than in 2021, yet it was still significant - as many as 20 per minute.

Figure 16. Daily distribution of Bulletin searches and individual users during 2022



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

per number of searches

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 four major formats: ISF2.1 (International Seismic Format, the latest version), ISF1.0 (Legacy ISF), QML (QuakeML) and CSV (comma separated variables). Figure 18 shows that the number of searches in CSV and QML formats exceeds those of ISF1.0 or ISF2.1. The QML searches though are performed by fewer users who tend to run automated queries that request larger volumes of data. It therefore appears that all four formats are so far popular and need to be maintained. We shall of course monitor when the ISF1.0 searches can be taken down in favour of ISF2.1.



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

Printed Summary of the ISC Bulletin



Figure 19. The 1st and 2nd issues of the printed Summary of the Bulletin of the ISC for data year 2019 were dealt with during 2022.

Each issue of the *Summary of the Bulletin of the ISC* covers six months of data. The Summary is prepared at the ISC and printed by *Cambrian Printers* in Wales within approximately two months after the relevant period of ISC data becomes available to users. Then, within a few months the Summary becomes openly available on the web. Physical postage of the Summary books to ISC Members and paying customers usually happens after its publication but has been disrupted during the epidemic. We have recently been posting two issues together once every second issue of each data year was available.

During 2022, we dealt with the 2019-I and 2019-II issues covered:

(Fig. 19). The following topics were covered:

- The ISC (Mandate, History, Evolution of the Bulletin, Member Institutions, Sponsors, Data Contributors, Staff)
- Operational Procedures (data collection, grouping, association, thresholds, location, magnitude determination, review, history of operational changes)
- IASPEI Standards
- Summary of Seismicity (for every 6 months)
- Invited article on the use of ISC data from the University of Bergen in Norway
- Statistics of Collected Data
- Overview of the ISC Bulletin
- Leading Data Contributors
- Advertisements for instrument producers Sponsors of the ISC

The invited network description articles (when published) usually become associated with general information available for each agency contributing to the *ISC Bulletin*. Notable event articles (when published) become included in the ISC Event Bibliography.

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

ISC-EHB

The ISC-EHB dataset (Weston *et al.*, 2018; Engdahl *et al.*, 2020) is a groomed subset of the ISC Bulletin that includes well-recorded events and uses the advantages of both the ISC (Bondar and Storchak, 2011) and EHB (Engdahl *et al.*, 1998) location techniques. Teleseismically well-constrained events are selected from the ISC Bulletin and are relocated using the EHB location algorithms to minimise errors in location (particularly depth) due to assumed 3D Earth structure. The EHB algorithm incorporates a specific phase identification algorithm for teleseismic depth constraining phases (pP, pwP, sP, PcP) and also uses PKiKP, PKPdf, PKPbc and PKPab phases.

During 2022, together with E.R. Engdahl of University of Colorado Boulder, we applied the ISC-EHB approach to events in the year 2019. The ISC-EHB dataset greatly benefitted from additional depth phase picks made by the ISC analysts using waveforms available at IRIS.





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

The ISC-EHB dataset has great potential to reveal complicated structures (Fig. 20). It is available from the ISC website along with **cross-section plots** for a large number of seismic regions. The entire dataset (1964-2019) now contains 192,545 seismic events. It is a valuable tool for global and regional seismicity studies and tomographic inversions.

IASPEI REFERENCE EVENT LIST (GT)

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



Figure 21a. The IASPEI List contains seismic events during 1959-2020 for which epicentre information is known with high confidence (to Xkm or better (GTX))

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

The global effort to collect and validate GT events is coordinated by the CoSOI/IASPEI working group on Reference Events for Improved Location which in 2022 included Bob Engdahl, Eric Bergman, István Bondár, Keith McLaughlin and Ryan Gallacher.

The GT database of 12,090 reference events (1959-2020) and 1,758,903 arrival times facilitates better visualization of the Earth's structure, better modelling of velocities of seismic waves, more accurate travel time determinations and increased accuracy of locations.

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

At the end of the analysis of each ISC Bulletin data year, we add new events to the Reference Event List. During 2022, 513 events were added or updated (Fig. 22).



Figure 22. Events (in red) updated or added to the IASPEI Reference Event List during 2022

ISC EVENT BIBLIOGRAPHY

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

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





Figure 23 illustrates the articles that were added to the Event Bibliography during 2022. A large proportion of this work for the 20th century benefitted from the bibliographical efforts of the ISC staff bringing reliable earthquake source mechanisms and moment tensors into the ISC-GEM catalogue.

SEISMOLOGICAL DATASET REPOSITORY

This relatively new supplementary ISC service (International Seismological Centre, 2021) allows individual researchers or groups to submit seismological datasets that they wish to be openly available to the scientific community for a long period of time. This service assists a positive trend in scientific publishing to require article authors to make the original research data openly available so that their conclusions can be tested by other researchers.

Examples of acceptable datasets include, but are not limited to:

- Event catalogues/bulletins
- Results of earthquake source studies
- Results of structure studies
- Velocity models

- Notable earthquake observations
- Seismological computer code

We do not store raw waveforms as part of the Dataset Repository because this role falls within the mission of other data centres.

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

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

We processed and made available **36** eligible submissions by the end of 2022.

SEISMOLOGICAL CONTACTS

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

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



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

ISC WEB and FTP SITES

In 2022, the ISC website experienced ~24.2 million hits which is considerably less than 43.8 million in 2021. This may be due to more efficient elimination of web crawlers in the above statistics this year. The majority of the ISC web data are distributed through the main ISC website and the mirror at IRIS DMC in Seattle. The load balancer automatically directs user queries to the least busy server.

The use of the ISC ftp site in 2022 decreased by 8% compared to the previous year. The ftpsite is used for downloading pdf copies of the printed ISC Bulletins and Summaries, the ISC Bulletin in FFB and ISF formats, the ISC-EHB bulletins and the text version of the IR station list. Figure 25 demonstrates worldwide interest in ISC data.



Figure 25. Statistics of ISC website hits (left) and ftp-site downloads (right) per country, where known.

ISC DATABASE, WEBSITE BACKUP and MIRRORS

The ISC continued maintaining a virtual server at the IRIS DMC in Seattle in order to hold a mirror of the ISC database and the ISC website. This was done with assistance from DMC and US NSF in order to achieve a general ISC data back-up and fall-over facility in case of a breakdown of services at the ISC itself (proved useful when the ISC database server crashed in April 2021) as well as to spread the load on the ISC internet line and give ISC data users faster access.

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

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

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

<u>4: DEVELOPMENT PROJECTS</u>

ADVANCEMENT of the ISC-GEM CATALOGUE

The ISC-GEM Global Instrumental Catalogue was originally requested and part-funded by the GEM Foundation. The catalogue is widely used for modelling seismic hazard on a regional and global scale. In addition, the catalogue is used as an authoritative reference and a starting point for regional studies in South America, Africa and Asia. The catalogue also has a multidisciplinary use in a wide range of other areas such as studies of global seismicity, tectonics, earthquake hazard forecasting, rapid determination of hazard etc. (Storchak *et al.*, 2013, 2015). Moreover, during the ISC-GEM project, we digitised a large volume of basic station observation data (Di Giacomo *et al.*, 2015a; Di Giacomo *et al.*, 2018a) which can now be used by individual researchers for historical earthquake studies. Notably, the ISC-GEM catalogue forms the basis of the USGS's ComCat Catalog (ANSS Catalog) before 1970s.

During 2022 we added to the catalogue:

- 18,576 earthquakes that occurred between 1976 and 2018 and with direct Mw from GCMT between 5.0 and 5.5 (thereby complementing the continental earthquakes down to magnitude 5 added in previous versions);
- 1,663 earthquakes that occurred in 2019 with Mw down to 5.0 globally.

Work to improve the content of the catalogue in the 1950s and 1960s has continued, with results to be demonstrated next year.



Figure 26. Annual number (top) and magnitude distribution (bottom) of earthquakes above a certain magnitude in ISC-GEM Ver.9 (at the end of year 2021, left) versus prototype of the Ver.10 at the end of Year 2022 (right).

The popularity of ISC-GEM has grown over the years (Fig. 27).



Figure 27. During the last 7.5 years, the ISC-GEM catalogue has, on average, been downloaded 17 times per day.

ELECTRONIC ARCHIVE of PRINTED STATION BULLETINS

The Electronic Archive of Printed Station / Network Bulletins (ISC, 2022; Di Giacomo *et al.*, 2022) is a new service set up in 2021 and further improved during 2022. This service has stemmed from our work on the ISC Bulletin and ISC-GEM catalogue.



Figure 28. The Electronic Archive of Printed Station Bulletins: the towns where paper-based station/network bulletins were produced (among those currently available)

In this archive users can find scans of printed seismological bulletins. These were the main sources of instrumental parametric data in seismology before the electronic era began. Printed bulletins may contain a single station (e.g., Riverview, Observatorio San Calixto) or a set of stations (network, e.g., as in former USSR from the late 1920s).

The bulletins have been scanned from various sources and have been indexed based on the town where each bulletin was produced. Hence, the town can coincide with the historical station name/location or, as it is often the case, it represents the headquarters of an organization producing the bulletins.

Users can search for bulletin scans by clicking on a town marker, as shown in Figure 28. Next, an inventory of the scans available that were produced at that site is shown with the pdf-copy of each scan freely available to download.

The ISC archive of printed bulletins is not comprehensive, but it is currently the best worldwide service available. We are working with colleagues in other institutions to improve this collection.

PROGRESS on COMBINED WAVEFORM DOWNLOAD

Given the current and projected future requirements for waveform processing at the ISC the current process of individual waveform downloads for each process is unsustainable. Development of a combined waveform download as a solution to this has continued through 2022. Combined waveform download has been designed in two parts, Station Availability and Waveform Download.

The Station Availability is checked by monthly download of the response files for all stations available through FDSN webservers. The information from these response files (lat, lon, channel, etc.) is stored in a psql database with the response files saved to disk. To avoid duplication the information stored in the database is checked against the station level response information available through FDSN webservers. Only when a discrepancy in the stored information is found is it necessary to download the whole response file.

The station availability is currently operational and has been extensively tested for use in obtaining FDSN station coordinates for picks reported to the ISC. This is part of the move towards allowing picks at non-IR stations in the ISC Bulletin.

The Waveform Download part is currently nearing completion, with a hierarchical download system having been implemented to prevent downloading the same waveforms from multiple FDSN servers. This system is also designed to select the best available instrument channel depending on whether single or three component data is available. To limit the amount of unnecessary waveform data being downloaded we have developed an empirical relationship between magnitude and maximum recorded distance of P and S wave picks being available. This table is used to inform what stations to download on an event-by-event basis. Outstanding issues with the system relate to the timescale/bandwidth of downloading waveforms and the best waveform storage structure/format. Solutions to these issues are still to be determined.

AUTOMATIC ESTIMATION of STANDARD MAGNITUDES

Earthquake magnitudes represent important input to a wide variety of seismological studies ranging from seismic hazard to statistical analysis of seismicity as well as nuclear explosion discrimination. Along with the phase arrival measurements provided by the reporting agencies, the ISC also compiles information about the magnitudes of the events and recomputes different types of magnitudes based on the reported amplitude and period measurements (Bondár and Storchak, 2011; Di Giacomo and Storchak, 2022). Those measurements, however, can be inconsistent between different agencies due to the peculiarities of the waveform processing, such as, differences in filtering limits, measuring the amplitudes within different time windows, applying different instrumental calibration functions etc. To address these inconsistencies, we are developing a procedure for routine automatic estimation of the standard body- and surface-wave magnitudes using publicly available broadband seismological data recorded worldwide. The procedure strictly follows the guidelines of the IASPEI Commission on Seismic Observation and Interpretation (CoSOI) adopted following the recommendations of the IASPEI Working Group on Magnitude Measurements on new standards for widely used local, regional, and teleseismic magnitude scales (IASPEI 2005, 2013; Bormann and Dewey 2012). Our main goal is to provide uniform characterization of the earthquake size by estimating different types of magnitudes in a consistent and reliable manner.

Among the variety of standard magnitude scales body- and surface-wave magnitudes are the two most common and (historically) important. Following the IASPEI recommendations for the body-wave measurement in the teleseismic distance range $(20^{\circ}-160^{\circ})$ we focus on two complementary standards defining short-period (m_b) and broadband (m_BBB) body-wave magnitudes; both calculated from the maximum trace amplitudes in the entire *P*-phase train (from P-arrival to PP-phase arrival). For shallow earthquakes with source depth h<60 km IASPEI (2005, 2013) suggests two standards of surface-wave magnitude estimations, namely, a teleseismic (20°-160°), narrowband surface-wave magnitude M_s20 and a broadband surface-wave magnitude M_sBB that is measured in wider epicentral distance and period ranges of 2°-160° and 3s - 60s respectively. The IASPEI guidelines for the amplitude and period measurements for magnitude estimations are transformed into an automated procedure for systematic calculation of the body- and surface-wave magnitudes. The procedure can be summarised as the following: given the origin time and coordinates of an event, available waveform data (BHZ components) from the stations satisfying the epicentral distance conditions and appearing in the ISC Bulletin with P- and/or S-phase arrival readings are downloaded from the IRIS Data Management Center through the FDSN web service client of ObsPy (Krischer et al., 2015). After the data integrity check and the pre-processing (demeaning and detrending) the broadband traces, proportional to ground velocity, are estimated by removing the instrumental sensitivity and the short- and long-period traces are obtained by applying corresponding WWSSN instrumental responses defined by IASPEI (2013). The amplitude and period measurements for the stations corresponding to the epicentral distance conditions of each magnitude type are carried after the signal-to-noise ratio check (SNR > = 2). For each station, we shall calculate and provide final network magnitudes evaluated as the station's mean. Estimated magnitudes will be reported together with the amplitude, period and phase-time measurements.

We confirm that this procedure generally provides estimates that are in good agreement with magnitudes reported in the ISC Bulletin, by analysing a dataset focused on the selected 4-year time period (2016-2019). It provides an automatic scheme for a consistent routine estimation of earthquake magnitudes that will offer a coherent global representation of the earthquakes' size and will be further integrated into the ISC Bulletin along with the magnitudes provided by agencies.

PROBABILISTIC STF, MT and DEPTH INVERTIONS

ISC-PPSM (Probabilistic Point Source Model) (Stähler and Sigloch, 2014, 2016) is a new method introduced at the ISC from data year 2019 onwards, to address the uncertainty in the earthquake moment tensor that is apparent from the range of moment tensors reported to the ISC. ISC-PPSM also adds new constraints on the earthquake source time function (STF), and the earthquake depth particularly for shallow moderate magnitude earthquakes. Currently, results are available for the period January 2019 – January 2021, and an example ISC-PPSM solution is shown in Figure 29.

Throughout the year 2022 ISC-PPSM has been running in Beta testing mode, publishing earthquake moment tensors, STFs and depths. The added depth resolution provided by ISC-PPSM is used to inform the depth of relatively shallow moderate magnitude earthquakes, where depth phase picking is not possible. During 2022 ISC-PPSM has produced 418 solutions for the time period January 2020 to March 2021 that are viewable and downloadable from the ISC website (via the ISC Bulletin). During this time period ISC-PPSM has been used to directly inform the depths of at least 22 earthquakes in the ISC

Bulletin, with the ISC-PPSM depth being used as a seed point for a stable relocation in many other instances. To enable the use of ISC-PPSM depths in the main review process, a provisional ISC-PPSM solution is produced before the main review. The ISC-PPSM solution is then recomputed for the revised ISC Bulletin location, and the depths are cross-checked if the ISC-PPSM depth has been used to fix the ISC hypocentre depth.

Throughout the year, small fixes to the methodology have been made to address issues highlighted during this beta testing phase. At the end of 2022, work commenced on making the final code updates to bring ISC-PPSM out of its beta testing phase, which is anticipated to occur in 2023.



Figure 29: Example of the probabilistic STF and moment tensor inversion; a) Bayesian beach ball b) best fitting beach ball c) observed seismograms (black) along with ensemble of fitted seismograms (red) d) probabilistic STF in grey, with best fitting STF in red e) depth probability density function.

FIRST MOTION POLARITY BASED FOCAL MECHANISMS (ISC-FM)

As part of a continuous review of the methodologies used at the ISC, we have discovered that many previously reported ISC-FM solutions are not of a good or acceptable quality. In the past, these solutions were reported via the ISC Bulletin, accompanied by a quality flag that informed the user whether the solution was reliable or not. We now only report ISC-FM solutions that have a quality metric indicating that the solution is usable and reliable. Unfortunately, this has greatly reduced the number of ISC-FM solutions available to users (approximately 90% of solutions have been removed from the Bulletin).

The issues that make many of the ISC-FM solutions unusable are largely a result of the polarity data used to calculate them. Reported polarities vary widely in quality, while the currently implemented system of automated polarity picking is not reliable for smaller events and is extremely sensitive to noise and cycle skipping. The development team at the ISC are working to address this, with two main innovations. The first is the 'polarity reversal tool', that evaluates the reliability of reported first motion polarity data, by station and reporter. Secondly, we are exploring more stable and reliable methods of adding automated polarity picks to the data in order to increase the number of viable ISC-FM solutions reported. We hope to release an updated revised version of the ISC-FM catalogue during 2023.

CTBTO LINK to the ISC DATABASE

In 2008, the UK Foreign and Commonwealth Office (FCO) awarded the ISC a three-year grant to set up a dedicated and secure link to the ISC database for the CTBTO Provisional Technical Secretariat (PTS) and National Data Centres (NDC). The FCO provided 90% of the total funding with GEUS (Denmark), NORSAR (Norway), FOI (Sweden) and University of Helsinki (Finland) complementing it with 2.5% each. From April 2011, the funding of the project was taken over by CTBTO. The previous contract ran from April 2015 until March 2020. A new annual contract has been signed and started in April 2020. It provides the possibility of four annual extensions.



Figure 30. The healthy stream of user activity on the *IDC/CTBTO Link to the ISC database.*

During 2022, we maintained a dedicated server at the ISC that held a mirror version of the ISC database. The dedicated web-based software package designed, maintained and upgraded by the ISC for this service allowed users from the PTS and NDCs at CTBTO to query the ISC database in ways specific to the nuclear test monitoring community (Fig. 30). The software package includes four types of bulletin searches: area

based, REB event based, GT event based and IMS station based through the wealth of parametric information in the ISC database.

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

- assessing historical seismicity in a specific region;
- putting an event of interest into context with the seismicity of the surrounding region;
- examination of observations reported by non-IMS stations;
- comparison of hypocentre solutions provided by various agencies;
- relocating an REB event based on user selected arrival times available in the ISC database using the *ak135* 1-D model with an 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 URL-links which initiate waveform download by channel.

The CTBTO Link was updated with two new features during 2022, relating to the already developed station polarity plots. The first was an interactive map of all FDSN & IR stations where a polarity reversal plot was available. Either by selecting a station on the map or by typing the station code into a search, a pop-up window on the map shows the polarity reversal plots for that station. The second new feature allows users to query the station polarity for a given reporter and time period. This tool provides more detailed information about whether a station is likely to have a reversed polarity, the number of changes in polarity over the time period, the number of correct polarities and the total number of observations.

The CTBTO Link work also benefits the ISC and the general ISC data users.

- The ISC development staff acquired relevant skills and experience during this project. The advances made under this project are gradually being implemented to improve the open ISC web services. For example, the station histories now form an essential part of the International Seismograph Station Registry, available from the ISC website.
- In particular, experience of downloading, quality checking and processing waveforms on an industrial scale helps the ISC's efforts towards making its own automatic waveform measurements to further improve the quality of the ISC Bulletin.
- The ISC and its Bulletin users have speedy access to the data from the REB Bulletin which is now available in **daily batches within 10-18 days after an event occurrence** as opposed to 6-12 months in the past (Fig. 31).
- Many NDCs are run by institutions that are either Members or Reporters to the ISC.
- Several NDC's either became ISC Members or increased their financial contributions, based on the added value of the ISC services.

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 dataset and the International Seismograph Station Registry.



REB data months

Figure 31. The availability of data from the ISC REB bulletins (not REB itself) to general ISC Bulletin users (days behind real time) has considerably improved as an indirect result of the 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.

<u>5: FINANCE</u>

In line with the legal requirements of the Charity Commission for England and Wales, charities with an annual turnover of less than a million pounds are subject to an independent financial examination as opposed to an audit. The detailed financial statements of the ISC for 2022 were prepared by Azets (Newbury, UK). These statements present the state of the ISC's financial affairs as at 31st December 2022.

Income

In 2022, the ISC had a total income of £907,328. This number includes all membership subscriptions (paid or unpaid). This number is lower than in any preceding years because the **US National Science Foundation (NSF)** sadly didn't manage to finalise their award for the next 4 years as is customary.

We welcomed the *National Institute of Geography* in Madrid, Spain who has re-started its 5-unit ISC membership after it was stopped due to economic hardship back in 2013.

As planned, the *Centre for Earth Evolution and Dynamics (CEED)* of the University of Oslo in Norway has paid its last ISC Membership contribution in 2022.

The ISC was expecting to receive contributions from 72 Member Institutions in 47 countries.

Several membership contributions were still unpaid on 31st Dec 2022:

- CGM, National Academy of Sciences, *Belarus*, 1 unit
- belspo, *Belgium*, 1 unit (paid 5th Jan 2023)
- National Observatory of Athens, *Greece*, 1 unit (paid 24th Feb 2023)
- CSIR-National Geophysical Research Institute, India, 2 units (paid 14th Jun 2023)
- Institute of Geophysics, PAS, Poland, 1 unit
- Russian Academy of Sciences, Russia, 20 units
- Institute of Marine Science (ICM), Spain, 1 unit

Notably, both the Russian and Belarusian Academies of Sciences are able and willing to pay their contributions. Due to UK Government sanctions imposed on the Russian and Belarusian banks, such transactions are impossible at the moment.

Grants for special projects and general sponsorship totalled £190,417, which is $\sim 21\%$ of the total income.

Traditionally, the income also includes the revenue from sales of the Bulletin Summary book, reduced by the cost of the book and DVD-ROM production and postage, which in 2022 amounted to a loss of \pounds 3,456.

We received £1,747 in interest on our bank accounts.

Expenditure

As much as 90.5% of ISC expenditure was committed to staff costs. These costs include salaries, pension contributions, and recruitment of new staff. The ISC salaries continue to follow the scales adopted in 2015 and approved by the Executive Committee. Each January, with the approval from the Chairs of the Governing Council and the Executive Committee

(Board of Trustees), we increase the staff salaries in line with the annual inflation index (CPI), published by the UK Office of National Statistics. Thus, salaries of all ISC staff were raised by 5.0% from January 2022. We also sustained the continuing rise in pension costs as experienced staff earn an increase in ISC contributions to their pension pots in line with their length of service. Although this measure is costly, it does help to retain good staff.

This year, the staff was helped by two contractors. PFSAC, a small consultancy company in Norway, helped with the depth phase picking and R.E. Engdahl helped with the ISC-EHB project.

The staff travel costs stayed low due to the continued Covid-19 pandemic. The building maintenance costs in 2022 were somewhat higher than those in 2021. The computer costs in 2022 were ~40% smaller than those in 2021.

The exchange rate between UK \pounds and US \$ changed throughout the year. Taking into account the timings of individual incoming and outgoing transactions, the ISC made a gain of £16,223 on foreign currency exchange in 2022.

Reserves

In understanding that all missing contributions will be paid, the ISC's income during 2022 exceeded its expenditure by £55,110, but, taking into account the unpaid membership contributions, the real loss at the year-end was £3,650. As a result, the total reserves, comprising cash in the bank, value of building and land, money owed to the ISC (debtors) minus money the ISC owes (creditors) have increased to £1,355,497 from £1,300,387 at the start of the year.

Cash Flow

The cash flow in Fig. 32 shows receipts and expenditure using dates when transactions were recorded at the bank and the bank balances where US Dollars are converted to Sterling using the exchange rate at the end of each month.

Due to the size of its General Reserve serving as a safety net, the ISC has not experienced problems with its cash flow in 2022. Nevertheless, the absence of the US NSF award for the last two months of 2022 as well as missing contributions from several Members has led to a decline of the cash balance at the year end.





<u>6: SCIENTIFIC COMMUNITY AWARENESS</u>

Visitors to the ISC

Ordinarily, two dozen colleagues visit the ISC each year, meet with the staff and make presentations of their work. In the aftermath of the pandemic, the ISC received only two visitors during 2022, both on a day trip from Oxford:

- Aidyn Mukambayev (Kazakhstan National Data Centre and Satbayev University)
- Chia-Hsin Tsai, also known as Wendy (*University of Oxford*)

Conferences, Meetings, Workshops, Training Courses

Members of the ISC staff presented at the following conferences, meetings and workshops some of which were run on-line:

- CTBTO WGB and Waveform Expert Group, Vienna, Austria
- International Seismic School, Minsk, Belarus
- General Assembly of the Latin American and Caribbean Seismological Commission (LACSC), Quito, *Ecuador*
- ORFEUS workshop, Potsdam, Germany
- CTBTO NDC and RSTT Workshop, Kathmandu, Nepal
- CTBTO NDC and RSTT Workshop, Muscat, Oman
- General Assembly of the European Seismological Commission (ESC), Bucharest, *Romania*
- GEM OpenQuake Training Workshop, Oxford, UK
- British Seismology Meeting (BSM), Cambridge, UK
- Powell Center Working Group for Earthquake Monitoring, Fort Collins, USA
- SSA meeting, Bellevue, USA
- Nordic Seismology Seminar, virtual
- ORFEUS webinar, *virtual*

ISC Staff Visiting Other Institutions

Often during scientific conferences, with the help of the hosting institution, members of the ISC staff visit and, where appropriate, give a presentation to the staff of local institutions involved in seismic monitoring or temporary seismic deployments:

- GFZ, Potsdam, Germany
- Instituto Geofísico de la Escuela Politécnica Nacional (IG-EPN), Quito, Ecuador
- National Earthquake Monitoring and Research Centre, Department of Mines and Geology, Kathmandu, *Nepal*

- National Tsunami Warning Centre, Meteorology and Air Navigation Complex (PACA), Muscat, *Oman*
- University of Cambridge, Cambridge, 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 Host Institution – the University of Oxford.

This year, the prize was given to Ms Julia Johnson, 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 this year to fulfil a general strategy of making the ISC standards, procedures, and services transparent to users. This also helps to keep an historical record of how the ISC data were put together at different times.

Di Giacomo, D. and Storchak, D.A., 2022. A Tribute to "Analog" Seismologists, *Seismol. Res. Lett.*, **93**, 5, 2921-2926, DOI: <u>10.1785/0220220166</u>

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APPENDIX 1: STANDARD BULLETIN REPORTERS

154 institutions in 94 countries reported reviewed seismic bulletin data to the ISC during 2022. This number also includes the ISC itself, which now produces depth phase arrival times, polarities of first motions, event source mechanisms, PPSM, and teleseismic event picks using waveforms of African stations in addition to the traditional set of hypocentre solutions and magnitudes.

Albania	The Institute of Seismology, Academy of Sciences of Albania
Algeria	Centre de Recherche en Astronomie, Astrophysique et Geophysique
Argentina	Universidad Nacional de La Plata
Argentina	Instituto Nacional de Prevencion Sismica
Armenia	National Survey of Seismic Protection
Australia	Geoscience Australia

Australia	Curtin University
Austria	International Data Centre, CTBTO
Austria	Zentralanstalt fur Meteorologie und Geodynamik (ZAMG)
Azerbaijan	Republican Seismic Survey Center of National Academy of Sciences
Belgium	Royal Observatory of Belgium
Bolivia	Observatorio San Calixto
Bosnia and Herzegovina	Republic Hydrometeorological Service, Seismological Observatory, Banja Luka
Botswana	Botswana Geoscience Institute
Brazil	Instituto Astronomico e Geofisico, USP
Brazil	Observatory Seismological of the University of Brasilia
Bulgaria	Geophysical Institute, Bulgarian Academy of Sciences
Canada	Canadian Hazards Information Service, Natural Resources Canada
Chile	Centro Sismologico Nacional, Universidad de Chile
China	China Earthquake Networks Center
Chinese Taipei	Institute of Earth Sciences, Academia Sinica
Chinese Taipei	CWB Weather Bureau
Colombia	Red Sismologica Nacional de Colombia
Colombia Costa Rica	Red Sismologica Nacional de ColombiaSeccion de Sismologia, Vulcanologia y Exploracion Geofisica
Colombia Costa Rica Croatia	Red Sismologica Nacional de ColombiaSeccion de Sismologia, Vulcanologia y Exploracion GeofisicaSeismological Survey of the Republic of Croatia
Colombia Costa Rica Croatia Cuba	Red Sismologica Nacional de ColombiaSeccion de Sismologia, Vulcanologia y Exploracion GeofisicaSeismological Survey of the Republic of CroatiaServicio Sismologico Nacional Cubano
Colombia Costa Rica Croatia Cuba Cyprus	Red Sismologica Nacional de ColombiaSeccion de Sismologia, Vulcanologia y Exploracion GeofisicaSeismological Survey of the Republic of CroatiaServicio Sismologico Nacional CubanoCyprus Geological Survey Department
Colombia Costa Rica Croatia Cuba Cyprus Czech Republic	Red Sismologica Nacional de ColombiaSeccion de Sismologia, Vulcanologia y Exploracion GeofisicaSeismological Survey of the Republic of CroatiaServicio Sismologico Nacional CubanoCyprus Geological Survey DepartmentThe Institute of Physics of the Earth (IPEC)
Colombia Costa Rica Croatia Cuba Cyprus Czech Republic Czech Republic	Red Sismologica Nacional de ColombiaSeccion de Sismologia, Vulcanologia y Exploracion GeofisicaSeismological Survey of the Republic of CroatiaServicio Sismologico Nacional CubanoCyprus Geological Survey DepartmentThe Institute of Physics of the Earth (IPEC)Geophysical Institute, Czech Academy of Sciences
Colombia Costa Rica Croatia Cuba Cyprus Czech Republic Czech Republic Czech Republic	Red Sismologica Nacional de ColombiaSeccion de Sismologia, Vulcanologia y Exploracion GeofisicaSeismological Survey of the Republic of CroatiaServicio Sismologico Nacional CubanoCyprus Geological Survey DepartmentThe Institute of Physics of the Earth (IPEC)Geophysical Institute, Czech Academy of SciencesWBNET, Geophysical Institute, Czech Academy of Sciences
Colombia Costa Rica Croatia Cuba Cyprus Czech Republic Czech Republic Czech Republic Denmark	Red Sismologica Nacional de ColombiaSeccion de Sismologia, Vulcanologia y Exploracion GeofisicaSeismological Survey of the Republic of CroatiaServicio Sismologico Nacional CubanoCyprus Geological Survey DepartmentThe Institute of Physics of the Earth (IPEC)Geophysical Institute, Czech Academy of SciencesWBNET, Geophysical Institute, Czech Academy of SciencesGeological Survey of Denmark and Greenland
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Colombia Costa Rica Croatia Cuba Cyprus Czech Republic Czech Republic Czech Republic Denmark Dominican Rep. Dominican Rep. DPRK	Red Sismologica Nacional de ColombiaSeccion de Sismologia, Vulcanologia y Exploracion GeofisicaSeismological Survey of the Republic of CroatiaServicio Sismologico Nacional CubanoCyprus Geological Survey DepartmentThe Institute of Physics of the Earth (IPEC)Geophysical Institute, Czech Academy of SciencesWBNET, Geophysical Institute, Czech Academy of SciencesGeological Survey of Denmark and GreenlandObservatorio Sismologico Politecnico LoyolaUniversidad Autonoma de Santo DomingoKorea Earthquake Administration
Colombia Costa Rica Croatia Cuba Cyprus Czech Republic Czech Republic Czech Republic Denmark Dominican Rep. Dominican Rep. DPRK Ecuador	Red Sismologica Nacional de ColombiaSeccion de Sismologia, Vulcanologia y Exploracion GeofisicaSeismological Survey of the Republic of CroatiaServicio Sismologico Nacional CubanoCyprus Geological Survey DepartmentThe Institute of Physics of the Earth (IPEC)Geophysical Institute, Czech Academy of SciencesWBNET, Geophysical Institute, Czech Academy of SciencesGeological Survey of Denmark and GreenlandObservatorio Sismologico Politecnico LoyolaUniversidad Autonoma de Santo DomingoKorea Earthquake AdministrationServcio Nacional de Sismologia y Vulcanologia
Colombia Costa Rica Croatia Cuba Cyprus Czech Republic Czech Republic Czech Republic Denmark Dominican Rep. Dominican Rep. DPRK Ecuador Egypt	Red Sismologica Nacional de ColombiaSeccion de Sismologia, Vulcanologia y Exploracion GeofisicaSeismological Survey of the Republic of CroatiaServicio Sismologico Nacional CubanoCyprus Geological Survey DepartmentThe Institute of Physics of the Earth (IPEC)Geophysical Institute, Czech Academy of SciencesWBNET, Geophysical Institute, Czech Academy of SciencesGeological Survey of Denmark and GreenlandObservatorio Sismologico Politecnico LoyolaUniversidad Autonoma de Santo DomingoKorea Earthquake AdministrationServcio Nacional de Sismologia y VulcanologiaNational Research Institute of Astronomy and Geophysics
Colombia Costa Rica Croatia Cuba Cyprus Czech Republic Czech Republic Czech Republic Denmark Dominican Rep. Dominican Rep. DPRK Ecuador Egypt El Salvador	Red Sismologica Nacional de ColombiaSeccion de Sismologia, Vulcanologia y Exploracion GeofisicaSeismological Survey of the Republic of CroatiaServicio Sismologico Nacional CubanoCyprus Geological Survey DepartmentThe Institute of Physics of the Earth (IPEC)Geophysical Institute, Czech Academy of SciencesWBNET, Geophysical Institute, Czech Academy of SciencesGeological Survey of Denmark and GreenlandObservatorio Sismologico Politecnico LoyolaUniversidad Autonoma de Santo DomingoKorea Earthquake AdministrationServcio Nacional de Sismologia y VulcanologiaNational Research Institute of Astronomy and GeophysicsServicio Nacional de Estudios Territoriales
Colombia Costa Rica Croatia Cuba Cyprus Czech Republic Czech Republic Czech Republic Denmark Dominican Rep. Dominican Rep. DPRK Ecuador Egypt El Salvador Finland	Red Sismologica Nacional de ColombiaSeccion de Sismologia, Vulcanologia y Exploracion GeofisicaSeismological Survey of the Republic of CroatiaServicio Sismologico Nacional CubanoCyprus Geological Survey DepartmentThe Institute of Physics of the Earth (IPEC)Geophysical Institute, Czech Academy of SciencesWBNET, Geophysical Institute, Czech Academy of SciencesGeological Survey of Denmark and GreenlandObservatorio Sismologico Politecnico LoyolaUniversidad Autonoma de Santo DomingoKorea Earthquake AdministrationServcio Nacional de Sismologia y VulcanologiaNational Research Institute of Astronomy and GeophysicsServicio Nacional de Estudios TerritorialesInstitute of Seismology, University of Helsinki

France	Centre Sismologique Euro-Mediterranen (CSEM/EMSC)
France	Institut de Physique du Globe de Paris
France	Laboratoire de Detection et de Geophysique / CEA
France	EOST / RENaSS
French Polynesia	Laboratoire de Geophysique/CEA
Georgia	Institute of Earth Sciences/ National Seismic Monitoring Center
Germany	Alfred Wegener Institute for Polar and Marine Research
Germany	Bundesanstalt fur Geowissenschaften und Rohstoffe
Germany	Seismological Observatory Berggiesshubel, TU Bergakademie Freiberg
Germany	Geophysikalisches Observatorium Collm
Germany	Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences
Germany	Landeserdbebendienst Baden-Wurttemberg
Greece	National Observatory of Athens
Greece	Department of Geophysics, Aristotle University of Thessaloniki
Greece	University of Patras, Department of Geology
Guatemala	INSIVUMEH
Hong Kong, China	Hong Kong Observatory
Hungary	KRSZO, Geodetic and Geophysical Research Institute
Iceland	Icelandic Meteorological Office
India	National Geophysical Research Institute
India India	National Geophysical Research Institute National Centre for Seismology of the Ministry of Earth Sciences of India
India India Indonesia	National Geophysical Research InstituteNational Centre for Seismology of the Ministry of Earth Sciences of IndiaBadan Meteorologi, Klimatologi dan Geofisika
India India Indonesia Iran	National Geophysical Research InstituteNational Centre for Seismology of the Ministry of Earth Sciences of IndiaBadan Meteorologi, Klimatologi dan GeofisikaInternational Institute of Earthquake Engineering and Seismology
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India India Indonesia Iran Iran Iraq	National Geophysical Research InstituteNational Centre for Seismology of the Ministry of Earth Sciences of IndiaBadan Meteorologi, Klimatologi dan GeofisikaInternational Institute of Earthquake Engineering and SeismologyTehran UniversityIraqi Meteorological and Seismology Organisation
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India India Indonesia Iran Iran Iraq Ireland Israel Italy	National Geophysical Research InstituteNational Centre for Seismology of the Ministry of Earth Sciences of IndiaBadan Meteorologi, Klimatologi dan GeofisikaInternational Institute of Earthquake Engineering and SeismologyTehran UniversityIraqi Meteorological and Seismology OrganisationDublin Institute for Advanced StudiesThe Geophysical Institute of Israel / Geological Survey of IsraelMedNet Regional Centroid - Moment Tensors
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India India Indonesia Iran Iran Iraq Ireland Israel Italy Italy Italy Italy Italy Italy Italy	National Geophysical Research InstituteNational Centre for Seismology of the Ministry of Earth Sciences of IndiaBadan Meteorologi, Klimatologi dan GeofisikaInternational Institute of Earthquake Engineering and SeismologyTehran UniversityIraqi Meteorological and Seismology OrganisationDublin Institute for Advanced StudiesThe Geophysical Institute of Israel / Geological Survey of IsraelMedNet Regional Centroid - Moment TensorsIstituto Nazionale di Geofisica e VulcanologiaIstituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS)Laboratory of Research on Experimental and Computational SeismologySARA Electronic Instrument s.r.l.

Japan	Japan Meteorological Agency
Japan	National Research Institute for Earth Science and Disaster Prevention
Japan	National Institute of Polar Research
Jordan	Jordan Seismological Observatory
Kazakhstan	National Nuclear Center
Kazakhstan	Seismological Experimental Methodological Expedition
Kyrgyzstan	Kyrgyz Seismic Network
Kyrgyzstan	Institute of Seismology, Academy of Sciences of Kyrgyz Republic
Latvia	Latvian Seismic Network
Lebanon	National Council for Scientific Research
Lithuania	Geological Survey of Lithuania
Macao	Macao Meteorological and Geophysical Bureau
Mexico	Centro de Investigacion Científica y de Educacion Superior de Ensenada
Mexico	Instituto de Geofisica de la UNAM
Montenegro	Seismological Institute of Montenegro
Morocco	National Centre for Scientific and Technical Research
Namibia	The Geological Survey of Namibia
Nepal	National Seismological Centre
New Caledonia	IRD Centre de Noumea
New Zealand	Institute of Geological and Nuclear Sciences
Nicaragua	Central American Tsunami Advisory Center
North Macedonia	Seismological Observatory Skopje
Norway	University of Bergen
Norway	Stiftelsen NORSAR
Oman	Sultan Qaboos University
Panama	Universidad de Panama
Philippines	Philippine Institute of Volcanology and Seismology
Philippines	Manila Observatory
Poland	Institute of Geophysics, Polish Academy of Sciences
Poland	Private Observatory of Pawel Jacek Wiejacz, D.Sc.
Portugal	Instituto Dom Luiz, University of Lisbon
Portugal	Instituto Portuges do Mar e da Atmosfera, I.P.
Portugal	Sistema de Vigilancia Sismologica dos Azores
Republic of Belarus	Centre of Geophysical Monitoring of the National Academy of Sciences

Republic of Crimea	Inst. of Seismology and Geodynamics, Vernadsky Crimean Federal Uni
Republic of Korea	Korea Meteorological Administration
Romania	National Institute for Earth Physics
Russia	Altai-Sayan Seismological Centre, GS RAS
Russia	Baykal Regional Seismological Centre, GS RAS
Russia	Federal Centre for Integrated Arctic Research
Russia	Kola Regional Seismic Centre, GS RAS
Russia	Kamchatkan Branch, GS RAS
Russia	Mining Institute of the Ural Branch of the Russian Academy of Sciences
Russia	Geophysical Survey of Russian Academy of Sciences, Obninsk
Russia	North Eastern Regional Seismological Centre, GS RAS
Russia	Sakhalin Branch, GS RAS
Russia	Institute of Geology, Komi Science Centre, UB, RAS
Russia	Yakutiya Regional Seismological Centre, GS RAS
Russia	Institute of Dynamics of Geosphere, RAS
Saudi Arabia	Saudi Geological Survey
Serbia	Seismological Survey of Serbia
Slovakia	Geophysical Institute, Slovak Academy of Sciences
Slovenia	Slovenian Environment Agency
South Africa	Council for Geosciences
Spain	Instituto Geografico Nacional
Spain	Institut Cartografic i Geologic de Catalunya
Spain	Real Instituto y Observatorio de la Armada
Sweden	University of Uppsala
Switzerland	Swiss Seismological Service (SED)
Thailand	Thai Meteorological Department
Trinidad & Tobago	Seismic Research Centre
Tunisia	Institut National de la Meteorologie
Turkey	Disaster and Emergency Management Presidency (AFAD)
Turkey	Kandilli Observatory and Research Institute
UAE	Dubai Seismic Network
Ukraine	Main Centre for Special Monitoring
Ukraine	Subbotin Institute of Geophysics, National Academy of Sciences
United Kingdom	British Geological Survey

United Kingdom	International Seismological Centre (ISC)
U.S.A.	Experimental (GSETT-2) International Data Center
U.S.A.	The Global CMT Project
U.S.A.	IRIS Data Management Center
U.S.A.	National Earthquake Information Center, USGS
U.S.A.	Pacific Northwest Seismic Network
U.S.A.	Pacific Tsunami Warning Center
U.S.A.	Red Sismica de Puerto Rico
U.S.A.	Texas Seismological Network, University of Texas at Austin
U.S.A.	Scripps Institution of Oceanography, UC San Diego
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

The list below is a result of a special effort to put together a collection of scientific papers published during 2022 that used ISC data. The list is by no means exhaustive. The ISC has become such a familiar name that many researchers sadly fail to reference their use of the ISC data.



Figure 34. Annual number of ISC data citations in scientific publications

To track publications that use one or more of the ISC dataset and services, we set up automatic alerts with Google Scholar for scientific papers that refer to ISC. The Google Scholar alerts return matches with different ways to refer to the ISC as normally done by authors, such as "International Seismological Centre", "International Seismological Center", "ISC-GEM", "ISC-EHB" and "EHB" + "seismic". No doubt many more references can be found by using different search phrases. Below are the bibliographic references to the 334 works in year 2022 as gathered by Google Scholar. The references to articles published in journals are listed first, followed by the

references to other types of publications (e.g., chapters in books, reports, thesis, preprints). The references are sorted by journal name. Most of the references below belong to journal articles.

Annual number of citations have been growing over the last few years since this tracking procedure was set up (Fig.34).

Placinta, A.-O., Borleanu, F., Moldovan, I.-A. and Coman, A. (2022). Correlation between Seismic Waves Velocity Changes and the Occurrence of Moderate Earthquakes at the Bending of the Eastern Carpathians (Vrancea), Acoustics, 4, 4, 934-947, DOI: <u>10.3390/acoustics4040057</u>

Xing, L., Li, Q., Meng, Q., Liu, H., Wei, J., Lv, B. and Zhou, H. (2022). Enlightenment of the Mariana Fore Arc Sedimentary Basin Evolution to the Subduction Process Study, Acta Geol. Sin., 96, 1, 71-80, DOI: <u>10.1111/1755-6724.14860</u>

Rahimi, M., Zamani, A. and Ghotbi, A.R. (2022). The study of seismicity of Alborz (Northern Iran) and Zagros (Southern Iran) regions by using time series analysis, Acta Geophys., 70, 1, 27-37, DOI: <u>10.1007/s11600-021-00701-7</u>

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