Data Collection at the International Seismological Centre

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INTRODUCTION

The International Seismological Centre (ISC) prepares a global seismicity catalog that is intended to represent a comprehensive summary of hypocenters and phase readings for all sufficiently large earthquakes. There is no firm definition of "sufficiently large" and in practice the completeness threshold varies from place to place [*Willemann*, 1999]. But the original intention was to relieve seismologists of the need to gather readings from multiple sources and re-compute locations as part of individual research projects. At a minimum, therefore, the ISC aims to include all earthquakes in its Bulletin that might be recorded by more than one independently operated network. Thus, the mission of the ISC has grown as data collection becomes more comprehensive (Figure 1).

The completeness of the ISC Bulletin, in terms of both earthquakes and phase readings, is essential to its utility for research. Completeness is facilitated by the ISC's status as a non-governmental, non-profit organization in working relations with UNESCO and by waiting nearly two years for final analyses of regional and national bulletins from around the world. As a result, the ISC Bulletin includes more than twice as many earthquakes annually as any other global seismicity catalog, and for most earthquakes more phase readings. The cumulative Bulletin database thus is the preferred resource for a variety of global and broad regional studies in seismology ranging from seismicity [*e.g.*, *Engdahl et al.*, 1998] to tomography [*e.g.*, *Bijwaard et al.*, 1998; *van der Hilst et al.*, 1997].

The enormous task of producing a comprehensive global bulletin is accomplished by building on, rather duplicating, the analysis that is carried out at individual stations and networks. The sources from which data analyses are collected and the means by which they are integrated into a processing system limit the completeness and accuracy of the

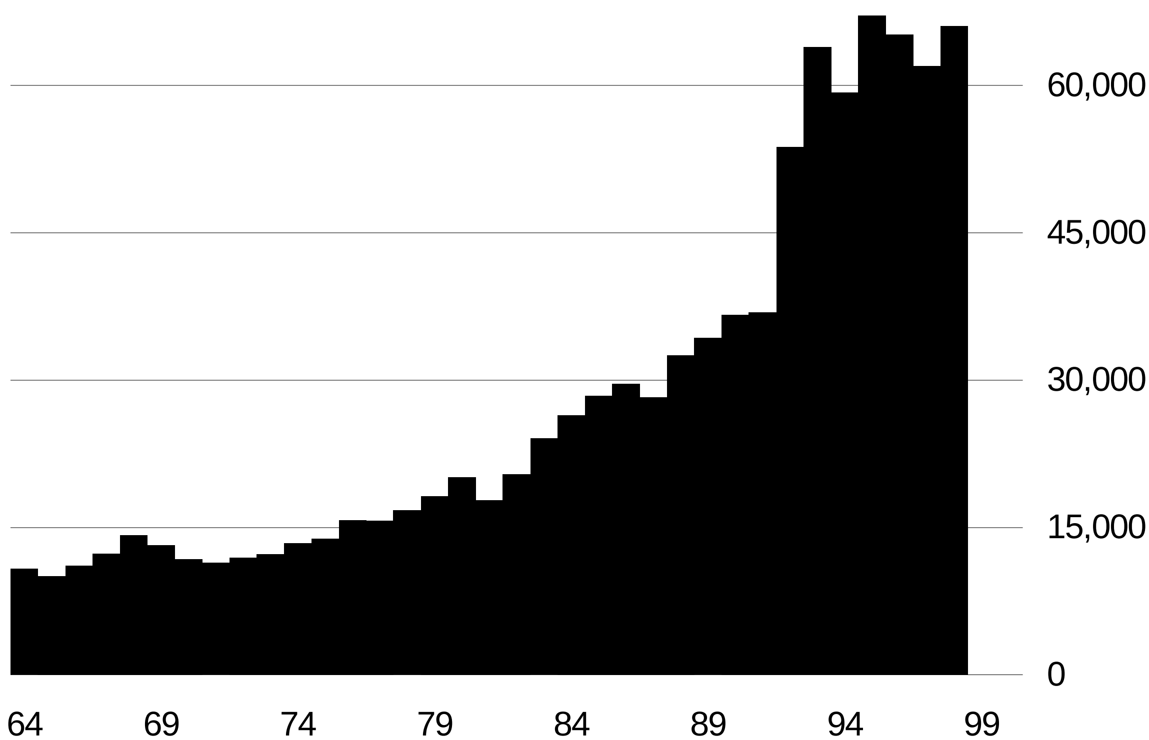

Figure 1. Number of events (earthquakes and explosions) in the ISC Bulletin from 1964 to 1998. The number for 1998 is estimated from the number during January – September.

ISC Bulletin. Our purpose in this paper is to explain the system in order to help seismologists understand these limitations and avoid misinterpretions.

DATA SOURCES

Registered Stations

Readings are used only from "registered" stations, *i.e.*, those appearing in the station list maintained jointly by the ISC and the World Data Center for Seismology, Denver (WDC), which is operated by the US National Earthquake Information Center (NEIC). Nearly 10,000 station codes are registered, even though there is no requirement for any agency to participate in the registration program. Indeed, the vast majority of seismic stations are operated without being registered internationally. The ISC and WDC encourage registrants to provide the most complete information possible about each station. In order to encourage registration, however, the only information required for registration is a reliable statement of the station's latitude and longitude. In many cases therefore, stations are registered without information about timing systems or sensors. Readings from these stations, including the operator's arrival time picks and measurements of ground-motion amplitude, nevertheless are included in the Bulletin and are used to compute hypocenters and magnitudes.

The primary purpose of the station list is to ensure unique station codes, which are 3 to 5 character alphanumeric sequences that identify each station in an international context. To fulfill this purpose, no station code from which even a single reading has ever been received by ISC or WDC is ever re-used. (Codes are sometimes reserved in anticipation of a station being installed. If the same code is requested for another station years later and no data or confirmation of installation of the first station were ever received, ISC and WDC occasionally agree to re-use a previously reserved code.)

When a station is closed, its registration must remain in the list in order to find the locations of stations in back issues of bulletins from their codes. If a station operator informs the ISC or WDC that a station is no longer in operation and that operations are not expected to resume, then it is marked as closed in the list. Of course, stations are occasionally re-opened, for example if an agency obtains new funding to install new sensors in the same vault or simply to resume operations with the existing sensors. Presently, 1504 codes are marked closed.

The number of registered codes that are not marked closed has grown by 1566 since the beginning of 1997 to 8024 in total, but this exaggerates the number of stations from which readings may be expected. A unique code is registered for each element of some arrays in order to ensure that the waveforms from each element remain identifiable, while readings from an array are normally attributed either to a code for the array beampoint or for the nearest array element. Setting aside all but one code from each array and the stations marked closed, there are 6673 separate registered stations in the list that may be operating now.

Reporting Stations

The number of stations for which readings are actually received has varied within a narrow range over the last few years (Figure 2), but this does not mean that the same

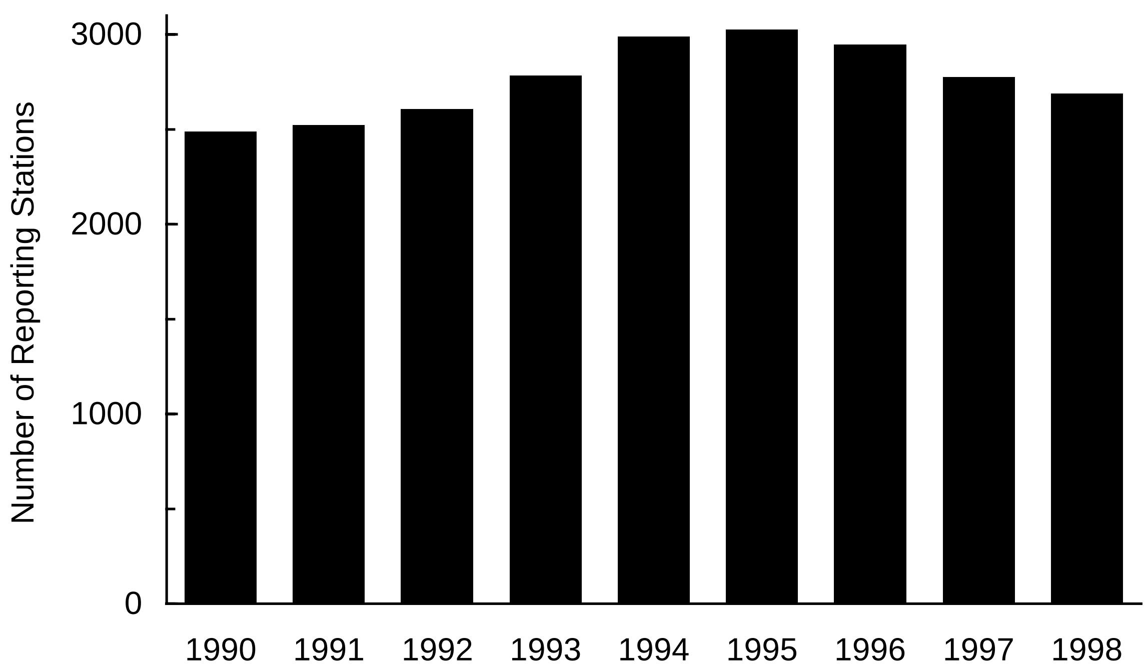

Figure 2. Number of stations with readings in the ISC Bulletin from 1990 to 1998.

stations continue to report. For example, around 2780 stations reported readings in each of 1993 and in 1997 but only 1904 stations reported in both of those years. In other words, nearly one out of three stations had been replaced by another in just four years. It is likely that reports attributed to a few station codes stopped as the result of assigning a new station code, for example after re-locating from a site that had grown too noisy. Nevertheless, there is clearly a sufficient turnover in reporting stations that changes in geographic, depth, or magnitude distributions must be interpreted carefully to avoid confusing anthropogenic artifacts with genuine changes in the behavior of the Earth.

The geographic distribution of reporting stations is extremely nonuniform. Averaged over each of the 728 Flinn-Engdahl geographic regions, station densities vary from more than 500 stations per 10^6km^2 (which corresponds to a station spacing 45 km) within the regions of California to, inevitably, 0 in oceanic regions without permanent stations (Figure 3). Wealth clearly has a significant role in controlling station distribution, explaining, for example the absence of stations across much of Africa. Where seismic risk is great, however, station density sufficient for adequate monitoring can been achieved despite limited local resources, as evidenced by Central America and parts of western South America. Among seismically active regions, the low density of reporting stations in many parts of Asia is striking, especially since much of the region is actually well monitored locally.

Averages over the 50 broader Flinn-Engdahl seismic regions provide information about station densities with lower resolution but are sufficiently concise to also examine trends over time (Table 1). Coverage of far northeastern Asia has improved substantially, resulting in an increased average density in Japan-Kurils-Kamchatka (region 19). But in other parts of Asia reporting has either not improved through the 1990s or even grown significantly worse. For example, station density fell between 1990 and 1997 from 15.1 to 4.1 per 10^6km^2 in Hindu Kush-Pamir (region 48) and from 4.5 to 1.6 per 10^6km^2 in Southeast Asia (region 25). Unfortunately, a decreasing density of reporting stations is not limited to Asia; over the 1990s it has fallen by 2/3 in Fiji Area (region 13) and by half in Mexico-Guatemala Area (region 5). The decline in reporting is such that even in Eastern North America (region 34) average station density is no longer much better than merely adequate (12.7 stations per 10^6km^2, or a spacing of 280 km), although this is an average across an area with a wide range of population density and accessibility.

Contributors

Organizations reading records from networks of stations and, usually, associating the readings at least with local or regional events and computing a preliminary location have an effect on the ISC bulletin that is comparable to the distribution of reporting stations. This effect arises, most importantly, because networks without regular, high-quality record reading contribute less than they otherwise would to global seismic monitoring. In addition, more than 99% of all events in the ISC Bulletin are based partly on preliminary locations from other agencies.

Similar to the station registry, the ISC maintains a list of agencies that have reported hypocenters to the ISC, assigning a three- to five-letter code for each agency. Each hypocenter in the ISC Bulletin is attributed to one of the registered agencies using these codes and, just as with station codes, agency codes are never re-used to avoid the possibility of ambiguity in attributing a hypocenter to an agency. Presently, there are 264 registered agencies but, again as with stations, many of the codes are disused. In the 1997 Bulletin, there are hypocenters attributed to 61 agencies apart from the ISC (Table 2), including several that do not contribute data directly to the ISC. The number of agencies with reported hypocenters in the Bulletin is less than the number of data contributors since some report only phase readings. Most contributors who do not report their own hypocenters send unassociated phase readings, although a few associate their readings with hypocenters from well-known catalogs such as the Preliminary Determination of Epicenters (PDE) of the US National Earthquake Information Center (NEIC) or Centroid-Moment Tensor (CMT) catalog of Harvard Univ.

For most agencies, the ISC uses hypocenters only within or near their station networks, but in six cases we use their hypocenter all around the world (Table 2). Each of these six is an important resource, providing preliminary locations that the ISC uses in areas where local monitoring is absent or not reported. Except perhaps in regions of special interest, however, Moscow (MOS), Beijing (BJI) and Harvard (HRVD) use further data to compute refined or additional source parameters for previously reported events. Norsar Array Observatory (NAO) locations, on the other hand, are based exclusively on Norsar Array data and so are limited in number and subject to large uncertainties.

Thus, only NEIC and the Experimental International Data Center (EIDC) aim to be comprehensive in reporting preliminary hypocenters around the world, and their bulletins are especially important in preparing the ISC Bulletin. NEIC is the most important contributor of phase arrivals, providing more than 80,000 arrivals in a typical month, including many that are reported too late to be included in NEIC's final re-analysis for their "Monthly PDE". Further, NEIC and EIDC each computes a preliminary location for more than 40% of the events that will appear in the ISC Bulletin. Since the events already identified by NEIC or EIDC are generally large, they are widely recorded and so their preliminary locations are even more helpful than might otherwise be expected. For example 69% of all phases in the 1997 ISC Bulletin were associated with events with a preliminary location from NEIC. Although fewer phases were associated with events with EIDC preliminary locations (62%), this is at least partly because the EIDC bulletin is strong in regions where local data are unavailable, such as mid-ocean ridges. In fact, EIDC reported a preliminary location for 86% of all $m_b \geq 4$ events in the ISC Bulletin of 1997 events versus 74%

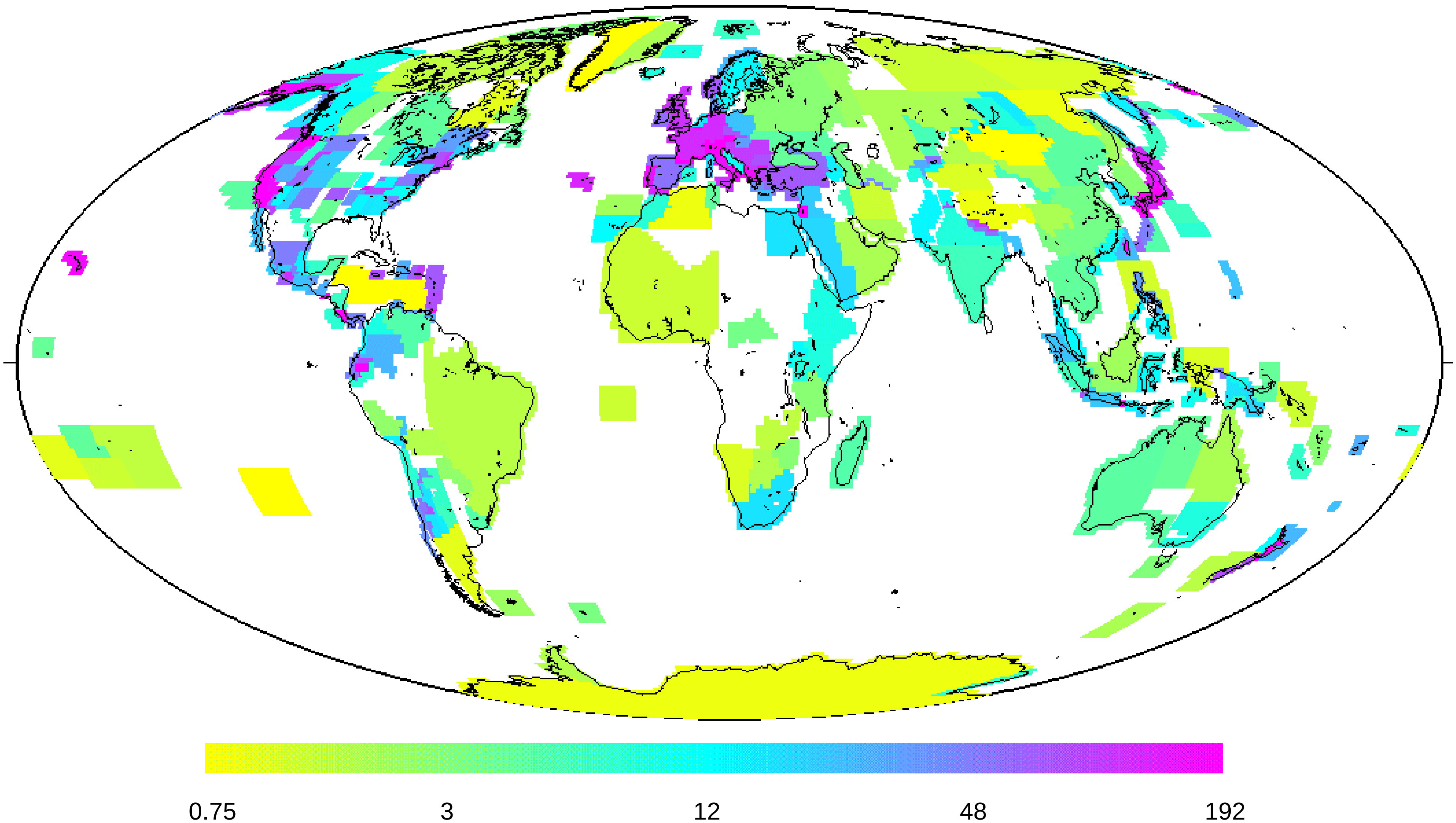

Figure 3. Geographic density of seismic stations with readings in the ISC Bulletin of seismic events in 1997, averaged over Flinn-Engdahl geographic regions.

TABLE 1 Geographic Densit of Seismic Station with Reading in the ISC Bulletin of Seismic Event in 1990 to 1997
(averaged over Flinn-Engdahl seismic regions)

Flinn-Engdahl Seismic Region		Number of Reporting Stations per Million Square Kilometers							
No.	Name	1990	1991	1992	1993	1994	1995	1996	1997
17	Caroline Islands to Guam								
44	Galapagos Area								
45	Macquarie Loop								
33	Indian Ocean	.1	.1						
43	Southeastern and Antarctic Pacific			.1	.1	.1			
10	Southern Antilles	.1	.1	.1	.2	.2	.1	.2	.4
9	Extreme South America	.4	.4	.4	.4	.8	.8	.4	.4
32	Atlantic Ocean	.1	.1	.1	.4	.4	.4	.4	.4
12	Kermadec-Tonga-Samoa Area	.5	.8	.5	.5	.5	.5	.5	.5
39	Pacific Basin	.9	1.0	1.0	.9	.9	.9	.7	.7
50	Antarctica	.6	.8	.8	.8	.8	.7	.9	.9
40	Arctic Zone	1.5	1.3	1.5	1.4	1.3	1.5	1.4	1.3
14	Vanuatu (New Hebrides)	1.3	1.3	1.3	1.3	2.2	1.8	1.8	1.3
15	Bismarck and Solomon Islands	2.4	1.9	1.9	1.9	1.9	1.4	1.9	1.4
35	Eastern South America	1.2	1.5	1.2	1.9	2.1	1.7	1.5	1.5
25	Myanmar and Southeast Asia	4.5	4.8	4.1	4.3	1.6	2.3	1.8	1.6
42	NE Asia, N. Alaska to Greenland	2.0	1.9	2.0	2.0	1.7	1.7	1.9	1.6
38	Australia	1.7	1.9	1.9	1.8	1.7	1.8	2.0	1.8
27	Southern Xinjiang to Gansu	1.9	1.9	1.9	1.5	1.5	1.5	1.9	1.9
49	Northern Eurasia	2.2	1.8	2.3	2.6	2.0	2.6	2.7	2.2
29	Western Asia	4.7	4.3	3.1	2.8	2.7	2.4	2.5	2.4
37	Africa	2.6	2.8	2.8	2.9	3.0	2.7	2.9	3.0
13	Fiji Area	9.1	8.4	6.8	6.1	6.8	3.0	2.3	3.0
41	Eastern Asia	2.3	2.4	2.4	2.4	2.3	2.4	3.2	3.1
18	Guam to Japan	2.2	2.6	4.3	5.2	5.2	6.5	4.8	3.9
23	Borneo-Sulawesi	2.8	4.4	4.4	4.0	4.0	4.4	4.4	4.0
48	Hindu Kush and Pamir	15.1	9.9	9.9	2.3	2.3	2.9	3.5	4.1
28	Alma-Ata to Lake Baikal	3.9	4.4	4.4	4.5	3.6	3.9	3.9	4.7
16	New Guinea	2.4	3.8	4.5	4.5	4.5	4.8	6.2	5.2
4	Baja and Gulf of California	5.2	5.2	5.9	4.5	4.5	3.0	.7	5.2
24	Sunda Arc	2.5	5.6	5.8	6.5	6.3	6.3	5.6	6.1
26	India-Xizang-Szechwan-Yunnan	6.5	6.2	5.4	5.7	6.5	7.0	4.3	6.5
46	Andaman Islands to Sumatera	3.5	4.8	7.4	7.4	6.5	6.1	5.6	6.5
5	Mexico-Guatemala Area	13.0	14.6	9.5	11.1	10.5	8.3	8.3	7.0
22	Philippines	4.5	8.7	6.8	7.6	6.8	6.8	6.8	7.2
47	Baluchistan	9.8	8.8	7.8	7.8	7.8	7.8	7.8	7.8
8	Andean South America	6.8	6.7	6.5	6.1	9.7	9.5	9.1	8.9
34	Eastern North America	18.6	16.4	17.3	17.6	16.3	17.3	13.3	12.7
11	New Zealand Region	19.0	18.3	17.0	17.2	16.7	16.5	16.5	14.0
7	Caribbean Loop	17.3	18.1	17.5	19.0	16.7	19.2	16.2	16.0
1	Alaska-Aleutian Arc	16.3	15.1	15.9	16.6	17.6	17.1	21.3	21.2
6	Central America	22.6	18.5	25.2	26.2	24.2	20.1	21.1	22.6
20	SW Japan and Ryukyu Islands	26.1	26.1	27.7	27.7	50.9	34.1	30.9	29.7
31	Western Mediterranean Area	35.3	37.4	38.8	38.8	37.7	38.2	39.4	37.2
2	E. Alaska to Vancouver Island	45.2	45.7	45.7	45.4	44.4	44.6	39.8	40.3
19	Japan-Kurils-Kamchatka	32.9	33.2	34.6	35.9	42.0	57.4	45.3	43.0
21	Taiwan	38.0	38.0	45.6	33.7	41.3	42.4	45.6	43.4
30	Middle East-Crimea-E. Balkans	41.2	42.3	44.9	42.1	42.1	46.3	52.6	47.4
36	Northwestern Europe	65.7	68.9	72.3	65.7	68.9	68.7	79.5	77.3
3	California-Nevada Region	46.5	54.2	69.0	148.1	208.1	208.1	202.2	157.8

TABLE 2.
Summary of Organizations Contributing Hypocenters or Readings Used in the ISC Bulletin of Seismic Events in 1997

North America					**Hypocentres**					**Stations**				
Code	**Name**	**Country**	**Typ**	**Criteria**	**No.**	**Latitude**		**Longitude**		**No.**	**Latitude**		**Longitude**	
OTT	Geological Survey of Canada	Canada	BU		72	36.5˚	78.8˚	-137.3˚	-34.8˚	295	41.7˚	74.7˚	-156.0˚	-57.5˚
PGC	Pacific Geoscience Centre, GSC	Canada	BU		195	47.4˚	76.7˚	-147.3˚	-101.8˚					
ECX	CICES de Ensenada	Mexico	C	$M \geq 3$	185	18.9˚	35.4˚	-118.7˚	-107.3˚	0				
MEX	Instituto de Geofisica, UNAM	Mexico	BU	$M \geq 3$	904	13.0˚	25.6˚	-110.0˚	-89.7˚	42	14.9˚	24.1˚	-110.3˚	-88.3˚
NEIC	Nat. Earthquake Info. Ctr., USGS	USA	BUM		19839	worldwide				2100	worldwide			
HRVD	Harvard University	USA	CM		831	worldwide				0	worldwide			
EIDC	Prototype International Data Ctr	USA	B		19984	worldwide				97	worldwide			
UWASH	University of Washington	USA	A							35	worldwide			
ASL	Albuquerque Seismic Lab., USGS	USA	A							90	worldwide			
SIO	Scripps Institute of Oceanography	USA	A							35	worldwide			
TUL	University of Tulsa	USA	C		116	34.0˚	36.2˚	-99.6˚	-95.3˚	0				

Central & South America					**Hypocentres**					**Stations**				
Code	**Name**	**Country**	**Typ**	**Criteria**	**No.**	**Latitude**		**Longitude**		**No.**	**Latitude**		**Longitude**	
CASC	Central Amer. Seismic Center	Costa Rica	B							87	-16.3˚	15.1˚	-92.1˚	-68.1˚
TRN	Seis. Res. Unit, U. of West Indies	Trinidad	CU		898	9.0˚	19.5˚	-72.9˚	-57.7˚	59	8.8˚	18.5˚	-68.8˚	-60.7˚
BAA	Instituto de Prevencion Sismica	Argentina	U							1	-34.9˚		-57.9˚	
BRAZL	Inst. Astronomico e Geofisico	Brazil	U							14	-30.1˚	-8.8˚	-51.1˚	-38.4˚
GUC	Seismol. Service, Univ. de Chile	Chile	CU		1700	-39.1˚	-28.0˚	-75.6˚	-66.1˚	13	-34.6˚	-32.7˚	-71.6˚	-70.3˚
BOG	Inst. Geofisico, Univ. Javeriana	Colombia	U							1	4.6˚		-74.1˚	
IGQ	Escuela Politecnica Nacional	Ecuador	CU		377	-6.8˚	9.5˚	-83.3˚	-73.6˚	31	-2.2˚	1.3˚	-81.0˚	-77.5˚
NNA	Instituto Geofisico del Peru	Peru	U							1	-12.0˚		-76.8˚	

Europe					**Hypocentres**					**Stations**				
Code	**Name**	**Country**	**Typ**	**Criteria**	**No.**	**Latitude**		**Longitude**		**No.**	**Latitude**		**Longitude**	
TIR	Seismological Inst., Acad. of Sci.	Albania	BU		194	39.1˚	42.7˚	10.2˚	21.6˚	13	39.9˚	42.4˚	19.5˚	20.8˚
VIE	Central Inst. for Met. and Geodyn.	Austria	U							10	46.5˚	48.3˚	11.1˚	16.3˚
UCC	Royal Observatory	Belgium	CU		39	49.1˚	51.4˚	4.5˚	8.1˚	5	49.7˚	50.8˚	4.3˚	6.2˚
SOF	Geophys. Inst., Acad. of Sci.	Bulgaria	CU		100	39.0˚	43.8˚	21.0˚	27.7˚	12	41.6˚	43.7˚	23.1˚	28.2˚
ZAG	Dept. of Geophys., Univ. Zagreb	Croatia	CU		10	44.9˚	45.9˚	14.5˚	16.3˚	5	43.2˚	45.9˚	14.4˚	16.4˚

The types of data supplied are indicated by B for a bulletin (*i.e.*, phase reading associated with hypocenters computed from them), C for a catalog (*i.e.*, hypocenters alone), U for unassociated phase readings, A for phase readings associated with hypocenters from other bulletins, and M for moment tensors. For a few organizations that contribute data for events to very low magnitudes, we give criteria used to select data for reanalysis and reprinting. Where a minimum magnitude is given, data are used for earthquakes with any type of magnitude at or above the threshold. Locations that are uncertain due to an azimuthal gap greater than 270° are excluded where the criteria include “az”. Some contributors operating geographically restricted networks identify events as local, regional or teleseismic, and we indicate with “loc” or “reg” where our selection criteria are based partly on the contributor’s event identification.

TABLE 2.
Summary of Organizations Contributing Hypocenters or Readings Used in the ISC Bulletin of Seismic Events in 1997

Europe (continued)					**Hypocentres**					**Stations**				
Code	**Name**	**Country**	**Typ**	**Criteria**	**No.**	**Latitude**		**Longitude**		**No.**	**Latitude**		**Longitude**	
NIC	Geological Survey	Cyprus	BU							10	29.7°	35.2°	32.3°	35.4°
PRA	Geophys. Inst., Acad. of Sci.	Czech Rep.	U							4	49.1°	50.4°	13.6°	18.1°
COP	Office of Seismology, KMS	Denmark	U							6	55.1°	76.8°	-22.0°	14.9°
HEL	Inst. of Seismology, U. Helsinki	Finland	CU	*M*≥2	72	57.0°	76.6°	-8.7°	57.7°	12	60.0°	69.8°	22.7°	31.3°
LDG	Lab. de Detection et de Geophys.	France	BU		2178	34.0°	60.7°	-18.9°	21.6°	29	42.9°	50.1°	-3.3°	7.4°
STR	Institute de Physique du Globe	France	BU	*M*≥3 & loc	327	35.5°	56.4°	-8.2°	20.7°	88	40.8°	50.6°	-4.1°	9.4°
BUG	Detp. Geophys., Ruhr Univ.	Germany	CU		229	51.5°	51.7°	6.5°	7.9°	1	51.4°		7.3°	
BREMR	Alfred Wegener Institute	Germany	U							4	-71.7°	-70.7°	-9.7°	-2.8°
CLL	Collm Observatory, Leipzig Univ.	Germany	U							1	51.3°	51.3°	13.0°	13.0°
SZGRF	Seismol. Central Obs. Grafenberg	Germany	BU		317	43.3°	56.6°	4.1°	18.8°	58	46.9°	52.3°	6.2°	13.9°
LEDBW	Geol. Land. Baden-Wuerttemberg	Germany	C		88	42.2°	50.4°	6.6°	13.6°	16	47.5°	49.9°	7.1°	10.2°
JEN	Geodynamic Obs. Moxa, U. Jena	Germany	U							1	50.7°		11.6°	
CSEM	Inst. Geosci., Univ. of Potsdam	Germany	M		9	33.8°	43.1°	12.8°	59.9°	0				
ATH	National Observatory of Athens	Greece	B		3227	34.0°	41.9°	19.0°	29.0°	21	35.3°	41.1°	19.8°	29.6°
THE	Aristotle University,Thessaloniki	Greece	BU		2210	34.0°	45.1°	12.7°	32.4°	53	29.7°	41.2°	19.8°	35.7°
DIAS	Dublin Inst. for Advanced Studies	Ireland	U							6	52.2°	53.9°	-7.3°	-6.2°
ROM	Inst.Nazionale di Geofisica, Rome	Italy	CU		3723	33.9°	47.6°	5.3°	25.9°	57	36.8°	46.6°	6.7°	18.1°
TRI	Univ. degli Studi di Trieste	Italy	U							1	45.7°		13.8°	
SKO	Skopje Sesimological Obs.	FYR Macedonia	BU		66	40.9°	42.2°	20.4°	22.6°	3	41.1°	42.0°	20.8°	22.6°
DBN	Royal Netherlands Met. Inst.	Netherlands	U							4	50.8°	52.8°	5.9°	6.8°
BER	Inst. Solid Earth Phys., Bergen U.	Norway	BU	*M*≥2.5 | loc	1355	55.0°	82.2°	-17.2°	61.6°	37	48.8°	78.9°	-8.7°	33.0°
NAO	NORSAR	Norway	CU		3892		worldwide			1	61.0°		11.2°	
WAR	Inst. of Geophysics, Acad. of Sci.	Poland	CU		244	50.0°	53.4°	15.3°	20.5°	6	49.4°	54.0°	16.3°	23.2°
ADH	Inst.de Meteorologia, Azores U.	Portugal	BU		447	36.0°	40.7°	-49.8°	-17.8°	32	-21.2°	39.8°	-31.2°	55.6°
LIS	Instituto de Meteorologia	Portugal	BU		449	33.2°	43.9°	-30.5°	-0.2°	28	32.7°	41.8°	-16.9°	-6.7°
BUC	National Inst. for Earth Physics	Romania	CU		303	43.4°	46.6°	22.5°	29.0°	9	44.3°	46.2°	25.5°	28.2°
BRA	Geophys. Inst., Acad. of Sci.	Slovakia	U							2	47.8°	48.2°	17.1°	18.3°

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TABLE 2.
Summary of Organizations Contributing Hypocenters or Readings Used in the ISC Bulletin of Seismic Events in 1997

Europe (continued)					**Hypocentres**					**Stations**				
Code	**Name**	**Country**	**Typ**	**Criteria**	**No.**	**Latitude**		**Longitude**		**No.**	**Latitude**		**Longitude**	
LJU	Geophysical Survey	Slovenia	BU		375	24.9°	47.3°	12.2°	85.5°	7	45.5°	46.6°	13.9°	15.5°
MDD	Instituto Geográfico Nacional	Spain	BU	*M*≥3 & loc	1309	27.2°	46.5°	-19.3°	10.6°	128	27.7°	48.3°	-18.0°	9.0°
EBR	Observatori de L'Ebre	Spain	U							1	40.8°		0.5°	
FBR	Fabra Observatory, Barcelona	Spain			7	41.7°	43.0°	0.2°	2.8°	0				
UPP	Dept. of Earth Sci., Uppsala Univ.	Sweden	CU		3	58.8°	65.3°	15.1°	22.5°	3	59.9°	67.8°	17.6°	20.4°
ZUR	Swiss Seismological Service	Switzerland	CU	*M*≥2 & az	57	45.7°	47.8°	6.0°	10.6°	12	46.1°	47.8°	6.9°	10.1°
ISK	Kandilli Obs., Bogazici Univ.	Turkey	CU		3238	32.9°	45.8°	22.5°	44.6°	41	35.1°	42.0°	26.3°	43.4°
ANK	General Dir. of Disaster Affairs	Turkey	U							18	36.5°	41.5°	27.2°	38.4°
IST	Mines Faculty, Istanbul Tech. U.	Turkey	U							0				
BGS	British Geological Survey	UK	CU		21	49.3°	66.4°	-5.7°	6.3°	57	49.2°	60.1°	-7.3°	1.0°
EKA	Blacknest Data Analysis Ctr, AWE	UK	U							1	55.3°		-3.2°	
LEEDS	School of Earth Sci., Univ. Leeds	UK	U							7	53.5°	54.7°	-1.9°	-0.3°
BEO	Seismological Institute	Yugoslavia	CU							1	44.8°		20.5°	
PDG	Montenegro Seismological Obs.	Yugoslavia	BU		593	34.7°	46.3°	12.2°	29.1°	9	42.0°	43.3°	18.5°	20.0°

Africa					**Hypocentres**					**Stations**				
Code	**Name**	**Country**	**Typ**	**Criteria**	**No.**	**Latitude**		**Longitude**		**No.**	**Latitude**		**Longitude**	
ARO	Observatoire Geophysique d'Arta	Djibouti	B		120	9.9°	15.2°	40.2°	43.9°	0				
CAIRO	Nat. Res. Inst. Astron. & Geophys.	Egypt	U							0				
EAF	East African Federation		BU	*M*≥3 & reg						11	-20.1°	15.4°	28.6°	38.9°
LIC	Station Geophysique de Lamto	Ivory Coast	U		1	5.8°	5.8°	0.2°	0.2°	0				
TAN	Inst & Obs Geophys D'Antananarivo	Malagasy Rep.	U							5	-19.8°	-18.6°	47.0°	47.7°
RBA	Inst. Sci, Univ. Mohammed V	Morocco	U		40	30.4°	37.3°	-11.2°	-1.6°	0				
PRE	Council for Geoscience	South Africa	BU	*M*≥2.5 & az	285	-29.4°	-25.7°	26.6°	34.6°	27	-33.9°	-22.3°	17.9°	31.1°
BUL	Goetz Observatory,Bulawayo	Zimbabwe	U							1	-20.1°		28.6°	
NAI	Geology Dept, Univ. of Nairobi	Kenya			151	-19.5°	30.3°	27.5°	49.5°	15	-20.1°	15.4°	28.2°	38.9°

Middle East					**Hypocentres**					**Stations**				
Code	**Name**	**Country**	**Typ**	**Criteria**	**No.**	**Latitude**		**Longitude**		**No.**	**Latitude**		**Longitude**	
IPRG	Geophysical Institute	Israel	B		447	27.2°	35.9°	32.0°	36.9°	33	29.6°	34.4°	34.4°	37.2°
JSO	Seismol. Obs., Natural Res. Auth.	Jordan	BU		431	27.4°	35.3°	27.4°	37.4°	17	29.4°	32.5°	35.1°	38.4°

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TABLE 2.
Summary of Organizations Contributing Hypocenters or Readings Used in the ISC Bulletin of Seismic Events in 1997

Middle East (continued)

Code	Name	Country	Typ	Criteria	Hypocentres No.	Hypocentres Latitude		Hypocentres Longitude		Stations No.	Stations Latitude		Stations Longitude	
TEH	Inst. of Geophys., Tehran Univ.	Iran	U							1	38.1°		46.3°	
KSA	National Geophysical Centre	Lebanon	U							1	33.9°		35.7°	
RYD	King Saud University	Saudi Arabia	BU	*M*≥3 | reg	585	9.6°	41.7°	20.5°	71.2°	25	16.9°	29.3°	34.8°	50.1°
DHMR	National Seismol. Observatory	Yemen	BU	*M*≥3	212	11.2°	16.8°	41.3°	45.9°					

Russia, FSU and Asia

Code	Name	Country	Typ	Criteria	Hypocentres No.	Hypocentres Latitude		Hypocentres Longitude		Stations No.	Stations Latitude		Stations Longitude	
NDI	India Meteorological Department	India	BU	*M*≥3.0 & az	130	5.9°	42.8°	53.4°	96.9°	55	8.5°	33.2°	69.7°	93.9°
HYB	Hyderabad	India	U							1	17.4°		78.6°	
DJA	Met. and Geophys. Agency	Indonesia	B	*M*≥2.5 & az	1055	-13.1°	6.9°	92.2°	143.2°	42	-9.7°	5.5°	95.3°	140.7°
NEPAL	National Seismol Ctr, Kathmandu	Nepal	U							17	26.9°	29.5°	80.6°	87.7°
BJI	China Seismological Bureau	China	B		5190	worldwide				24	23.1°	44.6°	76.0°	129.6°
TAP	Taiwan Weather Bureau	Taiwan	BC	*M*≥3.0	1659	21.0°	25.7°	119.1°	123.0°	28	21.9°	25.3°	118.4°	122.0°
HKC	Hong Kong Observatory	Hong Kong	U							1	22.3°		114.2°	
TIF	Inst. of Geophys., Acad. of Sci.	Georgia	CU							1	41.7°		44.8°	
JMA	Japan Meteorological Agency	Japan	BUM	*M*≥2.75	14690	21.5°	48.0°	120.4°	153.6°	187	24.1°	45.3°	94.2°	145.7°
MAT	Matsushiro Seismol.Obs., JMA	Japan	U							1	36.5°		138.2°	
SYO	National Inst. of Polar Research	Japan	U							1	-69.0°		39.6°	
MOS	Central Exper. Meth. Exp., GS RAS	Russia	BUM		2969	worldwide				54	38.0°	78.9°	11.9°	161.7°
KRSC	Kamchatka Reg. Seism. Ctr., GS RAS	Russia	BCU	*M*≥3.7	1204	48.9°	61.6°	153.1°	170.1°	70	38.0°	78.9°	11.9°	166.0°
SKHL	Sakhalin Exp. & Meth. Dep., GS RAS	Russia	BC		365	41.9°	54.9°	137.3°	157.8°	20	43.1°	62.9°	112.4°	158.7°

Southwestern Pacific

Code	Name	Country	Typ	Criteria	Hypocentres No.	Hypocentres Latitude		Hypocentres Longitude		Stations No.	Stations Latitude		Stations Longitude	
MAN	Philippine Inst. Volcan & Seismol	Philippines	CU							31	-44.4°	44.5°	-109.7°	170.3°
QCP	Manila Observatory	Philippines								2	7.1°	14.6°	121.1°	125.6°
KLM	Malaysian Met. Service	Malaysia	C		103	-6.0°	8.4°	93.6°	125.0°					
WEL	Seismological Observatory, IGNS	New Zealand	CU		1185	-47.3°	-32.3°	165.0°	182.0°	60	-77.5°	-29.3°	-177.9°	178.3°
NOU	Research Inst. for Development	New Caledonia	U							3	-22.1°	-17.7°	166.3°	168.2°
HNR	Ministry of Resources, Honiara	Solomon Isl.	U							0				
AUST	Australian Geol. Survey Org.	Australia	C		80	-44.5°	-10.9°	111.1°	155.9°	0				

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from NEIC. Furthermore, EIDC reports a P amplitude and/or LR amplitude for nearly every reading. Since many other agencies fail to report amplitudes, EIDC has been the source of nearly half of all amplitudes in the ISC Bulletin for each year since 1995. Reflecting the role of these two agencies in global seismic monitoring, the ISC has an explicit policy of re-publishing every NEIC Monthly PDE and EIDC Reviewed Event Bulletin (REB) location except in rare instances when local data unambiguously refute the existence of a purported event.

Among agencies that restrict themselves to contributing hypocenters within particular geographic regions, the Japan Meteorological Agency (JMA) offers the ISC more than four times as many hypocenters as the next largest contributor does. Of the 31% of all phases not associated with events with a preliminary hypocenter from NEIC, slightly more than half are associated with an event with a preliminary hypocenter from JMA. More generally, a few agencies provide preliminary hypocenters for nearly all events that appear in the ISC Bulletin. Agencies reporting regionally but contributing especially large numbers of hypocenters include several monitoring areas around the western Pacific (JMA, TAP, KRSC, WEL and DJA) where the seismicity is greatest and several monitoring areas around the Mediterranean (ROM, ISK, ATH, THE, LDG, MDD) where the seismicity is high and monitoring is generally excellent. In fact, more than 97% of all ISC Bulletin phases are associated events for which a preliminary hypocenter by an agency discussed above or by one of four moderately large contributors from otherwise isolated areas (GUC, MEX, PRE, TRN).

DATA REPORTS

Because of its inclusive mission, the ISC cannot require reporting in any particular format or by any particular means. Nevertheless we must make decisions about allocating limited resources, which may mean forgoing data that are too anomalous or obscure. Recognizing this, most agencies reporting to the ISC endeavor to supply data in a form similar to others, easing the burden on the ISC.

Report Media

The ISC currently receives data by post as hand-written coding sheets, printed bulletins and diskettes, and by the Internet as e-mail and computer files deposited by ftp. In the past, the ISC also received computer tapes and telexes. The common feature of all these is that they are “push” mechanisms. That is, after the ISC and a contributor settle arrangements, the agency sends data reports according to an agreed schedule rather than awaiting a request from the ISC for each report. The ISC does not take responsibility, for example, for routinely checking any contributor’s web site for recently released data, partly because of the difficulty of determining when the final version of a bulletin has been posted.

Printed bulletins are a traditional means of exchanging seismic parameter data and coding sheets are, in effect, hand-written bulletins for transmission to a single recipient. In either case, ISC creates a computer file by keying the data. We have not experimented with scanning and optical-character-recognition since we anticipate no further need for accepting data by this means within a few years. There is a very high degree of certainty that printed bulletins will be readable by recipients, but because of wide acceptance of ASCII for “plain-text” computer files, electronically transmitted data are virtually equally certain to be readable. Further, the cost of keying data is so high that decisions about selecting only the most critical data from printed bulletins are unavoidable. Thus, compared with computer-readable media, more data in printed bulletins are effectively lost to the ISC.

Diskettes and tapes are delivered to the ISC by post, and each requires a specific effort to interpret the item received and copy its data to a computer disk. But the level of effort is much lower than keying and nearly independent of the data volume. Thus, none of these data are lost as the result of decisions influenced by limited resources. Nevertheless, some diskettes are unreadable, and unlike transfer over computer networks there is no automatic checking that data packets were correctly delivered. The ISC contacts source agencies in the event that diskettes are unreadable, of course, but occasionally a readable replacement is not received before processing must begin. Internet transfer is preferred whenever possible.

Electronic mail is the preferred and predominant means of data transfer to the ISC. Received data e-mails are automatically scanned to determine from which of the known sources they come and then are filed. The automated system tabulates received reports and alerts ISC staff if an earlier report expected from that agency is missing. The system is being extended to carry through to the next step of automatically parsing data from the reports and integrating them with data from reports of other agencies.

Problems may arise in making arrangements with an agency reporting data by e-mail for the first time or for the first time after changing their e-mail system. The problems include truncating or wrapping of long lines and various types of encoding. Thus far, the ISC has been able to work with each reporting agency to overcome the problems. The growing use of e-mail programs with a graphical user interface (GUI) has degraded the completeness of data delivered to the ISC. Such mailers often replace older systems that offered more straightforward or transparent access to scripting, allowing agencies to write programs for assembling messages for the ISC. One or two daily files are often missed or duplicated in a monthly report assembled by repetitive manual use of an e-mail GUI.

A very few agencies find that the volume of data to be transferred is so large, or their e-mail programs are so recondite, that they cannot achieve complete transfer in the desired format. In such cases ftp is the best alternative, but it has significant disadvantages. Careful arrangements with each agency are necessary to allow them to push their data to the ISC while minimizing security concerns. The sending agency generally must have a person monitoring connection all the way through to the ISC and transfer of a complete file. A parallel e-mail notifying the ISC of successfully depositing a file is advisable.

Report Formats

Regardless of the means by which data are transferred, each data report must follow a format known to the ISC in order to be successfully parsed. Three goals for any format are: (1) straightforward preparation and parsing by computer programs, (2) easy scanning by seismologists, and (3) succinctness to avoid expense in transmission and storage. Traditional formats may sacrifice ease of scanning in favor of the other goals. With the falling cost of data storage and exchange, modern formats more often sacrifice brevity in favor of easier scanning while maintaining straightforward parsing. Other features of many modern formats are that they include a wide variety of data types in individually designated fields and that they are designed to be extensible. An extensible format must include some way for new types of data to be included without either collecting all of the new types into unformatted comment strings or making messages with the new data types unreadable by old parsers.

There is currently no generally accepted standard format for seismic parameter data. This fact has considerable disadvantages for the ISC and for seismologists generally. The wide use of telegraphic format for seismic parameters in the past and the more recent adoption of the Standard for Exchange of Earthquake Data (SEED) for waveforms by much of the broadband seismology community amply demonstrate the advantages of standards in seismology. The Working Group on Data Exchange Formats of the Commission on Practice of the International Association of Seismology and the Physics of the Earth's Interior (IASPEI) is developing a new standard, IASPEI Seismic Format (ISF) based partly on International Monitoring System (IMS) 1.0, which might be widely adopted.

Telegraphic format is documented in the Manual of Seismic Observatory Practice [*Willmore*, 1979]. This traditional-style format was developed to conform to the special limitations of telex messages (*e.g.*, no lower-case letters, no control over line breaks) in addition to minimizing the number of expensively transmitted characters. Telegraphic format is limited in the types of measurements for each arrival that can be represented, and when installing new systems many agencies choose not to develop routines for preparing telegraphic format messages.

A few agencies send reports to the ISC in traditional-style formats originally developed for internal use at the ISC, colloquially known as Formats 1, 2 and S, which are somewhat less succinct than telegraphic. Each format contains either only phase data or only hypocentral data, so they fail to show the association of phase readings with hypocenters. Use of ISC internal formats for data exchange is likely to decline as agencies update systems and find that it is not worthwhile to maintain certain previously important capabilities.

With no generally accepted standard format that encompasses modern requirements, many agencies simply send data reports in the format native to their own processing systems. Most of these are straightforward, but the need to maintain a program for each one is a significant cost for the ISC, partly because each agency may unilaterally introduce minor changes in its format from time to time. When ISC seismologists consult any original data report to confirm the content of data being processed by the ISC, the time that they require to re-acquaint themselves with each format slows preparation of the Bulletin.

A few agency-specific formats are particularly burdensome. Extraction of data from "documents" in the proprietary formats of word processing or spreadsheet applications is sufficiently time-consuming that the ISC must consider declining data that are available only in this form. Even some plain text data reports laid out for attractive appearance when printed, perhaps with page headers and multiple columns, can require interpretation programs that are surprisingly complex and that may fail entirely as the result of seemingly irrelevant changes in page or column headers.

Machine-readable Earthquake Data Reports (MCHEDR) are used to transmit data to the ISC by only the US National Earthquake Information Service and is thus an agency-specific format. But it is of special importance because data from so many other agencies are distributed onward by NEIC to the ISC. MCHEDR is succinct and easily parsed by computers, although difficult to scan by eye. But it has the important modern feature of being extensible. Thus the MCHEDR format does not, in itself, pose any obstacles to including newly important data types.

The freely available SEISAN suite of programs for manipulating seismic data [*Havskov and Ottemoller*, 1999] works with files in "Nordic" format, which is thus the native format for one choice of processing system. But Nordic format is documented independently from SEISAN itself and seismologists from the University of Bergen have assisted many national and regional agencies to implement effective network processing using SEISAN. Thus, Nordic format is a *de facto* standard, allowing the ISC to use its Nordic parsing program for data reports from agencies around the world. The standard is a modern one in the senses that it is easily scanned and includes a wide range of data types.

AutoDRM is both a protocol for requesting and returning seismic parameters and waveform data by e-mail and a program for fulfilling requests [*Kradolfer*, 1996]. The program is freely available, and both the protocol and the program have been widely adopted. The protocol was the basis for the Group of Scientific Experts (GSE) 2.0 format, which was used during GSE Technical Test 3 (GSETT-3), and for the IMS1.0 format, which is intended for use by the Comprehensive Test Ban Treaty (CTBT) monitoring system.

These standards are modern in the same senses as Nordic format.

IMS1.0 includes specifications for formatting a wide variety of data types used in treaty monitoring in addition to seismic data, while leaving out a few types of data important to earthquake monitoring. Nevertheless, it is expected to be widely adopted by seismologists working or exchanging data with National Data Centres for CTBT monitoring around the world. Several agencies already report to the ISC as GSE2.0 or IMS1.0 bulletins, and other recently developed standards such as that of the German Regional Seismic Network have many similarities. The IASPEI Commission on Practice is developing ISF, an extension of IMS1.0 that includes a wide variety of data types important in comprehensive earthquake data reporting that are not explicitly included in IMS1.0.

MANAGING COLLECTED DATA

Original Reports

Printed bulletins published by national and regional seismological agencies all over the world were collected to prepare the International Seismological Summary (ISS) even before the creation of the ISC. Published bulletins were supplemented by coding sheets filled out at individual stations and posted or telexed to the British Geological Survey office responsible for preparing the ISS. When the ISC was created, employment of data input clerks to key data from these sources was the most costly part of data collection. Many of these printed bulletins and coding sheets are still held at ISC.

Today most data reports are sent to the ISC as e-mail messages. In the past some e-mail messages were deleted after the data had been parsed, resulting in incomplete preservation of these data in their originally reported format. The ISC now has sufficient disk space to preserve on-line all reports received for the last several years and expected for some years to come. With the decreasing cost of disk space and increasing access speeds, no future need for removing data reports from the on-line system is anticipated. In contrast with an archive of tapes or other off-line media, on-line storage has the advantage of holding the entire dataset on a system that is demonstrated to function every day, even if very occasionally that demonstration consists only of being successfully scanned to prepare for backup and finding that no files have been created or modified.

Thresholds

If an earthquake is so small that it is detectable by only a single network, then there is little advantage to re-analyzing it at the ISC. The agency operating the detecting network may have used readings from additional stations that are not internationally registered or a travel-time model that is more appropriate in that location than the Jeffreys-Bullen tables used by the ISC. Collecting the readings and hypocentral estimates by local agencies for small earthquakes may help to make the data more widely available. But there are important questions about the cost of collection, the number of users of these data not in contact with the local agencies, and the error rate in exchanging data, which is inevitably non-zero no matter how small. Regardless, there must be thresh-olds in either the process of collecting data or the selecting of data for re-analysis among those that have been collected. Until the 1990s there was no need to explicitly apply thresholds since the practical difficulties of data exchange limited the number of data that could be collected to fewer than any seismologically desirable threshold would have.

To some extent, thresholds are applied by agencies sending data to the ISC. For example, many earthquakes are located by regional agencies within the United States that are not re-located by NEIC. The ISC uses preliminary locations within the U.S. almost only from NEIC, since we would be overwhelmed by an attempt to re-locate all earthquakes. Thresholds have been effectively implemented by choosing agencies from which data are accepted.

Improvements in communication technology have eliminated some of these implicit thresholds. The first important example of this came from the Japanese Meteorological Agency, which has contributed its complete national bulletin to the ISC since the early 1990's. The ISC had difficulty keeping up with the growing load, and the difficulty could be identified with data from a particular reporting agency. In the ISC's system, data can most easily be systematically attributed to a particular agency before being inserted into its Data Collection File (DCF), so this is the point at which thresholds were applied. Beginning from 1994, the ISC excluded hypocenters and associated readings for events in the JMA bulletin with magnitude <2.75.

Having established the principle that thresholds should be applied, and faced with an ever-growing data volume, it becomes logical to focus limited resources on the most important problems by applying similar thresholds to data from other agencies. It would be illogical to gradually fall behind the target publication schedule partly as a result of re-analyzing, say, ML 1.5 earthquakes in Norway while ignoring ML 2.5 earthquakes in Japan. Thus, ad-hoc, agency-by-agency thresholds were implemented gradually, often as obscure changes to programs used to parse data in various formats and insert them in the DCF.

Thresholds are not a serious disservice to users, since for such small earthquakes the Bulletin has always been both geographically and temporally inhomogeneous [*Adams and Richardson*, 1996]. Nevertheless, agency-based thresholds have led to some anomalies that might not occur under alternative schemes. For example, the number of events "discovered" by the ISC by searching among readings that could not be associated with reported events grew most in recent years within regions that are well monitored by agencies that report to the ISC, such as Alaska and New Zealand [*Bird et al.*, 1999]. There have been instances, as well, of including an event in the Bulletin with a hypocenter computed using a network far from the event but failing to include another, better constrained hypocenter. The second hypocenter can be excluded if it is contributed by another agency with a smaller magnitude that falls below a collection threshold.

In order to avoid anomalies of this sort, the ISC plans to postpone applying thresholds until after data collection to the extent possible. Instead, a threshold will by applied in selecting events for analysis after independently contributed hypocenters are collected and grouped into events. To do this, of course, automatic grouping must be reliable and reported associations of phases with hypocenters must carry through to associating the readings with the events. It is likely that the analysis thresholds will vary with location, being higher in seismically active, well-monitored regions regardless of the reporting agency and lower or nonexistent in inactive or poorly monitored regions such as the oceans. Earthquakes falling below a local threshold for ISC analysis would remain in the ISC database, but they probably would not be reprinted in the Bulletin or Catalogue.

Phase Identification

The reported phase identification has important uses in processing at the ISC. Only phases with recognized teleseismic names, for example, may be re-identified during automatic processing as *P*, *P*-diffracted, or *PKP*. A phase with mangled phase identification or an incorrect regional phase identification may not be automatically associated. Because resources for manual review are limited a significant fraction of these have failed to be associated at all and thus have not been published in the Bulletin. Another example of the importance of reported phase identifications occurs in the use of surface waves in computing M_S. Standard procedures call for use of the maximum of amplitude/period, but some agencies report amplitude and period at several times within the dispersed wavetrain. Thus, the ISC has used only phases explicitly identified as maxima (*e.g.*, phase identification MLR) in computing magnitude.

Because of these important uses, the ISC uses interpreted rather than original identifications of a few reported phases. For example, the prototype IDC Reviewed Event Bulletin includes the time, amplitude and period of the maximum of amplitude/period in the Rayleigh wavetrain as phase 'LR'. Based on the ISC's understanding of IDC policy, for readings from 1996 onward IDC 'LR' identifications are interpreted as 'MLR'. Beginning with readings for 1999, however, the ISC is preserving both the reported phase identification and the interpreted phase identification. These are in addition to the ISC's own identification of phase type, which could be based on association of the phase with a different earthquake.

Data Collection File

The ISC has used an in-house program, the "Seismic Input Program" (SIP) to manage a binary-format data collection file (DCF) holding all of the data collected but not yet analyzed by the ISC. This has provided important capabilities. Most importantly, processing of a month can begin by reading data from this single, homogeneously formatted file. The process of parsing data into the DCF has provided a prompt check on the content of reports; if there is trouble the ISC has contacted the reporting agency to begin resolving the problem before the data are urgently required. In addition, backing up the ISC's complete collection of not-yet-analyzed data has been accomplished simply by making a copy of its DCF, and the ISC has not suffered a serious loss of collected data in its entire history.

Because the types of data in the DCF are defined in the SIP source code, there is a very high cost for modifying the definitions of the data types, so they are rarely updated to reflect changing seismological practice. For example, while moment tensors have been included in the Bulletin for more than 17 years, they are still represented in the DCF by text strings that are ultimately printed as comments in the Bulletin. Thus, users find that moment tensors on the ISC CDs include typesetting characters.

To add to the DCF, SIP reads plain text files in one of a small set of formats; separate programs are used to read reports in any other format and write files in one of the formats read by SIP. Any necessary interpretation of the reported phase identifications and other data is carried out during this re-formatting. For example, some long-standing stations have been registered only recently but with different codes because those used traditionally were already registered for stations in other parts of the world. If the local agencies continue reporting readings with the locally traditional codes, the ISC's agency-specific re-formatting programs translate the reported codes.

Apart from the data attributes described below for different record types, each record in the DCF carries just two metadata: the entry date and the ISC internal format from which it was read by SIP. SIP maintains an external log of entry dates and source files, and the ISC holds to a convention of storing data files from different agencies in distinct directories. Because of this convention, it is usually possible, although tedious, to use the SIP log to determine the agency on whose report an individual record is based, provided the data are held in the DCF (or a backup) and the SIP logs are retained.

SIP writes three types of records in the DCF: epicenters, readings and comments. An epicenter record describes a single time, location, and size of an event; its attributes are conceptually the same as the fields of a "type 1" record and the "type 2" records that follow it in a Fixed-Format-Bulletin (FFB) file on the ISC CDs. A reading record describes a collection of phases from one station attributed by the reporting agency to a single event; its attributes are a subset of fields in a "type 5" and the following "type 6" records in the FFB files. Comment records usually give felt reports or source parameters. Records in the DCF have no meaningful order, and SIP has no means for recording associations of phases with events or groupings of hypocenters for the same event, even if they are reported. Consequently, groupings and associations, which are implicit in the ordering of records in bulletins sent to the ISC, have been neglected in ISC automatic processing. Nevertheless, reported associations help to resolve ambiguities before the final Bulletin is published since ISC seismologists routinely consult received bulletins during manual analysis.

Relational Database

Beginning with readings and events for 1999, collected data are parsed and stored in tables of a relational database. The definitions of the table formats are documented elsewhere, but an essential point is that the format definition is stored as configuration files that are separate from the code used to manage the data and are much more easily updated than SIP and the DCF format. The attributes of the tables of phases and hypocenters are supersets of the attributes of the reading and epicenter records of the DCF. Additional tables are used to preserve reported phase associations and hypocenter groupings.

Further tables have been created to record amplitudes, moment tensors, focal mechanisms and other measurements and event parameters in a purely parametric form that will provide flexibility in including these data in any format for exchanging data between agencies. Creation of additional tables to hold new data types is straightforward and would not require modification of any program written to work with the existing tables.

The same tables are used to hold both the collected data and the results from the ISC's processing and analysis as published in the Bulletin. This is anticipated to make it straightforward for the ISC to offer collected but not yet analyzed data fully integrated with the Bulletin data.

SUMMARY

Ultimately, work at the ISC remains simply the culmination of a worldwide collaborative effort to produce a comprehensive global seismic bulletin. Despite improvements in collecting and managing data, the essential limits on the accuracy and completeness of the Bulletin arise from the network of stations from which readings are reported to the ISC and on careful interpretation of seismic records and preparation of regional and preliminary global bulletins by seismologists and agencies around the world. Nevertheless, changes at the ISC are making it possible to handle larger quantities of data more efficiently, better track data in the Bulletin back to an original report, and more fully integrate reported data types into procedures for preparing the Bulletin.

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