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A view of South and Central America from the International Seismological Centre

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RESUMEN
Hasta ahora, el estudio de la sismicidad en América Central y Sur se dificulta por la distribución inhomogénea de las estaciones y los problemas de comunicación entre instituciones dentro y fuera de la región. Ello significa una detección de sismos muy dispareja, lo que hace incierta la estimación del riesgo sísmico. Además, hay inhomogeneidad de la cobertura en el tiempo, como el período de varios meses en 1991, cuando se reportó mucha actividad desde Colombia con un consiguiente alto número de detecciones. Ahora existe mayor cooperación regional en Centroamérica con un nuevo centro de datos que junta datos de seis países y localiza unos cien eventos mensuales, lo que significa un progreso considerable en la cobertura de la región. Al principio hubo algunos errores de localización, como era de esperarse. La red sudamericana más densa se encuentra en torno a Santiago, Chile lo que hace que esa zona se encuentre bien documentada. Los eventos cercanos están bien localizados, pero los que caen fuera de la red suelen reportarse con profundidades excesivas como ocurre comunmente en zonas de subducción. La profundidad reportada por Chile es mayor de la que indican las estaciones argentinas más cercanas. A medida que la instrumentación y el nivel de cooperación regional vayan mejorando, el registro sismológico de esta región irá mejorando en confiabilidad y podrá aportar una mejor evaluación del riesgo sísimico.

PALABRAS CLAVE: Sudamérica, América Central, sismicidad, localización de sismos.

ABSTRACT
Until now the study of seismicity in the region of South and Central America has been hindered by the very uneven distribution of stations and the lack of communication among agencies within the region and outside. There is thus a very uneven detection of earthquakes, which adds to uncertainty in estimation of seismic hazard. The reporting can also be very uneven in time, an example being a burst of reporting from Colombia for several months in 1991, resulting in greatly enhanced detection there for that period. There is now much regional co-operation in Central America, and a new data centre collects readings from six regional countries and determines origins for about a hundred earthquakes a month, greatly improving the seismological coverage of this area. As might be expected, early in its operation some earthquakes appear seriously mislocated. The densest network currently reporting in South America is that around Santiago in Chile, resulting in the seismicity of this area being well documented. Close earthquakes are well located, but as is common in subduction areas, earthquakes outside the network tend to be located too deep. There are many instances here in which the depth determined by the Chilean agency is deep, but closer Argentinian stations show that the focus must be shallower. As equipment becomes more uniform and regional co-operation improves, the current seismological record for this region should become more reliable and capable of providing better assessments of seismic hazard.

KEY WORDS: South America, Central America, seismicity, earthquake location.

INTRODUCTION

The prime task of the International Seismological Centre is to collect all available station readings of earthquakes throughout the world, to re-analyze them and to produce definitive origins, which are published with their associated phase readings. The procedures are described in Adams *et al.* (1982). The strength of ISC's analysis is its completeness in bringing together readings from different agencies, in being able to combine readings from local and distant agencies, and the fact that by delaying the start of analysis for nearly two years, its input data file is more complete than that available to other agencies.

South and Central America are among the most active seismological regions, with a wide variety of types of earthquakes, including some of the deepest known. Its large area and the number of different seismological agencies operating make it well suited to benefit from ISC re-evaluation of its earthquakes. ISC's analysis, however, is limited by the data supplied to it, and it appears that not all agencies in the region report fully. It also appears that there is often a lack of data exchange among different agencies, even those in neighbouring countries.

OVERALL SEISMICITY

The general pattern of seismicity in the region is well established. Figure 1 shows the larger South American earthquakes (M>5.5) in the ISC listings for the period 1980-92, of which there are 616, including deep events and those in the Atlantic Ocean that fall within the area plotted. The main activity is fairly evenly distributed down the western side of the continent, although there is some concentration at the latitude of central Chile. This concentration is much more obvious when smaller earthquakes are considered, as in Figure 2, which shows the earthquakes with magnitude between 4.0 and 4.5 for the same period (5,647 events). There is apparently a much greater concentration of small events around Santiago in Chile, than in, say, Peru.

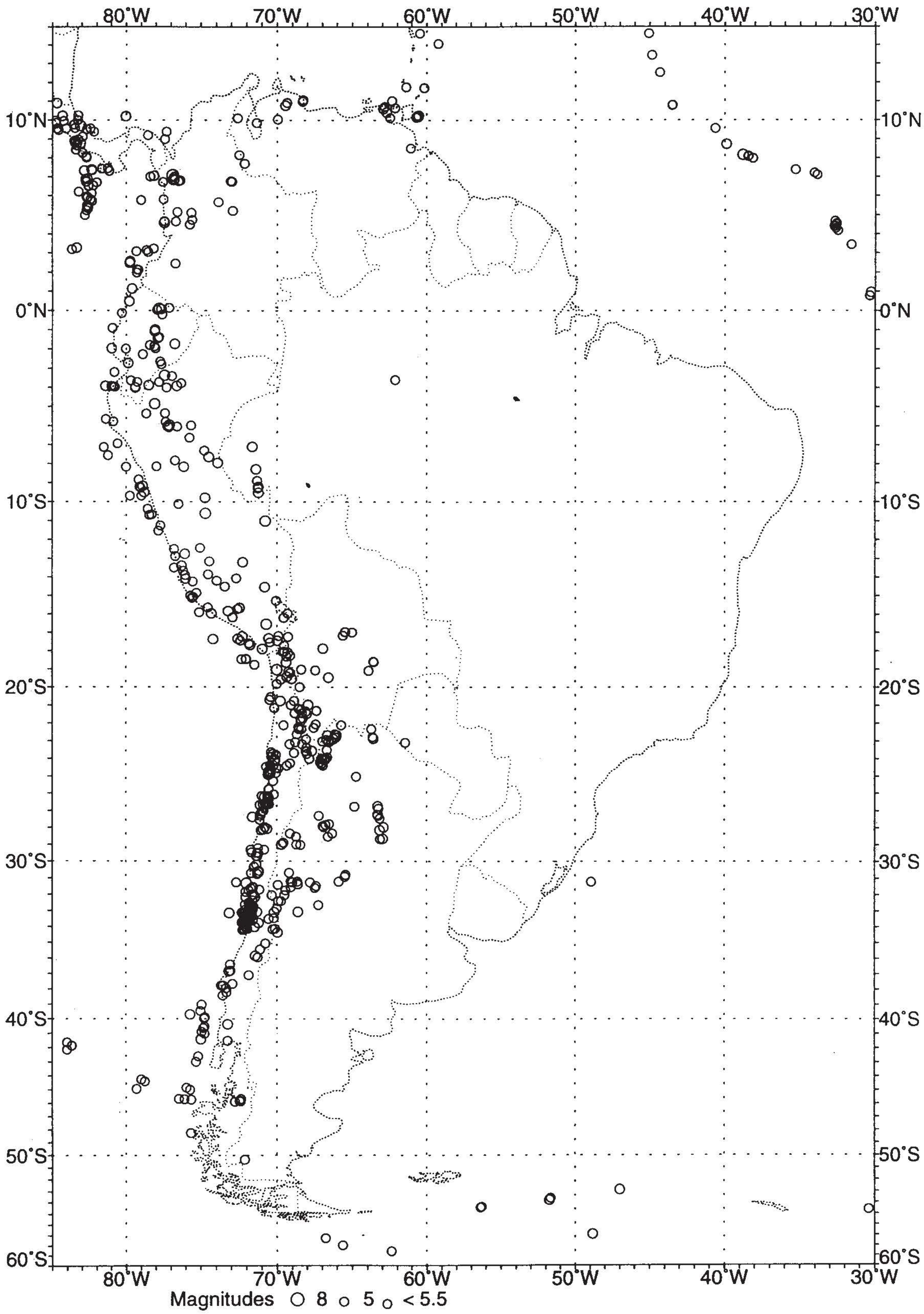

Fig. 1. South American earthquakes of magnitude (Mb) greater than 5.5 held in the ISC catalogues for the period 1980-92 (616 events).

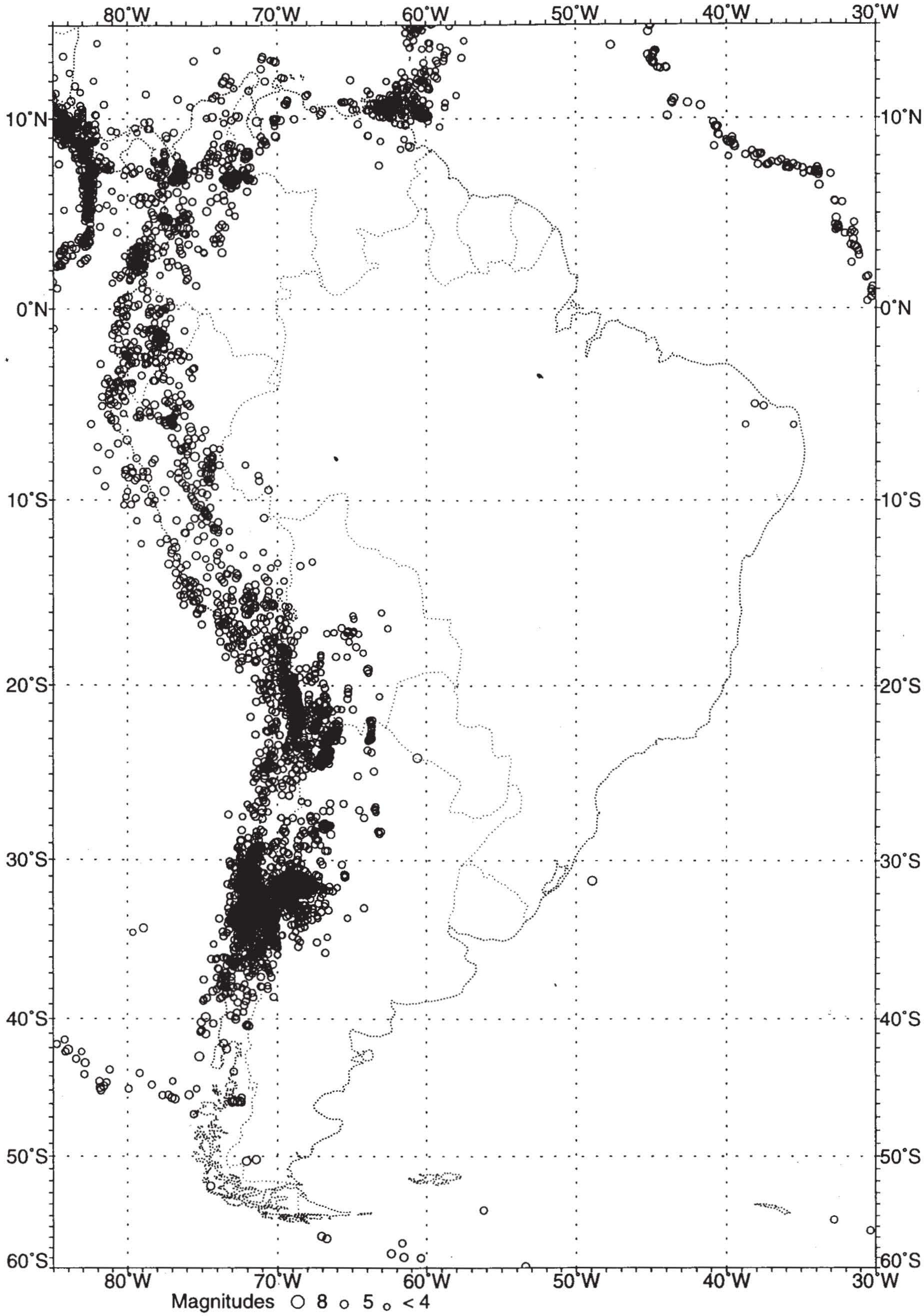

Fig. 2. South American earthquakes of magnitude (Mb) between 4.0 and 4.5 held in the ISC catalogues for the period 1980-92 (5,647 events).

Such plots reflect not just the level of seismicity, but the reporting from the region, both in the number of stations, and the proportion that actively report their readings to international agencies. It is usual for only a small proportion of internationally registered stations to report readings over any given period; for instance, the world-wide station list held at ISC contains more than 7,000 stations, but in a typical month less than 2,000 supply readings. Figure 3 shows all stations in the South American region, which as far as is known are not closed, 433 in all. In a recently analyzed month (June 1992) ISC received data from only 92 of these, which are shown as solid symbols in the figure. The distribution of reporting stations shows concentrations that are reflected in the reported seismicity; in particular the close network in central Chile and the neighbouring Argentinian stations contribute to the concentration of smaller events reported there. Possibly the stations have been deliberately placed in the areas of greatest seismic activity, but it is likely that here logistical considerations in ease of operating stations are equally important.

Temporary bursts of reporting can also distort seismicity patterns. An example is a period in the first half of 1991, when phase readings from a Colombian network reached ISC via NEIC. These were not accompanied by epicenters, but the ISC's "search" procedure for locating new events was able to locate many local earthquakes. Figure 4 shows 269 events in this area for the period January-June 1991. For the same period in 1992, during which no readings were received from this network, only eight earthquakes were found in this area. Care must be taken to ensure that such bursts of reporting are not interpreted as bursts of activity and given tectonic significance.

DETERMINATION OF DEPTH

Depth is the most difficult focal parameter to determine, particularly when the earthquakes are outside the recording network, where it seems that the routine location programs tend to place foci too deep. There are many examples of this for events near the Chilean-Argentinian border. Here the depth determined by the Chilean network is often much deeper than is allowed by the readings from the closer Argentinian stations. An example is shown in Figure 5 for an earthquake on 22 June 1992. The Departamento de Geofísica of the Universidad de Chile (GUC) gives a depth of 215 km. This solution fits the Chilean readings well, but the closer Argentinian stations are early by up to nearly 20s. ISC held the depth at 33 km to give a solution against which the residuals are much improved. The residuals remaining at the Chilean stations, which go from positive to negative with increasing distance, suggest, however, that the focus does have a greater depth, possibly as much as 100 km.

RECORDING IN CENTRAL AMERICA

The recent establishing of a Central American Data Center, originally in Guatemala, but later moved to Costa Rica has resulted in a great increase in the number of phase readings and origins reported from that region. The countries involved are Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, and Panama. ISC started receiving data from the centre from the beginning of 1992. Comparison of two months one year apart demonstrates the significant effect of the CADGC data. In June 1991 the ISC reports 66 events in the region shown in Figure 6. In the same region in June 1992 there are 269 events (Figure 7), of which only 70 have origins given by agencies other than CADGC. ISC uses CADGC data to obtain a solution for 43 events, and in the remaining 156 cases the CADGC position is adopted. For September 1992 the monthly total is even larger (805) due to the major Nicaraguan earthquake of 3 September 1992 and its aftershocks. Effective CADGC coverage does not extend into the western part of the area shown in Figures 6 and 7, and there is no obvious improvement in detection capability here.

The strength of a regional network is the joint analysis of readings from neighbouring national networks, and this has not always been done by the Central American Data Center in the early part of its operation. ISC often receives several origin estimates for a particular earthquake, each determined by one national agency. These can often be combined to produce an improved solution compatible with all the data. An example is shown in Figure 8 for an earthquake on 3 September 1992; the small stars are positions given by individual national agencies, which in the initial ISC analysis attracted 22, 21 and 8 readings respectively, of which 1, 5 and 7 were from local stations. These positions differ by up to about 150 km. By combining all readings ISC found a position shown by the large star, based on 50 readings, including the 13 local ones. This is the sort of improvement in reliability of location that will eventually be possible when the Data Center carries out full regional analysis. Regional locations have also been greatly improved since December 1993, with the installation of GPS clocks at each network in the region. This new and reliable time base will improve the overall quality of the final locations.

Other difficulties arise from analysis based on P phases only, which is commonly employed by location agencies. An example is shown in Figure 9 for an earthquake in February 1992. The Central American solution (CADCG) puts the earthquake 5.4° away from the nearest station, with S residuals of nearly one minute. The ISC location is still determined with P phases only, but careful selection of the trial origin resulted in a position which gave good residuals for both P and S phases. The revised position is about 500 km from the original one and only just over one degree from the nearest station.

Further improvement in location can be obtained by including distant stations in the analysis. Earthquakes in Central America are well recorded in northern Canada and readings from these stations often enable much better solutions to be found. Figure 10 shows an example from March 1992, in which the Central American agency

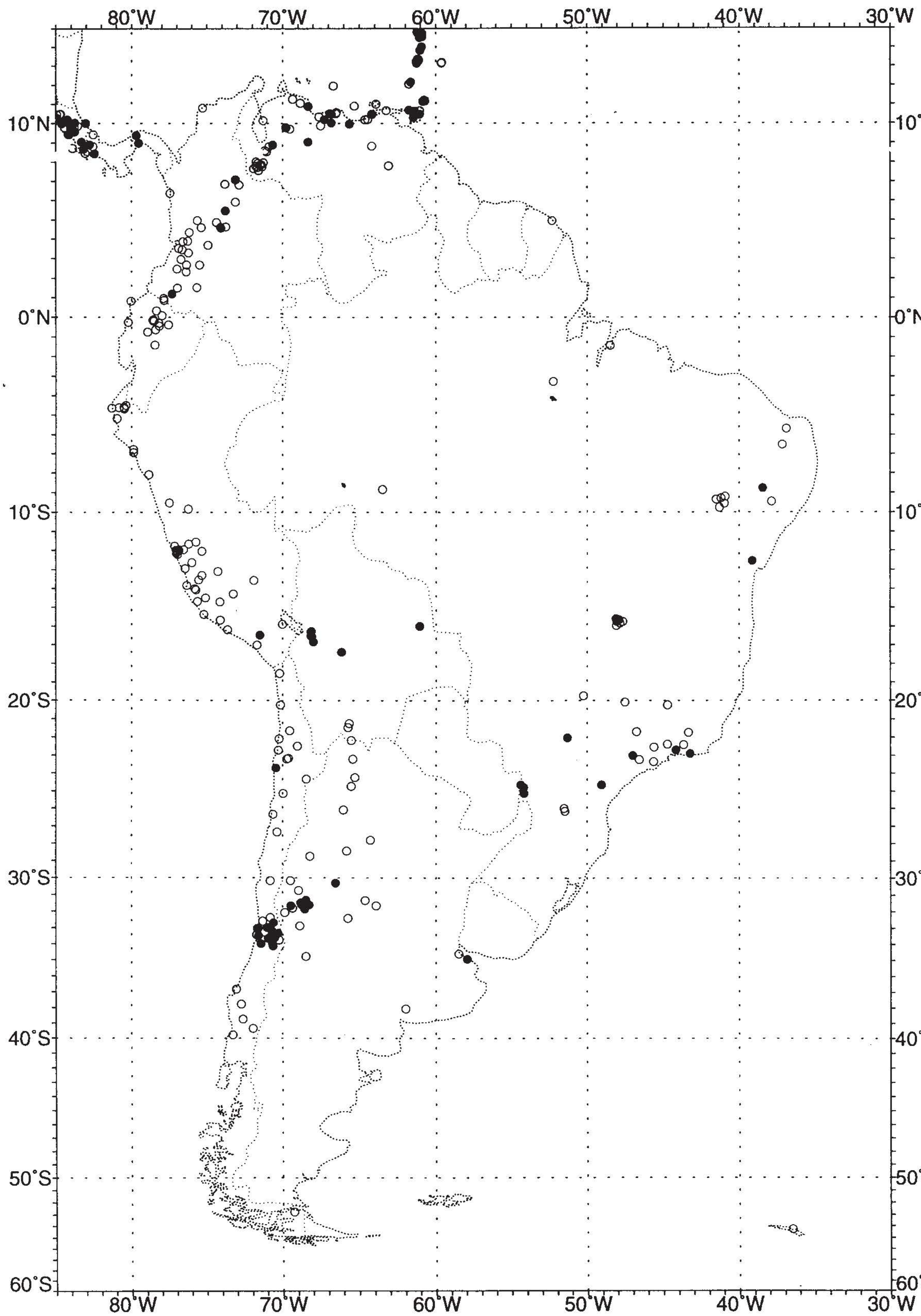

Fig. 3. Seismograph stations in South America listed as being open in 1993 (433 stations). Those that reported to ISC during June 1992 are shown by solid symbols (92 stations).

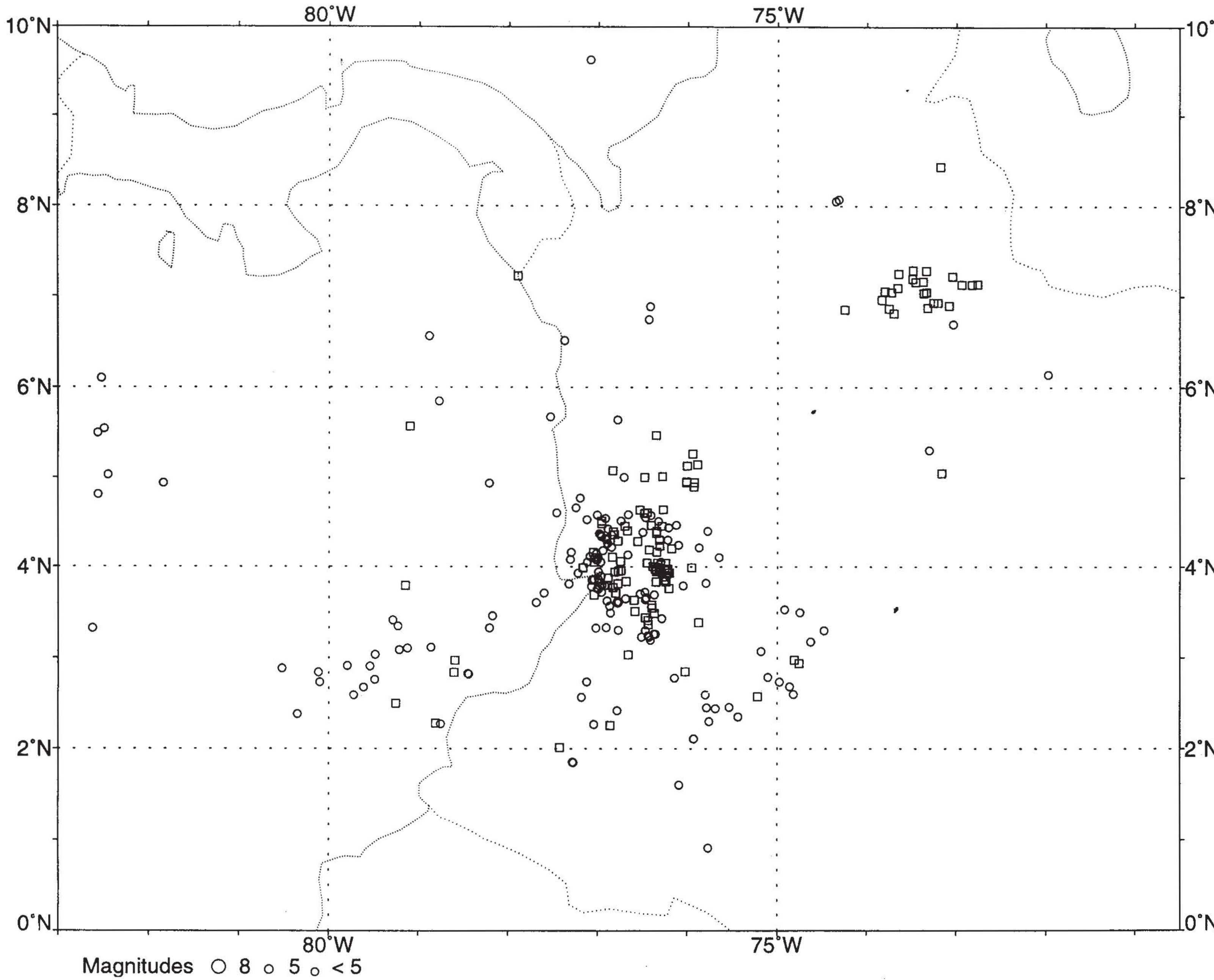

Fig. 4. Earthquakes located by ISC in the Colombian area for the period January-June 1992 (269 events).

1992			GUC	Jun 22d 02h 09m 52.8s	ISC	Jun 22d 02h 09m 57.6s ± 0.7
				31.95°S 69.10°W 215 km		31.8°S 68.8°W 33 km
						± 0.12 ± 0.16

Stat		Time h. m. s.	Dist deg.	Az deg.	Residual S	Residual P	Dist deg.	Az deg.	Residual S	Residual P
ZON	P	02 10 10.5	0.54	42		-11.6	0.32	23		+4.9
RTCB	P	02 10 05.7	0.53	29		-16.3	0.36	3		-0.4
CFA	P	02 10 09.9	0.81	65		-13.3	0.55	65		+1.0
	S	10 22.0			-25.5				+3.3	
RTBS	P	02 10 02.1	0.42	314		-19.6	0.57	288		-7.0
RTLL	P	02 10 08.8	0.82	41		-14.5	0.59	31		-0.7
JACH	P	02 10 28.1	1.46	240		+0.2	1.72	240		+2.5
	S	10 56.3			+0.7				+9.7	
FCH	P	02 10 30.0	1.70	216		0.0	1.93	220		+1.4
	S	11 00.0			+0.8				+8.0	
PEL	P	02 10 31.1	1.79	228		+0.3	2.04	230		+0.9
	S	11 00.5			0.0				+5.8	
ROCH	P	02 10 32.7	1.91	237		+0.8	2.17	238		+0.7
	S	11 03.4			+1.1				+5.4	
SAN	P	02 10 33.1	1.99	221		+0.4	2.23	224		+0.1
	S	11 02.5			-1.1				+2.9	
PCH	P	02 10 33.6	2.05	215		+0.3	2.27	218		0.0
	S	11 06.9			+2.3				+6.2	
TACH	P	02 10 36.6	2.30	222		+0.7	2.54	224		-0.7
	S	11 09.7			+0.2				+2.3	
CHCH	P	02 10 37.2	2.37	213		+0.5	2.59	216		-0.9
	S	11 12.4			+1.5				+3.6	
CACH	P	02 10 39.1	2.50	210		+1.0	2.72	213		-0.7
	S	11 15.2			+1.7				+3.3	
LNV	P	02 10 41.6	2.79	224		+0.3	3.03	225		-2.7
	S	11 18.7			-0.4				-1.2	

Fig. 5. Analysis of earthquake on 22 June 1992, giving readings reported to ISC and solutions, with residuals, found by the Chilean agency GUC and by ISC.

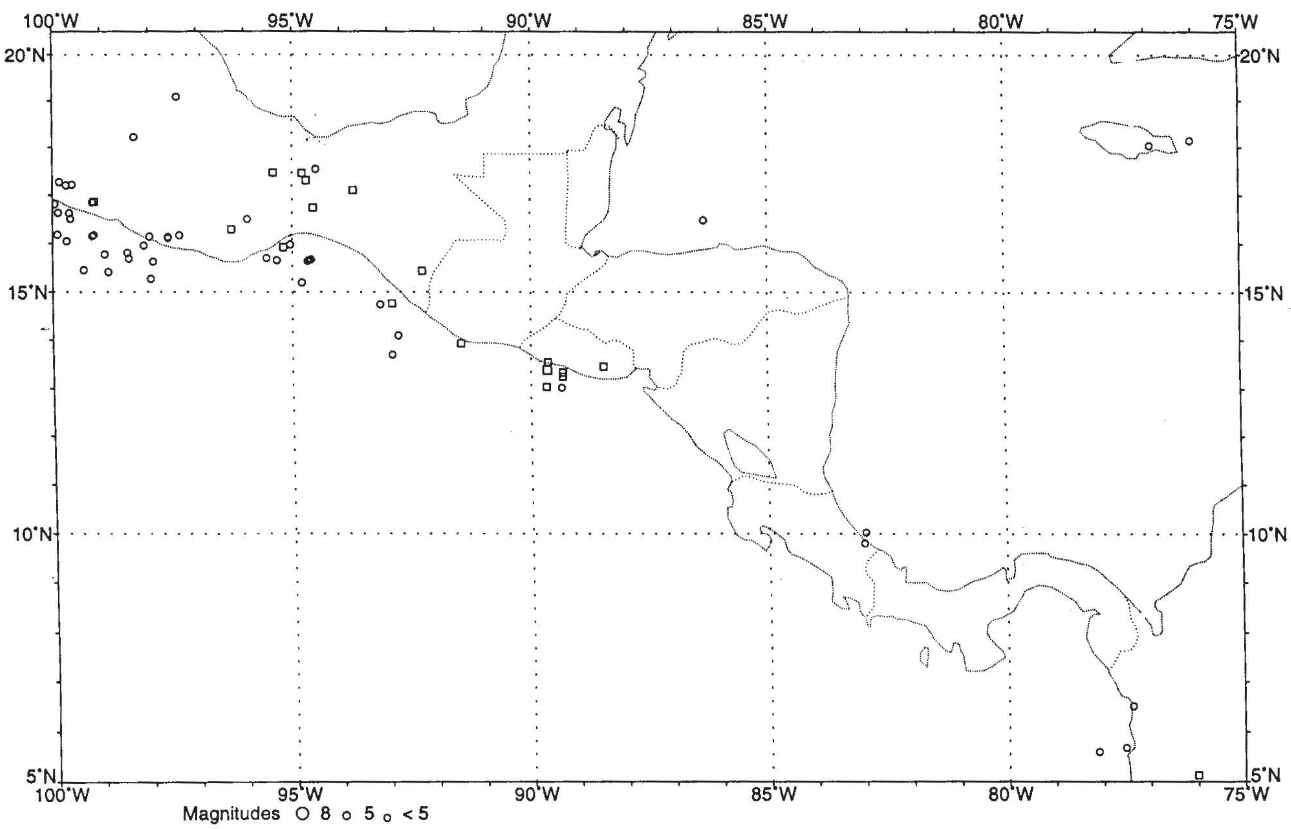

Fig. 6. Earthquakes located by ISC in the Central American region for June 1991 (66 events).

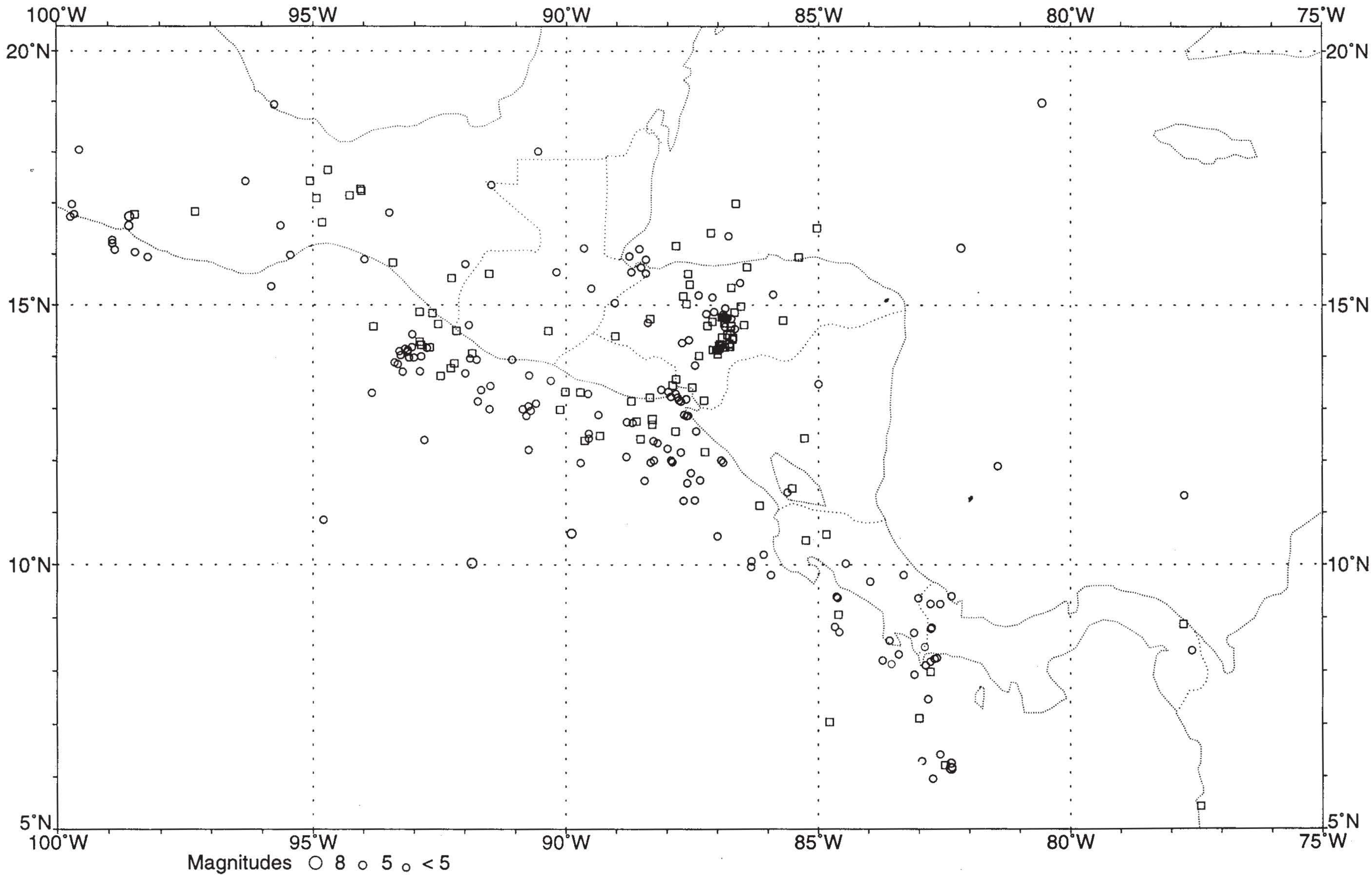

Fig. 7. Earthquakes located by ISC in the Central American region for June 1992 (269 events).

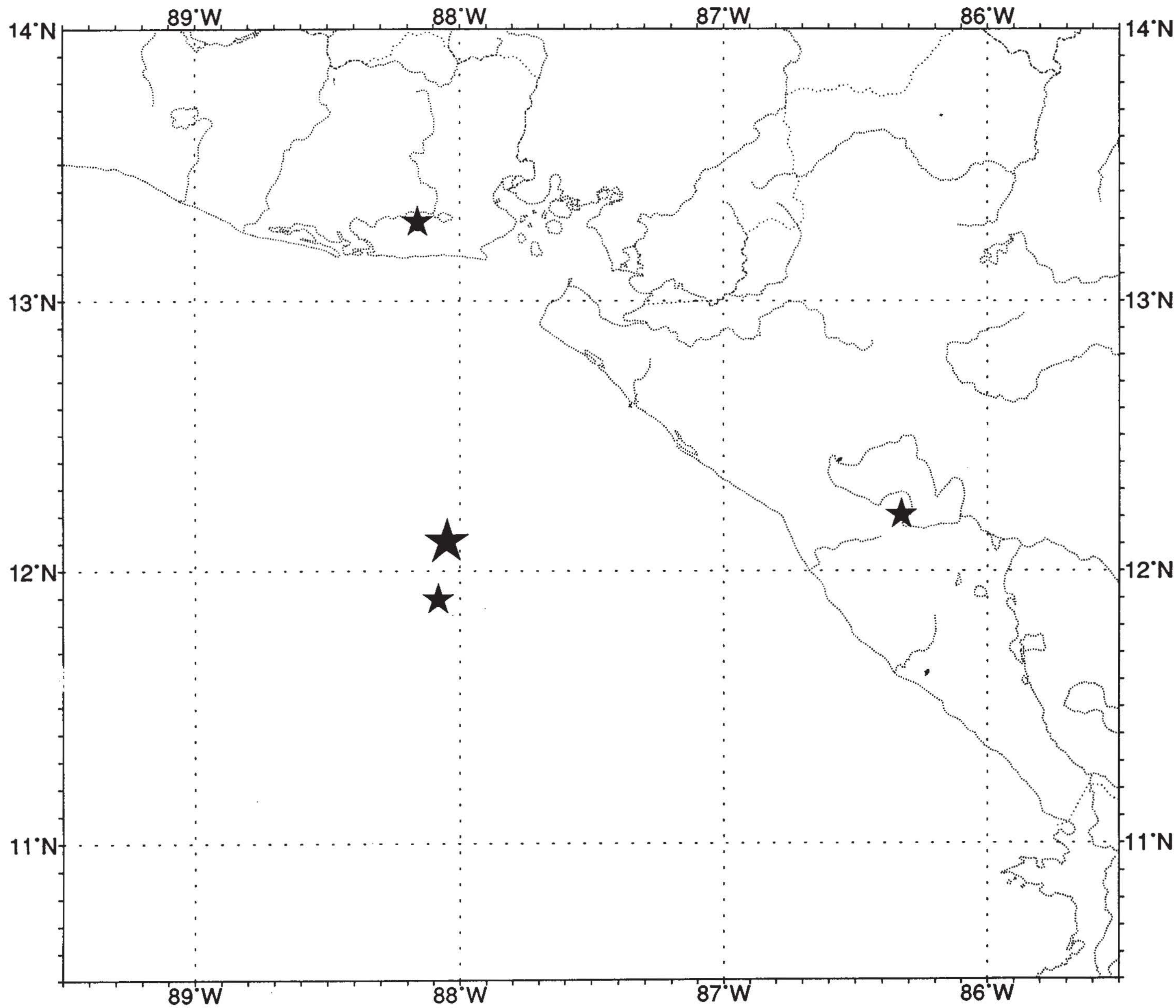

Fig. 8. Different locations given to an earthquake on 3 September 1992. Small stars show positions determined by three individual national agencies and large star the position found by ISC after combining all readings.

1992 CADCG Feb 02d 11h 12m 26.0s 3.4°N 80.5°W 20km — ISC Feb 02d 11h 13m 29s ± 3.8 7.3°N 82.9°W 33km ± 0.32 ± 0.11

Stat		Time h. m. s.	CADCG Dist deg.	CADCG Az deg.	CADCG Residual S	CADCG Residual P	ISC Dist deg.	ISC Az deg.	ISC Residual S	ISC Residual P
DVD	P	11 13 48.9	5.40	339		+1.4	1.17	20		0.0
	S	14 00.1			-50.4				-3.8	
CTCR	P	11 13 52.5	5.94	338		-2.6	1.56	3		-2.0
	S	14 06.9			-57.2				-6.9	
TIG	P	11 13 56.0	6.29	334		-4.0	1.75	345		-1.3
	S	14 12.9			-59.9				-5.8	
CDM	P	11 14 06.8	6.96	332		-2.6	2.39	338		+0.4
QPS	P	11 14 05.3	7.01	329		-4.8	2.42	328		-1.4
	S	14 32.4			-58.3				-3.2	
OCM	P	11 14 12.6	7.38	332		-2.3	2.78	337		+0.7
IRZ2	P	11 14 12.1	7.39	333		-3.2	2.82	339		-0.3
	S	14 44.9			-55.2				-0.8	
VTU	P	11 14 14.3	7.37	334		-0.8	2.82	342		+1.8
	S	14 48.5			-51.2				+2.7	
HDC2	P	11 14 14.2	7.54	331		-3.4	2.96	335		-0.3
POA2	P	11 14 19.2	7.73	331		-1.0	3.15	334		+2.1
EPA	P*	11 14 25.0					3.15	327		+1.0
	S	14 53.9							-0.4	
CAO	P	11 14 17.0	7.79	324		-4.0	3.24	31		-1.4
JTS	P	11 14 23.8	8.19	327		-2.8	3.60	325		+0.2
UPA	P	11 14 25.0					3.67	63		+0.5

Fig. 9. Analysis of earthquake on 2 February 1992, giving readings reported to ISC, and solutions found by the Central American agency CADCG and ISC, with their residuals. The ISC solution gives a better fit to S phases.

CADCG Mar 19d 20h 23m 04.1s 1.5°N 81.6°W 50km MD6.4

ISC Mar 19d 20h 24m 17s ± 2.1 6.7°N ± 0.19 82.71°W ± 0.096 50km Mb3.7

Stat.	Dist deg.	Az deg.	Phase	Time h. m. s.	Resid. s.	Mag
CTCR	2.14	353	P	20 24 51.2	+0.7	
TIG	2.35	346	P	24 54.2	+0.6	
CDM	2.98	340	P	25 03.2	+0.6	
QPS	3.00	332	P	25 01.7	-1.1	
OCM	3.37	338	P	25 08.5	+0.5	
IRZ2	3.41	340	P	25 09.7	+1.1	
VTU	3.42	342	P	25 09.9	+1.2	
HDC2	3.55	337	P	25 11.2	+0.7	
EPA	3.73	330	P	25 12.1	-0.8	
POA2	3.74	336	P	25 13.2	+0.1	
CAO	3.78	321	P	25 11.8	-1.9	
UPA	3.85	55	P	25 13.5	-1.3	
ECO	3.96	49	P	25 15.4	-0.9	
JTS	4.17	328	P	25 18.2	-1.0	
JUD	4.41	321	P	25 20.6	-2.0	
YKA	60.34	344	P	34 22.7	-2.0	Mb 3.7
INK	70.03	342	P	35 26.0	+1.3	
MBC	72.30	351	P	20 35 40.0	+1.7	

Fig. 10. Analysis of earthquake on 19 March 1992, giving readings reported to ISC, and origins found by the Central American agency CADCG and ISC. The ISC solution incorporated readings from three teleseismic stations, resulting in a substantial difference from the CADCG solution.

CADCG located an earthquake using local stations only, the farthest being JUD at 4.4°. The inclusion by ISC of three additional teleseismic stations at distances of more than 60° moved the epicenter by about 550 km to a position that is much more likely tectonically, and also resulted in a much more realistic magnitude.

The difficulties mentioned above are not exclusive to this region but are common to many areas where earthquakes occur outside the area of a local network; with growing experience and co-operation among neighbouring networks locations will become more reliable.

CONCLUSIONS

This region of South and Central America, although among the most seismologically active parts of the Earth, has never had adequate seismological coverage to ensure uniform detection of significant earthquakes. The installation of new networks and the setting up of new co-operative initiatives are going a long way towards improving the situation. The difficulties mentioned here are minor compared with the great advances being made, but are pointers towards ways in which reliability can be improved, and better catalogues prepared for tectonic studies and the estimation of seismic hazard.

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