Summary of the Bulletin of the International Seismological Centre

2016

July – December

Volume 53 Issue II

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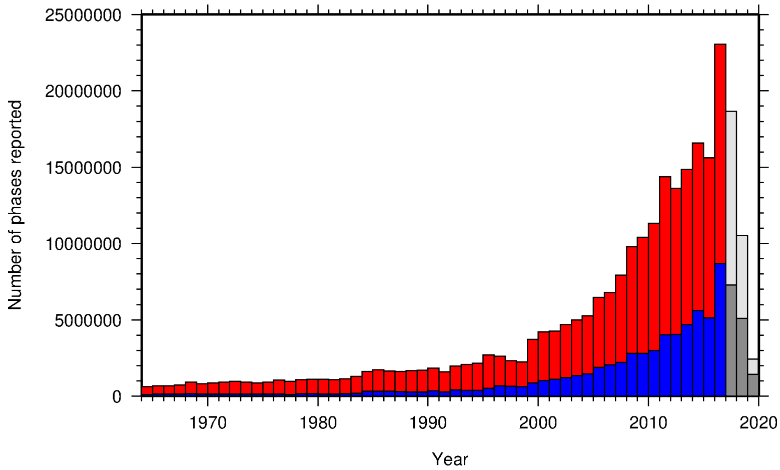
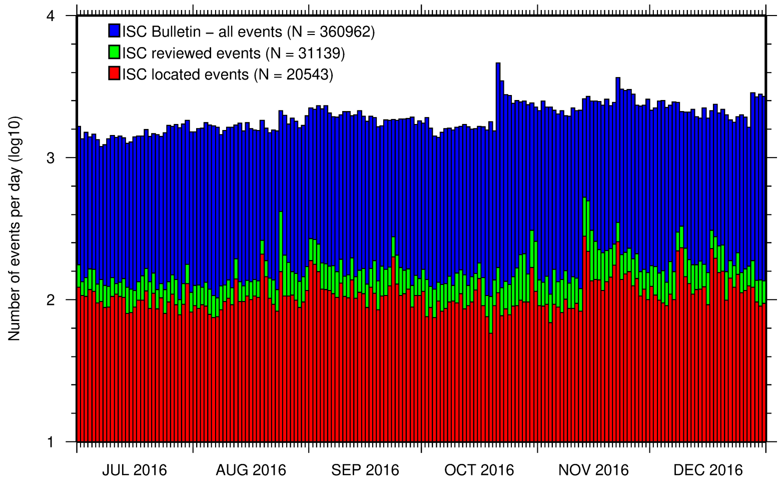
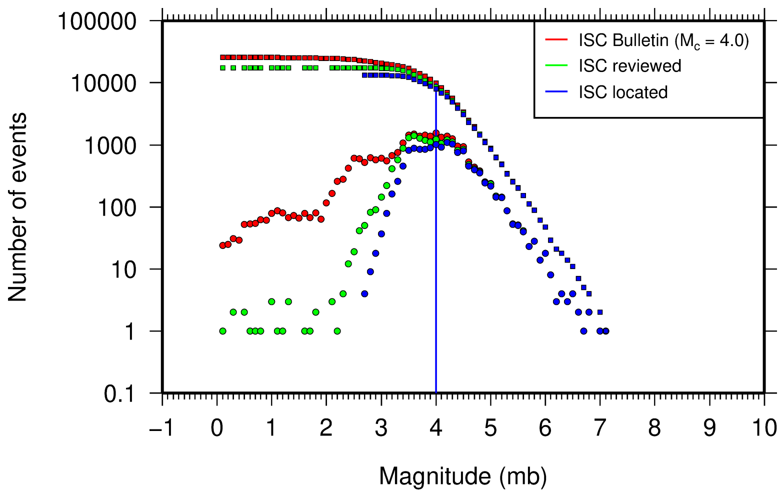


The number of phases (red) and number of amplitudes (blue) collected by the ISC for events each year since 1964. The data in grey covers the current period where data are still being collected before the ISC review takes place and are accurate at the time of publication. See Section 8.3.



The number of events within the Bulletin for the current summary period. The vertical scale is logarithmic. See Section 9.1.



Frequency and cumulative frequency magnitude distribution for all events in the ISC Bulletin, ISC reviewed events and events located by the ISC. The magnitude of completeness (M_C) is shown for the ISC Bulletin. Note: only events with values of m_b are represented in the figure. See Section 9.4.

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2016

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Volume 53 Issue II

Produced and edited by:
Kathrin Lieser, James Harris and Dmitry Storchak

Published by
International Seismological Centre

ISC Data Products
http://www.isc.ac.uk/products/

ISC Bulletin:
    http://www.isc.ac.uk/iscbulletin/search

ISC Bulletin and Catalogue monthly files, to the last reviewed month in FFB or ISF1 format:
    ftp://www.isc.ac.uk/pub/[isf|ffb]/bulletin/*yyyy*/*yyyymm*.gz
    ftp://www.isc.ac.uk/pub/[isf|ffb]/catalogue/*yyyy*/*yyyymm*.gz

Datafiles for the ISC Bulletin before the Rebuild project:
    ftp://www.isc.ac.uk/pub/prerebuild/[isf|ffb]/bulletin/*yyyy*/*yyyymm*.gz
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ISC-EHB Dataset:
    http://www.isc.ac.uk/isc-ehb/search/

IASPEI Reference Event (GT) List:
    http://www.isc.ac.uk/gtevents/search/

ISC-GEM Global Instrumental Earthquake Catalogue:
    http://http://www.isc.ac.uk/iscgem/download.php

ISC Event Bibliography:
    http://www.isc.ac.uk/event_bibliography/bibsearch.php

International Seismograph Station Registry:
    http://www.isc.ac.uk/registries/search/

Seismological Dataset Repository:
    http://www.isc.ac.uk/dataset_repository/

International Seismological Contacts:
    http://www.isc.ac.uk/projects/seismocontacts/

International Seismological Centre
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1

Preface

Dear Colleague,

This is the second and concluding 2016 issue of the Summary of the ISC Bulletin that remains the most fundamental reason for continued operations at the ISC. This issue covers seismic events that occurred during the period from July to December 2016.

This publication contains a description of the ISC data available on the included DVD-ROM and from the ISC website. It contains information on the ISC, its Members, Sponsors and Data Providers. It offers analysis of the data contributed to the ISC by many seismological agencies worldwide as well as analysis of the data in the ISC Bulletin itself. This somewhat smaller issue misses some of the standard information on routine procedures usually published in the first issue of each year.

We continue publishing invited articles describing the history, current status and operational procedures at those networks that contribute seismic bulletin data to the ISC. This time it is the turn for the Servicio Sismológico Nacional in Mexico and the Turkish National Seismic Network.

We hope that you find this publication useful in your work. If your home-institution or company is unable, for one reason or another, to support the long-term international operations of the ISC in full by becoming a Member, then, please, consider subscribing to this publication by contacting us at admin@isc.ac.uk.

With kind regards to our Data Contributors, Members, Sponsors and users,

Dr Dmitry A. Storchak
Director
International Seismological Centre (ISC)

2

The International Seismological Centre

2.1 The ISC Mandate

The International Seismological Centre (ISC) was set up in 1964 with the assistance of UNESCO as a successor to the International Seismological Summary (ISS) to carry forward the pioneering work of Prof. John Milne, Sir Harold Jeffreys and other British scientists in collecting, archiving and processing seismic station and network bulletins and preparing and distributing the definitive summary of world seismicity.

Under the umbrella of the International Association of Seismology and Physics of the Earth Interior (IASPEI/IUGG), the ISC has played an important role in setting international standards such as the International Seismic Bulletin Format (ISF), the IASPEI Standard Seismic Phase List (SSPL) and both the old and New IASPEI Manual of the Seismological Observatory Practice (NMSOP-2) (www.iaspei.org/projects/NMSOP.html).

The ISC has contributed to scientific research and prominent scientists such as John Hodgson, Eugine Herrin, Hal Thirlaway, Jack Oliver, Anton Hales, Ola Dahlman, Shigeji Suehiro, Nadia Kondorskaya, Vit Karnik, Stephan Müller, David Denham, Bob Engdahl, Adam Dziewonski, John Woodhouse and Guy Masters all considered it an important duty to serve on the ISC Executive Committee and the Governing Council.

The current mission of the ISC is to maintain:

- the ISC **Bulletin** – the longest continuous definitive summary of World seismicity (collaborating with 130 seismic networks and data centres around the world). (www.isc.ac.uk/iscbulletin/)
- the International Seismographic Station Registry (**IR**, jointly with the World Data Center for Seismology, Denver). (www.isc.ac.uk/registries/)
- the IASPEI Reference Event List (Ground Truth, **GT**, jointly with IASPEI). (www.isc.ac.uk/gtevents/)

These are fundamentally important tasks. Bulletin data produced, archived and distributed by the ISC for almost 50 years are the definitive source of such information and are used by thousands of seismologists worldwide for seismic hazard estimation, for tectonic studies and for regional and global imaging of the Earth's structure. Key information in global tomographic imaging is derived from the analysis of ISC data. The ISC Bulletin served as a major source of data for such well known products as the ak135 global 1-D velocity model and the EHB (*Engdahl et al.*, 1998) and Centennial (*Engdahl and Villaseñor*, 2002) catalogues. It presents an important quality-control benchmark for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO). Hypocentre parameters from the ISC Bulletin are used by the Data Management Center of the Incorporated Research Institutions for Seismology (IRIS DMC) to serve event-oriented user-requests for waveform data. The ISC-GEM Bulletin is a cornerstone of the ISC-GEM Global Instrumental Reference Earthquake Catalogue for Global Earthquake risk Model (GEM).

The ISC Bulletin contains over 8 million seismic events: earthquakes, chemical and nuclear explosions, mine blasts and mining induced events. Almost 2 million of them are regional and teleseismically recorded events that have been reviewed by the ISC analysts. The ISC Bulletin contains approximately 255 million individual seismic station readings of arrival times, amplitudes, periods, SNR, slowness and azimuth, reported by approximately 19,000 seismic stations currently registered in the IR. Over 9,000 stations have contributed to the ISC Bulletin in recent years. This number includes the numerous sites of the USArray. The IASPEI GT List currently contains 10187 events for which latitude, longitude and depth of origin are known with high confidence (to 5 km or better) and seismic signals were recorded at regional and/or teleseismic distances.

2.2 Brief History of the ISC

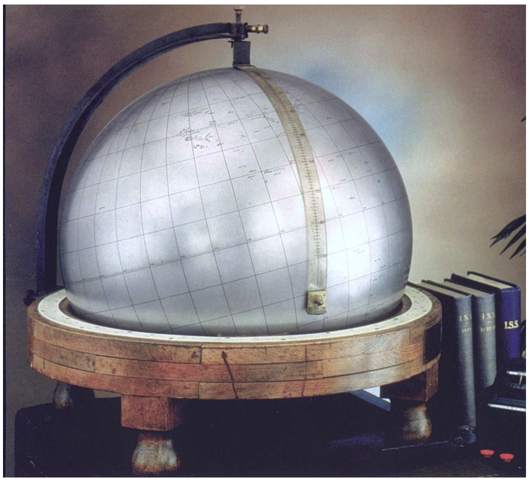


Figure 2.1: *The steel globe bearing positions of early seismic stations was used for locating positions of earthquakes for the International Seismological Summaries.*

Earthquake effects have been noted and documented from the earliest times, but it is only since the development of earthquake recording instruments in the latter half of the 19th century that a proper study of their occurrence has been possible. After the first teleseismic observation of an earthquake in 1889, the need for international exchange of readings was recognised in 1895 by Prof. John Milne and by Ernst von Rebeur Paschwitz together with Georg Gerland, resulting in the publication of the first international seismic bulletins. Milne's "Shide Circulars" were issued under the auspices of the Seismological Committee of the British Association for the Advancement of Science (BAAS), while co-workers of Gerland at the Central Bureau of the International Association of Seismology worked independently in Strasbourg (BCIS).

Following Milne's death in 1913, Seismological Bulletins of the BAAS were continued under Prof. H.H. Turner, later based at Oxford University. Upon formal post-war dissolution of the International Association of Seismology in 1922 the newly founded Seismological Section of the International Union of Geodesy and Geophysics (IUGG) set up the International Seismological Summary (ISS) to continue at Oxford under Turner, to produce the definitive global catalogues from the 1918 data-year onwards, under the auspices of IUGG and with the support of the BAAS.

ISS production, led by several professors at Oxford University, and Sir Harold Jeffreys at Cambridge

University, continued until it was superseded by the ISC Bulletin, after the ISC was formed in Edinburgh in 1964 with Dr P.L. Willmore as its first director.

During the period 1964 to 1970, with the help of UNESCO and other international scientific bodies, the ISC was reconstituted as an international non-governmental body, funded by interested institutions from various countries. Initially there were supporting members from seven countries, now there are almost 60, and member institutions include national academies, research foundations, government departments and research institutes, national observatories and universities. Each member, contributing a minimum unit of subscription or more, appoints a representative to the ISC's Governing Council, which meets every two years to decide the ISC's policy and operational programme. Representatives from the International Association of Seismology and Physics of the Earth's Interior also attend these meetings. The Governing Council appoints the Director and a small Executive Committee to oversee the ISC's operations.

Figure 2.2: *ISC building in Thatcham, Berkshire, UK.*

In 1975, the ISC moved to Newbury in southern England to make use of better computing facilities there. The ISC subsequently acquired its own computer and in 1986 moved to its own building at Pipers Lane, Thatcham, near Newbury. The internal layout of the new premises was designed for the ISC and includes not only office space but provision for the storage of extensive stocks of ISS and ISC publications and a library of seismological observatory bulletins, journals and books collected over many tens of years.

In 1997 the first set of the ISC Bulletin CD-ROMs was produced (not counting an earlier effort at USGS). The first ISC website appeared in 1998 and the first ISC database was put in day-to-day operations from 2001.

Throughout 2009-2011 a major internal reconstruction of the ISC building was undertaken to allow for more members of staff working in mainstream ISC operations as well as major development projects such as the CTBTO Link, ISC-GEM Catalogue and the ISC Bulletin Rebuild.

2.3 Former Directors of the ISC and its U.K. Predecessors

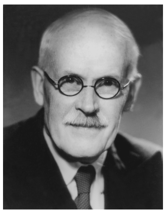
John Milne
Publisher of the Shide Cicular Reports on Earthquakes
1899-1913

Herbert Hall Turner

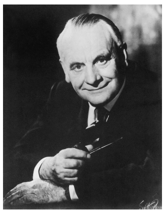
Seismological Bulletins of the BAAS

1913-1922
Director of the ISS
1922-1930

Harry Hemley Plaskett
Director of the ISS
1931-1946



Harold Jeffreys
Director of the ISS
1946-1957



Robert Stoneley
Director of the ISS
1957-1963

P.L. (Pat) Willmore
Director of the ISS
1963-1970
Director of the ISC
1964-1970

Edouard P. Arnold
Director of the ISC
1970-1977

Anthony A. Hughes
Director of the ISC
1977-1997

Raymond J. Willemann
Director of the ISC
1998-2003

Avi Shapira
Director of the ISC
2004-2007

2.4 Member Institutions of the ISC

Article IV(a-b) of the ISC Working Statutes stipulates that any national academy, agency, scientific institution or other non-profit organisation may become a Member of the ISC on payment to the ISC of a sum equal to at least one unit of subscription and the nomination of a voting representative to serve on the ISC's governing body. Membership shall be effective for one year from the date of receipt at the ISC of the annual contribution of the Member and is thereafter renewable for periods of one year.

The ISC is currently supported with funding from its 68 Member Institutions including a four-year Grant Award EAR-1417970 from the US National Science Foundation.

Figures 2.3 and 2.4 show major sectors to which the ISC Member Institutions belong and proportional financial contributions that each of these sectors make towards the ISC's annual budget.

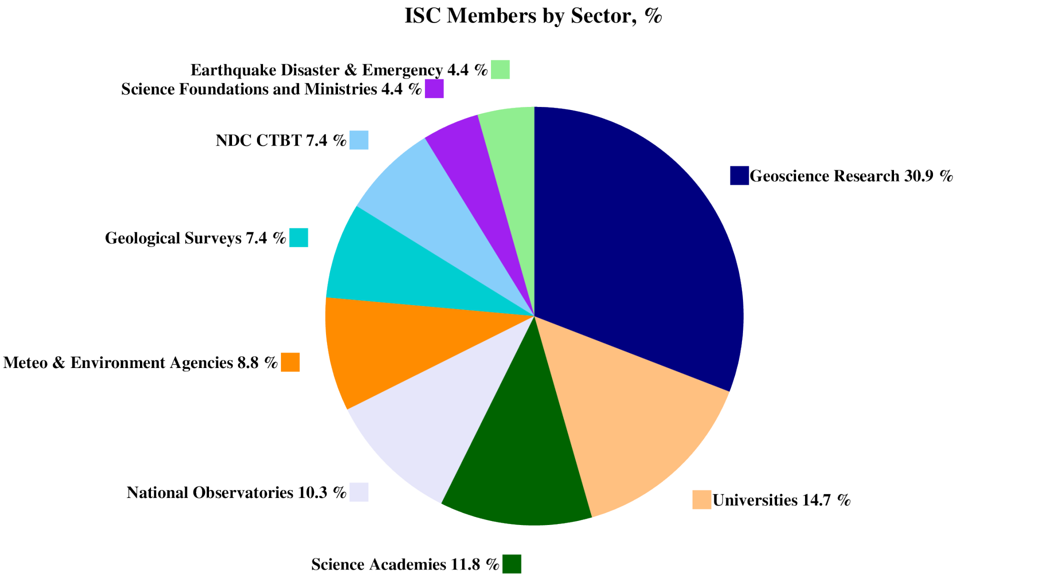


Figure 2.3: *Distribution of the ISC Member Institutions by sector in year 2013 as a percentage of total number of Members.*

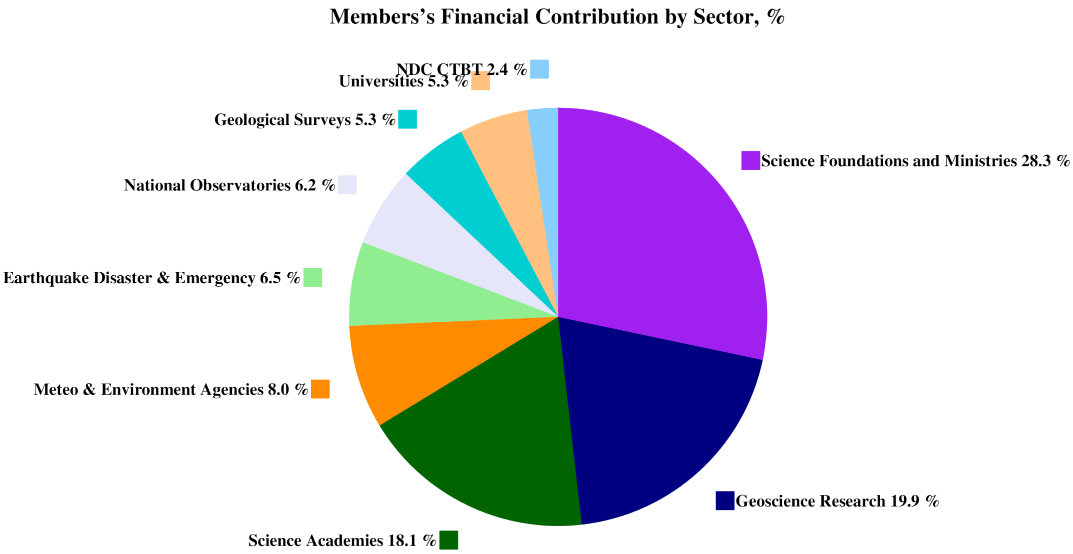


Figure 2.4: *Distribution of Member's financial contributions to the ISC by sector in year 2013 as a percentage of total annual Member contributions.*

There follows a list of all current Member Institutions with a category (1 through 9) assigned according to the ISC Working Statutes. Each category relates to the number of membership units contributed.

CRAAG	Centre de Recherche en Astronomie, Astrophysique et Géophysique (CRAAG) Algeria www.craag.dz Category: 1	INPRES	Instituto Nacional de Prevención Sísmica (INPRES) Argentina www.inpres.gov.ar Category: 1	Australian Government Geoscience Australia	Geoscience Australia Australia www.ga.gov.au Category: 4

Bundesministerium für Wissenschaft, Forschung und Wirtschaft (BMWFW)
Austria
www.bmbwk.gv.at
Category: 2

Centre of Geophysical Monitoring (CGM) of the National Academy of Sciences of Belarus
Belarus
www.cgm.org.by
Category: 1

Belgian Science Policy Office (BELSPO)
Belgium

Category: 1

Universidade de São Paulo, Centro de Sismologia
Brazil
www.sismo.iag.usp.br
Category: 1

Seismological Observatory, Institute of Geosciences, University of Brasilia
Brazil
www.obsis.unb.br
Category: 1

National Institute of Geophysics, Geodesy and Geography (NIGGG), Bulgarian Academy of Sciences
Bulgaria
www.niggg.bas.bg
Category: 1

The Geological Survey of Canada
Canada
gsc.nrcan.gc.ca
Category: 4

Centro Sismologico Nacional, Universidad de Chile
Chile
ingenieria.uchile.cl
Category: 1

China Earthquake Administration
China
www.cea.gov.cn
Category: 4

Institute of Earth Sciences, Academia Sinica
Chinese Taipei
www.earth.sinica.edu.tw
Category: 1

Geological Survey Department
Cyprus
www.moa.gov.cy
Category: 1

Insitute of Geophysics, Academy of Sciences of the Czech Republic
Czech Republic
www.avcr.cz
Category: 1

Geological Survey of Denmark and Greenland (GEUS)
Denmark
www.geus.dk
Category: 2

National Research Institute for Astronomy and Geophysics (NRIAG), Cairo
Egypt
www.nriag.sci.eg
Category: 1

The University of Helsinki
Finland
www.helsinki.fi
Category: 2

Institute National des Sciences de l'Univers
France
www.insu.cnrs.fr
Category: 4

Laboratoire de Détection et de Géophysique/CEA
France
www-dase.cea.fr
Category: 2

GeoForschungsZentrum Potsdam
Germany
www.gfz-potsdam.de
Category: 2

Bundesanstalt für Geowissenschaften und Rohstoffe
Germany
www.bgr.bund.de
Category: 4

The Seismological Institute, National Observatory of Athens
Greece
www.noa.gr
Category: 1

The Hungarian Academy of Sciences
Hungary
www.mta.hu
Category: 1

The Icelandic Meteorological Office
Iceland
www.vedur.is
Category: 1

National Centre for Seismology, Ministry of Earth Sciences of India
India
www.moes.gov.in
Category: 4

Iraqi Meteorological Organization and Seismology
Iraq
www.imos-tm.com
Category: 1

Dublin Institute for Advanced Studies
Ireland
www.dias.ie
Category: 1

The Geophysical Institute of Israel
Israel
www.gii.co.il
Category: 1

Soreq Nuclear Research Centre (SNRC)
Israel
www.soreq.gov.il
Category: 1

Istituto Nazionale di Geofisica e Vulcanologia
Italy
www.ingv.it
Category: 3

Istituto Nazionale di Oceanografia e di Geofisica Sperimentale
Italy
www.ogs.trieste.it
Category: 1

University of the West Indies at Mona
Jamaica
www.mona.uwi.edu
Category: 1

Earthquake Research Institute, University of Tokyo
Japan
www.eri.u-tokyo.ac.jp
Category: 3

Japan Agency for Marine-Earth Science and Technology (JAMSTEC)
Japan
www.jamstec.go.jp
Category: 2

National Institute of Polar Research (NIPR)
Japan
www.nipr.ac.jp
Category: 1

The Japan Meteorological Agency (JMA)
Japan
www.jma.go.jp
Category: 5

Royal Scientific Society
Jordan
www.rss.jo
Category: 1

Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE)
Mexico
resnom.cicese.mx
Category: 1

Institute of Geophysics, National University of Mexico
Mexico
www.igeofcu.unam.mx
Category: 1

The Royal Netherlands Meteorological Institute (KNMI)
Netherlands
www.knmi.nl
Category: 2

GNS Science
New Zealand
www.gns.cri.nz
Category: 3

Stiftelsen NORSAR
Norway
www.norsar.no
Category: 2

The University of Bergen
Norway
www.uib.no
Category: 2

Institute of Geophysics, Polish Academy of Sciences
Poland
www.igf.edu.pl
Category: 1

Instituto Português do Mar e da Atmosfera
Portugal
www.ipma.pt
Category: 2

Red Sísmica de Puerto Rico
Puerto Rico
redsismica.uprm.edu
Category: 1

Korean Meterological Administration
Republic of Korea
www.kma.go.kr
Category: 1

National Institute for Earth Physics
Romania
www.infp.ro
Category: 1

Russian Academy of Sciences
Russia
www.ras.ru
Category: 5

Earth Observatory of Singapore (EOS), an autonomous Institute of Nanyang Technological University
Singapore
www.earthobservatory.sg
Category: 1

Environmental Agency of Slovenia
Slovenia
www.arso.gov.si
Category: 1

Council for Geoscience
South Africa
www.geoscience.org.za
Category: 1

Institut Cartogràfic i Geològic de Catalunya (ICGC)
Spain
www.icgc.cat
Category: 1

Institute of Earth Sciences Jaume Almera
Spain
www.ictja.csic.es
Category: 1

Uppsala Universitet
Sweden
www.uu.se
Category: 2

National Defence Research Establishment (FOI)
Sweden
www.foi.se
Category: 1

The Swiss Academy of Sciences
Switzerland
www.scnat.ch
Category: 2

The Seismic Research Centre, University of the West Indies at St. Augustine
Trinidad and Tobago
www.uwiseismic.com
Category: 1

Disaster and Emergency Management Authority (AFAD)
Turkey
www.deprem.gov.tr
Category: 2

Kandilli Observatory and Earthquake Research Institute
Turkey
www.koeri.boun.edu.tr
Category: 1

British Geological Survey
United Kingdom
www.bgs.ac.uk
Category: 2

The Royal Society
United Kingdom
www.royalsociety.org
Category: 6

AWE Blacknest
United Kingdom
www.blacknest.gov.uk
Category: 1

Texas Seismological Network (TexNet), Bureau of Economic Geology, J.A. & K.G. Jackson School of Geosciences, University of Texas at Austin
U.S.A.
www.beg.utexas.edu
Category: 1

National Earthquake Information Center, U.S. Geological Survey
U.S.A.
www.neic.usgs.gov
Category: 1

The National Science Foundation of the United States. (Grant No. EAR-1811737)
U.S.A.
www.nsf.gov
Category: 9

Incorporated Research Institutions for Seismology
U.S.A.
www.iris.edu
Category: 1

In addition the ISC is currently in receipt of grants from the International Data Centre (IDC) of the Preparatory Commission of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO), FM Global, Lighthill risk Network, WRN, USGS (Award G15AC00202) and BGR.

2.5 Sponsoring Organisations

Article IV(c) of the ISC Working Statutes stipulates any commercial organisation with an interest in the objectives and/or output of the ISC may become an Associate Member of the ISC on payment of an Associate membership fee, but without entitlement to representation with a vote on the ISC's governing body.

MS&AD InterRisk Research & Consulting http://www.irric.co.jp/en/corporate/

MS&AD InterRisk Research & Consulting, Inc. is responsible for the core of risk-related service businesses in the MS&AD group. We provide services which meet various expectations of the clients, including consulting, research and investigation, seminars and publications for risk management in addition to the think-tank functions.

REF TEK A DIVISION OF TRIMBLE www.reftek.com

REF TEK designs and manufactures application specific, high-performance, battery-operated, field-portable geophysical data acquisition devices for the global market. With over 35 years of experience, REF TEK provides customers with complete turnkey solutions that include high resolution recorders, broadband sensors, state-of-the-art communications (V-SAT, GPRS, etc), installation, training, and continued customer support. Over 7,000 REF TEK instruments are currently being used globally for multiple applications. From portable earthquake monitoring to telemetry earthquake monitoring, earthquake aftershock recording to structural monitoring and more, REF TEK equipment is suitable for a wide variety of application needs.

GeoSIG swiss made to measure http://www.geosig.com/

GeoSIG provides earthquake, seismic, structural, dynamic and static monitoring and measuring solutions As an ISO Certified company, GeoSIG is a world leader in design and manufacture of a diverse range of high quality, precision instruments for vibration and earthquake monitoring. GeoSIG instruments are at work today in more than 100 countries around the world with well-known projects such as the NetQuakes installation with USGS and Oresund Bridge in Denmark. GeoSIG offers off-the-shelf solutions as well as highly customised solutions to fulfil the challenging requirements in many vertical markets including the following:

- Earthquake Early Warning and Rapid Response (EEWRR)
- Seismic and Earthquake Monitoring and Measuring
- Industrial Facility Seismic Monitoring and Shutdown
- Structural Analysis and Ambient Vibration Testing
- Induced Vibration Monitoring
- Research and Scientific Applications

http://www.guralp.com/

Güralp has been developing revolutionary force-feedback broadband seismic instrumentation for more than thirty years. Our sensors record seismic signals of all kinds, from teleseismic events occurring on the other side of the planet, to microseisms induced by unconventional hydrocarbon extraction. Our sophisticated digitisers record these signals with the highest resolution and accurate timing.

We supply individual instruments or complete seismic systems. Our services include field support such as installation and maintenance, to complete network and data management.

We design our instruments to meet increasingly complex requirements for deployment in the most challenging circumstances. As a result, you will find Güralp instruments gathering seismic data in the harshest of environments, from the Antarctic ice sheet; to boreholes 100s of metres deep; to the world's most active volcanoes and deepest ocean trenches.

SEISMOLOGY RESEARCH CENTRE http://src.com.au/

The Seismology Research Centre is an Australian earthquake observatory that began developing their own seismic recorders and data processing software in the late 1970s when digital recorders were uncommon. The Gecko is the SRC's 7th generation of seismic recorder, now available with a variety of integrated sensors to meet every monitoring requirement, including:

- Strong Motion Accelerographs
- 2Hz and 4.5Hz Blast Vibration Monitors
- Short Period 1Hz Seismographs
- Broadband 200s-1500Hz Optical Seismographs

Visit src.com.au/downloads/waves to grab a free copy of the SRC's MiniSEED waveform viewing and analysis software application, Waves.

2.6 Data Contributing Agencies

In addition to its Members and Sponsors, the ISC owes its existence and successful long-term operations to its 147 seismic bulletin data contributors. These include government agencies responsible for national seismic networks, geoscience research institutions, geological surveys, meteorological agencies, universities, national data centres for monitoring the CTBT and individual observatories. There would be no ISC Bulletin available without the regular stream of data that are unselfishly and generously contributed to the ISC on a free basis.

East African Network
EAF

The Institute of Seismology, Academy of Sciences of Albania
Albania
TIR

Centre de Recherche en Astronomie, Astrophysique et Géophysique
Algeria
CRAAG

Instituto Nacional de Prevención Sísmica
Argentina
SJA

Universidad Nacional de La Plata
Argentina
LPA

National Survey of Seismic Protection
Armenia
NSSP

Curtin University
Australia
CUPWA

Geoscience Australia
Australia
AUST

Zentralanstalt für Meteorologie und Geodynamik (ZAMG)
Austria
VIE

International Data Centre, CTBTO
Austria
IDC

Republican Seismic Survey Center of Azerbaijan National Academy of Sciences
Azerbaijan
AZER

Royal Observatory of Belgium
Belgium
UCC

Observatorio San Calixto
Bolivia
SCB

Republic Hydrometeorological Service, Seismological Observatory, Banja Luka
Bosnia and Herzegovina
RHSSO

Instituto Astronomico e Geofísico
Brazil
VAO

Geophysical Institute, Bulgarian Academy of Sciences
Bulgaria
SOF

Seismological Observatory of Mount Cameroon
Cameroon
SOMC

Canadian Hazards Information Service, Natural Resources Canada
Canada
OTT

Centro Sismológico Nacional, Universidad de Chile
Chile
GUC

China Earthquake Networks Center
China
BJI

Institute of Earth Sciences, Academia Sinica
Chinese Taipei
ASIES

CWB
Chinese Taipei
TAP

Red Sismológica Nacional de Colombia
Colombia
RSNC

Sección de Sismología, Vulcanología y Exploración Geofísica
Costa Rica
UCR

Seismological Survey of the Republic of Croatia
Croatia
ZAG

Servicio Sismológico Nacional Cubano
Cuba
SSNC

Cyprus Geological Survey Department
Cyprus
NIC

Institute of Geophysics, Czech Academy of Sciences
Czech Republic
WBNET

Geophysical Institute, Academy of Sciences of the Czech Republic
Czech Republic
PRU

The Institute of Physics of the Earth (IPEC)
Czech Republic
IPEC

Korea Earthquake Administration
Democratic People's Republic of Korea
KEA

Geological Survey of Denmark and Greenland
Denmark
DNK

Observatorio Sismologico Politecnico Loyola
Dominican Republic
OSPL

Servicio Nacional de Sismología y Vulcanología
Ecuador
IGQ

National Research Institute of Astronomy and Geophysics
Egypt
HLW

Servicio Nacional de Estudios Territoriales
El Salvador
SNET

University of Addis Ababa
Ethiopia
AAE

Seismological Observatory Skopje
FYR Macedonia
SKO

Institute of Seismology, University of Helsinki
Finland
HEL

EOST / RéNaSS
France
STR

Laboratoire de Détection et de Géophysique/CEA
France
LDG

Laboratoire de Géophysique/CEA
French Polynesia
PPT

Institute of Earth Sciences/ National Seismic Monitoring Center
Georgia
TIF

Alfred Wegener Institute for Polar and Marine Research
Germany
AWI

Geophysikalisches Observatorium Collm
Germany
CLL

Seismological Observatory Berggießhübel, TU Bergakademie Freiberg
Germany
BRG

Bundesanstalt für Geowissenschaften und Rohstoffe
Germany
BGR

Department of Geophysics, Aristotle University of Thessaloniki
Greece
THE

National Observatory of Athens
Greece
ATH

University of Patras, Department of Geology
Greece
UPSL

INSIVUMEH
Guatemala
GCG

Hong Kong Observatory
Hong Kong
HKC

Geodetic and Geophysical Reasearch Institute, Hungarian Academy of Sciences
Hungary
KRSZO

Geodetic and Geophysical Research Institute
Hungary
BUD

Icelandic Meteorological Office
Iceland
REY

National Centre for Seismology of the Ministry of Earth Sciences of India
India
NDI

National Geophysical Research Institute
India
HYB

Badan Meteorologi, Klimatologi dan Geofisika
Indonesia
DJA

International Institute of Earthquake Engineering and Seismology (IIEES)
Iran
THR

Tehran University
Iran
TEH

Iraqi Meteorological and Seismology Organisation
Iraq
ISN

The Geophysical Institute of Israel
Israel
GII

Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS)
Italy
TRI

Laboratory of Research on Experimental and Computational Seimology
Italy
RISSC

Istituto Nazionale di Geofisica e Vulcanologia
Italy
ROM

MedNet Regional Centroid - Moment Tensors
Italy
MED_RCMT

Dipartimento per lo Studio del Territorio e delle sue Risorse (RSNI)
Italy
GEN

Station Géophysique de Lamto
Ivory Coast
LIC

Jamaica Seismic Network
Jamaica
JSN

National Research Institute for Earth Science and Disaster Prevention
Japan
NIED

National Institute of Polar Research
Japan
SYO

Japan Meteorological Agency
Japan
JMA

Jordan Seismological Observatory
Jordan
JSO

National Nuclear Center
Kazakhstan
NNC

Seismological Experimental Methodological Expedition
Kazakhstan
SOME

Kyrgyz Seismic Network
Kyrgyzstan
KNET

Institute of Seismology, Academy of Sciences of Kyrgyz Republic
Kyrgyzstan
KRNET

Latvian Seismic Network
Latvia
LVSN

National Council for Scientific Research
Lebanon
GRAL

Geological Survey of Lithuania
Lithuania
LIT

Macao Meteorological and Geophysical Bureau
Macao, China
MCO

Antananarivo
Madagascar
TAN

Geological Survey Department Malawi
Malawi
GSDM

Malaysian Meteorological Service
Malaysia
KLM

Centro de Investigación Científica y de Educación Superior de Ensenada
Mexico
ECX

Instituto de Geofísica de la UNAM
Mexico
MEX

Institute of Geophysics and Geology
Moldova
MOLD

Seismological Institute of Montenegro
Montenegro
PDG

Centre National de Recherche
Morocco
CNRM

The Geological Survey of Namibia
Namibia
NAM

National Seismological Centre, Nepal
Nepal
DMN

IRD Centre de Nouméa
New Caledonia
NOU

Institute of Geological and Nuclear Sciences
New Zealand
WEL

Instituto Nicaraguense de Estudios Territoriales - INETER
Nicaragua
INET

Stiftelsen NORSAR
Norway
NAO

University of Bergen
Norway
BER

Sultan Qaboos University
Oman
OMAN

Micro Seismic Studies Programme, PINSTECH
Pakistan
MSSP

Universidad de Panama
Panama
UPA

Philippine Institute of Volcanology and Seismology
Philippines
MAN

Institute of Geophysics, Polish Academy of Sciences
Poland
WAR

Instituto Português do Mar e da Atmosfera, I.P.
Portugal
INMG

Instituto Dom Luiz, University of Lisbon
Portugal
IGIL

Sistema de Vigilância Sismológica dos Açores
Portugal
SVSA

Centre of Geophysical Monitoring of the National Academy of Sciences of Belarus
Republic of Belarus
BELR

Inst. of Seismology and Geodynamics, V.I. Vernadsky Crimean Federal University
Republic of Crimea
CFUSG

Korea Meteorological Administration
Republic of Korea
KMA

National Institute for Earth Physics
Romania
BUC

Yakutiya Regional Seismological Center, GS SB RAS
Russia
YARS

Mining Institute of the Ural Branch of the Russian Academy of Sciences
Russia
MIRAS

Geophysical Survey of Russian Academy of Sciences
Russia
MOS

Altai-Sayan Seismological Centre, GS SB RAS
Russia
ASRS

Kola Regional Seismic Centre, GS RAS
Russia
KOLA

Baykal Regional Seismological Centre, GS SB RAS
Russia
BYKL

Institute of Environmental Problems of the North, Russian Academy of Sciences
Russia
IEPN

Kamchatkan Experimental and Methodical Seismological Department, GS RAS
Russia
KRSC

North Eastern Regional Seismological Centre, GS RAS
Russia
NERS

Sakhalin Experimental and Methodological Seismological Expedition, GS RAS
Russia
SKHL

Saudi Geological Survey
Saudi Arabia
SGS

Seismological Survey of Serbia
Serbia
BEO

Geophysical Institute, Slovak Academy of Sciences
Slovakia
BRA

Slovenian Environment Agency
Slovenia
LJU

Council for Geoscience South Africa
PRE

Instituto Geográfico Nacional
Spain
MDD

Real Instituto y Observatorio de la Armada
Spain
SFS

Institut Cartogràfic i Geològic de Catalunya
Spain
MRB

Sudan Seismic Network
Sudan
SSN

University of Uppsala
Sweden
UPP

Swiss Seismological Service (SED)
Switzerland
ZUR

The Seismic Research Centre
Trinidad and Tobago
TRN

Disaster and Emergency Management Presidency
Turkey
DDA

Kandilli Observatory and Research Institute
Turkey
ISK

IRIS Data Management Center
U.S.A.
IRIS

The Global CMT Project
U.S.A.
GCMT

Red Sísmica de Puerto Rico
U.S.A.
RSPR

Pacific Northwest Seismic Network
U.S.A.
PNSN

National Earthquake Information Center
U.S.A.
NEIC

Main Centre for Special Monitoring
Ukraine
MCSM

Subbotin Institute of Geophysics, National Academy of Sciences
Ukraine
SIGU

Dubai Seismic Network
United Arab Emirates
DSN

British Geological Survey
United Kingdom
BGS

Institute of Seismology, Academy of Sciences, Republic of Uzbekistan
Uzbekistan
ISU

Fundación Venezolana de Investigaciones Sismológicas
Venezuela
FUNV

National Center for Scientific Research
Vietnam
PLV

Geological Survey Department of Zambia
Zambia
LSZ

Goetz Observatory
Zimbabwe
BUL

Revision and coninuation of the EHB project

ISC-EHB

2.7 ISC Staff

Listed below are the staff (and their country of origin) who were employed at the ISC at the time of this ISC Bulletin Summary.

- Dmitry Storchak
- Director
- Russia / United Kingdom

- Lynn Elms
- Administration Officer
- United Kingdom

- James Harris
- Senior System and Database Administrator
- United Kingdom

- Alfie James Barber
- System Administrator
- United Kingdom

- Gergely Csontos
- Web Developer
- Hungary

- John Eve
- Data Collection Officer
- United Kingdom

- Domenico Di Giacomo
- Senior Seismologist
- Italy

- Konstantinos Lentas
- Senior Seismologist / Developer
- Greece

- Rosemary Hulin (née Wylie)
- Analyst
- United Kingdom

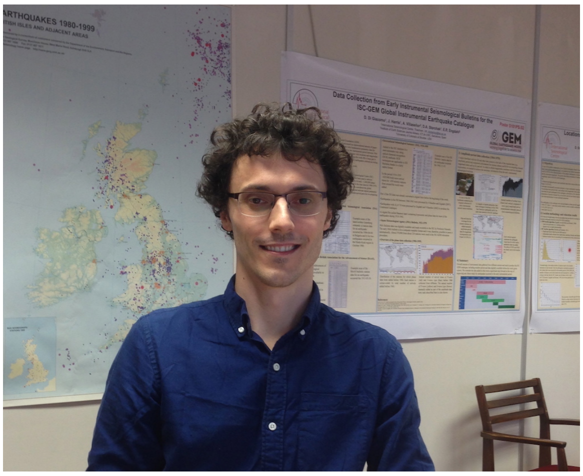
- Blessing Shumba
- Seismologist / Senior Analyst
- Zimbabwe

- Rebecca Verney
- Analyst
- United Kingdom

- Elizabeth Ayres (née Ball)
- Analyst / Historical Data Officer
- United Kingdom

- Kathrin Lieser
- Seismologist / Analyst / Summary Editor
- Germany

- Lonn Brown
- Seismologist / Analyst Administrator
- Canada



- Charikleia Gkarlaouni
- Seismologist / Analyst
- Greece

- Peter Franek
- Seismologist / Analyst
- Slovakia

- Angeliki Adamaki
- Seismologist / Analyst
- Greece

- Burak Sakarya
- Seismologist / Analyst
- Turkey

- Daniela Olaru
- Historical Data Officer
- Romania

- Tom Garth
- Seismologist, PDRA, jointly with Department of Earth Sciences at University of Oxford
- United Kingdom

3

Availability of the ISC Bulletin

The ISC Bulletin is available from the following sources:

- Web searches
  The entire ISC Bulletin is available directly from the ISC website via tailored searches.
  (www.isc.ac.uk/iscbulletin/search)
  (isc-mirror.iris.washington.edu/iscbulletin/search)

  - Bulletin search - provides the most verbose output of the ISC Bulletin in ISF or QuakeML.
  - Event catalogue - only outputs the prime hypocentre for each event, producing a simple list of events, locations and magnitudes.
  - Arrivals - search for arrivals in the ISC Bulletin. Users can search for specific phases for selected stations and events.

- CD-ROMs/DVD-ROMs

  CDs/DVDs can be ordered from the ISC for any published volume (one per year), or for all back issues of the Bulletin (not including the latest volume). The data discs contain the Bulletin as a PDF, in IASPEI Seismic Format (ISF), and in Fixed Format Bulletin (FFB) format. An event catalogue is also included, together with the International Registry of seismic station codes.

- FTP site

  The ISC Bulletin is also available to download from the ISC ftp site, which contains the Bulletin in PDF, ISF and FFB formats. (ftp://www.isc.ac.uk)
  (ftp://isc-mirror.iris.washington.edu)

Mirror service

A mirror of the ISC database, website and ftp site is available at IRIS DMC (isc-mirror.iris.washington.edu), which benefits from their high-speed internet connection, providing an alternative method of accessing the ISC Bulletin.

4

Citing the International Seismological Centre

Data from the ISC should always be cited. This includes use by academic or commercial organisations, as well as individuals. A citation should show how the data were retrieved and may be in one of these suggested forms:

4.1 The ISC Bulletin

International Seismological Centre (2019), On-line Bulletin, `https://doi.org/10.31905/D808B830`

The procedures used for producing the ISC Bulletin have been described in a number of scientific articles. Depending on the use of the Bulletin, users are encouraged to follow the citation suggestions below:

a) For current ISC location procedure:

Bondár, I. and D.A. Storchak (2011). Improved location procedures at the International Seismological Centre, *Geophys. J. Int.*, *186*, 1220-1244, `https://doi.org/10.1111/j.1365-246X.2011.05107.x`

b) For Rebuilt ISC Bulletin (currently: 1964-1990):

Storchak, D.A., Harris, J., Brown, L., Lieser, K., Shumba, B., Verney, R., Di Giacomo, D., Korger, E. I. M. (2017). Rebuild of the Bulletin of the International Seismological Centre (ISC), part 1: 1964–1979. *Geosci. Lett.* (2017) 4: 32. `https://doi.org/10.1186/s40562-017-0098-z`

c) For principles of the ISC data collection process:

R J Willemann, D A Storchak (2001). Data Collection at the International Seismological Centre, *Seis. Res. Lett.*, *72*, 440-453, `https://doi.org/10.1785/gssrl.72.4.440`

d) For interpretation of magnitudes:

Di Giacomo, D., and D.A. Storchak (2016). A scheme to set preferred magnitudes in the ISC Bulletin, *J. Seism.*, *20(2)*, 555-567, `https://doi.org/10.1007/s10950-015-9543-7`

e) For use of source mechanisms:

Lentas, K., Di Giacomo, D., Harris, J., and Storchak, D. A. (2019). The ISC Bulletin as a comprehensive source of earthquake source mechanisms, *Earth Syst. Sci. Data*, *11*, 565-578, `https://doi.org/10.5194/essd-11-565-2019`

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

f) For use of the original (pre-Rebuild) ISC Bulletin as a historical perspective:

Adams, R.D., Hughes, A.A., and McGregor, D.M. (1982). Analysis procedures at the International Seismological Centre. *Phys. Earth Planet. Inter. 30:* 85-93, https://doi.org/10.1016/0031-9201(82)90093-0

4.2 The Summary of the Bulletin of the ISC

International Seismological Centre (2019), Summary of the Bulletin of the International Seismological Centre, July - December 2016, *53(II)*, https://doi.org/10.31905/V1QQWEBC

4.3 The historical printed ISC Bulletin (1964-2009)

International Seismological Centre, Bull. Internatl. Seismol. Cent., 46(9-12), Thatcham, United Kingdom, 2009.

4.4 The IASPEI Reference Event List

International Seismological Centre (2019), IASPEI Reference Event (GT) List, https://doi.org/10.31905/32NSJF7V

Bondár, I. and K.L. McLaughlin (2009). A New Ground Truth Data Set For Seismic Studies, *Seismol. Res. Lett.*, *80*, 465-472, https://doi.org/10.1785/gssrl.80.3.465

Bondár, E. Engdahl, X. Yang, H. Ghalib, A. Hofstetter, V. Kirichenko, R. Wagner, I. Gupta, G. Ekström, E. Bergman, H. Israelsson, and K. McLaughlin (2004). Collection of a reference event set for regional and teleseismic location calibration, *Bull. Seismol. Soc. Am.*, *94*, 1528-1545, https://doi.org/10.1785/012003128

Bondár, E. Bergman, E. Engdahl, B. Kohl, Y.-L. Kung, and K. McLaughlin (2008). A hybrid multiple event location technique to obtain ground truth event locations, *Geophys. J. Int.*, *175*, https://doi.org/10.1111/j.1365-246X.2011.05011.x

4.5 The ISC-GEM Catalogue

International Seismological Centre (2019), ISC-GEM Earthquake Catalogue, https://doi.org/10.31905/d808b825, 2019.

Depending on the use of the Catalogue, to quote the appropriate scientific articles, as suggested below.

a) For a general use of the catalogue, please quote the following three papers (Storchak et al., 2013; 2015; Di Giacomo et al., 2018):

Storchak, D.A., D. Di Giacomo, I. Bondár, E.R. Engdahl, J. Harris, W.H.K. Lee, A. Villaseñor and P. Bormann (2013). Public Release of the ISC-GEM Global Instrumental Earthquake Catalogue (1900-2009). *Seism. Res. Lett.*, *84*, 5, 810-815, https://doi.org/10.1785/0220130034

Storchak, D.A., D. Di Giacomo, E.R. Engdahl, J. Harris, I. Bondár, W.H.K. Lee, P. Bormann and A. Villaseñor (2015). The ISC-GEM Global Instrumental Earthquake Catalogue (1900-2009): Introduction, *Phys. Earth Planet. Int.*, *239*, 48-63, https://doi.org/10.1016/j.pepi.2014.06.009

Di Giacomo, D., E.R. Engdahl and D.A. Storchak (2018). The ISC-GEM Earthquake Catalogue (1904–2014): status after the Extension Project, *Earth Syst. Sci. Data*, *10*, 1877-1899, https://doi.org/10.5194/essd-10-1877-2018

b) For use of location parameters, please quote (Bondár et al., 2015):

Bondár, I., E.R. Engdahl, A. Villaseñor, J. Harris and D.A. Storchak, 2015. ISC-GEM: Global Instrumental Earthquake Catalogue (1900-2009): II. Location and seismicity patterns, *Phys. Earth Planet. Int.*, *239*, 2-13, https://doi.org/10.1016/j.pepi.2014.06.002

c) For use of magnitude parameters, please quote (Di Giacomo et al., 2015a; 2018):

Di Giacomo, D., I. Bondár, D.A. Storchak, E.R. Engdahl, P. Bormann and J. Harris (2015a). ISC-GEM: Global Instrumental Earthquake Catalogue (1900-2009): III. Re-computed MS and mb, proxy MW, final magnitude composition and completeness assessment, *Phys. Earth Planet. Int.*, *239*, 33-47, https://doi.org/10.1016/j.pepi.2014.06.005

Di Giacomo, D., E.R. Engdahl and D.A. Storchak (2018). The ISC-GEM Earthquake Catalogue (1904–2014): status after the Extension Project, *Earth Syst. Sci. Data*, *10*, 1877-1899, https://doi.org/10.5194/essd-10-1877-2018

d) For use of station data from historical bulletins, please quote (Di Giacomo et al., 2015b; 2018):

Di Giacomo, D., J. Harris, A. Villaseñor, D.A. Storchak, E.R. Engdahl, W.H.K. Lee and the Data Entry Team (2015b). ISC-GEM: Global Instrumental Earthquake Catalogue (1900-2009), I. Data collection from early instrumental seismological bulletins, *Phys. Earth Planet. Int.*, *239*, 14-24, https://doi.org/10.1016/j.pepi.2014.06.005

Di Giacomo, D., E.R. Engdahl and D.A. Storchak (2018). The ISC-GEM Earthquake Catalogue (1904–2014): status after the Extension Project, *Earth Syst. Sci. Data*, *10*, 1877-1899, https://doi.org/10.5194/essd-10-1877-2018

e) For use of direct values of M0 from the literature, please quote (Lee and Engdahl, 2015):

Lee, W.H.K. and E.R. Engdahl (2015). Bibliographical search for reliable seismic moments of large earthquakes during 1900-1979 to compute MW in the ISC-GEM Global Instrumental Reference Earthquake Catalogue (1900-2009), *Phys. Earth Planet. Int.*, *239*, 25-32, https://doi.org/10.1016/j.pepi.2014.06.004

4.6 The ISC-EHB Dataset

International Seismological Centre (2019), ISC-EHB Dataset, https://doi.org/10.31905/PY08W6S3

Engdahl, E.R., R. van der Hilst, and R. Buland (1998). Global teleseismic earthquake relocation with improved travel times and procedures for depth determination, *Bull. Seism. Soc. Am.*, *88*, 3, 722-743.

http://www.bssaonline.org/content/88/3/722.abstract

Weston, J., Engdahl, E.R., Harris, J., Di Giacomo, D. and Storchack, D.A. (2018). ISC-EHB: Reconstruction of a robust earthquake dataset, *Geophys. J. Int.*, *214*, 1, 474-484, https://doi.org/10.1093/gji/ggy155

4.7 The ISC Event Bibliography

International Seismological Centre (2019), On-line Event Bibliography, https://doi.org/10.31905/EJ3B5LV6

Also, please reference the following SRL article that describes the details of this service:

Di Giacomo, D., Storchak, D.A., Safronova, N., Ozgo, P., Harris, J., Verney, R. and Bondár, I., 2014. A New ISC Service: The Bibliography of Seismic Events, *Seismol. Res. Lett.*, *85*, 2, 354-360, https://doi.org/10.1785/0220130143

4.8 International Registry of Seismograph Stations

International Seismological Centre (2019), International Seismograph Station Registry (IR), https://doi.org/10.31905/EL3FQQ40

4.9 Seismological Dataset Repository

International Seismological Centre (2019), Seismological Dataset Repository, https://doi.org/10.31905/6TJZECEY

4.10 Data transcribed from ISC CD-ROMs/DVD-ROMs

International Seismological Centre, Bulletin Disks 1-27 [CD-ROM], Internatl. Seismol. Cent., Thatcham, United Kingdom, 2019.

The ISC is named as a valid data centre for citations within American Geophysical Union (AGU) publications. As such, please follow the AGU guidelines when referencing ISC data in one of their journals. The ISC may be cited as both the institutional author of the Bulletin and the source from which the data were retrieved.

5

Operational Procedures of Contributing Agencies

5.1 Servicio Sismológico Nacional, Mexico

Xyoli Pérez-Campos, Víctor Hugo Espíndola, Jesús Pérez, Jorge A. Estrada, Caridad Cárdenas Monroy, Betty Zanolli Fabila, Delia Bello, Adriana González-López, Daniel González Ávila, Rafael Maldonado, Edgar Montoya-Quintanar, Reynaldo Vite, Luis D. Martínez, Yi Tan, Iván Rodríguez Rasilla, Miguel Ángel Vela Rosas, José Luis Cruz, Arturo Cárdenas, Fernando Navarro Estrada, Alejandro Hurtado and Antonio de Jesús Mendoza Carvajal

Instituto de Geofísica, Universidad Nacional Autónoma de México, Mexico City, Mexico

Team of the Servicio Sismológico Nacional, Mexico

5.1.1 History

The seismic instrumentation in Mexico started at the end of the 19th century when a Secchi and a Palmieri seismograph were installed in down town Mexico City. In 1903 Mexico participated in the 2nd conference of the International Association of Seismology and committed to the establishment of a national seismic network (*Rubinovich et al.*, 1991). The first network station was installed in Tacubaya, Mexico City; two more were installed in Oaxaca and Mazatlán (Fig. 5.1). The first was the central station which consisted of several Wiechert seismographs and Bosch-Omori pendulums. The other two stations were considered of second order, given the number and sensitivity of the instruments installed, and consisted of a horizontal 200 kg and a vertical 80 kg Wiechert seismograph. The initial plan for the Mexican network consisted of a central station, five first-order stations and 52 second-order stations (*Secretaría de Industria, Comercio y Trabajo*, 1919). By the time the Mexican Servicio Sismológico Nacional (SSN, National Seismological Service) was established in 1910, only the three mentioned stations were operating. In the same year, the Mexican Revolution ignited. Despite this, in the following three years, one more first-order station (Mérida) and three second-order stations (Zacatecas, Guadalajara, Monterrey) were installed (Fig. 5.1). The revolution lasted seven years, during which there were few hiatus on the monitoring activities. After the revolution, only four stations were operational: Tacubaya, Mérida, Mazatlán, Oaxaca (*Secretaría de Industria, Comercio y Trabajo*, 1919). In 1920, one more first-order station was installed in Colima, one second-order station, in Veracruz, and one third-order, in Puebla (Fig. 5.1). By 1925, the network consisted of seven stations distributed mainly in central and southern Mexico. By the end of the 1920s, two more stations were installed to cover the north of the country, one in Guadalajara, and the other in Chihuahua (Fig. 5.1).

Originally the SSN was under the umbrella of the Instituto Mexicano de Geología (the Mexican Institute of Geology), which was a government organisation. In 1929 the institute, including the SSN, was transferred to the Universidad Nacional Autónoma de México (UNAM, National Autonomous University of Mexico). In 1949, the Instituto de Geofísica (Institute of Geophysics) was founded and received the SSN in 1953, where it has been since then.

The history of the network can be divided into three epochs (*Pacheco*, 2001). The first one is from its beginnings to the late sixties when electromagnetic seismographs were installed. Telemetry started around 1988, 13 stations formed the Conventional Network (Figure 5.1), the instruments consisted of vertical short period seismometers. In the early nineties, the broadband network was born (Figure 5.1), telecommunication was improved and the central Station was modernised. The network was mainly concentrated in central and southern Mexico (Fig. 5.1), until 2006 when the network expanded to the north of the country. Also, by the mid 90's the Seismic Network of the Valley of Mexico was established with eight stations and continued to densify within Mexico City (Fig. 5.1).

5.1.2 Current Network Status

Currently, the SSN operates the National Network, for which the FDSN code is MX. It consists of 63 stations (Fig. 5.2) which include a broadband seismometer (120 s to 50 Hz) and an accelerometer; 43 of those stations also have a GPS/GNSS receiver and plans are to include a GPS/GNSS receiver in most of the stations. More details on the network, stations installation, and noise levels can be found in *Pérez-Campos et al.* (2018).

The SSN also operates and maintains the Valley of Mexico Seismic Network which currently has 34 operating stations (Fig. 5.2). They include a broadband seismometer (30 s to 50 Hz), and an accelerometer. The network has been described by *Quintanar et al.* (2018). Furthermore, SSN also maintains a three-station array at the Tacaná volcano at the border of Mexico and Guatemala.

The SSN also operates a hydroacoustic station (HA06) located at Socorro Island in the Pacific for the International Monitoring System of the Comprehensive Nuclear-Test-Ban Treaty Organisation (CTBTO). This is integrated with three seismic stations within the island. Furthermore, the SSN also operates

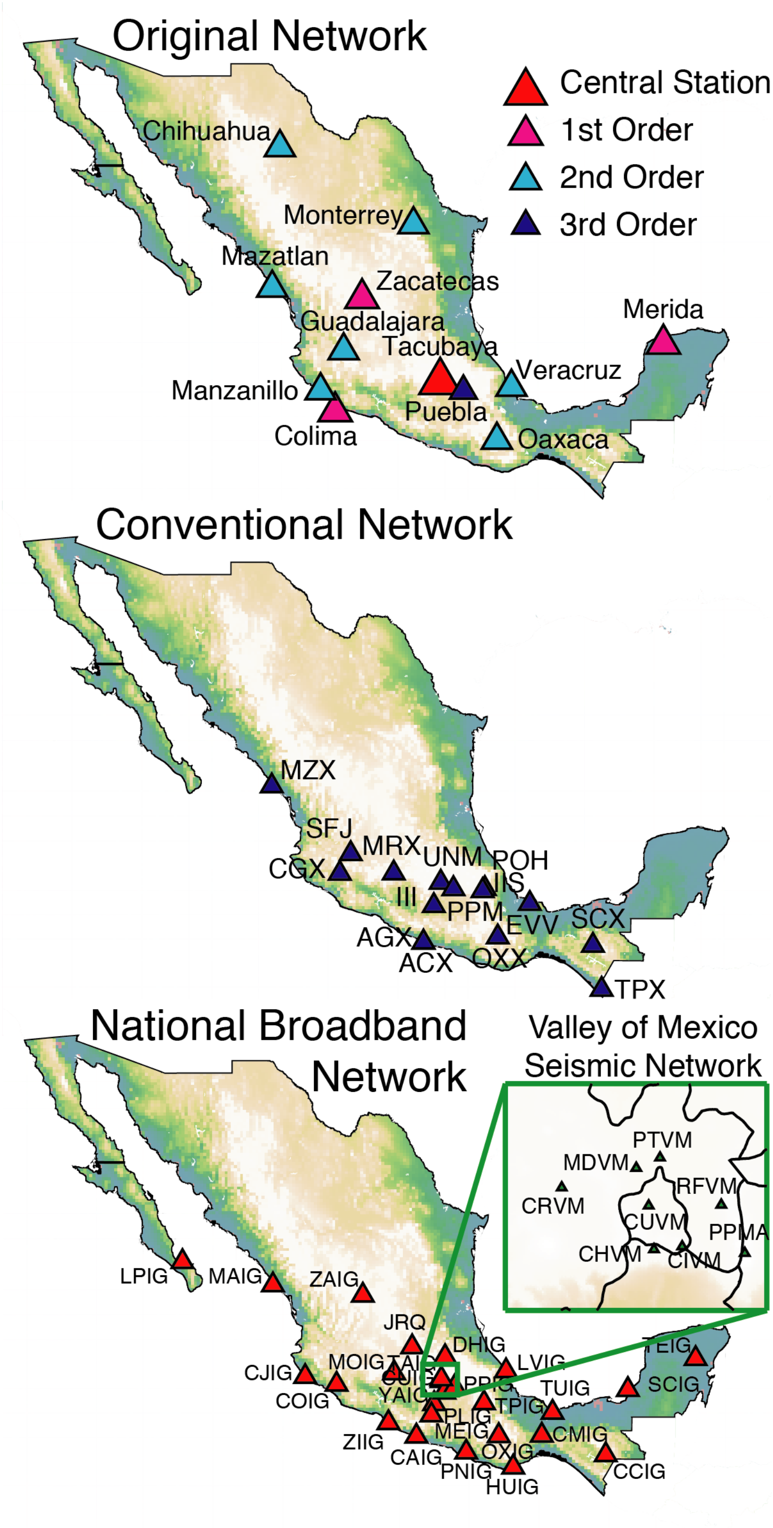


Figure 5.1: *Evolution of the network. Top: Original network, from the beginning of the SSN up to late sixties. Middle: Conventional Network, first time telemetry was implemented in the late eighties. Some stations operated until 2015. Bottom: National Broadband Network. It started with nine stations, the map corresponds to its configuration in 2005.*

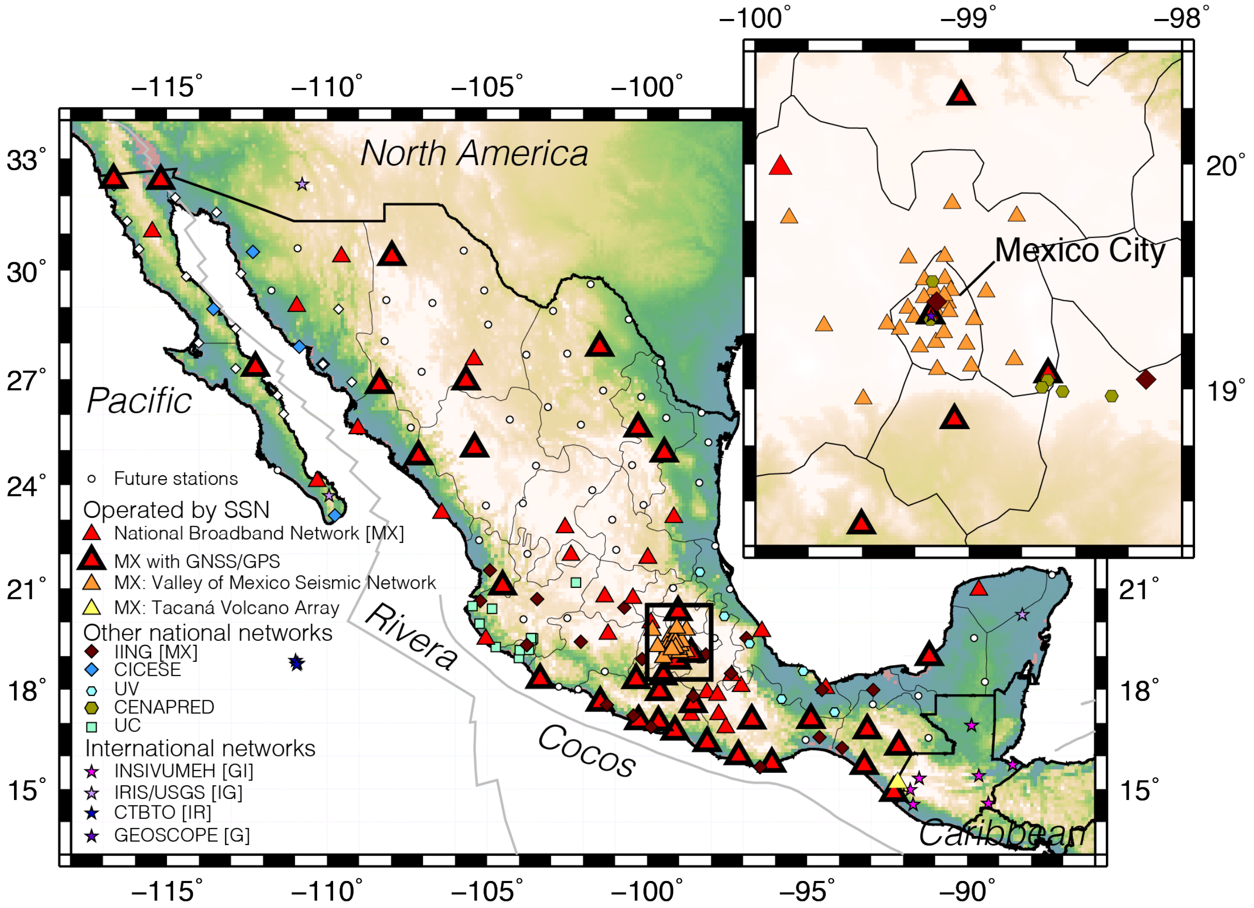


Figure 5.2: *Stations that contribute with data to the location of earthquakes within Mexico. Codes in brackets correspond to network codes in the FDSN.*

a GEOSCOPE station (UNM) located within Mexico City and a Global Seismograph Network station (TEIG) located in the Yucatán peninsula.

Future plans involve the installation of 52 new stations in the country (Fig. 5.2), mainly in those places where the current coverage is limited; this is northern Mexico and the Yucatán peninsula.

5.1.3 Data Exchange with Other Agencies

In order to improve detection and coverage capabilities nationwide, SSN exchanges data with other national and international monitoring agencies. Nationally, it exchanges data with the following institutions (see Fig. 5.2):

1. Instituto de Ingeniería, Universidad Nacional Autónoma de México (IING). The Institute of Engineering operates the largest accelerographic network (`http://aplicaciones.iingen.unam.mx/AcelerogramasRSM/Default.aspx`) in the country and is the institution responsible for generating the intensity maps for the country and for Mexico City. Most of their stations operate in stand-alone mode but twenty-four of them transmit their data in real time and are shared with the SSN. In return, the SSN sends the IING all the data from its accelerometers in the country. This contributes to the real-time national intensity map.

2. Centro de Investigación Científica y de Educación Superior de Ensenada, Baja California (CICESE). This centre operates several seismic and accelerographic networks focused on the northwest side of the county. These networks are described by *Vidal-Villegas et al.* (2018). The SSN receives data from six of its broadband stations and sends back data from 10 stations from its Broadband Network to help with regional monitoring.

3. Universidad Veracruzana (UV). This university installed, in collaboration with the government of the state of Veracruz, the Broadband Seismological Network of Veracruz, which consists of six broadband stations located along the Gulf of Mexico. A description of the network can be found in *Córdoba-Montiel et al.* (2018). The SSN receives data from all the UV stations and sends back data from SSN stations located within the state of Veracruz and in the neighbour states.

4. Centro Nacional de Prevención de Desastres (CENAPRED). The CENAPRED operates three small networks (*Gutiérrez et al.*, 2005). One is a five accelerograph array that serves as an attenuation line from Acapulco, Guerrero, to Mexico City. The second one is an accelerographic network located within Mexico City that consists of 12 stations, some of them are borehole stations. The third network is for monitoring the Popocatépetl volcano (*Guevara et al.*, 2003). Those stations consist of nine seismic stations, which have been recently updated from short period to broadband seismometers. The SSN receive data from two stations within Mexico City and four stations at the Popocatépetl volcano. In turn, the SSN sends the CENAPRED all its data in real time.

5. Universidad de Colima (UC). This university oversees the Colima volcano, and the seismicity in the region. For that purpose, it has the Red Sísmica Telemétrica del Estado de Colima (RESCO, Telemetric Seismic Network of the State of Colima; `https://portal.ucol.mx/cueiv/Sismico.htm`). Such network includes 11 broadband and four short-period stations, plus four acoustic sensors. Furthermore, the UC has a regional network that consists of four broadband and one short-period station. The SSN receive data from 15 broadband stations and in turn, sends data back from six stations in real time.

Internationally, the SSN receives data from 12 stations from the Red Sismológica Nacional (GI) of the Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología (INSIVUMEH) from Guatemala (Figure 5.2) and sends back data from nine stations. For manual processing, the SSN further incorporates data from stations TEIG, TUC and SLBS from network IU (Figure 5.2) using the real-time streaming of the Incorporated Research Institutions of Seismology (IRIS) Data Management Center (DMC), and includes the data from the CTBTO stations at Socorro Island into the analysis. On the other hand, the SSN sends data in real time from seven stations to IRIS-DMC and 11 to the Pacific Tsunami Warning Center.

Moreover, for proper real-time automatic discrimination of regional earthquakes from teleseismic ones, the SSN incorporates the real-time feed from 178 stations of networks GT, II, IU, NU, and US into SeisComP3.

Depth km	Velocity km/s
0.0	6.00
16.0	7.76
33.0	7.95
100.0	8.26
200.0	8.58
413.0	8.97

Table 5.1: *Velocity model for national earthquake location.*

5.1.4 Data Flow

All data from stations described above are received at the central facility in Mexico City. The SSN data is collected with the acquisition software specific for each model of the digitiser and transferred to Earthworm. Data from the other organisations, national and international, are received in real time through the import and seedlink modules of Earthworm. Then the data follows two paths (Fig. 5.3). The first one is via a seedlink protocol to SeisComP3 for the automatic event detection, ending with the publication of the event parameters. These parameters are also fed to a W-phase inversion to estimate the moment magnitude. The second path is for manual processing by the analysts. This is done with SEISAN (*Havskov and Ottemöller*, 1999). The earthquake information is then published on the SSN webpage, the RSS feed and SSN social networks (Twitter, @SismologicoMX and Facebook, /SismologicoMX). It is also sent by e-mail and SMS to selected authorities. Twitter has become the SSN main distribution channel with more than 3.76 million followers.

5.1.5 Data Analysis

Earthquake location is done with HYPOCENTER (*Lienert and Havskov*, 1995) within SEISAN. The velocity model is a modified version of the model of *Jeffreys and Bullen* (1940) to include a mid-crust discontinuity at 16 km depth (Tab. 5.1). Along with the hypocenter location, the SSN reports magnitudes, which are estimated using different methodologies, mainly depending on the earthquake size.

Magnitude Estimation

For earthquakes with magnitudes smaller than 5.2, the SSN gets the following estimates for magnitudes.

$\mathbf{M_A}$ Magnitude estimated from the amplitude of long period waves (15 - 30 s), based on *Singh and Pacheco* (1994):

$$M_A = \frac{1}{1.5}\left[\log_{10}(M_0) - 16.1\right],$$

where $M_0 = \left(\frac{A}{A_0}\right) \times 10^{23}$ dyn-cm, and $A = \sqrt{A_E^2 + A_N^2 + A_Z^2}$, where A_Z, A_N, A_E are the maximum amplitudes in m/s measured on vertical, north-south, and east-west components, respectively; and A_0 is the theoretical amplitude given a theoretical attenuation curve.

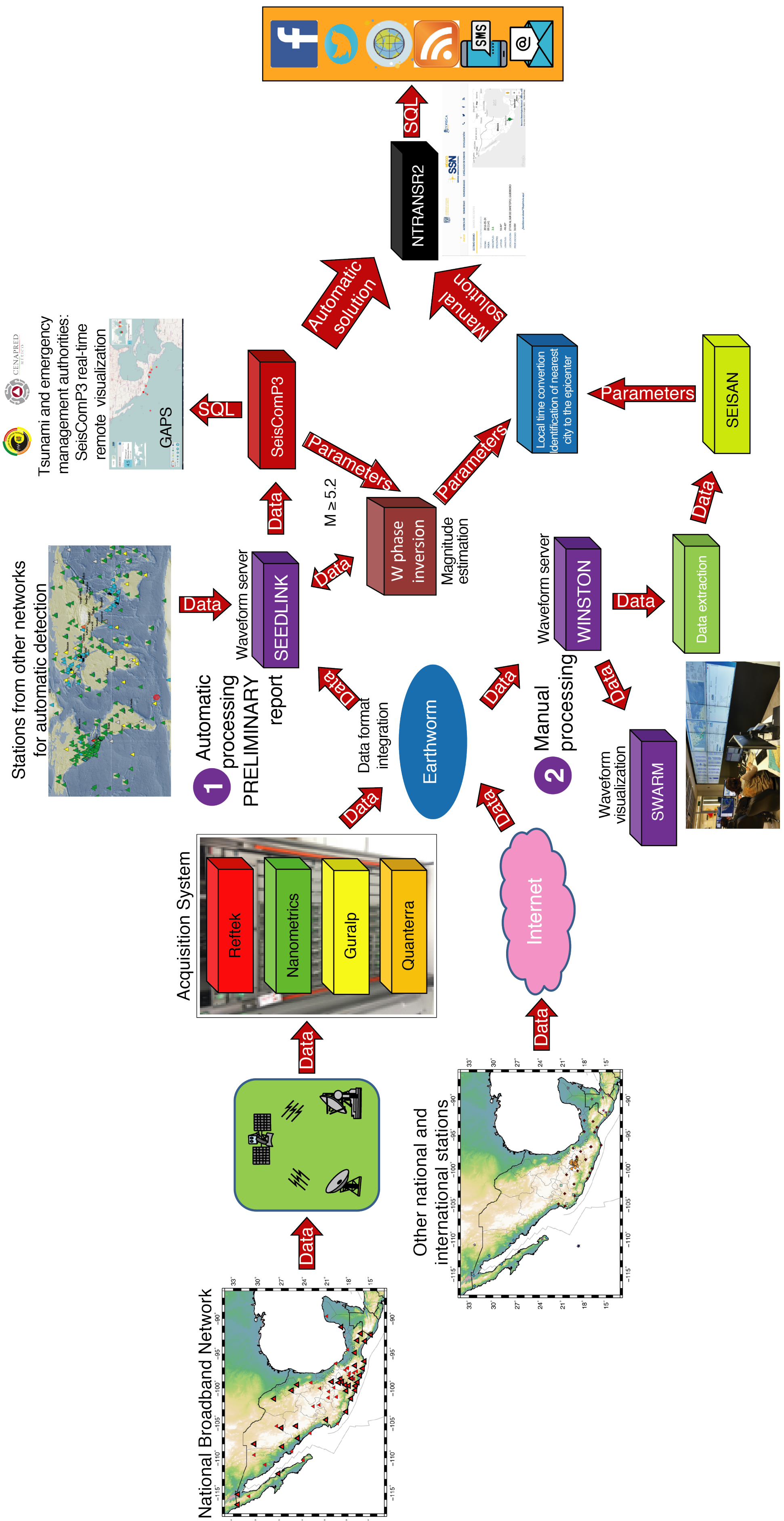


Figure 5.3: *Data flow, from the stations to the public.*

M_E Energy magnitude estimated following *Singh and Pacheco* (1994):

$$M_E = \frac{2}{3}\log_{10}(E_S) - 8.45,$$

where E_S is the seismic energy estimated, following *Singh and Ordaz* (1994), from the record of station CUIG located a few meters away from the SSN monitoring center.

M_A and M_E are single-station estimates. *Singh and Pacheco* (1994) only calibrated them for subduction earthquakes recorded at station CUIG. Given the close distance of this station to the SSN monitoring center these magnitudes represent a backup estimate in the event of losing communication with the network since data can be accessed manually.

M_C Coda duration magnitude calibrated by Jens Havskov in 1979 during a research visit to the Institute of Geophysics and the SSN:

$$M_C = 0.09 + 1.85\log_{10}(T) - 0.0004(D),$$

where T is the coda duration in seconds from the P wave onset and D is the epicentral distance in km. This magnitude has been reported by the SSN since 1986. This is the preferred magnitude for small earthquakes.

M_{w1} Amplitude magnitude calibrated with moment magnitude. It only uses stations that have STS-2, Trillium 120 and Trillium 240 seismometers. The methodology and calibration was reported by *Espíndola Castro and Valdés González* (2011). The expression is:

$$\log_{10}(M_{w1}) = -0.01295 + 0.0719\log_{10}(A_{max}) + 0.1543\log_{10}(D),$$

where A_{max} is the maximum amplitude of the record in counts measured from zero to peak and D is the hypocentral distance in km. The SSN has reported this magnitude since 2012 and it is the preferred value for earthquakes with magnitude above 4.0 but below 5.2.

For earthquakes larger than 5.2, the SSN estimates the moment magnitude M_w from a regional W-phase inversion (*Kanamori and Rivera*, 2008; *Hayes et al.*, 2009; *Duputel et al.*, 2012). This was implemented in real time in 2014. Also, the SSN estimates M_w from an inversion scheme that follows the procedure by *Dreger* (2003) and uses regional Green's functions and regional data.

Catalogue

Despite the first monthly seismic bulletin being from 1917, the information of the bulletins has not been incorporated in the current online catalogue yet (`http://www2.ssn.unam.mx:8080/catalogo/`). This is an ongoing task. Locations of earthquakes from 1900 to 1974 were taken from a compilation made by *Kostoglodov and Pacheco* (1999) based on various studies for such earthquakes. The instrumental history, network coverage and the processing capabilities are reflected in the catalogue. Figures 5.4a-d show some of these effects with four maps with the minimum magnitude reported by the SSN within 10x10 km^2 cells. Figure 5.4e shows the minimum magnitude reported in the whole catalogue which is

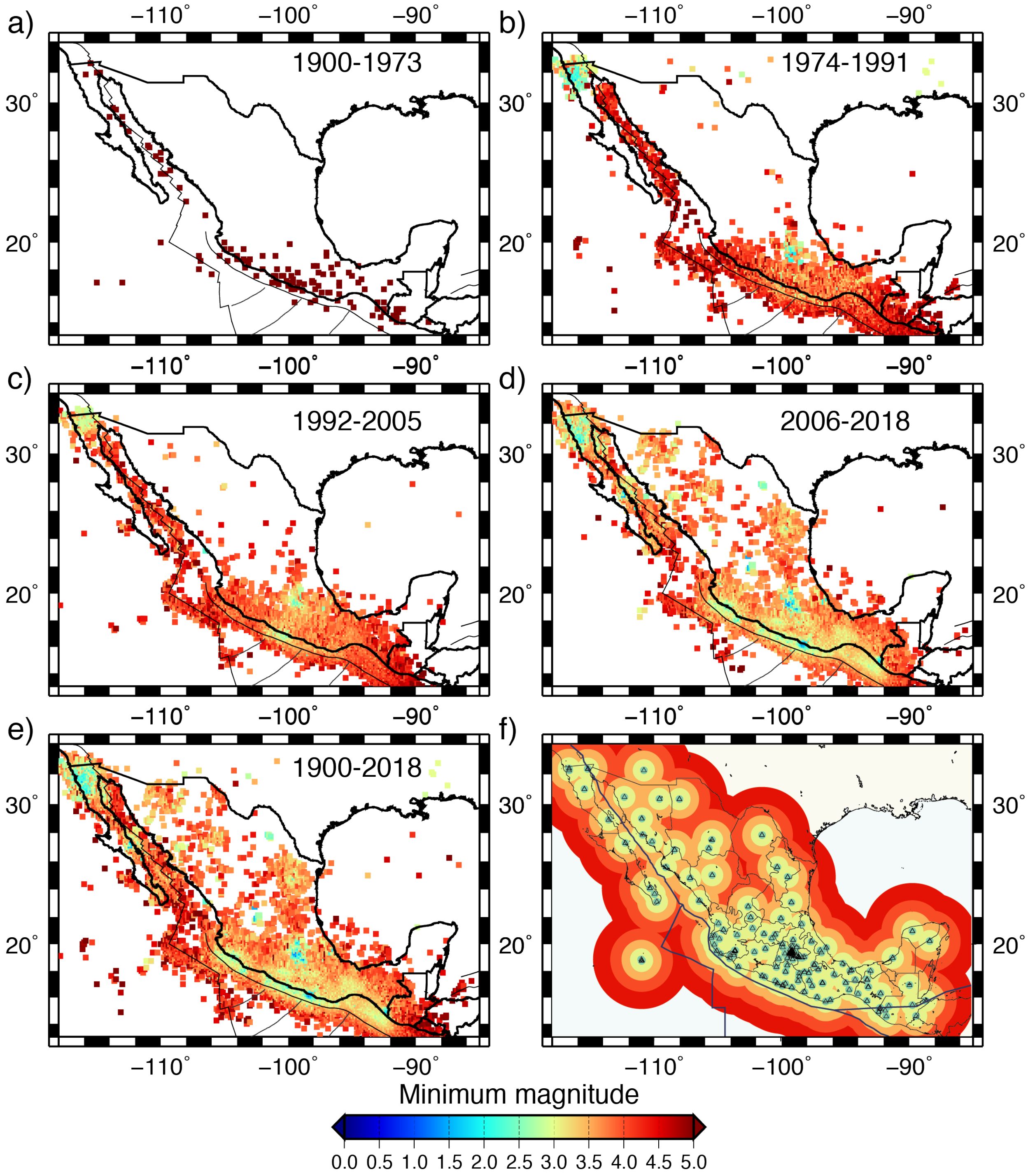


Figure 5.4: *Minimum magnitude reported and able to detect by the current network. a) Period 1900-1973, the location and magnitude information was taken from the compilation by* Kostoglodov and Pacheco *(1999). b) Period 1974-1991. The conventional network with telemetry operated during this epoch, computers were incorporated to location and magnitude estimates and magnitudes of coda duration and local magnitudes were started to be used. c) Period 1992-2005. The first stations of the National Broadband Network were installed in 1992. By 2005 the network distribution was as in Figure 5.1. d) Period 2006-2018. The broadband network expanded to other regions of the country and other national and international networks started exchanging data with the SSN. e) Minimum magnitude reported in the SSN catalogue. The area is divided into squares of 10x10* km^2. *f) Minimum magnitude that the current network can detect by a single station. It includes stations from other institutions that share data with the SSN.*

clearly related to Mexico's tectonics and station density. Furthermore, Figure 5.4f shows the minimum-magnitude event that can be detected by a single station in the network. This is assuming the same noise level at all stations, given by the 95 percentile of the level for all the SSN stations as reported by *Pérez-Campos et al.* (2018). For the magnitude, we use M_{w1} as stated above. As can be seen, there are still regions within Mexico where a magnitude 4.0 might go undetected by the current network. Therefore, the SSN is trying to expand the network to those regions.

5.1.6 Data Availability

An important collection of data is all the paper records accumulated since the first instrument was installed. These are stored at the Joint Library of Earth Sciences at UNAM (`http://www.sismoteca.unam.mx`). Scanned records can be requested by email (`SSNdata@sismologico.unam.mx`). The collection will be available online at `http://www.sismoteca.unam.mx`. For the digital data, as mentioned previously, seven SSN station are available through IRIS-DMC. All continuous velocity data from the broadband national network is currently available through a Seismic Transfer Protocol (STP) client, which can be requested following instructions at `http://www.ssn.unam.mx/doi/networks/mx/`. Acceleration and GPS data are available upon request by email (`SSNdata@sismologico.unam.mx`) with a moratorium of four months.

The agency code for the SNN at the ISC is MEX.

5.1.7 Acknowledgements

Figures 5.1, 5.2, and 5.4 were generated using the Generic Mapping Tools (*Wessel and Smith*, 1998).

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5.2 Seismic Monitoring at the Turkish National Seismic Network (TNSN)

Fatih Alver, Ömer Kılıçarslan, Kerem Kuterdem, Meltem Türkoğlu and M.Doruk Şentürk
Disaster and Emergency Management Authority (AFAD), Earthquake Department, Ankara, Turkey


Fatih Alver


Ömer Kılıçarslan


Kerem Kuterdem


Meltem Türkoğlu


M.Doruk Şentürk

Turkey ranks third in the world in terms of earthquake-related casualties and eighth with regard to the total number of people affected. Every year, the country experiences at least one 5+ magnitude earthquake – which renders the proper management and coordination of disasters absolutely crucial (*Türkoglu et al.*, 2014). The Disaster and Emergency Management Authority (AFAD) introduced a novel disaster management model which prioritizes Turkey's transition from crisis management to risk management – which came to be known as the Integrated Disaster Management System. AFAD currently has 81 provincial branches across Turkey in addition to 11 search and rescue units. Notwithstanding its position as the sole authority for disasters and emergencies, AFAD cooperates with a range of government institutions and non-governmental organisations depending on the nature and severity of individual cases. AFAD was established on 17th December 2009 by Law no. 5902. In 2018, with presidential legislation, AFAD was affiliated to the Ministry of Interior. It is a governmental organisation and some of the duties are as follows:

1. Provide emergency relief and coordination when a disaster occurs,
2. take effective measures before, during and after a disaster in order to reduce hazards,
3. make emergency settlements and shelters by establishing and providing communication and action with the related ministries, public organisations and institutions related to any kind of disaster issues,
4. establish nationwide seismic networks to observe and study earthquake activity to diminish casualties and damage,
5. prepare hazard maps and identify new safer areas for housing by making policies for safer building and cities by applying the seismic building code of Turkey,
6. coordinate and support research and studies about earthquakes in Turkey by institutes or NGOs.

AFAD is the sole governmental responsible organisation for monitoring and communicating earthquake related information to the public in Turkey.

Turkey is among the countries most affected from disasters on a global scale due to its tectonic, seismic, topographic and climactic structure. Although disasters such as floods, avalanches, landslides and fires are common in our country, earthquakes take first place when evaluated in terms of their devastating effects. Therefore, the Earthquake Department (ED), that was established in 1955 under the Ministry of Public Works, was also designed as a department under AFAD as a unique governmental organization in 2009.

The Earthquake Department has identified its objectives as:

1. The development of a national seismological network (strong and weak ground motion seismic observation networks) in terms of quality and quantity to meet the country's needs,
2. reduce the error tolerance in seismic hazard assessments by closer observation of seismic activity,
3. provide better quality data to groundwork engineering seismology and earthquake engineering studies into reducing damage from earthquakes,
4. play an active role in disaster risk management, regularly obtaining seismic data which are the main data in local, regional and national seismic hazard and risk maps,
5. to inform disaster managers and response teams quickly and reliably when an earthquake occurs.

5.2.1 Regional Seismicity

Turkey is one of the world's most earthquake prone countries, as it is located in an active seismic zone on the Alpine-Himalayan earthquake belt. Most of the population and industrial complexes are in active earthquake zones. The importance and urgency of the works related to the pre-disaster mitigation of earthquakes were emphasized after the 17 August 1999 Marmara Earthquake and 12 November 1999 Düzce Earthquake which killed nearly 18,000 people.

Turkey has frequently suffered from major damaging earthquakes in the 20th and 21st centuries. Furthermore, in the past century 120 moderate and large earthquakes, some of them causing considerable surface faulting, happened all over the main tectonic provinces of Turkey. Of these earthquakes the Erzincan quake (Ms=7.9) was the biggest Turkish earthquake, happened on 26 December 1939, produced 360 km surface faulting from Erzincan through Erbaa to Amasya along the North Anatolian fault (*Ambraseys*, 1970; *Ketin*, 1976). This earthquake caused 32,962 deaths and was accompanied by a 7.5 m right lateral coseismic slip near the middle part of the rupture. Eight large earthquakes ($Ms \geq 7.0$) occurred on the North Anatolian fault zone in the period from 1939 to 1999.

The Earthquake activity of Turkey and its surrounding regions is observed, evaluated, archived and published to the public via the website of the Earthquake Department (`https://deprem.afad.gov.tr`). An earthquake occurring anywhere in our country which has a magnitude greater than 1.0 can be recorded and evaluated. The number of earthquakes (2005–2018) processed by the Turkish National Seismic Network (TNSN) is shown in Figure 5.5. Figure 5.6 shows the distribution of seismicity from 2009 to 2019.

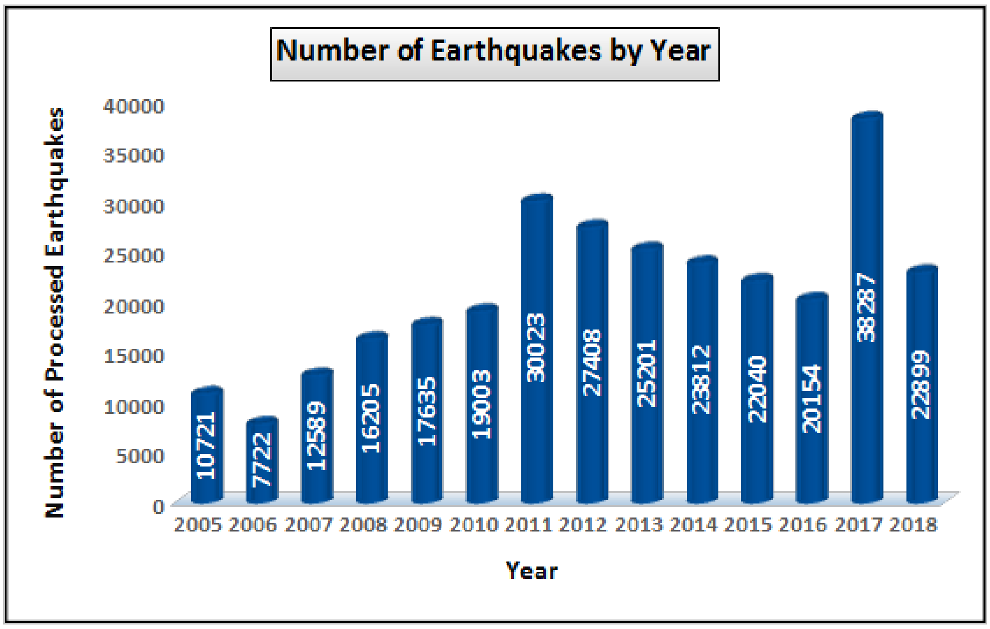

Figure 5.5: *Number of earthquakes by year since 2005 determined by the TNSN of AFAD. The increase in number of earthquakes in 2017 indicates the aftershock activity of Gökova Gulf (Mw=6.5 20.07.2017 UTC 22:31:09), Karaburun (Mw=6.2 12.06.2017 UTC 12:28:37) and Adıyaman Samsat (Mw=5.5 02.03.2017 UTC 11:07:25) earthquakes.*

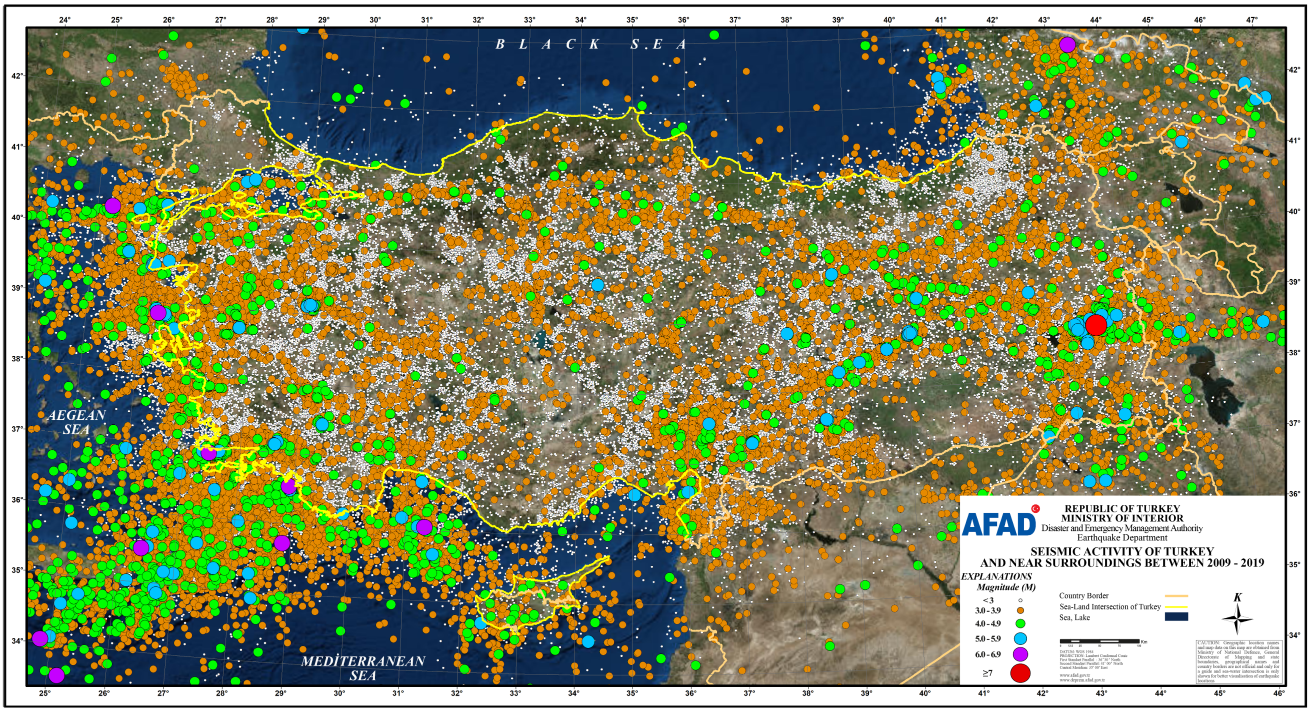

Figure 5.6: *Earthquake activity in Turkey between 2009-2019. Circles are colour coded by magnitude M, where white is M < 3, orange 3.0 - 3.9, green 4.0 - 4.9, blue 5.0 - 5.6, purple 6.0 - 6.9 and red M ≤ 7.*

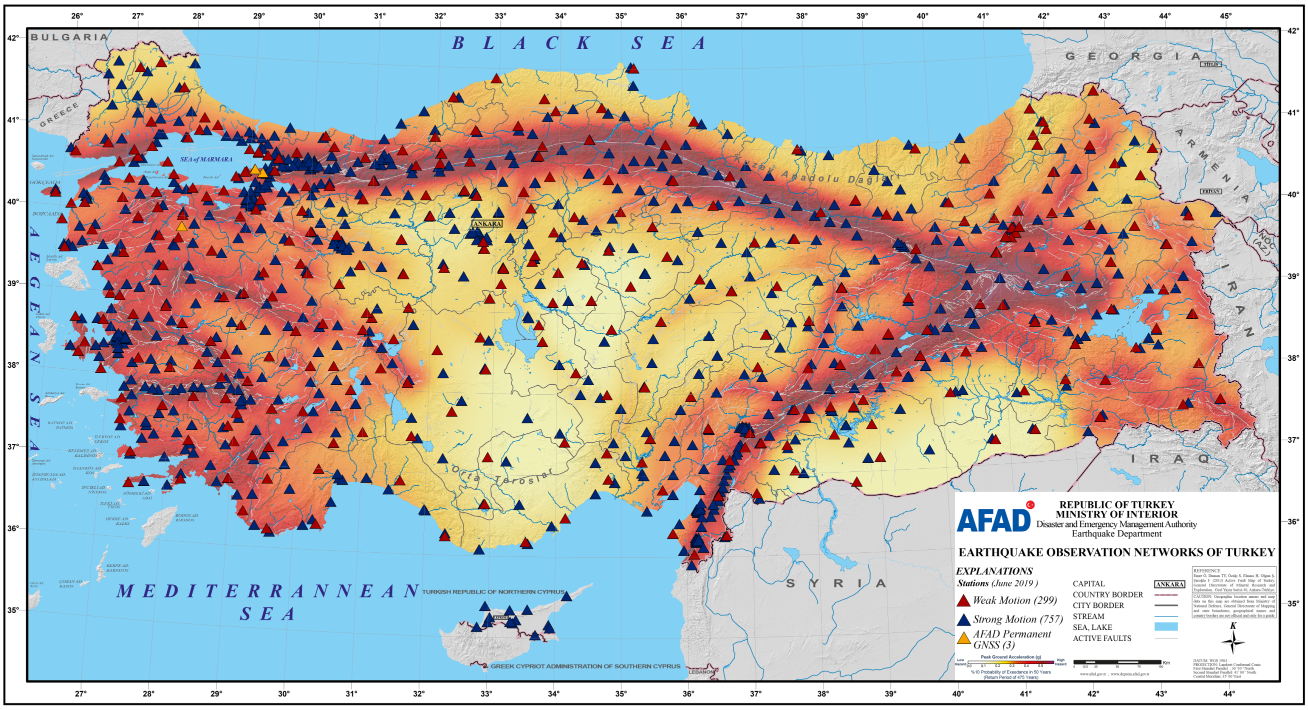

Figure 5.7: *Earthquake Hazard Map of Turkey and Turkey National Seismic Network. Red triangles are weak motion stations (299), blue triangles are strong motion stations (757) and yellow triangles are AFAD permanent GNSS stations (3), (June 2019).*

5.2.2 History of the Turkey National Seismic Network

TNSN mainly consists of four different seismological observation systems, namely: weak motion, strong ground motion, deep borehole and Global Navigation Satellite System (GNSS) networks.

Weak-Motion Network

AFAD Earthquake Department has been striving in depth on earthquake mitigation activities such as the establishment of seismic observation networks, development of earthquake resistant building codes and the preparation of seismic maps etc. since its inception date in 1955.

In an earthquake council meeting organised in Istanbul in 2004 it was decided to establish an advanced Turkish National Seismic Network for monitoring, recording, evaluating, archiving and announcing earthquakes across the country. The development of the network in terms of weak and strong motion instrumentation has accelerated following the 2004 meeting. As of May 2019 the earthquake activity of Turkey has been observed 7 days/24 hours with 299 weak motion stations and 757 strong motion stations (accelerometers). In addition to those networks, AFAD has started to enhance the national seismic network by adding permanent GNSS stations. By 2019 a total of 3 permanent GNSS stations have been installed by AFAD (Fig. 5.7 and Fig. 5.8).

The TNSN has 299 broadband (BB) seismic stations, all of which are installed on bedrock of varying qualities. The seismometer data is transmitted via GPRS, DSL or satellite depending on availability. Except for some 30 s CMG-6TD instruments, most of the BB instruments are 120 s CMG-3T (Fig. 5.9).

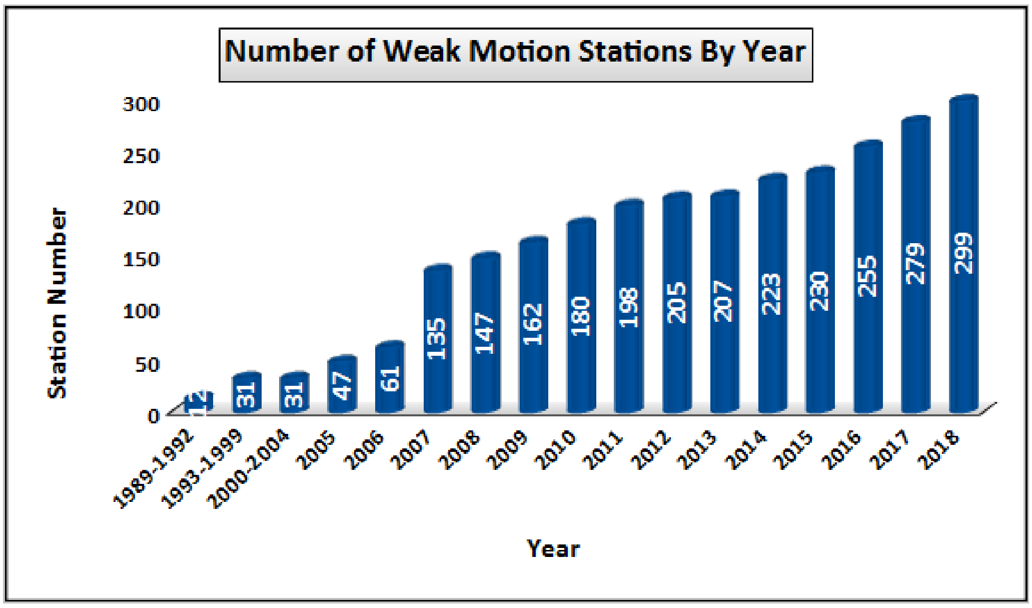

Figure 5.8: Number of seismometers in the TNSN between 1989-2018.

Figure 5.9: Station installation in the field (seismometer).

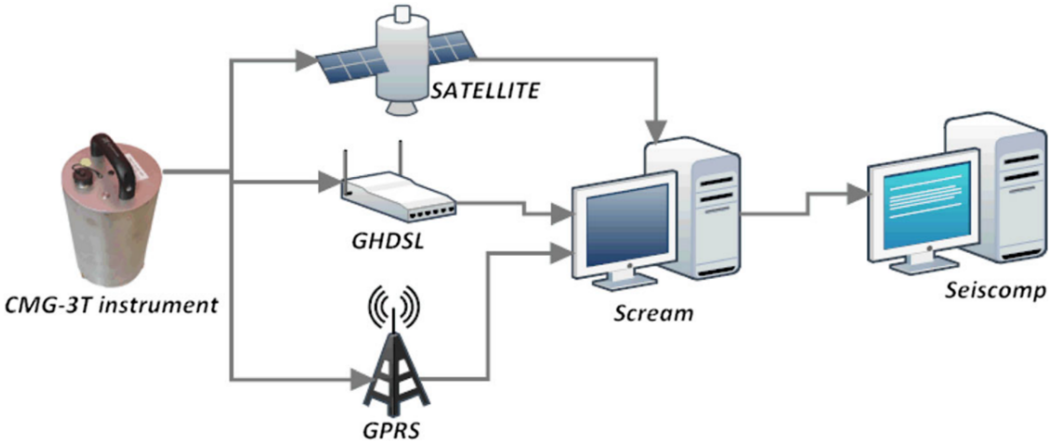

Figure 5.10: *Operation scheme of the TNSN (*Kılıç et.al.*, 2016a).*

The network is still being expanded. Data from various other small size local networks operated by universities (14 stations by Atatürk University, 5 by Cumhuriyet University, 4 by Süleyman Demirel University, 4 by Anadolu University) also contribute to the TNSN.

The real-time data from the TNSN is collected by the Güralp program SCREAM (`http://www.guralp.com`) and saved in 15-min GCF formatted segments and transferred in real time to a SEISCOMP system (Geofon-Gitews Development Group 2009) for automatic processing. The data is stored as daily files in MiniSeed format in the SEISCOMP data structure (SDS). A simple depiction of network operation and data transmission for a typical station is given in Figure 5.10. (*Kılıç et al.*, 2016a).

Strong-Motion Network

The first National Strong Motion Network of Turkey (TR-KYH) was established in 1973 under the Ministry of Public Works and has been operated by the Earthquake Department of AFAD since 2009.

The TR-KYH maintains the national network, a data center and a strong-motion data analysis and research center in support of this responsibility. The accelerometers are mainly installed on the North Anatolian Fault Zone (NAFZ), East Anatolian Fault Zone (EAFZ) and Aegean Graben System where large earthquakes occurred in the past. The TR-KYH consists of 757 strong motion observation stations (Fig. 5.11). The data management center of TR-KYH is located in Ankara. Currently there are 5 different types of digital accelerometers (GSR-16, GSR-18, GURALP, SARA, GMSplus) in the network. The instruments are mainly installed at government buildings such as meteorology stations or local ministerial offices for safety, ease of maintenance and data transmission opportunities. The total number of stations will increase to 1000 by 2023.

Accelerometers are installed both free-field in specially constructed enclosures (Fig. 5.12) and inside governmental buildings. Data is transferred to the central office continuously or by trigger mode applications (Dial-up, Internet, ADSL, GPRS/EDGE etc.) and is then submitted to users from the main network after being processed.

The access to strong motion data is free via AFAD Earthquake Department website (`http://kyhdata.deprem.gov.tr/2K/kyhdata_v4.php`).

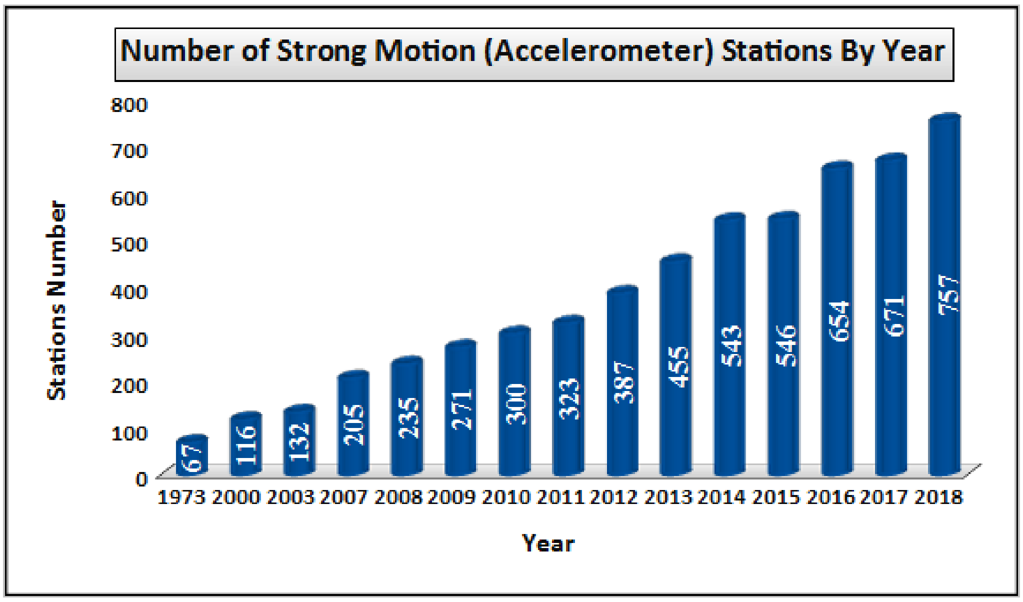

Figure 5.11: *Development of the number of accelerometers between 1973–2018.*

Figure 5.12: *Example of a strong motion station.*

Site Investigation for Stations

For the site selection of stations several conditions such as active tectonic faults of the area, the density of buildings for different geological structures, energy lines, communication, security, environmental noise, transportation etc. are considered.

In order to determine the station site characterisation, the non-invasive site exploration procedure MASW (Multi-channel analysis of surface waves) was conducted to determine the P- and S-wave velocity profiles. The soil column lithology at each strong-motion site was defined by drilling boreholes and carrying out geotechnical laboratory tests on the disturbed and undisturbed samples taken out from

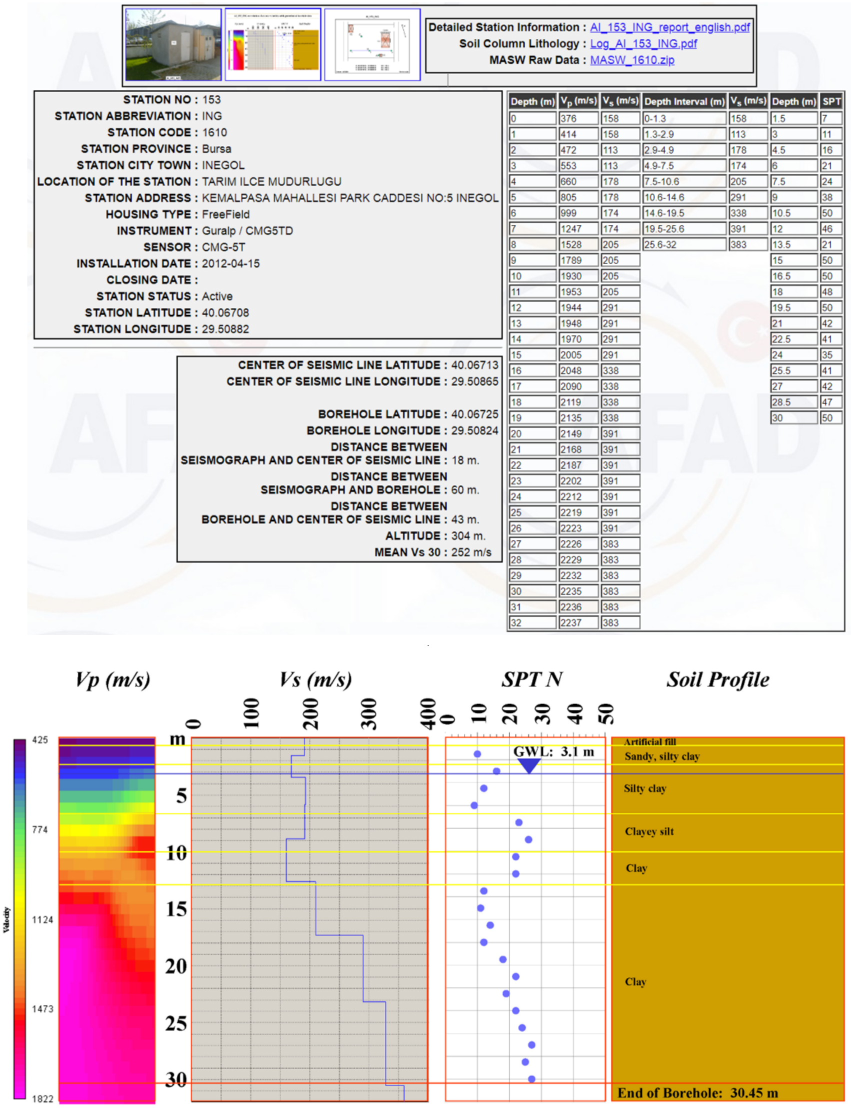

Figure 5.13: *Example for site information profiles for stations.*

these boreholes. In total, for 153 Strong Motion Station locations site characterisation was determined by both geotechnical and seismic methods (Fig. 5.13).

Borehole Seismic Network

The first Borehole Seismometer project in Turkey (GONAF) was set up in 2011 by AFAD and GFZ (German Research Centre for Geosciences) and station installation has been completed (*Prevedel et al.*, 2015). Analysis of data that is obtained from this project is continuing. In the GONAF Project, there are seven stations where four borehole sensors are installed at different depths (75, 150, 225 and 298 m). These stations are located in Istanbul (Tuzla, Büyükada and Sivriada) and Yalova (Kurtköy, Esenköy, Bozburun and Teşvikiye).

With the experience and knowledge gained in this project, AFAD developed the Borehole Seismometer Network Project and installed borehole seismometers at 100 m depth in İzmir, Çanakkale and Kahramanmaraş in 2016 and in Afyonkarahisar, İzmir, Denizli and Balıkesir in 2017 (Fig. 5.14). It is planned

Figure 5.14: *Borehole station installation.*

to install 36 borehole stations in Turkey (Fig. 5.15) at 160 km interval and 9 abroad. Negotiations are continuing with some countries in Eastern Europe and the Caucasian countries.

The main objectives of the project are:

- To understand the behaviour of faults before, during and after an earthquake,
- to evaluate teleseismic events recorded by Turkish stations,
- to improve the accuracy of earthquake parameters.

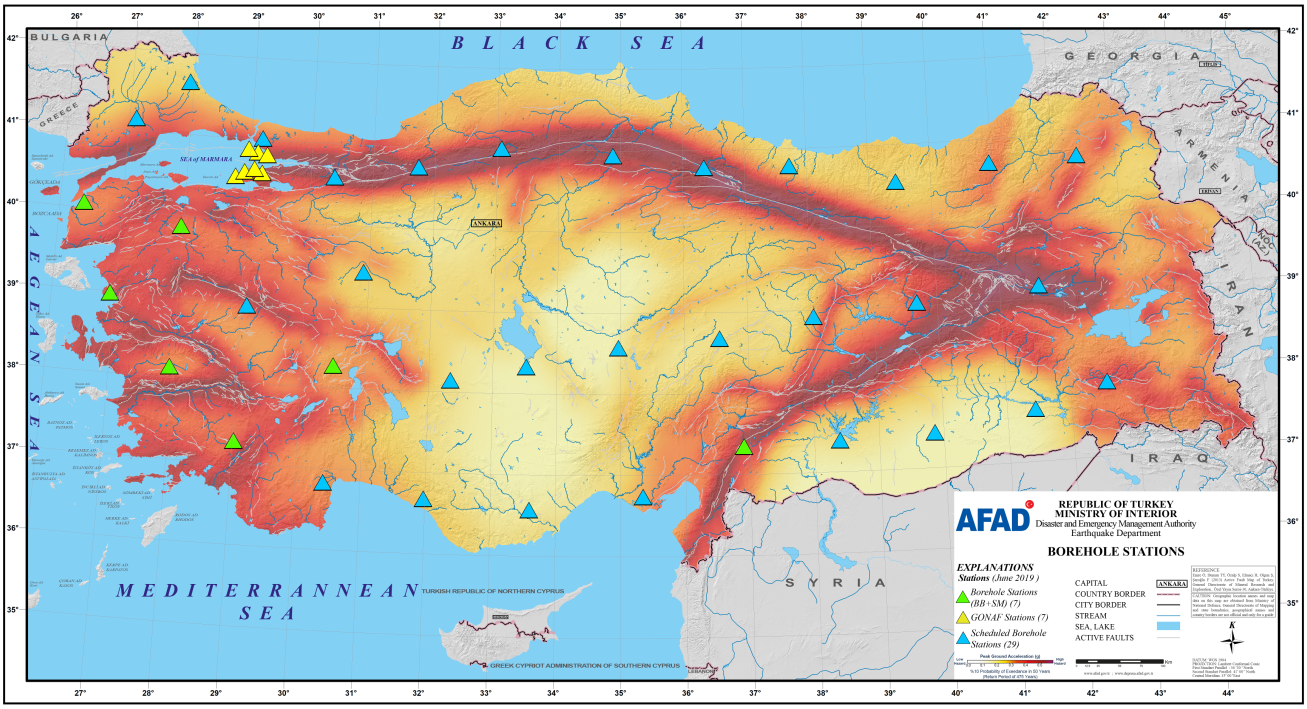

Figure 5.15: *Map of the Borehole Seismic Network. Green triangles are borehole stations (BB+SM) (7), yellow triangles are GONAF stations (7) and blue triangles are scheduled borehole stations (29), (June 2019). White colours are 0.0 g peak ground acceleration/low seismic hazard and red colours are 0.6 g peak ground acceleration/high seismic hazard (10% probability of exceedance in 50 years, return period of 475 years).*

GNSS Network

We are implementing real-time high-rate monitoring at co-located GNSS/seismic stations for rapid determination of earthquake magnitudes and rupture characterization. Coupled GNSS and seismometer data provides broadband (with true DC) displacement waveforms, which have huge potential for earthquake early warning as well as reliable filtering of accelerometer data.

The number of permanent GNSS stations, operated by public and private sectors, in Turkey already exceeds 200 and continues to grow each day. While not as sensitive as broadband seismometers, the non-inertial observation mechanism of GNSS enables obtaining measurements very close to the earthquake source without saturation, which makes it ideal for earthquake early warning systems. We are operating three permanent GNSS stations by our own capacity, as Figures 5.7 and 5.16 indicate. For earthquake monitoring and analysis we have real-time access to 158 nation-wide continuous Turkish National Permanent GNSS Network (CORS-TR) stations that are operated by other public institutions for mapping purposes.

We built a central GNSS analysis center which operates in real time and is capable of transferring data from remote GNSS stations, analysing raw GNSS data with both PPP (Precise Point Positioning) and Relative Kinematic modes, producing filtered instant coordinate time series and storing them in a database, and finally analysing coordinate time series for modelling the earthquake mechanism with coseismic offsets.

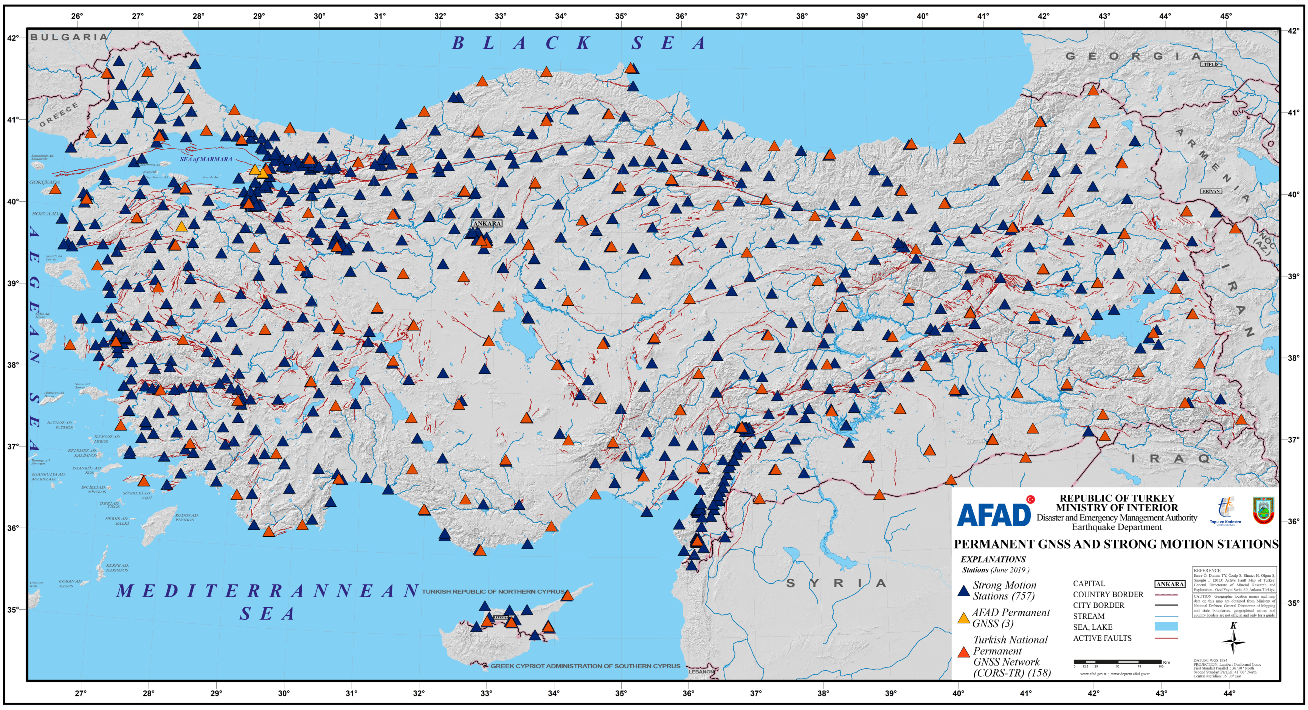

Figure 5.16: *Permanent GNSS Network and Strong Motion Stations. Blue triangles are strong motion stations (757), orange triangles are stations of the Turkish National Permanent GNSS Network (CORS-TR) (158) and yellow triangles are AFAD permanent GNSS stations (3), (June 2019).*

5.2.3 Data Processing

Weak-Motion and Borehole Data Processing

The waveform data are routinely processed manually for event location and magnitude determination using a programme called Earthquake Analysis (EA) that was developed at AFAD (*Yanık*, 2015). The data of the borehole network is integrated into EA in a similar way as the weak motion stations.

Earthquake Analysis Program (EA)

The EA system uses a relational database and has graphical features to quickly access and process the data. Under the current version of EA, Ml is calculated by reading the maximum amplitude on Wood Anderson simulated traces. Several other magnitudes (M_W from spectra, MS, MB, Ms, Mwp) can also be calculated within EA. The EA database can also accommodate other externally provided event parameters, such as fault plane solutions. AFAD also uses SEISAN (*Havskov and Ottemöller*, 1999; *Ottemöller et al.*, 2013) for manual processing of larger events (M$>$ 3.5) to calculate fault plane and moment tensor solutions (*Kılıç et al.*, 2016a).

Outstanding features of Earthquake Analysis (EA) software are:

- Windows based,
- user-friendly,
- easy to install,

- reads popular formats (gcf, sac, seisan, miniseed, suds) directly,
- rapid phase picking,
- computes magnitude automatically,
- based on a relational database.

EA has been developed with Microsoft's Visual Basic 6.0. Several users can simultaneously work with EA on data analysis if EA uses a SQL server. When using a SQL Server, sending e-mails and SMS as well as publishing information on our web pages is performed automatically (Fig. 5.17).

User information is recorded together with the analysed events making it possible to determine user errors (incorrect pickings, solutions with high RMS value etc.). EA matches events and wave forms according to time, station code and components.

EA can query catalogue information from its own database, the Seisan SFILE directory, Seiscomp3 and the USGS PDE catalogue. Data from Seiscomp3 is received via an ARC Link connection. By entering a specific time and the record length, waveforms can be displayed from the current time (UTC) to 5, 10 or 15 minutes backwards (Fig. 5.18). This process makes it easy to analyse the data in real time.

Different tools such as filters, move, resize etc. can be applied to one or more selected waveforms. Waveforms can be sorted according to station, agency and network code or P phase in ascending or descending order. Stations can be sorted according to distance from a selected station. All Butterworth filters such as LP, HP, BP can be applied.

EA can generate residual, Wadati and travel time graphs in order to check the accuracy of the phase readings. It is possible to use multiple crustal models for hypocentre determination. EA uses two different programs, either Hypo2000 (*Klein*, 2002) or Hypocenter (*Lienert and Havskov*, 1995).

We realized two significant projects with data obtained from the TNSN which are: "Development, Pro-

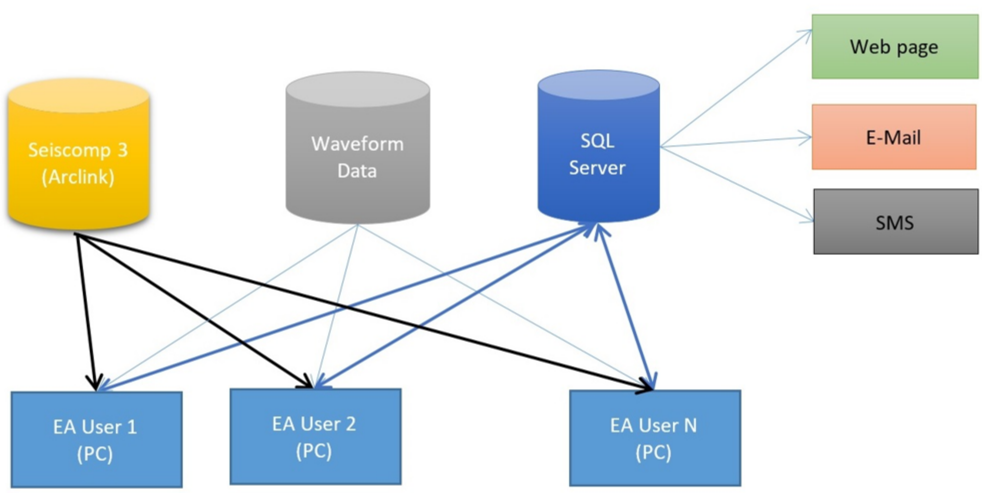

Figure 5.17: *General operational principles of EA Software.*

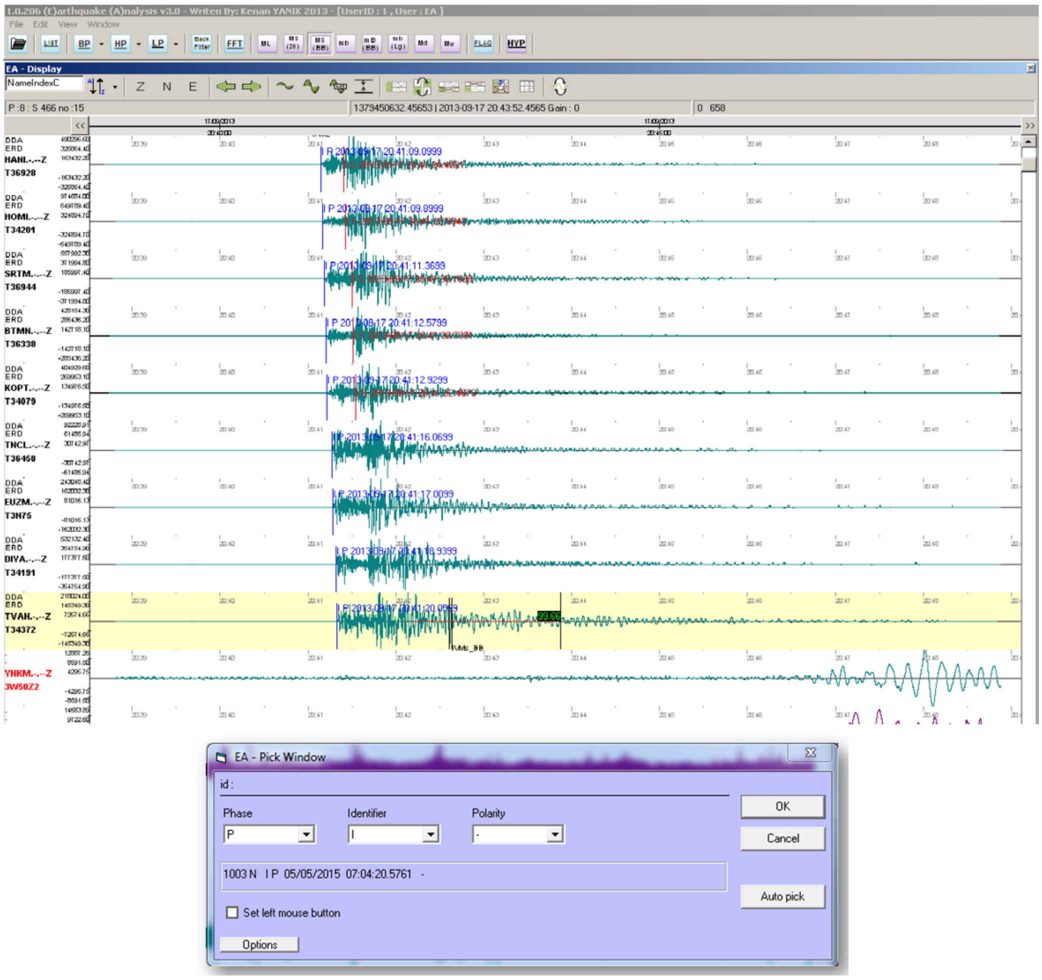

Figure 5.18: *EA waveform and picking window.*

gramming and Calibrating M_W, Ms and Ml Magnitude Scales for the Benefit of National Seismological Network of Turkey” and “The Ambient Noise Analysis of Turkish National Seismic Network”.

Development, Programming and Calibrating M_W, Ms and Ml Magnitude Scales for the Benefit of National Seismological Network of Turkey

The project’s aim is the calibration of Ml scale and implementation of standard Ml, M_W, MS magnitude computations into the Earthquake Analysis (EA) system.

Algorithms to compute Ml, Ms, MS, Mb, MB and M_W magnitudes are implemented into EA as new subroutines. The modules have been compared and verified against SEISAN. The new program module in EA computes M_W by a spectrum method. The attenuation parameters (Qo, alpha and kappa) are evaluated by two approaches (QLg inversion and by an iterative optimization technique). M_W magnitudes computed by the new codes comply with the values obtained from Dreger Moment Tensor Inversion (SEISAN) (*Dreger et al.*, 2000) as well as those reported by other international agencies. AFAD Earthquake Department is now capable of reporting seven different magnitudes for local and regional earthquakes (*Özyazıcıoğlu et al.*, 2013).

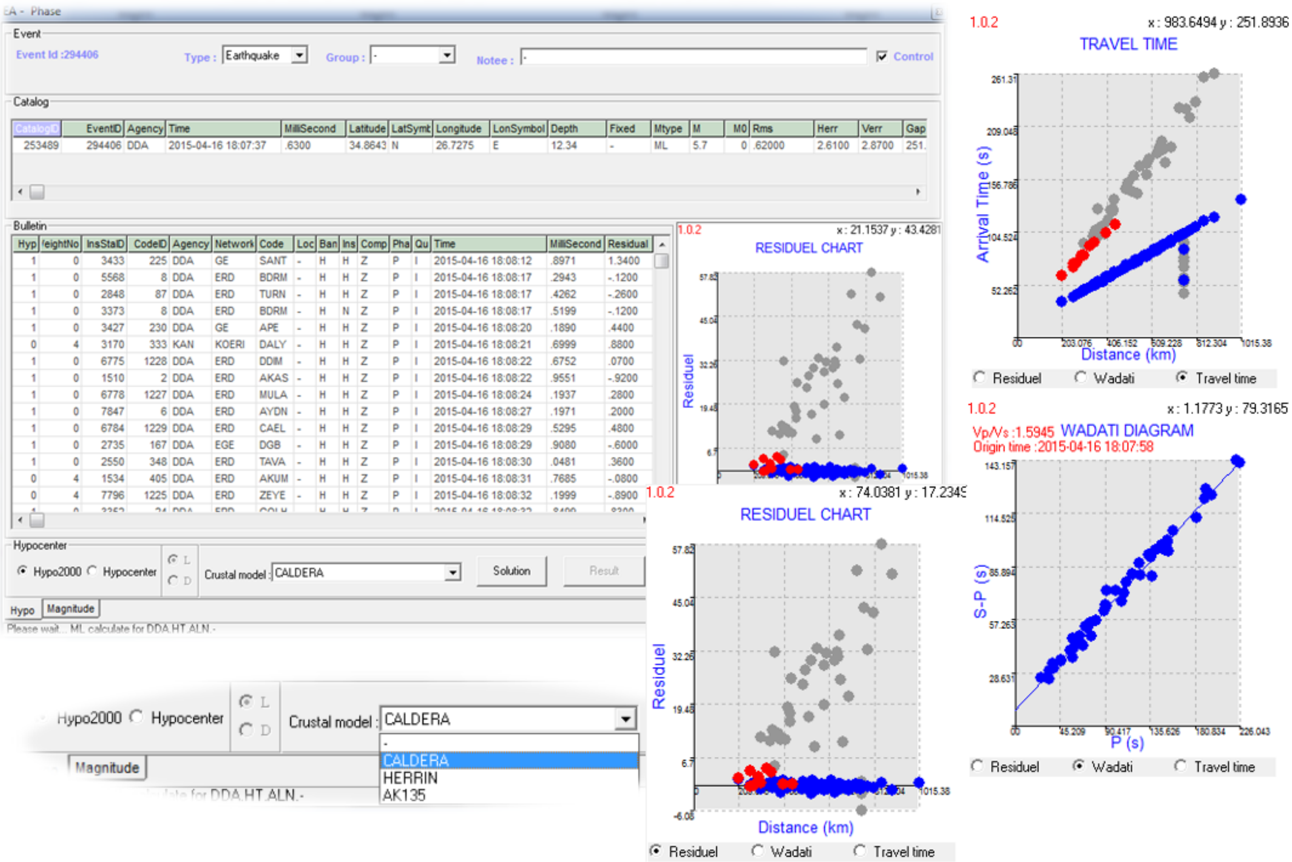

Figure 5.19: Phase and hypocenter solution windows and Wadati diagram, travel time curve and residuals plots in EA.

The Ambient Noise Analysis of the Turkish National Seismic Network

Ambient noise analysis is a routine evaluation of performance of seismic networks. With almost 300 broad band seismometer stations, the Turkish National Seismic Network is among the most notable in the world. This network is relatively young and is still expanding. Nevertheless, prior to the project, no efforts are reported to target evaluating the recording quality of this network or an overall noise analysis for Turkey (*Özyazıcıoğlu et al.*, 2015).

The project's aim is the determination of recording quality of Turkish National Seismic Network by extensive noise analyses and development of a noise model for Turkey. In this project diurnal, monthly and annual noise levels for each station were obtained and presented in PDF (Probability Density Function) plots and spectrograms. Ambient noise distribution and noise models for Turkey have been developed with additional stations. For the TNSN, annual, monthly and daily probabilistic density functions and spectrograms were generated and background noise levels were determined. Possible sources (i.e. near sea, volcanically active, weak bed rock etc.) were discussed and recommendations were made to eliminate noise. As a result, a considerable number of instruments have been found to be malfunctioning due to buggy firmware; when firmware updates were applied noise levels in these stations came to normal levels. Furthermore, nearly 50 stations are found to have been used with incorrectly defined response functions.

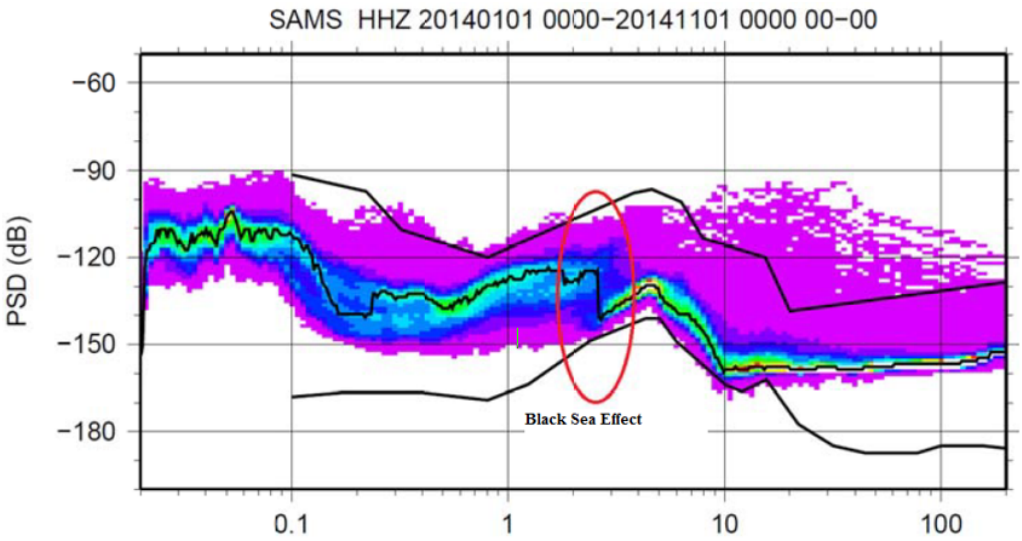

Figure 5.20: *PSD plot of noise related to the Black Sea (SAMS Station Black Sea Shore) (Kılıç et al., (2016b).*

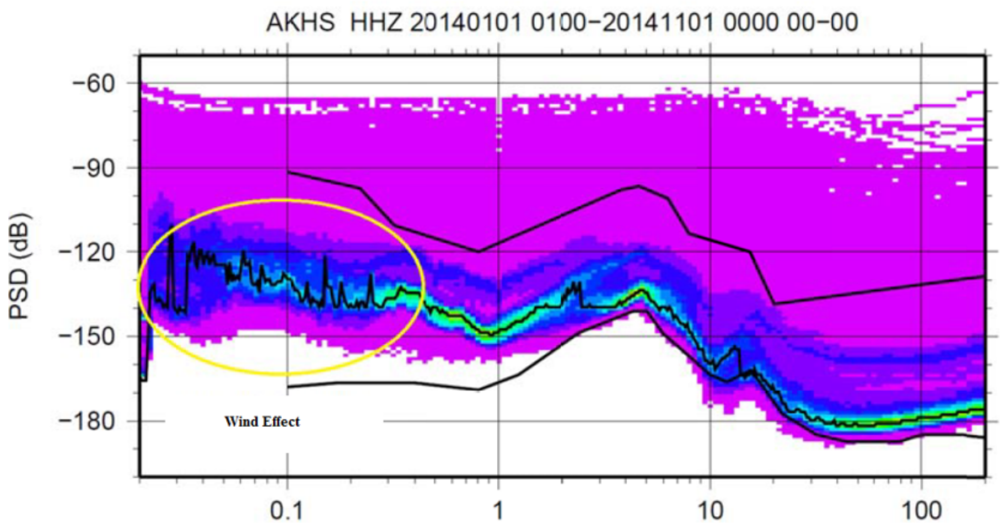

Figure 5.21: *Low-Period noise generated by a nearby post vibrating by the wind (AKHS Station, Manisa, Akhisar) (Kılıç et al., 2016b).*

Another interesting result of our research is the systematic display of high noise up to some characteristic period in stations close to the sea or large size inland lakes. It is seen that these characteristic periods of high noise are related to the size of the sea or lake (proportional to the surface area or volume of water).

Examples of power spectrum density (PSD) plots are given in Figures 5.20 and 5.21. (*Özyazıcıoğlu et al.*, 2015).

Strong-Motion Data Processing

Acceleration records in the database are composed of three types of data. These are: raw waveforms in ASCII format, processed data and RRSM (Rapid Raw Strong Motion Database, `http://www.orfeus-eu.org/rrsm/`) including PGA (Peak Ground Acceleration), PGV (Peak Ground Velocity), PSA (Peak Spectral Acceleration) and instrumental intensity for the purpose of providing input for ShakeMap (Wald et al. 2006). Unprocessed data obtained from different types of instruments are manually analysed and converted to ASCII format by the expert seismologist in the first 24h after the event origin time.

RRSM data, in other words, automatic peak-motion parametric data, that is used as input to ShakeMap is automatically obtained from the SeisComp3 scwfparam module (`http://www.seiscomp3.org/doc/seattle/current/apps/scwfparam.html`) (*Cauzzi et al.*, 2013) once a new earthquake origin is available. AFAD ShakeMaps are automatically generated using the measured ground motions recorded by the strong motion network. For earthquakes greater than 4.5, ShakeMap is revised with the AFAD magnitude, epicentre and fault parameters manually.

The processed data was obtained within the project "Compilation of The Turkish National Strong Motion Network Database According to International Standard" (*Akkar*, 2009). With this project, Turkish national strong-ground motion station site information was provided and accelerometric data was processed. These outputs have been disseminated via an internet-based interface. Information from a total of 17 national and international seismic agencies was used to obtain geophysical parameters of the earthquakes during the compilation of the strong-motion database. When the seismic agency information was insufficient, the relevant reports and technical papers were used to determine the required earthquake parameters. Raw accelerometric data was processed uniformly with a consistent methodology through the windows-based software called USDP (Utility Software for Data Processing) that was developed during the course of the project (*Akkar and Bommer*, 2006). In the framework of processing, 3000 events and 4600 raw accelerometric data between 1976 and 2008 were processed uniformly. Elastic spectral parameters of all records were also determined for researchers by using the same filter method.

5.2.4 Turkey Earthquake Data Center System (TDVM)

One of the major problems for geoscientists is the lack of access to data. With AFAD-TDVM, researchers will have access to the data they need from a single center. Thus, the number of researchers using reliable seismological data will increase and more contributions to solve seismological problems will be achieved.

AFAD-TDVM is coordinated by AFAD Earthquake Department for the purpose of providing data access to the TNSN from a single center. In this way, it is ensured that researchers in both our country and other countries have access to the data quickly and reliably.

Through the AFAD-TDVM, all users have access to data via high speed and performance systems without any discrimination such as person, university or institution. The most important point regarding the performance of this system is data transmission and forming appropriate transmission paths for national and international partners.

AFAD-Earthquake data center consist of 1059 stations (weak, strong motion, borehole and GNSS). All seismological data is sent to AFAD-TDVM via the internet.

At the moment only seismic data (Waveform, Catalogues, Bulletin, Station Information etc.) is stored within the system. Offline data will be included after related projects finish and restrictions on the use of those expired. We collect station information in dataless format, which allows us to revise all information in case of any instrument change. Seismic data is available via `tdvm.afad.gov.tr`. AFAD Earthquake Department shares earthquake data and bulletin catalogues with the ISC (agency code DDA), EMSC and ORFEUS. AFAD Earthquake Department also exchanges real time earthquake data with several countries (Azerbaijan, Geogia, Bulgaria, Romania, Albania, Uzbekistan, Bosnia and Herzegovina and Hungary) under mutual protocols.

The web page is designed to be user friendly. When the user makes a query, all data will be accessible within a minute. The data is sent to the user's e-mail as mini-seed, full-seed or dataless (SEED File).

Data providers for Turkey Earthquake Data Center are: AFAD Earthquake Department, Antalya Metropolitan Municipality, Atatürk University, Natural Movement Research Foundation, Düzce Municipality, Kocaeli Metropolitan Municipality, Osmangazi Municipality, Süleyman Demirel University, Gazi University, Anadolu University, General Directorate of Hydraulic Works, Cumhuriyet University, Dokuz Eylül University, İskenderun Municipality, Kocaeli Metropolitan Municipality, Sakarya University, TÜBİTAK-Marmara Research Centre Geo and Marine Sciences Institute, Boğaziçi University Kandilli Observatory And Earthquake Research Institute, General Directorate of Mineral Research and Exploration, General Directorate of Turkish State Railways.

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6

The ISC Bulletin Rebuild Project: 1985 – 1990

The ISC has completed work on the next 5 years of the Bulletin Rebuild project, covering the period from 1985 – 1990. The improved Bulletin has been uploaded to the live account and is now available for use by all interested parties.

The broad aims of the Rebuild project are to update, extend and homogenise the ISC Bulletin using the same velocity model, modern methods and consistent quality criteria, as well as adding additional previously unavailable data. For a more in-depth description please see the Summary from January – June 2015 (*International Seismological Centre*, 2018) and the paper published on the data years 1964 – 1979 (*Storchak et al.*, 2017). Figure 6.1 compares the ISC locations before and after the Rebuild project for the entirety of the released rebuilt ISC Bulletin from 1964 to 1990.

To clarify, the rebuilt ISC Bulletin becomes the ISC Bulletin as we release it. If you search for events before 1990 on our website, you are now viewing the rebuilt Bulletin. We welcome any feedback.

Also, please be aware that there are big plans for the Rebuild project this year and we plan to release the entire rebuild ISC Bulletin (1964 – 2010) early in 2020.

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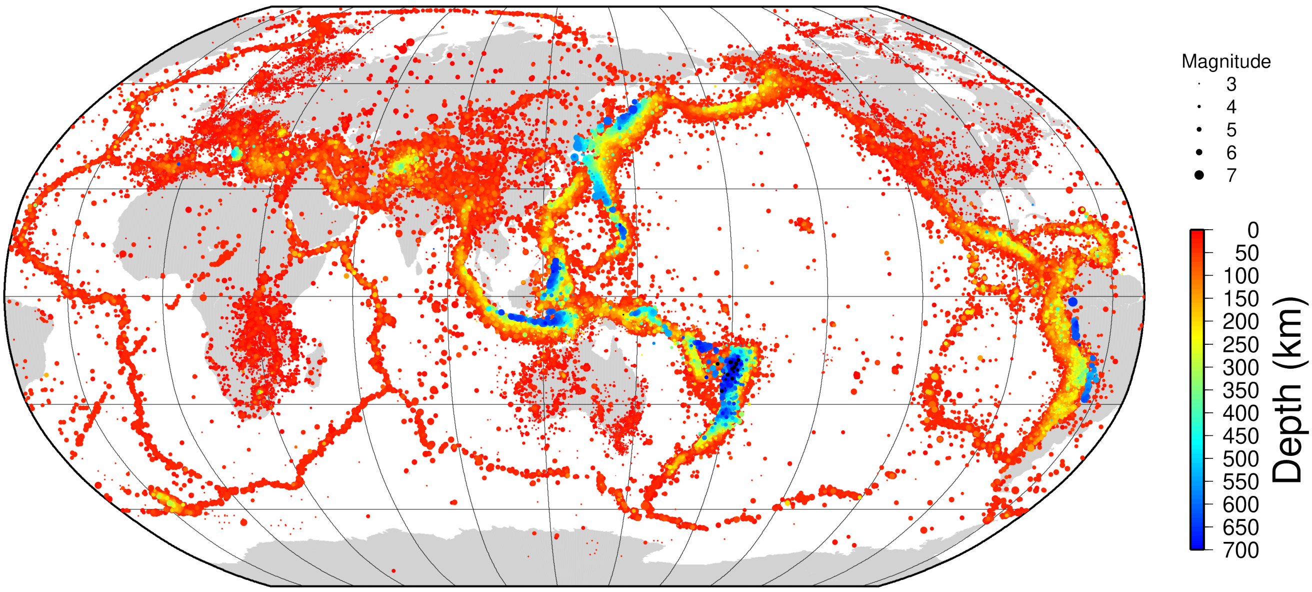
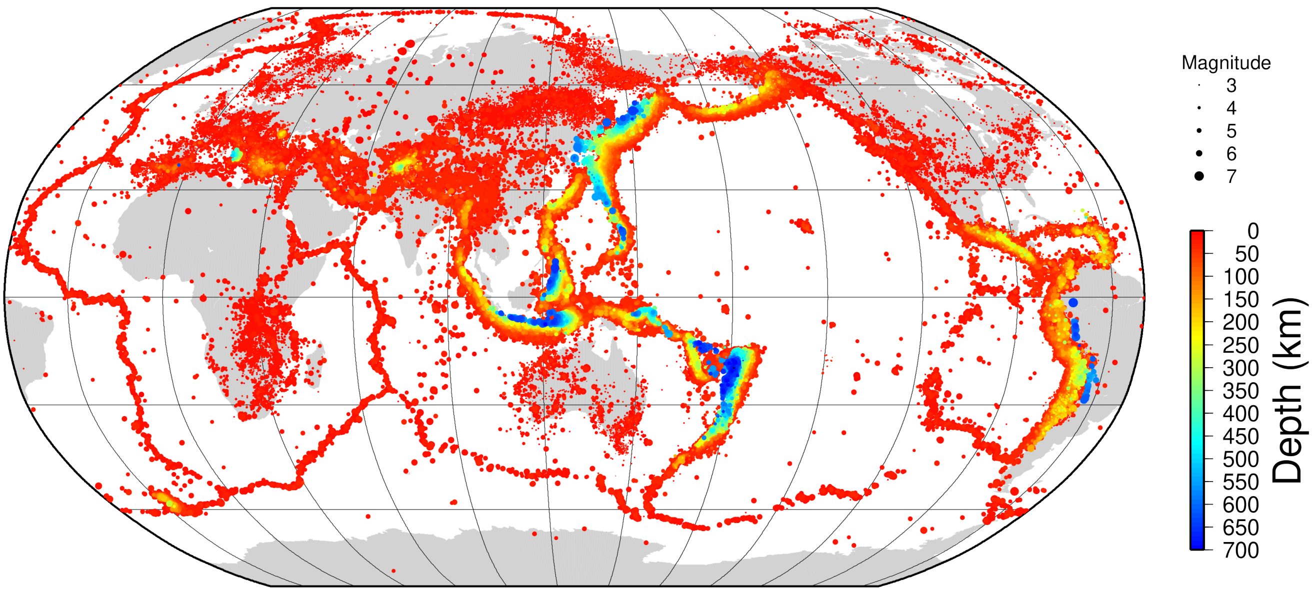


(a) Original ISC Bulletin



(b) Rebuilt ISC Bulletin

Figure 6.1: *Locations, depths and magnitudes of ISC relocated events, comparing the original ISC Bulletin (a) and the rebuilt ISC Bulletin (b). Data shown covers the period of 1964–1990.*

7

Summary of Seismicity, July – December 2016

The largest event reported in this Summary's time period was the M_W 7.9 Solomon Islands earthquake on 17 December 2016 (10:51:11.63 (UTC), 4.5611°S, 153.4407°E, 105.2 km, 2315 stations (ISC)). The event nucleated at about 100 km depth near the New Britain/Solomon Islands Trench where the Solomon Plate subducts beneath the South Bismark and Pacific Plates. Findings of *Lay et al.* (2017) suggest that the event first ruptured a deep intraslab fault, co-seismically triggering rupture along the plate boundary megathrust at shallower depth, while *Lee et al.* (2018) found that the rupture may have originated from the deep subduction interface and extended all the way up to the trench, implying that the deep subduction interface could be seismogenic.

The events that were discussed most by the scientific community in this Summary's time period were the events of the damaging central Italy seismic sequence that started in August 2016 and consisted of three main events. The sequence occurred along an approximately 60 km long normal-fault system in a northwest–southeast direction in the Central Apennines (*Luzi et al.*, 2017; *Chiaraluce et al.*, 2017). The first main event was the M_W 6.2 Amatrice event (24/08/2016, 01:36:33.73 (UTC), 42.6769°N, 13.1965°E, 11.6 km, 3111 stations (ISC), 147 articles to date in the ISC Event Bibliography (*Di Giacomo et al.*, 2014; *International Seismological Centre*, 2019)). The event caused about 300 fatalities and severe damage to the villages of Amatrice and Accumoli (*Luzi et al.*, 2017; *Chiaraluce et al.*, 2017). The second main event with a magnitude of M_W 6.1 occurred on 26 October farther north near Ussita (19:18:08.03 (UTC), 42.9119°N, 13.0960°E, 7.9 km, 3123 stations, 44 articles to date in the ISC Event Bibliography). The third and largest main event with a magnitude of M_W 6.6 hit the region a couple of days later on 30 October in an area between the two previous events close to Norcia (06:40:19.16 (UTC), 42.8320°N, 13.1035°E, 9.6 km, 3174 stations, 82 articles to date in the ISC Event Bibliography). Both October events caused additional damage and destruction to buildings and infrastructure that were already damaged by the Amatrice event. Fortunately, the events did not cause casualties because inhabitants were already evacuated or had abandoned the already damaged buildings. But about 20,000 people were left homeless because villages and towns in the area were severely damaged or destroyed by the sequence (*Luzi et al.*, 2017; *Chiaraluce et al.*, 2017).

Another event that raised a lot of scientific interest was the M_W 7.8 Kaikoura earthquake with 129 entries to date in the ISC Event Bibliography (13/11/2016 11:02:59.74 (UTC), 42.6653°S, 172.9227°E, 16.0 km, 2384 stations (ISC)). It was one of the largest events that struck New Zealand and showed an unusually complex rupture pattern where multiple faults in the Australian plate above the subduction-thrust broke and rupture was transferred between faults that were up to 15 km away (*Hamlin et al.*, 2017). There is an ongoing discussion if and to what extent the plate interface and/or other offshore seismic sources might be involved in the rupture process of the Kaikoura event (e.g. *Mouslopoulou et al.*, 2019, and references therein).

A non-tectonic event that was recorded by over 1500 stations around the globe was the DPR Korea underground nuclear test in September (09/09/2016 00:30:00.80 (UTC), 41.2826°N, 129.0435°E, 0 km, 1611 Stations (ISC)). It was the 5th test conducted at the North Korean Nuclear Test Site (NKTS) since 2006 (*CTBTO*, 2019) and the second test in 2016 after the first one was carried out in January.

The number of events in this Bulletin Summary categorised by type are given in Table 7.1.

Table 7.1: *Summary of events by type between July and December 2016.*

felt earthquake	1025
known earthquake	270114
known chemical explosion	8742
known induced event	3387
known mine explosion	1038
known rockburst	634
known experimental explosion	62
suspected collapse	1
suspected earthquake	69805
suspected chemical explosion	947
suspected induced event	132
suspected mine explosion	4673
suspected nuclear explosion	1
suspected rockburst	151
suspected experimental explosion	3
unknown	251
total	360966

Table 7.2: *Summary of the earthquakes of magnitude Mw ≥ 7 between July and December 2016.*

Date	lat	lon	depth	Mw	Flinn-Engdahl Region
2016-12-17 10:51:11	-4.56	153.44	105	7.9	New Ireland region
2016-11-13 11:02:59	-42.67	172.92	15	7.8	South Island
2016-12-08 17:38:46	-10.79	161.28	47	7.8	Bougainville-Solomon Islands region
2016-07-29 21:18:24	18.58	145.53	213	7.7	Mariana Islands
2016-12-25 14:22:26	-43.42	-73.92	33	7.6	Southern Chile
2016-08-19 07:32:23	-55.36	-31.99	15	7.5	South Georgia Island region
2016-08-12 01:26:35	-22.63	173.03	13	7.2	Southeast of Loyalty Islands
2016-08-29 04:30:00	-0.23	-17.85	23	7.1	North of Ascension Island
2016-09-01 16:38:01	-37.27	178.79	21	7.1	Off east coast of North Island
2016-11-24 18:43:47	11.92	-88.87	14	7.0	Off coast of central America

The period between July and December 2016 produced 10 earthquakes with $M_W \geq 7$; these are listed in Table 7.2.

Figure 7.1 shows the number of moderate and large earthquakes in the second half of 2016. The distribution of the number of earthquakes should follow the Gutenberg-Richter law.

Figures 7.2 to 7.5 show the geographical distribution of moderate and large earthquakes in various magnitude ranges.

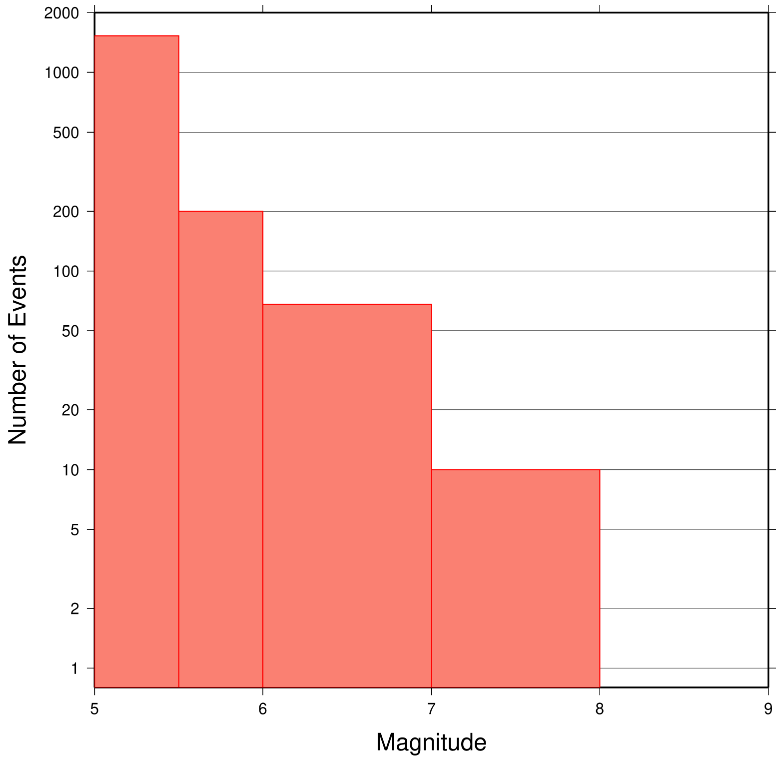


Figure 7.1: *Number of moderate and large earthquakes between July and December 2016. The non-uniform magnitude bias here correspond with the magnitude intervals used in Figures 7.2 to 7.5.*

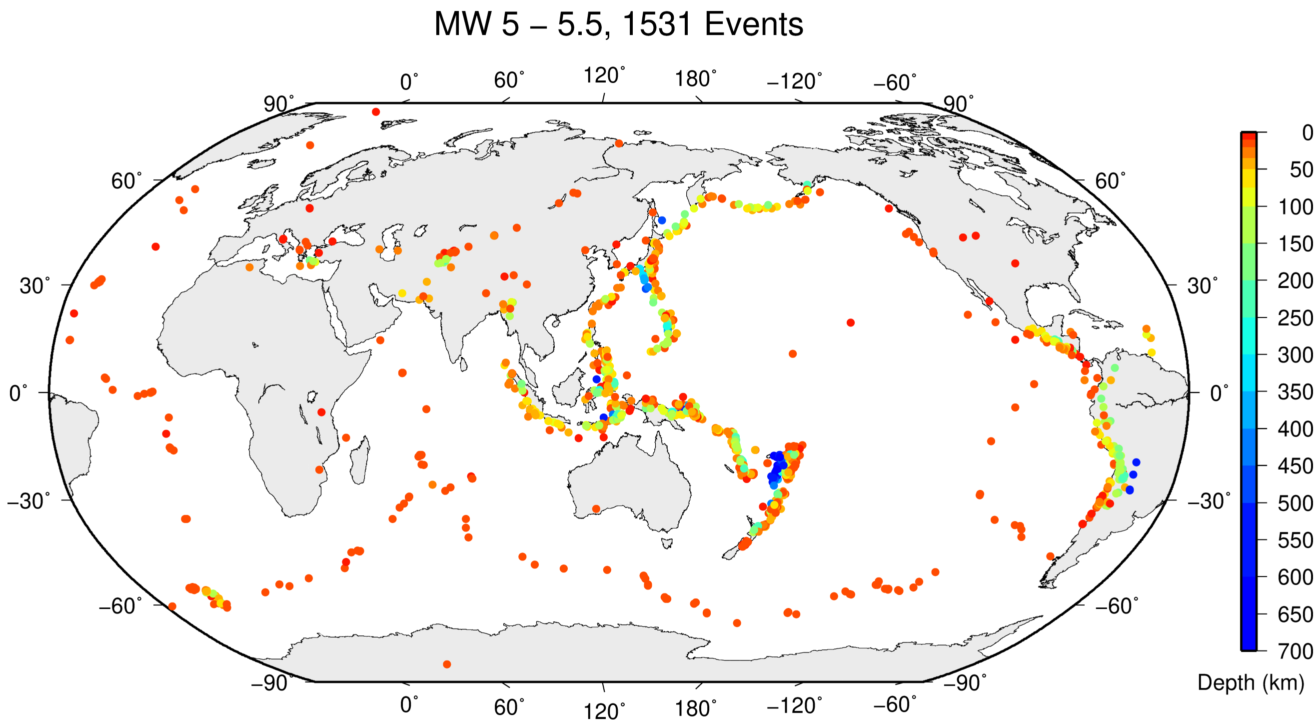


Figure 7.2: *Geographic distribution of magnitude 5-5.5 earthquakes between July and December 2016.*

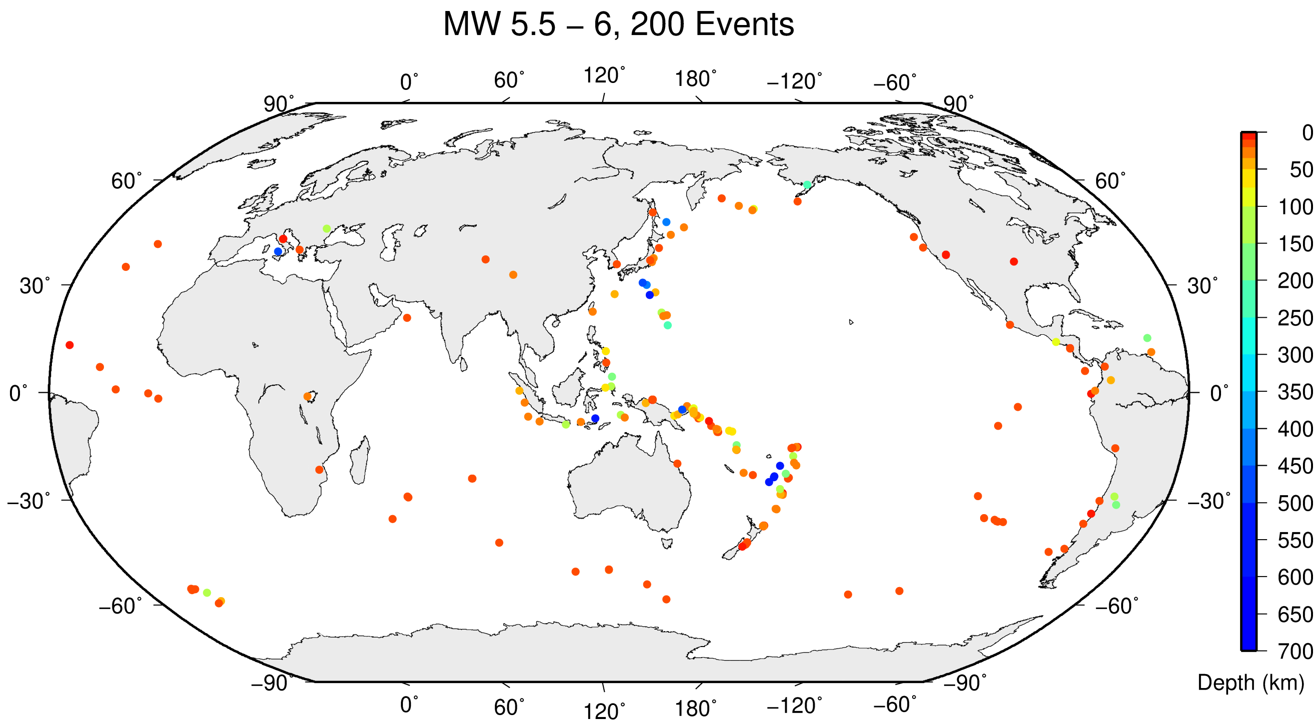


Figure 7.3: *Geographic distribution of magnitude 5.5-6 earthquakes between July and December 2016.*

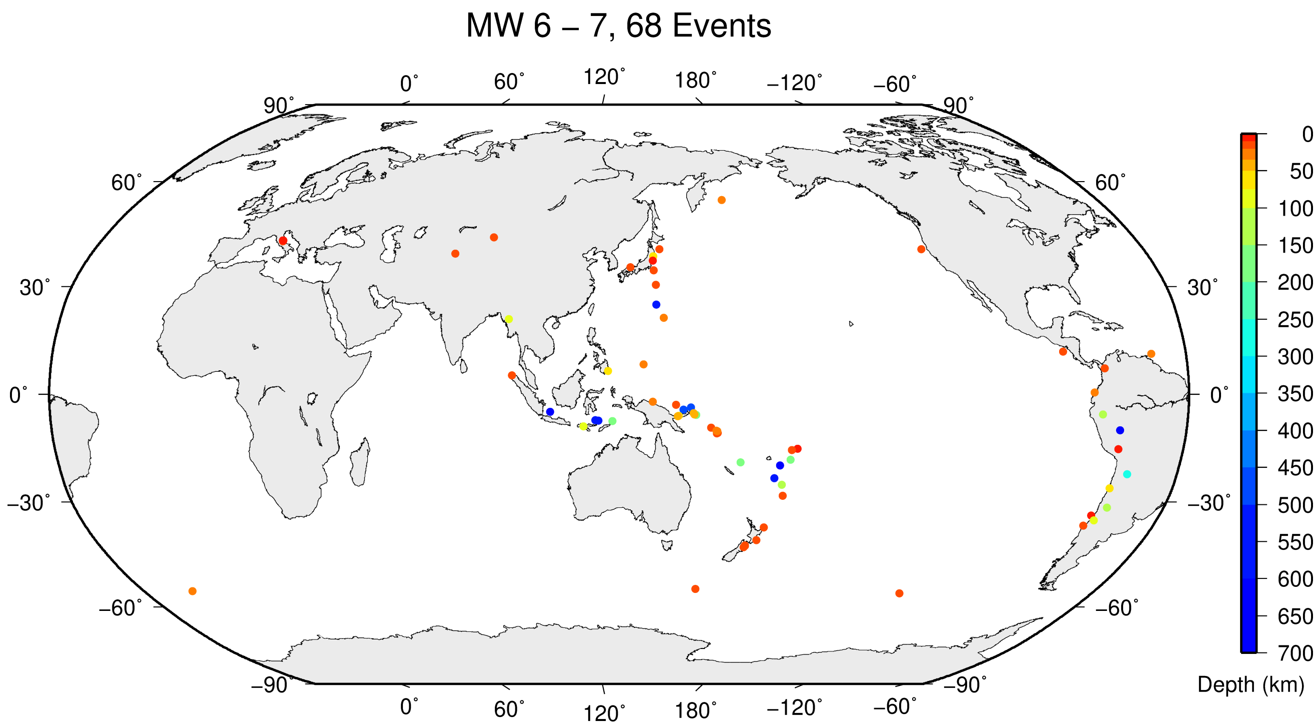


Figure 7.4: *Geographic distribution of magnitude 6-7 earthquakes between July and December 2016.*

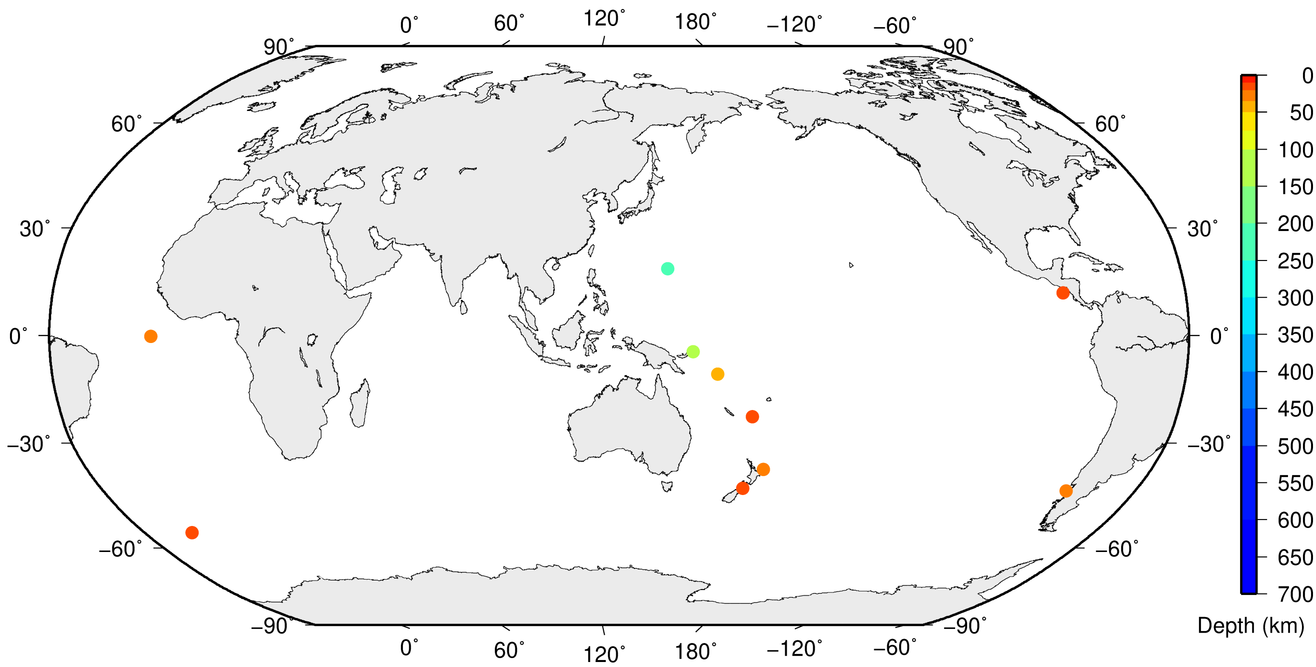


Figure 7.5: *Geographic distribution of magnitude 7-8 earthquakes between July and December 2016.*

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8

Statistics of Collected Data

8.1 Introduction

The ISC Bulletin is based on the parametric data reports received from seismological agencies around the world. With rare exceptions, these reports include the results of waveform review done by analysts at network data centres and observatories. These reports include combinations of various bulletin elements such as event hypocentre estimates, moment tensors, magnitudes, event type and felt and damaging data as well as observations of the various seismic waves recorded at seismic stations.

Data reports are received in different formats that are often agency specific. Once an authorship is recognised, the data are automatically parsed into the ISC database and the original reports filed away to be accessed when necessary. Any reports not recognised or processed automatically are manually checked, corrected and re-processed. This chapter describes the data that are received at the ISC before the production of the reviewed Bulletin.

Notably, the ISC integrates all newly received data reports into the automatic ISC Bulletin (available on-line) soon after these reports are made available to ISC, provided it is done before the submission deadline that currently stands at 12 months following an event occurrence.

With data constantly being reported to the ISC, even after the ISC has published its review, the total data shown as collected, in this chapter, is limited to two years after the time of the associated reading or event, i.e. any hypocentre data collected two years after the event are not reflected in the figures below.

8.2 Summary of Agency Reports to the ISC

A total of 146 agencies have reported data for July 2016 to December 2016. The parsing of these reports into the ISC database is summarised in Table 8.1.

Table 8.1: *Summary of the parsing of reports received by the ISC from a total of 146 agencies, containing data for this summary period.*

	Number of reports
Total collected	4282
Automatically parsed	3239
Manually parsed	1043

Data collected by the ISC consists of multiple data types. These are typically one of:

- Bulletin, hypocentres with associated phase arrival observations.
- Catalogue, hypocentres only.
- Unassociated phase arrival observations.

In Table 8.2, the number of different data types reported to the ISC by each agency is listed. The number of each data type reported by each agency is also listed. Agencies reporting indirectly have their data type additionally listed for the agency that reported it. The agencies reporting indirectly may also have 'hypocentres with associated phases' but with no associated phases listed - this is because the association is being made by the agency reporting directly to the ISC. Summary maps of the agencies and the types of data reported are shown in Figure 8.1 and Figure 8.2.

Table 8.2: *Agencies reporting to the ISC for this summary period. Entries in bold are for new or renewed reporting by agencies since the previous six-month period.*

Agency	Country	Directly or indirectly reporting (D/I)	Hypocentres with associated phases	Hypocentres without associated phases	Associated phases	Unassociated phases	Amplitudes
TIR	Albania	D	315	16	4914	53	971
CRAAG	Algeria	D	296	0	1079	144	0
LPA	Argentina	D	0	0	0	544	0
SJA	Argentina	D	286	102	13252	0	2905
NSSP	Armenia	D	59	0	642	0	0
AUST	Australia	D	983	91	23840	0	0
CUPWA	Australia	D	55	0	716	0	0
IDC	Austria	D	19392	0	610638	0	560837
VIE	Austria	D	5971	82	58578	2467	57658
AZER	Azerbaijan	D	164	0	6293	0	2
UCC	Belgium	D	870	34	7543	56	1521
SCB	Bolivia	D	598	0	7663	0	1412
RHSSO	Bosnia and Herzegovina	D	710	0	14211	8863	0
VAO	Brazil	D	1000	11	30556	0	0
SOF	Bulgaria	D	115	1	803	2424	0
SOMC	Cameroon	D	0	0	0	33	0
OTT	Canada	D	1858	22	49028	0	3371
PGC	Canada	I OTT	1272	0	37169	0	0
GUC	Chile	D	3747	361	118772	6030	33079
BJI	China	D	1543	39	112275	36088	77879
ASIES	Chinese Taipei	D	0	22	0	0	0
TAP	Chinese Taipei	D	18461	26	711152	0	0
RSNC	Colombia	D	8409	15	200148	15326	60656
UCR	Costa Rica	D	867	15	18894	35	876
ZAG	Croatia	D	0	1	0	43260	0
SSNC	Cuba	D	623	0	6520	0	2405
NIC	Cyprus	D	484	0	13877	0	7768
IPEC	Czech Republic	D	498	0	3345	23020	1516
PRU	Czech Republic	D	6171	2	51295	269	13372
WBNET	Czech Republic	D	203	0	3653	0	3644
KEA	Democratic People's Republic of Korea	D	207	0	3764	0	1988
DNK	Denmark	D	1715	1139	22680	18266	5708
OSPL	Dominican Republic	D	673	5	7612	0	2433
IGQ	Ecuador	D	0	101	5012	0	0
HLW	Egypt	D	833	0	6794	0	0
SNET	El Salvador	D	1105	76	20035	467	3107
SSS	El Salvador	I UCR	126	0	0	0	0
EST	Estonia	I HEL	259	7	0	0	0
AAE	Ethiopia	D	138	3	1210	992	144

Table 8.2: *(continued)*

Agency	Country	Directly or indirectly reporting (D/I)	Hypocentres with associated phases	Hypocentres without associated phases	Associated phases	Unassociated phases	Amplitudes
SKO	FYR Macedonia	D	1101	2	13611	3863	2758
FIA0	Finland	I HEL	2	2	0	0	0
HEL	Finland	D	8123	4153	194186	0	26247
CSEM	France	I NEIC	2111	805	0	0	0
LDG	France	D	3465	202	77254	0	31592
STR	France	D	2325	0	54408	2	0
PPT	French Polynesia	D	1516	1	10824	402	11031
TIF	Georgia	D	0	273	0	7073	0
AWI	Germany	D	2716	1	13010	2189	0
BGR	Germany	D	235	335	8315	0	221
BNS	Germany	I BGR	4	27	0	0	0
BRG	Germany	D	0	0	0	8543	4337
BUG	Germany	I BGR	1	21	0	0	0
CLL	Germany	D	8	0	300	11035	3515
GDNRW	Germany	I BGR	2	7	0	0	0
GFZ	Germany	I SJA	121	1	0	0	0
HLUG	Germany	I BGR	3	1	0	0	0
LEDBW	Germany	I BGR	26	9	0	0	0
LER	Germany	I BGR	0	1	0	0	0
ATH	Greece	D	7845	57	207144	0	71852
THE	Greece	D	4456	53	87129	5211	30438
UPSL	Greece	D	0	1	0	0	0
GCG	Guatemala	D	458	0	2914	0	0
HKC	Hong Kong	D	0	0	0	14	0
BUD	Hungary	D	0	0	0	6269	0
KRSZO	Hungary	D	275	18	3453	0	1319
REY	Iceland	D	42	0	1681	0	0
HYB	India	D	803	10	1981	0	189
NDI	India	D	534	408	14133	2574	3348
DJA	Indonesia	D	3854	86	68776	0	91299
TEH	Iran	D	547	45	27124	0	6300
THR	Iran	D	11	2	304	0	88
ISN	Iraq	D	186	0	1185	0	434
GII	Israel	D	479	0	7876	0	0
GEN	Italy	D	826	0	19267	4	0
MED_RCMT	Italy	D	0	206	0	0	0
RISSC	Italy	D	10	0	110	0	0
ROM	Italy	D	48842	160	5120274	1462030	3500169
TRI	Italy	D	0	0	0	6077	0
LIC	Ivory Coast	D	735	0	2205	0	2188
JSN	Jamaica	D	109	0	506	5	0
JMA	Japan	D	150629	6874	890971	0	28127
NIED	Japan	D	0	847	0	0	0
SYO	Japan	D	0	0	0	1149	0
JSO	Jordan	D	15	3	159	0	155
NNC	Kazakhstan	D	9090	0	108549	0	97551
SOME	Kazakhstan	D	5388	122	91991	0	82356
KNET	Kyrgyzstan	D	1225	0	10138	0	2466
KRNET	Kyrgyzstan	D	4454	0	57634	0	0
LVSN	Latvia	D	225	0	3032	0	1645
GRAL	Lebanon	D	265	0	1831	344	0
LIT	Lithuania	D	388	371	3290	2027	192
MCO	Macao, China	D	0	0	0	50	0
TAN	Madagascar	D	0	0	0	156	0
GSDM	Malawi	D	0	0	0	288	0
KLM	Malaysia	D	102	0	373	0	0
ECX	Mexico	D	815	3	20542	0	3905
MEX	Mexico	D	8457	114	126646	0	0
MOLD	Moldova	D	0	0	0	2208	1088
PDG	Montenegro	D	532	2	12365	0	6059
CNRM	Morocco	D	1855	0	18246	0	0
NAM	Namibia	D	97	0	791	12	0

Table 8.2: *(continued)*

Agency	Country	Directly or indirectly reporting (D/I)	Hypocentres with associated phases	Hypocentres without associated phases	Associated phases	Unassociated phases	Amplitudes
DMN	Nepal	D	1412	0	13313	0	8584
DBN	Netherlands	I BGR	0	2	0	0	0
NOU	New Caledonia	D	4722	32	74132	0	6196
WEL	New Zealand	D	17686	277	617933	80	594199
INET	Nicaragua	D	1581	8	10949	8	282
BER	Norway	D	3290	2037	60507	3792	15828
NAO	Norway	D	2631	1155	5787	0	2374
OMAN	Oman	D	588	0	19275	0	0
MSSP	Pakistan	D	0	0	0	1067	0
UPA	Panama	D	627	0	8797	92	61
ARE	Peru	I NEIC	12	88	0	0	0
LIM	Peru	I NDI	1	2	0	0	0
MAN	Philippines	D	0	4929	0	50611	11411
WAR	Poland	D	0	0	2	7707	382
IGIL	Portugal	D	395	0	1899	1555	1121
INMG	Portugal	D	1486	0	47591	2334	15457
PDA	Portugal	I SVSA	1	0	0	0	0
SVSA	Portugal	D	966	0	19909	3514	8297
BELR	Republic of Belarus	D	0	0	0	23590	7076
CFUSG	Republic of Crimea	D	56	5	988	605	925
KMA	Republic of Korea	D	204	0	3815	0	0
BUC	Romania	D	870	3	16706	59454	4411
ASRS	Russia	D	153	0	5359	0	1715
BYKL	Russia	D	72	0	9060	0	2961
DRS	Russia	I MOS	166	168	0	0	0
IEPN	Russia	D	136	1	1402	5344	1815
KOLA	Russia	D	335	0	2356	0	0
KRSC	Russia	D	593	0	18751	0	0
MIRAS	Russia	D	128	0	3534	0	2054
MOS	Russia	D	2162	320	322761	0	111149
NERS	Russia	D	25	0	753	0	371
NORS	Russia	I MOS	32	152	0	0	0
SKHL	Russia	D	804	791	16605	0	7598
YARS	Russia	D	422	0	5128	0	3617
SGS	Saudi Arabia	D	37	0	556	0	0
BEO	Serbia	D	1282	0	25483	0	0
BRA	Slovakia	D	0	0	0	15907	0
LJU	Slovenia	D	1266	367	18086	3370	6195
PRE	South Africa	D	1041	2	24549	0	8977
MDD	Spain	D	2842	0	62474	0	17630
MRB	Spain	D	630	0	15365	0	6499
SFS	Spain	D	688	0	4134	106	0
SSN	Sudan	D	42	1	197	0	20
UPP	Sweden	D	1429	3076	16600	0	0
ZUR	Switzerland	D	608	0	10309	0	6820
TRN	Trinidad and Tobago	D	1	1936	0	43506	0
DDA	Turkey	D	10395	2	213833	0	72558
ISK	Turkey	D	8545	28	122260	3185	73896
AEIC	U.S.A.	I NEIC	1141	525	40270	0	0
ANF	U.S.A.	I IRIS	156	1175	0	0	0
BUT	U.S.A.	I NEIC	17	14	412	0	0
GCMT	U.S.A.	D	0	2341	0	0	0
HVO	U.S.A.	I NEIC	174	8	8430	0	0
IRIS	U.S.A.	D	3078	1175	313784	0	0
LDO	U.S.A.	I NEIC	6	5	163	0	0
NCEDC	U.S.A.	I NEIC	161	20	14354	0	0
NEIC	U.S.A.	D	16166	8368	1370168	0	626562
PAS	U.S.A.	I NEIC	75	12	10357	0	0
PNSN	U.S.A.	D	0	51	0	0	0
REN	U.S.A.	I NEIC	122	24	4320	0	0

Table 8.2: *(continued)*

Agency	Country	Directly or indirectly reporting (D/I)	Hypocentres with associated phases	Hypocentres without associated phases	Associated phases	Unassociated phases	Amplitudes
RSPR	U.S.A.	D	3080	7	37900	0	0
SCEDC	U.S.A.	I IRIS	1	0	0	0	0
SEA	U.S.A.	I NEIC	40	5	2696	0	0
SLM	U.S.A.	I NEIC	37	2	1206	0	0
TUL	U.S.A.	I NEIC	887	2	0	0	0
UUSS	U.S.A.	I NEIC	34	1	748	0	0
MCSM	Ukraine	D	66	0	1483	0	178
SIGU	Ukraine	D	49	41	1280	0	630
DSN	United Arab Emirates	D	486	0	6037	0	0
BGS	United Kingdom	D	275	20	8318	0	2867
EAF	Unknown	D	1066	5	8318	3772	83
ISC-EHB	Unknown	D	0	3212	0	0	0
ISU	Uzbekistan	D	396	0	3436	0	0
CAR	Venezuela	I NEIC	1	8	0	0	0
FUNV	Venezuela	D	158	0	2919	0	0
PLV	Vietnam	D	5	0	61	0	32
LSZ	Zambia	D	3	0	10	0	0
BUL	Zimbabwe	D	968	2	7808	295	6

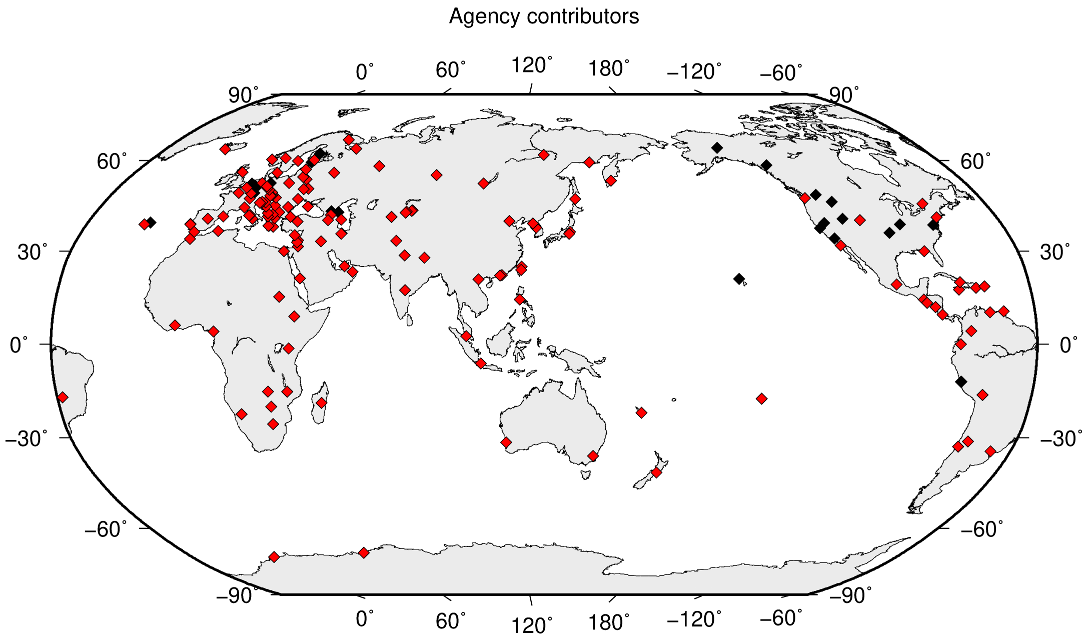


Figure 8.1: *Map of agencies that have contributed data to the ISC for this summary period. Agencies that have reported directly to the ISC are shown in red. Those that have reported indirectly (via another agency) are shown in black. Any new or renewed agencies, since the last six-month period, are shown by a star. Each agency is listed in Table 8.2.*

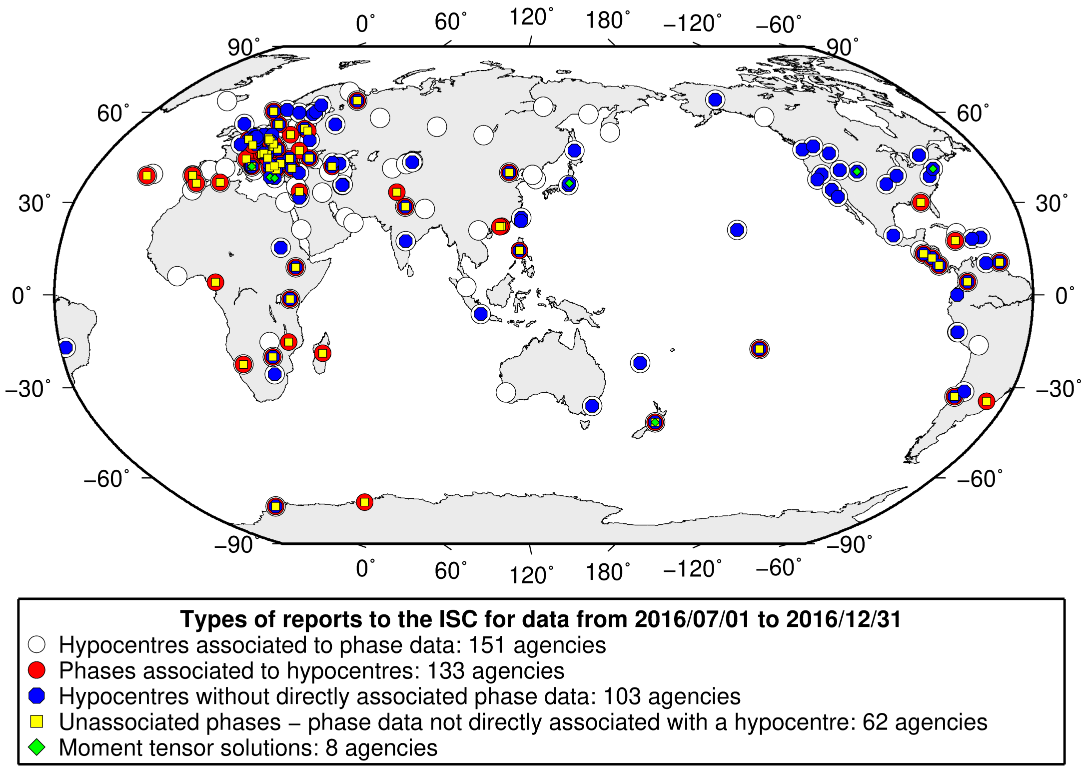


Figure 8.2: *Map of the different data types reported by agencies to the ISC. A full list of the data types reported by each agency is shown in Table 8.2.*

8.3 Arrival Observations

The collection of phase arrival observations at the ISC has increased dramatically with time. The increase in reported phase arrival observations is shown in Figure 8.3.

The reports with phase data are summarised in Table 8.3. This table is split into three sections, providing information on the reports themselves, the phase data, and the stations reporting the phase data. A map of the stations contributing these phase data is shown in Figure 8.4.

The ISC encourages the reporting of phase arrival times together with amplitude and period measurements whenever feasible. Figure 8.5 shows the percentage of events for which phase arrival times from each station are accompanied with amplitude and period measurements.

Figure 8.6 indicates the number of amplitude and period measurement for each station.

Together with the increase in the number of phases (Figure 8.3), there has been an increase in the number of stations reported to the ISC. The increase in the number of stations is shown in Figure 8.7. This increase can also be seen on the maps for stations reported each decade in Figure 8.8.

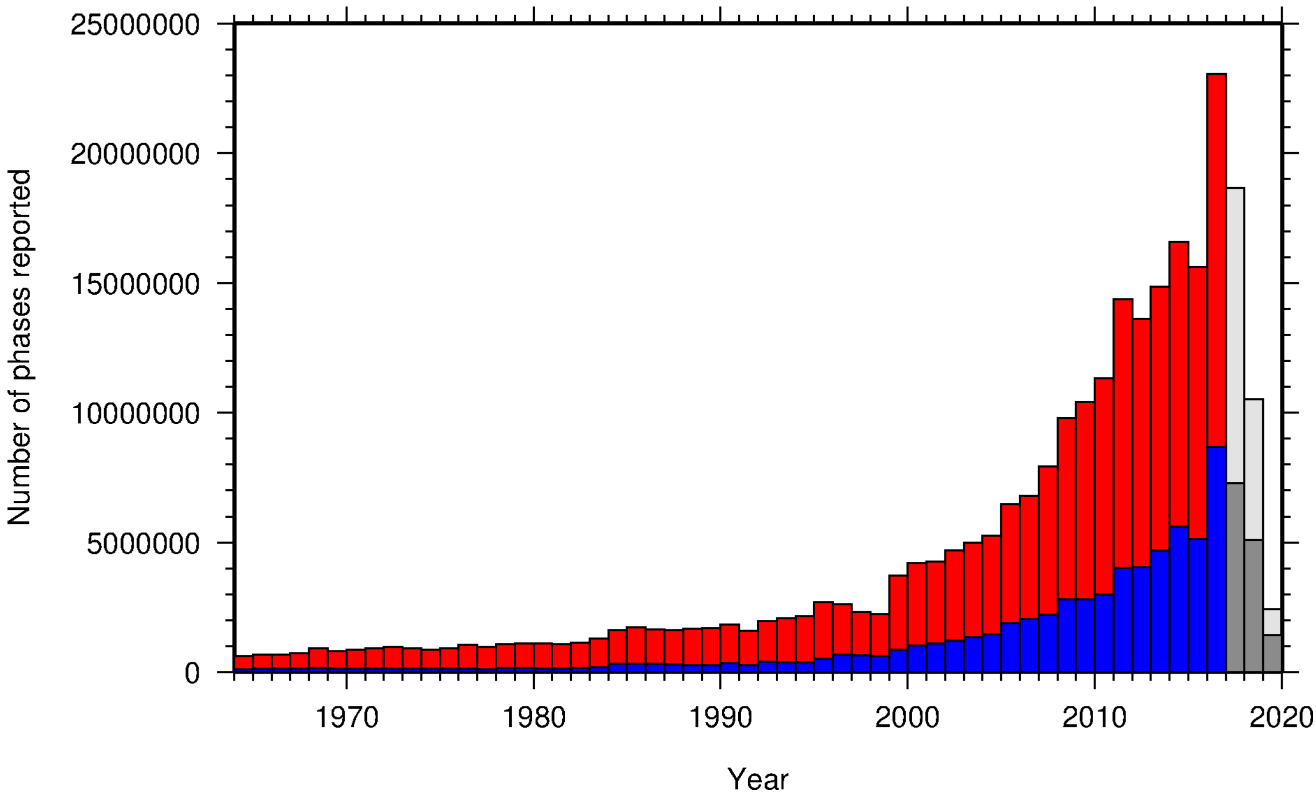


Figure 8.3: *Histogram showing the number of phases (red) and number of amplitudes (blue) collected by the ISC for events each year since 1964. The data in grey covers the current period where data are still being collected before the ISC review takes place and is accurate at the time of publication.*

Table 8.3: *Summary of reports containing phase arrival observations.*

Reports with phase arrivals	4069
Reports with phase arrivals including amplitudes	1415
Reports with only phase arrivals (no hypocentres reported)	233
Total phase arrivals received	14714380
Total phase arrival-times received	10983722
Number of duplicate phase arrival-times	1441327 (13.1%)
Number of amplitudes received	6454892
Stations reporting phase arrivals	8450
Stations reporting phase arrivals with amplitude data	4924
Max number of stations per report	2162

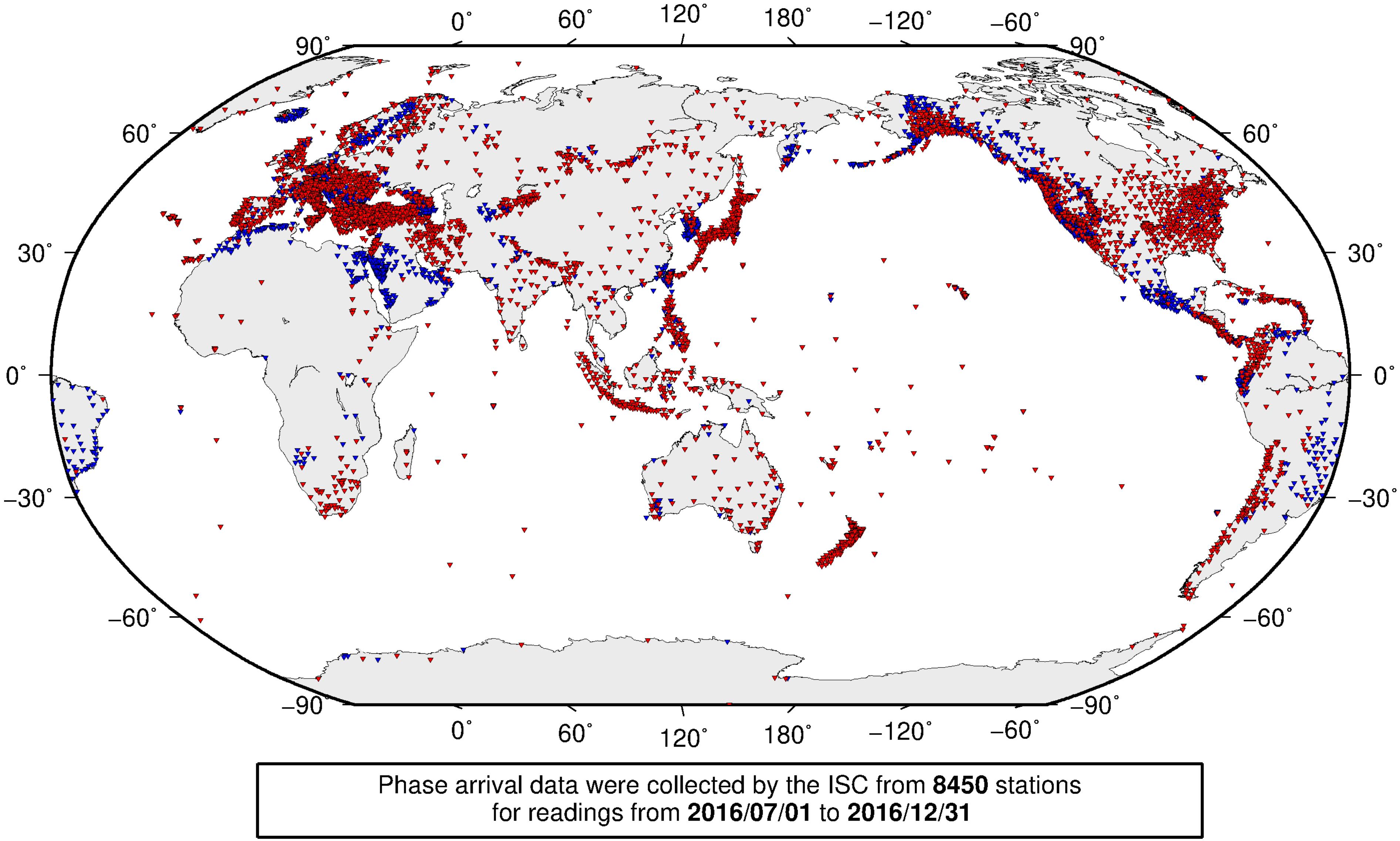


Figure 8.4: *Stations contributing phase data to the ISC for readings from July 2016 to the end of December 2016. Stations in blue provided phase arrival times only; stations in red provided both phase arrival times and amplitude data.*

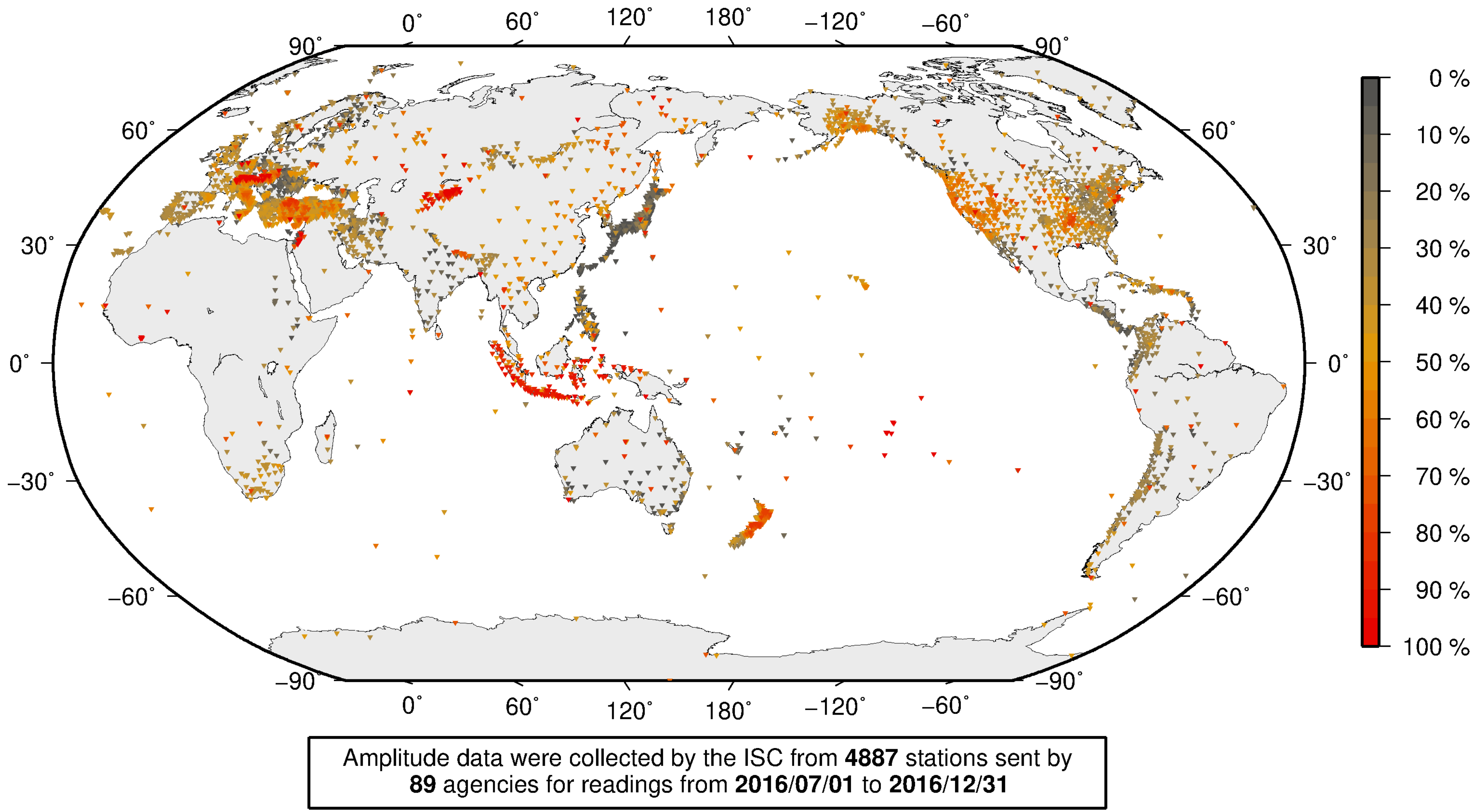


Figure 8.5: *Percentage of events for which phase arrival times from each station are accompanied with amplitude and period measurements.*

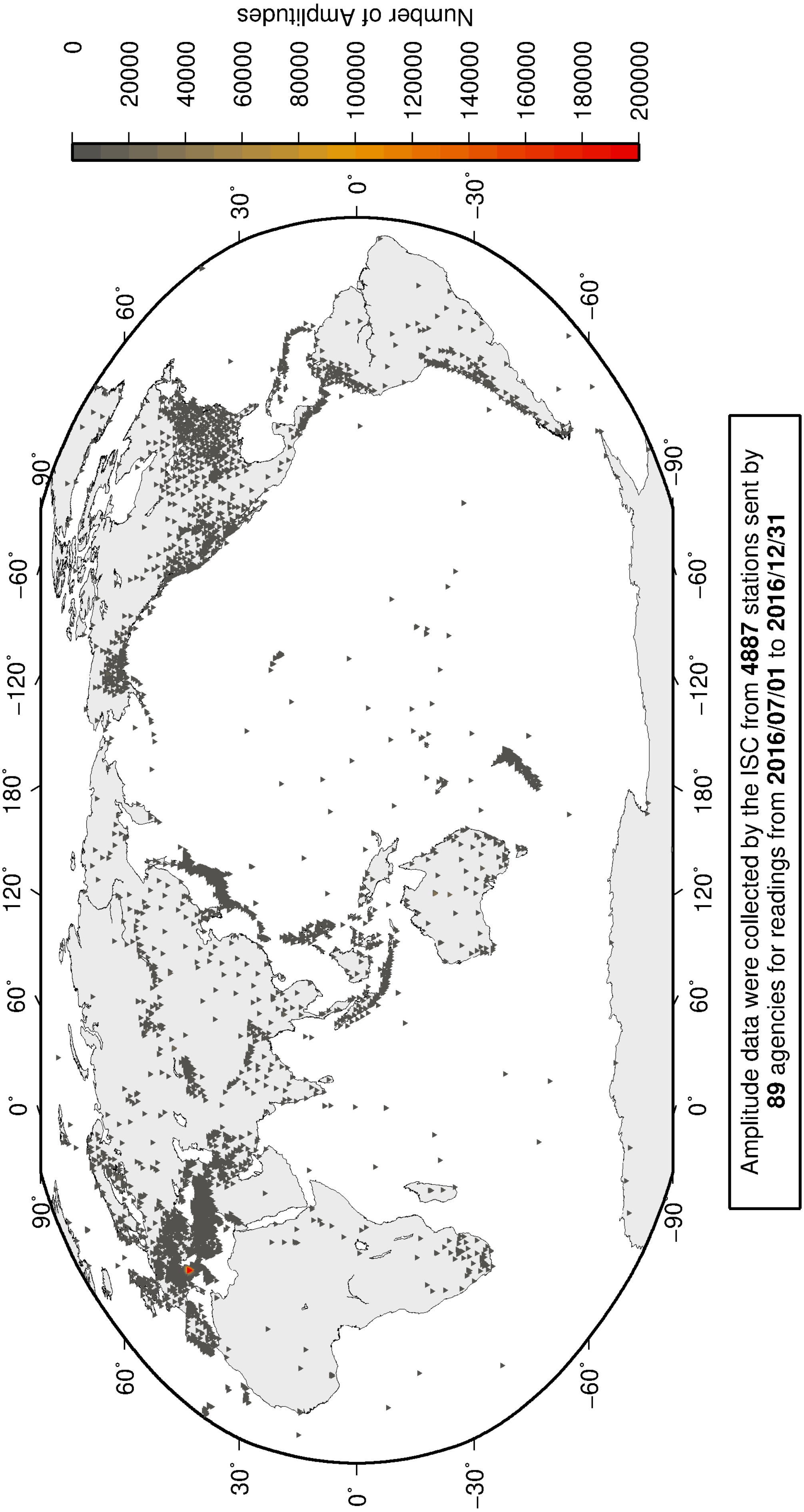


Figure 8.6: *Number of amplitude and period measurements for each station.*

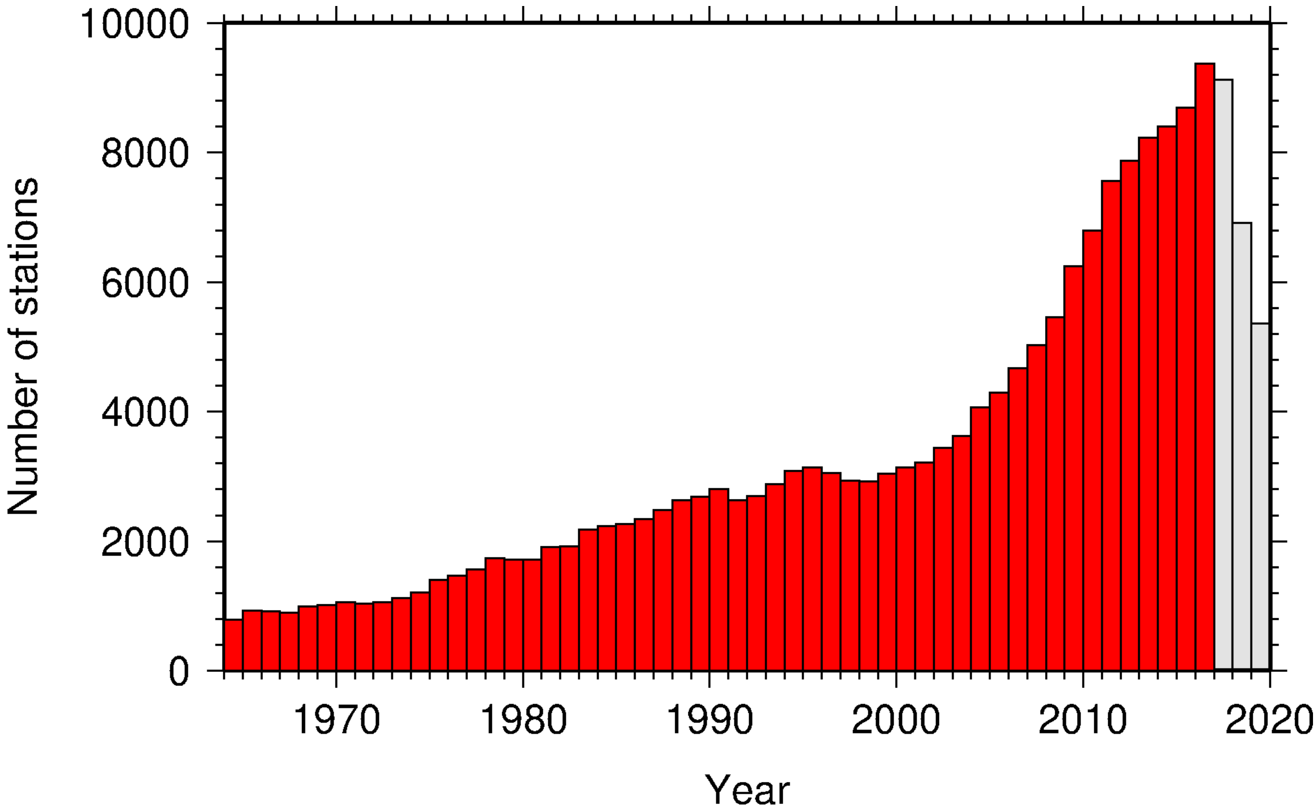


Figure 8.7: *Histogram showing the number of stations reporting to the ISC each year since 1964. The data in grey covers the current period where station information is still being collected before the ISC review of events takes place and is accurate at the time of publication.*

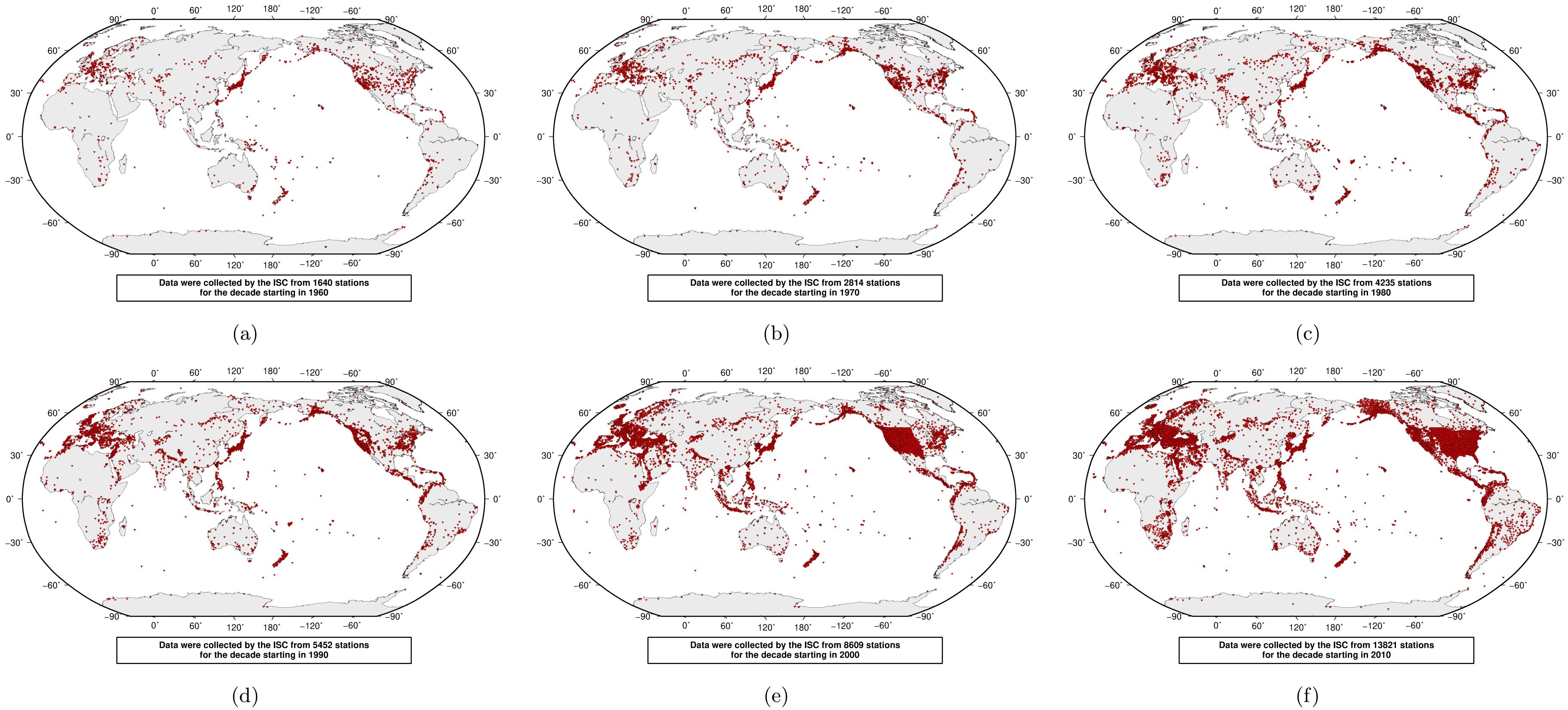


Figure 8.8: *Maps showing the stations reported to the ISC for each decade since 1960. Note that the last map covers a shorter time period.*

8.4 Hypocentres Collected

The ISC Bulletin groups multiple estimates of hypocentres into individual events, with an appropriate prime hypocentre solution selected. The collection of these hypocentre estimates are described in this section.

The reports containing hypocentres are summarised in Table 8.4. The number of hypocentres collected by the ISC has also increased significantly since 1964, as shown in Figure 8.9. A map of all hypocentres reported to the ISC for this summary period is shown in Figure 8.10. Where a network magnitude was reported with the hypocentre, this is also shown on the map, with preference given to reported values, first of M_W followed by M_S, m_b and M_L respectively (where more than one network magnitude was reported).

Table 8.4: *Summary of the reports containing hypocentres.*

Reports with hypocentres	3947
Reports of hypocentres only (no phase readings)	111
Total hypocentres received	479771
Number of duplicate hypocentres	11628 (2.4%)
Agencies determining hypocentres	164

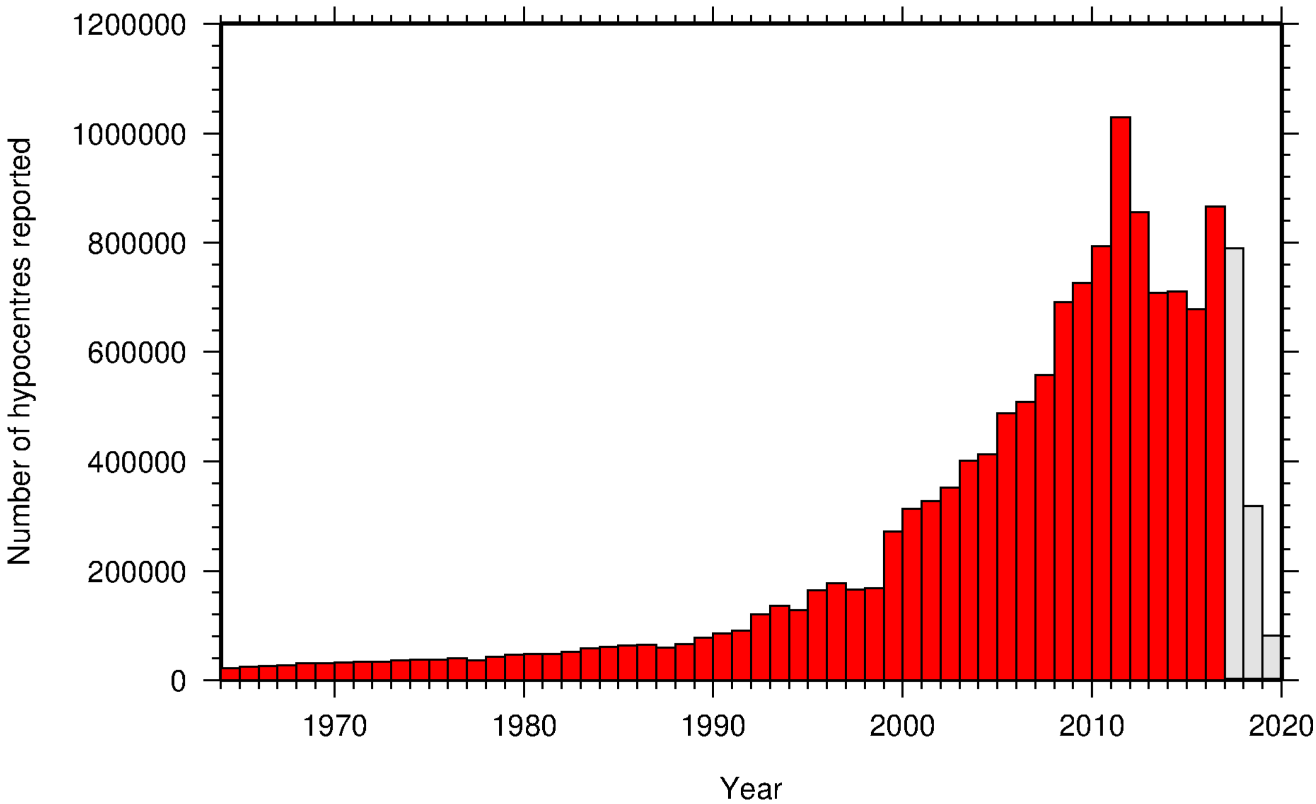


Figure 8.9: *Histogram showing the number of hypocentres collected by the ISC for events each year since 1964. For each event, multiple hypocentres may be reported.*

All the hypocentres that are reported to the ISC are automatically grouped into events, which form the basis of the ISC Bulletin. For this summary period 501431 hypocentres (including ISC) were grouped into 368090 events, the largest of these having 60 hypocentres in one event. The total number of events

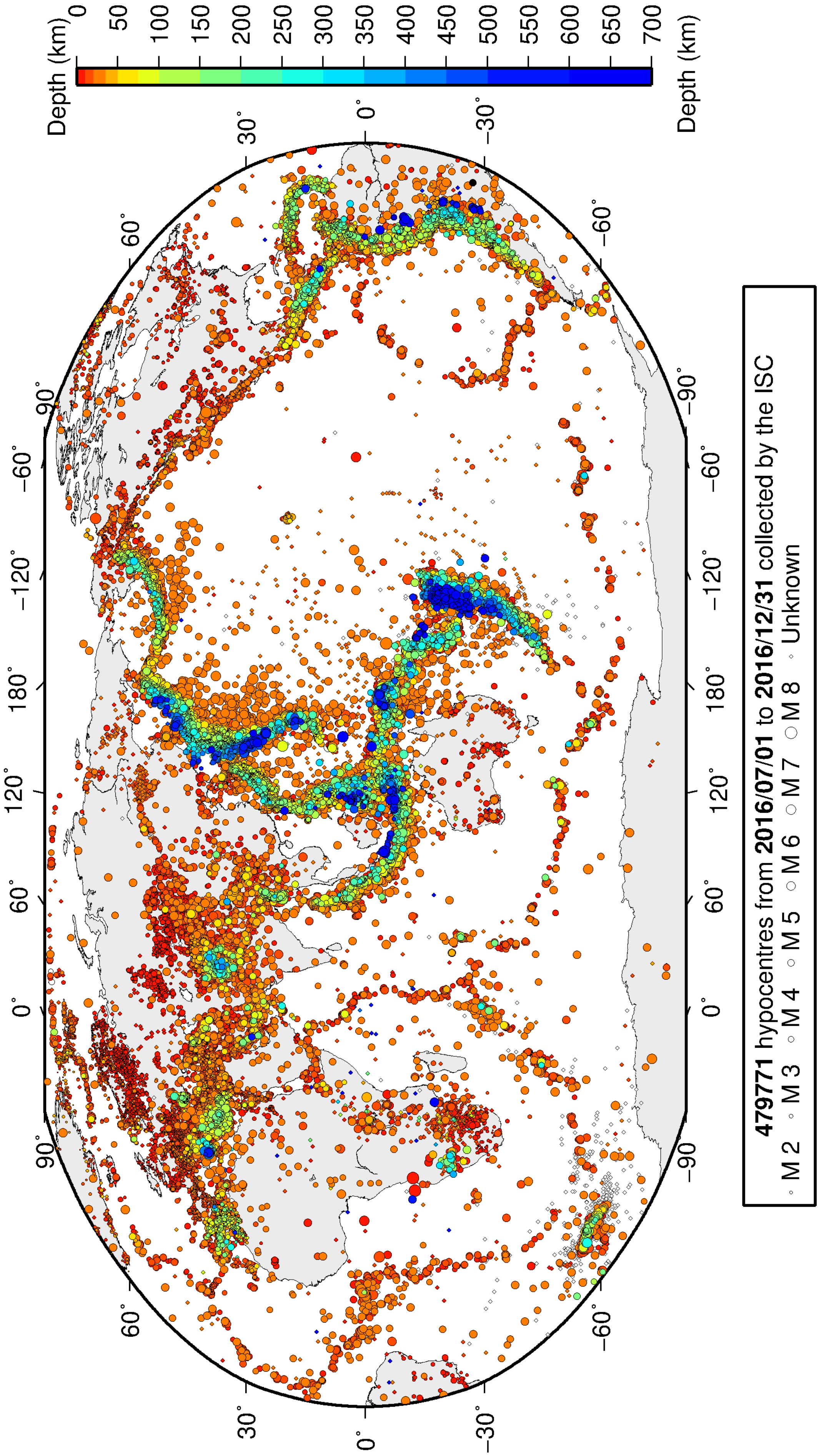


Figure 8.10: *Map of all hypocentres collected by the ISC. The scatter shows the large variation of the multiple hypocentres that are reported for each event. The magnitude corresponds with the reported network magnitude. If more than one network magnitude type was reported, preference was given to values of* M_W, M_S, m_b *and* M_L *respectively. Compare with Figure 9.2*

shown here is the result of an automatic grouping algorithm, and will differ from the total events in the published ISC Bulletin, where both the number of events and the number of hypocentre estimates will have changed due to further analysis. The process of grouping is detailed in Section 11.1.3 of the January to June Bulletin Summary. Figure 9.2 on page 95 shows a map of all prime hypocentres.

8.5 Collection of Network Magnitude Data

Data contributing agencies normally report earthquake hypocentre solutions along with magnitude estimates. For each seismic event, each agency may report one or more magnitudes of the same or different types. This stems from variability in observational practices at regional, national and global level in computing magnitudes based on a multitude of wave types. Differences in the amplitude measurement algorithm, seismogram component(s) used, frequency range, station distance range as well as the instrument type contribute to the diversity of magnitude types. Table 8.5 provides an overview of the complexity of reported network magnitudes reported for seismic events during the summary period.

Table 8.5: *Statistics of magnitude reports to the ISC; M – average magnitude of estimates reported for each event.*

	M<3.0	3.0≤M<5.0	M≥5.0
Number of seismic events	297848	45450	566
Average number of magnitude estimates per event	1.2	3.2	17.7
Average number of magnitudes (by the same agency) per event	1.1	1.9	2.8
Average number of magnitude types per event	1.1	2.5	8.7
Number of magnitude types	24	38	32

Table 8.6 gives the basic description, main features and scientific paper references for the most commonly reported magnitude types.

Table 8.6: *Description of the most common magnitude types reported to the ISC.*

Magnitude type	Description	References	Comments
M	Unspecified		Often used in real or near-real time magnitude estimations
mB	Medium-period and Broad-band body-wave magnitude	*Gutenberg* (1945a); *Gutenberg* (1945b); *IASPEI* (2005); *IASPEI* (2013); *Bormann et al.* (2009); *Bormann and Dewey* (2012)	
mb	Short-period body-wave magnitude	*IASPEI* (2005); *IASPEI* (2013); *Bormann et al.* (2009); *Bormann and Dewey* (2012)	Classical mb based on stations between 21°-100° distance

Table 8.6: *continued*

Magnitude type	Description	References	Comments
mb1	Short-period body-wave magnitude	*IDC* (1999) and references therein	Reported only by the IDC; also includes stations at distances less than 21°
mb1mx	Maximum likelihood short-period body-wave magnitude	*Ringdal* (1976); *IDC* (1999) and references therein	Reported only by the IDC
mbtmp	short-period body-wave magnitude with depth fixed at the surface	*IDC* (1999) and references therein	Reported only by the IDC
mbLg	Lg-wave magnitude	*Nuttli* (1973); *IASPEI* (2005); *IASPEI* (2013); *Bormann and Dewey* (2012)	Also reported as MN
Mc	Coda magnitude		
MD (Md)	Duration magnitude	*Bisztricsany* (1958); *Lee et al.* (1972)	
ME (Me)	Energy magnitude	*Choy and Boatwright* (1995)	Reported only by NEIC
MJMA	JMA magnitude	*Tsuboi* (1954)	Reported only by JMA
ML (Ml)	Local (Richter) magnitude	*Richter* (1935); *Hutton and Boore* (1987); *IASPEI* (2005); *IASPEI* (2013)	
MLSn	Local magnitude calculated for Sn phases	*Balfour et al.* (2008)	Reported by PGC only for earthquakes west of the Cascadia subduction zone
MLv	Local (Richter) magnitude computed from the vertical component		Reported only by DJA and BKK
MN (Mn)	Lg-wave magnitude	*Nuttli* (1973); *IASPEI* (2005)	Also reported as mbLg
MS (Ms)	Surface-wave magnitude	*Gutenberg* (1945c); *Vaněk et al.* (1962); *IASPEI* (2005)	Classical surface-wave magnitude computed from station between 20°-160° distance
Ms1	Surface-wave magnitude	*IDC* (1999) and references therein	Reported only by the IDC; also includes stations at distances less than 20°
ms1mx	Maximum likelihood surface-wave magnitude	*Ringdal* (1976); *IDC* (1999) and references therein	Reported only by the IDC

Table 8.6: *continued*

Magnitude type	Description	References	Comments
Ms7	Surface-wave magnitude	*Bormann et al.* (2007)	Reported only by BJI and computed from records of a Chinese-made long-period seismograph in the distance range 3°-177°
MW (Mw)	Moment magnitude	*Kanamori* (1977); *Dziewonski et al.* (1981)	Computed according to the *IASPEI* (2005) and *IASPEI* (2013) standard formula
Mw(mB)	Proxy Mw based on mB	*Bormann and Saul* (2008)	Reported only by DJA and BKK
Mwp	Moment magnitude from P-waves	*Tsuboi et al.* (1995)	Reported only by DJA and BKK and used in rapid response
mbh	Unknown		
mbv	Unknown		
MG	Unspecified type		Contact contributor
Mm	Unknown		
msh	Unknown		
MSV	Unknown		

Table 8.7 lists all magnitude types reported, the corresponding number of events in the ISC Bulletin and the agency codes along with the number of earthquakes.

Table 8.7: *Summary of magnitude types in the ISC Bulletin for this summary period. The number of events with values for each magnitude type is listed. The agencies reporting these magnitude types are listed, together with the total number of values reported.*

Magnitude type	Events	Agencies reporting magnitude type (number of values)
M	17284	WEL (17084), PRU (101), RSPR (95), FDF (3), SKO (1)
mb	30110	IDC (18217), NEIC (8166), KRNET (4451), NNC (4363), MAN (3028), VIE (1737), MOS (1654), BJI (1295), DJA (1264), NOU (579), VAO (474), IASPEI (189), MDD (156), OMAN (69), CFUSG (45), GII (33), SIGU (33), STR (29), NDI (27), MCSM (20), ROM (12), PRE (10), DSN (7), PGC (5), BGS (4), DNK (4), DMN (2), WEL (1), GUC (1), CSEM (1)
MB	1	IPEC (1)
mB	1991	BJI (1329), DJA (769), WEL (196), NOU (2)
mb_Lg	3641	MDD (2666), NEIC (927), TEH (46), OTT (2)
mBc	2	DJA (2)
mbR	93	VAO (93)
mbtmp	19081	IDC (19081)
Mc	17	DNK (12), OSPL (2), SIGU (2), RSNC (1)
MC	32	DDA (32)

Table 8.7: *Continued.*

Magnitude type	Events	Agencies reporting magnitude type (number of values)
MD	13162	ROM (2872), LDG (2614), TRN (1795), RSPR (1595), HLW (825), ECX (781), SSNC (549), GCG (455), JMA (441), TIR (272), GRAL (264), GII (186), PDG (117), SOF (113), MEX (111), SNET (101), SJA (95), JSN (51), UPA (50), PNSN (46), INMG (37), SLM (37), BUG (21), NAM (16), NCEDC (12), HVO (10), CFUSG (7), SIGU (4), LSZ (3), INET (2), HDC (2), UCR (2), SSS (2), SEA (1), NIC (1)
Mjma	40	DJA (37), WEL (3)
ML	158761	ROM (44954), TAP (18482), WEL (16702), IDC (10687), DDA (10095), ISK (8561), RSNC (8305), HEL (8283), ATH (7811), THE (4496), GUC (3892), UPP (3706), LDG (3190), MAN (3137), VIE (2690), BER (2628), NEIC (1971), INMG (1881), AEIC (1628), CNRM (1420), ANF (1319), BEO (1280), LJU (1224), PGC (1167), SNET (1085), PRE (919), TUL (884), DNK (880), BUC (869), ECX (801), GEN (784), RHSSO (710), OSPL (674), MRB (630), SCB (591), KRSC (590), SFS (550), SSNC (550), TEH (536), IPEC (497), NIC (482), PDG (469), NAO (339), KOLA (331), OMAN (296), TIR (282), IGIL (254), CRAAG (249), KRSZO (249), SJA (242), BJI (220), LVSN (217), HLW (205), INET (204), WB-NET (200), NDI (193), BGR (189), DSN (187), ISN (186), KNET (177), HVO (172), UCR (145), MIRAS (125), SSS (124), REN (112), BGS (111), ARE (103), NOU (96), UCC (72), PAS (68), KEA (66), PPT (59), NCEDC (52), OTT (47), SEA (43), SGS (37), DJA (36), UUSS (34), MCSM (33), BNS (31), UPA (30), BUT (29), BUG (22), CUPWA (22), AAE (18), DMN (16), THR (13), SKO (11), RISSC (9), LDO (8), DRS (6), EAF (5), PLV (5), FIA0 (4), CLL (3), CSEM (3), AUST (2), ALG (2), VAO (2), SIGU (1), JSO (1), HDC (1), SOF (1), LIT (1), ZAG (1), RSPR (1)
MLh	687	ZUR (536), ASRS (151)
MLSn	284	PGC (284)
MLv	23712	WEL (17211), DJA (2852), NOU (2300), STR (2287), MCSM (13), KRSZO (6), JSO (3), ASRS (1)
Mm	384	GII (384)
MN	400	OTT (400)
mpv	4808	NNC (4808)
MPVA	300	MOS (250), NORS (178)
MS	11691	IDC (8688), MAN (3146), BJI (1015), MOS (454), IASPEI (70), SOME (69), NSSP (59), VIE (33), KEA (30), OMAN (10), LDG (5), DSN (2), NDI (2), UPA (1), GUC (1), SSNC (1), IPEC (1)
Ms(BB)	31	DJA (29), WEL (2)
Ms7	1009	BJI (1009)
Ms_20	189	NEIC (189)
msh	3	SIGU (3)
MV	148901	JMA (148901)

Table 8.7: *Continued.*

Magnitude type	Events	Agencies reporting magnitude type (number of values)
MW	6194	INET (1405), GCMT (1170), NIED (847), UCR (548), UPA (546), SSNC (464), PGC (312), RSNC (272), SJA (238), DDA (216), WEL (210), SCB (193), FUNV (158), JMA (130), ROM (108), MED_RCMT (103), ASIES (22), DJA (17), ATH (16), BER (12), CRAAG (6), GUC (6), MOS (2), IEC (2), UPSL (1), LVSN (1), GFZ (1), DNK (1), SNET (1)
Mw(mB)	196	WEL (196)
Mwb	200	NEIC (200)
Mwc	40	NEIC (26), GCMT (14)
Mwp	127	DJA (108), ROM (10), OMAN (7), STR (2)
Mwpd	2	ROM (2)
Mwr	532	NEIC (401), GUC (102), NCEDC (33), SLM (29), REN (17), RSNC (12), VIE (11), CAR (8), PAS (7), OTT (6), ROM (5), ISK (3), UCR (2), ATH (1)
Mww	312	NEIC (312)

The most commonly reported magnitude types are short-period body-wave, surface-wave, local (or Richter), moment, duration and JMA magnitude type. For a given earthquake, the number and type of reported magnitudes greatly vary depending on its size and location. The large earthquake of October 25, 2010 gives an example of the multitude of reported magnitude types for large earthquakes (Listing 8.1). Different magnitude estimates come from global monitoring agencies such as the IDC, NEIC and GCMT, a local agency (GUC) and other agencies, such as MOS and BJI, providing estimates based on the analysis of their networks. The same agency may report different magnitude types as well as several estimates of the same magnitude type, such as NEIC estimates of Mw obtained from W-phase, centroid and body-wave inversions.

Listing 8.1: *Example of reported magnitudes for a large event*

```
Event   15264887 Southern Sumatera
   Date        Time        Err   RMS Latitude Longitude  Smaj  Smin  Az Depth   Err Ndef Nsta Gap  mdist  Mdist Qual   Author      OrigID
2010/10/25 14:42:22.18    0.27 1.813  -3.5248  100.1042 4.045 3.327  54  20.0  1.37 2102 2149  23   0.76 176.43 m i de ISC       01346132
 (#PRIME)

Magnitude  Err Nsta Author      OrigID
mb      6.1       61 BJI       15548963
mB      6.9       68 BJI       15548963
Ms      7.7       85 BJI       15548963
Ms7     7.5       86 BJI       15548963
mb      5.3 0.1   48 IDC       16686694
mb1     5.3 0.1   51 IDC       16686694
mb1mx   5.3 0.0   52 IDC       16686694
mbtmp   5.3 0.1   51 IDC       16686694
ML      5.1 0.2    2 IDC       16686694
MS      7.1 0.0   31 IDC       16686694
Ms1     7.1 0.0   31 IDC       16686694
ms1mx   6.9 0.1   44 IDC       16686694
mb      6.1      243 ISCJB     01677901
MS      7.3      228 ISCJB     01677901
M       7.1      117 DJA       01268475
mb      6.1 0.2  115 DJA       01268475
mB      7.1 0.1  117 DJA       01268475
MLv     7.0 0.2   26 DJA       01268475
        7.1 0.4  117 DJA       01268475
Mwp     6.9 0.2  102 DJA       01268475
mb      6.4       49 MOS       16742129
MS      7.2       70 MOS       16742129
mb      6.5      110 NEIC      01288303
ME      7.3          NEIC      01288303
MS      7.3      143 NEIC      01288303
MW      7.7          NEIC      01288303
MW      7.8      130 GCMT      00125427
mb      5.9          KLM       00255772
ML      6.7          KLM       00255772
MS      7.6          KLM       00255772
mb      6.4       20 BGR       16815854
Ms      7.2        2 BGR       16815854
mb      6.3 0.3  250 ISC       01346132
MS      7.3 0.1  237 ISC       01346132
```

An example of a relatively small earthquake that occurred in northern Italy for which we received magnitude reports of mostly local and duration type from six agencies in Italy, France and Austria is given in Listing 8.2.

Listing 8.2: *Example of reported magnitudes for a small event*

```
Event 15089710 Northern Italy
   Date        Time         Err   RMS Latitude Longitude  Smaj  Smin  Az Depth   Err Ndef Nsta Gap  mdist  Mdist Qual   Author      OrigID
2010/08/08 15:20:46.22   0.94 0.778  45.4846    8.3212 2.900 2.539 110   28.6  9.22  172  110  82   0.41   5.35 m i ke ISC        01249414
 (#PRIME)

Magnitude  Err Nsta Author      OrigID
ML      2.4       10 ZUR       15925566
Md      2.6 0.2   19 ROM       16861451
Ml      2.2 0.2    9 ROM       16861451
ML      2.5          GEN       00554757
ML      2.6 0.3   28 CSEM      00554756
Md      2.3 0.0    3 LDG       14797570
Ml      2.6 0.3   32 LDG       14797570
```

Figure 8.11 shows a distribution of the number of agencies reporting magnitude estimates to the ISC according to the magnitude value. The peak of the distribution corresponds to small earthquakes where many local agencies report local and/or duration magnitudes. The number of contributing agencies rapidly decreases for earthquakes of approximately magnitude 5.5 and above, where magnitudes are mostly given by global monitoring agencies.

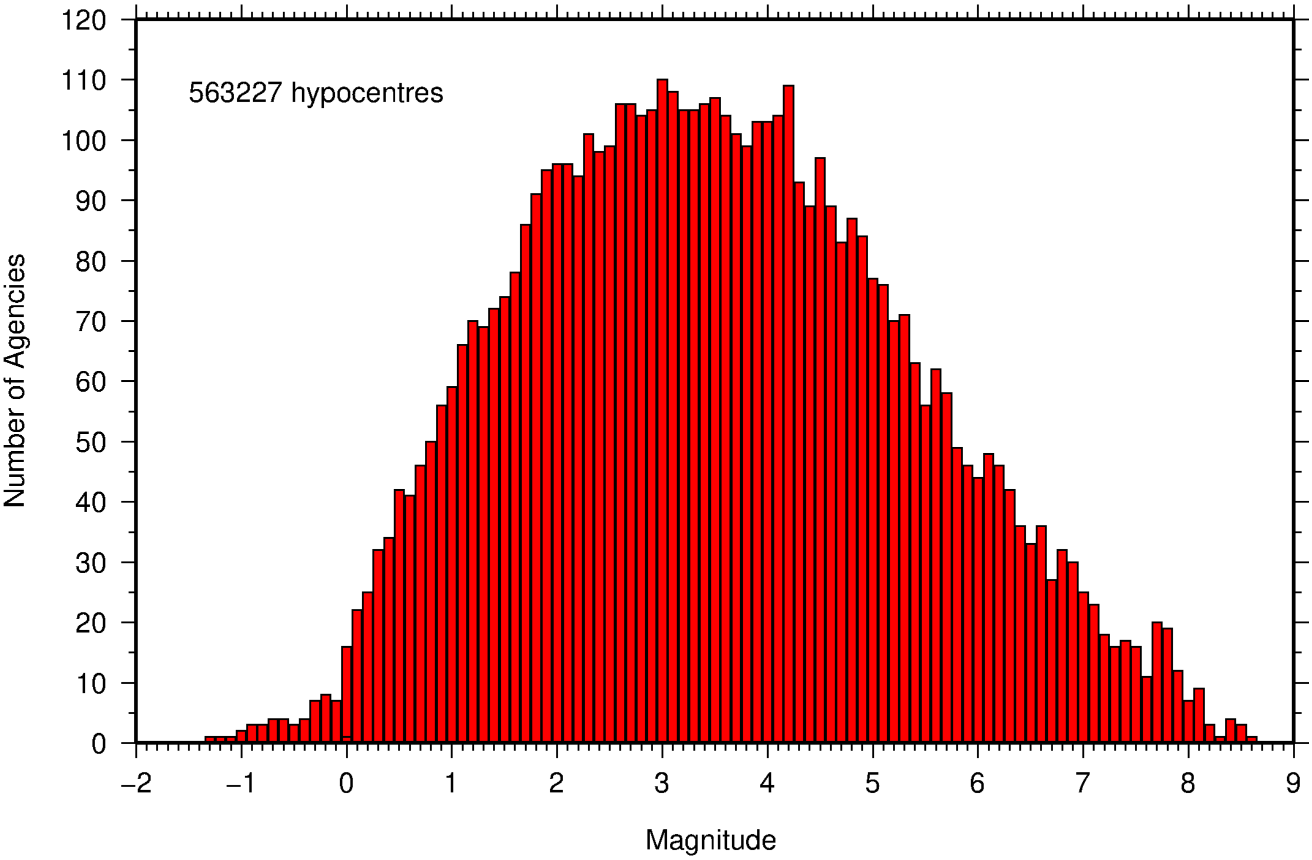


Figure 8.11: *Histogram showing the number of agencies that reported network magnitude values. All magnitude types are included.*

8.6 Moment Tensor Solutions

The ISC Bulletin publishes moment tensor solutions, which are reported to the ISC by other agencies. The collection of moment tensor solutions is summarised in Table 8.8. A histogram showing all moment tensor solutions collected throughout the ISC history is shown in Figure 8.12. Several moment tensor solutions from different authors and different moment tensor solutions calculated by different methods from the same agency may be present for the same event.

Table 8.8: *Summary of reports containing moment tensor solutions.*

Reports with Moment Tensors	94
Total moment tensors received	7312
Agencies reporting moment tensors	8

The number of moment tensors for this summary period, reported by each agency, is shown in Table 8.9. The moment tensor solutions are plotted in Figure 8.13.

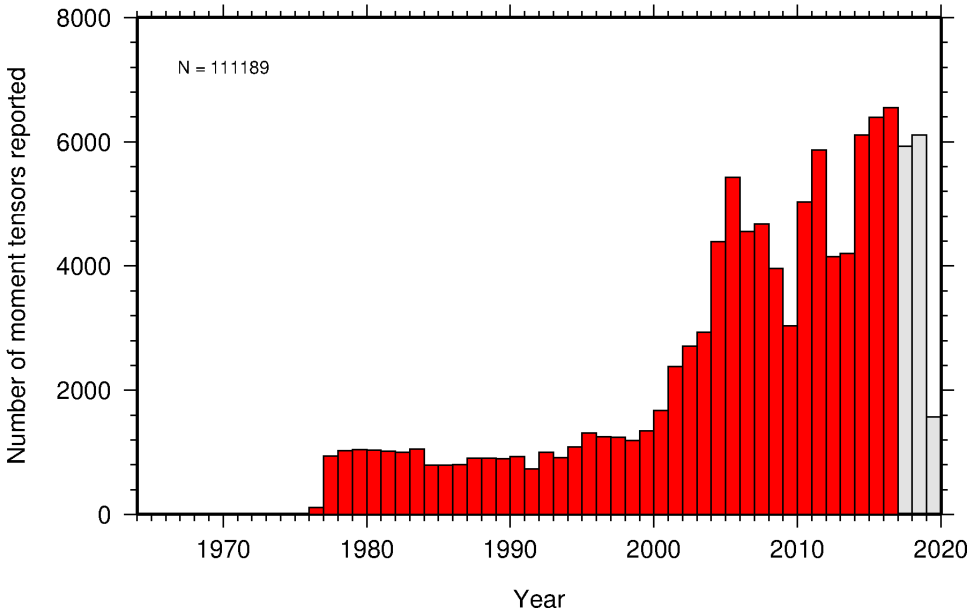
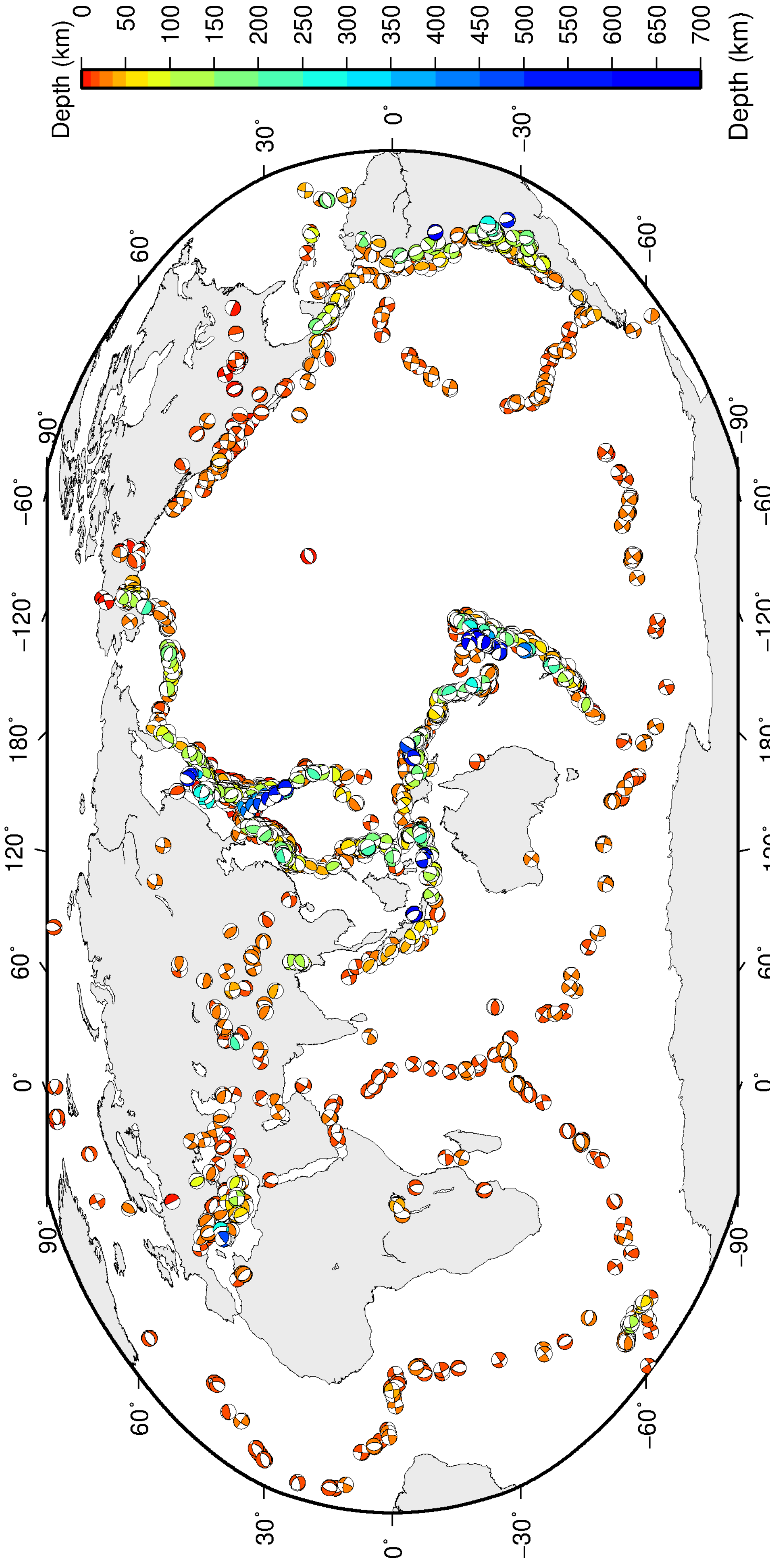


Figure 8.12: *Histogram showing the number of moment tensors reported to the ISC since 1964. The regions in grey represent data that are still being actively collected.*



ISC Bulletin: **3522** focal mechanism solutions for **2521** events from **2016/07/01** to **2016/12/31**

Figure 8.13: *Map of all moment tensor solutions in the ISC Bulletin for this summary period.*

Table 8.9: *Summary of moment tensor solutions in the ISC Bulletin reported by each agency.*

Agency	Number of moment tensor solutions
ISC	1192
GCMT	1170
NEIC	1071
NIED	847
WEL	210
ROM	104
MED_RCMT	103
RSNC	94
PNSN	46
MOS	20
PRE	18
ATH	16
ECX	10
UPA	6
INET	5
UCR	5
IEC	4
OSPL	4
SJA	1
GUC	1
UPSL	1

8.7 Timing of Data Collection

Here we present the timing of reports to the ISC. Please note, this does not include provisional alerts, which are replaced at a later stage. Instead, it reflects the final data sent to the ISC. The absolute timing of all hypocentre reports, regardless of magnitude, is shown in Figure 8.14. In Figure 8.15 the reports are grouped into one of six categories - from within three days of an event origin time, to over one year. The histogram shows the distribution with magnitude (for hypocentres where a network magnitude was reported) for each category, whilst the map shows the geographic distribution of the reported hypocentres.

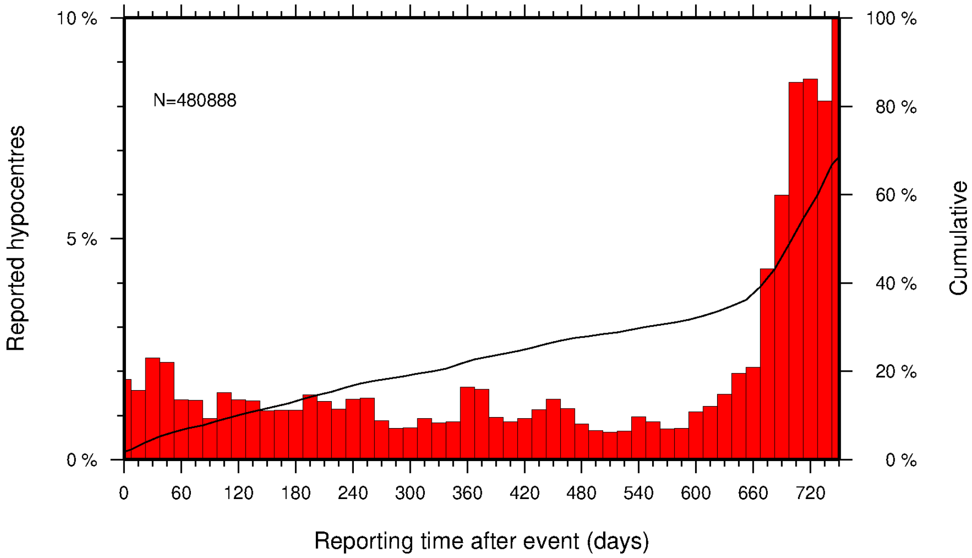


Figure 8.14: *Histogram showing the timing of final reports of the hypocentres (total of N) to the ISC. The cumulative frequency is shown by the solid line.*

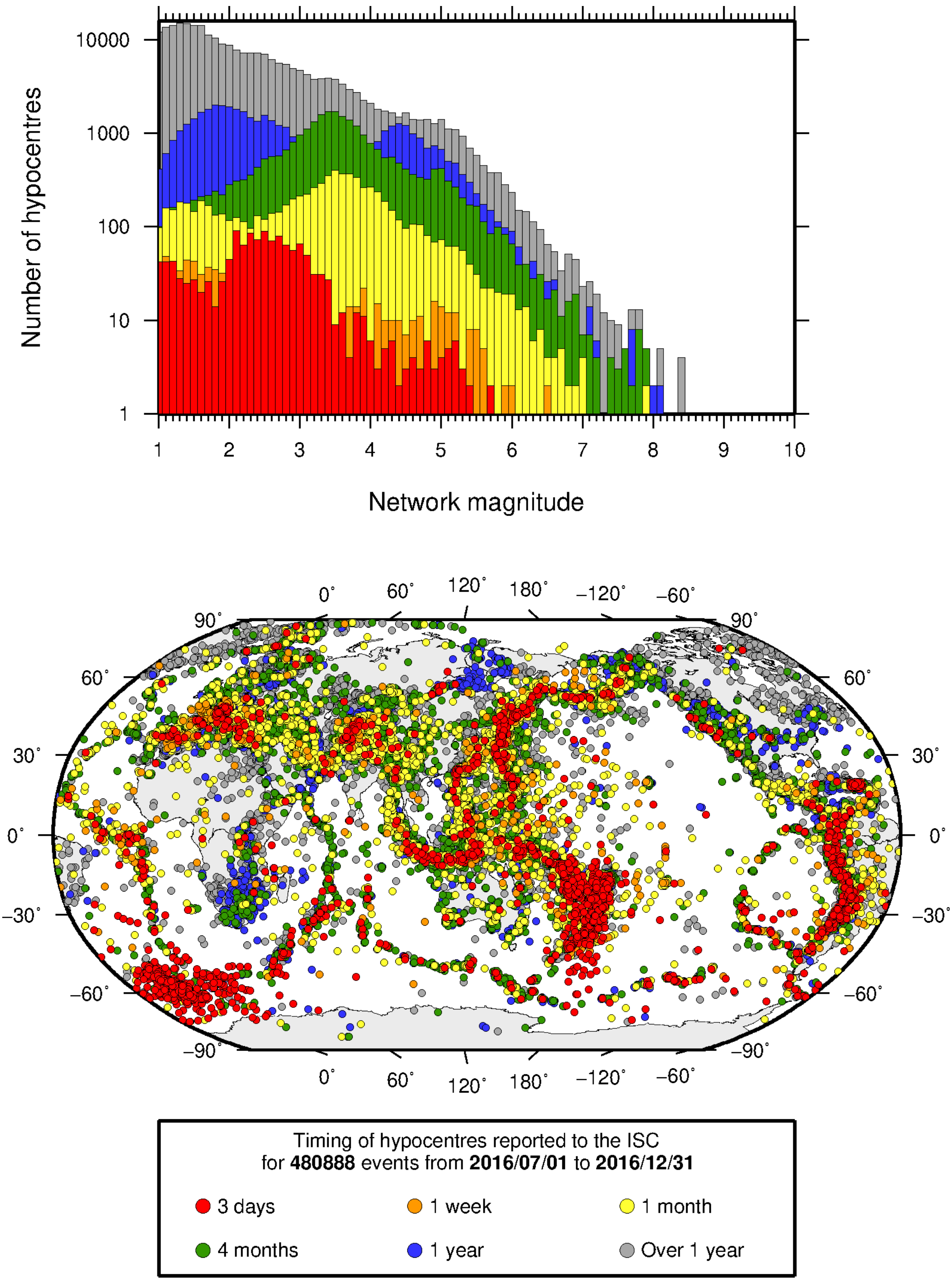


Figure 8.15: *Timing of hypocentres reported to the ISC. The colours show the time after the origin time that the corresponding hypocentre was reported. The histogram shows the distribution with magnitude. If more than one network magnitude was reported, preference was given to a value of M_W followed by M_S, m_b and M_L respectively; all reported hypocentres are included on the map. Note: early reported hypocentres are plotted over later reported hypocentres, on both the map and histogram.*

9

Overview of the ISC Bulletin

This chapter provides an overview of the seismic event data in the ISC Bulletin. We indicate the differences between all ISC events and those ISC events that are reviewed or located. We describe the wealth of phase arrivals and phase amplitudes and periods observed at seismic stations worldwide, reported in the ISC Bulletin and often used in the ISC location and magnitude determination. Finally, we make some comparisons of the ISC magnitudes with those reported by other agencies, and discuss magnitude completeness of the ISC Bulletin.

9.1 Events

The ISC Bulletin had 360966 reported events in the summary period between July and December 2016. Some 94% (340944) of the events were identified as earthquakes, the rest (20022) were of anthropogenic origin (including mining and other chemical explosions, rockbursts and induced events) or of unknown origin. As discussed in Section 11.1.3 of the January to June Bulletin Summary, typically about 15% of the events are selected for ISC review, and about half of the events selected for review are located by the ISC. In this summary period 8% of the events were reviewed and 5% of the events were located by the ISC. For events that are not located by the ISC, the prime hypocentre is identified according to the rules described in Section 11.1.3 of the January to June Bulletin Summary.

Of the 14986308 reported phase observations, 26% are associated to ISC-reviewed events, and 24% are associated to events selected for ISC location. Note that all large events are reviewed and located by the ISC. Since large events are globally recorded and thus reported by stations worldwide, they will provide the bulk of observations. This explains why only about one-fifth of the events in any given month is reviewed although the number of phases associated to reviewed events has increased nearly exponentially in the past decades.

Figure 9.1 shows the daily number of events throughout the summary period. Figure 9.2 shows the locations of the events in the ISC Bulletin; the locations of ISC-reviewed and ISC-located events are shown in Figures 9.3 and 9.4, respectively.

Figure 9.5 shows the hypocentral depth distributions of events in the ISC Bulletin for the summary period. The vast majority of events occur in the Earth's crust. Note that the peaks at 0, 10, 35 km, and at every 50 km intervals deeper than 100 km are artifacts of analyst practices of fixing the depth to a nominal value when the depth cannot be reliably resolved.

Figure 9.6 shows the depth distribution of free-depth solutions in the ISC Bulletin. The depth of a hypocentre reported to the ISC is assumed to be determined as a free parameter, unless it is explicitly labelled as a fixed-depth solution. On the other hand, as described in Section 11.1.4 of the January

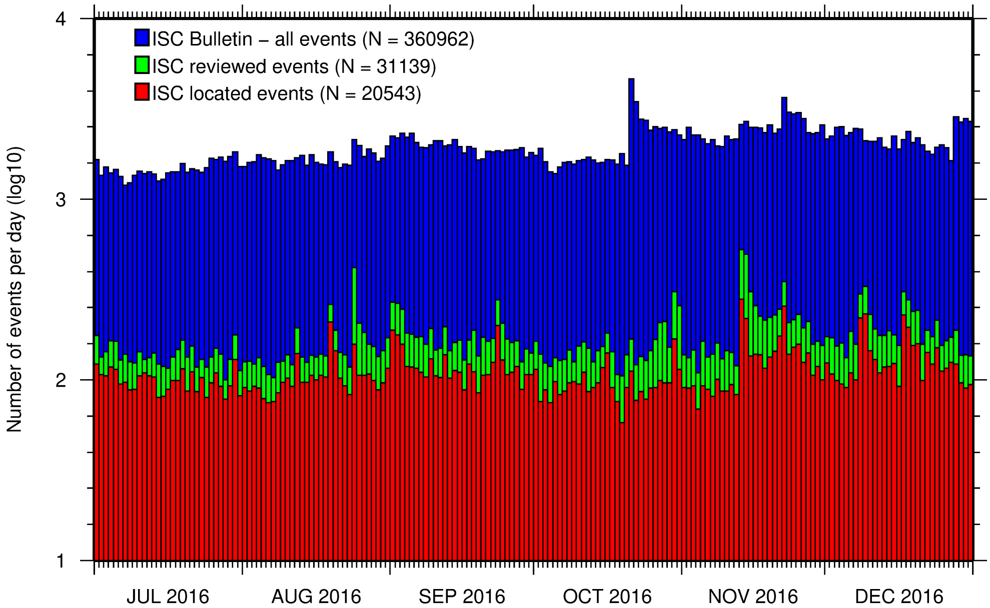


Figure 9.1: *Histogram showing the number of events in the ISC Bulletin for the current summary period. The vertical scale is logarithmic.*

to June Bulletin Summary, the ISC locator attempts to get a free-depth solution if, and only if, there is resolution for the depth in the data, i.e. if there is a local network and/or sufficient depth-sensitive phases are reported.

Figure 9.7 shows the depth distribution of fixed-depth solutions in the ISC Bulletin. Except for a fraction of events whose depth is fixed to a shallow depth, this set comprises mostly ISC-located events. If there is no resolution for depth in the data, the ISC locator fixes the depth to a value obtained from the ISC default depth grid file, or if no default depth exists for that location, to a nominal default depth assigned to each Flinn-Engdahl region (see details in Section 11.1.4 of the January to June Bulletin Summary). During the ISC review editors are inclined to accept the depth obtained from the default depth grid, but they typically change the depth of those solutions that have a nominal (10 or 35 km) depth. When doing so, they usually fix the depth to a round number, preferably divisible by 50.

For events selected for ISC location, the number of stations typically increases as arrival data reported by several agencies are grouped together and associated to the prime hypocentre. Consequently, the network geometry, characterised by the secondary azimuthal gap (the largest azimuthal gap a single station closes), is typically improved. Figure 9.8 illustrates that the secondary azimuthal gap is indeed generally smaller for ISC-located events than that for all events in the ISC Bulletin. Figure 9.9 shows the distribution of the number of associated stations. For large events the number of associated stations is usually larger for ISC-located events than for any of the reported event bulletins. On the other hand, events with just a few reporting stations are rarely selected for ISC location. The same is true for the number of defining stations (stations with at least one defining phase that were used in the location). Figure 9.10 indicates that because the reported observations from multiple agencies are associated to the prime, large ISC-located events typically have a larger number of defining stations than any of the reported event bulletins.

The formal uncertainty estimates are also typically smaller for ISC-located events. Figure 9.11 shows the

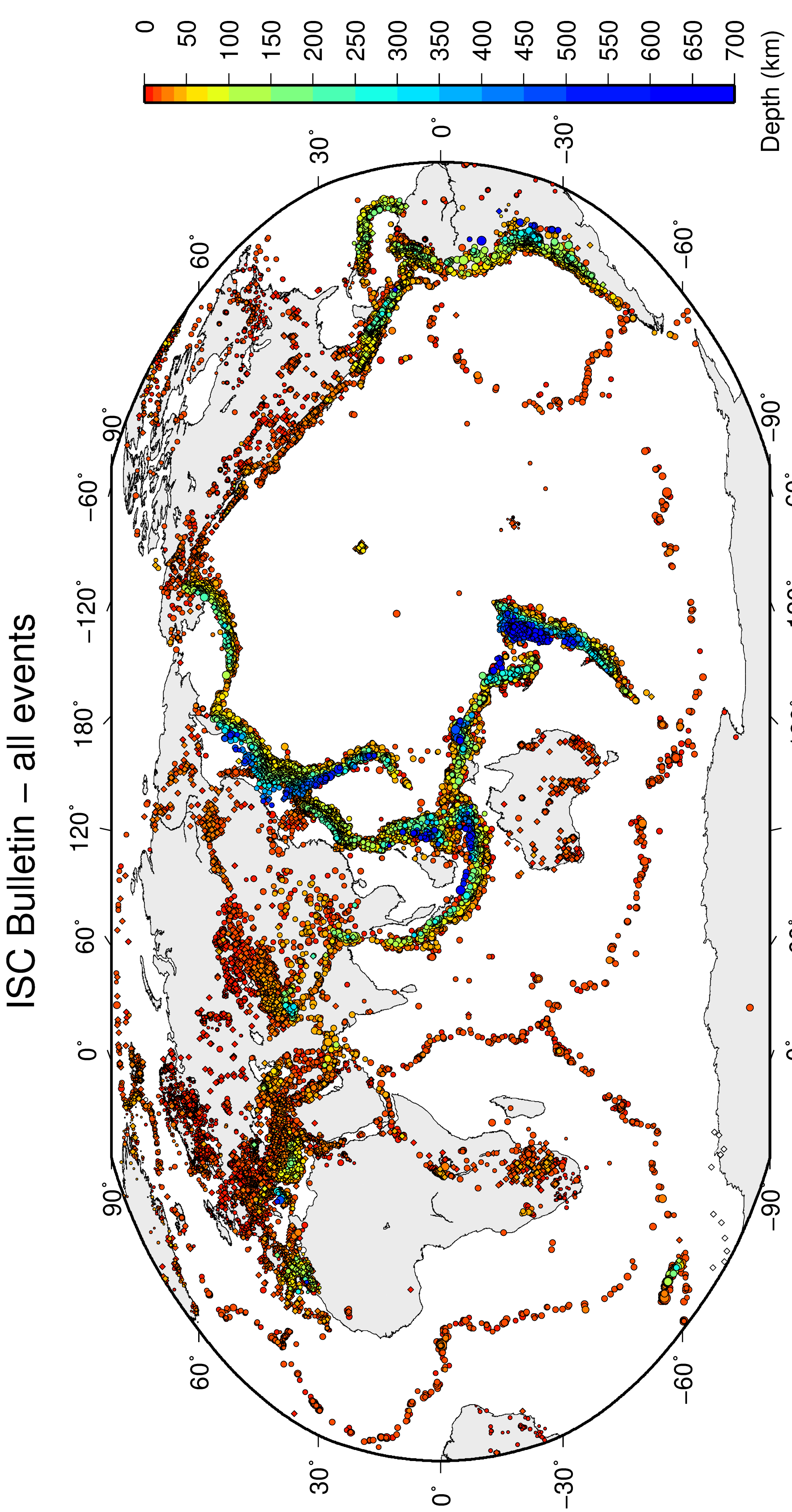


Figure 9.2: *Map of all events in the ISC Bulletin. Prime hypocentre locations are shown. Compare with Figure 8.10.*

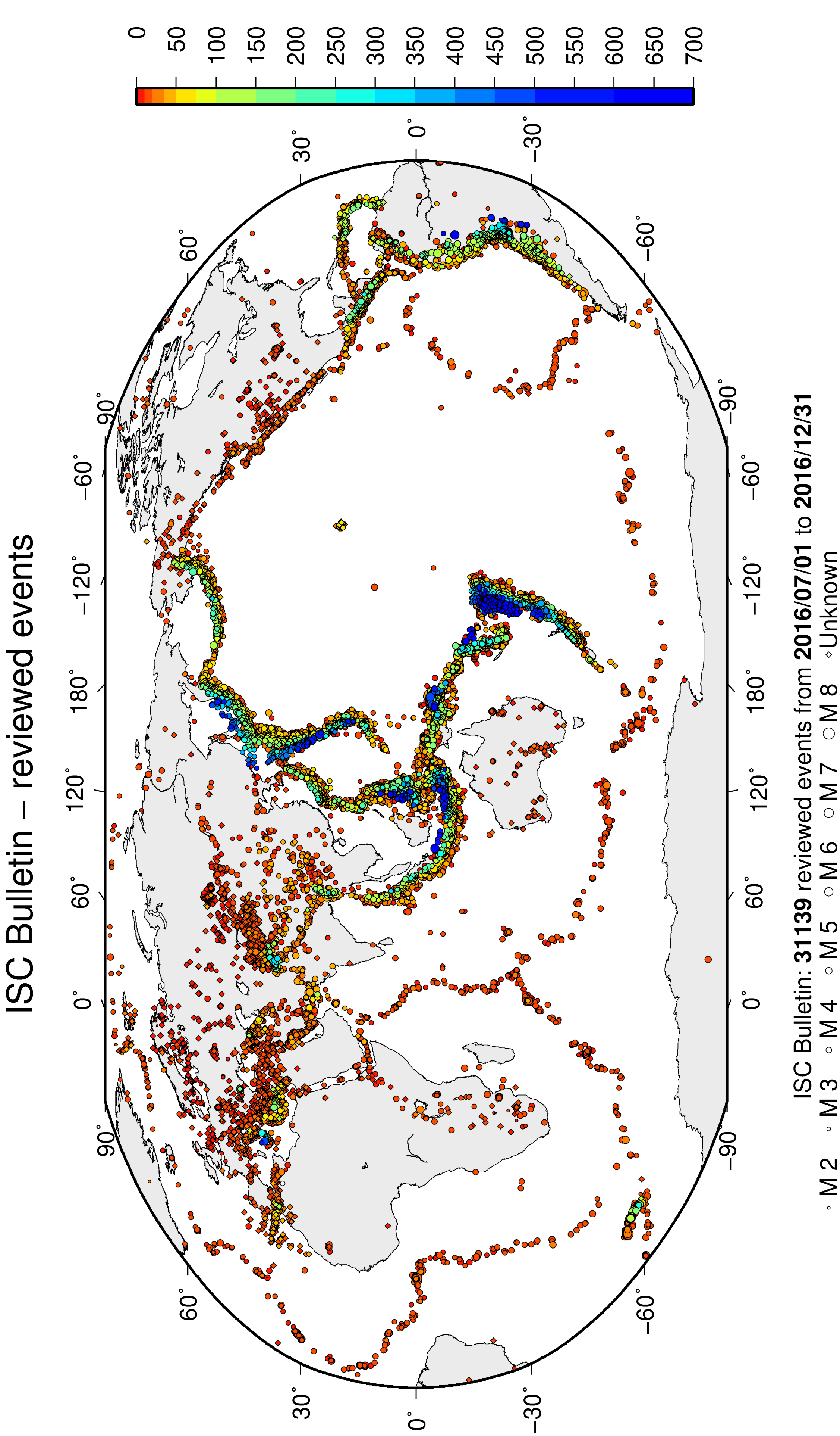


Figure 9.3: *Map of all events reviewed by the ISC for this time period. Prime hypocentre locations are shown.*

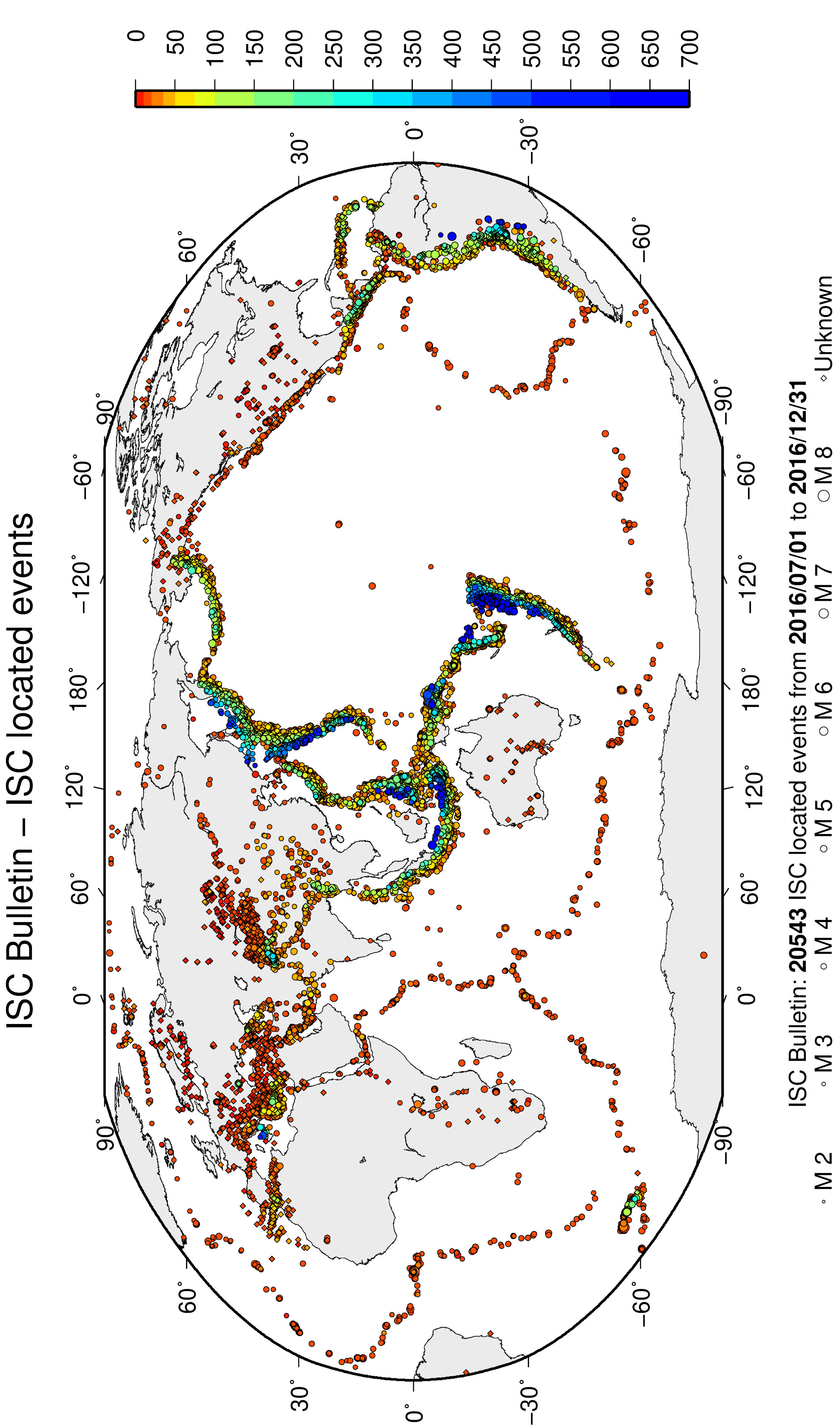


Figure 9.4: *Map of all events located by the ISC for this time period. ISC determined hypocentre locations are shown.*

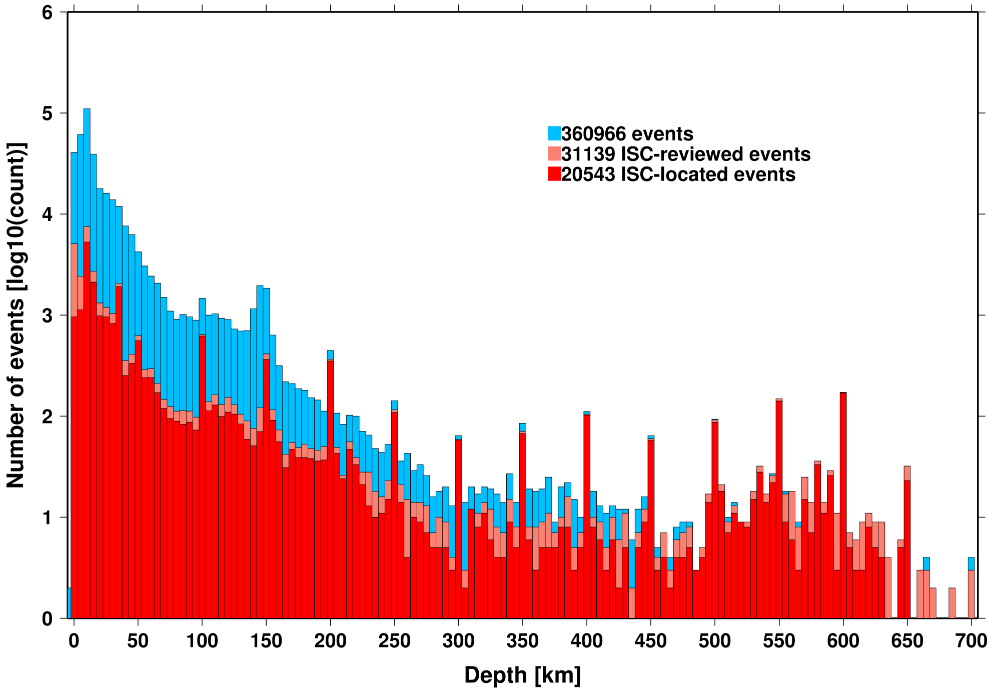


Figure 9.5: *Distribution of event depths in the ISC Bulletin (blue) and for the ISC-reviewed (pink) and the ISC-located (red) events during the summary period. All ISC-located events are reviewed, but not all reviewed events are located by the ISC. The vertical scale is logarithmic.*

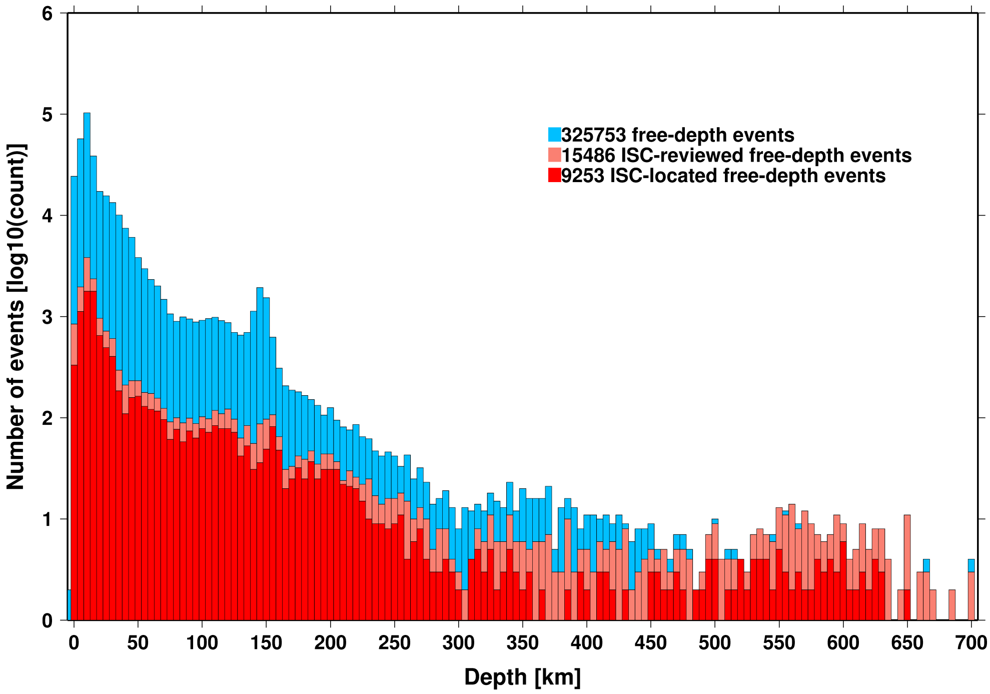


Figure 9.6: *Hypocentral depth distribution of events where the prime hypocentres are reported/located with a free-depth solution in the ISC Bulletin. The vertical scale is logarithmic.*

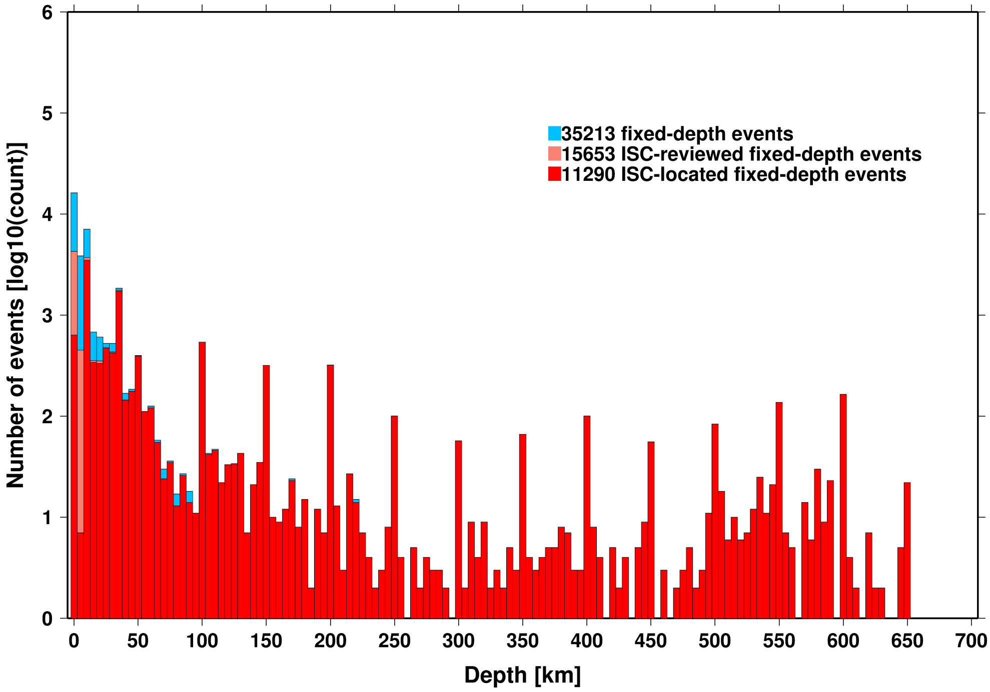


Figure 9.7: *Hypocentral depth distribution of events where the prime hypocentres are reported/located with a fixed-depth solution in the ISC Bulletin. The vertical scale is logarithmic.*

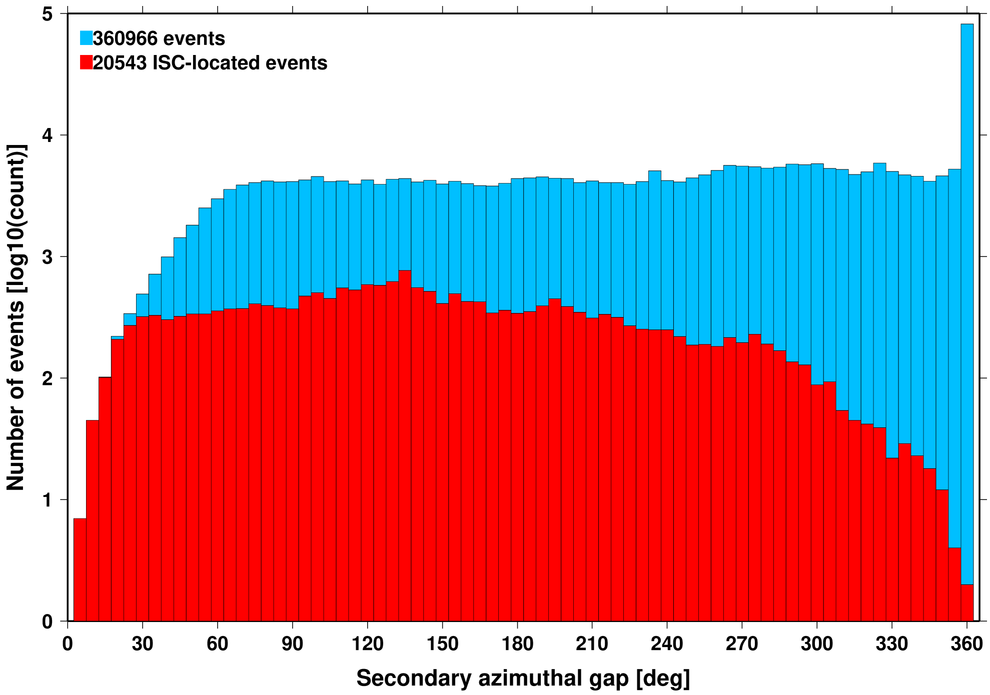


Figure 9.8: *Distribution of secondary azimuthal gap for events in the ISC Bulletin (blue) and those selected for ISC location (red). The vertical scale is logarithmic.*

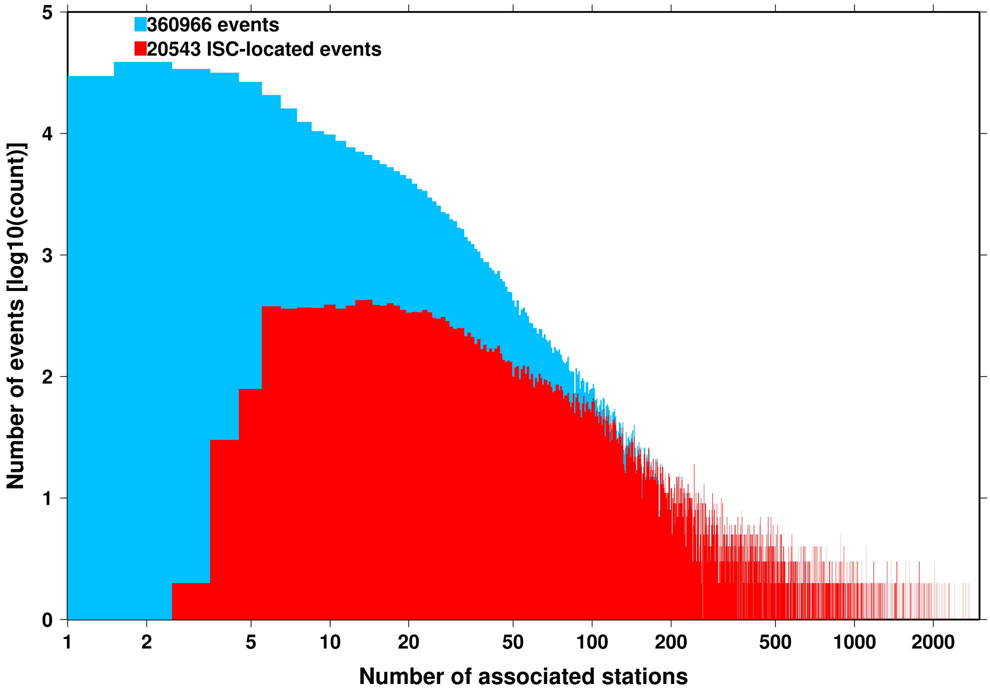


Figure 9.9: *Distribution of the number of associated stations for events in the ISC Bulletin (blue) and those selected for ISC location (red). The vertical scale is logarithmic.*

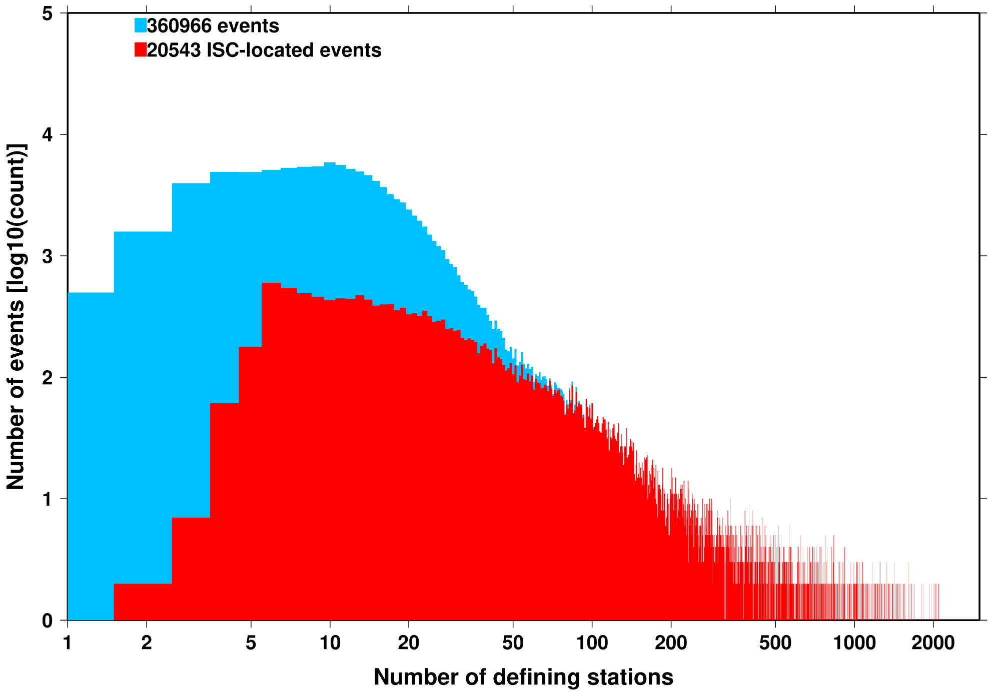


Figure 9.10: *Distribution of the number of defining stations for events in the ISC Bulletin (blue) and those selected for ISC location (red). The vertical scale is logarithmic.*

distribution of the area of the 90% confidence error ellipse for ISC-located events during the summary period. The distribution suffers from a long tail indicating a few poorly constrained event locations. Nevertheless, half of the events are characterised by an error ellipse with an area less than 205 km^2, 90% of the events have an error ellipse area less than 1299 km^2, and 95% of the events have an error ellipse area less than 2249 km^2.

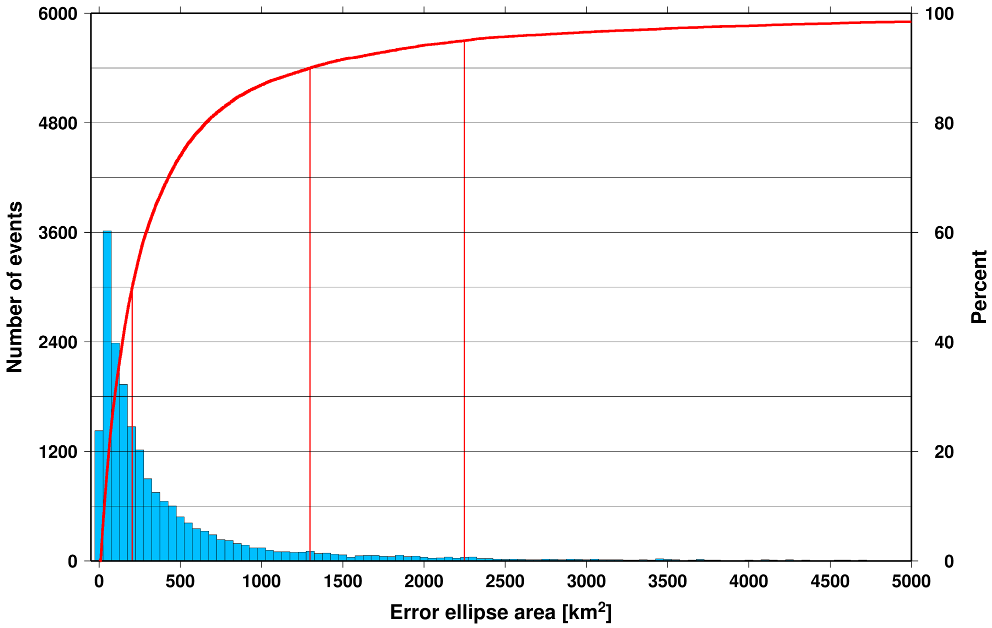


Figure 9.11: *Distribution of the area of the 90% confidence error ellipse of the ISC-located events. Vertical red lines indicate the 50th, 90th and 95th percentile values.*

Figure 9.12 shows one of the major characteristic features of the ISC location algorithm (Bondár and Storchak, 2011). Because the ISC locator accounts for correlated travel-time prediction errors due to unmodelled velocity heterogeneities along similar ray paths, the area of the 90% confidence error ellipse does not decrease indefinitely with increasing number of stations, but levels off once the information carried by the network geometry is exhausted, thus providing more realistic uncertainty estimates.

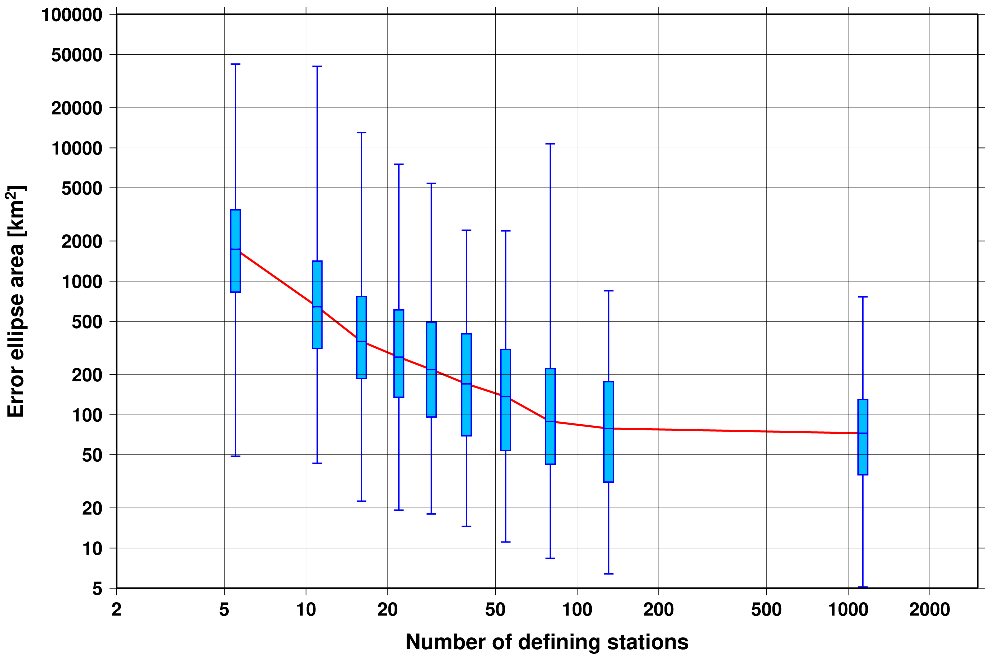


Figure 9.12: *Box-and-whisker plot of the area of the 90% confidence error ellipse of the ISC-located events as a function of the number of defining stations. Each box represents one-tenth-worth of the total number of data. The red line indicates the median 90% confidence error ellipse area.*

9.2 Seismic Phases and Travel-Time Residuals

The number of phases that are associated to events over the summary period in the ISC Bulletin is shown in Figure 9.13. Phase types and their total number in the ISC Bulletin is shown in the Appendix, Table 11.2. A summary of phase types is indicated in Figure 9.14.

In computing ISC locations, the current (for events since 2009) ISC location algorithm (*Bondár and Storchak*, 2011) uses all *ak135* phases where possible. Within the Bulletin, the phases that contribute to an ISC location are labelled as *time defining*. In this section, we summarise these time defining phases.

In Figure 9.15, the number of defining phases is shown in a histogram over the summary period. Each defining phase is listed in Table 9.1, which also provides a summary of the number of defining phases per event. A pie chart showing the proportion of defining phases is shown in Figure 9.16. Figure 9.17 shows travel times of seismic waves. The distribution of residuals for these defining phases is shown for the top five phases in Figures 9.18 through 9.22.

Table 9.1: *Numbers of 'time defining' phases (N) within the ISC Bulletin for 20543 ISC located events.*

Phase	Number of 'defining' phases	Number of events	Max per event	Median per event
P	1009890	15161	2653	14
Pn	658349	18936	960	16
Sn	166239	15699	199	5
Pb	109621	8967	116	7
Pg	100857	7146	278	7
PKPdf	66184	4559	630	2
Sg	65245	6822	199	5
Sb	59335	8409	103	4
S	53073	3415	761	3
PKiKP	39141	3685	472	2
PKPbc	30831	4466	199	1
PKPab	18868	3044	129	2

Table 9.1: *(continued)*

Phase	Number of 'defining' phases	Number of events	Max per event	Median per event
Pdif	12549	1027	747	2
PcP	12340	3742	101	2
pP	10372	1421	229	3
PP	9359	1267	257	2
ScP	4347	1168	104	2
sP	4312	1090	71	2
SS	4256	1050	58	2
SKSac	2757	456	118	2
PKKPbc	2297	433	107	2
pwP	1994	599	78	2
ScS	1145	374	36	1
SKPbc	1056	349	31	2
pPKPdf	961	367	39	1
SnSn	922	497	13	1
PnPn	850	427	18	1
sS	730	340	12	1
P'P'df	694	174	30	2
SKiKP	673	285	30	1
PS	583	219	53	1
pPKPab	559	186	41	1
PKKPab	551	229	24	1
PKKPdf	471	200	16	1
pPKPbc	398	211	20	1
sPKPdf	370	206	18	1
SKSdf	325	221	13	1
PcS	261	172	7	1
SKPab	243	147	10	1
SKKSac	242	128	14	1
sPKPab	175	84	14	1
SKPdf	162	84	31	1
PnS	148	109	4	1
sPKPbc	141	100	7	1
SP	138	54	13	1
SKKPbc	132	40	26	2
Sdif	125	63	16	1
PKSdf	107	64	8	1
pS	102	85	4	1
SKKSdf	98	88	4	1
pPdif	80	31	29	1
pPKiKP	49	26	15	1
sPdif	47	12	34	1
SKKPab	33	13	18	1
PbPb	26	19	3	1
P'P'bc	23	17	3	1
P'P'ab	22	14	4	1
SPn	20	16	3	1
PKSbc	15	15	1	1
SKKPdf	12	11	2	1
PKSab	10	2	9	5
sSKSac	10	9	2	1
sPKiKP	7	7	1	1
SbSb	5	5	1	1
sSdif	4	4	1	1
S'S'ac	3	3	1	1
pPn	3	2	2	2
sPn	3	3	1	1
PgS	2	2	1	1
sSKSdf	2	2	1	1
PgPg	1	1	1	1
PKKSdf	1	1	1	1

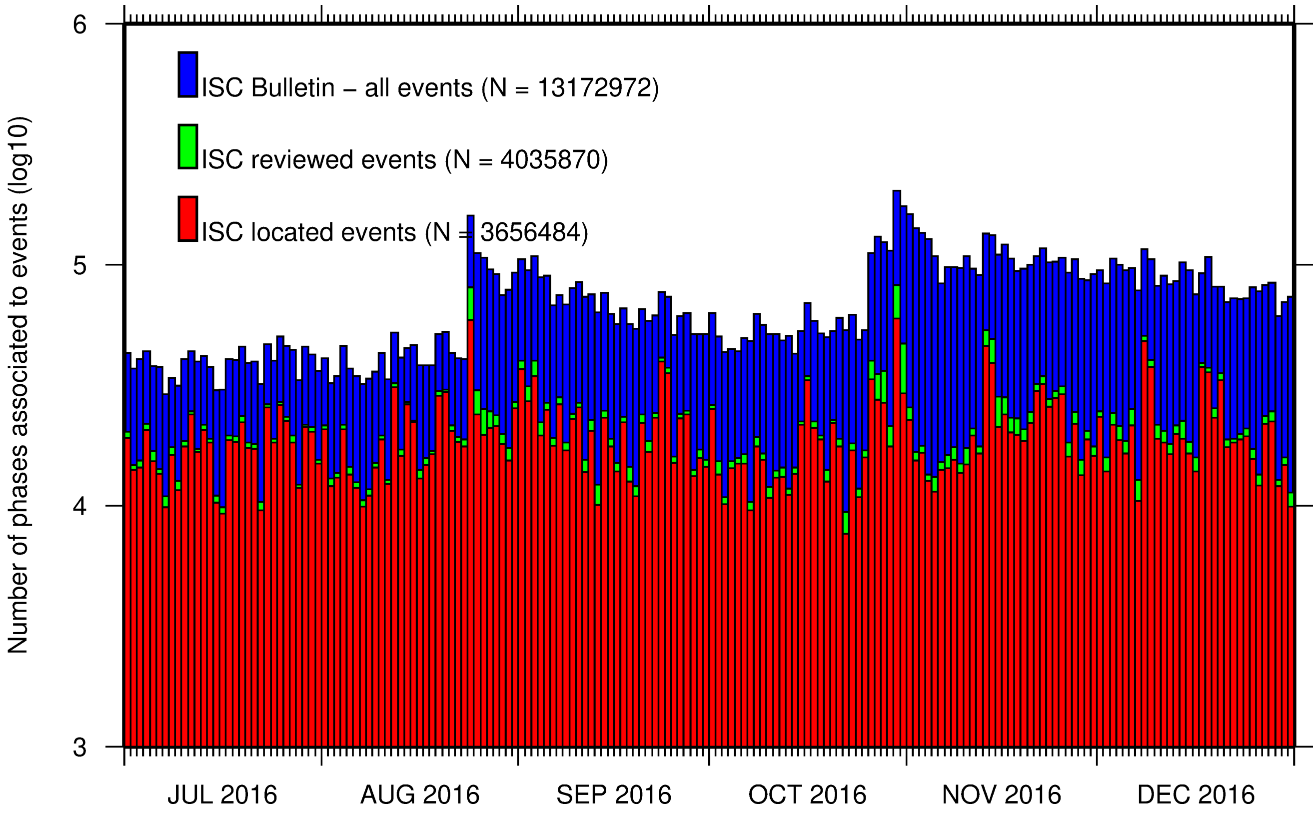


Figure 9.13: *Histogram showing the number of phases (N) that the ISC has associated to events within the ISC Bulletin for the current summary period.*

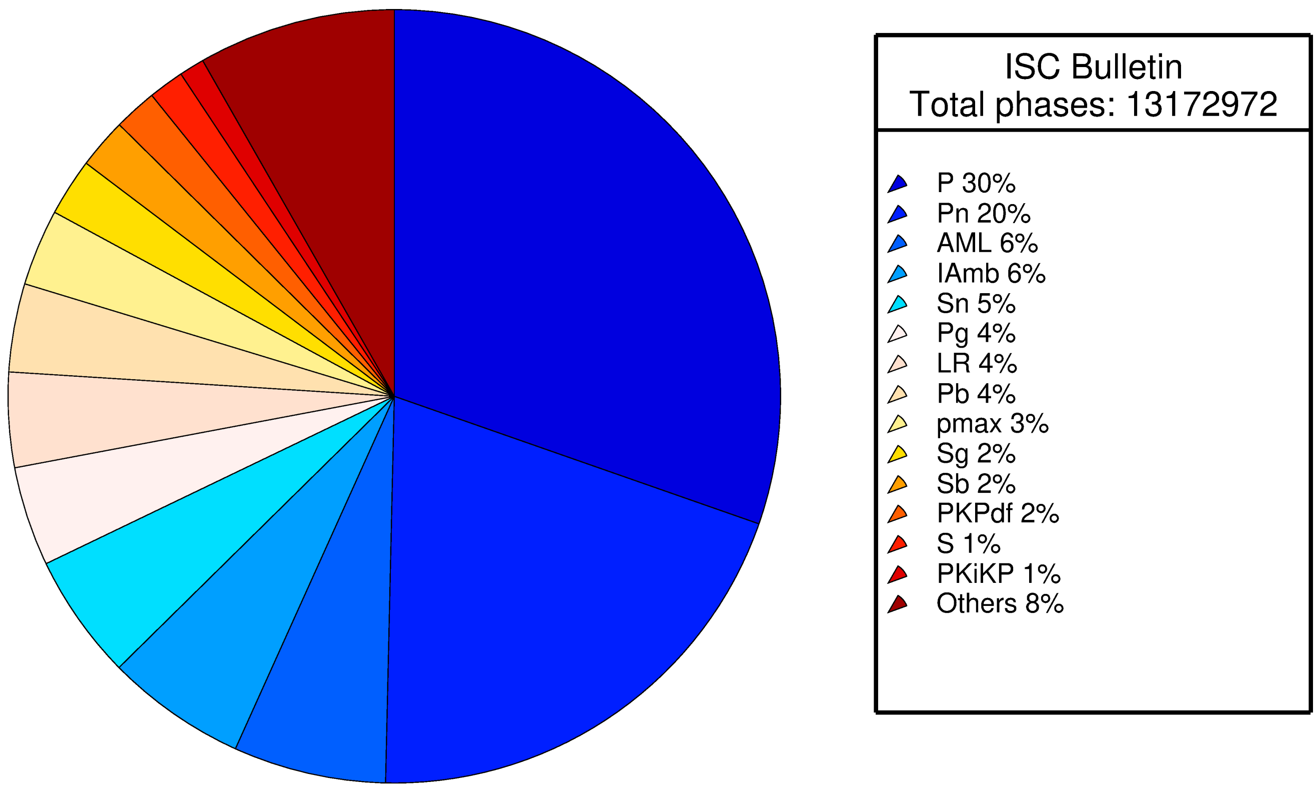


Figure 9.14: *Pie chart showing the fraction of various phase types in the ISC Bulletin for this summary period.*

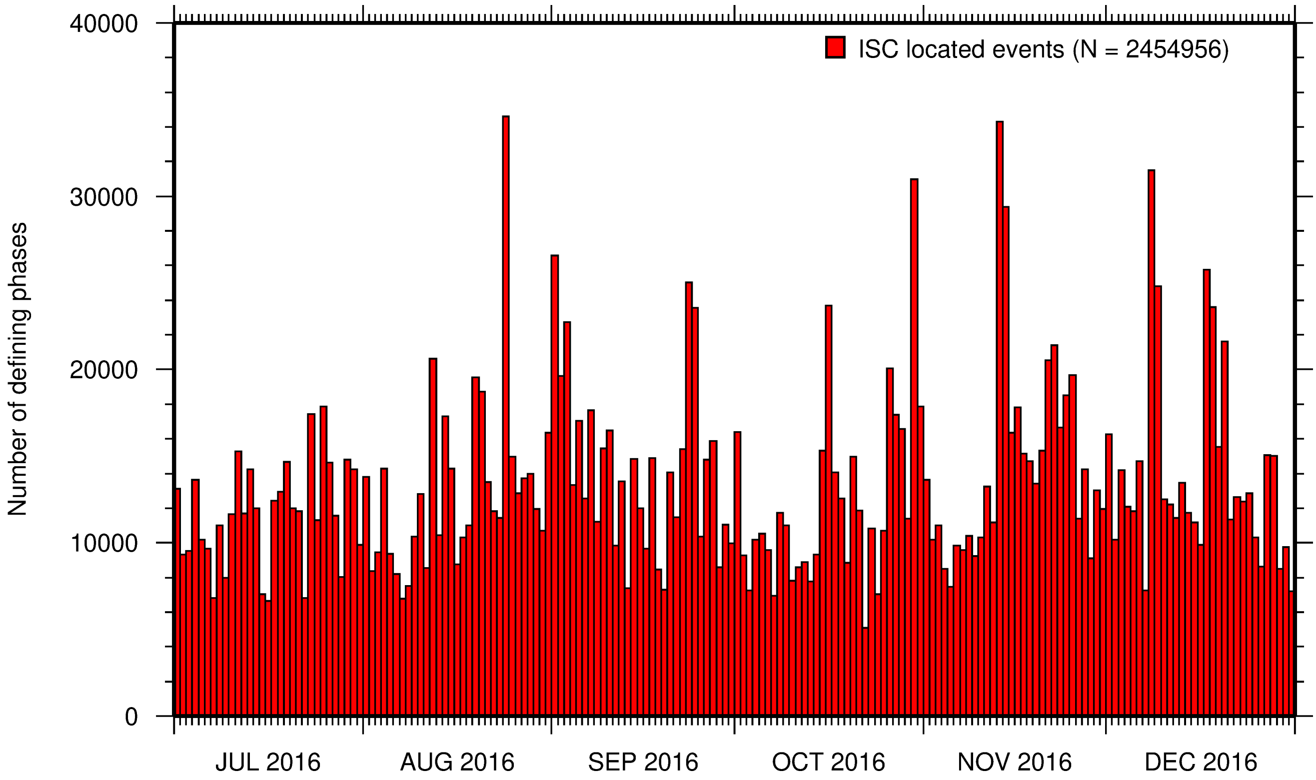


Figure 9.15: *Histogram showing the number of defining phases in the ISC Bulletin, for events located by the ISC.*

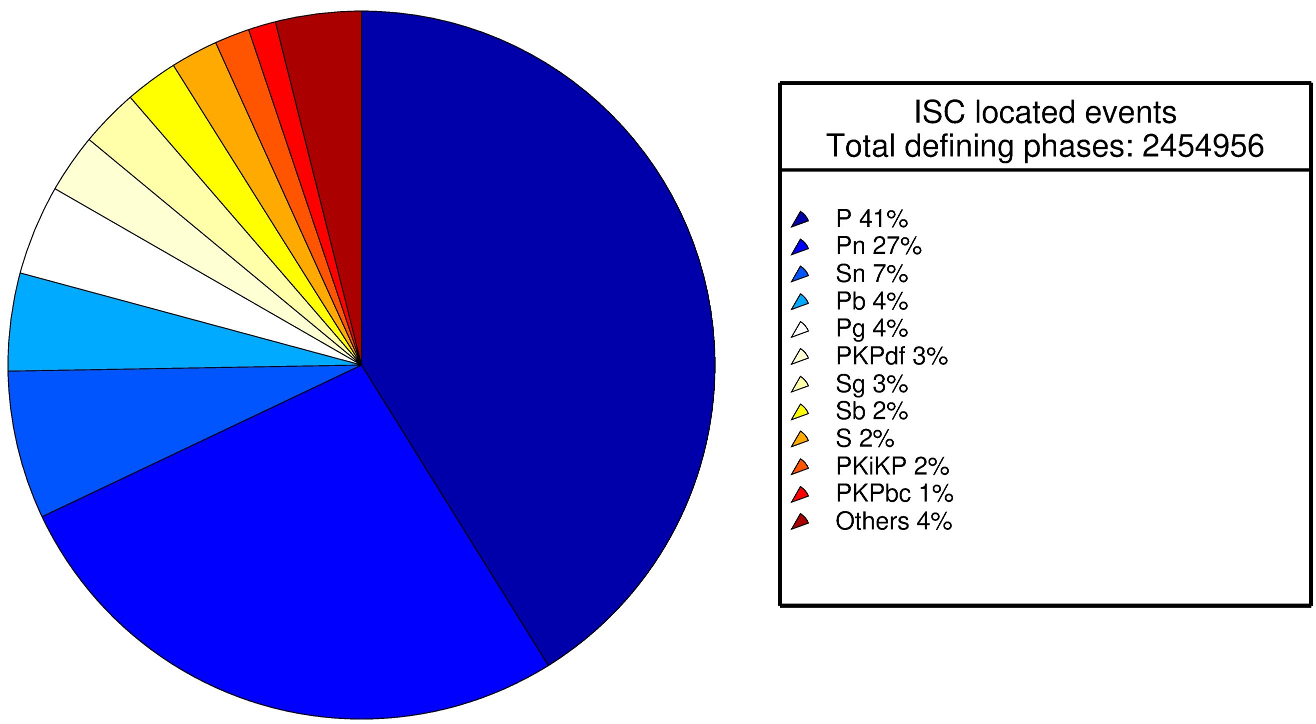


Figure 9.16: *Pie chart showing the defining phases in the ISC Bulletin, for events located by the ISC. A complete list of defining phases is shown in Table 9.1.*

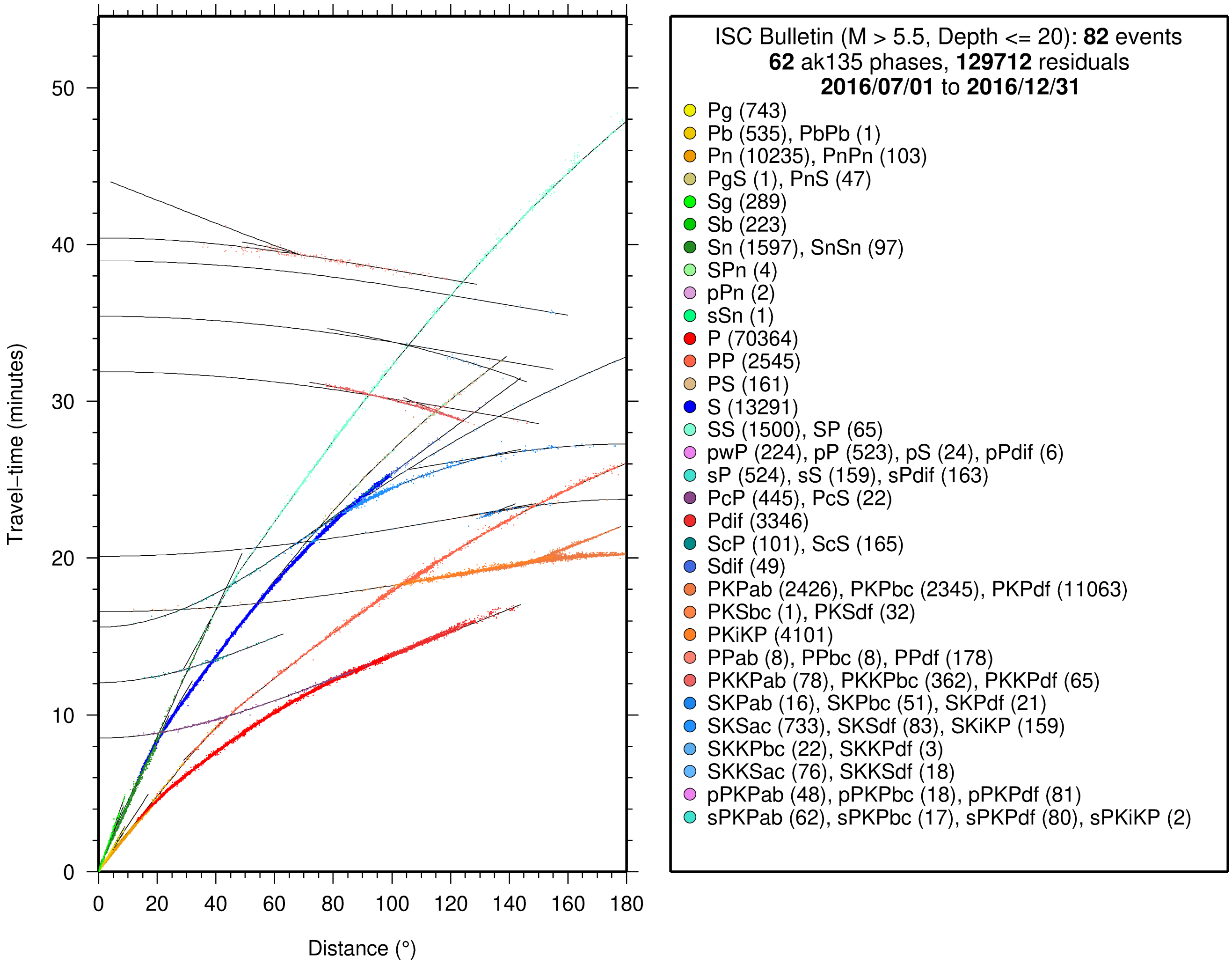


Figure 9.17: *Distribution of travel-time observations in the ISC Bulletin for events with M > 5.5 and depth less than 20 km. The travel-time observations are shown relative to a 0 km source and compared with the theoretical ak135 travel-time curves (solid lines). The legend lists the number of each phase plotted.*

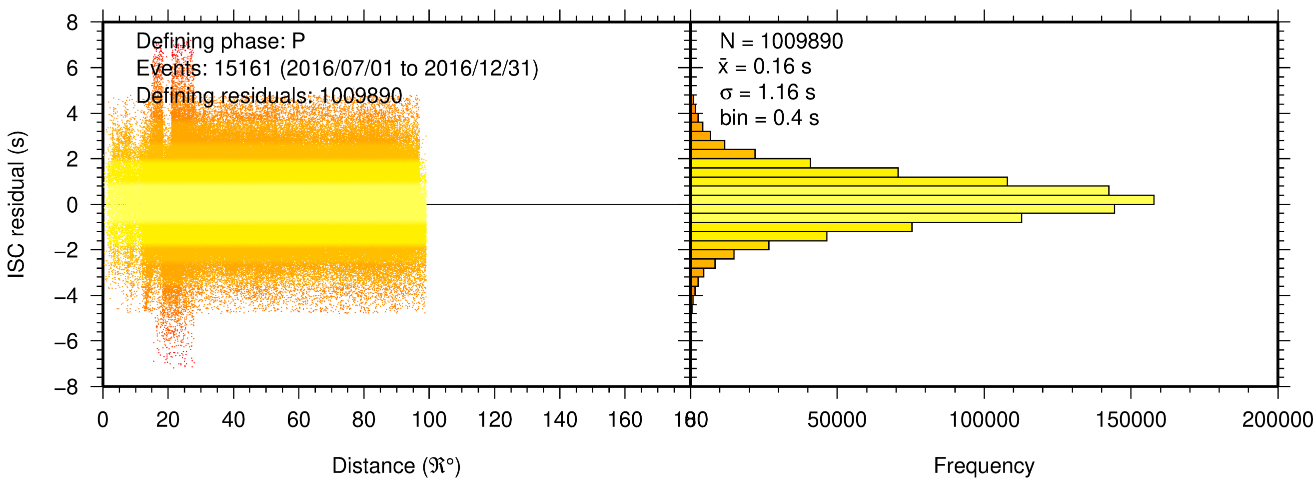


Figure 9.18: *Distribution of travel-time residuals for the defining P phases used in the computation of ISC located events in the Bulletin.*

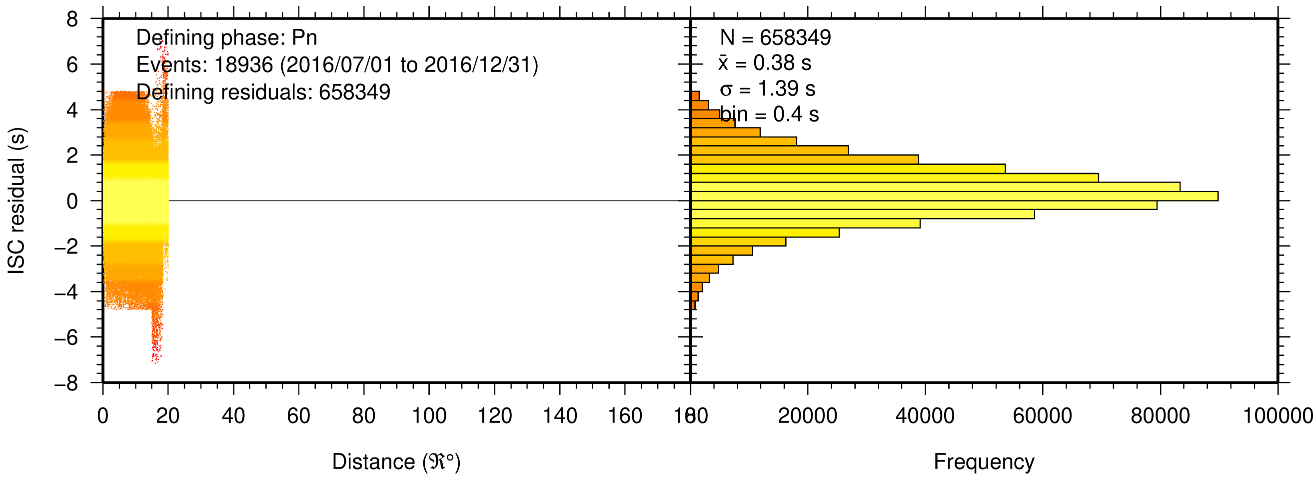


Figure 9.19: *Distribution of travel-time residuals for the defining Pn phases used in the computation of ISC located events in the Bulletin.*

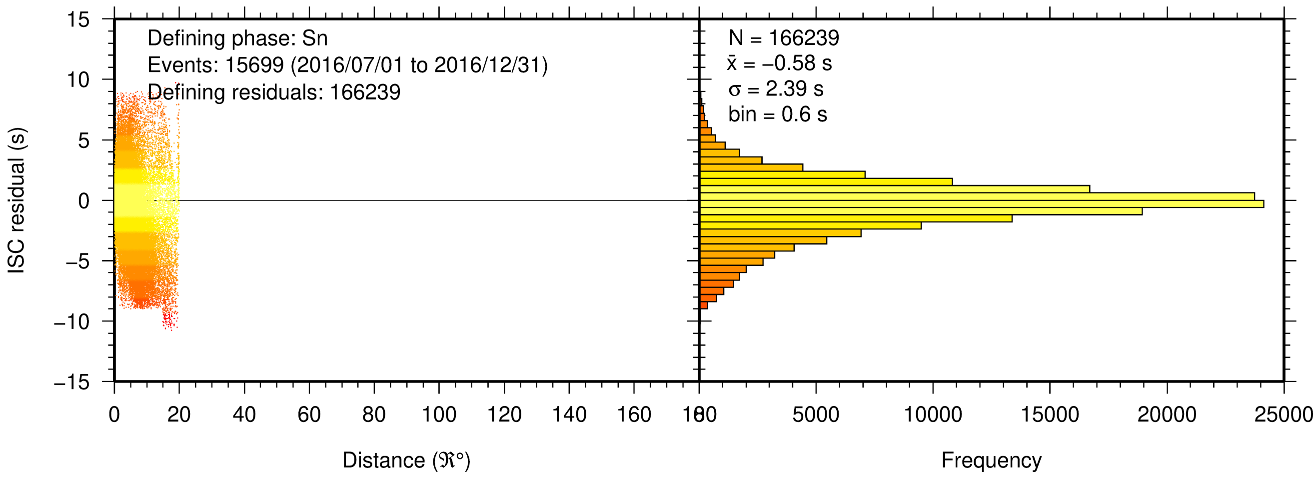


Figure 9.20: *Distribution of travel-time residuals for the defining Sn phases used in the computation of ISC located events in the Bulletin.*

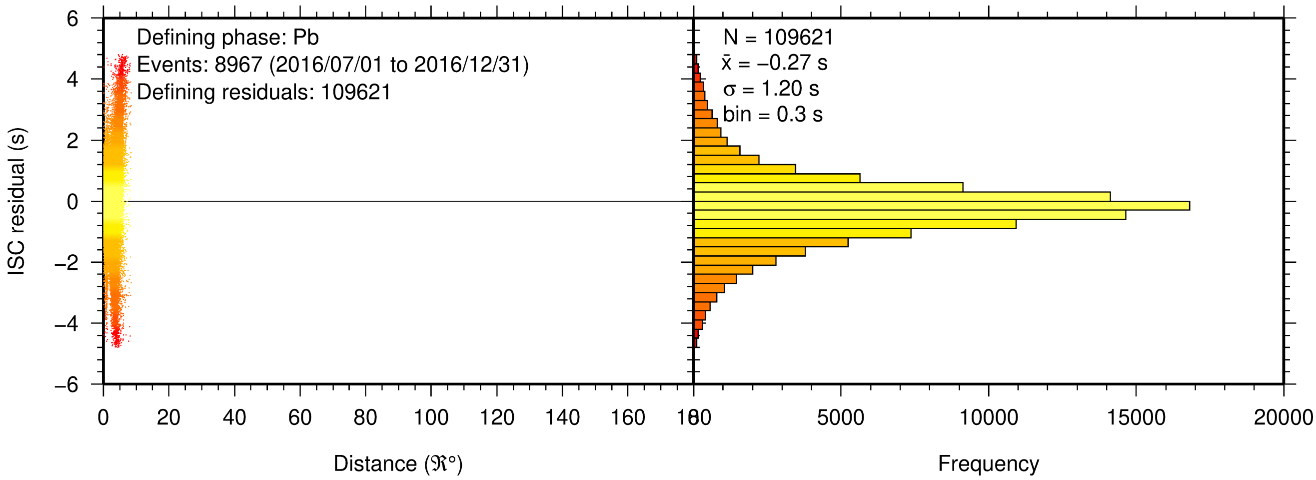


Figure 9.21: *Distribution of travel-time residuals for the defining Pb phases used in the computation of ISC located events in the Bulletin.*

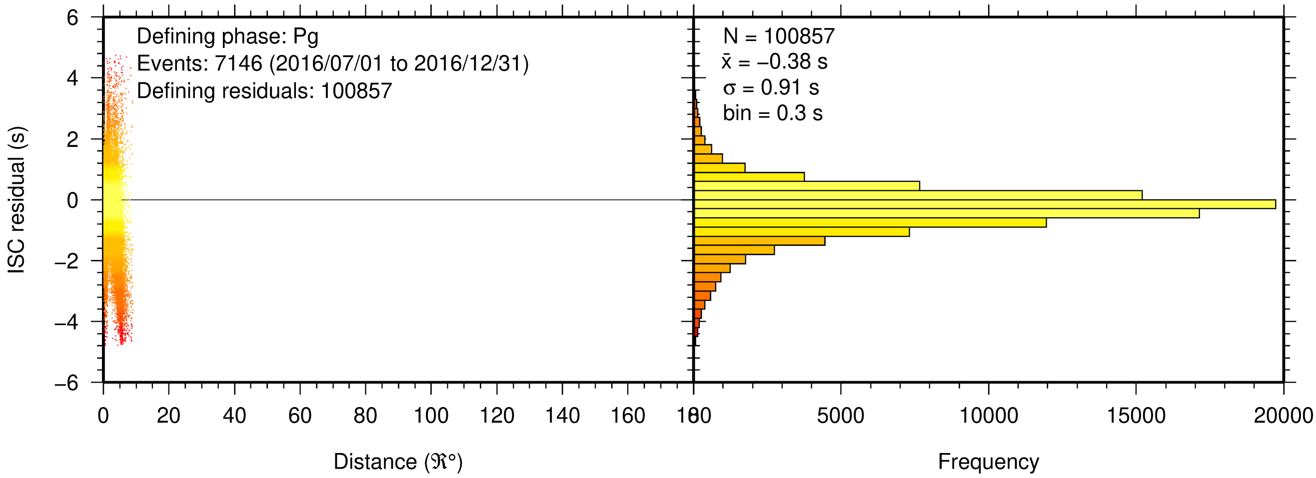


Figure 9.22: *Distribution of travel-time residuals for the defining Pg phases used in the computation of ISC located events in the Bulletin.*

9.3 Seismic Wave Amplitudes and Periods

The ISC Bulletin contains a variety of seismic wave amplitudes and periods measured by reporting agencies. For this Bulletin Summary, the total of collected amplitudes and periods is 6454892 (see Section 8.3). For the determination of the ISC magnitudes MS and mb, only a fraction of such data can be used. Indeed, the ISC network magnitudes are computed only for ISC located events. Here we recall the main features of the ISC procedure for MS and mb computation (see detailed description in Section 11.1.4 of the January to June Bulletin Summary). For each amplitude-period pair in a reading the ISC algorithm computes the magnitude (a reading can include several amplitude-period measurements) and the reading magnitude is assigned to the maximum A/T in the reading. If more than one reading magnitude is available for a station, the station magnitude is the median of the reading magnitudes. The network magnitude is computed then as the 20% alpha-trimmed median of the station magnitudes (at least three required). MS is computed for shallow earthquakes (depth $\leq$ 60 km) only and using amplitudes and periods on all three components (when available) if the period is within 10-60 s and the epicentral distance is between 20° and 160°. mb is computed also for deep earthquakes (depth down to 700 km) but only with amplitudes on the vertical component measured at periods $\leq$ 3 s in the distance range 21°-100°.

Table 9.2 is a summary of the amplitude and period data that contributed to the computation of station and ISC MS and mb network magnitudes for this Bulletin Summary.

Table 9.2: *Summary of the amplitude-period data used by the ISC Locator to compute MS and mb.*

	MS	mb
Number of amplitude-period data	150078	452996
Number of readings	131513	448485
Percentage of readings in the ISC located events with qualifying data for magnitude computation	14.9	40.9
Number of station magnitudes	126456	410207
Number of network magnitudes	3925	13282

A small percentage of the readings with qualifying data for MS and mb calculation have more than one amplitude-period pair. Notably, only 14.9% of the readings for the ISC located (shallow) events included qualifying data for MS computation, whereas for mb the percentage is much higher at 40.9%. This is due to the seismological practice of reporting agencies. Agencies contributing systematic reports of amplitude and period data are listed in Appendix Table 11.3. Obviously the ISC Bulletin would benefit if more agencies included surface wave amplitude-period data in their reports.

Figure 9.23 shows the distribution of the number of station magnitudes versus distance. For mb there is a significant increase in the distance range 70°-90°, whereas for MS most of the contributing stations are below 100°. The increase in number of station magnitude between 70°-90° for mb is partly due to the very dense distribution of seismic stations in North America and Europe with respect to earthquake occurring in various subduction zones around the Pacific Ocean.

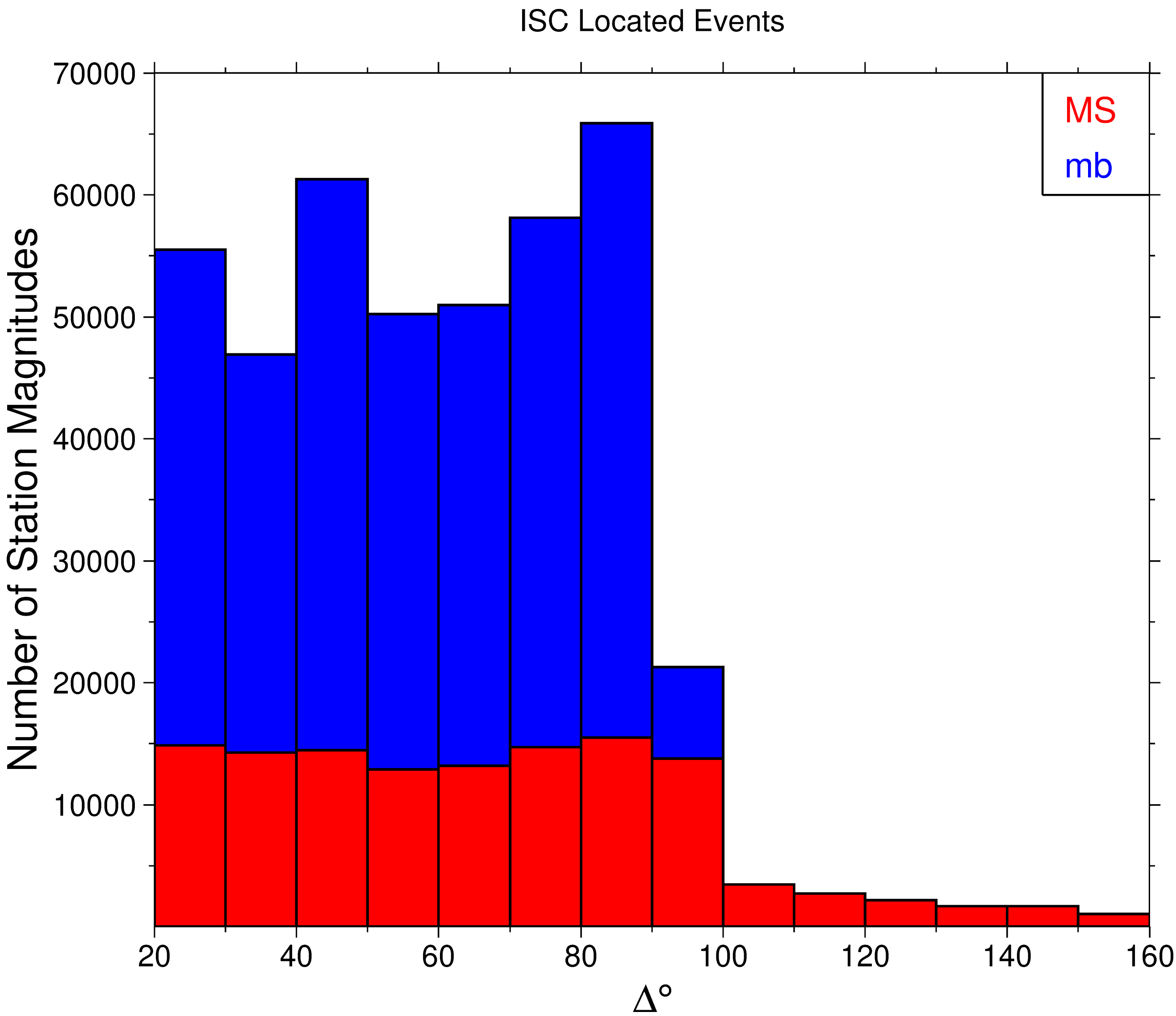


Figure 9.23: *Distribution of the number of station magnitudes computed by the ISC Locator for mb (blue) and MS (red) versus distance.*

Finally, Figure 9.24 shows the distribution of network MS and mb as well as the median number of stations for magnitude bins of 0.2. Clearly with increasing magnitude the number of events is smaller but with a general tendency of having more stations contributing to the network magnitude.

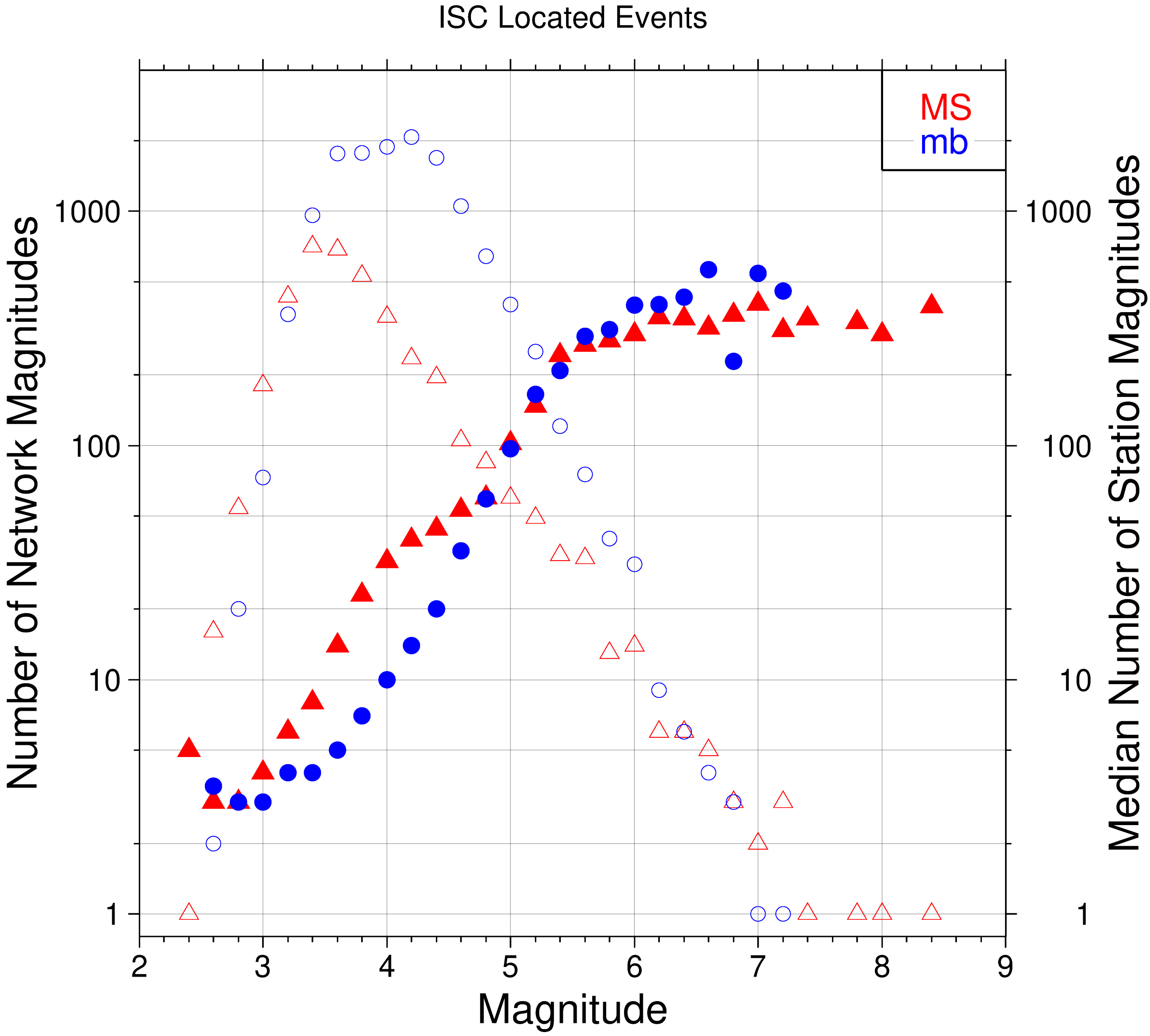


Figure 9.24: *Number of network magnitudes (open symbols) and median number of stations magnitudes (filled symbols). Blue circles refer to mb and red triangles to MS. The width of the magnitude interval* δM *is 0.2, and each symbol includes data with magnitude in* $M \pm \delta M/2$.

9.4 Completeness of the ISC Bulletin

The completeness of the ISC Bulletin can be expressed as a magnitude value, above which we expect the Bulletin to contain 100% of events. This magnitude of completeness, M_C can be measured as the point where the seismicity no longer follows the Gutenberg-Richter relationship. We compute an estimate of M_C using the maximum curvature technique of *Woessner and Wiemer* (2005).

The completeness of the ISC Bulletin for this summary period is shown in Figure 9.25. A history of completeness for the ISC Bulletin is shown in Figure 9.26. The step change in 1996 corresponds with the inclusion of the Prototype IDC (EIDC) Bulletin, followed by the Reviewed Event Bulletin (REB) of the IDC.

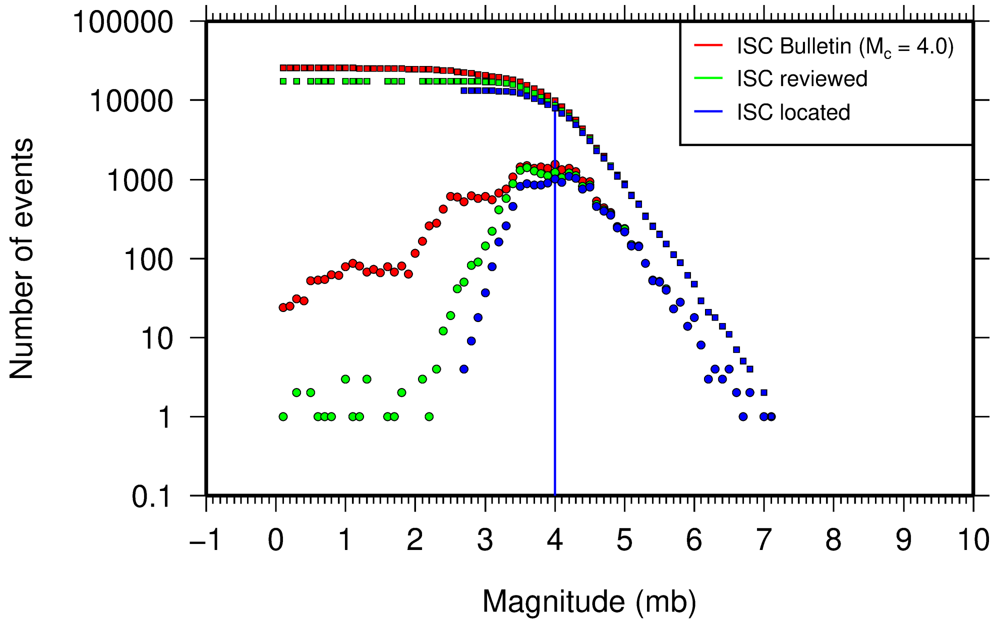


Figure 9.25: *Frequency and cumulative frequency magnitude distribution for all events in the ISC Bulletin, ISC reviewed events and events located by the ISC. The magnitude of completeness (M_C) is shown for the ISC Bulletin. Note: only events with values of mb are represented in the figure.*

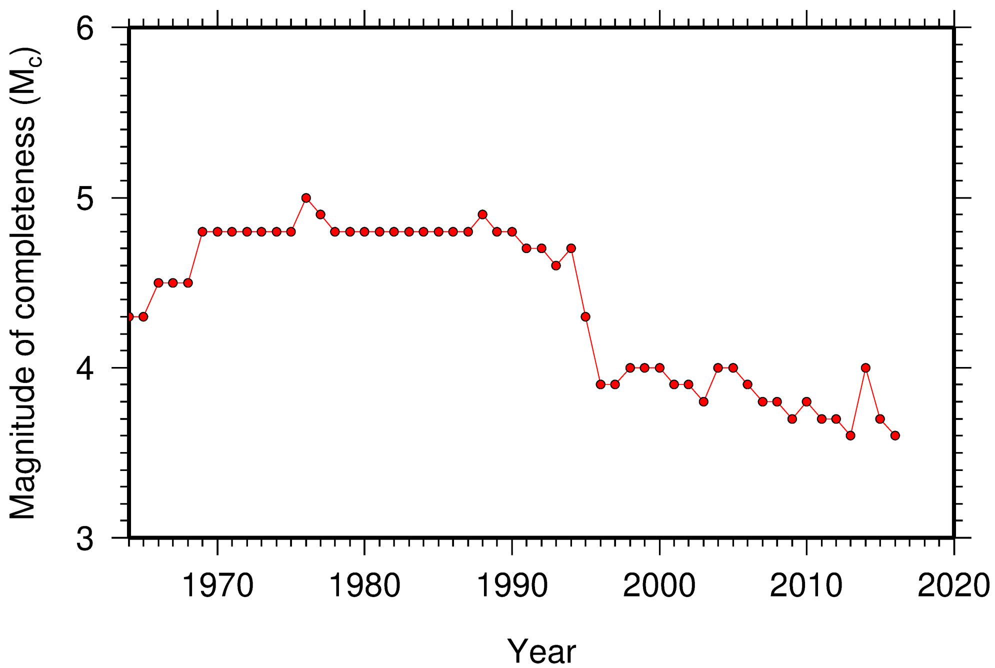


Figure 9.26: *Variation of magnitude of completeness (M_C) for each year in the ISC Bulletin. Note: M_C is calculated only using those events with values of mb.*

9.5 Magnitude Comparisons

The ISC Bulletin publishes network magnitudes reported by multiple agencies to the ISC. For events that have been located by the ISC, where enough amplitude data has been collected, the *MS* and *mb* magnitudes are calculated by the ISC (MS is computed only for depths $\leq$ 60 km). In this section, ISC magnitudes and some other reported magnitudes in the ISC Bulletin are compared.

The comparison between MS and mb computed by the ISC locator for events in this summary period is shown in Figure 9.27, where the large number of data pairs allows a colour coding of the data density. The scatter in the data reflects the fundamental differences between these magnitude scales.

Similar plots are shown in Figure 9.28 and 9.29, respectively, for comparisons of ISC mb and ISC MS with M_W from the GCMT catalogue. Since M_W is not often available below magnitude 5, these distributions are mostly for larger, global events. Not surprisingly, the scatter between mb and M_W is larger than the scatter between MS and M_W. Also, the saturation effect of mb is clearly visible for earthquakes with $M_W > 6.5$. In contrast, MS scales well with $M_W > 6$, whereas for smaller magnitudes MS appears to be systematically smaller than M_W.

In Figure 9.30 ISC values of mb are compared with all reported values of mb, values of mb reported by NEIC and values of mb reported by IDC. Similarly in Figure 9.31, ISC values of MS are compared with all reported values of MS, values of MS reported by NEIC and values of MS reported by IDC. There is a large scatter between the ISC magnitudes and the mb and MS reported by all other agencies.

The scatter decreases both for mb and MS when ISC magnitudes are compared just with NEIC and IDC magnitudes. This is not surprising as the latter two agencies provide most of the amplitudes and periods used by the ISC locator to compute MS and mb. However, ISC mb appears to be smaller than NEIC mb for $mb < 4$ and larger than IDC mb for $mb > 4$. Since NEIC does not include IDC amplitudes, it seems these features originate from observations at the high-gain, low-noise sites reported by the IDC. For the MS comparisons between ISC and NEIC a similar but smaller effect is observed for $MS < 4.5$, whereas a good scaling is generally observed for the MS comparisons between ISC and IDC.

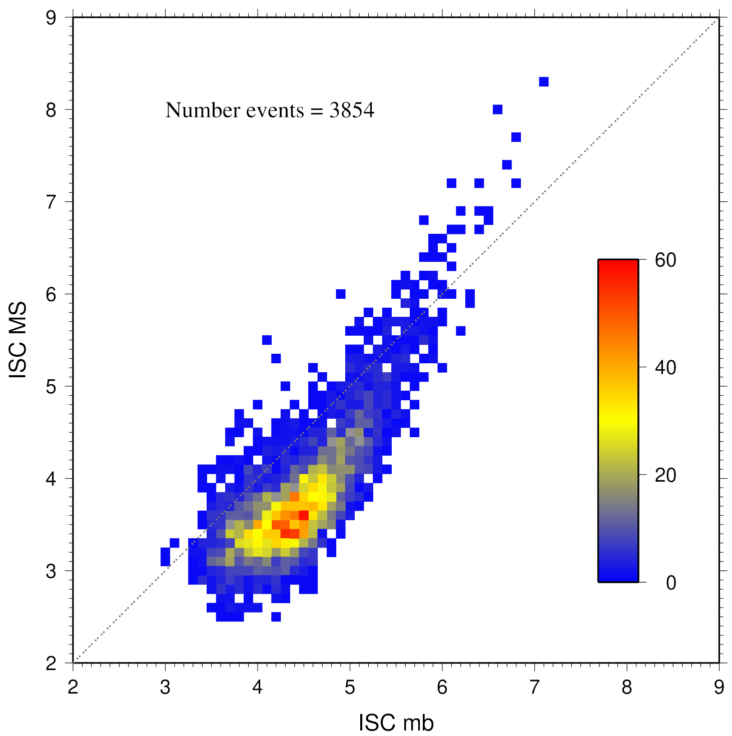


Figure 9.27: *Comparison of ISC values of MS with mb for common event pairs.*

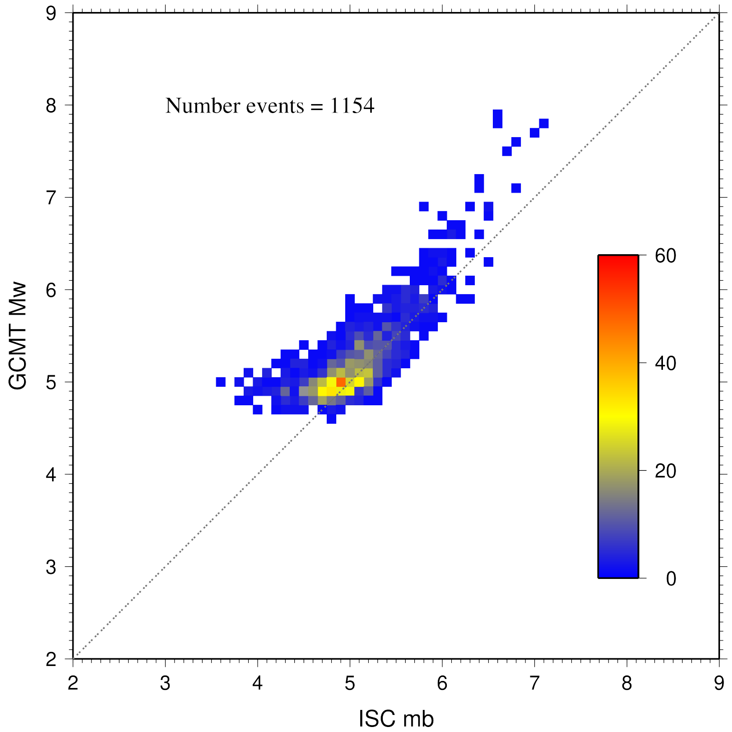


Figure 9.28: *Comparison of ISC values of mb with GCMT M_W for common event pairs.*

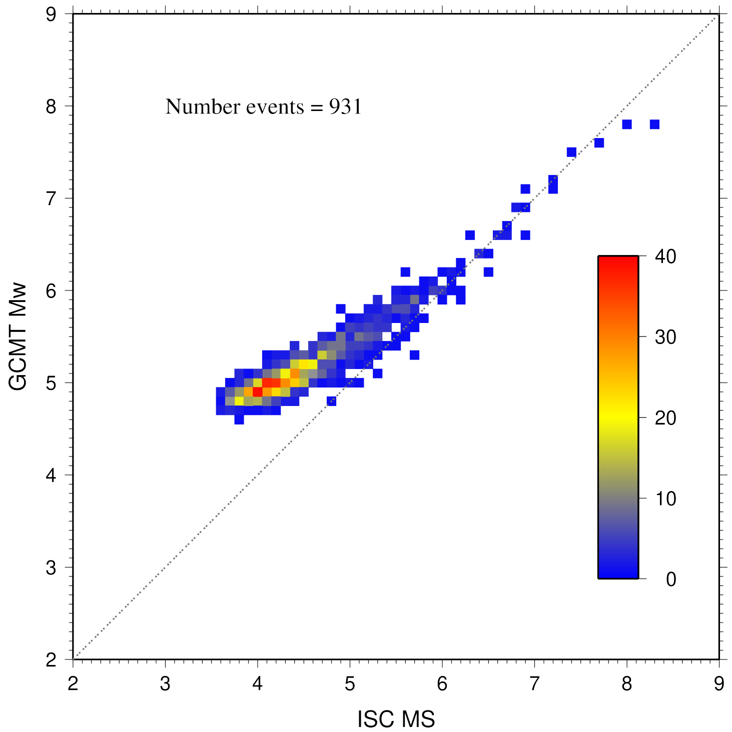


Figure 9.29: *Comparison of ISC values of MS with GCMT M_W for common event pairs.*

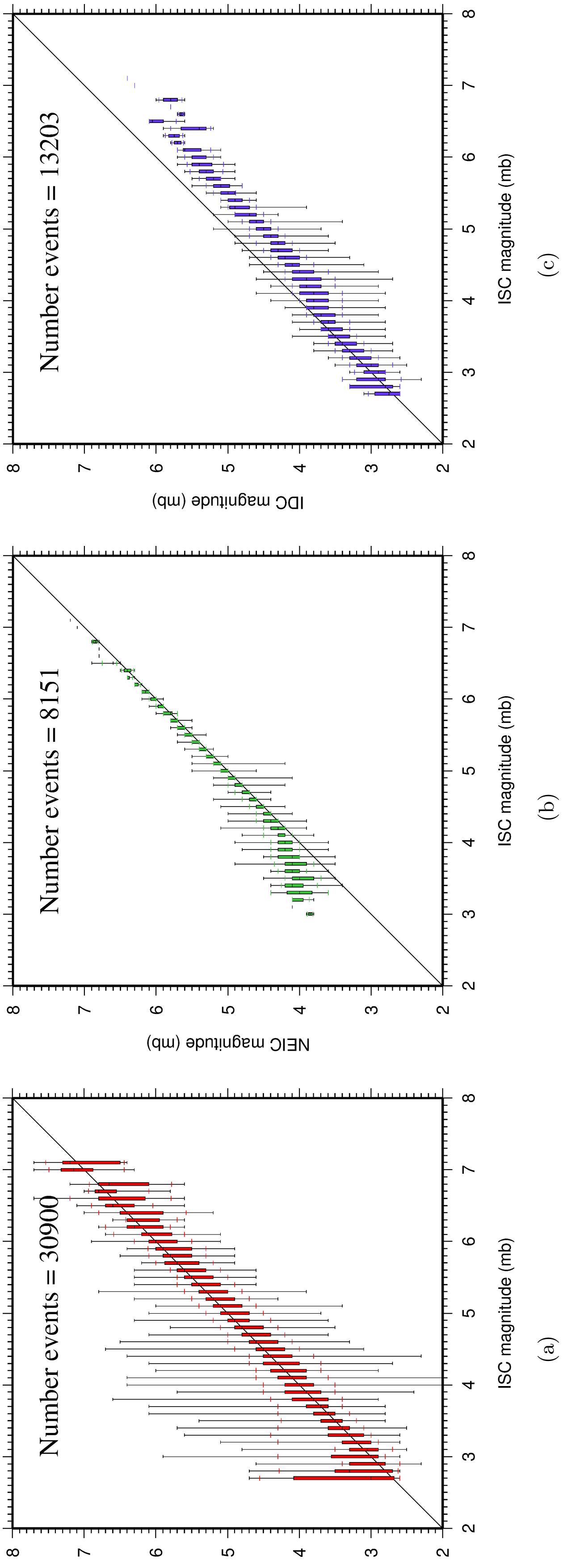
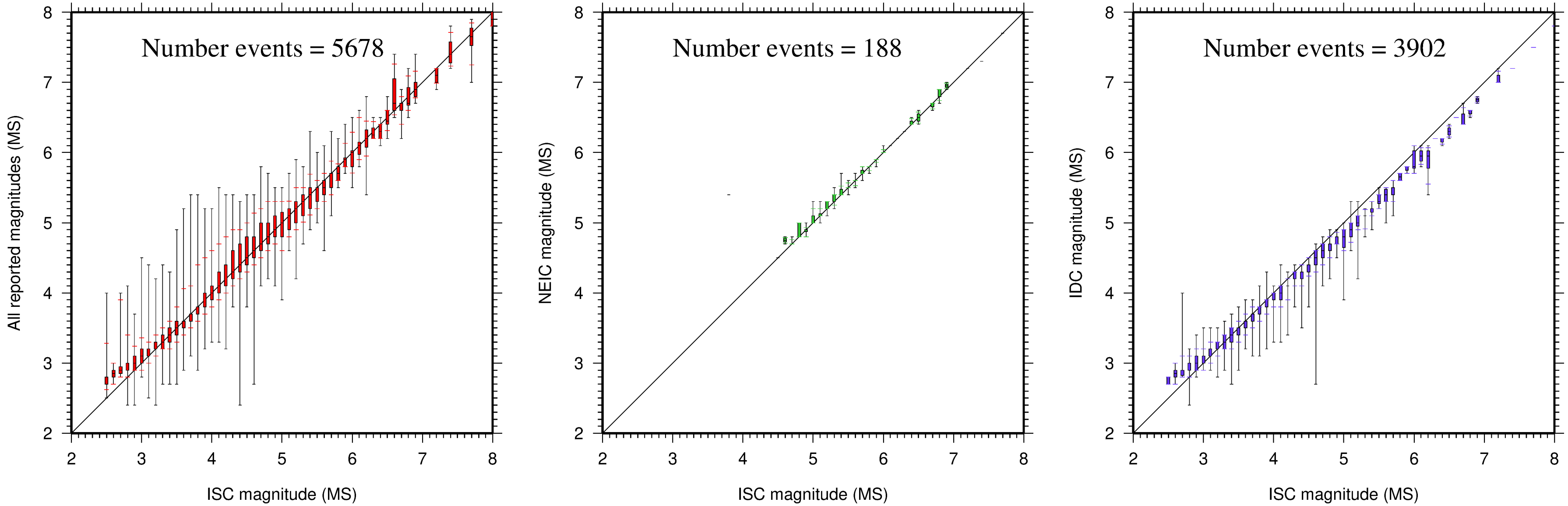


Figure 9.30: *Comparison of ISC magnitude data (mb) with additional agency magnitudes (mb). The statistical summary is shown in box-and-whisker plots where the 10th and 90th percentiles are shown in addition to the max and min values. (a): All magnitudes reported; (b): NEIC magnitudes; (c): IDC magnitudes.*



(a) (b) (c)

Figure 9.31: *Comparison of ISC magnitude data (MS) with additional agency magnitudes (MS). The statistical summary is shown in the box-and-whisker plots where the 10th and 90th percentiles are shown in addition to the max and min values. (a): All magnitudes reported; (b): NEIC magnitudes; (c): IDC magnitudes.*

10

The Leading Data Contributors

For the current six-month period, 147 agencies reported related bulletin data. Although we are grateful for every report, we nevertheless would like to acknowledge those agencies that made the most useful or distinct contributions to the contents of the ISC Bulletin. Here we note those agencies that:

- provided a comparatively large volume of parametric data (see Section 10.1),
- reported data that helped quite considerably to improve the quality of the ISC locations or magnitude determinations (see Section 10.2),
- helped the ISC by consistently reporting data in one of the standard recognised formats and in-line with the ISC data collection schedule (see Section 10.3).

We do not aim to discourage those numerous small networks who provide comparatively smaller yet still most essential volumes of regional data regularly, consistently and accurately. Without these reports the ISC Bulletin would not be as comprehensive and complete as it is today.

10.1 The Largest Data Contributors

We acknowledge the contribution of IDC, NEIC, MOS, BJI, AWI and a few others (Figure 10.1) that reported the majority of moderate to large events recorded at teleseismic distances. The contributions of NEIC, IDC, MEX, WEL, and several others are also acknowledged with respect to smaller seismic events. The contributions of JMA, MEX, NEIC, IDC, TAP, WEL, ROM and a number of others are also acknowledged with respect to small seismic events. Note that the NEIC bulletin accumulates a contribution of all regional networks in the USA. Several agencies monitoring highly seismic regions routinely report large volumes of small to moderate magnitude events, such as those in Japan, Chinese Taipei, Turkey, Italy, Greece, New Zealand, Mexico and Columbia. Contributions of small magnitude events by agencies in regions of low seismicity, such as Finland are also gratefully received.

We also would like to acknowledge contributions of those agencies that report a large portion of arrival time and amplitude data (Figure 10.2). For small magnitude events, these are local agencies in charge of monitoring local and regional seismicity. For moderate to large events, contributions of IDC, USArray, NEIC, MOS are especially acknowledged. Notably, three agencies (IDC, NEIC and MOS) together reported over 70% of all amplitude measurements made for teleseismically recorded events. We hope that other agencies would also be able to update their monitoring routines in the future to include the amplitude reports for teleseismic events compliant with the IASPEI standards.

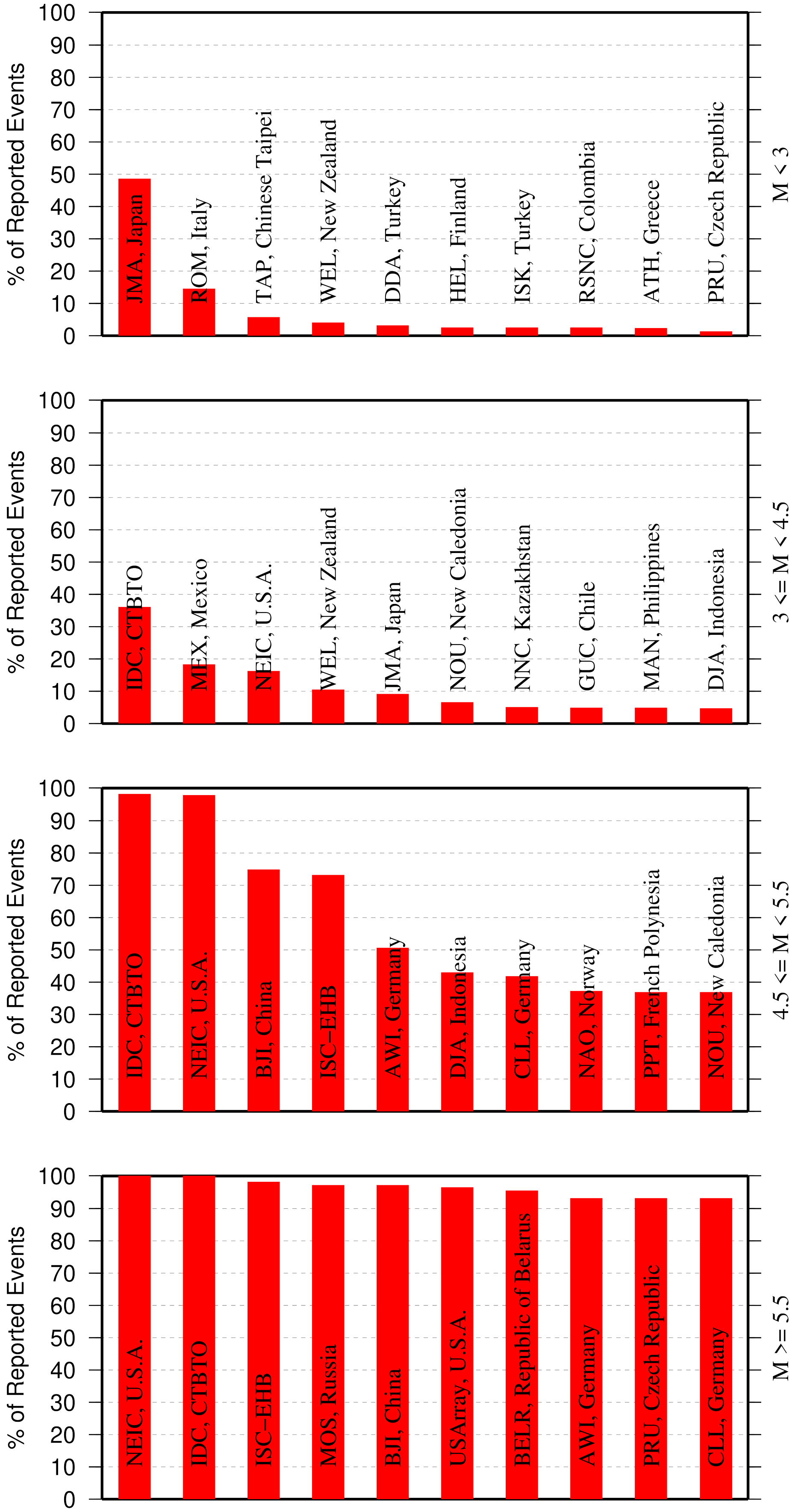


Figure 10.1: *Frequency of events in the ISC Bulletin for which an agency reported at least one item of data: a moment tensor, a hypocentre, a station arrival time or an amplitude. The top ten agencies are shown for four magnitude intervals.*

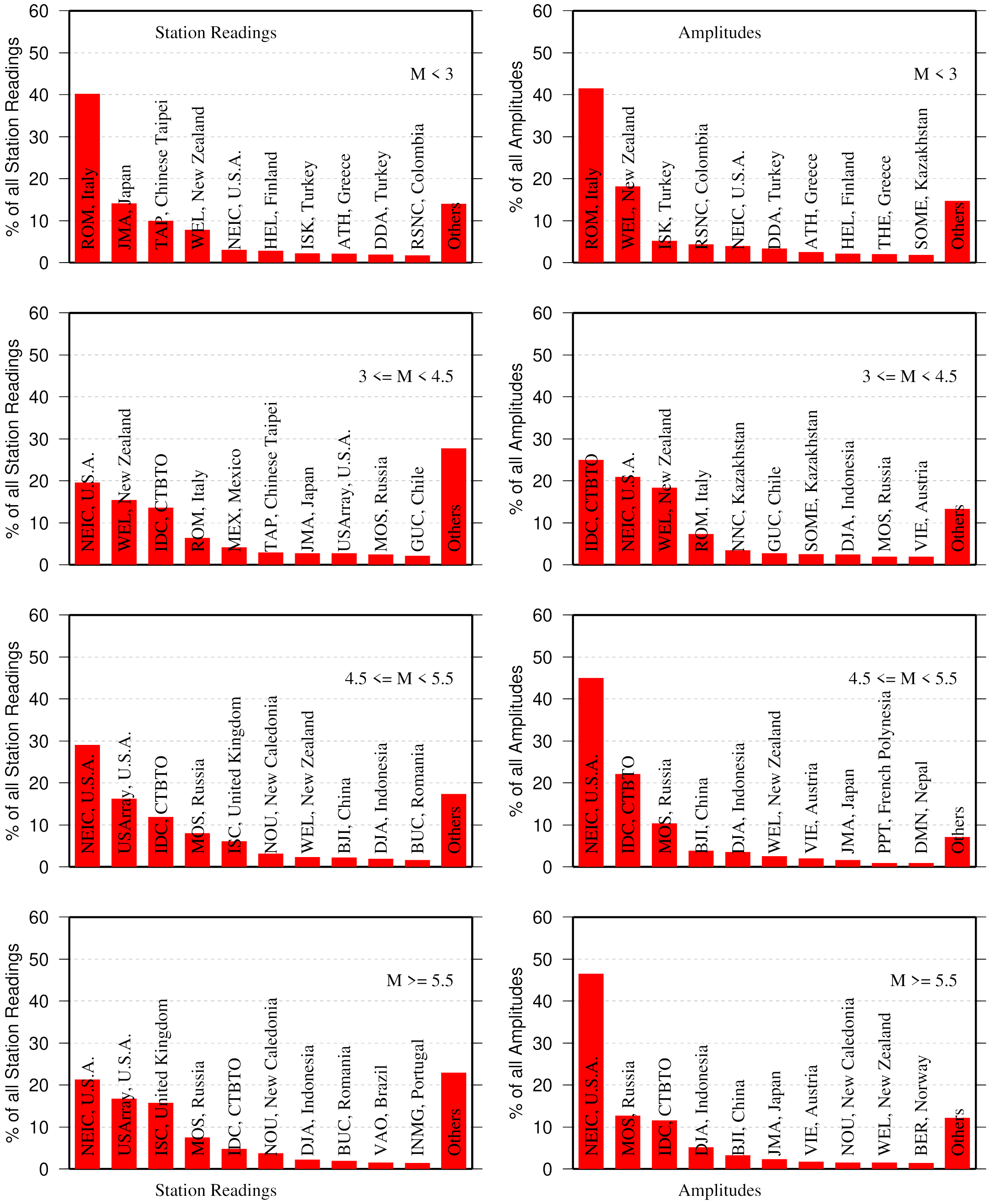


Figure 10.2: *Contributions of station arrival time readings (left) and amplitudes (right) of agencies to the ISC Bulletin. Top ten agencies are shown for four magnitude intervals.*

10.2 Contributors Reporting the Most Valuable Parameters

One of the main ISC duties is to re-calculate hypocentre estimates for those seismic events where a collective wealth of all station reports received from all agencies is likely to improve either the event location or depth compared to the hypocentre solution from each single agency. For areas with a sparse local seismic network or an unfavourable station configuration, readings made by other networks at teleseismic distances are very important. All events near mid-oceanic ridges as well as those in the majority of subduction zones around the world fall into this category. Hence we greatly appreciate the effort made by many agencies that report data for remote earthquakes (Figure 10.3). For some agencies, such as the IDC and the NEIC, it is part of their mission. For instance, the IDC reports almost every seismic event that is large enough to be recorded at teleseismic distance (20 degrees and beyond). This is largely because the International Monitoring System of primary arrays and broadband instruments is distributed at quiet sites around the world in order to be able to detect possible violations of the Comprehensive Nuclear-Test-Ban Treaty. The NEIC reported over 40% of those events as their mission requires them to report events above magnitude 4.5 outside the United States of America. For other agencies reporting distant events it is an extra effort that they undertake to notify their governments and relief agencies as well as to help the ISC and academic research in general. Hence these agencies usually report on the larger magnitude events. BJI, AWI, NAO, CLL, MOS, NOU, WEL and PPT each reported individual station arrivals for several percent of all relevant events. We encourage other agencies to report distant events to us.

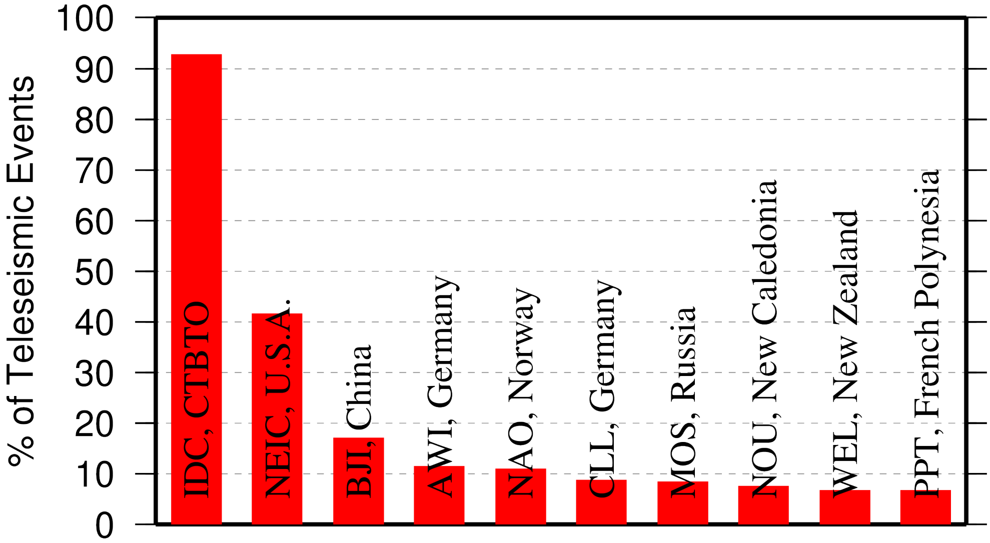


Figure 10.3: *Top ten agencies that reported teleseismic phase arrivals for a large portion of ISC events.*

In addition to the first arriving phase we encourage reporters to contribute observations of secondary seismic phases that help constrain the event location and depth: S, Sn, Sg and pP, sP, PcP (Figure 10.4). We expect though that these observations are actually made from waveforms, rather than just predicted by standard velocity models and modern software programs. It is especially important that these arrivals are manually reviewed by an operator (as we know takes place at the IDC and NEIC), as opposed to some lesser attempts to provide automatic phase readings that are later rejected by the ISC due to a generally poor quality of unreviewed picking.

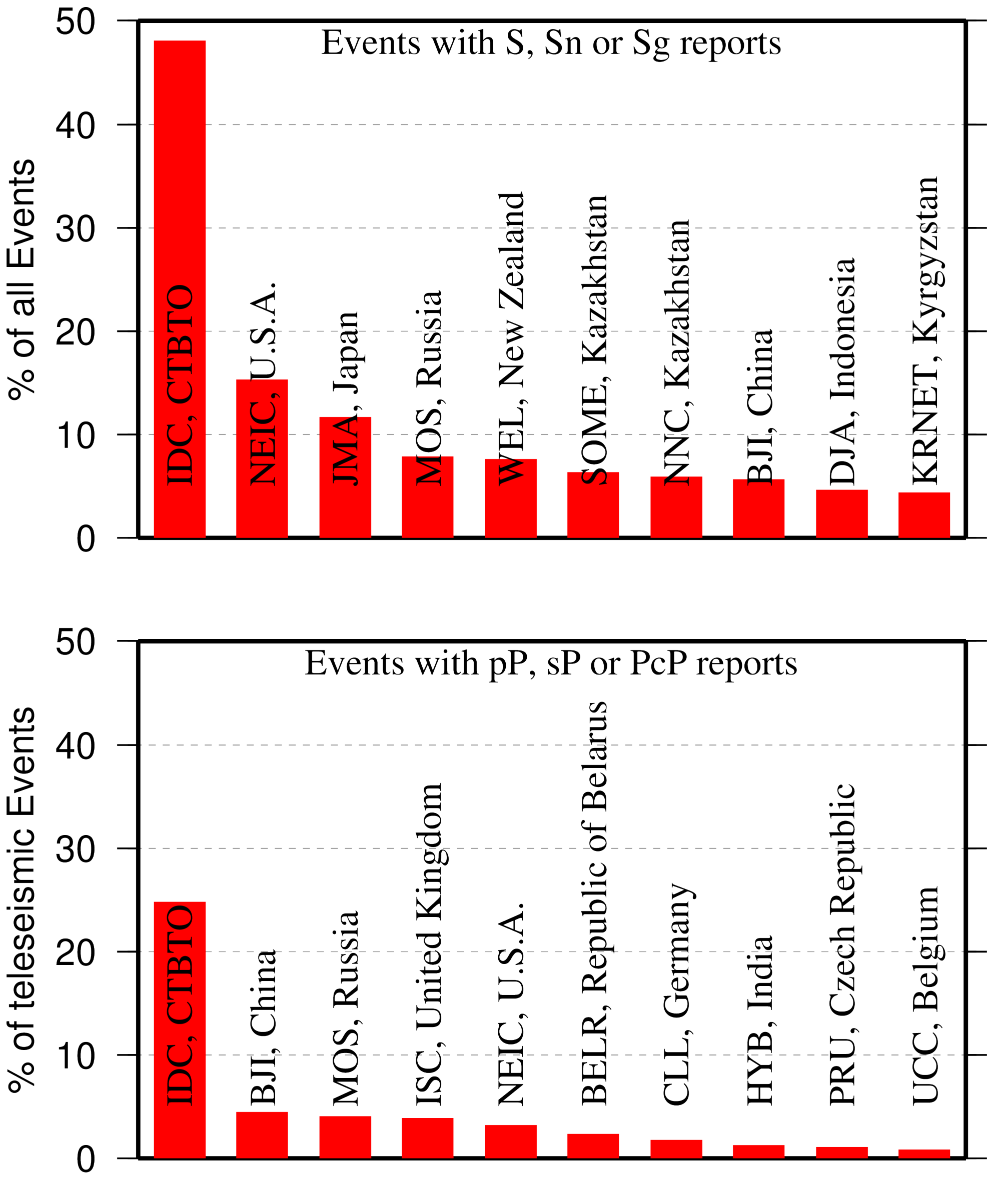


Figure 10.4: *Top ten agencies that reported secondary phases important for an accurate epicentre location (top) and focal depth determination (bottom).*

Another important long-term task that the ISC performs is to compute the most definitive values of MS and mb network magnitudes that are considered reliable due to removal of outliers and consequent averaging (using alpha-trimmed median) across the largest network of stations, generally not feasible for a single agency. Despite concern over the bias at the lower end of mb introduced by the body wave amplitude data from the IDC, other agencies are also known to bias the results. This topic is further discussed in Section 9.5.

Notably, the IDC reports almost 100% of all events for which MS and mb are estimated. This is due to the standard routine that requires determination of body and surface wave magnitudes useful for discrimination purposes. NEIC, BJI, MOS, PPT, NAO, BELR, PRU and a few other agencies (Figure 10.5) are also responsible for the majority of the amplitude and period reports that contribute towards the ISC magnitudes.

Since the ISC does not routinely process waveforms, we rely on other agencies to report moment magnitudes as well as moment tensor determinations (Figure 10.6).

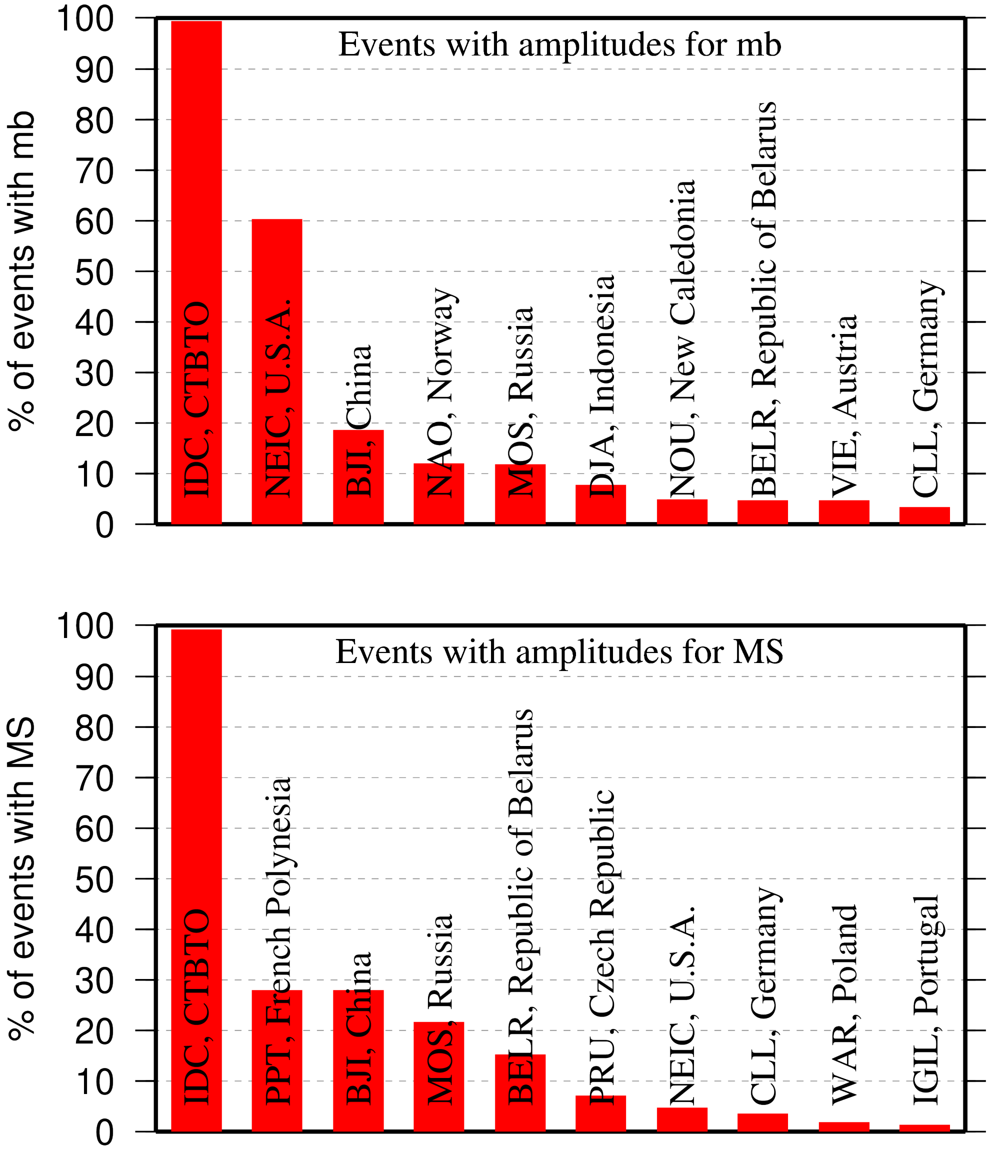


Figure 10.5: *Agencies that report defining body (top) and surface (bottom) wave amplitudes and periods for the largest fraction of those ISC Bulletin events with MS/mb determinations.*

Among other event parameters the ISC Bulletin also contains information on event type. We cannot independently verify the type of each event in the Bulletin and thus rely on other agencies to report the event type to us. Practices of reporting non-tectonic events vary greatly from country to country. Many agencies do not include anthropogenic events in their reports. Suppression of such events from reports to the ISC may lead to a situation where a neighbouring agency reports the anthropogenic event as an earthquake for which expected data are missing. This in turn is detrimental to ISC Bulletin users studying natural seismic hazard. Hence we encourage all agencies to join the agencies listed on Figure 10.7 and several others in reporting both natural and anthropogenic events to the ISC.

The ISC Bulletin also contains felt and damaging information when local agencies have reported it to us. Agencies listed on Figure 10.8 provide such information for the majority of all felt or damaging events in the ISC Bulletin.

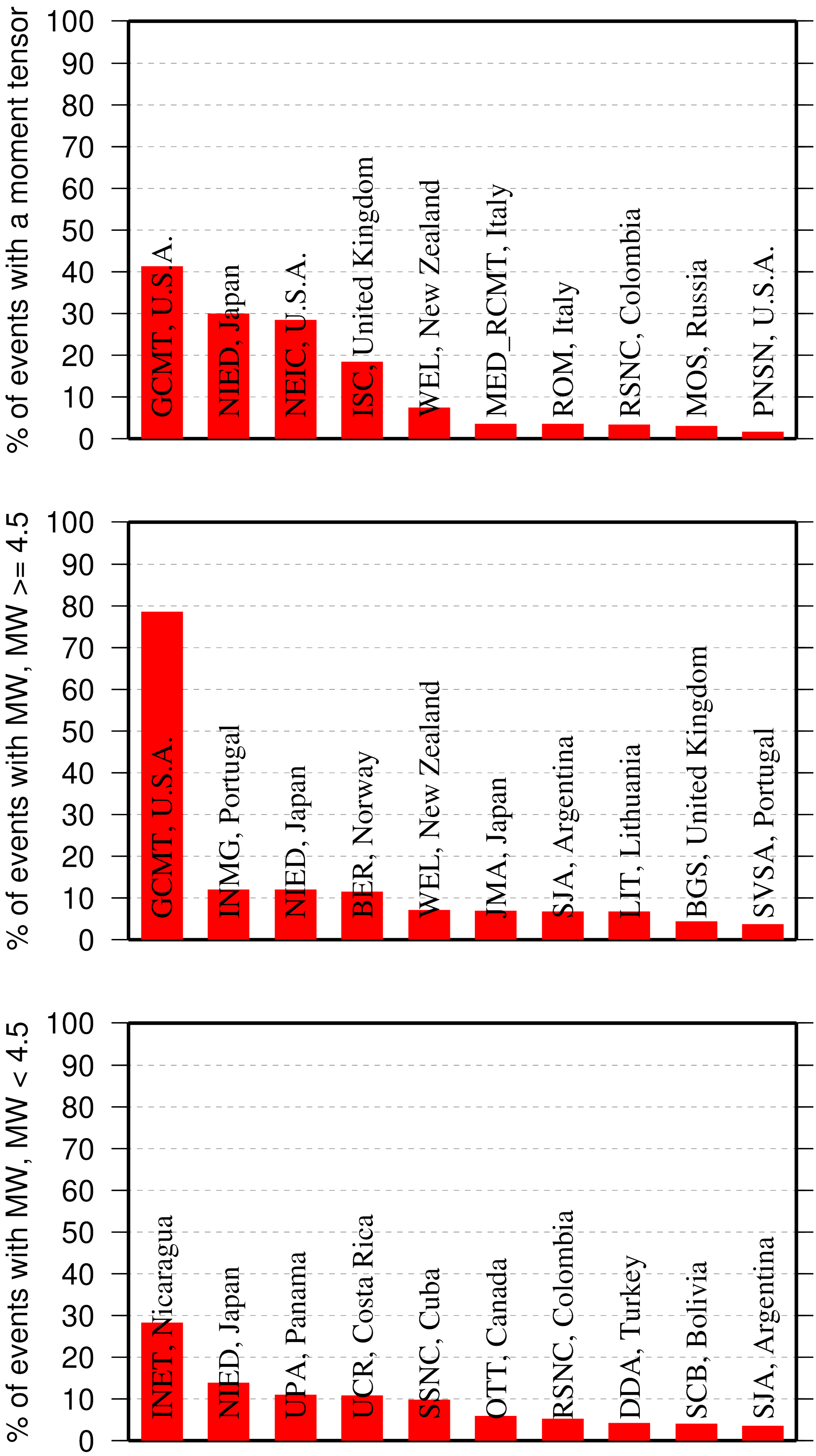


Figure 10.6: *Top ten agencies that most frequently report determinations of seismic moment tensor (top) and moment magnitude (middle/bottom for M greater/smaller than 4.5).*

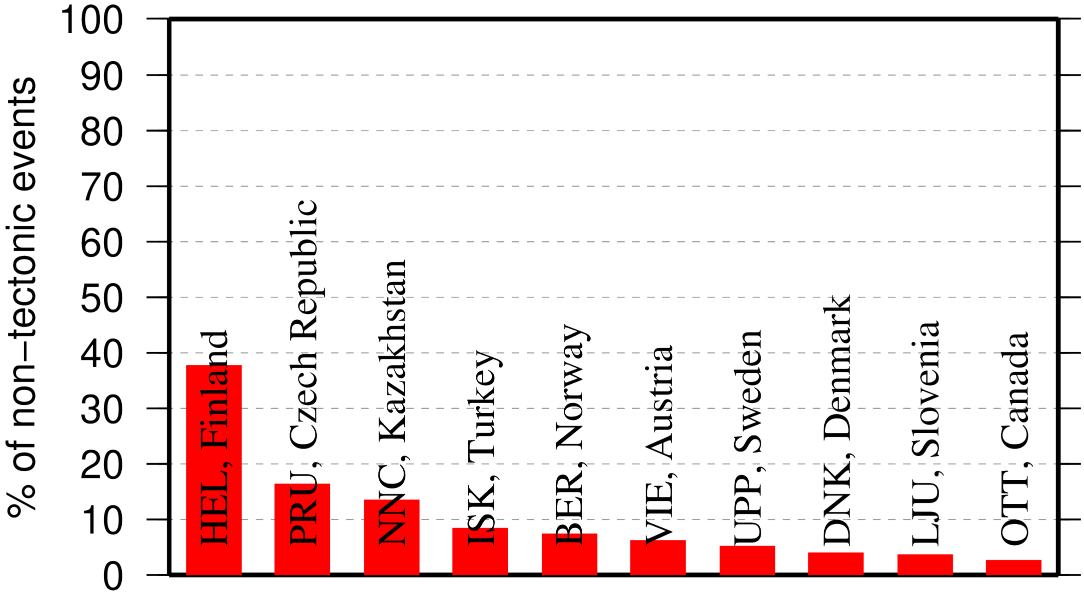


Figure 10.7: *Top ten agencies that most frequently report non-tectonic seismic events to the ISC.*

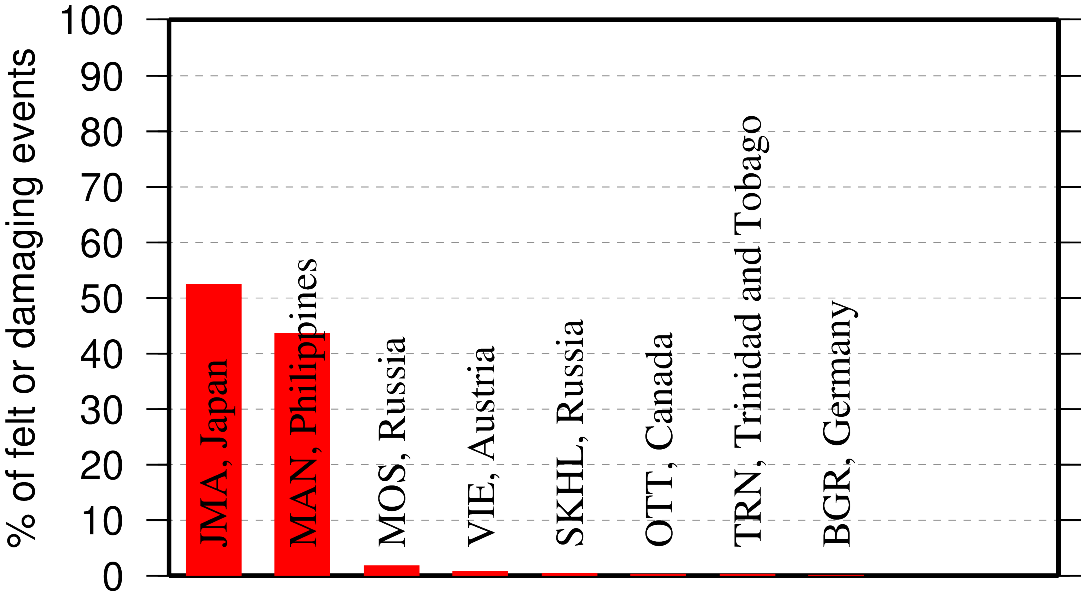


Figure 10.8: *Top ten agencies that most frequently report macroseismic information to the ISC.*

10.3 The Most Consistent and Punctual Contributors

During this six-month period, 33 agencies reported their bulletin data in one of the standard seismic formats (ISF, IMS, GSE, Nordic or QuakeML) and within the current 12-month deadline. Here we must reiterate that the ISC accepts reviewed bulletin data after a final analysis as soon as they are ready. These data, even if they arrive before the deadline, are immediately parsed into the ISC database, grouped with other data and become available to the ISC users on-line as part of the preliminary ISC Bulletin. There is no reason to wait until the deadline to send the data to the ISC. Table 10.1 lists all agencies that have been helpful to the ISC in this respect during the six-month period.

Table 10.1: *Agencies that contributed reviewed bulletin data to the ISC in one of the standard international formats before the submission deadline.*

Agency Code	Country	Average Delay from real time (days)
ZUR	Switzerland	16
ATH	Greece	19
LIC	Ivory Coast	26
NAO	Norway	29
IGIL	Portugal	32
ECX	Mexico	33
KNET	Kyrgyzstan	35
LDG	France	40
BUC	Romania	47
PRE	South Africa	53
IDC	Austria	54
ISN	Iraq	54
PPT	French Polynesia	66
INMG	Portugal	78
ISK	Turkey	105
BGS	United Kingdom	106
AUST	Australia	109
SVSA	Portugal	127
VIE	Austria	154
THE	Greece	184
RHSSO	Bosnia and Herzegovina	201
BJI	China	209
NEIC	U.S.A.	211
UCC	Belgium	223
IRIS	U.S.A.	234
YARS	Russia	270
RSNC	Colombia	287
IPEC	Czech Republic	306
MOS	Russia	327
BYKL	Russia	334
LIT	Lithuania	347
BEO	Serbia	354
BUL	Zimbabwe	363

11

Appendix

11.1 Tables

Table 11.1: *Listing of all 380 agencies that have directly reported to the ISC. The 146 agencies highlighted in bold have reported data to the ISC Bulletin for the period of this Bulletin Summary.*

Agency Code	Agency Name
AAA	Alma-ata, Kazakhstan
AAE	**University of Addis Ababa, Ethiopia**
AAM	University of Michigan, USA
ADE	Primary Industries and Resources SA, Australia
ADH	Observatorio Afonso Chaves, Portugal
AEIC	Alaska Earthquake Information Center, USA
AFAR	The Afar Depression: Interpretation of the 1960-2000 Earthquakes, Israel
AFUA	University of Alabama, USA
ALG	Algiers University, Algeria
ANDRE	, USSR
ANF	USArray Array Network Facility, USA
ANT	Antofagasta, Chile
ARE	Instituto Geofisico del Peru, Peru
ARO	Observatoire Géophysique d'Arta, Djibouti
ASIES	**Institute of Earth Sciences, Academia Sinica, Chinese Taipei**
ASL	Albuquerque Seismological Laboratory, USA
ASM	University of Asmara, Eritrea
ASRS	**Altai-Sayan Seismological Centre, GS SB RAS, Russia**
ATA	The Earthquake Research Center Ataturk University, Turkey
ATH	**National Observatory of Athens, Greece**
AUST	**Geoscience Australia, Australia**
AVETI	, USSR
AWI	**Alfred Wegener Institute for Polar and Marine Research, Germany**
AZER	**Republican Seismic Survey Center of Azerbaijan National Academy of Sciences, Azerbaijan**
BCIS	Bureau Central International de Sismologie, France
BDF	Observatório Sismológico da Universidade de Brasília, Brazil
BELR	**Centre of Geophysical Monitoring of the National Academy of Sciences of Belarus, Republic of Belarus**
BEO	**Seismological Survey of Serbia, Serbia**
BER	**University of Bergen, Norway**
BERK	Berkheimer H, Germany
BGR	**Bundesanstalt für Geowissenschaften und Rohstoffe, Germany**
BGS	**British Geological Survey, United Kingdom**

Table 11.1: Continued.

Agency Code	Agency Name
BGSI	Botswana Geoscience Institute, Botswana
BHUJ2	Study of Aftershocks of the Bhuj Earthquake by Japanese Research Team, Japan
BIAK	Biak earthquake aftershocks (17-Feb-1996), USA
BJI	**China Earthquake Networks Center**, **China**
BKK	Thai Meteorological Department, Thailand
BNS	Erdbebenstation, Geologisches Institut der Universität, Köl, Germany
BOG	Universidad Javeriana, Colombia
BRA	**Geophysical Institute, Slovak Academy of Sciences**, **Slovakia**
BRG	**Seismological Observatory Berggießhübel, TU Bergakademie Freiberg**, **Germany**
BRK	Berkeley Seismological Laboratory, USA
BRS	Brisbane Seismograph Station, Australia
BUC	**National Institute for Earth Physics**, **Romania**
BUD	**Geodetic and Geophysical Research Institute**, **Hungary**
BUEE	Earth & Environment, USA
BUG	Institute of Geology, Mineralogy & Geophysics, Germany
BUL	**Goetz Observatory**, **Zimbabwe**
BUT	Montana Bureau of Mines and Geology, USA
BYKL	**Baykal Regional Seismological Centre, GS SB RAS**, **Russia**
CADCG	Central America Data Centre, Costa Rica
CAN	Australian National University, Australia
CANSK	Canadian and Scandinavian Networks, Sweden
CAR	Instituto Sismologico de Caracas, Venezuela
CASC	Central American Seismic Center, Costa Rica
CENT	Centennial Earthquake Catalog, USA
CERI	Center for Earthquake Research and Information, USA
CFUSG	**Inst. of Seismology and Geodynamics, V.I. Vernadsky Crimean Federal University**, **Republic of Crimea**
CLL	**Geophysikalisches Observatorium Collm**, **Germany**
CMWS	Laboratory of Seismic Monitoring of Caucasus Mineral Water Region, GSRAS, Russia
CNG	Seismographic Station Changalane, Mozambique
CNRM	**Centre National de Recherche**, **Morocco**
COSMOS	Consortium of Organizations for Strong Motion Observations, USA
CRAAG	**Centre de Recherche en Astronomie, Astrophysique et Géophysique**, **Algeria**
CSC	University of South Carolina, USA
CSEM	Centre Sismologique Euro-Méditerranéen (CSEM/EMSC), France
CUPWA	**Curtin University**, **Australia**
DASA	Defense Atomic Support Agency, USA
DBN	Koninklijk Nederlands Meteorologisch Instituut, Netherlands
DDA	**Disaster and Emergency Management Presidency**, **Turkey**
DHMR	Yemen National Seismological Center, Yemen
DIAS	Dublin Institute for Advanced Studies, Ireland
DJA	**Badan Meteorologi, Klimatologi dan Geofisika**, **Indonesia**
DMN	**National Seismological Centre, Nepal**, **Nepal**

Table 11.1: *Continued.*

Agency Code	Agency Name
DNAG	, USA
DNK	**Geological Survey of Denmark and Greenland, Denmark**
DRS	Dagestan Branch, Geophysical Survey, Russian Academy of Sciences, Russia
DSN	**Dubai Seismic Network, United Arab Emirates**
DUSS	Damascus University, Syria, Syria
EAF	**East African Network, Unknown**
EAGLE	Ethiopia-Afar Geoscientific Lithospheric Experiment, Unknown
EBR	Observatori de l'Ebre, Spain
EBSE	Ethiopian Broadband Seismic Experiment, Unknown
ECGS	European Center for Geodynamics and Seismology, Luxembourg
ECX	**Centro de Investigación Científica y de Educación Superior de Ensenada, Mexico**
EFATE	OBS Experiment near Efate, Vanuatu, USA
EHB	Engdahl, van der Hilst and Buland, USA
EIDC	Experimental (GSETT3) International Data Center, USA
EKA	Eskdalemuir Array Station, United Kingdom
ENT	Geological Survey and Mines Department, Uganda
EPSI	Reference events computed by the ISC for EPSI project, United Kingdom
ERDA	Energy Research and Development Administration, USA
EST	Geological Survey of Estonia, Estonia
EUROP	, Unknown
EVBIB	Data from publications listed in the ISC Event Bibliography, Unknown
FBR	Fabra Observatory, Spain
FDF	Fort de France, Martinique
FIA0	Finessa Array, Finland
FOR	Unknown Historical Agency, Unknown - historical agency
FUBES	Earth Science Dept., Geophysics Section, Germany
FUNV	**Fundación Venezolana de Investigaciones Sismológicas, Venezuela**
FUR	Geophysikalisches Observatorium der Universität München, Germany
GBZT	Marmara Research Center, Turkey
GCG	**INSIVUMEH, Guatemala**
GCMT	**The Global CMT Project, USA**
GDNRW	Geologischer Dienst Nordrhein-Westfalen, Germany
GEN	**Dipartimento per lo Studio del Territorio e delle sue Risorse (RSNI), Italy**
GEOAZ	UMR Géoazur, France
GEOMR	GEOMAR, Germany
GFZ	Helmholtz Centre Potsdam GFZ German Research Centre For Geosciences, Germany
GII	**The Geophysical Institute of Israel, Israel**
GOM	Observatoire Volcanologique de Goma, Democratic Republic of the Congo
GRAL	**National Council for Scientific Research, Lebanon**
GSDM	**Geological Survey Department Malawi, Malawi**

Table 11.1: *Continued.*

Agency Code	Agency Name
GSET2	Group of Scientific Experts Second Technical Test 1991, April 22 - June 2, Unknown
GTFE	German Task Force for Earthquakes, Germany
GUC	**Centro Sismológico Nacional, Universidad de Chile**, **Chile**
HAN	Hannover, Germany
HDC	Observatorio Vulcanológico y Sismológico de Costa Rica, Costa Rica
HEL	**Institute of Seismology, University of Helsinki**, **Finland**
HFS	Hagfors Observatory, Sweden
HFS1	Hagfors Observatory, Sweden
HFS2	Hagfors Observatory, Sweden
HIMNT	Himalayan Nepal Tibet Experiment, USA
HKC	**Hong Kong Observatory**, **Hong Kong**
HLUG	Hessisches Landesamt für Umwelt und Geologie, Germany
HLW	**National Research Institute of Astronomy and Geophysics**, **Egypt**
HNR	Ministry of Mines, Energy and Rural Electrification, Solomon Islands
HON	Pacific Tsunami Warning Center - NOAA, USA
HRVD	Harvard University, USA
HRVD_LR	Department of Geological Sciences, Harvard University, USA
HVO	Hawaiian Volcano Observatory, USA
HYB	**National Geophysical Research Institute**, **India**
HYD	National Geophysical Research Institute, India
IAG	Instituto Andaluz de Geofisica, Spain
IASBS	Institute for Advanced Studies in Basic Sciences, Iran
IASPEI	IASPEI Working Group on Reference Events, USA
ICE	Instituto Costarricense de Electricidad, Costa Rica
IDC	**International Data Centre, CTBTO**, **Austria**
IDG	Institute of Dynamics of Geosphere, Russian Academy of Sciences, Russia
IEC	Institute of the Earth Crust, SB RAS, Russia
IEPN	**Institute of Environmental Problems of the North, Russian Academy of Sciences**, **Russia**
IGGSL	Seismology Lab, Institute of Geology & Geophysics, Chinese Academy of Sciences, China
IGIL	**Instituto Dom Luiz, University of Lisbon**, **Portugal**
IGQ	**Servicio Nacional de Sismología y Vulcanología**, **Ecuador**
IGS	Institute of Geological Sciences, United Kingdom
INAM	Instituto Nacional de Meteorologia e Geofisica - INAMET, Angola
INDEPTH3	International Deep Profiling of Tibet and the Himalayas, USA
INET	**Instituto Nicaraguense de Estudios Territoriales - INETER**, **Nicaragua**
INMG	**Instituto Português do Mar e da Atmosfera, I.P.**, **Portugal**
INMGC	Instituto Nacional de Meteorologia e Geofísica, Cape Verde
IPEC	**The Institute of Physics of the Earth (IPEC)**, **Czech Republic**
IPER	Institute of Physics of the Earth, Academy of Sciences, Moscow, Russia
IPGP	Institut de Physique du Globe de Paris, France
IPRG	Institute for Petroleum Research and Geophysics, Israel

Table 11.1: *Continued.*

Agency Code	Agency Name
IRIS	**IRIS Data Management Center**, **USA**
IRSM	Institute of Rock Structure and Mechanics, Czech Republic
ISK	**Kandilli Observatory and Research Institute**, **Turkey**
ISN	**Iraqi Meteorological and Seismology Organisation**, **Iraq**
ISS	International Seismological Summary, United Kingdom
IST	Institute of Physics of the Earth, Technical University of Istanbul, Turkey
ISU	**Institute of Seismology, Academy of Sciences, Republic of Uzbekistan**, **Uzbekistan**
ITU	Faculty of Mines, Department of Geophysical Engineering, Turkey
JEN	Geodynamisches Observatorium Moxa, Germany
JMA	**Japan Meteorological Agency**, **Japan**
JOH	Bernard Price Institute of Geophysics, South Africa
JSN	**Jamaica Seismic Network**, **Jamaica**
JSO	**Jordan Seismological Observatory**, **Jordan**
KBC	Institut de Recherches Géologiques et Minières, Cameroon
KEA	**Korea Earthquake Administration**, **Democratic People's Republic of Korea**
KEW	Kew Observatory, United Kingdom
KHC	Geofysikalni Ustav, Ceske Akademie Ved, Czech Republic
KISR	Kuwait Institute for Scientific Research, Kuwait
KLM	**Malaysian Meteorological Service**, **Malaysia**
KMA	**Korea Meteorological Administration**, **Republic of Korea**
KNET	**Kyrgyz Seismic Network**, **Kyrgyzstan**
KOLA	**Kola Regional Seismic Centre, GS RAS**, **Russia**
KRAR	Krasnoyarsk Scientific Research Inst. of Geology and Mineral Resources, Russia, Russia
KRL	Geodätisches Institut der Universität Karlsruhe, Germany
KRNET	**Institute of Seismology, Academy of Sciences of Kyrgyz Republic**, **Kyrgyzstan**
KRSC	**Kamchatkan Experimental and Methodical Seismological Department, GS RAS**, **Russia**
KRSZO	**Geodetic and Geophysical Reasearch Institute, Hungarian Academy of Sciences**, **Hungary**
KSA	Observatoire de Ksara, Lebanon
KUK	Geological Survey Department of Ghana, Ghana
LAO	Large Aperture Seismic Array, USA
LDG	**Laboratoire de Détection et de Géophysique/CEA**, **France**
LDN	University of Western Ontario, Canada
LDO	Lamont-Doherty Earth Observatory, USA
LED	Landeserdbebendienst Baden-Württemberg, Germany
LEDBW	Landeserdbebendienst Baden-Württemberg, Germany
LER	Besucherbergwerk Binweide Station, Germany
LIB	Tripoli, Libya
LIC	**Station Géophysique de Lamto**, **Ivory Coast**
LIM	Lima, Peru
LIS	Instituto de Meteorologia, Portugal
LIT	**Geological Survey of Lithuania**, **Lithuania**

Table 11.1: *Continued.*

Agency Code	Agency Name
LJU	**Slovenian Environment Agency**, **Slovenia**
LPA	**Universidad Nacional de La Plata**, **Argentina**
LPZ	Observatorio San Calixto, Bolivia
LRSM	Long Range Seismic Measurements Project, Unknown
LSZ	**Geological Survey Department of Zambia**, **Zambia**
LVSN	**Latvian Seismic Network**, **Latvia**
MAN	**Philippine Institute of Volcanology and Seismology**, **Philippines**
MAT	The Matsushiro Seismological Observatory, Japan
MATSS	, USSR
MCO	**Macao Meteorological and Geophysical Bureau**, **Macao, China**
MCSM	**Main Centre for Special Monitoring**, **Ukraine**
MDD	**Instituto Geográfico Nacional**, **Spain**
MED_RCMT	**MedNet Regional Centroid - Moment Tensors**, **Italy**
MERI	Maharashta Engineering Research Institute, India
MES	Messina Seismological Observatory, Italy
MEX	**Instituto de Geofísica de la UNAM**, **Mexico**
MIRAS	**Mining Institute of the Ural Branch of the Russian Academy of Sciences**, **Russia**
MNH	Institut für Angewandte Geophysik der Universitat Munchen, Germany
MOLD	**Institute of Geophysics and Geology**, **Moldova**
MOS	**Geophysical Survey of Russian Academy of Sciences**, **Russia**
MOZ	Direccao Nacional de Geologia, Mozambique
MOZAR	, Mozambique
MRB	**Institut Cartogràfic i Geològic de Catalunya**, **Spain**
MSI	Messina Seismological Observatory, Italy
MSSP	**Micro Seismic Studies Programme, PINSTECH**, **Pakistan**
MSUGS	Michigan State University, Department of Geological Sciences, USA
MUN	Mundaring Observatory, Australia
NAI	University of Nairobi, Kenya
NAM	**The Geological Survey of Namibia**, **Namibia**
NAO	**Stiftelsen NORSAR**, **Norway**
NCEDC	Northern California Earthquake Data Center, USA
NDI	**National Centre for Seismology of the Ministry of Earth Sciences of India**, **India**
NEIC	**National Earthquake Information Center**, **USA**
NEIS	National Earthquake Information Service, USA
NERS	**North Eastern Regional Seismological Centre, GS RAS**, **Russia**
NIC	**Cyprus Geological Survey Department**, **Cyprus**
NIED	**National Research Institute for Earth Science and Disaster Prevention**, **Japan**
NKSZ	, USSR
NNC	**National Nuclear Center**, **Kazakhstan**
NORS	North Ossetia (Alania) Branch, Geophysical Survey, Russian Academy of Sciences, Russia
NOU	**IRD Centre de Nouméa**, **New Caledonia**
NSSC	National Syrian Seismological Center, Syria
NSSP	**National Survey of Seismic Protection**, **Armenia**

Table 11.1: Continued.

Agency Code	Agency Name
OBM	Research Centre of Astronomy and Geophysics, Mongolia
OGAUC	Centro de Investigação da Terra e do Espaço da Universidade de Coimbra, Portugal
OGSO	Ohio Geological Survey, USA
OMAN	**Sultan Qaboos University**, **Oman**
ORF	Orfeus Data Center, Netherlands
OSPL	**Observatorio Sismologico Politecnico Loyola**, **Dominican Republic**
OSUB	Osservatorio Sismologico Universita di Bari, Italy
OTT	**Canadian Hazards Information Service, Natural Resources Canada**, **Canada**
PAL	Palisades, USA
PAS	California Institute of Technology, USA
PDA	Universidade dos Açores, Portugal
PDG	**Seismological Institute of Montenegro**, **Montenegro**
PEK	Peking, China
PGC	Pacific Geoscience Centre, Canada
PLV	**National Center for Scientific Research**, **Vietnam**
PMEL	Pacific seismicity from hydrophones, USA
PMR	Alaska Tsunami Warning Center,, USA
PNNL	Pacific Northwest National Laboratory, USA
PNSN	**Pacific Northwest Seismic Network**, **USA**
PPT	**Laboratoire de Géophysique/CEA**, **French Polynesia**
PRE	**Council for Geoscience**, **South Africa**
PRU	**Geophysical Institute, Academy of Sciences of the Czech Republic**, **Czech Republic**
PTO	Instituto Geofísico da Universidade do Porto, Portugal
PTWC	Pacific Tsunami Warning Center, USA
QCP	Manila Observatory, Philippines
QUE	Pakistan Meteorological Department, Pakistan
QUI	Escuela Politécnica Nacional, Ecuador
RAB	Rabaul Volcanological Observatory, Papua New Guinea
RBA	Université Mohammed V, Morocco
REN	MacKay School of Mines, USA
REY	**Icelandic Meteorological Office**, **Iceland**
RHSSO	**Republic Hydrometeorological Service, Seismological Observatory, Banja Luka**, **Bosnia and Herzegovina**
RISSC	**Laboratory of Research on Experimental and Computational Seimology**, **Italy**
RMIT	Royal Melbourne Institute of Technology, Australia
ROC	Odenbach Seismic Observatory, USA
ROM	**Istituto Nazionale di Geofisica e Vulcanologia**, **Italy**
RRLJ	Regional Research Laboratory Jorhat, India
RSMAC	Red Sísmica Mexicana de Apertura Continental, Mexico
RSNC	**Red Sismológica Nacional de Colombia**, **Colombia**
RSPR	**Red Sísmica de Puerto Rico**, **USA**
RYD	King Saud University, Saudi Arabia

Table 11.1: Continued.

Agency Code	Agency Name
SAPSE	Southern Alps Passive Seismic Experiment, New Zealand
SAR	Sarajevo Seismological Station, Bosnia and Herzegovina
SBDV	, USSR
SCB	**Observatorio San Calixto, Bolivia**
SCEDC	Southern California Earthquake Data Center, USA
SCSIO	Key Laboratory of Ocean and Marginal Sea Geology, South China Sea, China
SDD	Universidad Autonoma de Santo Domingo, Dominican Republic
SEA	Geophysics Program AK-50, USA
SET	Setif Observatory, Algeria
SFS	**Real Instituto y Observatorio de la Armada, Spain**
SGS	**Saudi Geological Survey, Saudi Arabia**
SHL	Central Seismological Observatory, India
SIGU	**Subbotin Institute of Geophysics, National Academy of Sciences, Ukraine**
SIK	Seismic Institute of Kosovo, Unknown
SIO	Scripps Institution of Oceanography, USA
SJA	**Instituto Nacional de Prevención Sísmica, Argentina**
SJS	Instituto Costarricense de Electricidad, Costa Rica
SKHL	**Sakhalin Experimental and Methodological Seismological Expedition, GS RAS, Russia**
SKL	Sakhalin Complex Scientific Research Institute, Russia
SKO	**Seismological Observatory Skopje, FYR Macedonia**
SLC	Salt Lake City, USA
SLM	Saint Louis University, USA
SNET	**Servicio Nacional de Estudios Territoriales, El Salvador**
SNM	New Mexico Institute of Mining and Technology, USA
SNSN	Saudi National Seismic Network, Saudi Arabia
SOF	**Geophysical Institute, Bulgarian Academy of Sciences, Bulgaria**
SOMC	**Seismological Observatory of Mount Cameroon, Cameroon**
SOME	**Seismological Experimental Methodological Expedition, Kazakhstan**
SPA	USGS - South Pole, Antarctica
SPGM	Service de Physique du Globe, Morocco
SPITAK	, Armenia
SRI	Stanford Research Institute, USA
SSN	**Sudan Seismic Network, Sudan**
SSNC	**Servicio Sismológico Nacional Cubano, Cuba**
SSS	Centro de Estudios y Investigaciones Geotecnicas del San Salvador, El Salvador
STK	Stockholm Seismological Station, Sweden
STR	**EOST / RéNaSS, France**
STU	Stuttgart Seismological Station, Germany
SVSA	**Sistema de Vigilância Sismológica dos Açores, Portugal**
SYO	**National Institute of Polar Research, Japan**
SZGRF	Seismologisches Zentralobservatorium Gräfenberg, Germany
TAC	Estación Central de Tacubaya, Mexico

Table 11.1: Continued.

Agency Code	Agency Name
TAN	**Antananarivo**, **Madagascar**
TANZANIA	Tanzania Broadband Seismic Experiment, USA
TAP	**CWB**, **Chinese Taipei**
TAU	University of Tasmania, Australia
TEH	**Tehran University**, **Iran**
TEIC	Center for Earthquake Research and Information, USA
THE	**Department of Geophysics, Aristotle University of Thessaloniki**, **Greece**
THR	**International Institute of Earthquake Engineering and Seismology (IIEES)**, **Iran**
TIF	**Institute of Earth Sciences/ National Seismic Monitoring Center**, **Georgia**
TIR	**The Institute of Seismology, Academy of Sciences of Albania**, **Albania**
TRI	**Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS)**, **Italy**
TRN	**The Seismic Research Centre**, **Trinidad and Tobago**
TTG	Titograd Seismological Station, Montenegro
TUL	Oklahoma Geological Survey, USA
TUN	Institut National de la Météorologie, Tunisia
TVA	Tennessee Valley Authority, USA
TZN	University of Dar Es Salaam, Tanzania
UAF	Department of Geosciences, USA
UATDG	The University of Arizona, Department of Geosciences, USA
UAV	Red Sismológica de Los Andes Venezolanos, Venezuela
UCB	University of Colorado, Boulder, USA
UCC	**Royal Observatory of Belgium**, **Belgium**
UCDES	Department of Earth Sciences, United Kingdom
UCR	**Sección de Sismología, Vulcanología y Exploración Geofísica**, **Costa Rica**
UCSC	Earth & Planetary Sciences, USA
UESG	School of Geosciences, United Kingdom
UGN	Institute of Geonics AS CR, Czech Republic
ULE	University of Leeds, United Kingdom
UNAH	Universidad Nacional Autonoma de Honduras, Honduras
UPA	**Universidad de Panama**, **Panama**
UPIES	Institute of Earth- and Environmental Science, Germany
UPP	**University of Uppsala**, **Sweden**
UPSL	**University of Patras, Department of Geology**, **Greece**
UREES	Department of Earth and Environmental Science, USA
USAEC	United States Atomic Energy Commission, USA
USCGS	United States Coast and Geodetic Survey, USA
USGS	United States Geological Survey, USA
UTEP	Department of Geological Sciences, USA
UUSS	The University of Utah Seismograph Stations, USA
UVC	Universidad del Valle, Colombia
UWMDG	University of Wisconsin-Madison, Department of Geoscience, USA

Table 11.1: Continued.

Agency Code	Agency Name
VAO	**Instituto Astronomico e Geofísico**, **Brazil**
VIE	**Zentralanstalt für Meteorologie und Geodynamik (ZAMG)**, **Austria**
VKMS	Lab. of Seismic Monitoring, Voronezh region, GSRAS & Voronezh State University, Russia
VLA	Vladivostok Seismological Station, Russia
VSI	University of Athens, Greece
VUW	Victoria University of Wellington, New Zealand
WAR	**Institute of Geophysics, Polish Academy of Sciences**, **Poland**
WASN	, USA
WBNET	**Institute of Geophysics, Czech Academy of Sciences**, **Czech Republic**
WEL	**Institute of Geological and Nuclear Sciences**, **New Zealand**
WES	Weston Observatory, USA
WUSTL	Washington University Earth and Planentary Sciences, USA
YARS	**Yakutiya Regional Seismological Center, GS SB RAS**, **Russia**
ZAG	**Seismological Survey of the Republic of Croatia**, **Croatia**
ZEMSU	, USSR
ZUR	**Swiss Seismological Service (SED)**, **Switzerland**
ZUR_RMT	Zurich Moment Tensors, Switzerland

Table 11.2: *Phases reported to the ISC. These include phases that could not be matched to an appropriate* ak135 *phases. Those agencies that reported at least 10% of a particular phase are also shown.*

Reported Phase	Total	Agencies reporting
P	5794348	ROM (36%)
AML	3639301	ROM (96%)
S	2561374	ROM (38%), JMA (17%), TAP (13%)
NULL	461285	IDC (38%), NEIC (25%)
IAmb	424945	NEIC (97%)
Pn	267601	NEIC (39%)
IAML	235453	NEIC (53%), GUC (14%), RSNC (13%)
Pg	199190	NEIC (13%), NNC (12%), STR (12%)
Sg	164650	LDG (12%)
LR	152967	IDC (69%), BJI (25%)
pmax	124063	MOS (70%), BJI (30%)
PG	106560	ISK (45%), HEL (30%), PRU (12%)
SG	92598	HEL (39%), ISK (27%), PRU (19%)
Sn	88535	LDG (18%), IDC (14%)
PN	76203	ISK (58%), MOS (15%), HEL (14%)
IAMs_20	55072	NEIC (98%)
Lg	42335	NNC (74%), IDC (14%)
A	37462	JMA (38%), INMG (29%), SVSA (21%), SKHL (12%)
IAmb_Lg	34718	NEIC (100%)
T	32644	IDC (95%)
PKP	31444	IDC (51%)
SN	28101	HEL (64%), ISK (14%)
MSG	26341	HEL (99%)
pP	19365	BJI (41%), ISC1 (18%), IDC (18%)
PKPbc	18058	IDC (71%), NEIC (13%)
PKIKP	16959	MOS (98%)
MLR	16318	MOS (100%)
END	16269	ROM (100%)
Vmb_Lg	15819	MDD (100%)
SB	13605	HEL (100%)
PKPdf	13231	NEIC (60%), INMG (12%)
PcP	12070	IDC (66%)
PP	11710	BJI (23%), IDC (23%), BELR (17%)
PB	10774	HEL (100%)
sP	9232	BJI (67%), ISC1 (19%)
SS	8931	MOS (33%), BJI (23%), BELR (22%)
smax	7181	MOS (79%), BJI (21%)
PKPab	7142	IDC (48%), NEIC (23%), INMG (12%)
x	6564	CLL (31%), NDI (24%), BRG (18%), PRU (18%)
AMS	5296	PRU (71%), KEA (24%)
Amp	4337	BRG (100%)
PKiKP	4269	IRIS (39%), IDC (31%)
Sb	4207	IRIS (85%), BELR (12%)
ScP	4180	IDC (70%), BJI (13%), ISC1 (11%)
PPP	3827	MOS (47%), BELR (46%)
PKP2	3568	MOS (95%)
LRM	3514	BELR (87%), MOLD (13%)
AMB	3469	SKHL (77%), BJI (23%)
Trac	3372	OTT (100%)
SPECP	3348	DDA (100%)
Pdiff	3193	IRIS (72%), IDC (16%)
SSS	3067	BELR (57%), MOS (32%)
LQ	2624	BELR (54%), INMG (27%), IEPN (14%)
AMP	2499	IEPN (57%), TIR (39%)
Pb	2466	IRIS (69%), BELR (20%)
*PP	2414	MOS (100%)
PKKPbc	2377	IDC (97%)
sS	2315	BJI (84%), BELR (13%)
LG	2194	BRA (75%), OTT (24%)
Vmb_V	1807	MDD (100%)
SKS	1779	BJI (42%), BELR (34%), PRU (11%)
PKhKP	1734	IDC (100%)
pPKP	1473	IDC (34%), BJI (28%), PRU (15%)
Smax	1409	BYKL (100%)
PS	1308	MOS (39%), BELR (29%), CLL (12%)

Table 11.2: *(continued)*

Reported Phase	Total	Agencies reporting
SKPbc	1288	IDC (91%)
I	1214	IDC (100%)
ScS	1122	BJI (61%), IDC (15%), BELR (12%)
Pmax	1045	BYKL (94%)
Pdif	990	BER (22%), NEIC (14%), IRIS (12%)
X	986	JMA (93%)
PKHKP	880	MOS (100%)
L	859	MOLD (44%), WAR (44%)
PKPDF	820	PRU (99%)
PKPPKP	808	IDC (96%)
SKKS	754	BELR (51%), BJI (40%)
PKPAB	748	PRU (100%)
Sm	684	CFUSG (74%), SIGU (26%)
IVMs_BB	636	BER (81%), HYB (14%)
PKKP	617	IDC (55%), PRU (14%), AWI (13%)
SKSac	574	BER (44%), CLL (14%), INMG (12%)
IVmB_BB	552	BER (79%), HYB (15%)
max	542	BYKL (100%)
sPKP	509	BJI (73%), BELR (15%)
SP	504	BER (32%), MOS (22%), PRU (15%)
*SP	477	MOS (100%)
pPKPbc	463	IDC (80%)
SKP	460	IDC (50%), BELR (18%), PRU (13%)
IVmBBB	459	BER (97%)
Pm	433	CFUSG (56%), SIGU (44%)
PKP1	413	LIC (92%)
pPKPdf	397	NEIC (42%), BER (25%), CLL (12%)
PDIFF	380	PRU (48%), BRA (33%), IPEC (18%)
pwP	365	NEIC (72%), ISC1 (28%)
Lm	356	CLL (100%)
*SS	353	MOS (100%)
PKKPab	343	IDC (91%)
LmV	304	CLL (100%)
AmB	297	KEA (100%)
PPS	295	CLL (55%), MOS (23%)
PcS	288	BJI (88%)
SKKPbc	274	IDC (93%)
Sgmax	270	NERS (97%)
p	269	ROM (100%)
E	254	ZAG (96%)
PmP	233	BGR (80%), ZUR (19%)
SmS	231	BGR (92%)
Rg	230	NNC (50%), IDC (35%)
PKP2bc	226	IDC (100%)
PKS	182	BJI (46%), BELR (42%)
PKPpre	179	NEIC (68%), PRU (26%)
LmH	177	CLL (100%)
(P)	167	BRG (99%)
P3KPbc	162	IDC (100%)
SSSS	155	CLL (100%)
pPKPab	155	CLL (39%), IDC (35%), NEIC (12%)
SKPdf	143	CLL (45%), BER (32%)
PCP	135	PRU (65%), MOS (17%), LPA (17%)
-	134	INMG (100%)
Lmax	114	CLL (100%)
SKKSac	112	CLL (55%), IEPN (16%), HYB (15%)
Snm	105	SIGU (53%), CFUSG (47%)
Pgmax	105	NERS (99%)
m	104	SIGU (100%)
LQM	100	MOLD (100%)
(Sg)	99	CLL (97%)
P4KPbc	97	IDC (100%)
AMSG	86	PRE (100%)
PKP2ab	82	IDC (100%)
pPKiKP	67	CLL (42%), UCC (24%), HYB (18%)
sPP	66	CLL (100%)
pPcP	66	IDC (91%)

Table 11.2: *(continued)*

Reported Phase	Total	Agencies reporting
pPP	65	CLL (54%), LPA (34%)
SKPab	62	IDC (92%)
SKKP	59	IDC (54%), AWI (24%)
MSN	53	HEL (60%), BER (34%)
Sdif	52	CLL (79%), INMG (12%)
ATPG	51	PRE (55%), OSPL (45%)
ASPG	51	PRE (55%), OSPL (45%)
ASSG	51	PRE (55%), OSPL (45%)
P*	49	BGR (76%), MOS (24%)
ATSG	49	PRE (53%), OSPL (47%)
Pnm	48	CFUSG (54%), SIGU (46%)
PSKS	46	CLL (100%)
PKKPdf	46	AWI (59%), CLL (33%)
SKSdf	44	BER (50%), HYB (23%), CLL (23%)
mb	44	KMA (100%)
H	43	IDC (98%)
Px	43	CLL (100%)
pPdiff	43	SYO (70%), LJU (12%), AWI (12%)
PPPP	41	CLL (100%)
PKSdf	38	CLL (63%), BER (34%)
SCS	37	LPA (62%), IPEC (22%), PRU (16%)
AMPG	36	PRE (100%)
PKPf	35	BRG (100%)
del	35	AUST (91%)
SPP	35	BELR (54%), CLL (23%), MOS (23%)
SCP	34	PRU (56%), IPEC (44%)
(Sn)	33	CLL (88%), SIGU (12%)
rx	33	SKHL (100%)
SKIKS	33	LPA (100%)
P'P'df	33	AWI (91%)
SKIKP	32	LPA (100%)
sSS	31	CLL (97%)
P3KP	30	IDC (100%)
SgSg	29	BYKL (93%)
PKIKS	29	LPA (100%)
PgPg	28	BYKL (93%)
s	28	ROM (93%)
sPKPdf	27	CLL (67%), AWI (22%)
(Pg)	27	CLL (78%), BRG (22%)
PKPdif	26	CLL (88%)
PKPc	26	WAR (100%)
(SSS)	24	CLL (100%)
SDIF	22	PRU (100%)
(sP)	21	CLL (100%)
(Pn)	21	CLL (67%), BRG (19%), SIGU (14%)
SKiKP	20	IDC (45%), HYB (35%), IEPN (15%)
sPdiff	20	SYO (75%), AWI (15%)
sSKS	20	BELR (95%)
SKKSdf	20	CLL (60%), HYB (30%)
LqM	19	MOLD (100%)
M	19	MOLD (63%), LJU (37%)
PPPrev	19	CLL (100%)
SKPa	18	NAO (89%), BER (11%)
(PP)	18	CLL (94%)
S*	18	BGR (100%)
(PKP)	16	CLL (69%), BRG (31%)
SDIFF	16	LPA (50%), IPEC (44%)
(PKPdf)	15	CLL (100%)
SKSp	15	BRA (73%), WAR (27%)
Sc	15	WAR (100%)
R2	15	CLL (100%)
PKPPKPdf	15	CLL (100%)
(PKPab)	15	CLL (100%)
(SS)	15	CLL (100%)
sPPP	15	CLL (100%)
LMZ	14	WAR (100%)
PKSbc	14	CLL (100%)

Table 11.2: *(continued)*

Reported Phase	Total	Agencies reporting
Plp	14	CLL (100%)
(SSSS)	14	CLL (100%)
SKSP	14	CLL (71%), MOLD (29%)
sSSS	14	CLL (100%)
Sgm	14	SIGU (100%)
pPdif	14	CLL (57%), IEPN (43%)
sPKPab	14	CLL (57%), AWI (36%)
(pP)	13	CLL (100%)
PSPS	13	CLL (100%)
RG	13	IPEC (100%)
sPKiKP	12	CLL (75%), HYB (17%)
sPS	12	CLL (100%)
(PPP)	11	CLL (100%)
MPN	11	HEL (64%), BER (36%)
SKKPdf	11	CLL (55%), AWI (45%)
sSKSac	10	CLL (100%)
IVMsBB	10	BER (60%), HYB (20%), DNK (20%)
sPPS	9	CLL (100%)
PKPlp	9	CLL (100%)
sPdif	9	CLL (100%)
(PKiKP)	9	CLL (100%)
(pPKPab)	9	CLL (100%)
PSS	9	CLL (100%)
Sdiff	8	LJU (62%), IDC (38%)
tx	8	IEPN (100%)
PKKS	8	IEPN (100%)
(PcP)	8	CLL (100%)
PnPn	7	SYO (100%)
sPKPbc	7	CLL (57%), IDC (43%)
PKPac	7	IRIS (100%)
PPlp	7	CLL (100%)
e	6	INMG (100%)
sSdif	6	CLL (100%)
Lq	6	MOLD (67%), NNC (33%)
P(2)	6	CLL (100%)
AP	6	MOS (83%), NAO (17%)
PKKSbc	6	CLL (67%), HYB (33%)
pPc	6	WAR (100%)
Pgm	6	SIGU (100%)
Siff	6	BRG (100%)
sPcP	5	CLL (100%)
SKPDF	5	BRA (100%)
Sgd	5	WAR (100%)
Sglp	5	CLL (100%)
PSSrev	5	CLL (100%)
(PKPbc)	5	CLL (100%)
SSSrev	5	CLL (100%)
(PPS)	5	CLL (100%)
P9	5	EAF (60%), OSPL (20%), RSNC (20%)
PKPmax	5	CLL (100%)
(sPKPdf)	5	CLL (100%)
LV	5	CLL (100%)
pPPP	5	CLL (80%), LJU (20%)
Sx	5	CLL (100%)
R3	5	CLL (100%)
pPS	4	CLL (100%)
(PKPdif)	4	CLL (100%)
(PS)	4	CLL (100%)
SKSSKSac	4	CLL (100%)
AMPN	4	INET (100%)
sSP	4	CLL (75%), LJU (25%)
(Pdif)	4	CLL (100%)
AMSN	4	INET (100%)
4	4	MEX (100%)
PSmax	4	CLL (100%)
(pPKPdf)	4	CLL (100%)
Amb	4	MDD (100%)

Table 11.2: (continued)

Reported Phase	Total	Agencies reporting
SKSc	4	WAR (100%)
sSKPdf	4	CLL (100%)
LH	4	CLL (100%)
IAMS_20	3	LJU (100%)
PPmax	3	CLL (100%)
(SKPdf)	3	CLL (100%)
pSP	3	LJU (67%), CLL (33%)
XSKS	3	PRU (100%)
pS	3	HYB (33%), BRG (33%), UCC (33%)
(PPPP)	3	CLL (100%)
Li	3	MOLD (100%)
PKPbc(2)	3	CLL (100%)
PsP	3	MOLD (100%)
pPmax	3	CLL (100%)
pPKKPab	3	CLL (100%)
pPDIFF	3	IPEC (100%)
PSlp	3	CLL (100%)
pPPS	3	CLL (100%)
PSKSrev	3	CLL (100%)
pSKPdf	3	CLL (100%)
AMb	3	LVSN (100%)
sSKKSac	3	CLL (100%)
(sPP)	3	CLL (100%)
Pdifc	3	WAR (100%)
pPiff	3	BRG (100%)
pPn	3	LJU (67%), SYO (33%)
SKSDF	3	BRA (100%)
PN4	3	LVSN (100%)
(SKKSac)	2	CLL (100%)
PKPM	2	MOLD (100%)
(SKS)	2	BRG (100%)
(PKSdf)	2	CLL (100%)
PKKSab	2	IEPN (100%)
SKPPKPdf	2	CLL (100%)
(PKSab)	2	CLL (100%)
PKKSdf	2	HYB (50%), CLL (50%)
mH	2	CLL (100%)
(SKKSdf)	2	CLL (100%)
R	2	LDG (50%), MOLD (50%)
PKPab(2)	2	CLL (100%)
SH	2	SYO (100%)
(SP)	2	CLL (100%)
(Sdif)	2	CLL (100%)
pPKKPdf	2	CLL (100%)
sPSKS	2	CLL (100%)
SKPPKPbc	2	CLL (100%)
LgM	2	MOLD (100%)
S(2)	2	CLL (50%), LPA (50%)
pSKSac	2	CLL (100%)
sPKKPdf	2	CLL (100%)
SN4	2	LVSN (100%)
pPKP2	2	BJI (100%)
AMd	2	NIC (100%)
pPKIKP	2	IPEC (100%)
PKKPb	2	BRG (100%)
DIFF	2	BRA (100%)
PM	2	MOLD (100%)
PC	2	PRE (50%), MEX (50%)
pPKKPbc	2	CLL (100%)
(SKKPbc)	2	CLL (100%)
pPKSdf	2	CLL (100%)
(pPKPbc)	2	CLL (100%)
sSKSdf	2	CLL (100%)
XP	2	MOS (100%)
PKikP	2	NDI (100%)
PPPPrev	2	CLL (100%)
PKPdf(2)	2	CLL (100%)

Table 11.2: (continued)

Reported Phase	Total	Agencies reporting
Pn(2)	2	CLL (100%)
(ScS)	2	CLL (100%)
LM	2	MOLD (100%)
Sd	2	WAR (100%)
-Mb	2	SVSA (50%), INMG (50%)
Pd0	2	ATH (100%)
sPiff	1	BRG (100%)
SSP	1	CLL (100%)
PKSab	1	CLL (100%)
PRKPbc	1	CLL (100%)
SKKPab	1	IDC (100%)
PPrev	1	CLL (100%)
RM	1	MOLD (100%)
PPPlp	1	CLL (100%)
sSiff	1	BRG (100%)
Pdifflp	1	CLL (100%)
(pPKiKP)	1	CLL (100%)
(sSSS)	1	CLL (100%)
PKPE	1	IPEC (100%)
(sPKPab)	1	CLL (100%)
PKikp	1	NDI (100%)
Sn(2)	1	CLL (100%)
(SKSdf)	1	CLL (100%)
pPKKSbc	1	CLL (100%)
IX	1	SYO (100%)
SSmax	1	CLL (100%)
Sgr	1	BER (100%)
SSrev	1	CLL (100%)
(SKSac)	1	CLL (100%)
PKPdfmax	1	CLL (100%)
pPKPlp	1	CLL (100%)
PPPmax	1	CLL (100%)
PPk	1	CLL (100%)
(PKKSdf)	1	CLL (100%)
(PKKPab)	1	CLL (100%)
Pdi4	1	BER (100%)
(SKPbc)	1	CLL (100%)
S'S'ac	1	HYB (100%)
PDIF	1	PRU (100%)
(PKKPbc)	1	CLL (100%)
(pPcP)	1	CLL (100%)
PKPPKPbc	1	CLL (100%)
(PcS)	1	CLL (100%)
pp	1	SYO (100%)
pPKSbc	1	CLL (100%)
SPSrev	1	CLL (100%)
PP(2)	1	CLL (100%)
pPPPP	1	CLL (100%)
(PSS)	1	CLL (100%)
sPKKPab	1	CLL (100%)
PN5	1	GUC (100%)
pPP(2)	1	CLL (100%)
pSKKSac	1	CLL (100%)
PPP(2)	1	LPA (100%)
(sSS)	1	CLL (100%)
PKKPf	1	BRG (100%)
SKKSacr	1	CLL (100%)
Sd2	1	ATH (100%)
pPg	1	NDI (100%)
(SSrev)	1	CLL (100%)
(PKSbc)	1	CLL (100%)
Sgc	1	WAR (100%)
PKiK	1	HYB (100%)
(sPdif)	1	CLL (100%)
(sPKiKP)	1	CLL (100%)
pKP	1	SVSA (100%)
sSKPbc	1	CLL (100%)

Table 11.2: *(continued)*

Reported Phase	Total	Agencies reporting
sPPPP	1	CLL (100%)
SM	1	MOLD (100%)
Rq	1	MOLD (100%)
pPKPdiff	1	CLL (100%)
PKPpB	1	WAR (100%)
sSKKSdf	1	CLL (100%)
PKPabmax	1	CLL (100%)
sSSSS	1	CLL (100%)
pSPP	1	CLL (100%)
PSP	1	LPA (100%)
(sSKSac)	1	CLL (100%)
sPKKPbc	1	CLL (100%)
PKPPKP'	1	BRG (100%)

Table 11.3: Reporters of amplitude data

Agency	Number of reported amplitudes	Number of amplitudes in ISC located events	Number used for ISC mb	Number used for ISC MS
ROM	3500167	103117	0	0
NEIC	626711	265855	189592	25836
WEL	594199	106189	0	0
IDC	560837	528253	135149	77021
MOS	111147	107637	53573	10690
NNC	97551	40072	92	0
DJA	91299	61234	15329	0
SOME	82356	32091	2013	0
BJI	77879	72480	19750	23466
ISK	73896	11276	0	0
DDA	72558	6043	0	0
ATH	71852	10618	0	0
RSNC	60656	4511	0	0
VIE	57658	29740	7330	0
GUC	33079	6837	16	23
LDG	31592	9887	4	0
THE	30438	5858	0	0
JMA	28127	27941	0	0
HEL	26247	757	0	0
MDD	17630	4078	0	0
BER	15828	5843	2552	77
INMG	15457	8346	2929	0
PRU	13372	4887	7	2785
MAN	11411	2958	0	0
PPT	11031	9657	815	4028
PRE	8977	3221	2171	35
DMN	8584	8213	0	0
SVSA	8297	660	431	0
NIC	7768	2739	0	0
SKHL	7598	3990	0	0
BELR	7076	5404	743	1458
ZUR	6820	1095	0	0
MRB	6499	362	0	0
TEH	6297	3303	0	0
NOU	6196	5985	4196	0
LJU	6195	382	0	6
PDG	6059	4452	0	0
DNK	5708	2995	2382	65
BUC	4411	1122	0	0
BRG	4337	2654	0	0
ECX	3905	491	0	0
WBNET	3644	63	0	0
YARS	3617	61	0	0
CLL	3515	3065	465	238
OTT	3371	170	0	0
NDI	3348	2850	1116	86
SNET	3107	1250	0	0
BYKL	2961	1266	0	0
SJA	2905	2902	0	0
BGS	2867	1877	994	310

Table 11.3: *Continued.*

Agency	Number of reported amplitudes	Number of amplitudes in ISC located events	Number used for ISC mb	Number used for ISC MS
SKO	2758	305	0	0
KNET	2466	1260	0	0
OSPL	2433	649	0	0
SSNC	2405	420	14	5
NAO	2374	2332	1596	0
LIC	2188	1946	931	0
MIRAS	2054	70	0	0
KEA	1988	1485	0	181
IEPN	1815	1507	19	0
ASRS	1715	941	0	0
LVSN	1645	45	0	0
UCC	1521	1336	1143	0
IPEC	1516	268	0	0
SCB	1412	319	0	0
KRSZO	1319	123	0	0
IGIL	1121	590	129	136
MOLD	1088	763	116	0
TIR	971	602	0	0
CFUSG	925	798	0	0
UCR	876	602	0	0
SIGU	630	331	0	0
ISN	434	187	0	0
WAR	382	360	0	259
NERS	371	46	0	0
INET	282	111	4	0
BGR	221	106	0	0
LIT	192	121	3	0
HYB	189	186	0	0
MCSM	178	146	0	0
JSO	155	155	0	0
AAE	144	105	0	21
THR	88	88	0	0
EAF	83	69	0	10
UPA	61	3	0	2
PLV	32	4	0	0
SSN	20	13	0	0
BUL	6	6	0	0
AZER	2	2	0	0

12

Glossary of ISC Terminology

- Agency/ISC data contributor

  An academic or government institute, seismological organisation or company, geological/meteorological survey, station operator or author that reports or contributed data in the past to the ISC or one of its predecessors. Agencies may contribute data to the ISC directly, or indirectly through other ISC data contributors.

- Agency code

  A unique, maximum eight-character code for a data reporting agency (e.g. NEIC, GFZ, BUD) or author (e.g. ISC, ISC-EHB, IASPEI). Often the agency code is the commonly used acronym of the reporting institute.

- Arrival

  A phase pick at a station is characterised by a phase name and an arrival time.

- Associated phase

  Associated phase arrival or amplitude measurements represent a collection of observations belonging to (i.e. generated by) an event. The complete set of observations are associated to the prime hypocentre.

- Azimuthal gap/Secondary azimuthal gap

  The azimuthal gap for an event is defined as the largest angle between two stations with defining phases when the stations are ordered by their event-to-station azimuths. The secondary azimuthal gap is the largest azimuthal gap a single station closes.

- BAAS

  Seismological bulletins published by the British Association for the Advancement of Science (1913-1917) under the leadership of H.H. Turner. These bulletins are the predecessors of the ISS Bulletins and include reports from stations distributed worldwide.

- Bulletin

  An ordered list of event hypocentres, uncertainties, focal mechanisms, network magnitudes, as well as phase arrival and amplitude observations associated to each event. An event bulletin may list all the reported hypocentres for an event. The convention in the ISC Bulletin is that the preferred (prime) hypocentre appears last in the list of reported hypocentres for an event.

- Catalogue

  An ordered list of event hypocentres, uncertainties and magnitudes. An event catalogue typically lists only the preferred (prime) hypocentres and network magnitudes.

- CoSOI/IASPEI

  Commission on Seismological Observation and Interpretation, a commission of IASPEI that prepares and discusses international standards and procedures in seismological observation and interpretation.

- Defining/Non-defining phase

  A defining phase is used in the location of the event (time-defining) or in the calculation of the network magnitude (magnitude-defining). Non-defining phases are not used in the calculations because they suffer from large residuals or could not be identified.

- Direct/Indirect report

  A data report sent (e-mailed) directly to the ISC, or indirectly through another ISC data contributor.

- Duplicates

  Nearly identical phase arrival time data reported by one or more agencies for the same station. Duplicates may be created by agencies reporting observations from other agencies, or several agencies independently analysing the waveforms from the same station.

- Event

  A natural (e.g. earthquake, landslide, asteroid impact) or anthropogenic (e.g. explosion) phenomenon that generates seismic waves and its source can be identified by an event location algorithm.

- Grouping

  The ISC algorithm that organises reported hypocentres into groups of events. Phases associated to any of the reported hypocentres will also be associated to the preferred (prime) hypocentre. The grouping algorithm also attempts to associate phases that were reported without an accompanying hypocentre to events.

- Ground Truth

  An event with a hypocentre known to certain accuracy at a high confidence level. For instance, GT0 stands for events with exactly known location, depth and origin time (typically explosions); GT5 stands for events with their epicentre known to 5 km accuracy at the 95% confidence level, while their depth and origin time may be known with less accuracy.

- Ground Truth database

  On behalf of IASPEI, the ISC hosts and maintains the IASPEI Reference Event List, a bulletin of ground truth events.

- IASPEI

  International Association of Seismology and Physics of the Earth Interior, www.iaspei.org.

- International Registry of Seismograph Stations (IR)

  Registry of seismographic stations, jointly run by the ISC and the World Data Center for Seismology, Denver (NEIC). The registry provides and maintains unique five-letter codes for stations participating in the international parametric and waveform data exchange.

- ISC Bulletin

  The comprehensive bulletin of the seismicity of the Earth stored in the ISC database and accessible through the ISC website. The bulletin contains both natural and anthropogenic events. Currently the ISC Bulletin spans more than 50 years (1960-to date) and it is constantly extended by adding both recent and past data. Eventually the ISC Bulletin will contain all instrumentally recorded events since 1900.

- ISC Governing Council

  According to the ISC Working Statutes the Governing Council is the governing body of the ISC, comprising one representative for each ISC Member.

- ISC-located events

  A subset of the events selected for ISC review are located by the ISC. The rules for selecting an event for location are described in Section 11.1.3 of the January to June Bulletin Summary; ISC-located events are denoted by the author ISC.

- ISC Member

  An academic or government institute, seismological organisation or company, geological/meteorological survey, station operator, national/international scientific organisation that contribute to the ISC budget by paying membership fees. ISC members have voting rights in the ISC Governing Council.

- ISC-reviewed events

  A subset of the events reported to the ISC are selected for ISC analyst review. These events may or may not be located by the ISC. The rules for selecting an event for review are described in Section 11.1.3 of the January to June Bulletin Summary. Non-reviewed events are explicitly marked in the ISC Bulletin by the comment following the prime hypocentre "Event not reviewed by the ISC".

- ISF

  International Seismic Format (www.isc.ac.uk/standards/isf). A standard bulletin format approved by IASPEI. The ISC Bulletin is presented in this format at the ISC website.

- ISS

  International Seismological Summary (1918-1963). These bulletins are the predecessors of the ISC Bulletin and represent the major source of instrumental seismological data before the digital era. The ISS contains regionally and teleseismically recorded events from several hundreds of globally distributed stations.

- Network magnitude

The event magnitude reported by an agency or computed by the ISC locator. An agency can report several network magnitudes for the same event and also several values for the same magnitude type. The network magnitude obtained with the ISC locator is defined as the median of station magnitudes of the same magnitude type.

- Phase

  A maximum eight-character code for a seismic, infrasonic, or hydroacoustic phase. During the ISC processing, reported phases are mapped to standard IASPEI phase names. Amplitude measurements are identified by specific phase names to facilitate the computation of body-wave and surface-wave magnitudes.

- Prime hypocentre

  The preferred hypocentre solution for an event from a list of hypocentres reported by various agencies or calculated by the ISC.

- Reading

  Parametric data that are associated to a single event and reported by a single agency from a single station. A reading typically includes one or more phase names, arrival time and/or amplitude/period measurements.

- Report/Data report

  All data that are reported to the ISC are parsed and stored in the ISC database. These may include event bulletins, focal mechanisms, moment tensor solutions, macroseismic descriptions and other event comments, as well as phase arrival data that are not associated to events. Every single report sent to the ISC can be traced back in the ISC database via its unique report identifier.

- Shide Circulars

  Collections of station reports for large earthquakes occurring in the period 1899-1912. These reports were compiled through the efforts of J. Milne. The reports are mainly for stations of the British Empire equipped with Milne seismographs. After Milne's death, the Shide Circulars were replaced by the Seismological Bulletins of the BAAS.

- Station code

  A unique, maximum six-character code for a station. The ISC Bulletin contains data exclusively from stations registered in the International Registry of Seismograph Stations.

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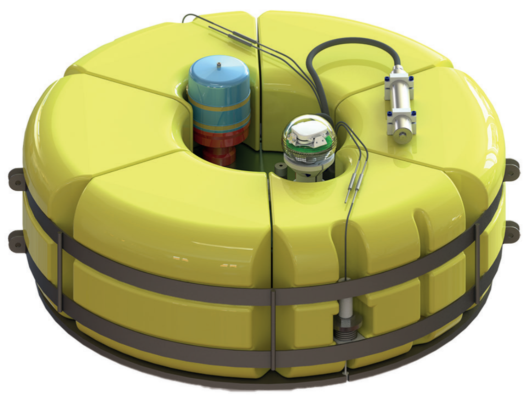

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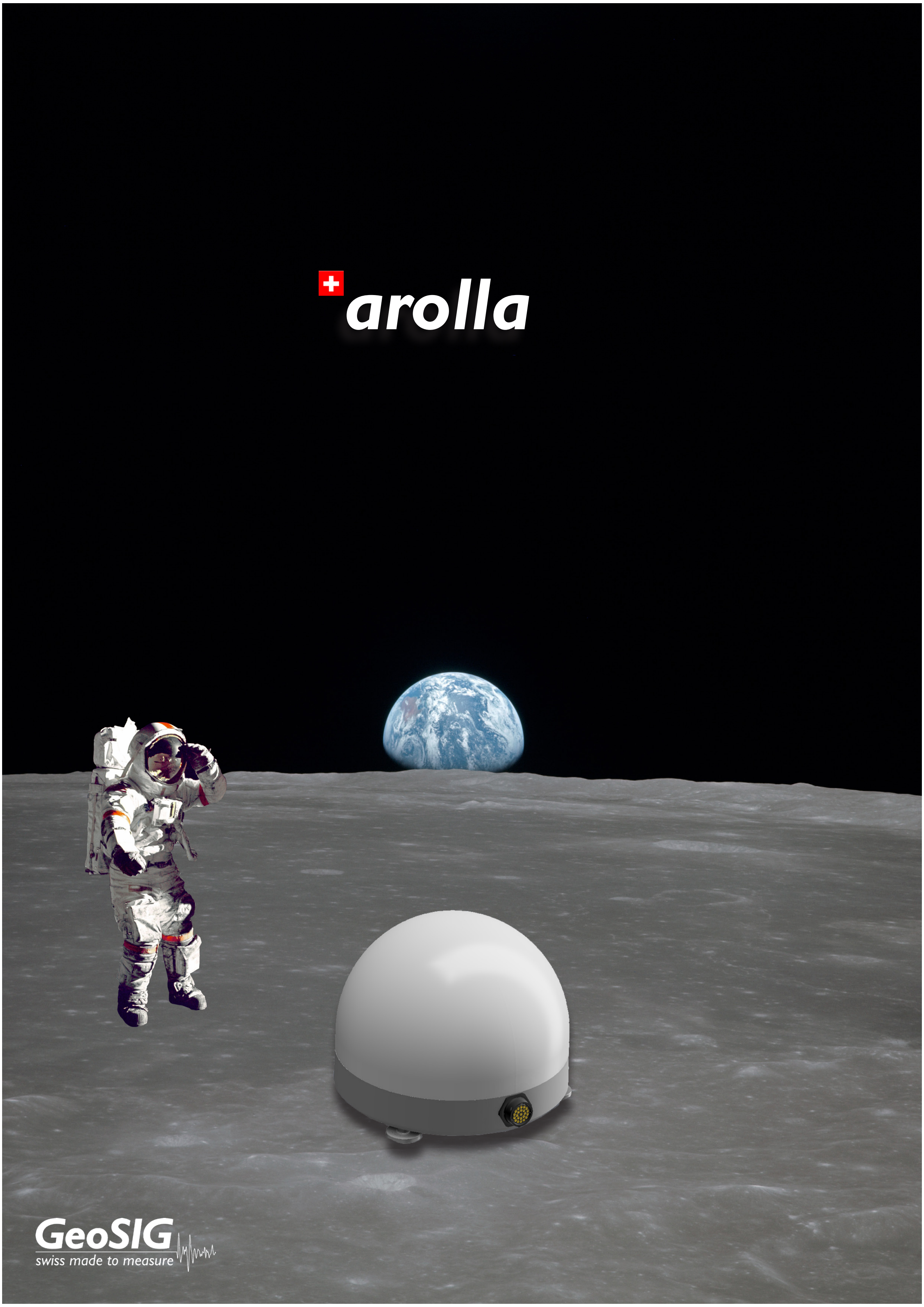
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