Summary of the Bulletin of the International Seismological Centre

2014

July – December

Volume 51 Issue II

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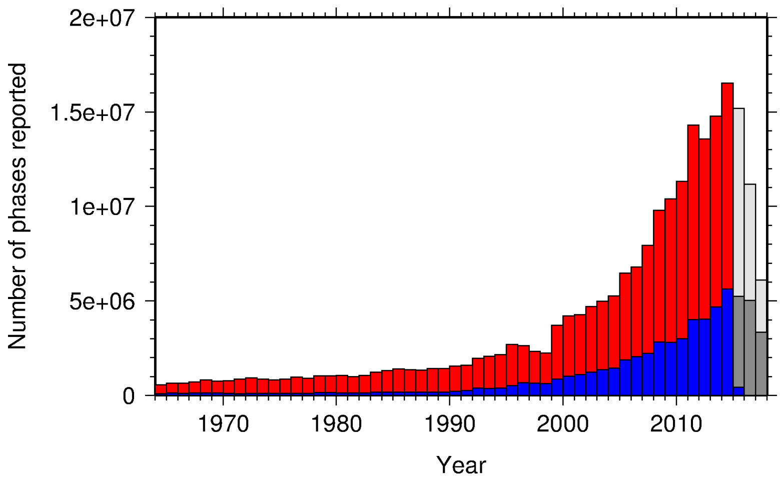
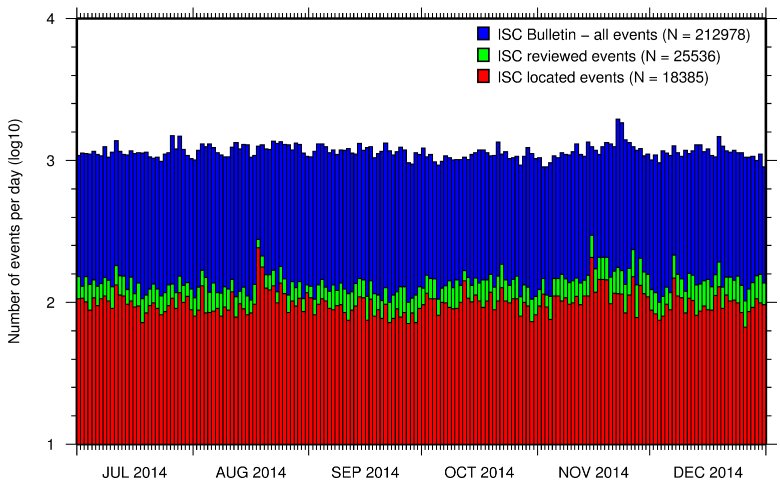
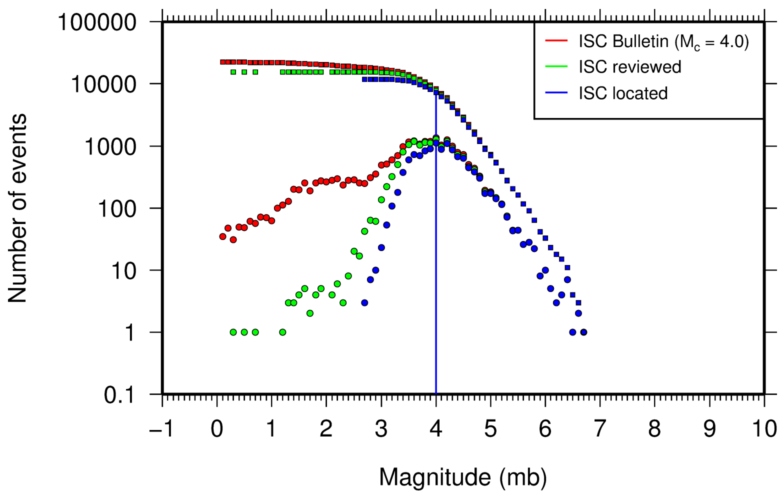


The number of phases (red) and number of amplitudes (blue) collected by the ISC for events each year since 1964. The data in grey covers the current period where data are still being collected before the ISC review takes place and are accurate at the time of publication. See Section 7.3.



The number of events within the Bulletin for the current summary period. The vertical scale is logarithmic. See Section 8.1.



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 8.4.

Summary of the Bulletin of the International Seismological Centre

2014

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Volume 51 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

ISC-EHB Bulletin:

http://www.isc.ac.uk/isc-ehb/search/

IASPEI Reference Event List (GT bulletin):

http://www.isc.ac.uk/gtevents/search/

ISC-GEM Global Instrumental Earthquake Catalogue:

http://http://www.isc.ac.uk/iscgem/download.php

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http://www.isc.ac.uk/event_bibliography/bibsearch.php

International Seismograph Station Registry:

http://www.isc.ac.uk/registries/search/

Seismological Contacts:

http://www.isc.ac.uk/projects/seismocontacts/

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Preface

Dear Colleague,

This is the second and concluding 2014 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 2014.

This publication contains a description of the ISC data available on the included DVD-ROM (with updated catalogue files for 1964-present that include the GT-locations) 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 data to the ISC. This time it is the turn for the Antarctic seismic network of the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI) in Germany.

We hope that you find this relatively new 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 6 million seismic events: earthquakes, chemical and nuclear explosions, mine blasts and mining induced events. At least 1.7 million of them are regional and teleseismically recorded events that have been reviewed by the ISC analysts. The ISC Bulletin contains approximately 200 million individual seismic station readings of arrival times, amplitudes, periods, SNR, slowness and azimuth, reported by approximately 17,000 seismic stations currently registered in the IR. Over 6,000 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 8816 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

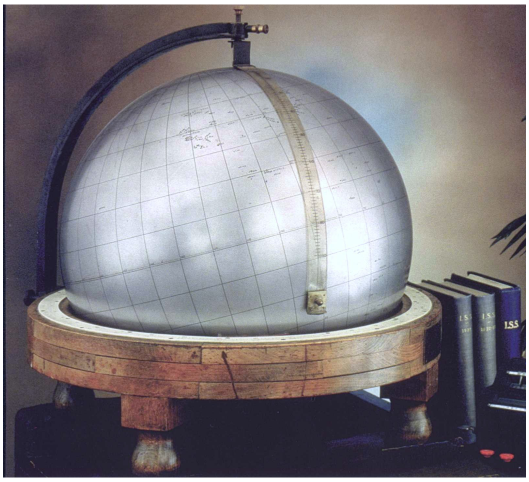


Figure 2.1: *The steel globe bearing positions of early seismic stations was used for locating positions of earthquakes for the International Seismological Summaries.*

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

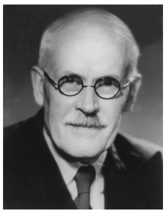
John Milne
Publisher of the Shide Circular Reports on Earthquakes
1899-1913

Herbert Hall Turner

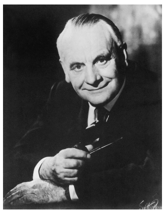
Seismological Bulletins of the BAAS

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 62 Member Institutions and 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.

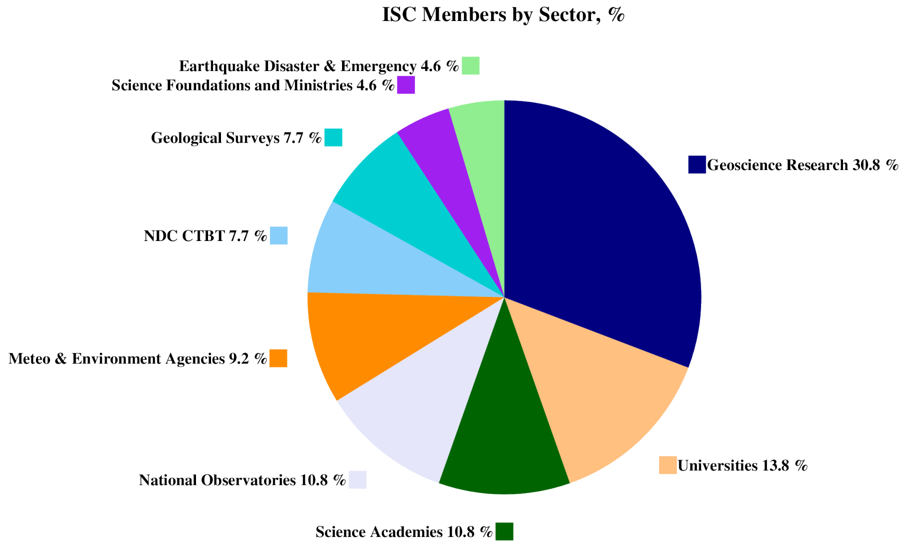


Figure 2.3: *Distribution of the ISC Member Institutions by sector in year 2013 as a percentage of total number of Members.*

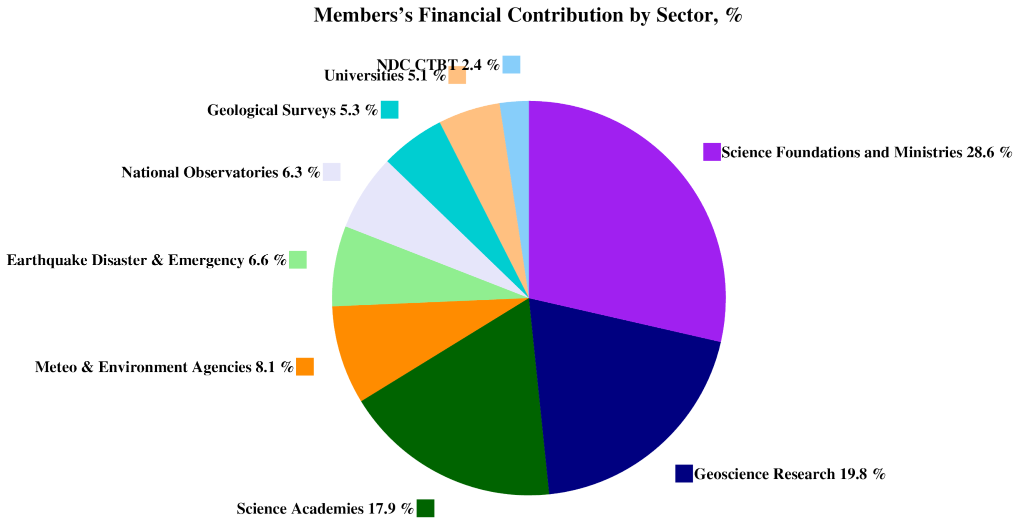


Figure 2.4: *Distribution of Member's financial contributions to the ISC by sector in year 2013 as a percentage of total annual Member contributions.*

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.

Centre de Recherche en Astronomie, Astrophysique et Géophysique (CRAAG)
Algeria
www.craag.dz
Category: 1

Instituto Nacional de Prevención Sísmica (INPRES)
Argentina
www.inpres.gov.ar
Category: 1

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

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.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

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

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

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

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

The Geophysical Institute of Israel
Israel
www.gii.co.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

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

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

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

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

Stiftelsen NORSAR
Norway
www.norsar.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

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

Institut Cartogràfic i Geològic de Catalunya (ICGC)
Spain
www.igc.cat
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

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

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

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

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

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

Incorporated Research Institutions for Seismology
U.S.A.
www.iris.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-1417970)
U.S.A.
www.nsf.gov
Category: 9

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, OYO, 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.

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.

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.

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 148 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

Universidad Nacional de La Plata
Argentina
LPA

Instituto Nacional de Prevención Sísmica
Argentina
SJA

National Survey of Seismic Protection
Armenia
NSSP

Curtin University
Australia
CUPWA

Geoscience Australia
Australia
AUST

International Data Centre, CTBTO
Austria
IDC

Zentralanstalt für Meteorologie und Geodynamik (ZAMG)
Austria
VIE

Republic Center of Seismic Survey
Azerbaijan
AZER

Royal Observatory of Belgium
Belgium
UCC

Observatorio San Calixto
Bolivia
SCB

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

Instituto Astronomico e Geofísico
Brazil
VAO

Geophysical Institute, Bulgarian Academy of Sciences
Bulgaria
SOF

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

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

West Bohemia Seismic Network
Czech Republic
WBNET

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

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

Laboratoire de Détection et de Géophysique/CEA
France
LDG

EOST / RéNaSS
France
STR

Laboratoire de Géophysique/CEA
French Polynesia
PPT

Institute of Earth Sciences/ National Seismic Monitoring Center
Georgia
TIF

Seismological Observatory Berggießhübel, TU Bergakademie Freiberg
Germany
BRG

Geophysikalisches Observatorium Collm
Germany
CLL

Alfred Wegener Institute for Polar and Marine Research
Germany
AWI

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 Research Institute
Hungary
BUD

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

Icelandic Meteorological Office
Iceland
REY

National Geophysical Research Institute
India
HYB

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

Badan Meteorologi, Klimatologi dan Geofisika
Indonesia
DJA

Tehran University
Iran
TEH

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

Iraqi Meteorological and Seismology Organisation
Iraq
ISN

The Geophysical Institute of Israel
Israel
GII

Laboratory of Research on Experimental and Computational Seimology
Italy
RISSC

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

Osservatorio Sismologico Universita di Bari
Italy
OSUB

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

MedNet Regional Centroid - Moment Tensors
Italy
MED_RCMT

Istituto Nazionale di Geofisica e Vulcanologia
Italy
ROM

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

The Matsushiro Seismological Observatory
Japan
MAT

Japan Meteorological Agency
Japan
JMA

Jordan Seismological Observatory
Jordan
JSO

Seismological Experimental Methodological Expedition
Kazakhstan
SOME

National Nuclear Center
Kazakhstan
NNC

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

Kyrgyz Seismic Network
Kyrgyzstan
KNET

Latvian Seismic Network
Latvia
LVSN

National Council for Scientific Research
Lebanon
GRAL

Geological Survey of Lithuania
Lithuania
LIT

European Center for Geodynamics and Seismology
Luxembourg
ECGS

Macao Meteorological and Geophysical Bureau
Macao, China
MCO

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

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

Manila Observatory
Philippines
QCP

Philippine Institute of Volcanology and Seismology
Philippines
MAN

Institute of Geophysics, Polish Academy of Sciences
Poland
WAR

Sistema de Vigilância Sismológica dos Açores
Portugal
SVSA

Instituto Geofisico do Infante Dom Luiz
Portugal
IGIL

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

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

National Institute for Earth Physics
Romania
BUC

North Eastern Regional Seismological Centre, GS RAS
Russia
NERS

Kamchatkan Experimental and Methodical Seismological Department, GS RAS
Russia
KRSC

Yakutiya Regional Seismological Center, GS SB RAS
Russia
YARS

Geophysical Survey of Russian Academy of Sciences
Russia
MOS

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

Sakhalin Experimental and Methodological Seismological Expedition, GS RAS
Russia
SKHL

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

Altai-Sayan Seismological Centre, GS SB RAS
Russia
ASRS

Baykal Regional Seismological Centre, GS SB RAS
Russia
BYKL

Kola Regional Seismic Centre, GS RAS
Russia
KOLA

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

Ministry of Mines, Energy and Rural Electrification
Solomon Islands
HNR

Council for Geoscience
South Africa
PRE

Instituto Geográfico Nacional
Spain
MDD

Institut Cartogràfic i Geològic de Catalunya
Spain
MRB

Instituto Andaluz de Geofisica
Spain
IAG

Real Instituto y Observatorio de la Armada
Spain
SFS

University of Uppsala
Sweden
UPP

Swiss Seismological Service (SED)
Switzerland
ZUR

Thai Meteorological Department
Thailand
BKK

The Seismic Research Centre
Trinidad and Tobago
TRN

Institut National de la Météorologie
Tunisia
TUN

Kandilli Observatory and Research Institute
Turkey
ISK

Disaster and Emergency Management Presidency
Turkey
DDA

The Earthquake Research Center Ataturk University
Turkey
ATA

IRIS Data Management Center
U.S.A.
IRIS

National Earthquake Information Center
U.S.A.
NEIC

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

Department of Geosciences
U.S.A.
UAF

Pacific Northwest Seismic Network
U.S.A.
PNSN

The Global CMT Project
U.S.A.
GCMT

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

National Center for Scientific Research
Vietnam
PLV

Geological Survey Department of Zambia
Zambia
LSZ

Goetz Observatory
Zimbabwe
BUL

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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

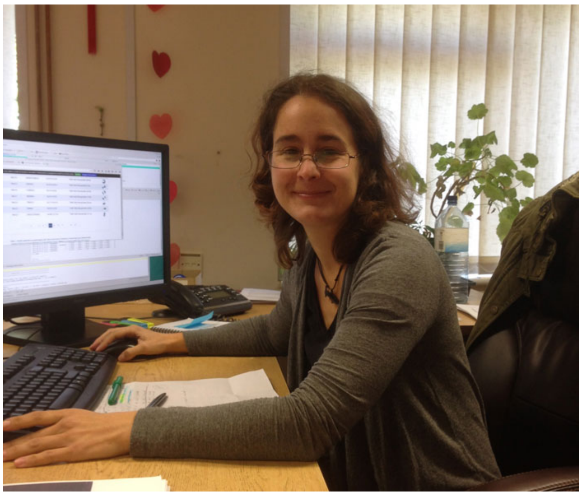
- James Harris
- Senior System and Database Administrator
- United Kingdom

- Alfie James Barber
- System Administrator
- United Kingdom

- Gergely Csontos
- Web Developer
- Hungary

- John Eve
- Data Collection Officer
- United Kingdom

- Edith Korger
- Data Collection Seismologist
- Austria



- Domenico Di Giacomo
- Seismologist
- Italy

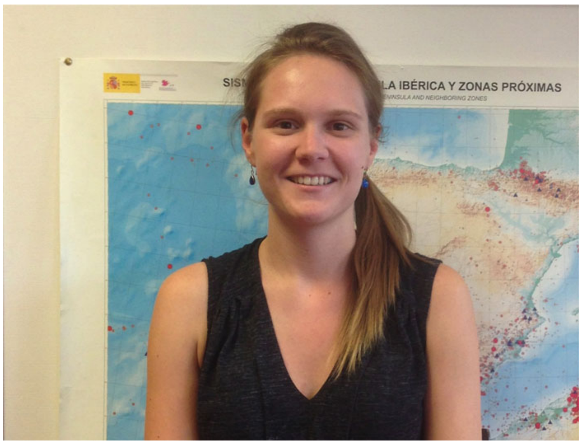
- Konstantinos Lentas
- Seismologist/Developer
- Greece

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

- Blessing Shumba
- Seismologist/Analyst
- Zimbabwe

- Rebecca Verney
- Analyst
- United Kingdom

- Jennifer Weston
- Seismologist/Analyst
- United Kingdom

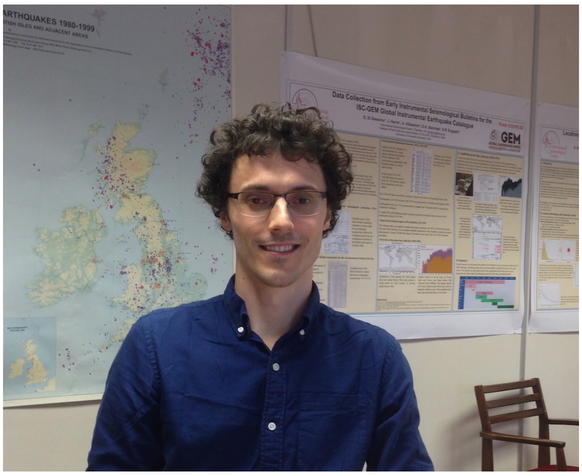


- Elizabeth Entwistle
- Seismologist/Analyst
- United Kingdom

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

- Kathrin Lieser
- Seismologist/Analyst
- Germany

- Lonn Brown
- Seismologist/Analyst
- Canada



- Daniela Olaru
- Historical Data Entry Officer
- Romania

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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)

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- International Seismological Centre, Reference Event Bulletin, http://www.isc.ac.uk, Internatl. Seismol. Cent., Thatcham, United Kingdom, 2018.

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- International Seismological Centre, EHB Bulletin, http://www.isc.ac.uk, Internatl. Seismol. Cent., Thatcham, United Kingdom, 2018.

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- International Seismological Centre, Bulletin Disks 1-25 [CD-ROM], Internatl. Seismol. Cent., Thatcham, United Kingdom, 2018.

Data transcribed from the printed Bulletin:

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

Data transcribed from the printed Summary of the Bulletin:

- International Seismological Centre, Summ. Bull. Internatl. Seismol. Cent., July - December 2014, 51(II), Thatcham, United Kingdom, 2018.

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organization = "Internatl. Seismol. Cent.",
note = "http://www.isc.ac.uk",
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year = "2018"
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5

Operational Procedures of Contributing Agencies

5.1 The AWI Network Antarctica – Alfred-Wegener Institute, Germany

Tanja Fromm, Alfons Eckstaller and Jölund Asseng, Alfred-Wegener-Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany

Tanja Fromm

Alfons Eckstaller

Jölund Asseng

5.1.1 Introduction

Antarctica is a seismically quiet continent with low earthquake hazard, as subduction zones and large active faults are missing. Apart from some researchers, no population would be endangered by catastrophic earthquakes. Seismic stations in Antarctica are therefore scattered and more of scientific interest: they contribute important data for global Earth models and local events provide information about neotectonic or cryogenic processes.

Most seismometers are installed at research stations, where power and telemetry are available; the site selection is not usually made to provide ideal conditions for a seismic station but is based on logistical considerations. Some autonomous stations are installed away from research bases and thus suffer, for example, from the extreme cold in winter and from long periods of darkness causing serious power shortages and often leading to data gaps during the austral winter months (May to September).

The Alfred Wegener Institute (AWI) is a German research institute for polar science based in Bremerhaven, Germany. AWI operates the regional seismic network with the network code AW in Dronning Maud Land, East Antarctica (Fig. 5.1) increasing the global station coverage and revealing local earthquakes undetected by global networks.

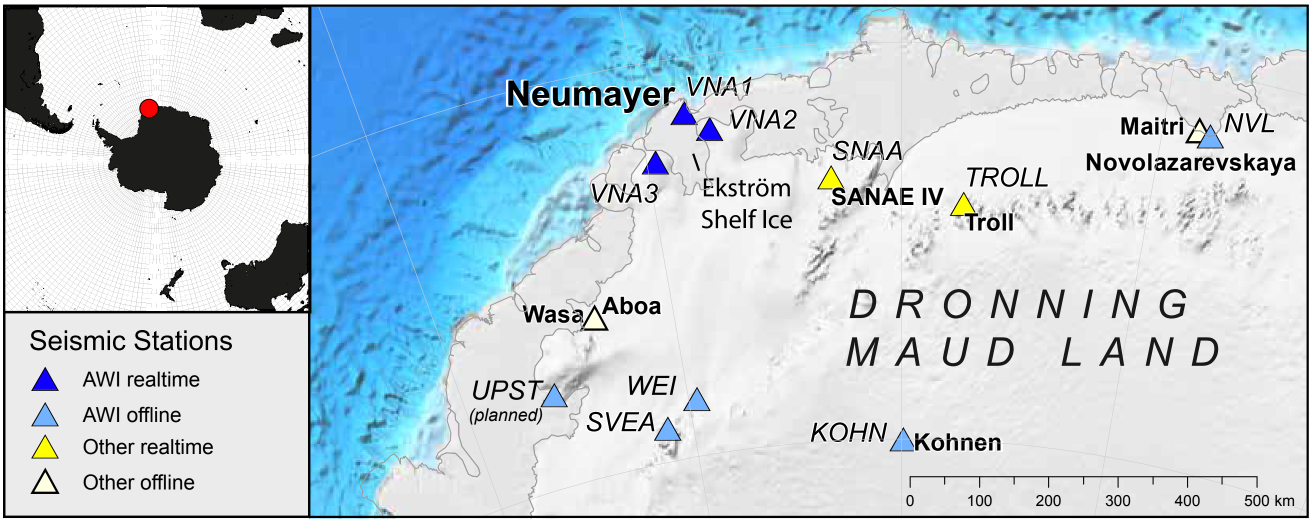

Figure 5.1: *Currently operating long term seismic stations in Dronning Maud Land organzied by AWI and others. The red dot in the upper left overview map indicates Neumayer Station. Grey lines in the map mark the extend of shelf ice.*

5.1.2 Seismicity

Large earthquakes within Antarctica have not been observed so far. Antarctica is surrounded by passive margins and small regional events occur regularly at the oceanic spreading ridges more than 800 km distant. Nevertheless, the unique environment of the ice-covered continent is a source of signals of its own: icequakes caused by moving and breaking ice emit signals similar to earthquakes caused by moving and breaking tectonic plates. Figure 5.2 displays an overview of local, cryogenic and teleseismic events observed by the AW network.

The AW network is very sensitive to teleseismic events from the South Sandwich Island arc, South America, the Fiji/Tonga region and for core phases from Japan (Fig. 5.2B). Many moderate events from the subduction zone at the South Sandwich Island arc (epicentral distance $\Delta = 13-18°$) are not detected by the global network in real-time and are located only during the ISC review process, when AW arrivals and core phases recorded in Japan are analysed simultaneously.

The AW network recorded some local tectonic seismicity in Dronning Maud Land, mainly in the area of the Jutul Penck Graben and around Cape Norvegia (Fig. 5.2A). The events at the continental margin around Cape Norvegia might be isostatic rebound events related to changes in the Antarctic ice mass. The seismic activity at the Jutul Penck Graben is likely to be of tectonic origin, although further analysis is needed to constrain this assumption (*Eckstaller et al.*, 2007). The Jutul Penck Graben is assumed to be a failed rift from the Jurassic (*Grantham and Hunter*, 1991) and represents the tectonic boundary between the Grunehogna Craton and the East African Antarctic orogen (*Mieth and Jokat*, 2014). This old rift might have been reactivated causing the observed seismic activity.

Apart from tectonic events, numerous cryogenic events are detected by the AW network (Fig. 5.2C). Some are similar to earthquakes generated by brittle failure of the ice, while others are related to tides and icebergs (*Hammer et al.*, 2015). While icebergs move along the margin, they collide with the continental shelf from time to time and generate impact events as shown in Figure 5.2C. The frequency content of these events is lower than that of tectonic earthquakes.

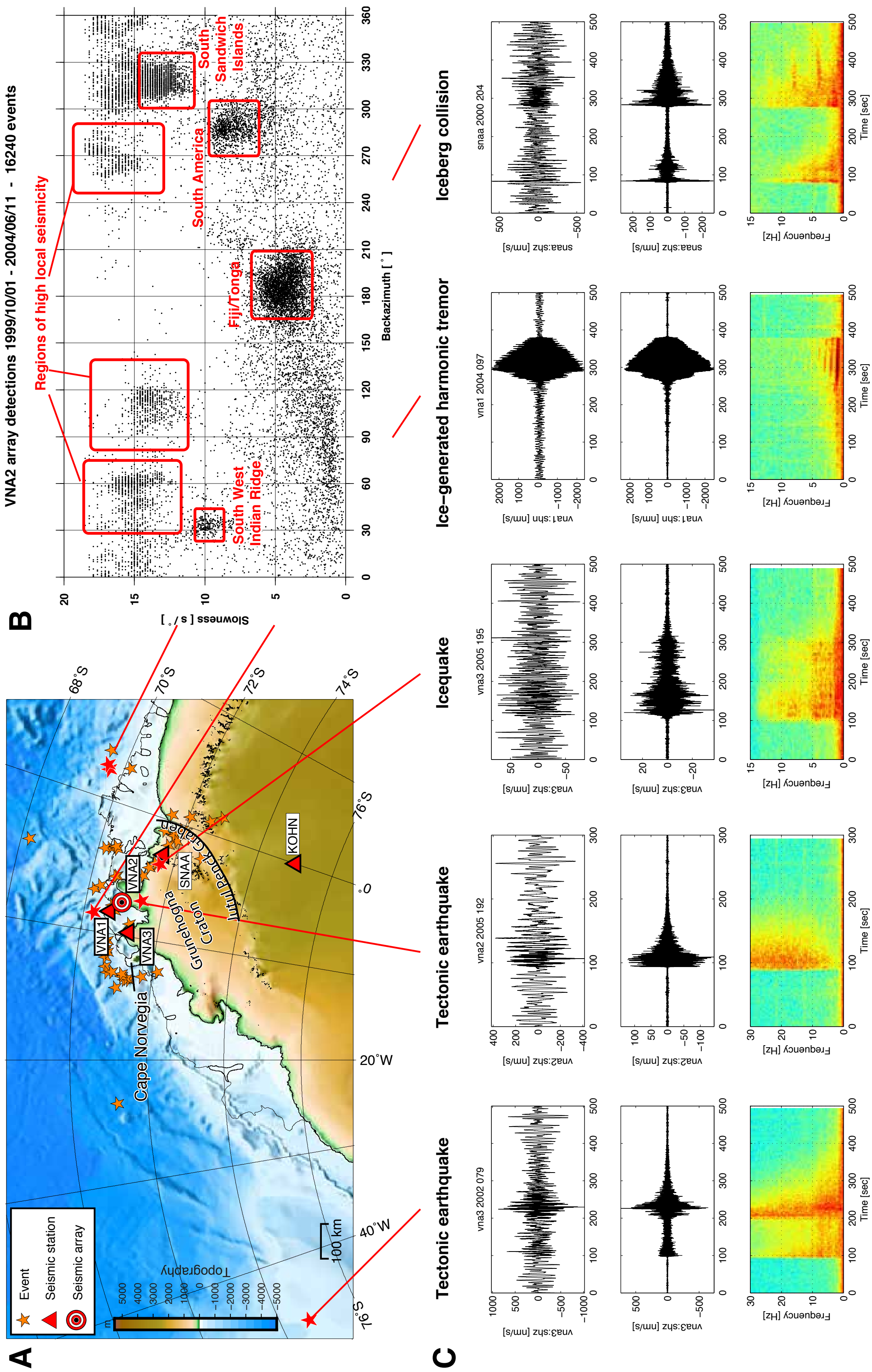

Figure 5.2: Examples for types of local seismicity observed at the AW-network. (A) Topographic map showing the location of events. (B) Distribution of backazimuth and slowness for events detected at VNA2 array (C) Waveform examples (upper: raw waveform, middle: filtered (0.5-10 Hz), lower: spectrogram). Figure from Eckstaller et al. (2007).

Another type of cryogenic event is similar to seismic tremors generated at volcanoes. *Müller et al.* (2005) interpret events at Neumayer (see Figure 5.1 and Section 5.1.3) as tremors generated within icebergs moving along the coast. It is also possible to track icebergs locating the tremors.

5.1.3 History

The development of the AW network is coupled to the foundation of the Alfred Wegner Institute in 1980. The first wintering station, Georg-von-Neumayer, was built in 1981 at the Ekström ice shelf and scientific research started a year later. The first seismometer was setup in 1982 (*Augstein*, 1984), but during the early years of research seismometers were not being operated as long-term observatory stations. Instead, small arrays were installed for dedicated studies of icequakes, shelf ice dynamics or crustal structures (*Osten-Woldenburg*, 1990; *Nixdorf*, 1992; *Eckstaller*, 1988; *Eckstaller and Miller*, 1993).

The first long term observatory station VNA1 was registered in 1992 and installed during the construction of the second research base, Neumayer Station 2 (summary in Tab. 5.1). Since then, phase arrival information have been sent to the ISC on a daily base. Four years later, in 1996, data became available from two additional stations (VNA2 and VNA3) at 45 and 83 km distance from VNA1 on grounded ice (Fig. 5.1, *Eckstaller et al.* (1997)). VNA2 was extended by an array of 15 seismometers with an aperture of 1.8 km in 1997 (*Büsselberg et al.*, 2001). All VNA stations were equipped with three component Lennartz seismometers with eigenperiods of 1, 5 or 20 s. The array seismometers at VNA2 are one component 1 Hz vertical Mark L4 sensors. Data was recorded with a Lennartz PCM system – first in triggered mode and since 1999 continuously – and transmitted in real-time via radio links from the remote sites to Neumayer 2 (*Eckstaller et al.*, 1997). The daily bulletin was expanded to arrival information from all three stations. This small local network allowed for the first time the analysis of local seismicity in the remote region of the Dronning Maud Land. Especially, the VNA2 array enabled us to identify the local events shown in Figure 5.2.

In 2006, we installed the first remote station working autonomously and without real-time data transmission at the unmanned Swedish summer station SVEA approximately 450 km south of Neumayer. The next major hardware upgrade of the network was performed during the construction of Neumayer Station III between 2007 and 2009. The sensors of the VNA stations were replaced by broad band seismometers and the recording system was modernized to the current state (see Section 5.1.4 Network Description). The whole network was further extended by autonomous stations at logistically accessible locations for 'easy' maintenance (Fig. 5.1).

5.1.4 Network Description

Currently, the network consists of three broadband stations available in real-time and four offline stations (Fig. 5.1). The real-time stations (VNA1, 2, 3) are equipped with Q330 datalogger and Guralp three-component seismometers (CMG-3ESP 120 s, 50 Hz sampling rate). The four offline stations are equipped with Reftek 130 datalogger and either Guralp (CMG-3ESP 120s) or three component LE-3D 20s seismometers. The data is recorded to memory cards and collected once a year, if possible.

Apart from NVL and VNA1, all stations are in remote areas without power infrastructure and require

Year	Station	Comment
1992	VNA1	Station installation
1988	VNA2,3	Station installation
1996	VNA2,3	Daily analysis routine with triggered data
1997	VNA2	Installation of array seismometers, continuous recording
2006	SVEA	Station installation
2009	KOHN, NVL	Station installation
2010	VNA1,2,3	Major hardware upgrade of acquisition system
2010	WEI	Station installation
2010	VNA2,3	Installation of broadband sensor
2012	VNA1	Installation of broadband sensor
2018	UPST	Planned installation of broadband sensor and mini-array on rock outcrop

Table 5.1: *Historical changes in the AW network. Refer to Figure 5.1 for station locations.*

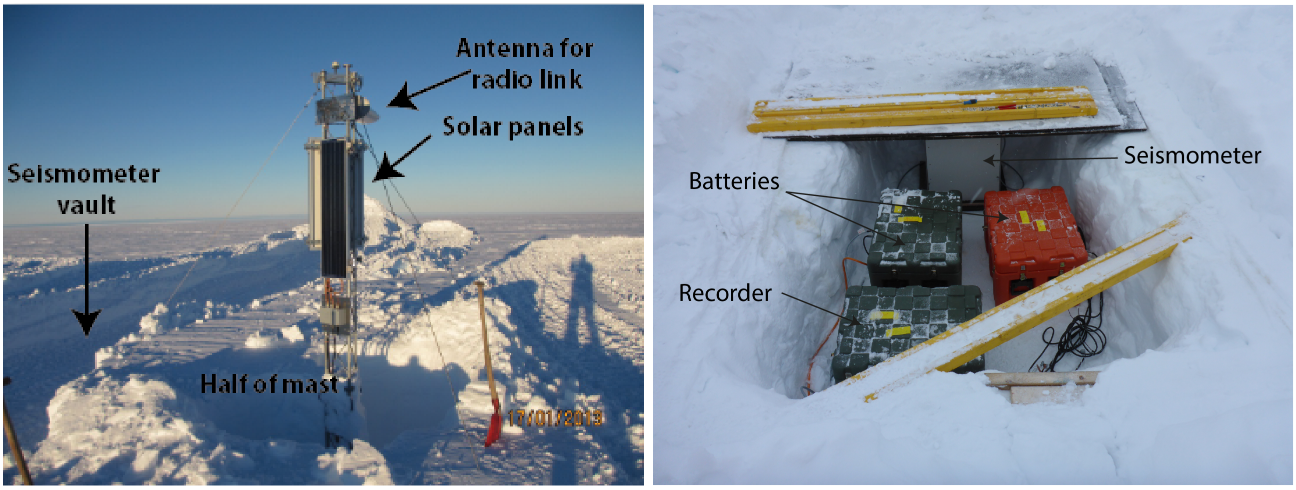

Figure 5.3: *During the yearly maintenance at VNA3 we recover all instruments and constructions, which can be buried under up to 3 m snow (left). The seismometer and all electrical devices are set up in a snow pit (right).*

specialized technical development to withstand the harsh environment including extremely low temperatures of sometimes less than -50°C. Power is supplied by solar panels and, for some stations, by additional wind mills to cover the periods of darkness during the austral winter (Fig. 5.3). Depending on the surroundings, the sensors are either buried in snow pits or installed on bare rock. Snow pits are easy to build and isolate the sensor from large temperature variations and wind induced noise (Fig. 5.3, right). However, ice deformation can cause significant tilting of the sensor during a year. Sensor installation on rock requires more solid housings to shield the sensor from wind, blowing snow and water, since dark rock increases melting during the summer. Bare rocks are rare and not always available for seismometer installations as 95% of the Antarctic continent is ice covered.

5.1.5 Data Processing

Data are recorded and managed with the BRTT Antelope software package. In addition to our own real-time stations, we import additional data from other Antarctic stations via IRIS and Geofon to allow for a simple daily processing routine and event review. The winterer at Neumayer station analyse the data manually and pick teleseismic and potential local events. Seismic Handler calculates azimuth and slowness values for the array at VNA2 greatly facilitating the initial localisation. We use BRTTs GUI dbloc2 for event localisation and association. Nearly all recorded events occur far outside our network, so our own locations have large uncertainties. Instead we associate the picked arrivals with preliminary locations from NEIC or EMSC catalogs. Only if catalog events are absent, we locate the event using dblocsat2 (written by Bratt and Nagy) or genloc (written by Gary L. Pavlis). Finally, all event related data are sent to the ISC. Data from the offline stations is later merged with the data base. We are currently working on automated detection and association routines to add those data to our database and make them available via the ISC database.

5.1.6 Data Quality

The ambient noise level, and therefore the data quality, depends highly on the station location and the weather, whereas man-made noise is mostly irrelevant. We analysed the ambient noise following the procedure published by *McNamara and Buland* (2004) carried out with ObsPy (Fig. 5.4, *Beyreuther et al.*, 2010).

VNA1 shows remarkably high noise levels well above the high noise model in the long periods from 10 to 100 s (*Peterson*, 1993). This noise is unique to all our stations (VNA1 and temporary deployments) on the ice shelf. Since the ice shelf floats on the ocean, it is subject to ocean driven motions such as tides and swell, which can excite infra-gravity waves in this period band (*Bromirski et al.*, 2010; *Tezkan and Yaramanci*, 1993).

The diversification in the period band of the primary microseismic noise between 10 and 30 s is a seasonal variation likely related to the opening of the sea ice cover in front of the shelf ice. Ocean waves reaching shallow waters cause this primary microseismic noise. The opening of the sea ice in front of the shelf

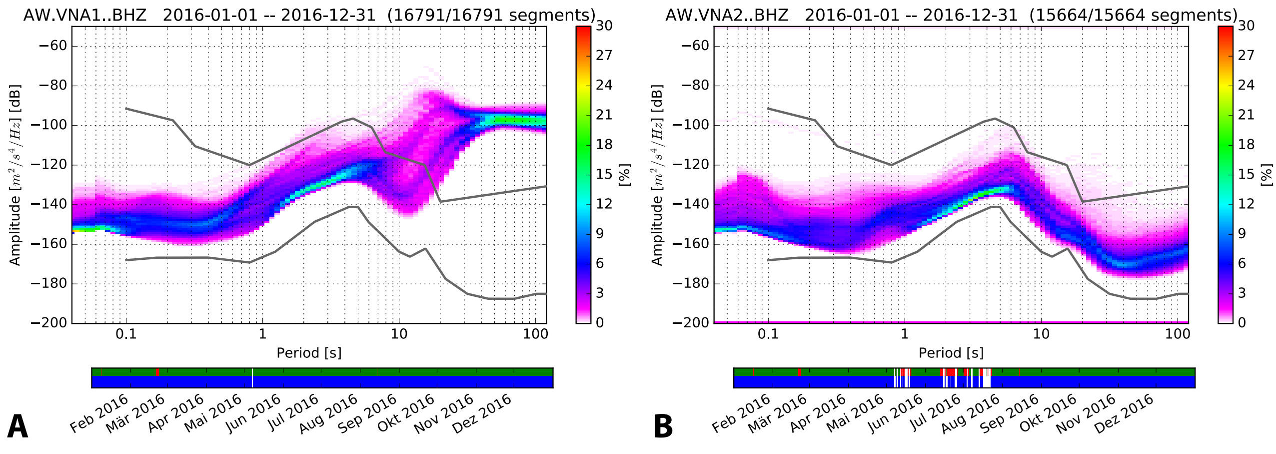

Figure 5.4: *Probabilistic noise spectra for stations VNA1 (left) and VNA2 (right) calculated with ObsPy (Beyreuther et al., 2010) after McNamara and Buland (2004). The high and low noise models after Peterson (1993) are indicated by the black lines. Data coverage is shown below the graphs. 'The top row shows data fed into the PPSD, green patches represent available data, red patches represent gaps in streams that were added to the PPSD. The bottom row in blue shows the single psd measurements that go into the histogram. The default processing method fills gaps with zeros, these data segments then show up as single outlying psd lines.' from ObsPy documentation.)*

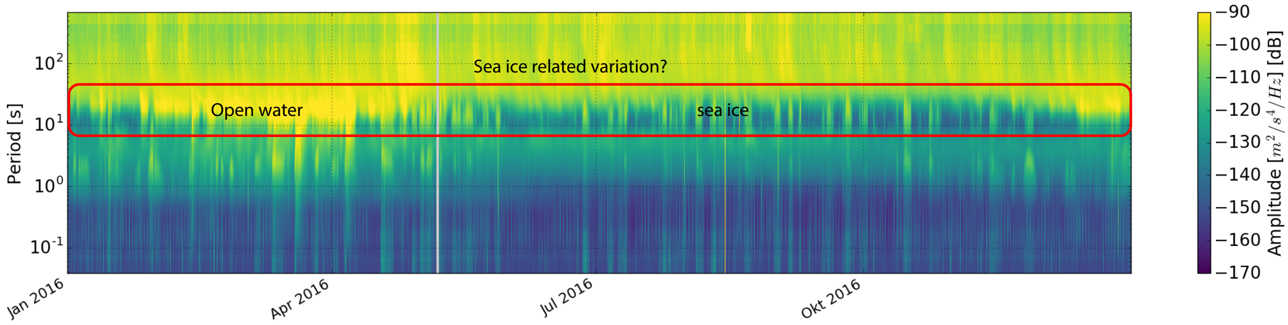

Figure 5.5: *Seasonal probabilistic noise spectra for station VNA1 calculated with ObsPy (Beyreuther et al., 2010) after McNamara and Buland (2004). Note the seasonal variation of the long period noise above 10 s.*

edge moves the 'shoreline' during the late austral summer and early autumn (*Beucler et al.*, 2015: and references therein). This effect was especially strong in 2016 (Fig. 5.5).

The noise level for VNA1 is quite low for frequencies above 1 Hz compared to the noise models, but the location on floating ice has more effects on the data quality not visible in the noise spectra. Even though the noise level is low, the detection threshold for seismic events for VNA1 is higher than for VNA2 and VNA3. Often events are clearly visible at VNA2 and 3, but cannot be observed on VNA1. This is likely an effect of the ocean underneath the shelf ice attenuating ground motions. The water layer also effects the observable phases: S-wave detection is challenging. True S-phases cannot reach the station, only S-waves converted to P-waves can travel through the water column and then be observed. However, much less S-waves are converted to P-waves than theoretically calculated and only strong earthquakes show converted S-phases (*Wüster et al.*, 1992).

The ambient noise levels for VNA2 and VNA3 are generally low, although there is some variation for frequencies higher than 1 Hz (Fig. 5.4b). This wind induced noise depends largely on the local weather. Wind speed often reaches 100 km/h and more causing such elevated noise levels. During storms the sensitivity of the network is strongly affected and small events remain undetected. The noise levels differ between VNA2 and VNA3 because the local wind speed can differ greatly and the snow cover on VNA3 is much thicker compared to VNA2. VNA3 has three metres a year accumulation compared to less than a metre at VNA2. The ice sheet at both stations is grounded on bedrock. Therefore, VNA2 and VNA3 have a better coupling to the ground motion than VNA1.

Timing accuracy is another factor for data quality. While stations VNA1-3 have no timing issues, our remote stations occasionally suffer from failing GPS due to electro-static discharge during storms with blowing snow. In combination with power loss in the winter, this can lead to a complete loss of time information. In this case, time information can be manually recovered using teleseismic earthquakes from regions with accurately known traveltimes. Nevertheless, this recovery can only add crude time information and analysis requiring high accuracy of absolute time should not utilize this data. However, the data can be used for analysis, which only operates on relative time information.

5.1.7 Data Availability

The waveform data for stations VNA1, 2 and 3 are available in real-time through the Geofon data portal (`www.geofon.de`). Archived data can be accessed online for the years from 2006, data before 2006 can be shared on request. The arrival data are available in the ISC catalog for the stations VNA1, 2 and 3 for the whole lifetime of the stations.

Data from our other stations is currently only available on request.

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5.1.8 References

Augstein, E. (1984), The observatories of the Georg-von-Neumayer Station, *Berichte zur Polarforschung (Reports on Polar Research)*, *Special Issue 5*, pp.18, DOI:10.2312/BzP_SH_5_1984.

Beucler, E., A. Mocquet, M. Schimmel, S. Chevrot, O. Quillard, J. Vergne and M. Sylvander (2015), Observation of deep water microseisms in the North Atlantic Ocean using tide modulations, *Geophysical Research Letters*, *42*(2), 316–322, DOI:10.1002/2014gl062347.

Beyreuther, M., R. Barsch, L. Krischer, T. Megies, Y. Behr and J. Wassermann (2010), ObsPy: A Python Toolbox for Seismology, *Seismological Research Letters*, *81*(3), 530–533, DOI:10.1785/gssrl.81.3.530.

Bromirski, P. D., O. V. Sergienko and D. R. MacAyeal (2010), Transoceanic infragravity waves impacting Antarctic ice shelves, *Geophysical Research Letters*, *37*(2), L02502, DOI:10.1029/2009GL041488.

Büsselberg, T., C. Müller and A. Eckstaller (2001), The Neumayer Array and its impact on seismological research in the Southern Atlantic and Antarctica, *Terra Antartica*, *8*(2), 41–48.

Eckstaller, A. (1988), Seismologische Untersuchungen mit Daten der Georg-von-Neumayer Station, Antarktis, 1982-1984, *PhD thesis*, Universität München.

Eckstaller, A. and H. Miller (1993), Seismological research at Georg-von-Neumayer-Base, Antarctica - Part II. The analysis of travel time residuals, *Polarforschung*, *62*(1), 39–50, DOI:10.2312/polarforschung.62.1.39.

Eckstaller, A., T. Schmidt, V. Gaw, C. Müller and J. Rogenhagen (1997), The Geophysical Obervatory at Neumayer Station, Antarctica, Geomagnetic and Seismological Observations in 1995 and 1996, *Berichte zur Polar-und Meeresforschung (Reports on Polar and Marine Research)*, *244*, pp.141, DOI:10.2312/BzP_0244_1997.

Eckstaller, A., C. Müller, L. Ceranna and G. Hartmann (2007), The Geophysics Observatory at Neumayer Stations - GvN and NM II - (Antarctica), *Polarforschung*, *76*(1-2), 3–24, DOI:10.2312/polarforschung.76.1-2.3.

Grantham, G.H. and D.R. Hunter (1991), The timing and nature of faulting and jointing adjacent to the Pencksökket, western Dronning Maud Land, Antarctica, *Geological evolution of Antarctica*, 47–51.

Hammer, C., M. Ohrnberger and V. Schlindwein (2015), Pattern of cryospheric seismic events observed at Ekström ice shelf, Antarctica, *Geophysical Research Letters*, *42*, DOI:10.1002/2015GL064029.

McNamara, D.E. and R.P. Buland (2004), Ambient Noise Levels in the Continental United States, *Bulletin of the Seismological Society of America*, *94*(4), 1517–1527, DOI:10.1785/012003001.

Mieth, M. and W. Jokat (2014), New aeromagnetic view of the geological fabric of southern Dronning Maud Land and Coats Land, East Antarctica, *Gondwana Research*, *25*(1), 358–367, DOI:10.1016/j.gr.2013.04.003.

Müller, C., V. Schlindwein, A. Eckstaller and H. Miller (2005), Singing Icebergs, *Science*, *310*, DOI:10.1126/science.1117145.

Nixdorf, U. (1992), Dehnungsbeben an einer Störungszone im Ekström-Schelfeis nördlich der Georg-von-Neumayer Station, Antarktis. - Eine Untersuchung mit seismologischen und geodätischen Methoden, *PhD thesis*, Universität Bremen.

Osten-Woldenburg, H. von der (1990), Icequakes on Ekström ice shelf near Atkabay, Antarctica, *Journal of Glaciology*, *36*(122), 31–36, DOI:10.1017/S0022143000005517.

Peterson, J. (1993), Observations and modeling of seismic background noise, *U.S.G.S Open-File Report 92-322*.

Tezkan, B. and U. Yaramanci (1993), The effect of sea tides on gravity tidal observations on the Antarctic Ekstrom ice shelf, *Geophysical Journal International*, *114*(3), 561–568.

Wüster, J., A. Eckstaller and H. Miller (1992), Seismological research at Georg-von-Neumayer-Base, Antarctica - Part I. The seismological observatory, *Polarforschung*, *62*(1), 27–38, DOI:10.2312/polarforschung.62.1.27.

6

Summary of Seismicity, July - December 2014

In contrast to the first half of 2014, where 8 events with magnitudes larger than M_W 7 occured within 19 days in April, the second half of 2014 was much quieter with only five events larger than M_W 7 occurring during the entire time period (Tab. 6.2). The largest event was a M_W 7.3 earthquake off the coast of central America (14/10/2014 03:51:37 UTC, 12.5893°N 88.0720°W, 63.9 km, 2597 stations (ISC)) within the central American subduction zone where the Cocos Plate subducts under the Caribbean Plate (*USGS*, 2014a). Other large events were two deep events in the Fiji Islands region, a shallow event in the Southern East Pacific Rise and a M_W 7.1 event in the Northern Molucca Sea. Out of those five largest events only the latter has an entry in the ISC Event Biblography (*Di Giacomo et al.*, 2014; *International Seismological Centre*, 2018). It is not always the largest events that raise the most interest in the scientific community.

The event with the highest number of entries in the ISC Event Bibliography is the M_W 6.1 Napa event of 24 August 2014 with 35 entries so far (10:20:46 UTC, 38.1734°N 122.2985°W, 8.3 km, 1813 stations (ISC)). It was the largest earthquake in the San Franscisco Bay area since the M_W 6.9 event in 1989 (*Brocher et al.*, 2015) but produced fewer aftershocks than expected (*Llenos and Michael*, 2017; *Brocher et al.*, 2015). The earthquake is located within a 70 km to 80 km wide set of major faults of the San Andreas Fault system that forms the boundary between the Pacific and North American tectonic plate (*USGS*, 2014b; *Brocher et al.*, 2015).

Another event of interest to the scientific community during this Summary's time period was the destructive M_W 6.2 Ludian event with 21 entries in the ISC Event Bibliography so far. The shallow strike-slip earthquake occured in a densly populated area of Yunnan province, China (03/08/2014 08:30:14 UTC, 27.2188°N 103.4360°E, 13.7 km, 1891 stations (ISC)), over 600 people were killed and over 3000 injured. Due to major landslides and poor quality of construction many houses were destroyed or seriously damaged and almost 230,000 people were left homeless (*Hong et al.*, 2016).

The number of events in this Bulletin Summary categorised by type are given in Table 6.1.

The period between July and December 2014 produced 5 earthquakes with $M_W \geq 7$; these are listed in Table 6.2.

Figure 6.1 shows the number of moderate and large earthquakes in the second half of 2014. The distribution of the number of earthquakes should follow the Gutenberg-Richter law.

Figures 6.2 to 6.5 show the geographical distribution of moderate and large earthquakes in various magnitude ranges.

Table 6.1: *Summary of events by type between July and December 2014.*

felt earthquake	1281
known earthquake	168057
known chemical explosion	6129
known induced event	2980
known mine explosion	673
known rockburst	17
known experimental explosion	41
suspected earthquake	28260
suspected chemical explosion	280
suspected induced event	19
suspected mine explosion	4275
suspected rockburst	587
suspected experimental explosion	70
unknown	889
total	213558

Table 6.2: *Summary of the earthquakes of magnitude $M_W \geq 7$ between July and December 2014.*

Date	lat	lon	depth	M_W	Flinn-Engdahl Region
2014-10-14 03:51:37	12.59	-88.07	63	7.3	Off coast of central America
2014-11-01 18:57:22	-19.80	-177.83	435	7.2	Fiji Islands region
2014-11-15 02:31:42	1.83	126.46	47	7.1	Northern Molucca Sea
2014-10-09 02:14:29	-32.30	-110.92	4	7.0	Southern East Pacific Rise
2014-07-21 14:54:40	-19.84	-178.41	613	7.0	Fiji Islands region

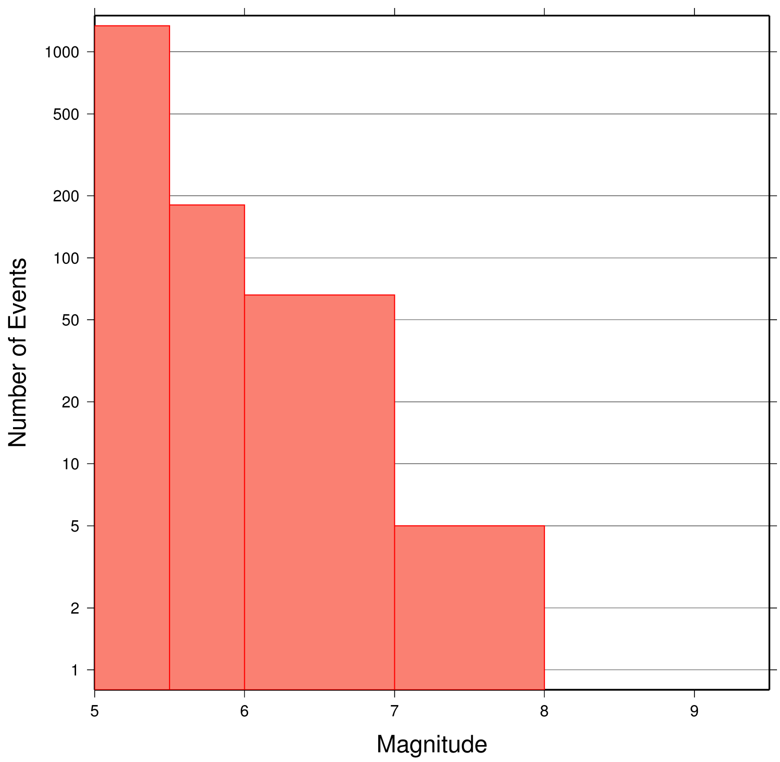


Figure 6.1: *Number of moderate and large earthquakes between July and December 2014. The non-uniform magnitude bias here correspond with the magnitude intervals used in Figures 6.2 to 6.5.*

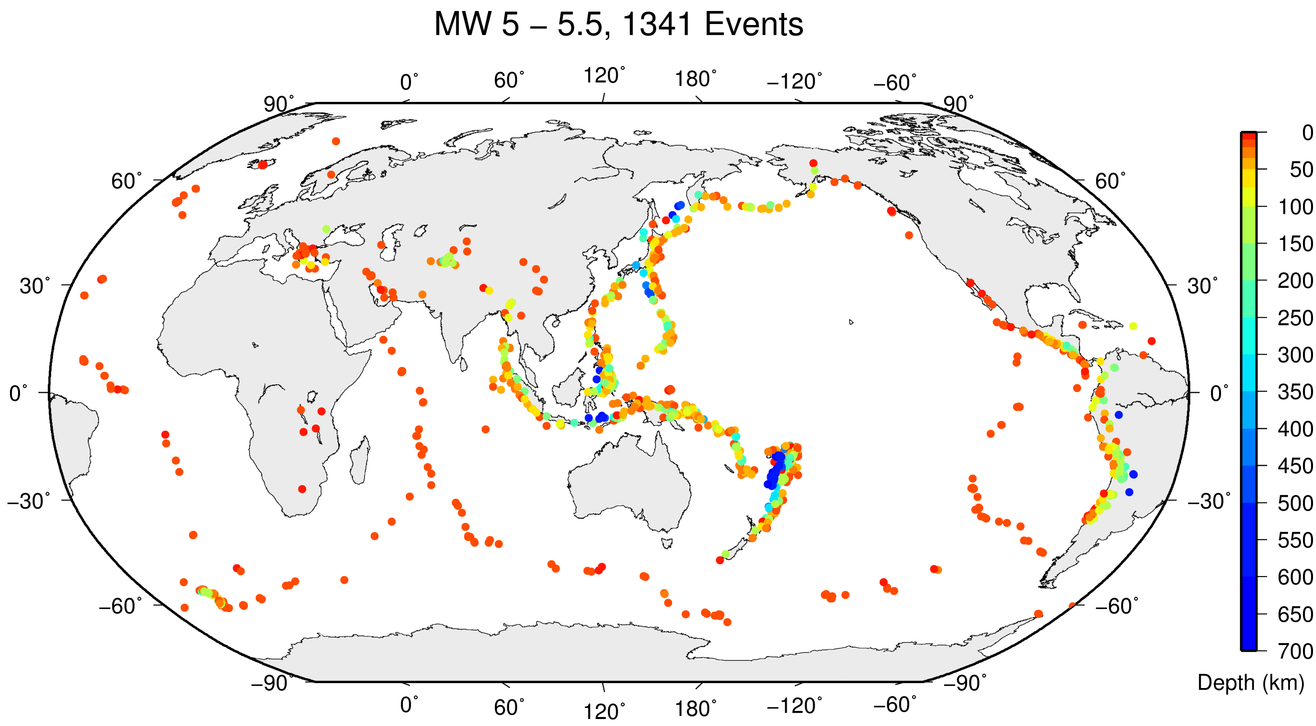


Figure 6.2: *Geographic distribution of magnitude 5-5.5 earthquakes between July and December 2014.*

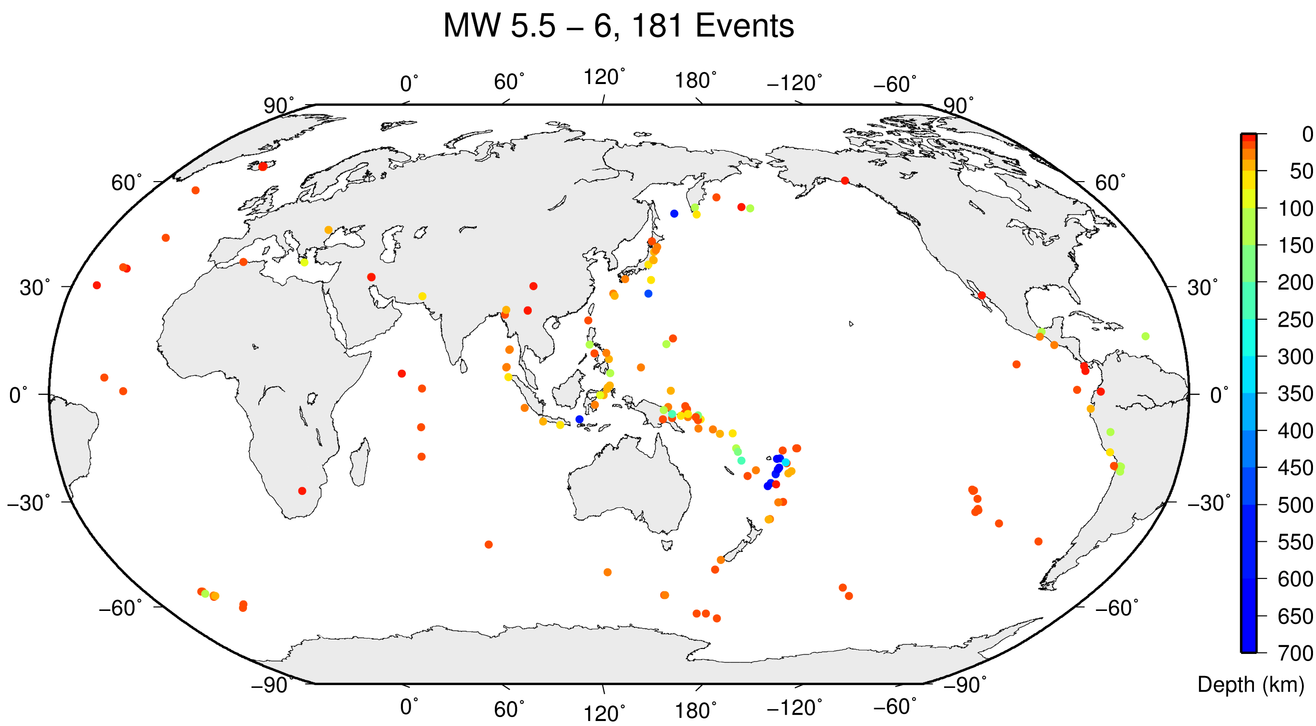


Figure 6.3: *Geographic distribution of magnitude 5.5-6 earthquakes between July and December 2014.*

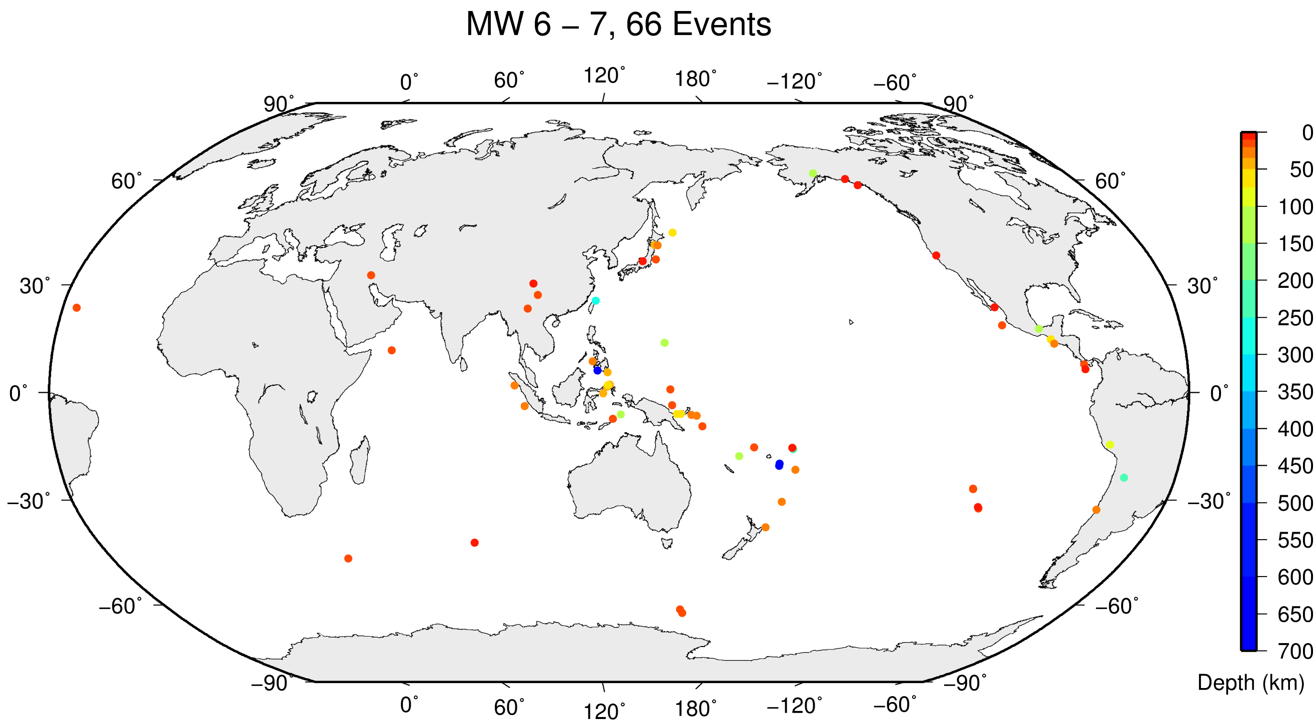


Figure 6.4: *Geographic distribution of magnitude 6-7 earthquakes between July and December 2014.*

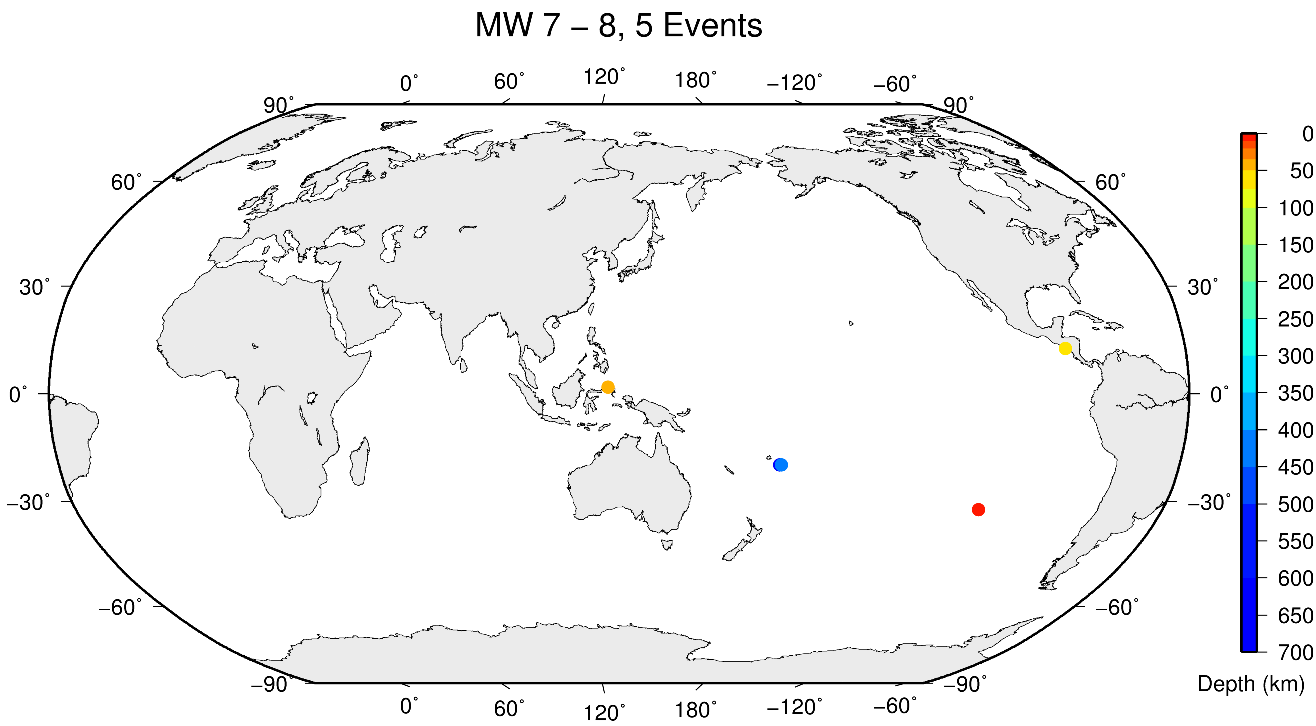


Figure 6.5: *Geographic distribution of magnitude 7-8 earthquakes between July and December 2014.*

References

Brocher, T. M. et al. (2015), The Mw 6.0 24 August 2014 South Napa Earthquake, *Seismol. Res. Lett.*, *86*(2A), 309–326, DOI:10.1785/0220150004.

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

Hong, H., J. You and X. Bi (2016), The Ludian earthquake of 3 August 2014, *Geomatics Natural Hazards Risk*, *7*(2), 450–457, DOI:10.1080/19475705.2015.1060639.

International Seismological Centre, On-line Event Bibliography, `www.isc.ac.uk/event_bibliography`, Internatl. Seis. Cent., Thatcham, United Kingdom, 2018.

Llenos, A. L. and A. J. Michael (2017), Forecasting the (Un)Productivity of the 2014 M 6.0 South Napa Aftershock Sequence, *Seismological Research Letters*, *88*(5), 1241–1251, DOI:10.1785/0220170050.

USGS (2014a), Earthquake Summary Poster, `https://earthquake.usgs.gov/archive/product/poster/20141013/us/1480721058269/poster.pdf` (visited on 4 January 2018).

USGS (2014b), Earthquake Summary Poster, `https://earthquake.usgs.gov/archive/product/poster/20140824/us/1480721358422/poster.pdf` (visited on 4 January 2018).

7

Statistics of Collected Data

7.1 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.

7.2 Summary of Agency Reports to the ISC

A total of 148 agencies have reported data for July 2014 to December 2014. The parsing of these reports into the ISC database is summarised in Table 7.1.

Table 7.1: *Summary of the parsing of reports received by the ISC from a total of 148 agencies, containing data for this summary period.*

	Number of reports
Total collected	3398
Automatically parsed	2510
Manually parsed	886

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 7.2, 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 7.1 and Figure 7.2.

Table 7.2: *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	325	11	3285	75	230
ALG	**Algeria**	**I NEIC**	**0**	**0**	**27**	**0**	**0**
CRAAG	Algeria	D	372	0	1579	182	0
LPA	Argentina	D	0	0	0	523	0
SJA	Argentina	D	363	43	11712	0	2553
NSSP	Armenia	D	66	0	620	0	0
AUST	Australia	D	852	2	21737	0	0
CUPWA	**Australia**	**D**	**24**	**1**	**261**	**0**	**0**
IDC	Austria	D	17068	2	422396	0	328238
VIE	Austria	D	4411	50	39353	507	39046
AZER	Azerbaijan	D	52	59	2681	0	0
UCC	Belgium	D	0	0	0	7285	712
SCB	Bolivia	D	35	0	770	0	122
SAR	Bosnia and Herzegovina	I KRSZO	0	5	0	0	0
RHSSO	Bosnia-Herzegovina	D	623	0	10764	6083	0
VAO	Brazil	D	922	7	23402	0	0
SOF	Bulgaria	D	106	0	733	4258	0
OTT	Canada	D	1343	69	34097	0	1296
PGC	Canada	I OTT	996	1	27263	0	0
GUC	Chile	D	2556	131	79018	1471	20902
BJI	China	D	1879	19	96560	28487	66183
ASIES	Chinese Taipei	D	0	25	0	0	0
TAP	Chinese Taipei	D	18139	18	681774	0	0
RSNC	Colombia	D	7848	3	194201	21210	59825
CASC	**Costa Rica**	**I NEIC**	**0**	**1**	**0**	**0**	**0**
HDC	Costa Rica	I NEIC	1	0	0	0	0
ICE	Costa Rica	I UCR	0	5	0	0	0
UCR	Costa Rica	D	591	28	17871	0	1510
ZAG	Croatia	D	0	0	0	39324	0
SSNC	Cuba	D	1211	0	13564	0	6045
NIC	Cyprus	D	598	0	13817	0	6294
IPEC	Czech Republic	D	418	0	2799	23620	1248
PRU	Czech Republic	D	5235	13	49121	213	13666
WBNET	Czech Republic	D	385	0	7118	0	7094
KEA	Democratic People's Republic of Korea	D	260	0	2180	0	0
DNK	Denmark	D	1256	880	11301	28108	9847
OSPL	Dominican Republic	D	246	9	2430	0	803
IGQ	Ecuador	D	52	2	2197	0	0
HLW	Egypt	D	223	5	2494	0	0
SNET	El Salvador	D	1101	51	22377	10	3877
SSS	El Salvador	I UCR	0	9	0	0	0

Table 7.2: *(continued)*

Agency	Country	Directly or indirectly reporting (D/I)	Hypocentres with associated phases	Hypocentres without associated phases	Associated phases	Unassociated phases	Amplitudes
EST	Estonia	I HEL	306	0	0	0	0
AAE	Ethiopia	D	24	0	159	241	0
SKO	FYR Macedonia	D	1040	2	5538	3897	2441
FIA0	Finland	I HEL	8	3	0	0	0
HEL	Finland	D	5761	3021	104009	0	14557
CSEM	France	I SVSA	1438	739	0	0	0
LDG	France	D	2484	81	58514	24	22536
STR	France	D	2183	0	28947	0	0
PPT	French Polynesia	D	1323	0	10280	654	10834
TIF	Georgia	D	0	260	0	4821	0
AWI	Germany	D	2183	0	7239	87	0
BGR	Germany	D	854	222	20052	0	7799
BNS	Germany	I BGR	1	24	0	0	0
BRG	Germany	D	0	0	0	5503	4199
BUG	Germany	I BGR	5	9	0	0	0
CLL	Germany	D	4	0	0	9188	3098
GDNRW	Germany	I BGR	0	9	0	0	0
GFZ	Germany	I INMG	56	1	0	0	0
LEDBW	Germany	I BGR	21	1	0	0	0
ATH	Greece	D	14536	27	406299	0	128321
THE	Greece	D	4632	65	107987	5859	33886
UPSL	**Greece**	**D**	**0**	**5**	**0**	**0**	**5**
GCG	Guatemala	D	753	0	4324	0	0
HKC	Hong Kong	D	0	0	0	28	0
BUD	Hungary	D	82	0	1056	0	0
KRSZO	Hungary	D	89	57	3949	0	351
REY	Iceland	D	537	46	23960	0	0
HYB	India	D	797	131	5414	0	1756
NDI	India	D	535	458	13502	2568	4229
DJA	Indonesia	D	3513	77	63119	0	80597
TEH	Iran	D	2364	82	63172	0	5
THR	Iran	D	598	52	4584	0	838
ISN	Iraq	D	799	0	6274	0	1918
GII	Israel	D	468	0	7770	0	0
GEN	Italy	D	837	2	8569	1223	0
MED_RCMT	Italy	D	0	174	0	0	0
OSUB	Italy	D	0	0	0	709	0
RISSC	Italy	D	12	0	185	0	0
ROM	Italy	D	11243	164	730177	273447	498044
TRI	Italy	D	0	0	0	5588	0
LIC	Ivory Coast	D	1046	0	3164	0	2091
JSN	Jamaica	D	94	0	651	10	0
JMA	Japan	D	67459	0	549196	916	0
MAT	Japan	D	0	0	0	13284	0
NIED	Japan	D	0	731	0	0	0
SYO	Japan	D	0	0	0	5713	0
JSO	Jordan	D	21	0	330	0	294
NNC	Kazakhstan	D	7983	0	94494	0	88386
SOME	Kazakhstan	D	5624	221	85738	0	77122
KNET	Kyrgyzstan	D	1174	0	9513	0	1697
KRNET	Kyrgyzstan	D	3897	0	65357	0	0
LVSN	Latvia	D	245	1	3049	0	1513
GRAL	Lebanon	D	365	0	2423	483	0
LIT	Lithuania	D	350	352	2781	1240	182
ECGS	**Luxembourg**	**D**	**96**	**0**	**833**	**0**	**0**
MCO	Macao, China	D	0	0	0	29	0
GSDM	Malawi	D	0	0	0	779	0
KLM	Malaysia	D	546	0	2295	0	0
ECX	Mexico	D	712	1	13558	0	2029
MEX	Mexico	D	4395	232	42108	4	0
MOLD	Moldova	D	0	0	0	999	473
PDG	Montenegro	D	288	1	7069	0	3593

Table 7.2: *(continued)*

Agency	Country	Directly or indirectly reporting (D/I)	Hypocentres with associated phases	Hypocentres without associated phases	Associated phases	Unassociated phases	Amplitudes
CNRM	Morocco	D	1468	0	16061	0	0
NAM	Namibia	D	9	0	45	0	0
DMN	Nepal	D	1288	0	13578	0	10134
DBN	Netherlands	I BGR	0	11	0	0	0
WEL	New Zealand	D	6539	66	204816	299	207049
INET	Nicaragua	D	0	1191	0	0	0
BER	Norway	D	2151	1893	42999	2937	8963
NAO	Norway	D	2516	1013	6408	0	2049
OMAN	Oman	D	596	0	14948	0	0
MSSP	Pakistan	D	0	0	0	582	0
UPA	Panama	D	611	0	12368	0	35
ARE	Peru	I NEIC	18	47	0	0	0
LIM	Peru	I NDI	6	6	0	0	0
MAN	Philippines	D	0	1811	0	36746	7680
QCP	Philippines	D	0	0	0	109	0
WAR	Poland	D	0	0	0	12645	451
IGIL	Portugal	D	620	2	2240	2	747
INMG	Portugal	D	1917	1	38067	1797	13522
PDA	Portugal	I SVSA	1	0	0	0	0
SVSA	Portugal	D	623	0	11243	2638	4926
BELR	Republic of Belarus	D	0	0	0	3896	810
BUC	Romania	D	1226	20	21496	57636	7469
ASRS	Russia	D	124	0	5362	0	1705
BYKL	Russia	D	204	0	16556	0	5267
DRS	Russia	I MOS	117	96	0	0	0
IEPN	Russia	D	188	0	1906	5438	2112
KOLA	Russia	D	154	0	529	0	0
KRSC	Russia	D	557	0	22290	0	0
MIRAS	Russia	D	10	0	87	0	43
MOS	Russia	D	1920	256	333195	0	123132
NERS	Russia	D	93	0	1445	0	703
NORS	Russia	I MOS	50	151	0	0	0
SKHL	Russia	D	686	698	17301	0	8260
YARS	Russia	D	662	0	9209	0	6234
SGS	Saudi Arabia	D	31	14	310	0	0
BEO	Serbia	D	1342	7	21963	0	0
BRA	Slovakia	D	0	0	0	19852	0
LJU	Slovenia	D	1290	547	16230	4441	5695
HNR	Solomon Islands	D	0	0	0	197	0
PRE	South Africa	D	1080	7	17392	0	5792
IAG	**Spain**	**D**	**0**	**3**	**0**	**0**	**3**
MDD	Spain	D	3117	14	86087	0	63775
MRB	Spain	D	446	0	11127	0	4731
SFS	Spain	D	598	0	4397	392	0
UPP	Sweden	D	1127	1979	12180	0	0
ZUR	Switzerland	D	573	20	12998	0	6045
BKK	Thailand	D	1106	2	16026	0	12888
TRN	Trinidad and Tobago	D	0	1287	92	34097	0
TUN	Tunisia	D	35	1	156	0	0
ATA	Turkey	D	140	0	1742	0	540
DDA	Turkey	D	11274	6	222774	0	76606
ISK	Turkey	D	9013	19	138175	7018	81924
AEIC	U.S.A.	I NEIC	1847	267	59305	0	0
ANF	U.S.A.	I IRIS	1296	1317	0	0	0
BUT	U.S.A.	I NEIC	50	10	17	0	0
CERI	U.S.A.	I IRIS	13	3	0	0	0
GCMT	U.S.A.	D	1	2998	0	0	0
HON	U.S.A.	I HYB	0	5	0	0	0
HVO	U.S.A.	I NEIC	88	3	0	0	0
IRIS	U.S.A.	D	3573	5249	232317	0	0
LDO	U.S.A.	I IRIS	6	7	159	0	0

Table 7.2: (continued)

Agency	Country	Directly or indirectly reporting (D/I)	Hypocentres with associated phases	Hypocentres without associated phases	Associated phases	Unassociated phases	Amplitudes
NCEDC	U.S.A.	I NEIC	261	119	11360	0	0
NEIC	U.S.A.	D	17883	10822	1352931	0	559265
PAS	U.S.A.	I NEIC	70	16	10254	0	0
PMR	U.S.A.	I HYB	0	9	0	0	0
PNSN	U.S.A.	D	6	140	0	0	0
REN	U.S.A.	I NEIC	716	203	1343	0	0
RSPR	U.S.A.	D	2258	15	27361	0	0
SCEDC	U.S.A.	I IRIS	282	175	0	0	0
SEA	U.S.A.	I NEIC	60	276	1538	0	0
SLM	U.S.A.	I NEIC	21	1	0	0	0
TUL	U.S.A.	I NEIC	1271	103	0	0	0
UAF	**U.S.A.**	**D**	**0**	**5**	**0**	**0**	**5**
UUSS	U.S.A.	I NEIC	25	5	408	0	0
WES	U.S.A.	I IRIS	4	0	0	0	0
SIGU	Ukraine	D	88	90	1802	4	596
DSN	United Arab Emirates	D	436	0	5365	0	0
BGS	United Kingdom	D	347	13	9837	86	3837
EAF	Unknown	D	640	3	4126	8794	0
ISU	Uzbekistan	D	126	0	1200	0	0
CAR	Venezuela	I NEIC	2	7	0	0	0
PLV	Vietnam	D	7	0	132	0	61
LSZ	Zambia	D	136	0	446	102	23
BUL	Zimbabwe	D	352	0	1898	1144	0

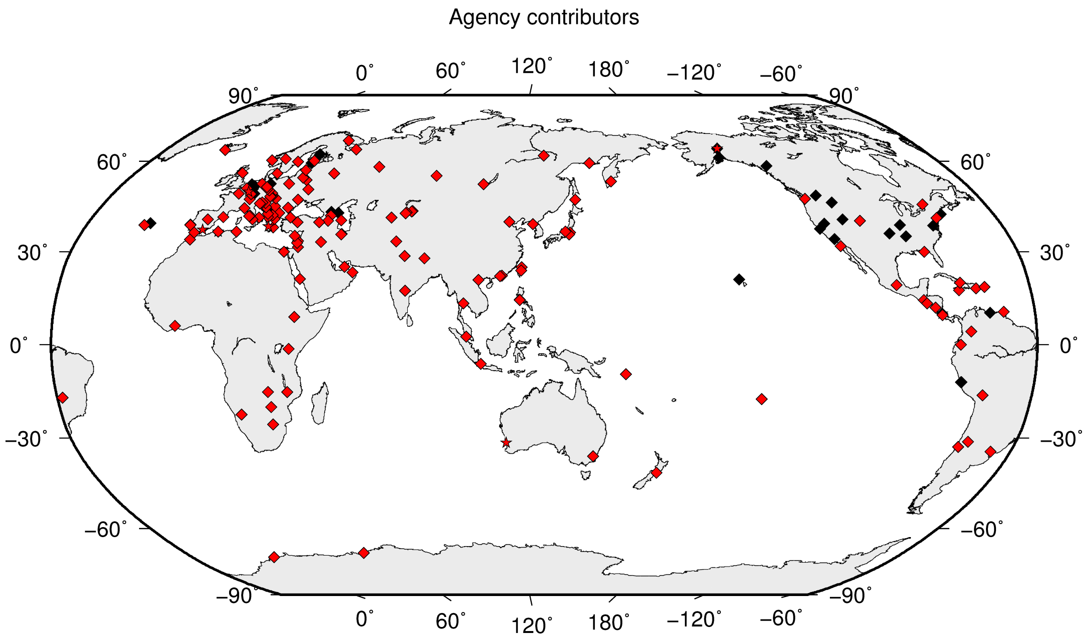


Figure 7.1: *Map of agencies that have contributed data to the ISC for this summary period. Agencies that have reported directly to the ISC are shown in red. Those that have reported indirectly (via another agency) are shown in black. Any new or renewed agencies, since the last six-month period, are shown by a star. Each agency is listed in Table 7.2.*

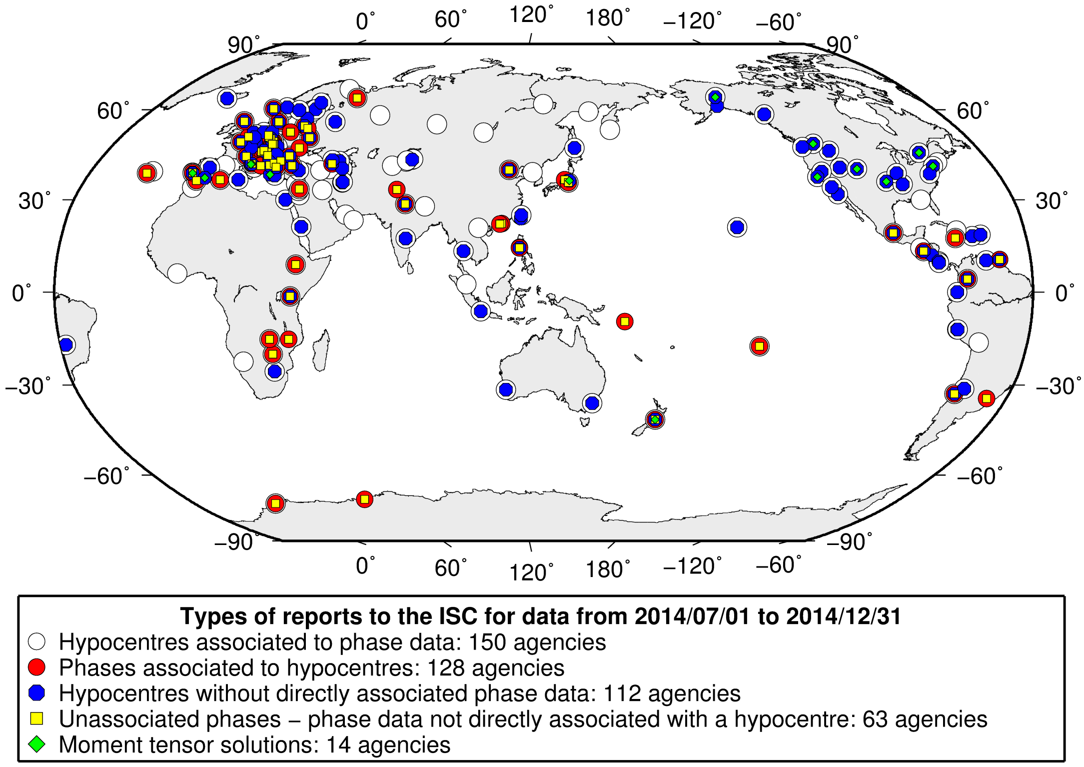


Figure 7.2: *Map of the different data types reported by agencies to the ISC. A full list of the data types reported by each agency is shown in Table 7.2.*

7.3 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 7.3.

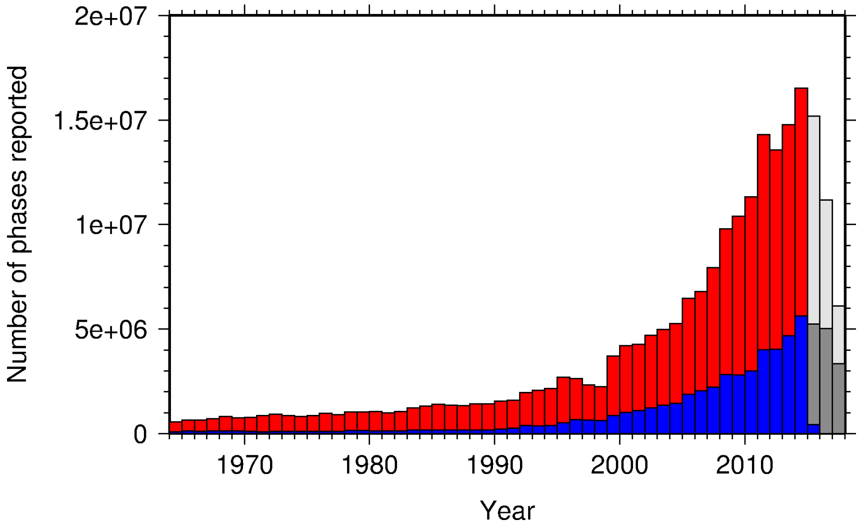


Figure 7.3: *Histogram showing the number of phases (red) and number of amplitudes (blue) collected by the ISC for events each year since 1964. The data in grey covers the current period where data are still being collected before the ISC review takes place and is accurate at the time of publication.*

The reports with phase data are summarised in Table 7.3. 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 7.5.

The ISC encourages the reporting of phase arrival times together with amplitude and period measurements whenever feasible. Figure 7.6 shows the percentage of events for which phase arrival times from each station are accompanied with amplitude and period measurements.

Figure 7.7 indicates the number of amplitude and period measurement for each station.

Table 7.3: *Summary of reports containing phase arrival observations.*

Reports with phase arrivals	3282
Reports with phase arrivals including amplitudes	1215
Reports with only phase arrivals (no hypocentres reported)	257
Total phase arrivals received	7909111
Total phase arrival-times received	7216044
Number of duplicate phase arrival-times	692754 (9.6%)
Number of amplitudes received	2784126
Stations reporting phase arrivals	7744
Stations reporting phase arrivals with amplitude data	4163
Max number of stations per report	2067

Together with the increase in the number of phases (Figure 7.3), 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 7.4. This increase can also be seen on the maps for stations reported each decade in Figure 7.8.

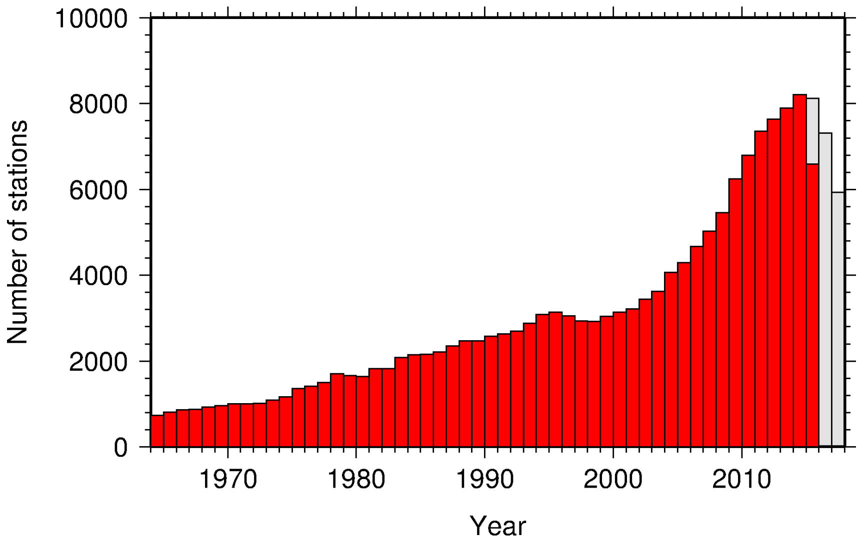


Figure 7.4: *Histogram showing the number of stations reporting to the ISC each year since 1964. The data in grey covers the current period where station information is still being collected before the ISC review of events takes place and is accurate at the time of publication.*

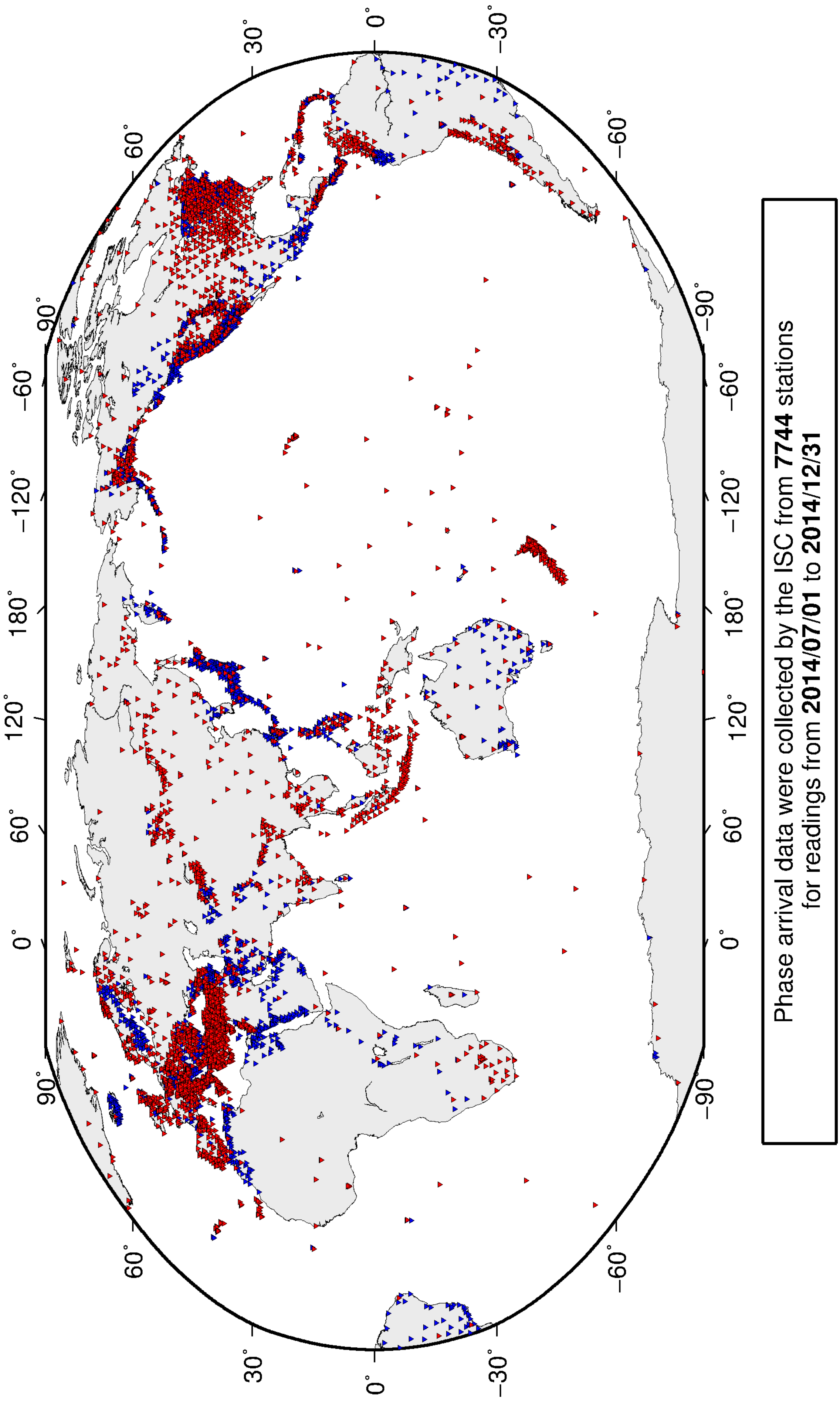


Figure 7.5: *Stations contributing phase data to the ISC for readings from July 2014 to the end of December 2014. Stations in blue provided phase arrival times only; stations in red provided both phase arrival times and amplitude data.*

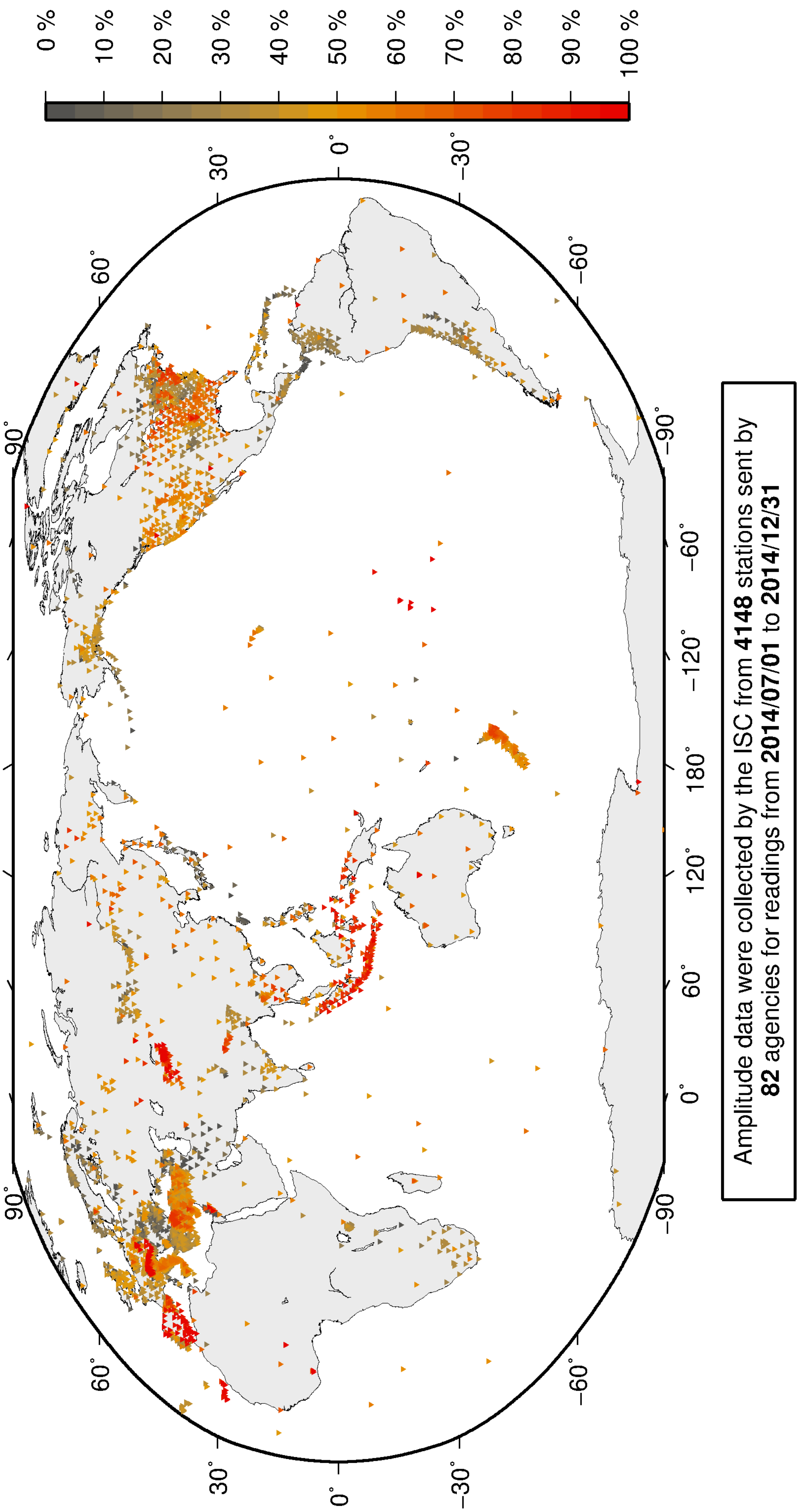


Figure 7.6: *Percentage of events for which phase arrival times from each station are accompanied with amplitude and period measurements.*

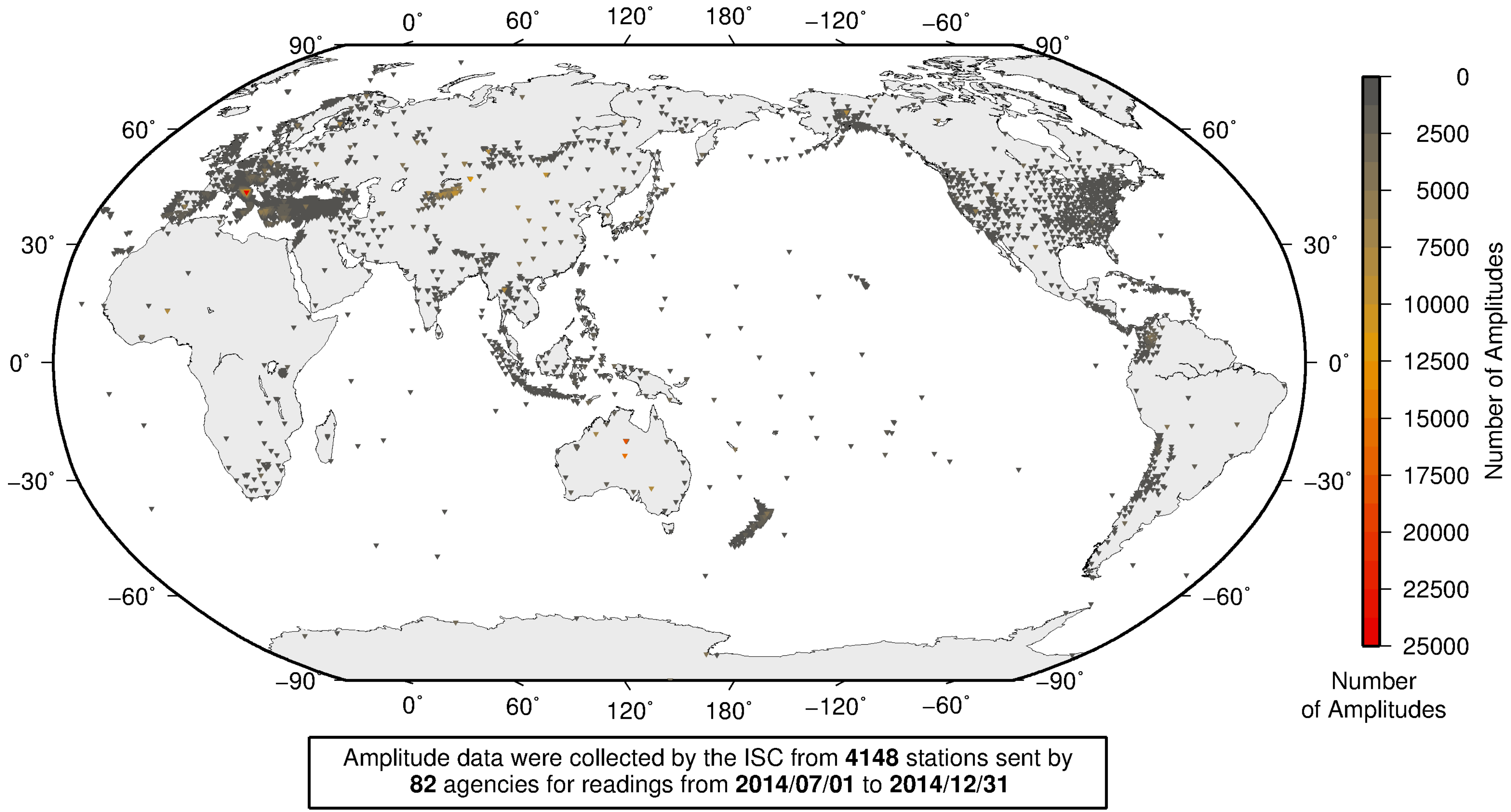


Figure 7.7: *Number of amplitude and period measurements for each station.*

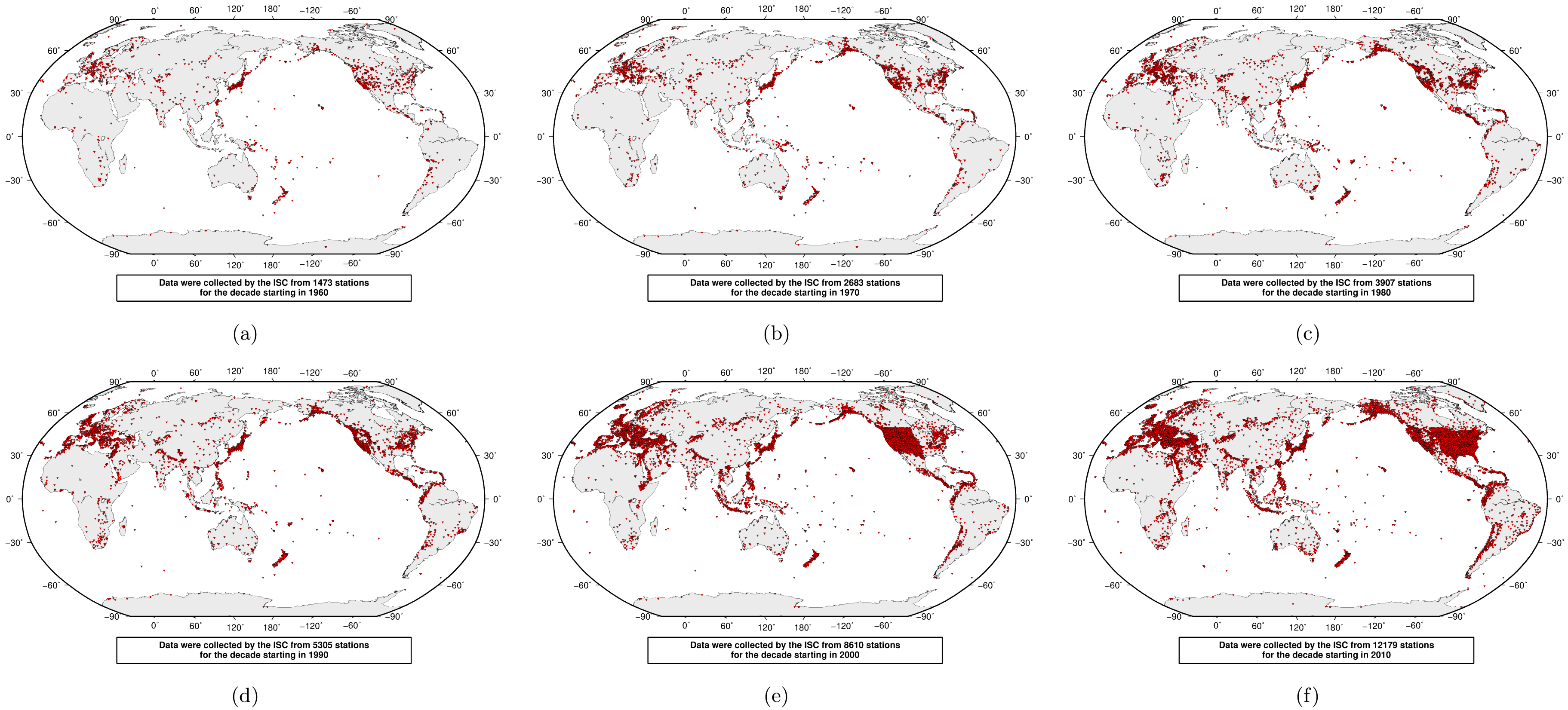


Figure 7.8: *Maps showing the stations reported to the ISC for each decade since 1960. Note that the last map covers a shorter time period.*

7.4 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 7.4. The number of hypocentres collected by the ISC has also increased significantly since 1964, as shown in Figure 7.9. A map of all hypocentres reported to the ISC for this summary period is shown in Figure 7.10. 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 7.4: *Summary of the reports containing hypocentres.*

Reports with hypocentres	3141
Reports of hypocentres only (no phase readings)	116
Total hypocentres received	324364
Number of duplicate hypocentres	11924 (3.7%)
Agencies determining hypocentres	168

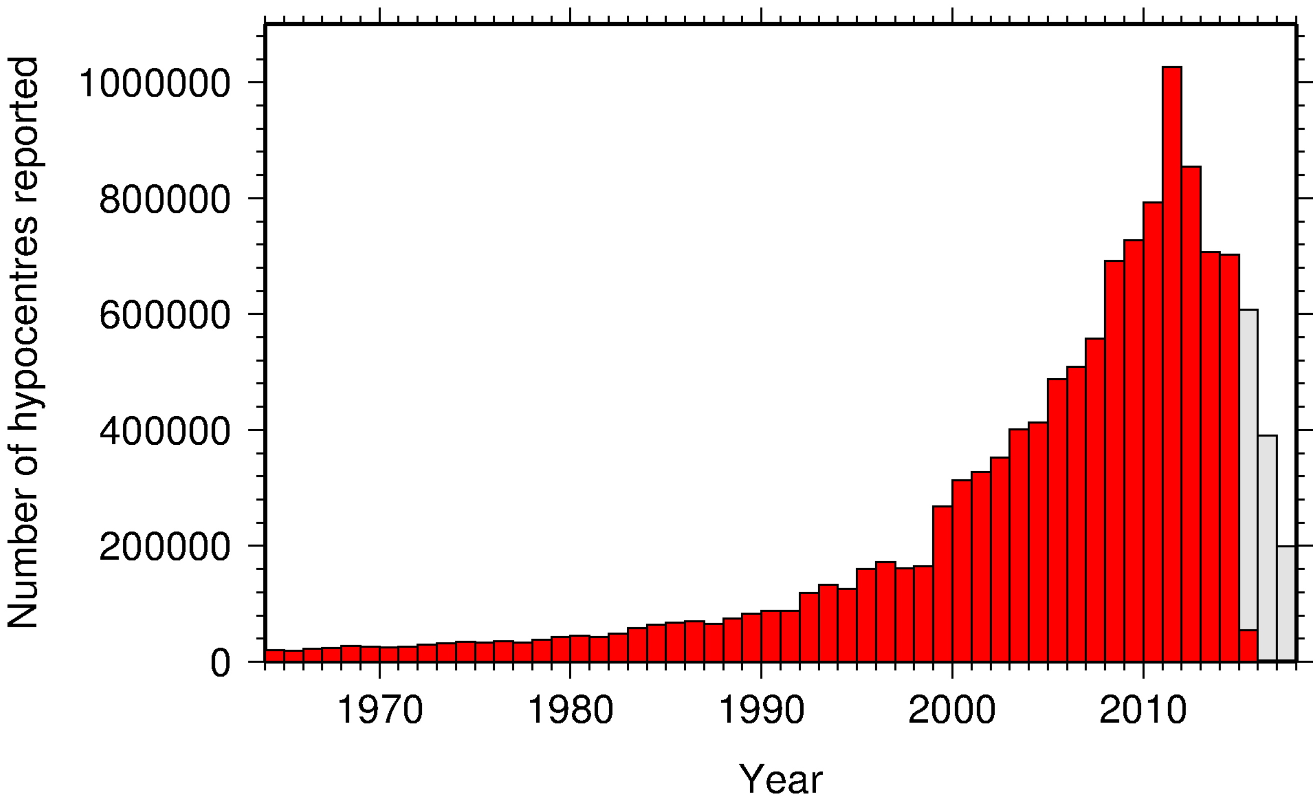


Figure 7.9: *Histogram showing the number of hypocentres collected by the ISC for events each year since 1964. For each event, multiple hypocentres may be reported.*

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 342772 hypocentres (including ISC) were grouped into 220480 events, the largest of these having 53 hypocentres in one event. The total number of events

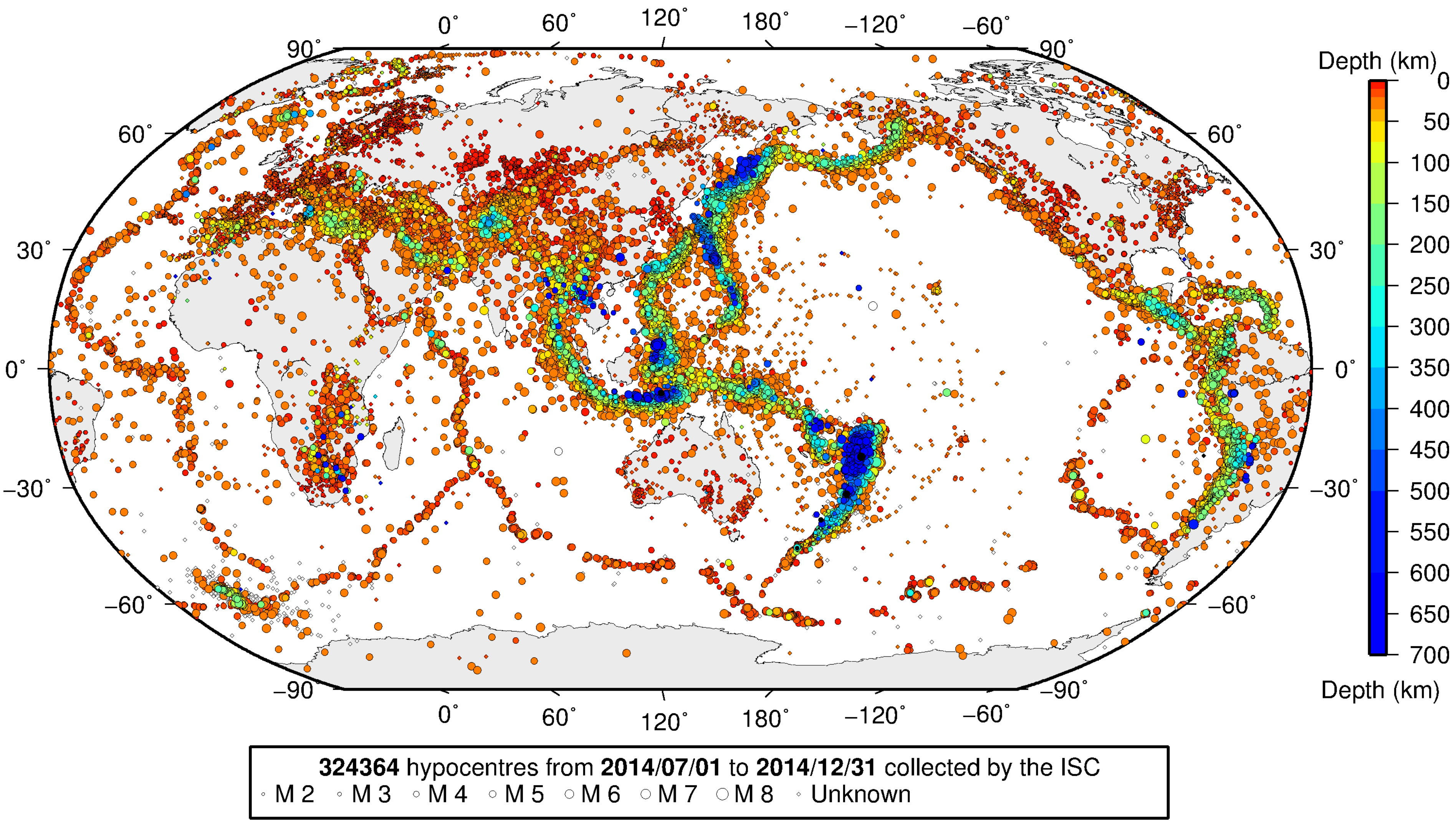


Figure 7.10: *Map of all hypocentres collected by the ISC. The scatter shows the large variation of the multiple hypocentres that are reported for each event. The magnitude corresponds with the reported network magnitude. If more than one network magnitude type was reported, preference was given to values of M_W, M_S, m_b and M_L respectively. Compare with Figure 8.2*

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 10.1.3 of Issue I of the 2014 Summary. Figure 8.2 on page 65 shows a map of all prime hypocentres.

7.5 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 7.5 provides an overview of the complexity of reported network magnitudes reported for seismic events during the summary period.

Table 7.5: *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	167801	33670	412
Average number of magnitude estimates per event	1.3	5.0	32.2
Average number of magnitudes (by the same agency) per event	1.1	2.6	3.9
Average number of magnitude types per event	1.2	4.0	14.1
Number of magnitude types	27	47	38

Table 7.6 gives the basic description, main features and scientific paper references for the most commonly reported magnitude types.

Table 7.6: *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 7.6: *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 7.6: *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 7.7 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 7.7: *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	6294	WEL (6062), RSPR (116), IGQ (51), PRU (23), SCEDC (22), JSO (6), FDF (5), NCEDC (4), REN (4), CERI (1), ROM (1)
mB	2006	BJI (1450), DJA (766), WEL (153), KEA (32)
MB	5	IPEC (4), NCEDC (1)
mb	25648	IDC (16308), NEIC (7992), NNC (4294), KRNET (3894), MOS (1559), VIE (1461), BJI (1440), MAN (1257), DJA (1256), VAO (402), BGR (369), MDD (246), KLM (120), OMAN (77), GII (57), NDI (52), SIGU (40), DNK (30), DSN (26), STR (24), INMG (17), PGC (14), PDG (6), BGS (5), DMN (3), INET (2), IGIL (2), THR (1), CRAAG (1), GUC (1), BER (1), KRSZO (1)
mb1	16953	IDC (16953)
mb1mx	16953	IDC (16953)
mB_BB	26	BGR (26)
mb_Lg	210	NEIC (175), TEH (33), OTT (2)
mbLg	2815	MDD (2815)

Table 7.7: Continued.

Magnitude type	Events	Agencies reporting magnitude type (number of values)
mbR	95	VAO (95)
mbtmp	16953	IDC (16953)
Mc	1	OSPL (1)
MD	14258	MEX (4460), LDG (2001), ROM (1346), SSNC (1182), TRN (1082), RSPR (1081), GCG (729), ECX (683), GRAL (365), TIR (280), GII (234), HLW (192), UCR (167), SEA (140), PNSN (100), SOF (98), EAF (87), LSZ (86), SNET (85), INET (85), PDG (83), SVSA (70), JSN (53), NCEDC (53), INMG (45), SJA (37), BUL (32), TUN (30), DDA (30), BUT (29), UPA (21), SLM (20), BUG (14), NDI (11), HVO (9), ISK (9), IGQ (2), LDO (1), NAM (1), OSPL (1), CERI (1), DJA (1), ATA (1)
Me	1	PAS (1)
Mjma	6	JSO (6)
MJMA	64670	JMA (64670)
ML	111443	TAP (18155), ATH (13518), DDA (10991), ROM (10457), IDC (8962), ISK (8961), RSNC (7815), HEL (5766), WEL (4952), THE (4617), ANF (2621), VIE (2547), GUC (2446), UPP (2426), LDG (2252), TEH (2207), AEIC (1864), BER (1448), BEO (1339), LJU (1297), MAN (1281), BUC (1223), TUL (1207), SSNC (1205), PRE (1086), SNET (1044), INMG (909), INET (877), GEN (833), DNK (799), ISN (798), PGC (739), ECX (662), RHSSO (623), NIC (598), THR (597), KRSC (555), NAO (459), YARS (450), MRB (446), REN (441), SFS (419), IPEC (418), WBNET (385), BJI (373), IGIL (368), UCR (324), CRAAG (295), OMAN (258), OSPL (244), SJA (241), PDG (238), LVSN (228), NEIC (205), SEA (194), SCEDC (183), HLW (148), NDI (146), DSN (144), ATA (140), KEA (136), KNET (133), BGR (118), PPT (117), BGS (103), ECGS (96), HVO (82), BUD (82), KRSZO (80), SVSA (77), ARE (71), TIR (70), PAS (68), OTT (65), AZER (59), NCEDC (51), SCB (34), PNSN (27), SGS (27), BNS (25), UUSS (23), UPA (23), DMN (22), CUPWA (18), BUT (18), LSZ (16), BUG (14), FIA0 (11), RISSC (10), MIRAS (10), SSS (9), REY (8), ALG (8), PLV (7), DRS (5), JSO (4), CLL (4), LDO (3), CSEM (2), CASC (1), HDC (1), IGQ (1)
MLh	601	ZUR (485), ASRS (116)
MLSn	331	PGC (331)
MLv	9814	WEL (6075), DJA (2536), STR (1242), ASRS (7), JSO (6)
Mm	162	GII (162)
MN	172	OTT (172)
mpv	4560	NNC (4560)
MPVA	267	NORS (199), MOS (189)

Table 7.7: *Continued.*

Magnitude type	Events	Agencies reporting magnitude type (number of values)
MS	9608	IDC (7989), MAN (1771), BJI (1164), MOS (481), BGR (194), NSSP (66), BGS (54), OMAN (52), DNK (49), SOME (40), KEA (19), BER (18), VIE (11), NDI (4), IPEC (4), YARS (3), LDG (2), DSN (2), IGIL (2), MEX (1), SSNC (1)
Ms1	7988	IDC (7988)
ms1mx	7988	IDC (7988)
Ms7	1144	BJI (1144)
Ms_20	204	NEIC (204)
MW	5029	GCMT (1280), SSNC (946), NIED (731), UPA (586), PGC (357), RSNC (314), INET (272), DDA (246), SJA (239), UCR (141), ATA (103), MED_RCMT (87), ASIES (25), GUC (25), ROM (24), SNET (11), BER (9), IEC (8), WEL (7), DJA (5), UAF (5), UPSL (5), INMG (3), IAG (3), NDI (3), CSEM (2), GFZ (2), CRAAG (1), SCB (1), SIGU (1), SVSA (1), SCEDC (1), OTT (1)
Mw(mB)	153	WEL (153)
Mwb	235	NEIC (235)
Mwc	259	GCMT (259), NEIC (34)
Mwp	151	DJA (135), OMAN (16)
Mwr	292	NEIC (188), SLM (40), NCEDC (37), OTT (14), CAR (8), UCR (7), PAS (3), GUC (3), RSNC (2), CSEM (1)
MWR	1	SCEDC (1)
Mww	237	NEIC (238)

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 7.1). 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 7.1: *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 7.2.

Listing 7.2: *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 7.11 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.

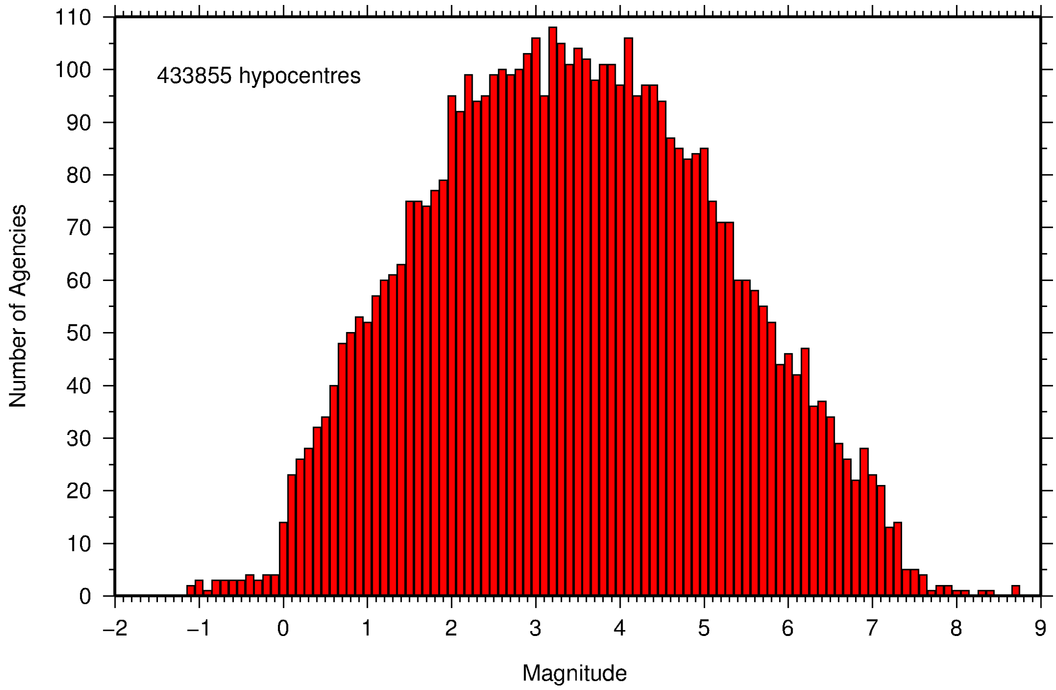


Figure 7.11: *Histogram showing the number of agencies that reported network magnitude values. All magnitude types are included.*

7.6 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 7.8. A histogram showing all moment tensor solutions collected throughout the ISC history is shown in Figure 7.12. 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 7.8: *Summary of reports containing moment tensor solutions.*

Reports with Moment Tensors	56
Total moment tensors received	7031
Agencies reporting moment tensors	14

The number of moment tensors for this summary period, reported by each agency, is shown in Table 7.9. The moment tensor solutions are plotted in Figure 7.13.

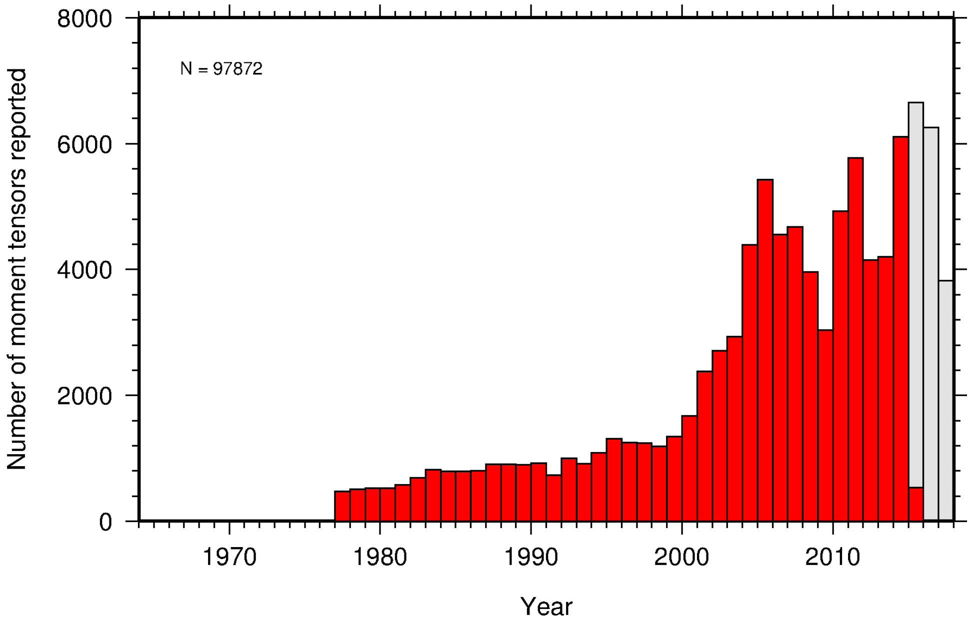


Figure 7.12: *Histogram showing the number of moment tensors reported to the ISC since 1964. The regions in grey represent data that are still being actively collected.*

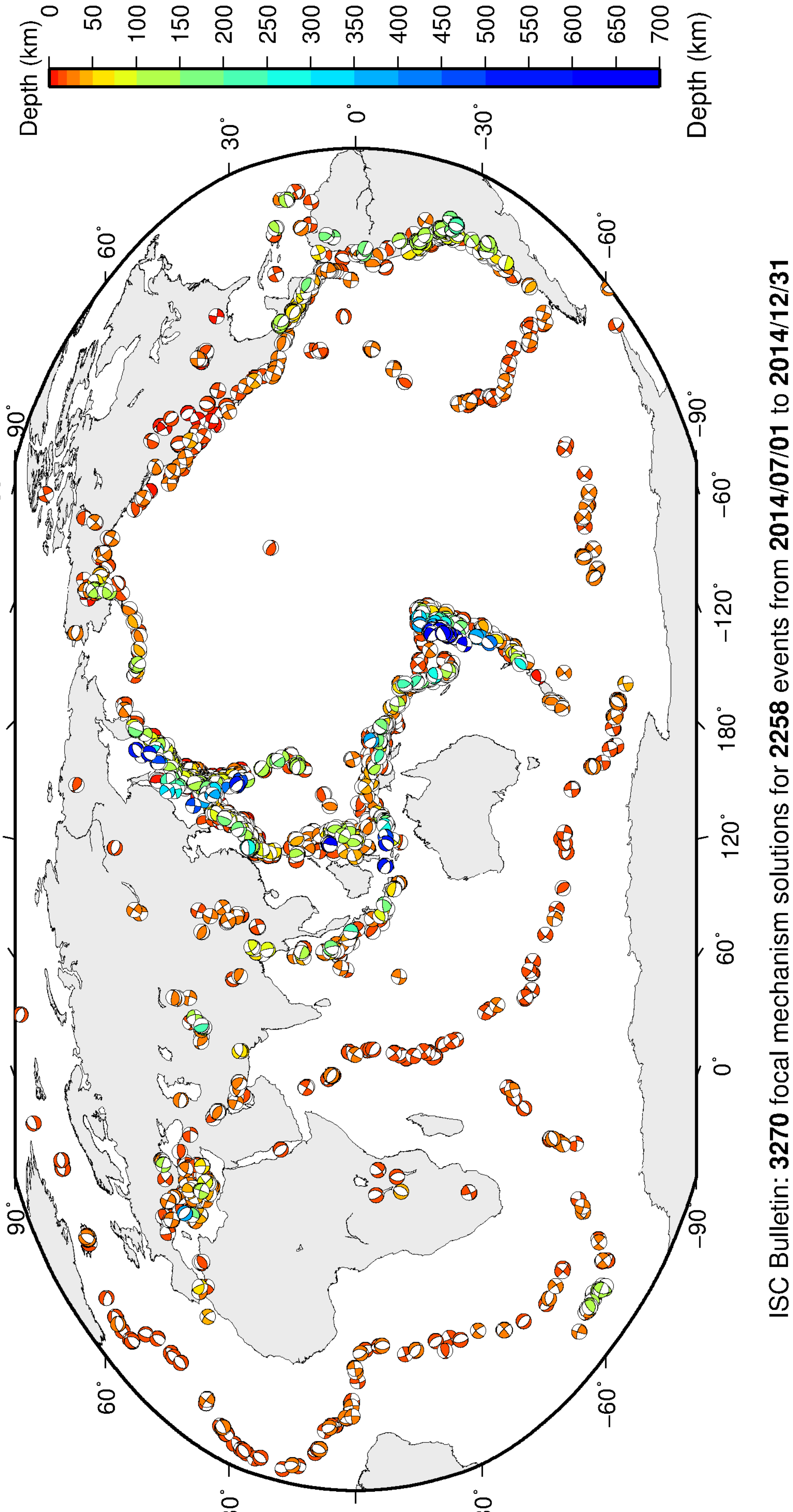


Figure 7.13: *Map of all moment tensor solutions in the ISC Bulletin for this summary period.*

Table 7.9: *Summary of moment tensor solutions in the ISC Bulletin reported by each agency.*

Agency	Number of moment tensor solutions	Agency	Number of moment tensor solutions
GCMT	1280	UPSL	5
NEIC	1118	UAF	5
NIED	731	MOS	4
JMA	450	UCR	4
RSNC	136	OSPL	3
MED_RCMT	87	IAG	3
PNSN	83	MEX	2
ROM	23	NCEDC	1
IEC	16	BER	1
UPA	12	SEA	1
ECX	11	OTT	1
TUL	8	DNK	1
WEL	7	SNET	1

7.7 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 7.14. In Figure 7.15 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.

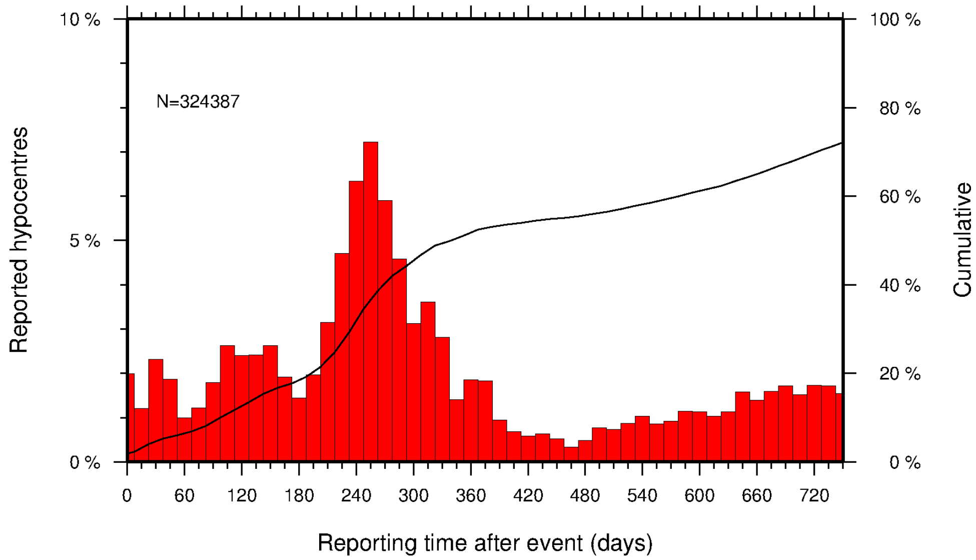
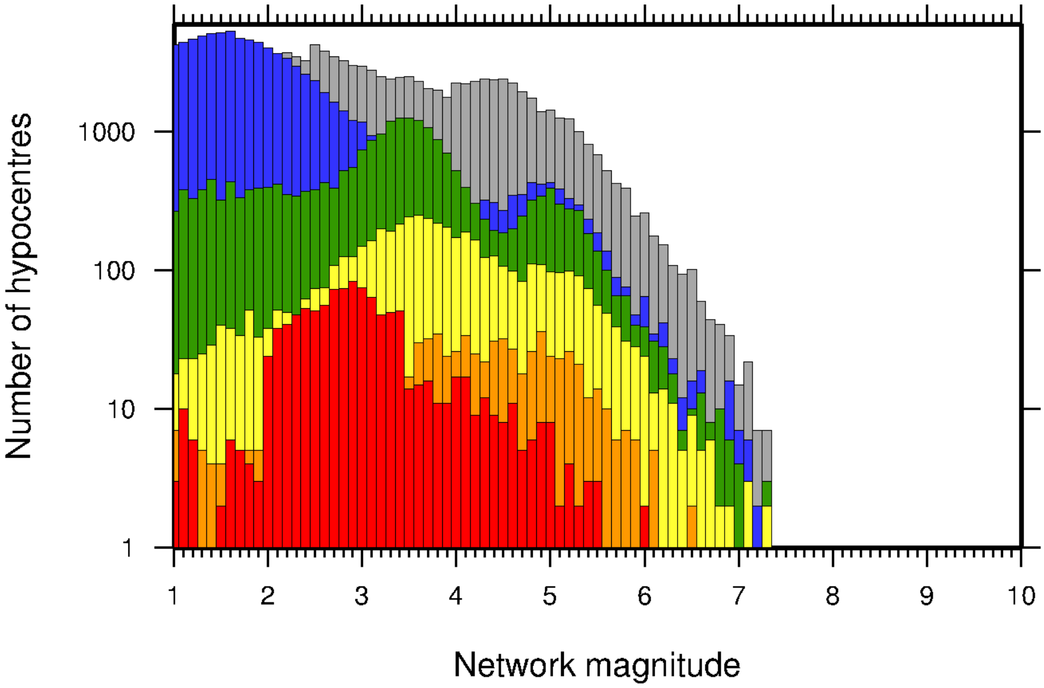


Figure 7.14: *Histogram showing the timing of final reports of the hypocentres (total of N) to the ISC. The cumulative frequency is shown by the solid line.*



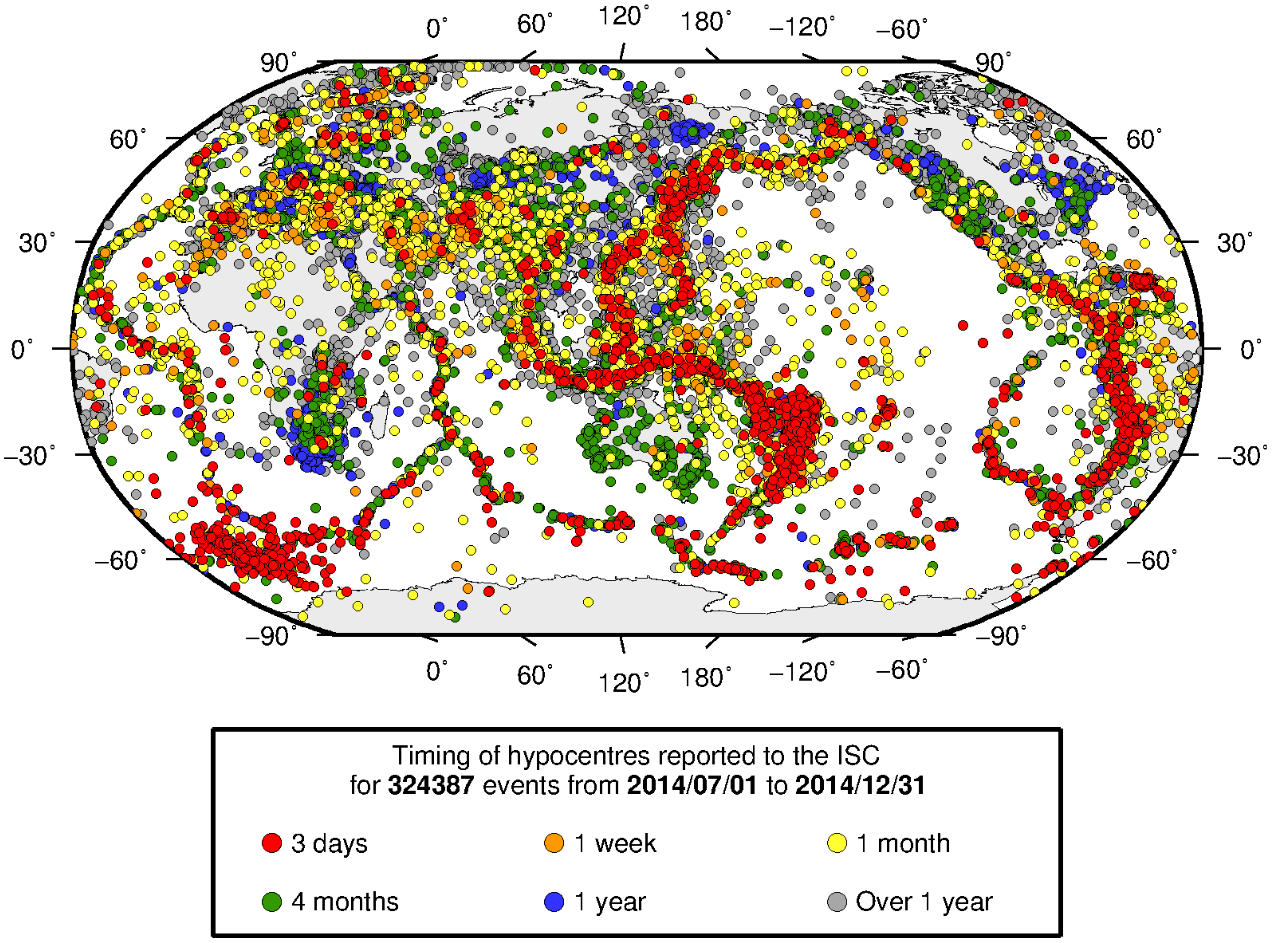


Figure 7.15: *Timing of hypocentres reported to the ISC. The colours show the time after the origin time that the corresponding hypocentre was reported. The histogram shows the distribution with magnitude. If more than one network magnitude was reported, preference was given to a value of M_W followed 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.*

8

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.

8.1 Events

The ISC Bulletin had 213558 reported events in the summary period between July and December 2014. Some 92% (197598) of the events were identified as earthquakes, the rest (15960) were of anthropogenic origin (including mining and other chemical explosions, rockbursts and induced events) or of unknown origin. As discussed in Section 10.1.3 of Issue I of the 2014 Summary, typically about 20% 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 11% of the events were reviewed and 8% 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 10.1.3 of Issue I of the 2014 Summary.

Of the 7952486 reported phase observations, 37% are associated to ISC-reviewed events, and 35% 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 8.1 shows the daily number of events throughout the summary period. Figure 8.2 shows the locations of the events in the ISC Bulletin; the locations of ISC-reviewed and ISC-located events are shown in Figures 8.3 and 8.4, respectively.

Figure 8.5 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 8.6 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 10.1.4 of Issue I of the

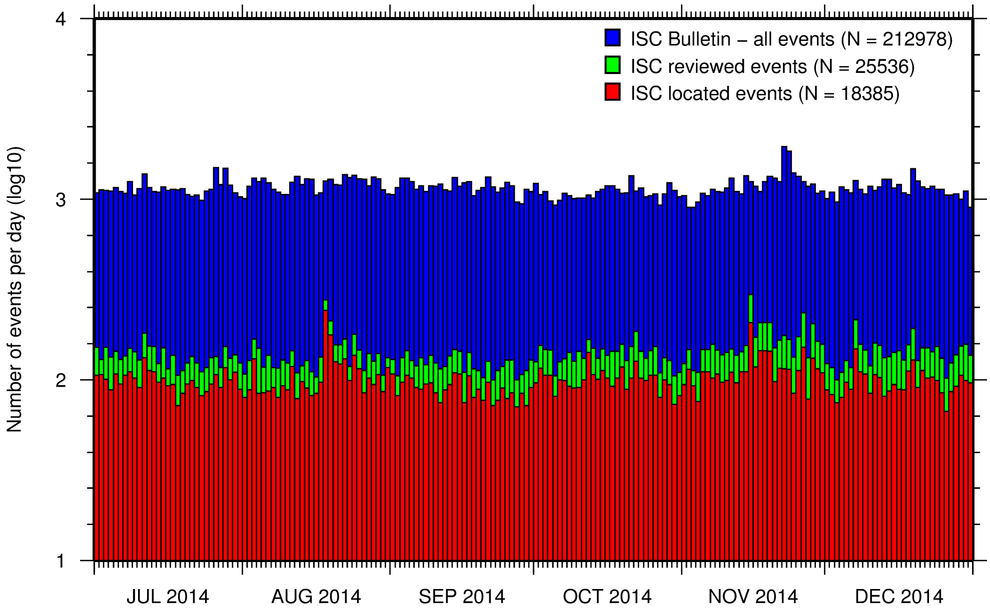


Figure 8.1: *Histogram showing the number of events in the ISC Bulletin for the current summary period. The vertical scale is logarithmic.*

2014 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 8.7 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 10.1.4 of Issue I of the 2014 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 8.8 illustrates that the secondary azimuthal gap is indeed generally smaller for ISC-located events than that for all events in the ISC Bulletin. Figure 8.9 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 8.10 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 8.11 shows the

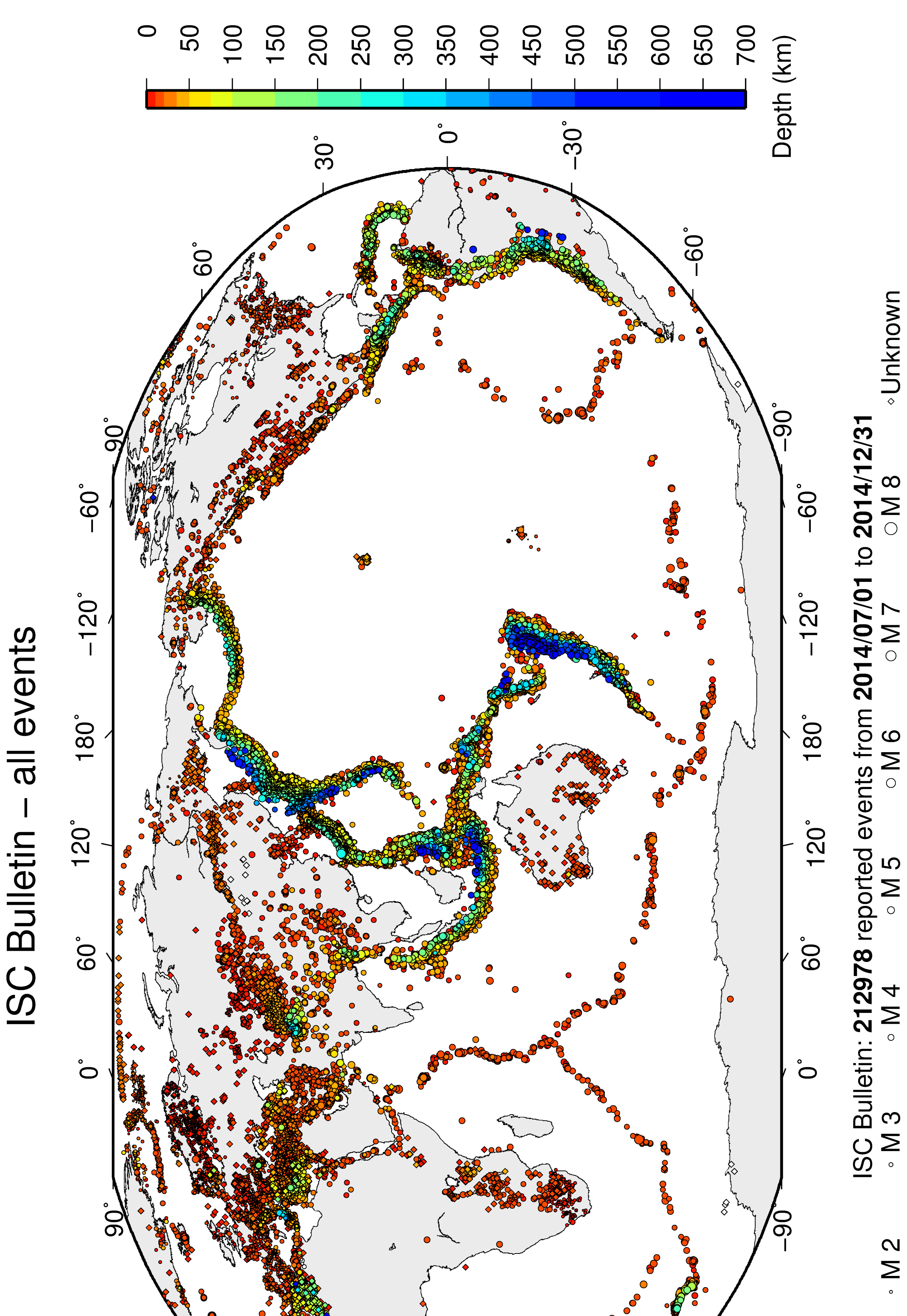


Figure 8.2: *Map of all events in the ISC Bulletin. Prime hypocentre locations are shown. Compare with Figure 7.10.*

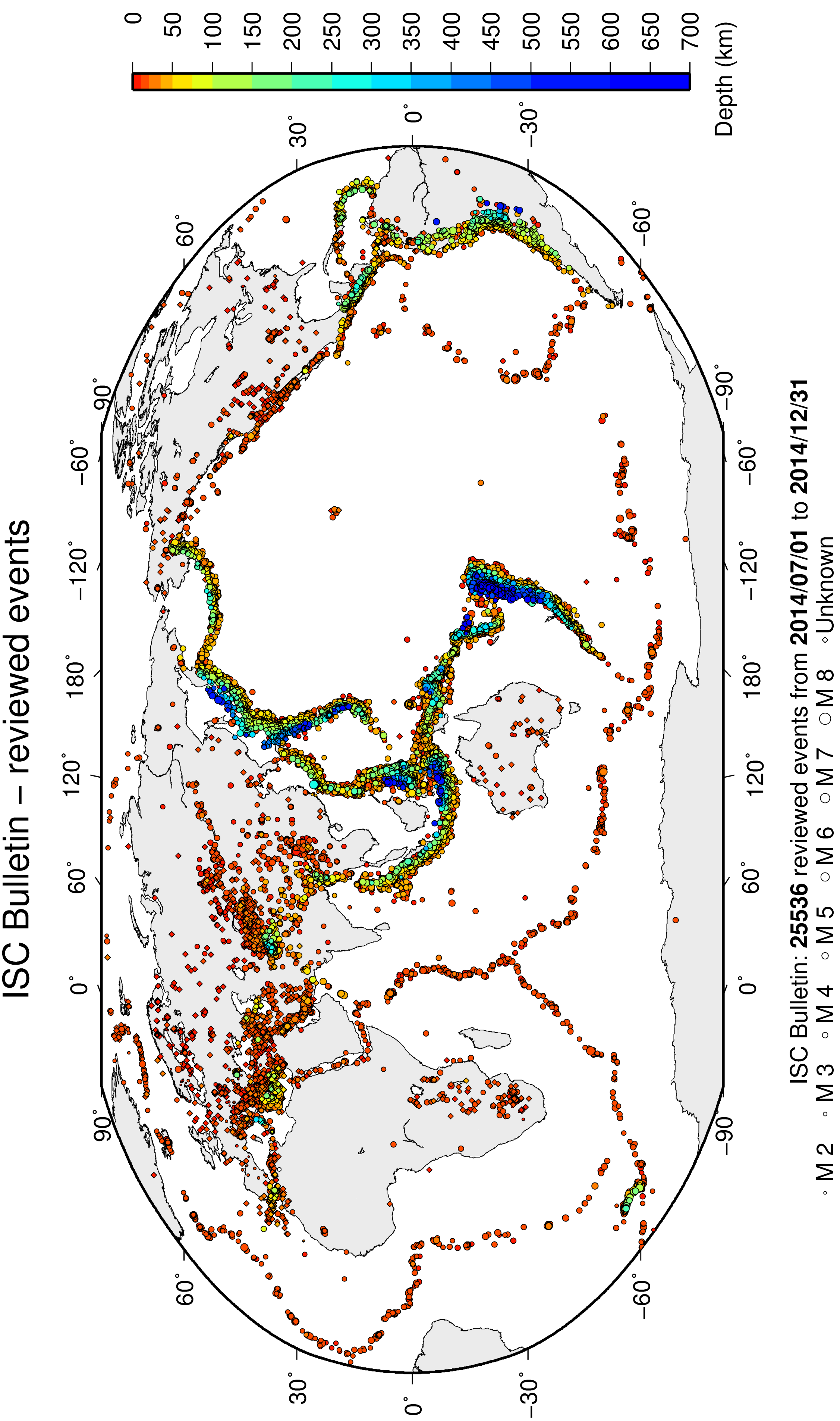


Figure 8.3: Map of all events reviewed by the ISC for this time period. Prime hypocentre locations are shown.

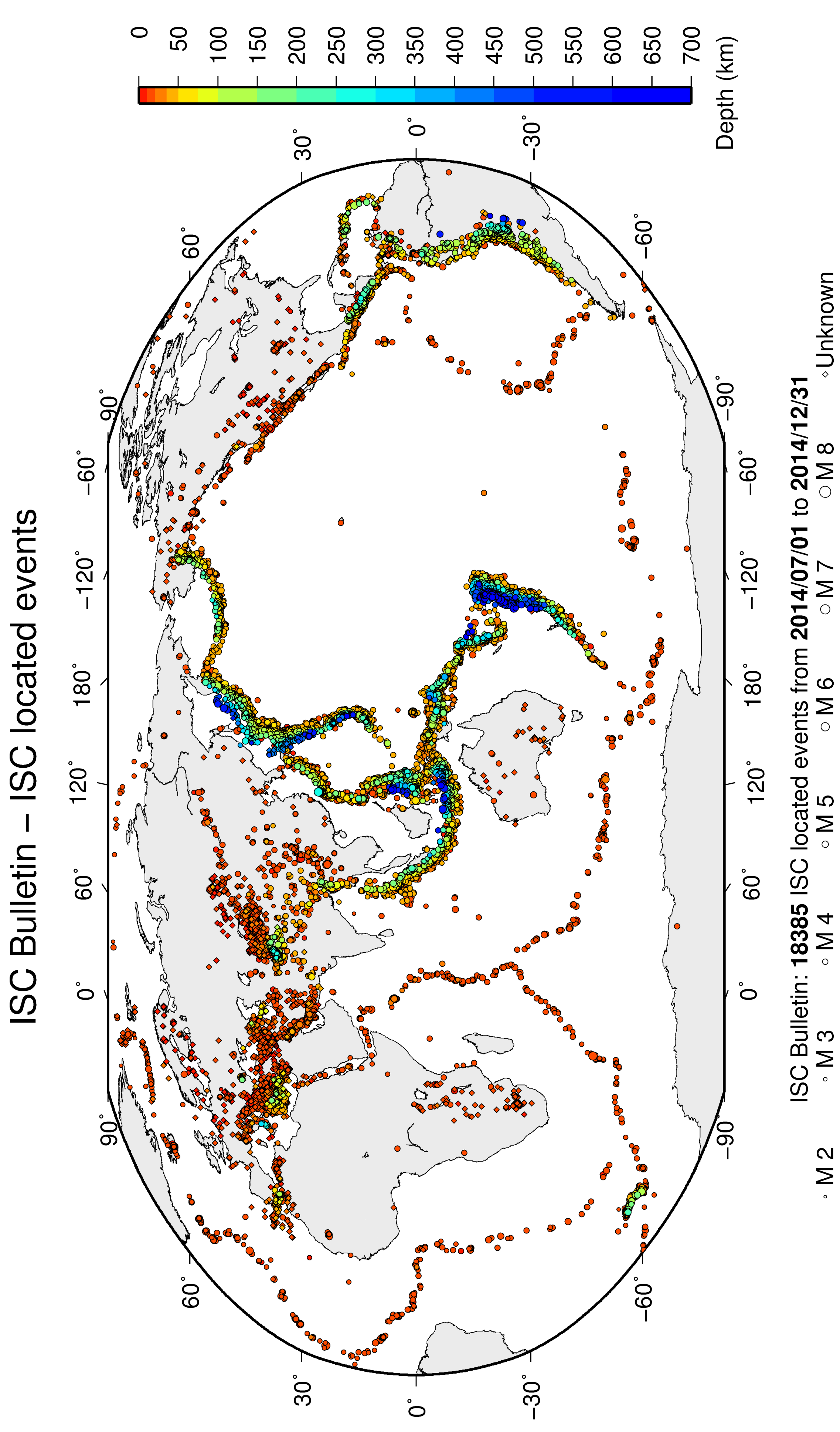


Figure 8.4: *Map of all events located by the ISC for this time period. ISC determined hypocentre locations are shown.*

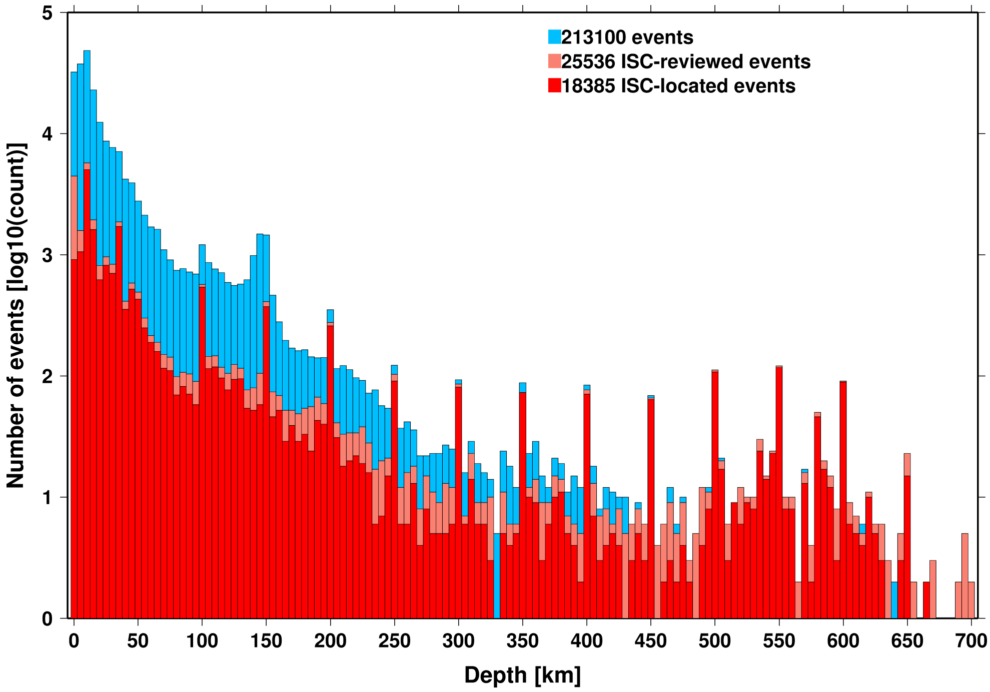


Figure 8.5: *Distribution of event depths in the ISC Bulletin (blue) and for the ISC-reviewed (pink) and the ISC-located (red) events during the summary period. All ISC-located events are reviewed, but not all reviewed events are located by the ISC. The vertical scale is logarithmic.*

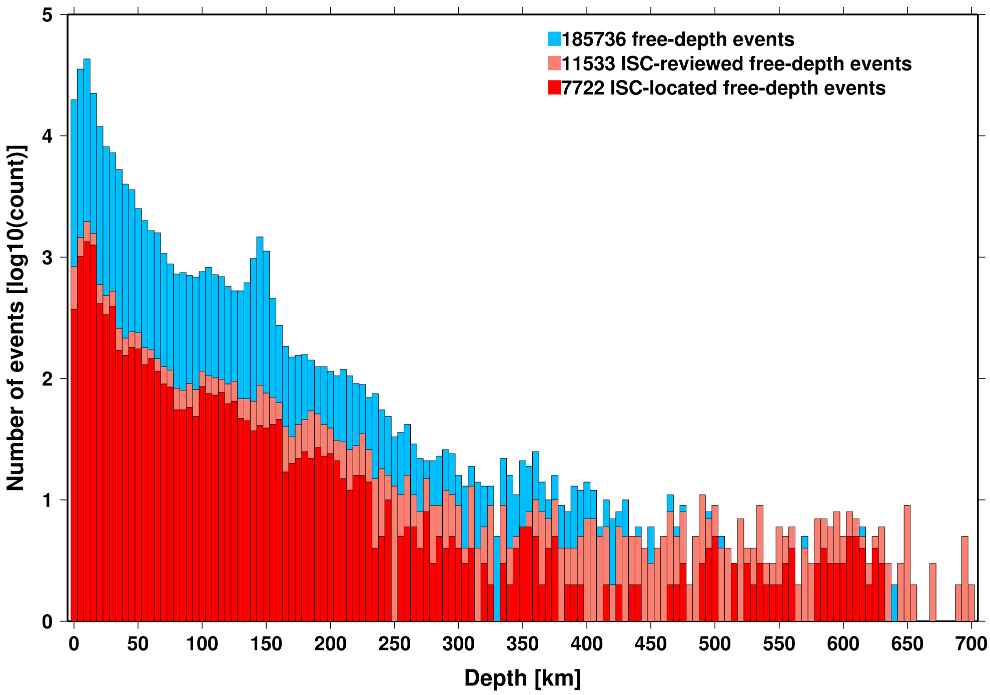


Figure 8.6: *Hypocentral depth distribution of events where the prime hypocentres are reported/located with a free-depth solution in the ISC Bulletin. The vertical scale is logarithmic.*

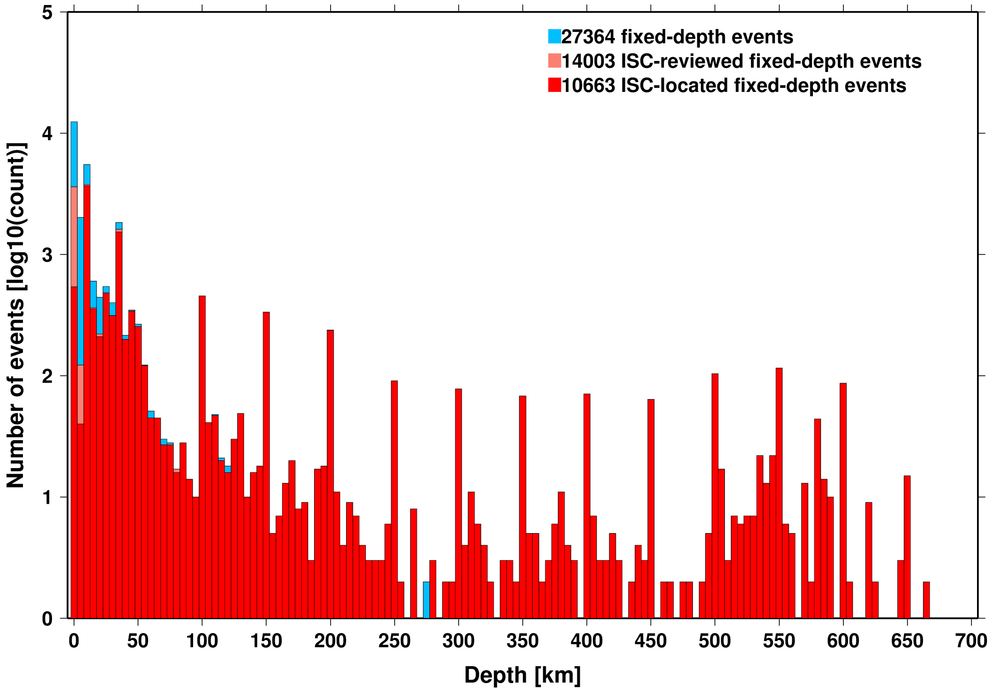


Figure 8.7: *Hypocentral depth distribution of events where the prime hypocentres are reported/located with a fixed-depth solution in the ISC Bulletin. The vertical scale is logarithmic.*

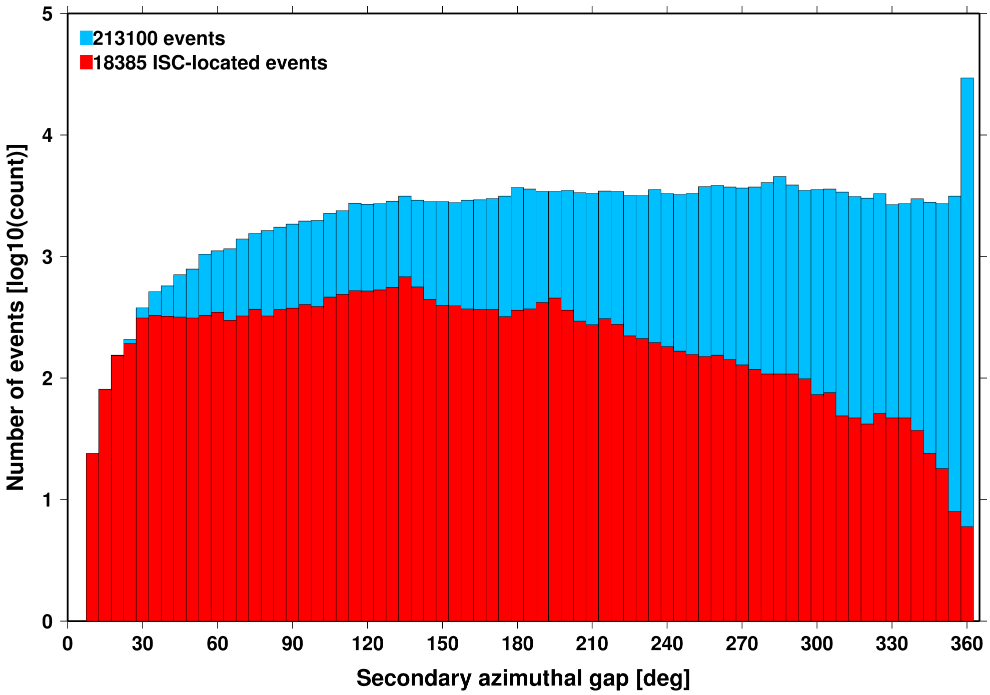


Figure 8.8: *Distribution of secondary azimuthal gap for events in the ISC Bulletin (blue) and those selected for ISC location (red). The vertical scale is logarithmic.*

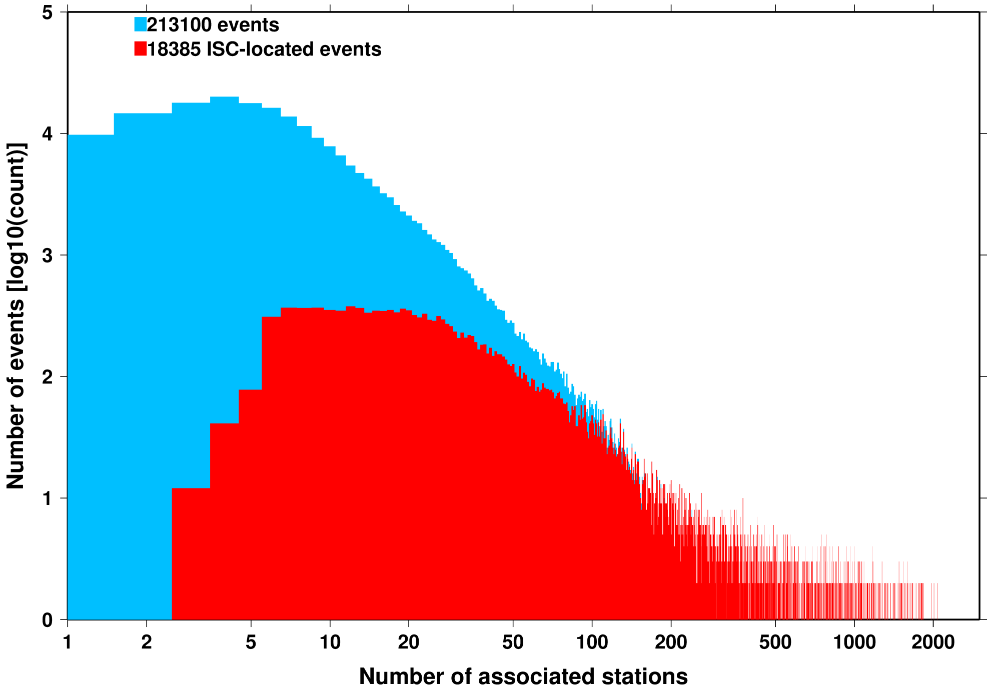


Figure 8.9: *Distribution of the number of associated stations for events in the ISC Bulletin (blue) and those selected for ISC location (red). The vertical scale is logarithmic.*

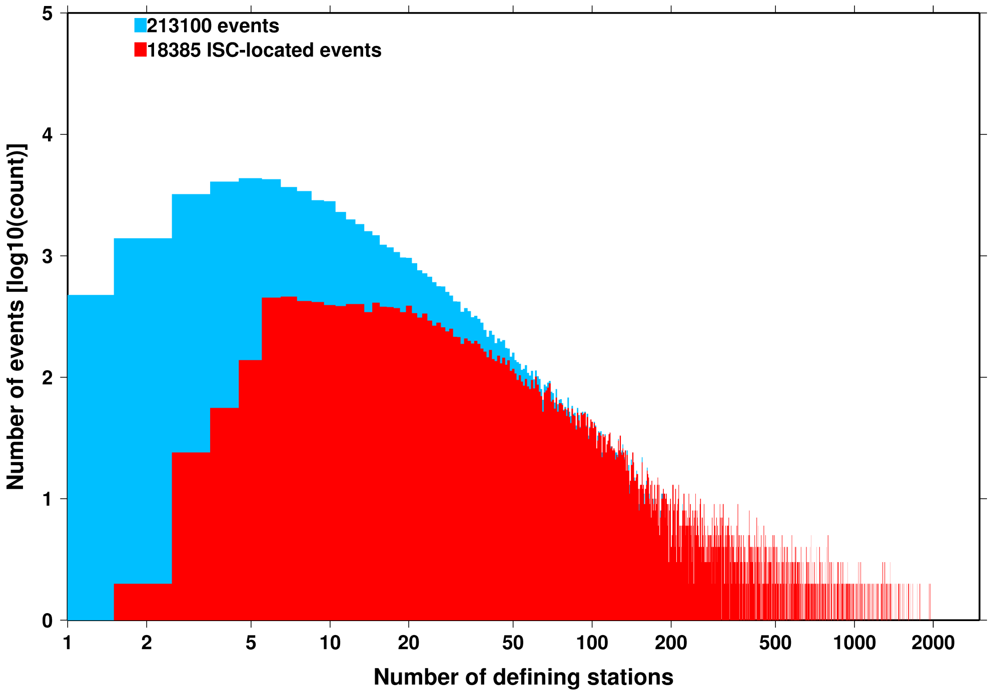


Figure 8.10: *Distribution of the number of defining stations for events in the ISC Bulletin (blue) and those selected for ISC location (red). The vertical scale is logarithmic.*

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 195 km^2, 90% of the events have an error ellipse area less than 1151 km^2, and 95% of the events have an error ellipse area less than 1883 km^2.

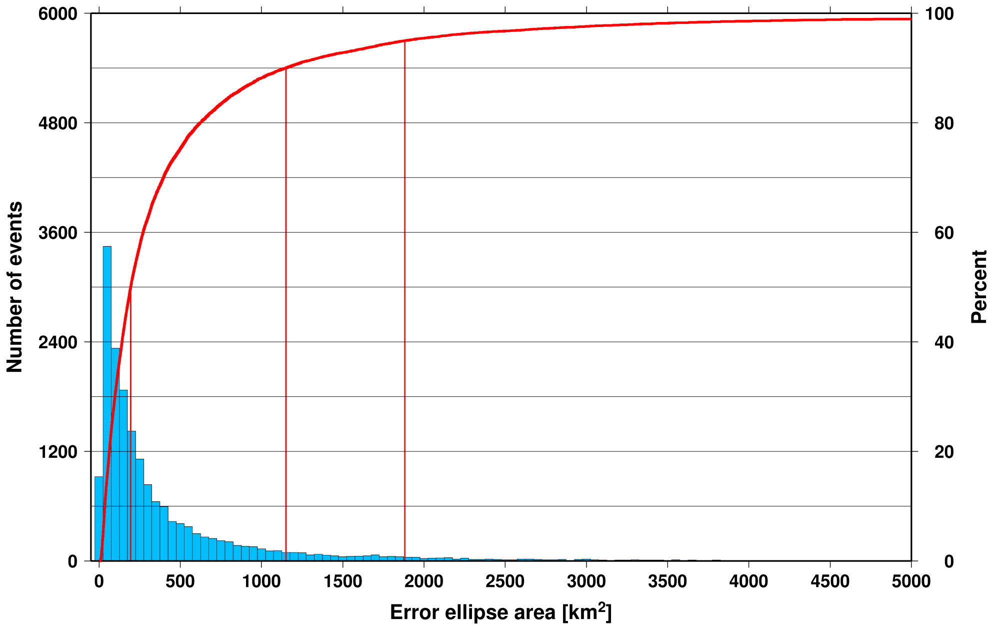


Figure 8.11: *Distribution of the area of the 90% confidence error ellipse of the ISC-located events. Vertical red lines indicate the 50th, 90th and 95th percentile values.*

Figure 8.12 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.

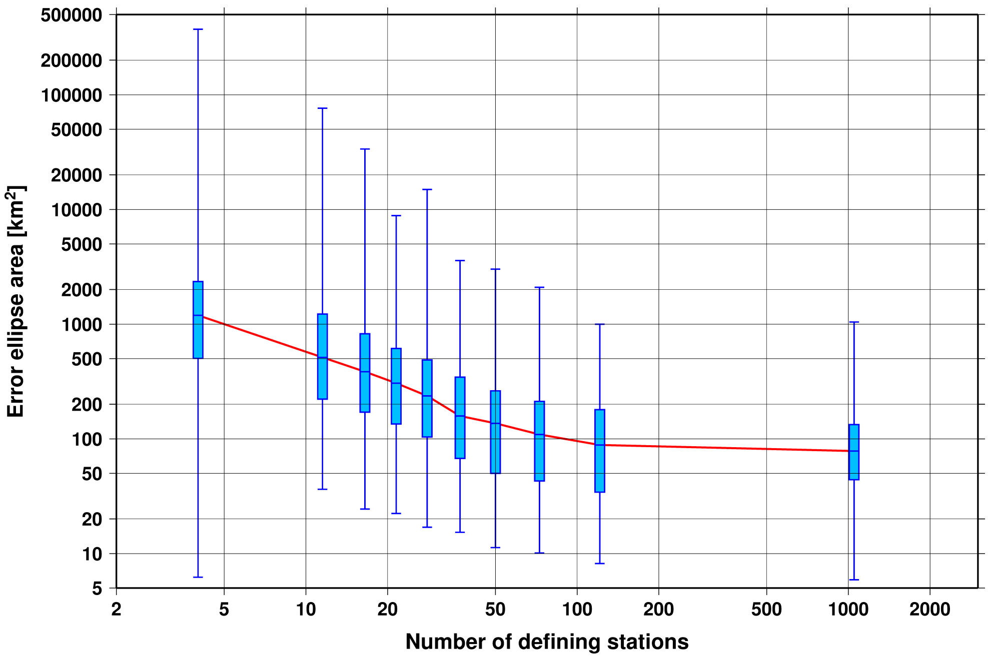


Figure 8.12: *Box-and-whisker plot of the area of the 90% confidence error ellipse of the ISC-located events as a function of the number of defining stations. Each box represents one-tenth-worth of the total number of data. The red line indicates the median 90% confidence error ellipse area.*

8.2 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 8.13. Phase types and their total number in the ISC Bulletin is shown in the Appendix, Table 10.2. A summary of phase types is indicated in Figure 8.14.

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 8.15, the number of defining phases is shown in a histogram over the summary period. Each defining phase is listed in Table 8.1, 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 8.16. Figure 8.17 shows travel times of seismic waves. The distribution of residuals for these defining phases is shown for the top five phases in Figures 8.18 through 8.22.

Table 8.1: *Numbers of 'time defining' phases (N) within the ISC Bulletin for 18385 ISC located events.*

Phase	Number of 'defining' phases	Number of events	Max per event	Median per event
P	940824	13366	2072	17
Pn	506753	16964	715	15
Sn	150205	14323	223	5
Pb	80378	7574	291	6
Pg	65874	6323	146	6
PKPdf	59471	4155	888	2
Sg	48524	5924	122	5
S	48054	3404	524	3
Sb	47890	6955	99	4
PKiKP	37379	3462	478	2
PKPbc	25369	3444	221	2
PKPab	16101	2645	192	2

Table 8.1: *(continued)*

Phase	Number of 'defining' phases	Number of events	Max per event	Median per event
PcP	12778	3723	70	2
Pdif	8086	849	430	2
pP	7780	1220	316	3
PP	7503	1314	180	2
ScP	4296	1125	101	2
SS	3324	819	53	2
sP	2623	769	63	2
SKSac	2081	319	93	2
PKKPbc	2055	416	88	2
SnSn	997	545	8	1
pwP	976	366	48	2
pPKPdf	916	333	48	1
PnPn	914	561	7	1
ScS	888	323	24	1
SKPbc	867	295	52	2
SKiKP	605	287	25	1
pPKPab	510	170	39	1
pPKPbc	463	201	33	1
PKKPab	452	209	24	1
P'P'df	439	145	28	2
sS	433	258	10	1
PKKPdf	420	200	16	1
sPKPdf	312	178	16	1
SKKSac	255	110	24	1
PS	254	115	24	1
SKPab	230	126	21	1
PcS	199	150	17	1
SP	176	53	47	1
SKPdf	171	66	20	1
SKSdf	143	72	18	1
PnS	141	113	4	1
Sdif	134	56	13	1
SKKPbc	100	35	16	1
sPKPbc	98	72	13	1
sPKPab	95	61	8	1
PKSdf	88	61	7	1
pPKiKP	72	24	10	1
pS	70	58	4	1
pPdif	53	21	13	1
sPKiKP	33	9	7	4
PbPb	23	14	7	1
SPn	19	19	1	1
SKKPab	16	10	5	1
sPdif	12	2	11	6
SKKSdf	10	7	3	1
pPn	10	5	4	2
sPn	8	6	3	1
PgPg	6	5	2	1
SbSb	5	4	2	1
sSKSac	4	3	2	1
sSn	4	2	3	2
P'P'ab	3	3	1	1
SKKPdf	3	3	1	1
sSdif	3	3	1	1
PKSbc	2	2	1	1
S'S'ac	2	2	1	1
SgSg	1	1	1	1
P'P'bc	1	1	1	1

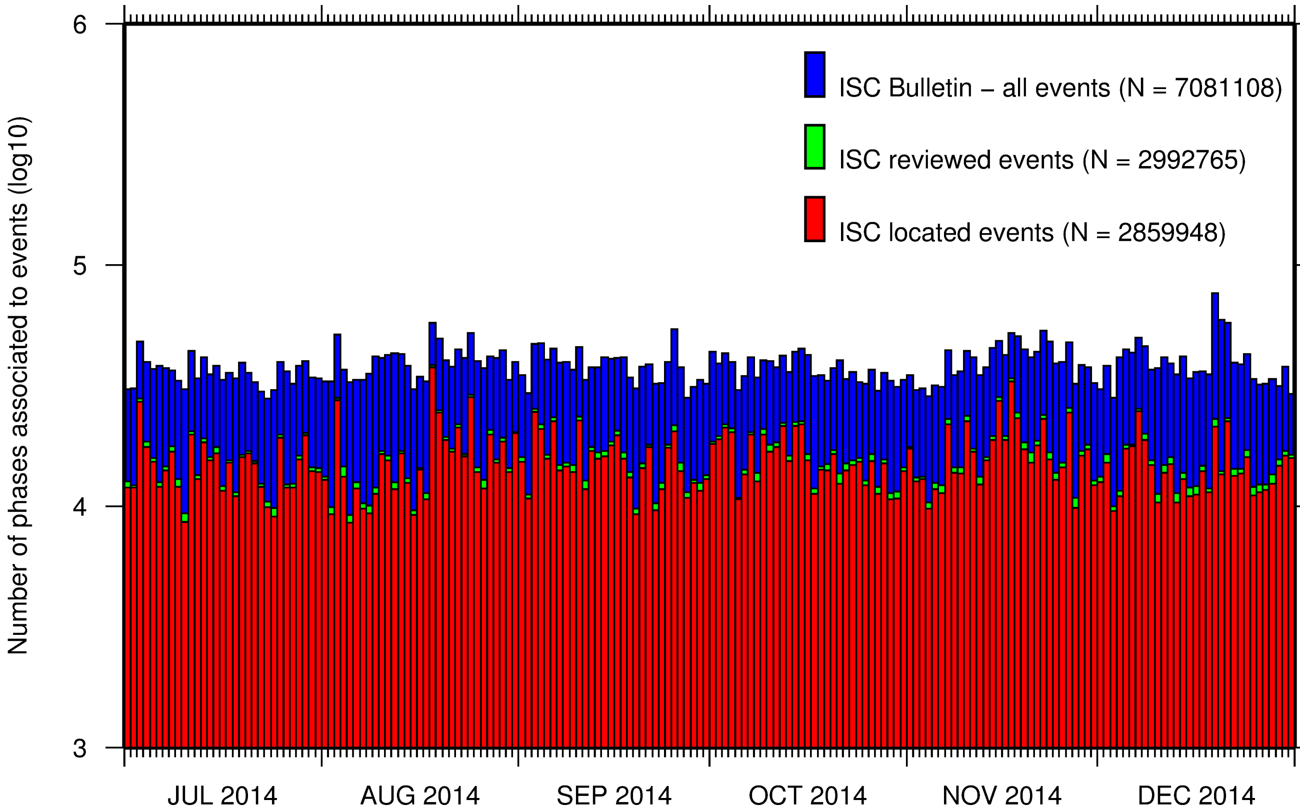


Figure 8.13: *Histogram showing the number of phases (N) that the ISC has associated to events within the ISC Bulletin for the current summary period.*

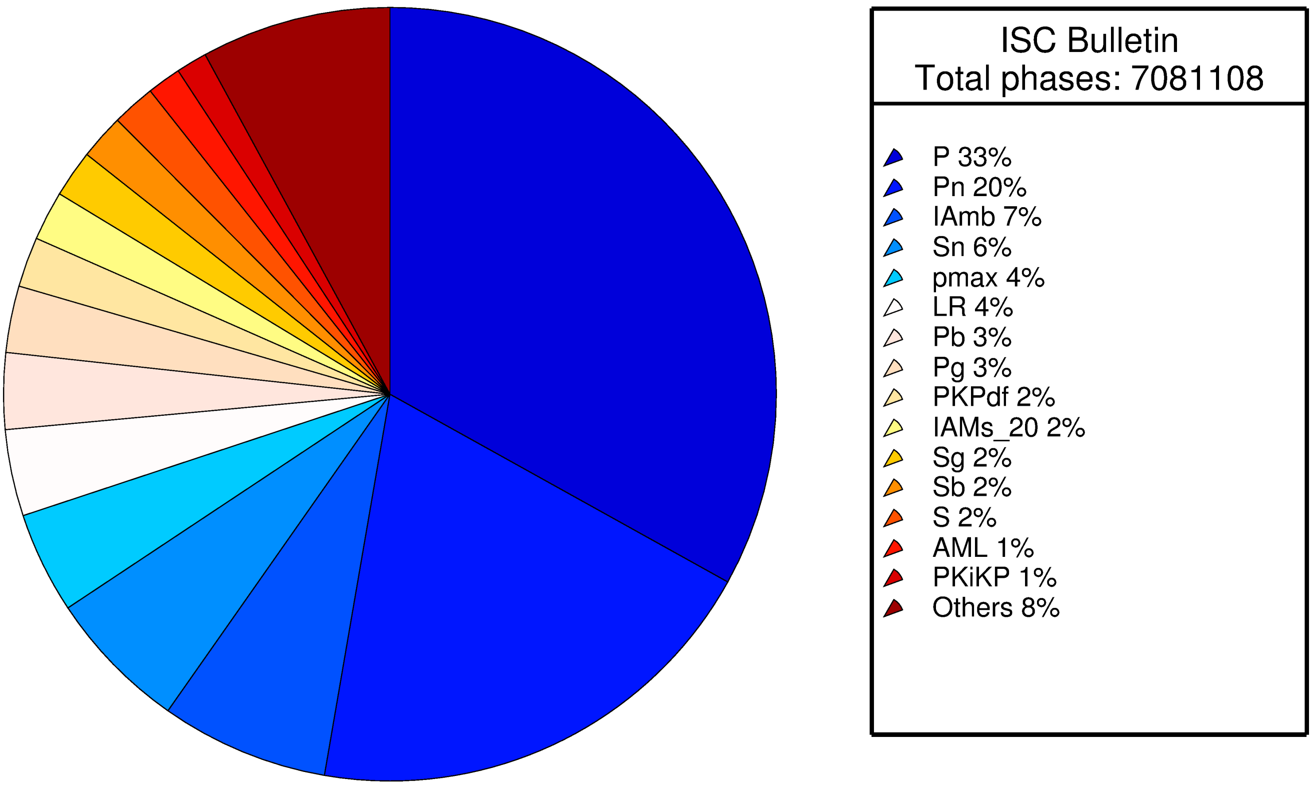


Figure 8.14: *Pie chart showing the fraction of various phase types in the ISC Bulletin for this summary period.*

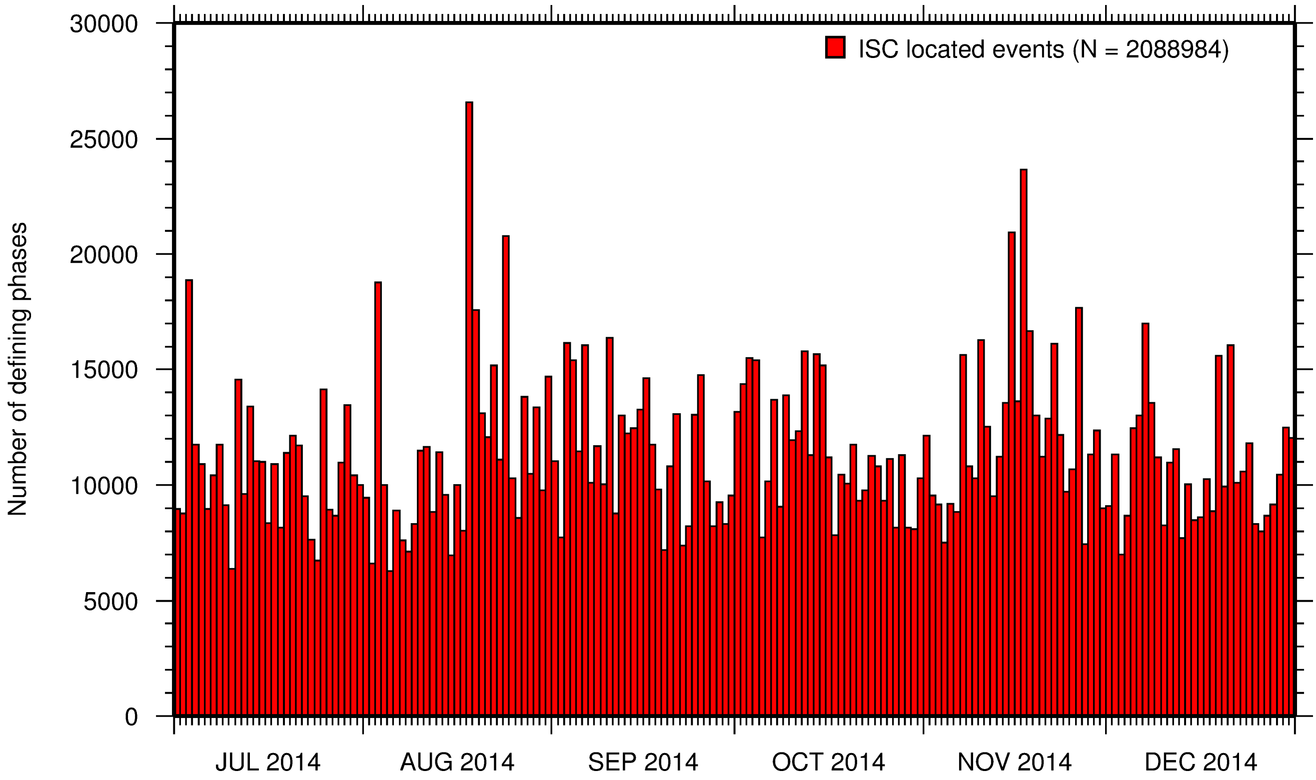


Figure 8.15: *Histogram showing the number of defining phases in the ISC Bulletin, for events located by the ISC.*

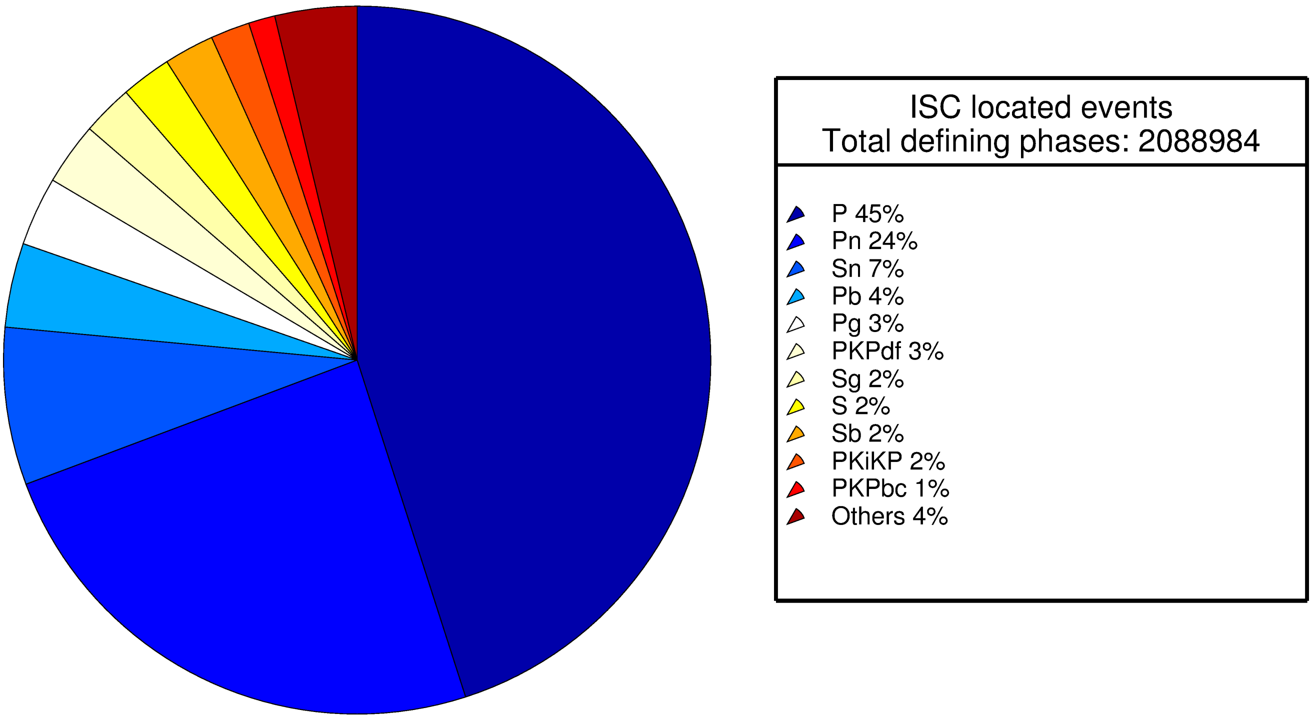


Figure 8.16: *Pie chart showing the defining phases in the ISC Bulletin, for events located by the ISC. A complete list of defining phases is shown in Table 8.1.*

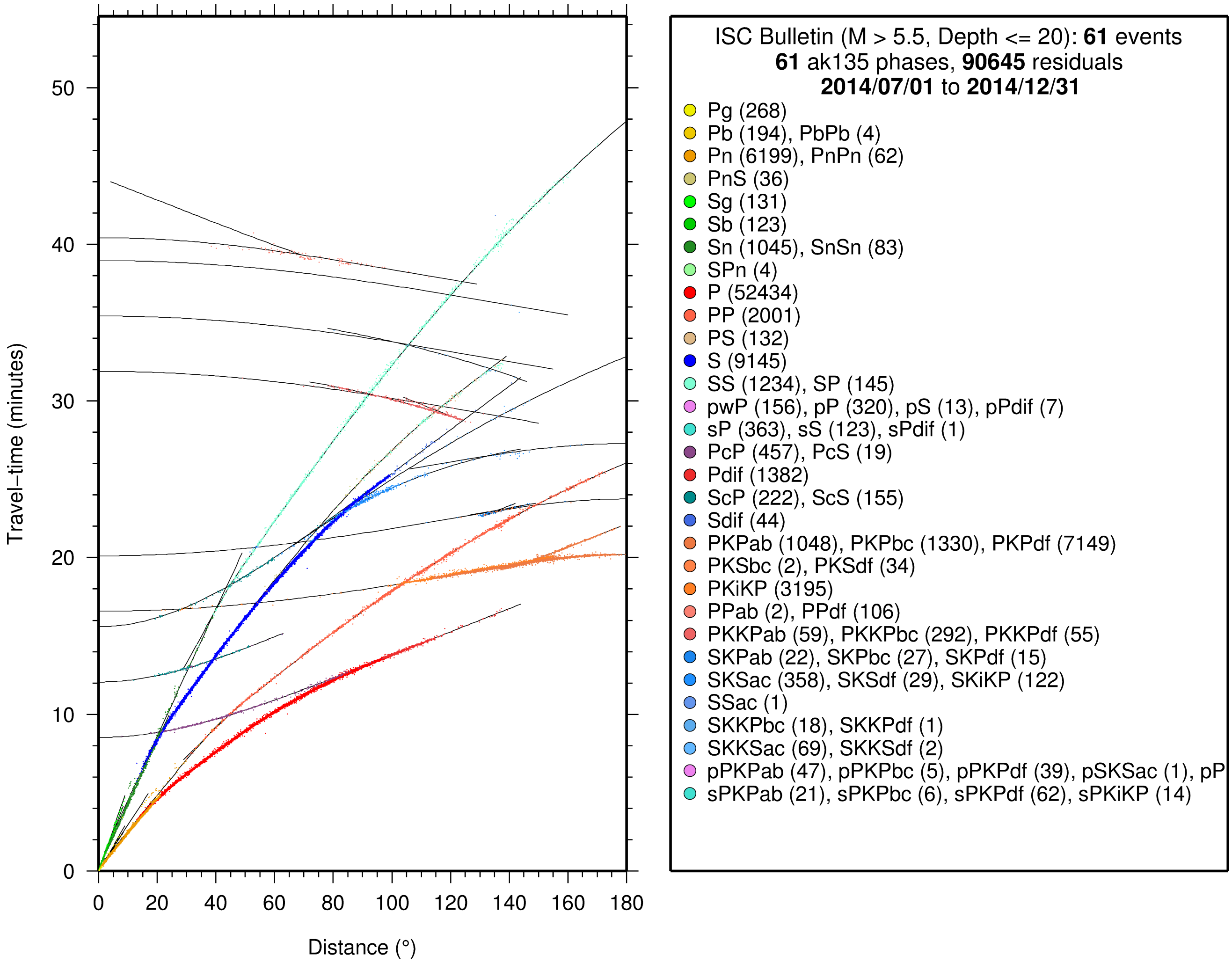


Figure 8.17: *Distribution of travel-time observations in the ISC Bulletin for events with M > 5.5 and depth less than 20 km. The travel-time observations are shown relative to a 0 km source and compared with the theoretical ak135 travel-time curves (solid lines). The legend lists the number of each phase plotted.*

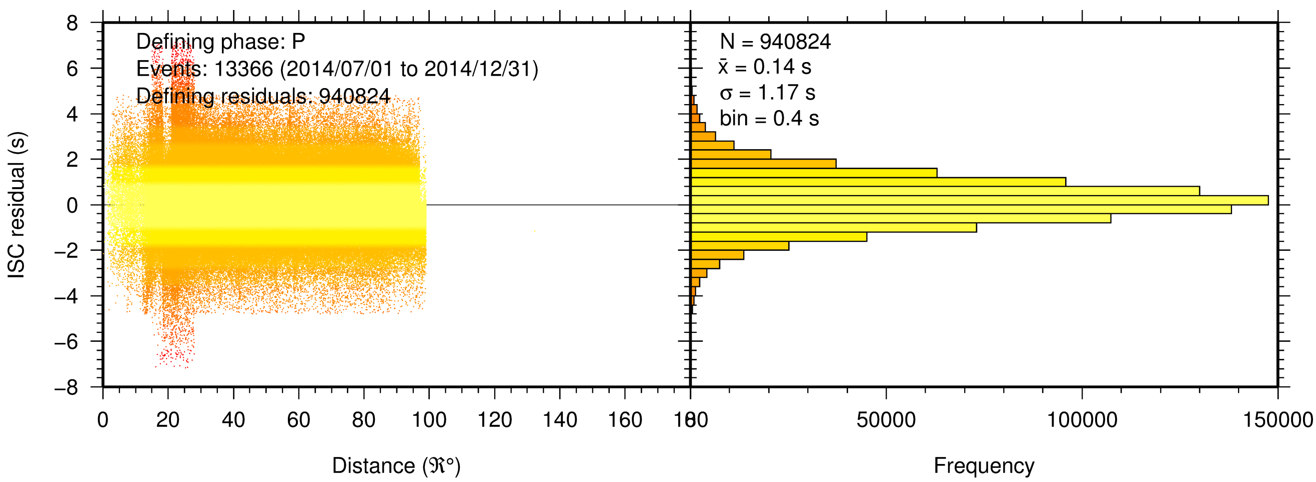


Figure 8.18: *Distribution of travel-time residuals for the defining P phases used in the computation of ISC located events in the Bulletin.*

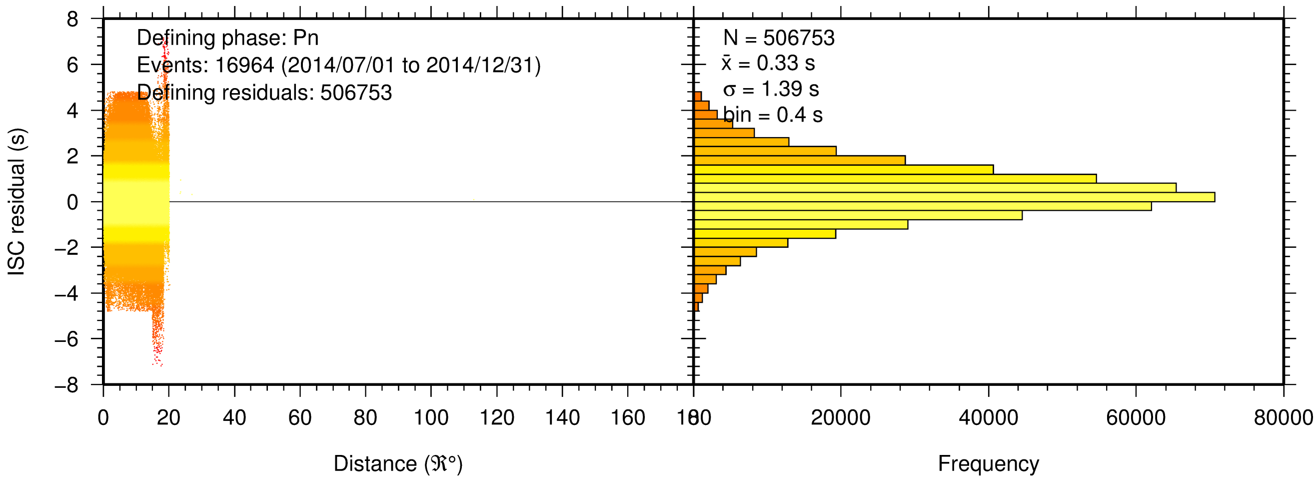


Figure 8.19: *Distribution of travel-time residuals for the defining Pn phases used in the computation of ISC located events in the Bulletin.*

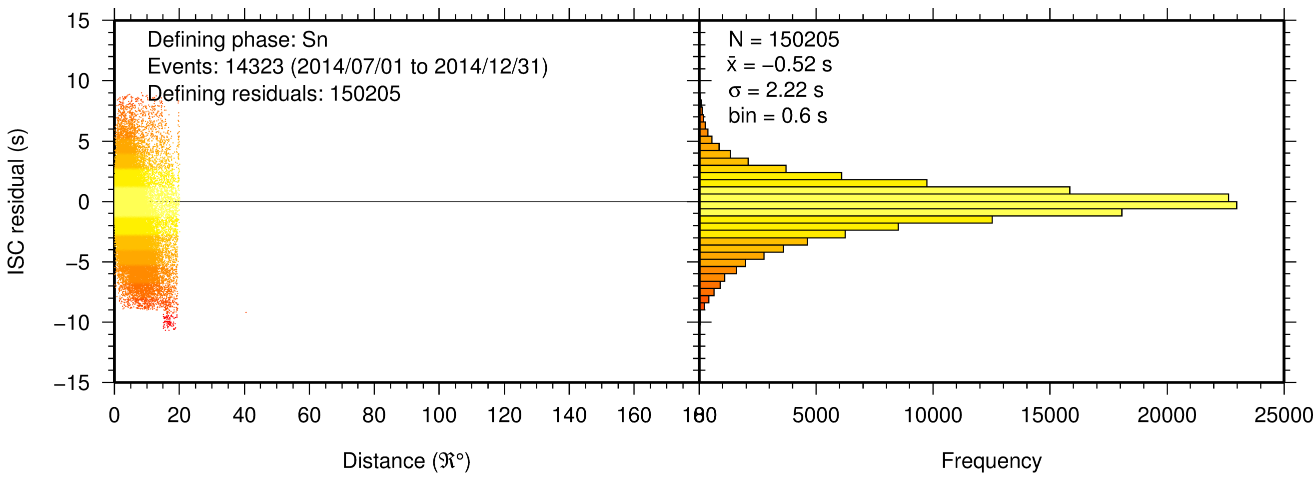


Figure 8.20: *Distribution of travel-time residuals for the defining Sn phases used in the computation of ISC located events in the Bulletin.*

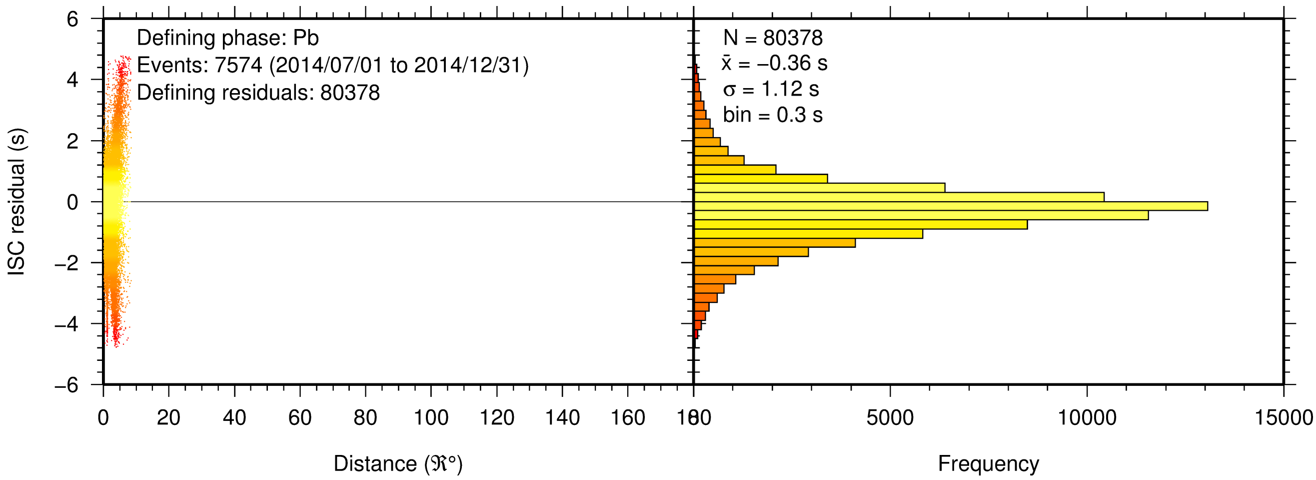


Figure 8.21: *Distribution of travel-time residuals for the defining Pb phases used in the computation of ISC located events in the Bulletin.*

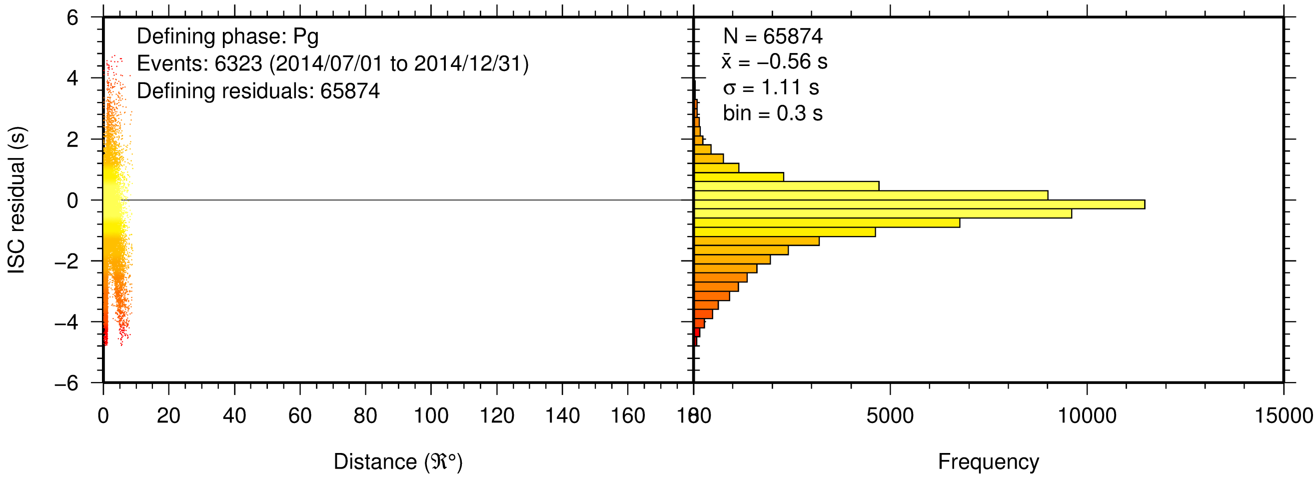


Figure 8.22: *Distribution of travel-time residuals for the defining Pg phases used in the computation of ISC located events in the Bulletin.*

8.3 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 2795664 (see Section 7.3). 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 10.1.4 of Issue I of the 2014 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 8.2 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 8.2: *Summary of the amplitude-period data used by the ISC Locator to compute MS and mb.*

	MS	mb
Number of amplitude-period data	145172	442604
Number of readings	130292	438487
Percentage of readings in the ISC located events with qualifying data for magnitude computation	15.3	43.8
Number of station magnitudes	124787	395161
Number of network magnitudes	3295	11795

A small percentage of the readings with qualifying data for MS and mb calculation have more than one amplitude-period pair. Notably, only 15.3% of the readings for the ISC located (shallow) events included qualifying data for MS computation, whereas for mb the percentage is much higher at 43.8%. This is due to the seismological practice of reporting agencies. Agencies contributing systematic reports of amplitude and period data are listed in Appendix Table 10.3. Obviously the ISC Bulletin would benefit if more agencies included surface wave amplitude-period data in their reports.

Figure 8.23 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.

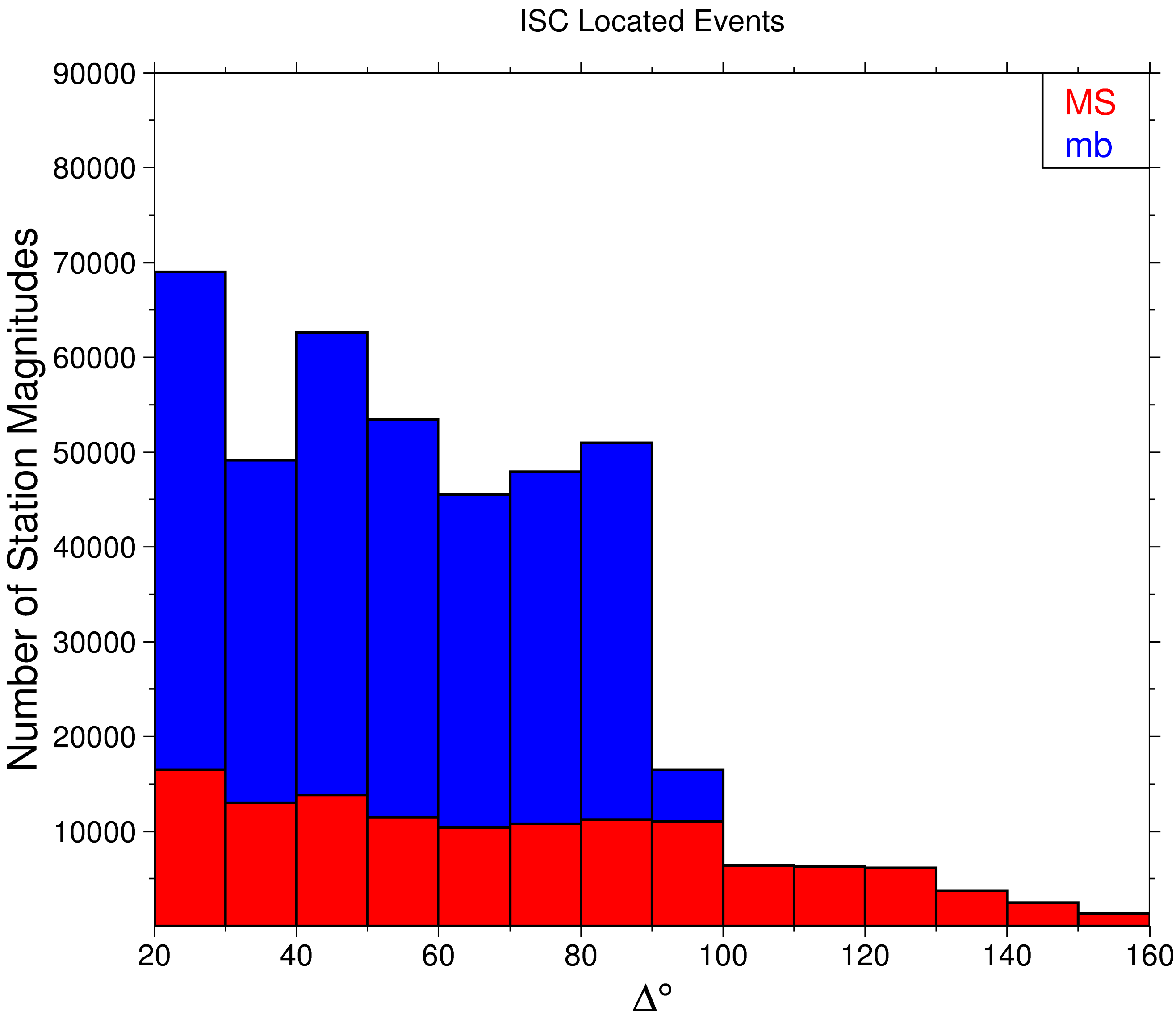


Figure 8.23: Distribution of the number of station magnitudes computed by the ISC Locator for mb (blue) and MS (red) versus distance.

Finally, Figure 8.24 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.

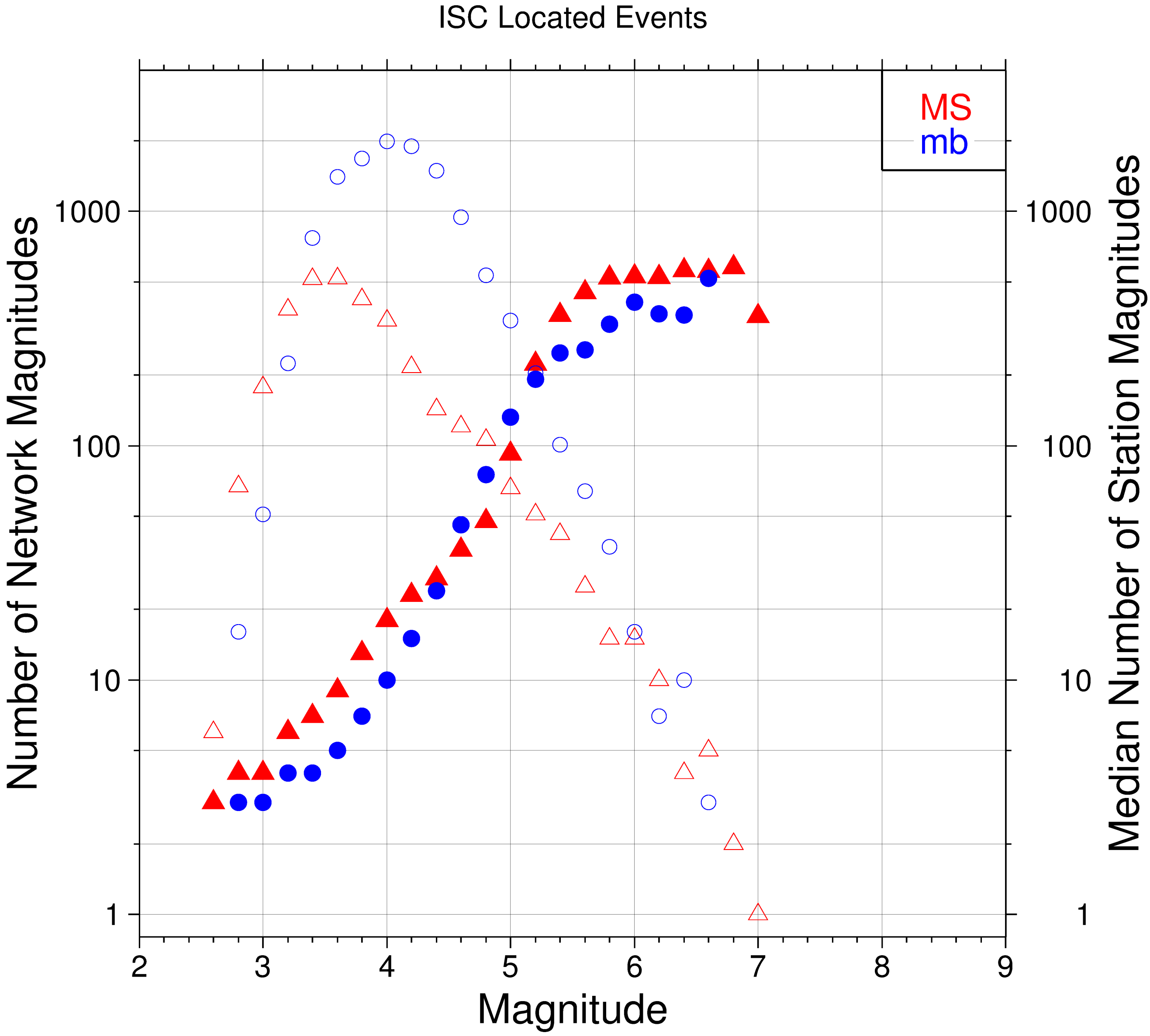


Figure 8.24: *Number of network magnitudes (open symbols) and median number of stations magnitudes (filled symbols). Blue circles refer to mb and red triangles to MS. The width of the magnitude interval δM is 0.2, and each symbol includes data with magnitude in $M \pm \delta M/2$.*

8.4 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 8.25. A history of completeness for the ISC Bulletin is shown in Figure 8.26. 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.

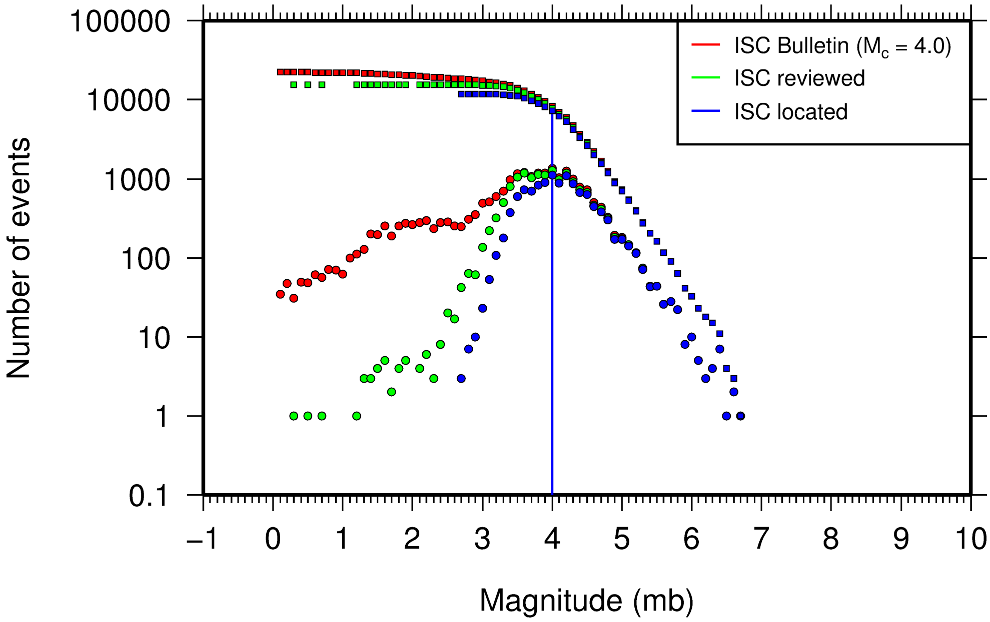


Figure 8.25: *Frequency and cumulative frequency magnitude distribution for all events in the ISC Bulletin, ISC reviewed events and events located by the ISC. The magnitude of completeness (M_C) is shown for the ISC Bulletin. Note: only events with values of mb are represented in the figure.*

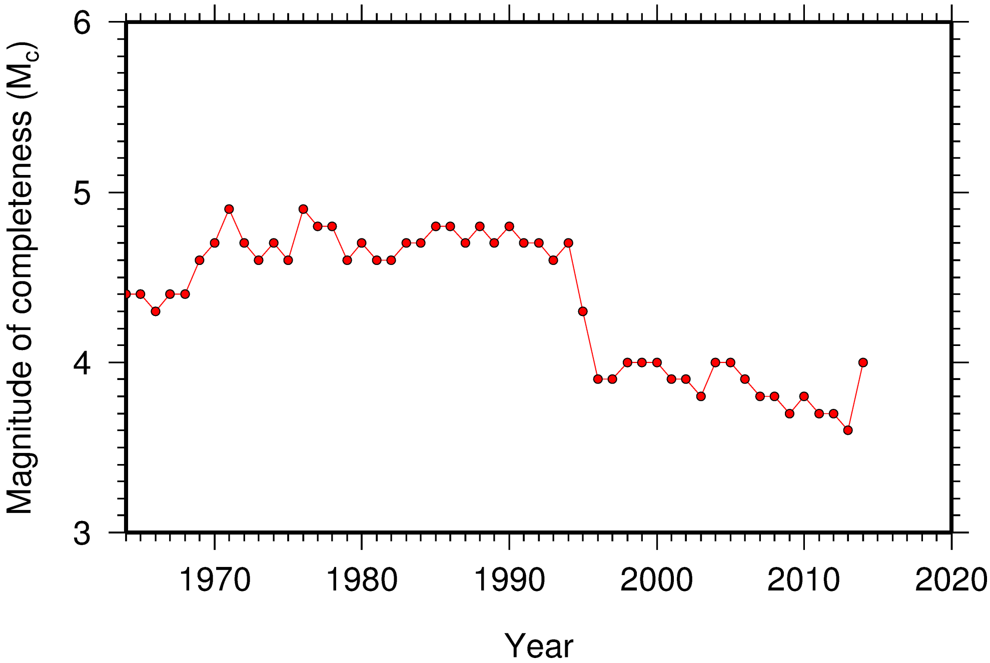


Figure 8.26: *Variation of magnitude of completeness (M_C) for each year in the ISC Bulletin. Note: M_C is calculated only using those events with values of mb.*

8.5 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 8.27, 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 8.28 and 8.29, 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 8.30 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 8.31, 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.

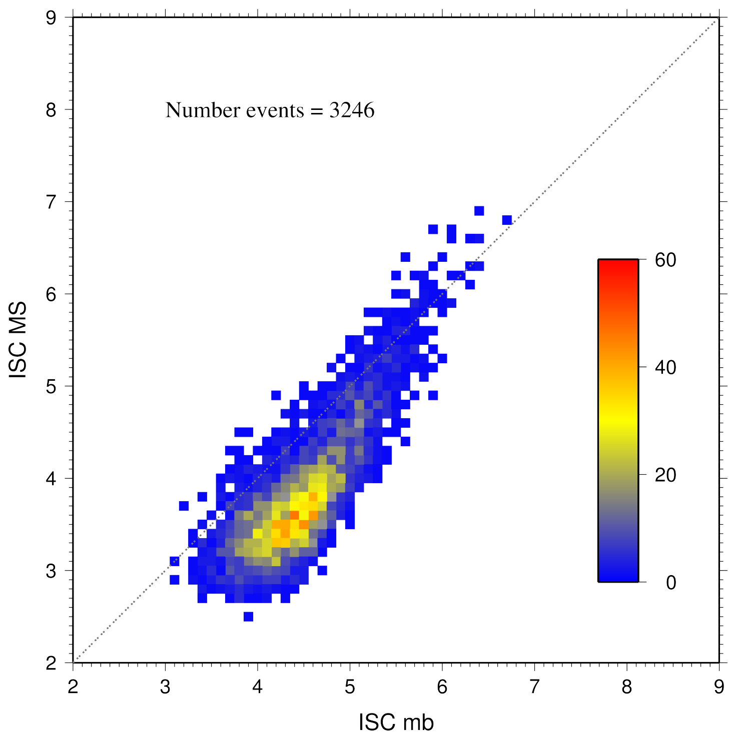


Figure 8.27: *Comparison of ISC values of MS with mb for common event pairs.*

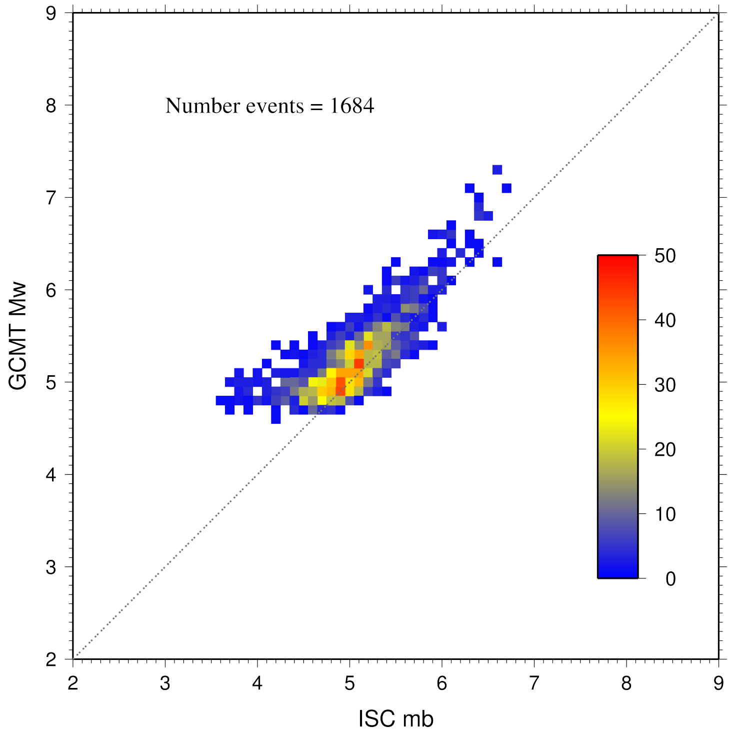


Figure 8.28: *Comparison of ISC values of mb with GCMT M_W for common event pairs.*

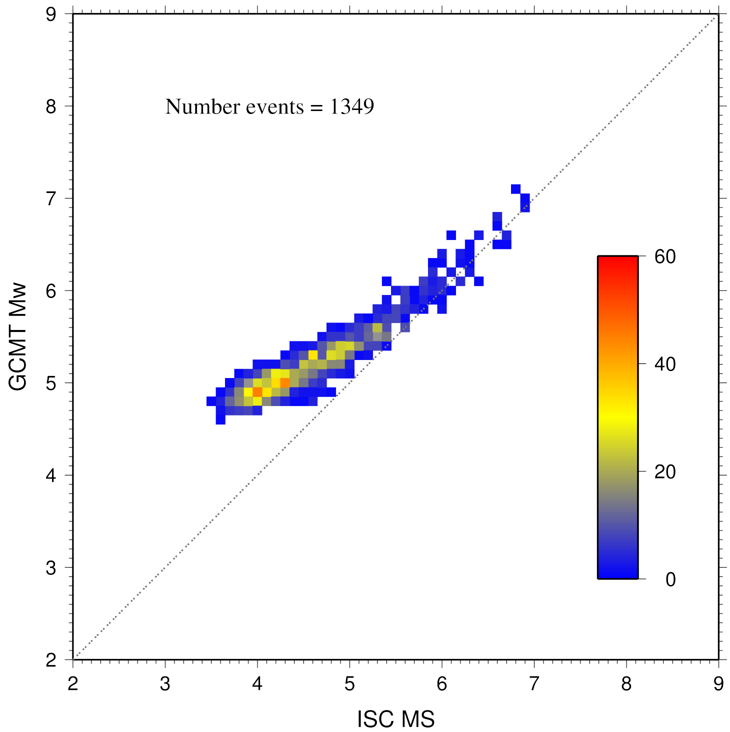


Figure 8.29: *Comparison of ISC values of MS with GCMT M_W for common event pairs.*

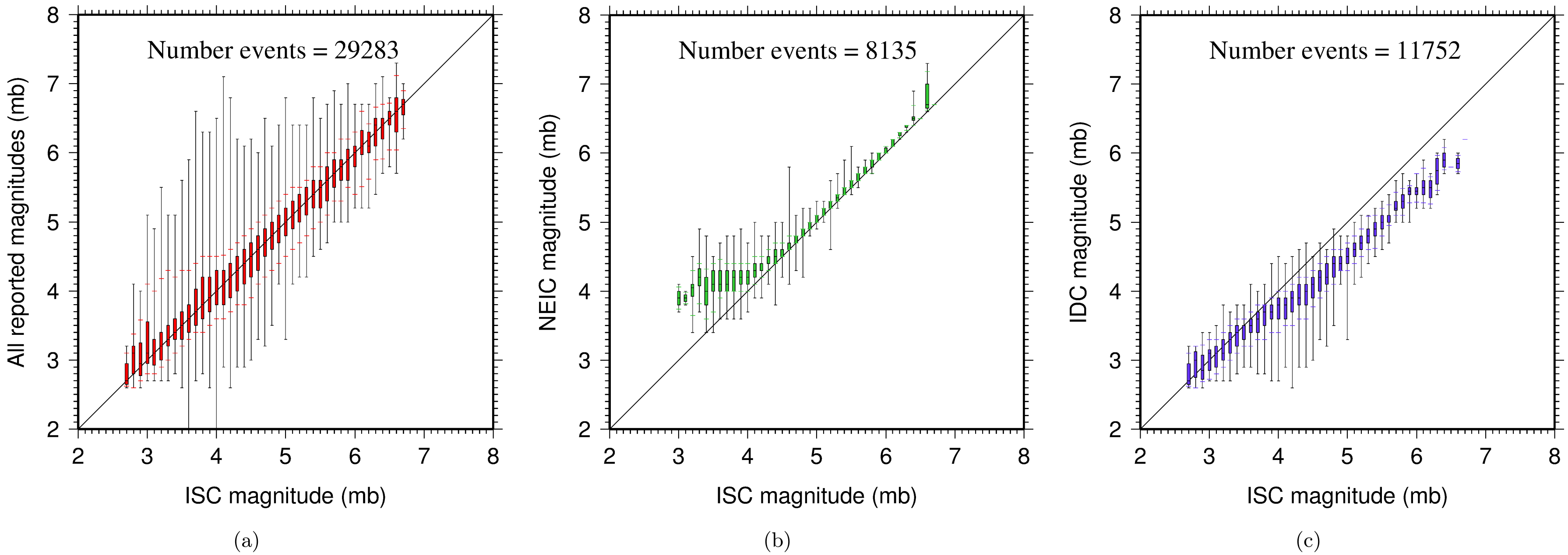


Figure 8.30: *Comparison of ISC magnitude data (mb) with additional agency magnitudes (mb). The statistical summary is shown in box-and-whisker plots where the 10th and 90th percentiles are shown in addition to the max and min values. (a): All magnitudes reported; (b): NEIC magnitudes; (c): IDC magnitudes.*

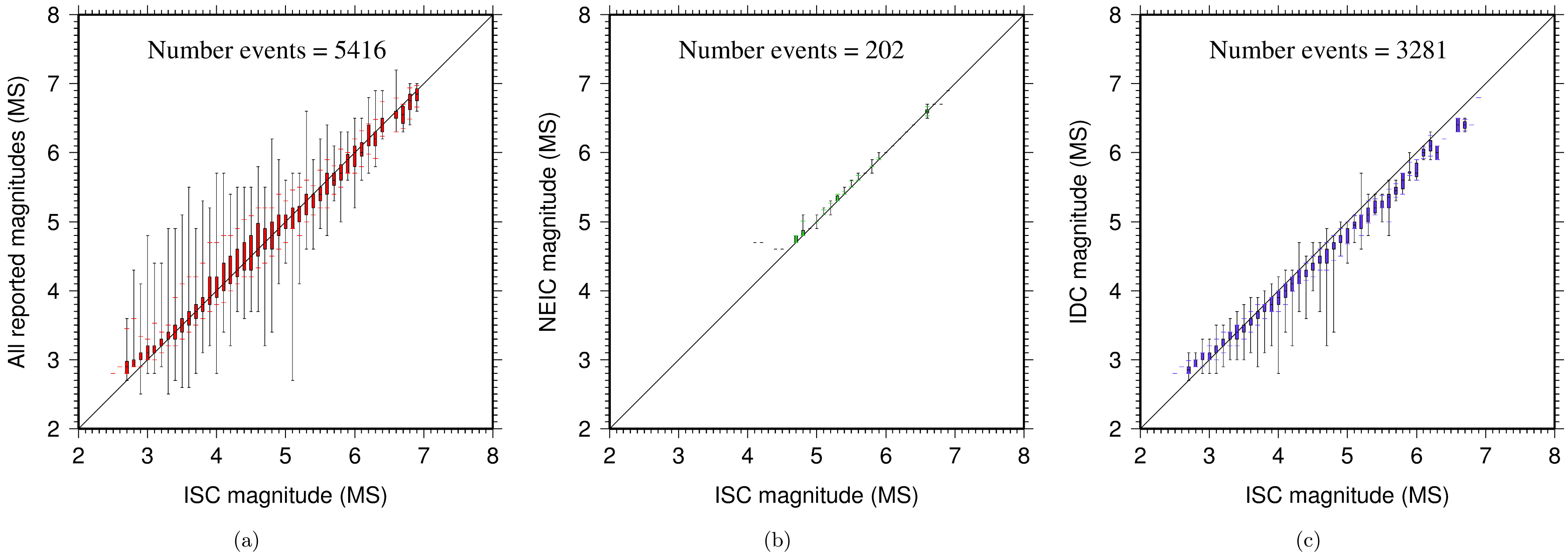


Figure 8.31: *Comparison of ISC magnitude data (MS) with additional agency magnitudes (MS). The statistical summary is shown in the box-and-whisker plots where the 10th and 90th percentiles are shown in addition to the max and min values. (a): All magnitudes reported; (b): NEIC magnitudes; (c): IDC magnitudes.*

9

The Leading Data Contributors

For the current six-month period, 148 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 9.1),
- reported data that helped quite considerably to improve the quality of the ISC locations or magnitude determinations (see Section 9.2),
- 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 9.3).

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.

9.1 The Largest Data Contributors

We acknowledge the contribution of IDC, NEIC, MOS, BJI, DJA, CLL and a few others (Figure 9.1) that reported the majority of moderate to large events recorded at teleseismic distances. The contributions of NEIC, IDC, MEX, JMA and several others are also acknowledged with respect to smaller seismic events. The contributions of JMA, NEIC, IDC, TAP, ATH, 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 9.2). 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 75% 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.

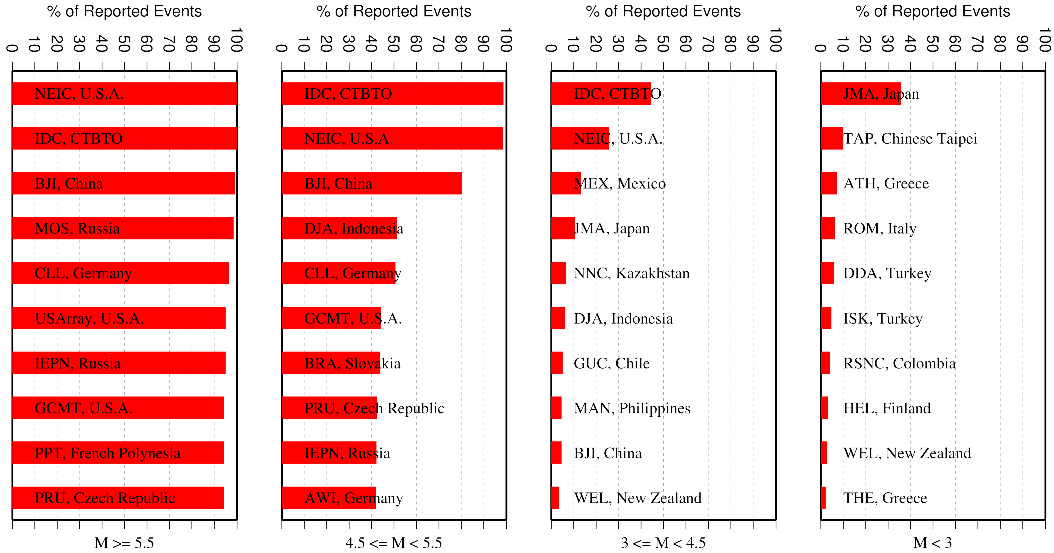


Figure 9.1: *Frequency of events in the ISC Bulletin for which an agency reported at least one item of data: a moment tensor, a hypocentre, a station arrival time or an amplitude. The top ten agencies are shown for four magnitude intervals.*

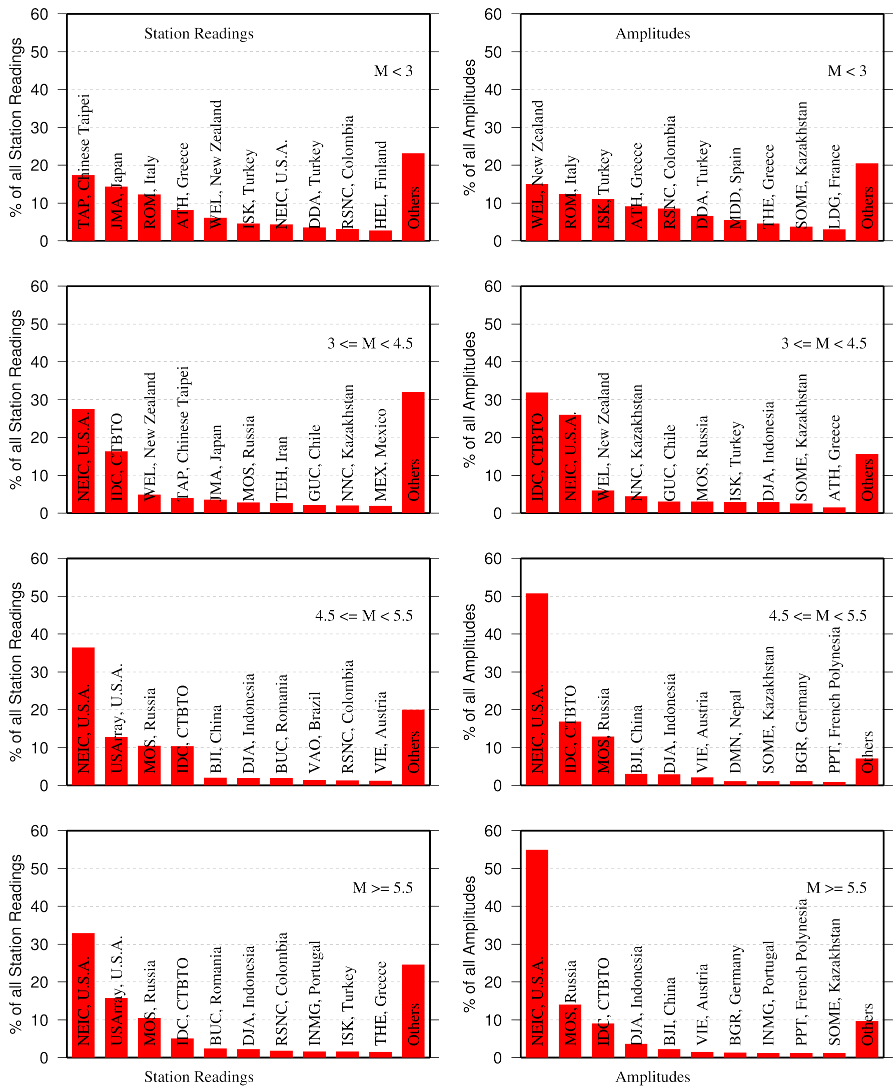


Figure 9.2: *Contributions of station arrival time readings (left) and amplitudes (right) of agencies to the ISC Bulletin. Top ten agencies are shown for four magnitude intervals.*

9.2 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 9.3). 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 51% 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, CLL, NAO, MOS, PRU, BRA, AWI and IEPN each reported individual station arrivals for several percent of all relevant events. We encourage other agencies to report distant events to us.

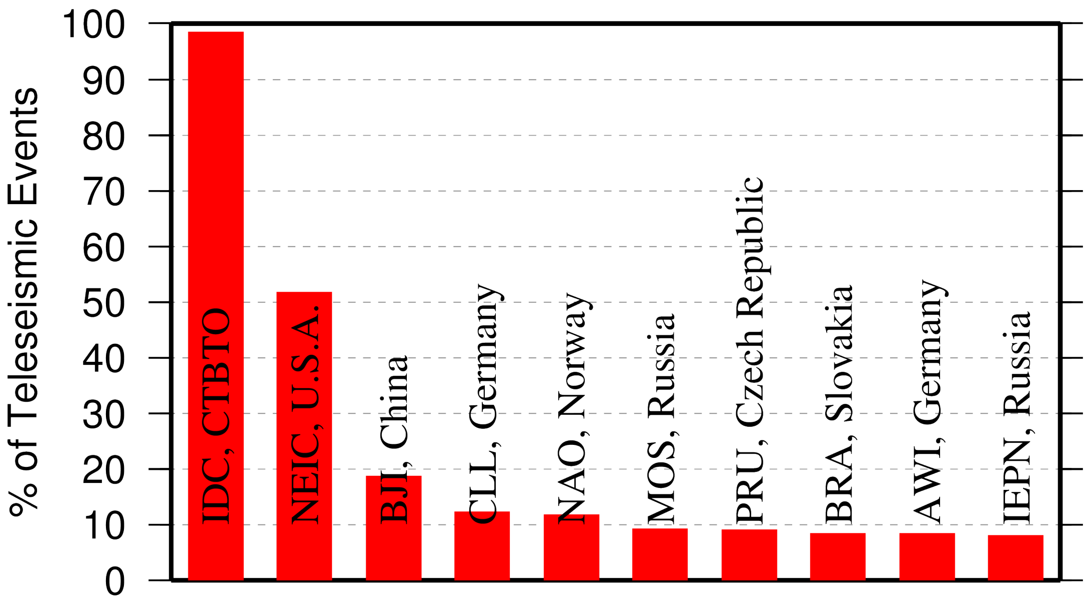


Figure 9.3: *Top ten agencies that reported teleseismic phase arrivals for a large portion of ISC events.*

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 9.4). 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.

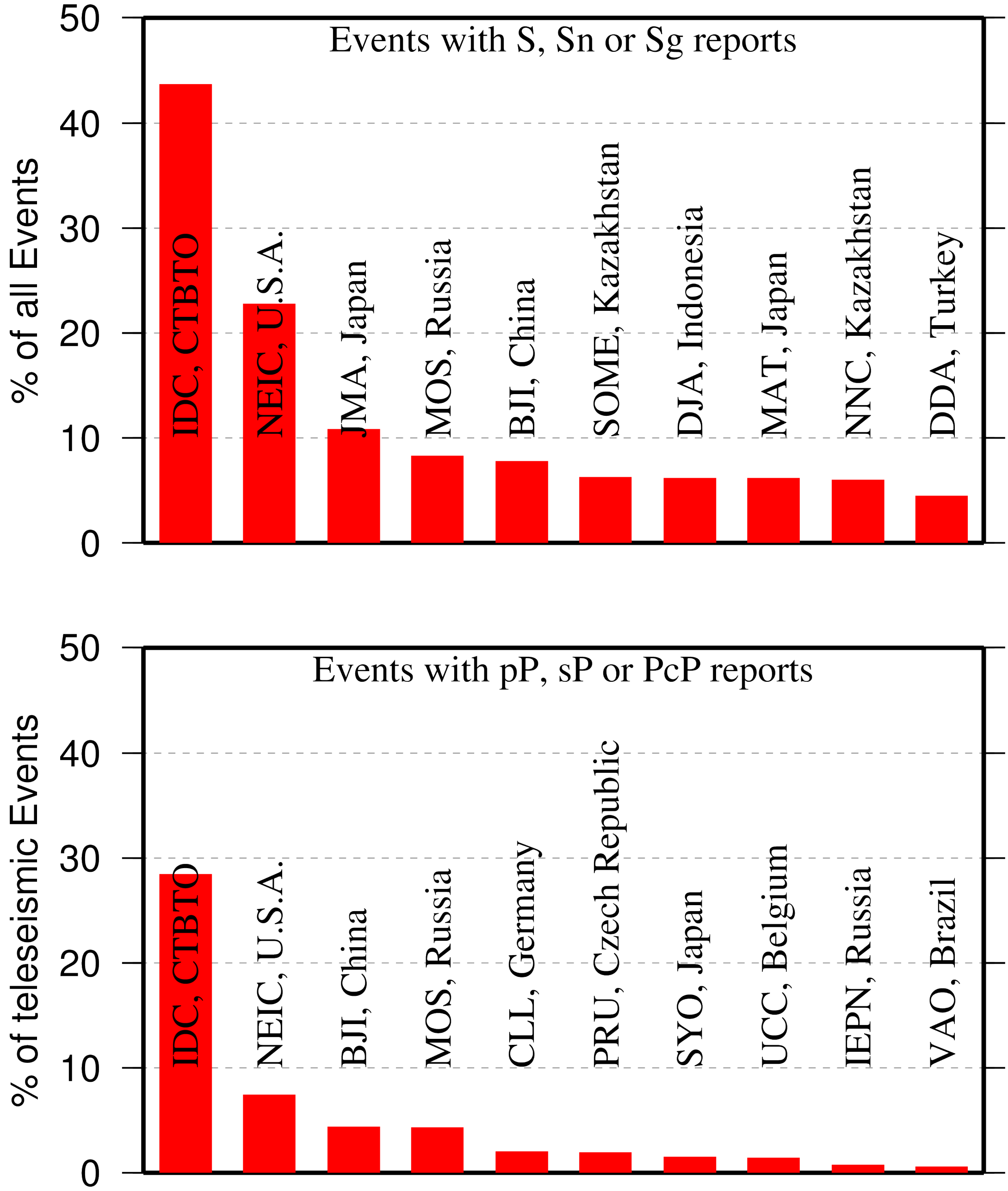


Figure 9.4: *Top ten agencies that reported secondary phases important for an accurate epicentre location (top) and focal depth determination (bottom).*

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 8.5.

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, PRU and a few other agencies (Figure 9.5) 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 9.6).

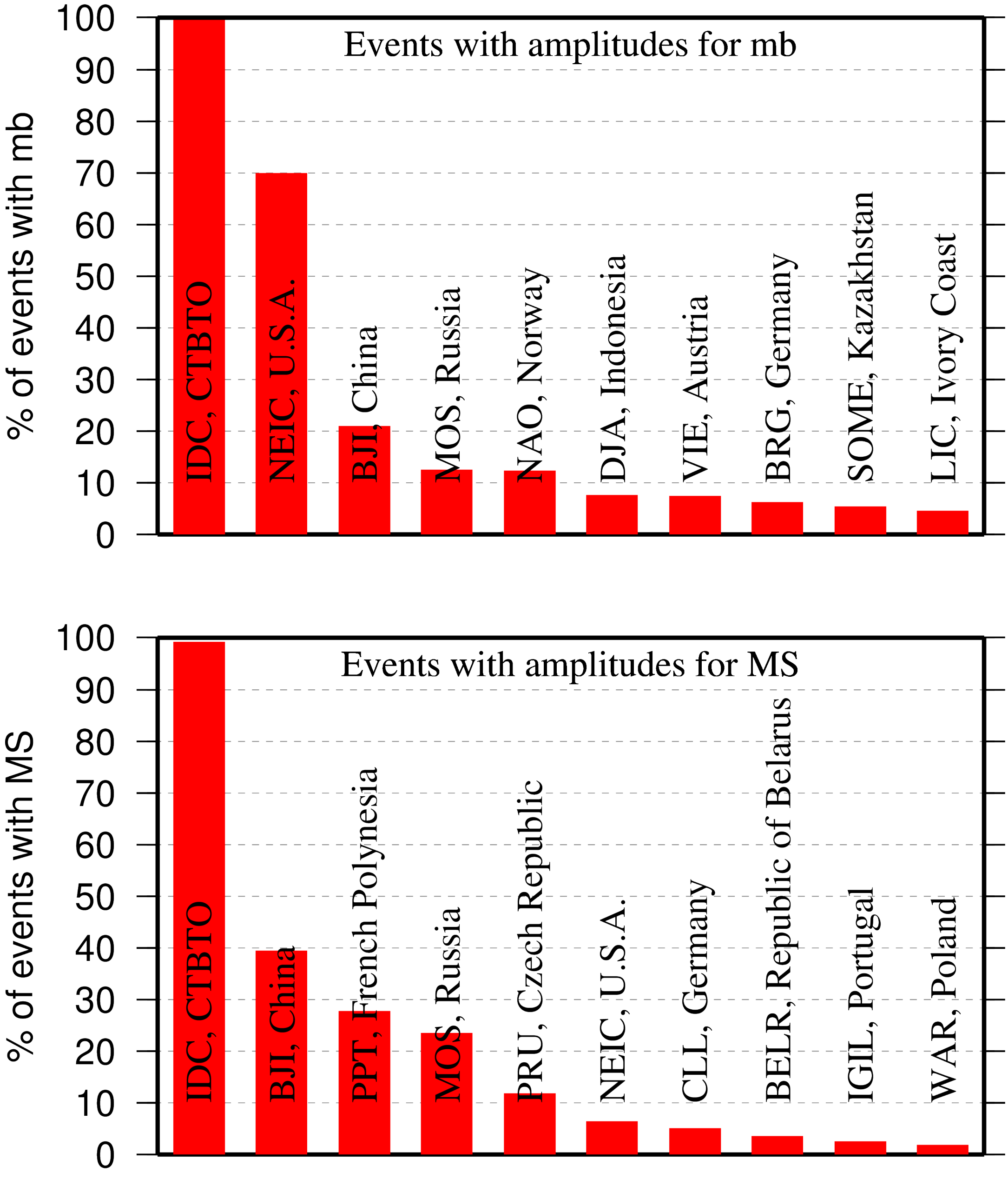


Figure 9.5: *Agencies that report defining body (top) and surface (bottom) wave amplitudes and periods for the largest fraction of those ISC Bulletin events with MS/mb determinations.*

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 9.7 and several others in reporting both natural and anthropogenic events to the ISC.

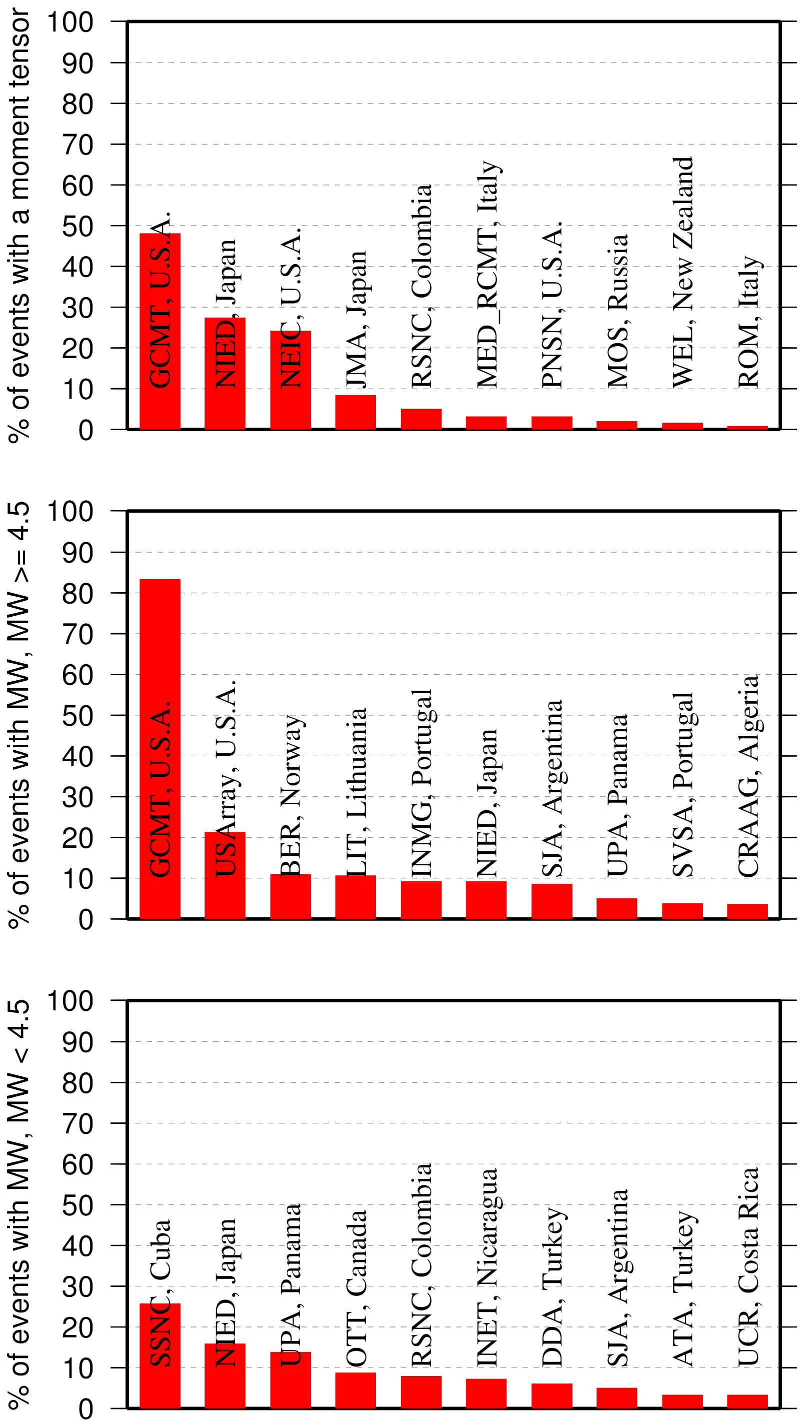


Figure 9.6: *Top ten agencies that most frequently report determinations of seismic moment tensor (top) and moment magnitude (middle/bottom for M greater/smaller than 4.5).*

The ISC Bulletin also contains felt and damaging information when local agencies have reported it to us. Agencies listed on Figure 9.8 provide such information for the majority of all felt or damaging events in the ISC Bulletin.

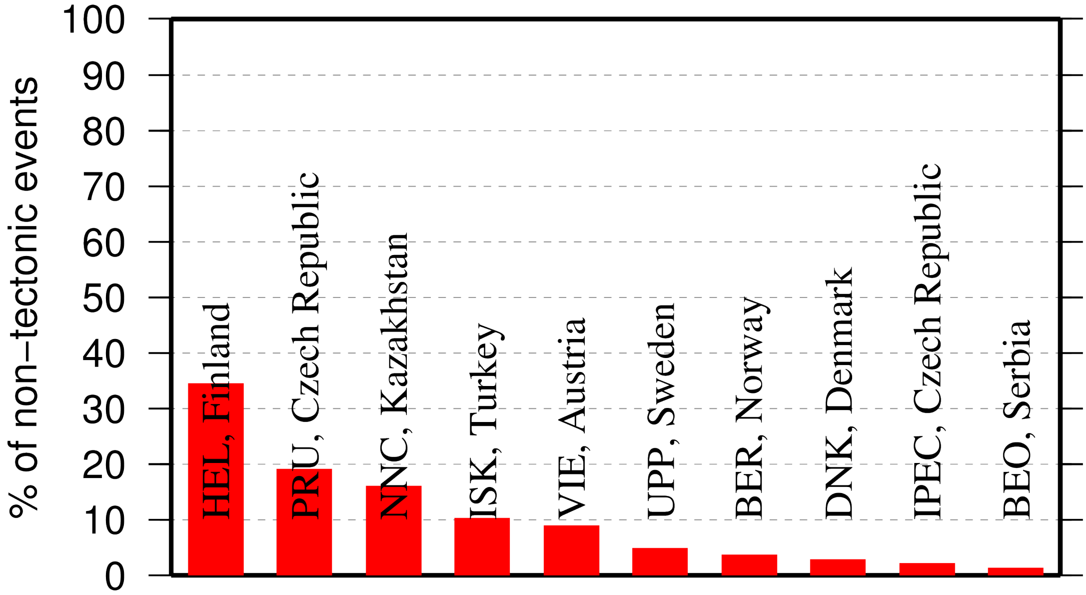


Figure 9.7: *Top ten agencies that most frequently report non-tectonic seismic events to the ISC.*

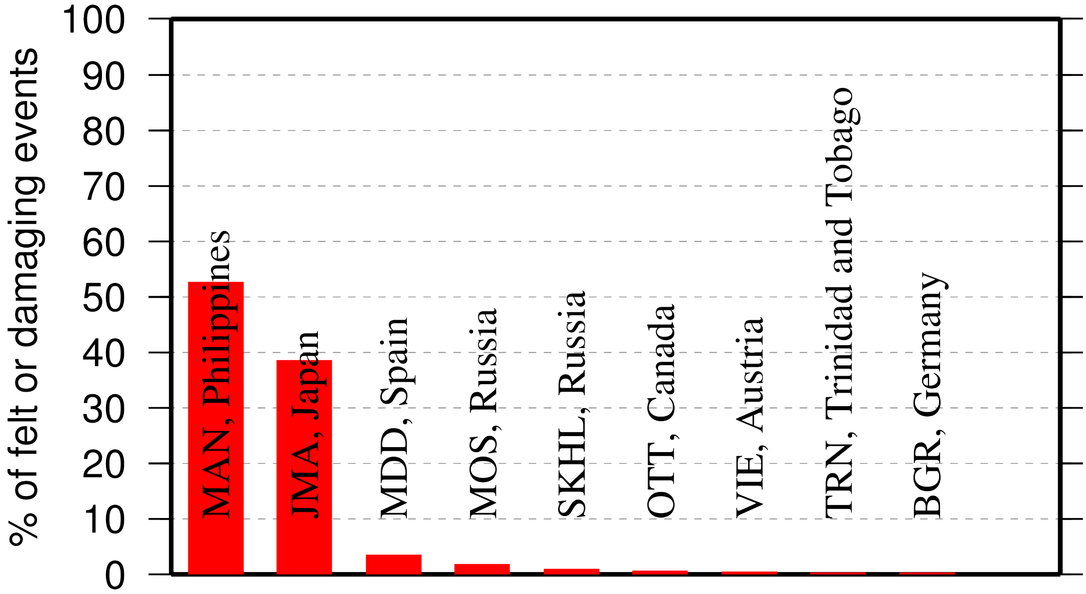


Figure 9.8: *Top ten agencies that most frequently report macroseismic information to the ISC.*

9.3 The Most Consistent and Punctual Contributors

During this six-month period, 31 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 9.1 lists all agencies that have been helpful to the ISC in this respect during the six-month period.

Table 9.1: *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
PPT	French Polynesia	19
NAO	Norway	26
LIC	Ivory Coast	31
IGIL	Portugal	35
IDC	Austria	51
ISN	Iraq	56
ISK	Turkey	69
SVSA	Portugal	71
KRSC	Russia	77
BUD	Hungary	78
INMG	Portugal	90
AUST	Australia	93
ATA	Turkey	106
UCC	Belgium	109
BJI	China	139
ATH	Greece	141
BUL	Zimbabwe	154
THE	Greece	154
LIT	Lithuania	163
IRIS	U.S.A.	176
PRE	South Africa	206
BGS	United Kingdom	212
LDG	France	218
BEO	Serbia	229
BYKL	Russia	271
NAM	Namibia	284
EAF		293
SOME	Kazakhstan	295
BUC	Romania	351
IPEC	Czech Republic	360

10

Appendix

Table 10.1: *Listing of all 340 agencies that have directly reported to the ISC. The 148 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
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**
AWI	**Alfred Wegener Institute for Polar and Marine Research, Germany**
AZER	**Republic Center of Seismic Survey, 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**
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

Table 10.1: *Continued.*

Agency Code	Agency Name
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**
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**
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

Table 10.1: *Continued.*

Agency Code	Agency Name
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
FBR	Fabra Observatory, Spain
FDF	Fort de France, Martinique
FIA0	Finessa Array, Finland
FOR	Unknown Historical Agency, Unknown - historical agency
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**
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**
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
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**

Table 10.1: Continued.

Agency Code	Agency Name
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**
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
IEPN	**Institute of Environmental Problems of the North, Russian Academy of Sciences, Russia**
IGIL	**Instituto Geofisico do Infante Dom Luiz, Portugal**
IGQ	**Servicio Nacional de Sismología y Vulcanología, Ecuador**
IGS	Institute of Geological Sciences, United Kingdom
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**
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
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

Table 10.1: Continued.

Agency Code	Agency Name
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**
LJU	**Slovenian Environment Agency**, **Slovenia**
LPA	**Universidad Nacional de La Plata**, **Argentina**
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**
MCO	**Macao Meteorological and Geophysical Bureau**, **Macao, China**
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**
MOLD	**Institute of Geophysics and Geology**, **Moldova**
MOS	**Geophysical Survey of Russian Academy of Sciences**, **Russia**
MOZ	Direccao Nacional de Geologia, Mozambique
MRB	**Institut Cartogràfic i Geològic de Catalunya**, **Spain**
MSI	Messina Seismological Observatory, Italy
MSSP	**Micro Seismic Studies Programme, PINSTECH**, **Pakistan**
MUN	Mundaring Observatory, Australia
NAI	University of Nairobi, Kenya

Table 10.1: Continued.

Agency Code	Agency Name
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**
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**
OBM	Research Centre of Astronomy and Geophysics, Mongolia
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

Table 10.1: *Continued.*

Agency Code	Agency Name
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-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
SAPSE	Southern Alps Passive Seismic Experiment, New Zealand
SAR	Sarajevo Seismological Station, Bosnia and Herzegovina
SCB	**Observatorio San Calixto**, **Bolivia**
SCEDC	Southern California Earthquake Data Center, USA
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
SRI	Stanford Research Institute, USA

Table 10.1: Continued.

Agency Code	Agency Name
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
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**
UAV	Red Sismológica de Los Andes Venezolanos, Venezuela
UCC	**Royal Observatory of Belgium**, **Belgium**
UCR	**Sección de Sismología, Vulcanología y Exploración Geofísica**, **Costa Rica**
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**
USAEC	United States Atomic Energy Commission, USA
USCGS	United States Coast and Geodetic Survey, USA

Table 10.1: *Continued.*

Agency Code	Agency Name
USGS	United States Geological Survey, USA
UUSS	The University of Utah Seismograph Stations, USA
UVC	Universidad del Valle, Colombia
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
WAR	**Institute of Geophysics, Polish Academy of Sciences**, **Poland**
WBNET	**West Bohemia Seismic Network**, **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**
ZUR	**Swiss Seismological Service (SED)**, **Switzerland**
ZUR_RMT	Zurich Moment Tensors, Switzerland

Table 10.2: *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	3258757	NEIC (11%), TAP (11%)
S	1502186	TAP (22%), JMA (18%), ROM (11%)
AML	637046	ROM (77%), ATH (20%)
IAmb	430061	NEIC (99%)
NULL	358806	NEIC (32%), RSNC (17%), AEIC (17%)
Pn	233784	NEIC (42%), TEH (12%)
Pg	179559	NNC (12%), MDD (12%)
IAML	139987	DDA (55%), GUC (15%)
Sg	126652	LDG (13%), ZAG (12%)
pmax	125620	MOS (76%), BJI (24%)
IAMs_20	120024	NEIC (98%)
LR	106898	IDC (60%), BJI (32%)
PG	94974	ISK (57%), HEL (16%), PRU (12%)
PN	75598	ISK (73%), MOS (12%)
SG	74452	ISK (34%), HEL (24%), PRU (22%), IPEC (12%)
Sn	73209	LDG (15%), IDC (13%)
Lg	63271	MDD (43%), NNC (41%)
T	26204	IDC (93%)
PKP	25687	IDC (57%)
MLR	20539	MOS (100%)
A	17396	INMG (47%), SKHL (27%), SVSA (26%)
PKPbc	16796	IDC (57%), BGR (16%), NEIC (12%)
pP	16671	BJI (41%), IDC (20%)
PKIKP	14700	MOS (97%)
MSG	14644	HEL (99%)
PKPdf	13946	NEIC (59%)
SN	12554	HEL (48%), ISK (28%)
PcP	11853	IDC (70%)
PP	9830	BJI (29%), IDC (25%)
Sb	9007	IRIS (96%)
IAmb_Lg	8585	NEIC (100%)
PB	7533	HEL (100%)
smax	7436	MOS (72%), BJI (28%)
PKPab	7110	IDC (40%), NEIC (19%)
sP	6848	BJI (83%)
SS	6737	MOS (40%), BJI (28%)
SB	6354	HEL (99%)
END	5426	ROM (100%)
Pb	5201	IRIS (93%)
AMS	5187	PRU (88%)
PKiKP	4754	IDC (29%), IRIS (22%), VIE (18%), UCC (13%)
x	4496	NDI (49%), PRU (37%), UCC (11%)
ScP	3909	IDC (83%)
AMB	3787	SKHL (83%), BJI (17%)
PKP2	2588	MOS (91%)
Smax	2354	BYKL (100%)
LQ	2301	PPT (35%), IEPN (24%), INMG (24%), BELR (13%)
AMP	2272	IEPN (70%), HLW (13%)
LG	2271	BRA (92%)
PKKPbc	2176	IDC (93%)
*PP	2166	MOS (100%)
Pmax	1924	BYKL (96%)
L	1728	BGR (59%), WAR (26%)
sS	1689	BJI (94%)
Pdiff	1650	IRIS (34%), IDC (28%), BGR (15%)
PPP	1612	MOS (78%)
PKhKP	1610	IDC (100%)
X	1493	JMA (81%), SYO (17%)
IVMs_BB	1450	BER (55%), HYB (44%)
Trac	1296	OTT (100%)
pPKP	1286	IDC (37%), BJI (34%), PRU (17%)
SSS	1222	MOS (59%), CLL (21%), BELR (12%)
IVmB_BB	1202	HYB (56%), BER (40%)
SKPbc	1153	IDC (91%)
max	1047	BYKL (100%)

Table 10.2: *(continued)*

Reported Phase	Total	Agencies reporting
SKS	905	BJI (44%), PRU (22%)
Pdif	900	BER (27%), NEIC (26%)
PS	855	MOS (46%), CLL (16%)
ScS	769	BJI (72%), IDC (19%)
PKHKP	690	MOS (100%)
pPKPbc	664	IDC (50%), BGR (28%)
SKSac	650	BER (53%)
PKPPKP	650	IDC (92%)
SP	573	BER (27%), MOS (24%), PRU (17%)
PKP1	558	LIC (91%)
PKPAB	553	PRU (100%)
sPKP	551	BJI (94%)
PKPDF	549	PRU (100%)
Sgmax	544	NERS (100%)
PDIFF	492	PRU (39%), BRA (38%), IPEC (17%)
LRM	483	BELR (84%), MOLD (12%)
*SP	466	MOS (100%)
PKKP	452	IDC (76%), PRU (12%)
E	419	ZAG (99%)
Lm	400	CLL (100%)
IVmBBB	394	HYB (73%), BER (27%)
pPKPdf	367	VIE (28%), NEIC (16%), CLL (13%)
PKKPab	323	IDC (75%), VIE (12%)
*SS	304	MOS (100%)
PM	302	BELR (99%)
SKP	300	IDC (68%), PRU (15%)
LmV	274	CLL (100%)
SKKS	252	BJI (72%)
pPKPab	236	VIE (30%), CLL (24%), IDC (21%)
PKP2bc	231	IDC (100%)
PmP	210	BGR (63%), ZUR (36%)
Rg	209	NAO (37%), NNC (37%), IDC (21%)
PcS	208	BJI (86%)
pPKiKP	195	VIE (65%), UCC (16%)
PPS	192	CLL (73%), MOS (21%)
SKKPbc	188	IDC (92%)
Sgm	186	SIGU (100%)
PnPn	183	UCC (89%)
P3KPbc	177	IDC (100%)
Sm	176	SIGU (100%)
Pm	166	SIGU (100%)
(P)	166	BRG (59%), CLL (41%)
AMb	158	IGIL (87%), NDI (11%)
SSSS	156	CLL (100%)
Pgmax	154	NERS (100%)
SmS	147	BGR (85%), ZUR (14%)
LmH	142	CLL (100%)
SKPdf	133	BER (53%), VIE (24%), CLL (19%)
PKS	131	BJI (64%)
PKPpre	119	NEIC (66%), PRU (22%), CLL (12%)
Lmax	115	CLL (100%)
SKKSac	113	CLL (43%), WAR (19%), SOME (11%)
PCP	111	PRU (42%), LPA (27%), BRG (18%)
IVMsBB	108	HYB (69%), BER (29%)
RG	103	IPEC (92%)
m	98	SIGU (100%)
P4KPbc	93	IDC (100%)
pPn	89	UCC (99%)
Sdif	75	CLL (51%), HYB (16%), WAR (16%), PPT (13%)
Snm	74	SIGU (100%)
pPcP	69	IDC (70%), BGR (22%)
pPP	62	CLL (50%), LPA (34%), LJU (16%)
PKP2ab	60	IDC (100%)
PgPg	56	BYKL (91%)
SH	56	SYO (100%)
p	52	ROM (85%)
Pgm	51	SIGU (100%)

Table 10.2: *(continued)*

Reported Phase	Total	Agencies reporting
SDIFF	51	IPEC (39%), BRG (27%), BRA (18%), LPA (16%)
pPdiff	51	SYO (41%), LJU (29%), VIE (25%)
sPKiKP	49	VIE (39%), UCC (35%), OMAN (14%)
s	46	ROM (63%), SFS (26%)
SM	45	BELR (100%)
SKPab	42	IDC (90%)
sPP	42	CLL (93%)
sPKPdf	41	VIE (78%)
P'P'df	41	VIE (93%)
P*	41	BGR (56%), BUD (29%)
LQM	40	BELR (78%), MOLD (22%)
PKKPdf	38	VIE (84%), CLL (13%)
PSKS	36	CLL (100%)
SCP	36	PRU (50%), BRG (39%), IPEC (11%)
SKIKS	35	LPA (100%)
(PP)	33	CLL (100%)
SgSg	33	BYKL (100%)
MSN	32	HEL (53%), BER (47%)
-	31	INMG (100%)
PPPP	30	CLL (100%)
(sP)	27	CLL (100%)
pPdif	26	CLL (50%), HYB (42%)
rx	25	SKHL (100%)
SCS	24	LPA (75%), IPEC (17%)
SKKP	24	IDC (83%), PRU (12%)
P3KP	24	IDC (100%)
SKSp	23	BRA (100%)
(pP)	22	CLL (100%)
S*	21	BGR (52%), BUD (38%)
sSS	21	CLL (95%)
sPn	20	UCC (95%)
SKIKP	20	LPA (100%)
SKSdf	19	BER (74%), CLL (16%), HYB (11%)
Sdiff	19	LJU (95%)
PKPM	19	BELR (95%)
Pnm	19	SIGU (100%)
(SS)	18	CLL (100%)
PbPb	18	UCC (100%)
PKSdf	18	CLL (61%), BER (39%)
(PcP)	17	CLL (100%)
SKiKP	17	IDC (94%)
(Sn)	17	OSUB (65%), CLL (35%)
PPPrev	16	CLL (100%)
PSP	16	LPA (100%)
(Pg)	16	CLL (81%), OSUB (19%)
sPdif	15	HYB (73%), CLL (27%)
PKPPKPdf	15	CLL (100%)
sPKPbc	14	VIE (64%), CLL (29%)
(SSSS)	13	CLL (100%)
(SSS)	13	CLL (100%)
Plp	13	CLL (100%)
PKPdiff	13	CLL (100%)
(S)	13	CLL (77%), OSUB (23%)
sPKPab	12	CLL (42%), VIE (25%), LJU (25%)
SPP	12	CLL (50%), MOS (25%), BELR (17%)
SnSn	12	UCC (100%)
del	12	AUST (67%), KNET (33%)
pPKKPab	12	BGR (100%)
(PKPdf)	12	CLL (100%)
AP	12	MOS (100%)
SKSP	11	CLL (73%), BELR (27%)
PSPS	11	CLL (100%)
Cod	10	SFS (100%)
MPN	10	BER (50%), HEL (50%)
SKKSdf	10	CLL (50%), WAR (40%)
SKKPdf	9	VIE (78%), CLL (22%)
H	9	IDC (100%)

Table 10.2: *(continued)*

Reported Phase	Total	Agencies reporting
(SP)	9	CLL (100%)
PPM	9	BELR (100%)
sSSS	9	CLL (89%), LJU (11%)
(PKiKP)	8	CLL (100%)
LV	7	CLL (100%)
PKPdif	7	NEIC (71%), LJU (29%)
(PKPab)	7	CLL (100%)
sSdiff	7	CLL (100%)
(sPP)	7	CLL (100%)
PKIKS	6	LPA (100%)
PKPbcd	6	WAR (100%)
Li	6	MOLD (100%)
PPPPrev	6	CLL (100%)
pwP	6	NEIC (100%)
sPdiff	6	SYO (100%)
PDIF	6	BRG (100%)
n	6	BUD (100%)
AMPG	6	BER (100%)
R	6	LDG (100%)
LH	6	CLL (100%)
AMSG	5	BER (100%)
(Sg)	5	CLL (80%), OSUB (20%)
PPlp	5	CLL (100%)
tx	5	SOME (80%), IEPN (20%)
sPS	5	CLL (100%)
PsP	5	MOLD (80%), BELR (20%)
PSSrev	5	CLL (100%)
SKKKS	5	BELR (100%)
(PPP)	5	CLL (100%)
PKPlp	5	CLL (100%)
(pPKPdf)	4	CLL (100%)
SKSSKSac	4	CLL (100%)
sPPP	4	CLL (100%)
sSn	4	UCC (100%)
sPPS	4	CLL (100%)
Lq	4	MOLD (100%)
P9	4	UPA (50%), BER (50%)
SKKSp	4	BRA (100%)
sPKKPbc	4	CLL (100%)
pPKPPKPd	4	CLL (100%)
Lm(360	4	CLL (100%)
PSS	4	CLL (100%)
pPPP	4	CLL (75%), LJU (25%)
(pPKPab)	4	CLL (100%)
P4KP	4	IDC (100%)
(pPdif)	3	CLL (100%)
pS	3	IEPN (100%)
sPcP	3	CLL (100%)
pPDIFF	3	BRG (100%)
Slp	3	CLL (100%)
pPPS	3	CLL (100%)
(PPS)	3	CLL (100%)
(SKSac)	3	CLL (100%)
LPM	3	BELR (100%)
PcPPKPre	3	CLL (100%)
PKKS	3	BRG (100%)
SDIF	3	BRG (100%)
Pd2	3	ATH (100%)
SKKSacre	3	CLL (100%)
(Pdif)	3	CLL (100%)
SKKSDF	3	BRA (100%)
pPmax	3	CLL (100%)
IS	3	SFS (100%)
(PG)	2	BRG (100%)
sPSKS	2	CLL (100%)
SSP	2	CLL (50%), HYB (50%)
sZP	2	SYO (100%)

Table 10.2: (continued)

Reported Phase	Total	Agencies reporting
(pPP)	2	CLL (100%)
sPPPPrev	2	CLL (100%)
sPKKPdf	2	CLL (100%)
PKSbc	2	CLL (100%)
(sSSS)	2	CLL (100%)
(sSdiff)	2	CLL (100%)
IPd	2	SFS (100%)
pPKKPbc	2	CLL (100%)
LRM1	2	MOLD (50%), BELR (50%)
(sPPP)	2	CLL (100%)
PKPdf(2)	2	CLL (100%)
PPmax	2	CLL (100%)
sSKKSac	2	CLL (100%)
PCS	2	NDI (50%), BRG (50%)
XM	2	MOLD (100%)
(PS)	2	CLL (100%)
sSP	2	CLL (100%)
PKPab(2)	2	CLL (100%)
(PKSdf)	2	CLL (100%)
LmV(360	2	CLL (100%)
(sPdif)	2	CLL (100%)
XP	2	MOS (100%)
SbSb	2	UCC (100%)
sSKSac	2	CLL (100%)
(pPKiKP)	2	CLL (100%)
P(2)	2	CLL (100%)
sPKSdf	2	CLL (100%)
sPKKPab	1	CLL (100%)
PKPM1	1	MOLD (100%)
sSKSP	1	BELR (100%)
PxPxdf	1	BGR (100%)
PKPac	1	CLL (100%)
(SKSP)	1	CLL (100%)
(SKPdf)	1	CLL (100%)
PPP(2)	1	LPA (100%)
SKO	1	BRG (100%)
TP	1	BRG (100%)
e	1	CLL (100%)
-ML	1	INMG (100%)
pPKP1	1	BELR (100%)
(sPcP)	1	CLL (100%)
PKPPKPab	1	CLL (100%)
PK	1	EAF (100%)
pPS	1	CLL (100%)
h	1	KRSC (100%)
sPKPPKPd	1	CLL (100%)
pPSKS	1	CLL (100%)
PZ	1	MEX (100%)
eSS	1	BELR (100%)
-Mb	1	INMG (100%)
(PSKS)	1	CLL (100%)
(PKP)	1	BRG (100%)
sp	1	SYO (100%)
PFIF	1	BRG (100%)
sPDIFF	1	BRG (100%)
pSKKSac	1	CLL (100%)
sPPPP	1	CLL (100%)
W	1	CLL (100%)
sPKP1	1	BELR (100%)
NG	1	IPEC (100%)
pPDIF	1	BRG (100%)
Lr	1	SFS (100%)
(PPPrev)	1	CLL (100%)
sSKKPdf	1	CLL (100%)
(PKPbc)	1	CLL (100%)
pScP	1	CLL (100%)
PKKSbc	1	CLL (100%)

Table 10.2: (continued)

Reported Phase	Total	Agencies reporting
(SKPbc)	1	CLL (100%)
(ScP)	1	CLL (100%)
EP	1	SFS (100%)
PKPM2	1	MOLD (100%)
PcPPKP	1	HYB (100%)
pSKS	1	CLL (100%)
PkP2	1	KEA (100%)
SNE	1	BRA (100%)
PM1	1	MOLD (100%)
LRM2	1	MOLD (100%)
SKPa	1	NAO (100%)
KRM	1	BELR (100%)
sPcS	1	CLL (100%)
SSrev	1	CLL (100%)
PKKSdf	1	CLL (100%)
(sPKiKP)	1	CLL (100%)
(sSSSS)	1	CLL (100%)
KSac	1	INMG (100%)
Pcp	1	BELR (100%)
SSPrev	1	CLL (100%)
(Pn)	1	CLL (100%)
CUPPER	1	PRU (100%)
pPKPdiff	1	CLL (100%)
ScPPKPre	1	CLL (100%)
(Sb)	1	CLL (100%)
S‘	1	RSNC (100%)
PKPbab	1	CLL (100%)
PPk	1	CLL (100%)
LRq	1	MOLD (100%)
PKP M	1	BELR (100%)
SSSrev	1	CLL (100%)
PcZP	1	SYO (100%)
APKP	1	MOS (100%)
PKKPRbc	1	CLL (100%)
pSKKPbc	1	CLL (100%)
RpP	1	CLL (100%)
pSKSac	1	CLL (100%)
pPiKP	1	SYO (100%)
(PKKPdf)	1	CLL (100%)
sPg	1	OMAN (100%)
(SPP)	1	CLL (100%)
eS	1	CLL (100%)
Pnn	1	ZAG (100%)
PM2	1	MOLD (100%)
LMV	1	CLL (100%)
PC	1	UPA (100%)
sPKPab)	1	CLL (100%)
PKPfd	1	INMG (100%)
(pPKPbc)	1	CLL (100%)
Pn(2)	1	CLL (100%)
Pn4	1	INMG (100%)
PSKSrev	1	CLL (100%)
pPKKPdf	1	CLL (100%)
PW	1	NDI (100%)
PKPPKP’	1	BRG (100%)
(sPKPdf)	1	CLL (100%)
(ScS)	1	CLL (100%)
PKpab	1	CLL (100%)
Pdiffmax	1	CLL (100%)
sPSPS	1	CLL (100%)
sPKKSdf	1	CLL (100%)
sPmax	1	CLL (100%)
(SKKSdf)	1	CLL (100%)
LM	1	NDI (100%)
SN4	1	ISN (100%)
PcP2	1	UCC (100%)
SKPPKPbc	1	CLL (100%)

Table 10.2: (continued)

Reported Phase	Total	Agencies reporting
Ep	1	SFS (100%)
sPSS	1	CLL (100%)
PKPbc(2)	1	CLL (100%)
PKPdF	1	BER (100%)

Table 10.3: 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
NEIC	559291	262444	178787	57424
ROM	498044	10138	0	0
IDC	328238	309493	130022	40693
WEL	207049	20099	0	0
ATH	128321	14764	0	0
MOS	123123	121103	63478	15275
NNC	88386	29290	60	0
ISK	81924	14497	0	0
DJA	80597	49131	10199	0
SOME	77122	26470	4976	0
DDA	76606	11187	0	0
BJI	66183	63959	15263	19836
MDD	63775	11273	0	0
RSNC	59825	4009	0	0
VIE	39046	22095	9797	0
THE	33886	6173	0	0
LDG	22536	3435	3	0
GUC	20902	5121	0	0
HEL	14557	400	0	0
PRU	13666	5598	0	3790
INMG	13522	7644	3645	0
BKK	12888	8180	2596	0
PPT	10834	8908	1135	2863
DMN	10134	9834	0	0
DNK	9847	4271	1599	185
BER	8963	2482	18	0
SKHL	8260	5517	0	0
BGR	7799	7676	5039	0
MAN	7680	1229	0	0
BUC	7469	1702	0	0
WBNET	7094	20	0	0
NIC	6294	2655	0	0
YARS	6234	278	0	0
SSNC	6045	362	0	0
ZUR	6045	1100	0	0
PRE	5792	671	0	0
LJU	5695	221	12	0
BYKL	5268	1768	0	0
SVSA	4926	486	301	0
MRB	4731	28	0	0
NDI	4229	3781	1582	43
BRG	4199	2926	758	0
SNET	3877	1899	0	0
BGS	3837	2986	1163	563

Table 10.3: *Continued.*

Agency	Number of reported amplitudes	Number of amplitudes in ISC located events	Number used for ISC mb	Number used for ISC MS
PDG	3593	2574	0	0
CLL	3098	2832	446	304
SJA	2553	2532	3	0
SKO	2441	333	0	0
IEPN	2112	1871	280	0
LIC	2091	1785	1100	0
NAO	2049	2014	1460	0
ECX	2029	418	0	0
ISN	1918	1744	0	0
HYB	1756	1749	42	0
ASRS	1705	695	0	0
KNET	1697	862	0	0
LVSN	1513	147	0	0
UCR	1510	1437	0	0
OTT	1296	152	0	0
IPEC	1248	215	0	0
THR	838	666	7	0
BELR	810	766	0	294
OSPL	803	259	0	0
IGIL	747	424	126	153
UCC	712	571	349	0
NERS	703	29	0	0
SIGU	596	310	0	0
ATA	540	228	0	0
MOLD	473	305	32	0
WAR	451	447	0	380
KRSZO	351	116	0	0
ISC	297	296	0	0
JSO	294	274	0	0
TIR	230	154	0	0
LIT	182	165	33	0
SCB	122	116	0	0
PLV	61	61	0	0
MIRAS	43	5	0	0
UPA	35	5	0	0
LSZ	23	4	0	0
TEH	5	0	0	0

11

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, 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 10.1.3 of Issue I of the 2014 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 10.1.3 of Issue I of the 2014 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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References

Balfour, N., R. Baldwin, and A. Bird (2008), Magnitude calculations in Antelope 4.10, *Analysis Group Note of Geological Survey of Canada*, pp. 1–13.

Bisztricsany, E. A. (1958), A new method for the determination of the magnitude of earthquakes, *Geofiz. Kozl*, pp. 69–76.

Bondár, I., and D. Storchak (2011), Improved location procedures at the International Seismological Centre, *Geophysical Journal International*, *186*, 1220–1244.

Bormann, P., and J. W. Dewey (2012), The new iaspei standards for determining magnitudes from digital data and their relation to classical magnitudes, is 3.3, *New Manual of Seismological Observatory Practice 2 (NMSOP-2), P. Bormann (Ed.)*, pp. 1–44, doi:10.2312/GFZ.NMSOP-2_IS_3.3,10.2312/GFZ.NMSOP-2, `http://nmsop.gfz-postsdam.de`.

Bormann, P., and J. Saul (2008), The new IASPEI standard broadband magnitude mB, *Seism. Res. Lett*, *79*(5), 698–705.

Bormann, P., R. Liu, X. Ren, R. Gutdeutsch, D. Kaiser, and S. Castellaro (2007), Chinese national network magnitudes, their relation to NEIC magnitudes and recommendations for new IASPEI magnitude standards, *Bulletin of the Seismological Society of America*, *97*(1B), 114–127, doi:10.1785/012006007835.

Bormann, P., R. Liu, Z. Xu, R. Ren, and S. Wendt (2009), First application of the new IASPEI teleseismic magnitude standards to data of the China National Seismographic Network, *Bulletin of the Seismological Society of America*, *99*, 1868–1891, doi:10.1785/0120080010.

Choy, G. L., and J. L. Boatwright (1995), Global patterns of readiated seismic energy and apparent stress, *J. Geophys. Res.*, *100*(B9), 18,205–18,228.

Dziewonski, A. M., T.-A. Chou, and J. H. Woodhouse (1981), Determination of earthquake source parameters from waveform data for studies of global and regional seismicity, *J. Geophys. Res.*, *86*, 2825–2852.

Engdahl, E. R., and A. Villaseñor (2002), Global seismicity: 1900-1999, *International Handbook of Earthquake Engineering and Seismology, International Geophysics series*, *81A*, 665–690.

Engdahl, E. R., R. van der Hilst, and R. Buland (1998), Global teleseismic earthquake relocation with improved travel times and procedures for depth determination, *Bulletin of the Seismological Society of America*, *88*, 722–743.

Gutenberg, B. (1945a), Amplitudes of P, PP and S and magnitude of shallow earthquakes, *Bulletin of the Seismological Society of America*, *35*, 57–69.

Gutenberg, B. (1945b), Magnitude determination of deep-focus earthquakes, *Bulletin of the Seismological Society of America*, *35*, 117–130.

Gutenberg, B. (1945c), Amplitudes of surface waves and magnitudes of shallow earthquakes, *Bulletin of the Seismological Society of America*, *35*, 3–12.

Hutton, L. K., and D. M. Boore (1987), The ML scale in southern California, *Bulletin of the Seismological Society of America*, *77*, 2074–2094.

IASPEI (2005), Summary of magnitude working group recommendations on standard procedures for determining earthquake magnitudes from digital data, `http://www.iaspei.org/commissions/CSOI.html#wgmm`,`http://www.iaspei.org/commissions/CSOI/summary_of_WG_recommendations_2005.pdf`.

IASPEI (2013), Summary of magnitude working group recommendations on standard procedures for determining earthquake magnitudes from digital data, `http://www.iaspei.org/commissions/CSOI/Summary_of_WG_recommendations_20130327.pdf`.

IDC (1999), IDC processing of seismic, hydroacoustic and infrasonic data, *IDC Documentation*.

Kanamori, H. (1977), The energy release in great earthquakes, *J. Geophys. Res.*, *82*, 2981–2987.

Lee, W. H. K., R. Bennet, and K. Meagher (1972), A method of estimating magnitude of local earthquakes from signal duration, *U.S. Geol. Surv.*, Open-File Rep.

Nuttli, O. W. (1973), Seismic wave attenuation and magnitude relations for eastern North America, *J. Geophys. Res.*, *78*, 876–885.

Richter, C. F. (1935), An instrumental earthquake magnitude scale, *Bulletin of the Seismological Society of America*, *25*, 1–32.

Ringdal, F. (1976), Maximum-likelihood estimation of seismic magnitude, *Bulletin of the Seismological Society of America*, *66*(3), 789–802.

Tsuboi, C. (1954), Determination of the Gutenberg-Richter's magnitude of earthquakes occurring in and near Japan, *Zisin (J. Seism. Soc. Japan)*, *Ser. II*(7), 185–193.

Tsuboi, S., K. Abe, K. Takano, and Y. Yamanaka (1995), Rapid determination of Mw from broadband P waveforms, *Bulletin of the Seismological Society of America*, *85*(2), 606–613.

Vaněk, J., A. Zapotek, V. Karnik, N. V. Kondorskaya, Y. V. Riznichenko, E. F. Savarensky, S. L. Solov'yov, and N. V. Shebalin (1962), Standardization of magnitude scales, *Izvestiya Akad. SSSR.*, *Ser. Geofiz.*(2), 153–158, pages 108–111 in the English translation.

Woessner, J., and S. Wiemer (2005), Assessing the quality of earthquake catalogues: estimating the magnitude of completeness and its uncertainty, *Bulletin of the Seismological Society of America*, *95*(2), doi:10/1785/012040,007.

Case Study
Structural Monitoring
Second Penang Bridge
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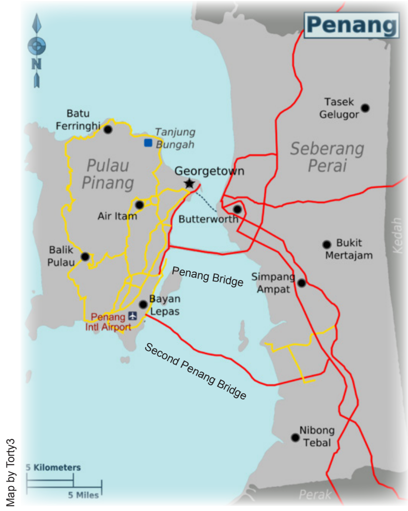
Background

The Second Penang Bridge is a 24 km bridge linking Penang Island to Penang in mainland Malaysia. The E28 expressway crosses the dual carriageway toll bridge, which is 30 m above water. It's the second link to Penang Island after Penang Bridge. Construction began in November 2008 and was completed in February 2014, with the opening ceremony on 1 March 2014.

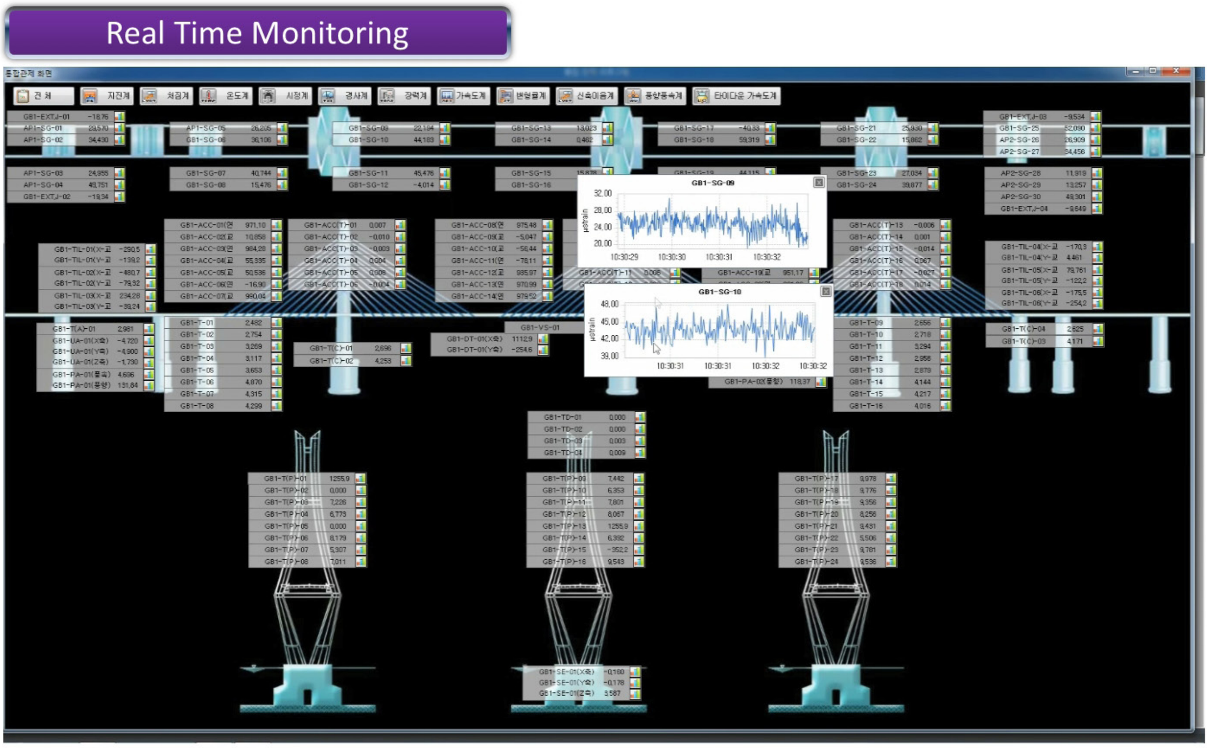
Challenge

The Second Penang Bridge is the longest bridge in Malaysia. Although the Malay Peninsula is located on a stable part of the Eurasian Plate, according to historical records the earthquakes that influence the Malay Peninsula originate from two earthquake faults: Sumatran subduction zone and Sumatran fault. For the safety of bridge users and as protection of such an investment, the firm responsible for the bridge wanted a structural health monitoring system (SHMS).

The SHMS is used for disaster control, structural health management and data analysis. There were many considerations before implementation which included: force (wind, earthquake, temperature, vehicles); weather (air temperature, wind, humidity and precipitation); and response (strain, acceleration, cable tension, displacement and tilt).



The Second Penang Bridge is the second link to Penang Island.



The Second Penang Bridge is a dual carriageway bridge crossed by the E28 expressway. At 24 km, it is Malaysia's longest bridge.

Photo by Marufish

Solution

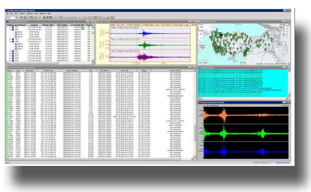
Such a high profile project required a company with extensive background in this area. Our Partner in South Korea, EJtech, focuses on top-level civil engineering, measurement, surveying, assessment and instrument sales. They have been successfully implementing solutions for their clients since their founding in 1994.

The SHMS they implemented included instrumentation from GeoSIG: 10 x GMSplus measuring systems with GPS receivers, 2 x CR-6plus modular multichannel recording systems with GPS receivers, 26 x AC-72-HV biaxial force balance accelerometers, 9 x AC-72-H accelerometers, 1 AC-73 accelerometer, and GeoDAS software.

Bridge management have access to a wealth of data with real-time monitoring of anemometers, accelerometers, temperature sensors, static strain gauges, dynamic strain gauges, GPS, inclinometer, displacement transducers, buffer sensors, bearing sensors, cable tension meter, weather station, corrosion cells, digital video cameras, and speed radar -- all of which are easily accessible with the DAQ software. The SHMS is not only a boon during the time of an SMS event, but following an event it can be used to inspect the site and monitor abnormalities, as well as be used for measurement and analysis of the solution.

Another Solution using GeoSIG instruments and a capable Partner effectively showing that quality and reliability can also be cost-effective.

GMS^Plus



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Gecko Compact

Gecko Rugged

Gecko SMA or Blast

Gecko SMA-HR

Gecko Prism, Helix or Blast-HR

Model	Features *(applies to all models)*	Price
Compact	40Vpp, 142dB RMS-FS, 32-bit ADC	★½
Rugged	gain x1 to x256, 40sps to 4000sps	★★
- comparative price of leading-brand competitors:		★★★

Model	Sensitivity	Frequency	Price
Blast	28.8V/m/s	4.5Hz to 1kHz+	★★
SMA	2g to 400g full scale	DC to 400Hz+	★★½
Blast-HR	78.74V/m/s	2Hz to 1kHz+	★★★
SMA-HR	2g or 4g full scale	DC to 100Hz	★★★½
Helix	400V/m/s	1Hz to 100Hz	★★★★½
Prism	868V/m/s	30sec to 80Hz	★★★★★

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