The Research Council of Norway (NFR)

NORSAR

NORSAR Scientific Report No. 1-95/96

Semiannual Technical Summary

1 April - 30 September 1995

Kjeller, November 1995

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED

7.5 Recommendation on Auxiliary Seismic Stations for the IMS Network

This contribution is a lightly edited version of a paper prepared by the GSETT-3 Working Group on Planning (WGP) in preparation for the 42nd GSE session in Geneva during 27 November - 1 December 1995. The main purpose of this GSE meeting was to make a specific recommendation for the auxiliary seismic network of the International Monitoring System (IMS), which will be installed to verify compliance with a Comprehensive Test Ban Treaty.

Introduction

In its progress report of the 41st session, the GSE decided on a work plan for the GSE meeting from 27 November through 1 December. One of the tasks contained therein is to recommend a list of auxiliary stations for the seismic component of the IMS network based on the experience in GSETT-3.

In a letter to the GSE delegates on 26 September 1995, the GSE Chairman, Ola Dahlman, informed the GSE of the Ad Hoc Committee's expressed desire that the GSE submit, as one of the results of its forthcoming session, 27 November - 1 December, sufficient technical material to enable the IMS Expert Group, which is scheduled to meet the following two weeks, to agree on a list of auxiliary stations for the IMS. This will then facilitate subsequent decisions on the network by the Ad Hoc Committee.

In the same letter the GSE Chairman asked the Working Group on Planning to start work on a list of auxiliary stations, and to provide an initial recommendation for the auxiliary network at the beginning of the 42nd session. The status of this work was addressed at a GSE Convenors' meeting in Lahti, Finland, on 14 October 1995, and was also discussed in a coordination meeting between the Working Group on Evaluation (WGE) and the WGP in Paris on 7 November 1995.

This report provides the preliminary recommendation from the WGP and is intended as a basis for discussions during this GSE session. The network designs proposed herein will be reviewed and revised during the GSE session as additional information is received from GSE participants. Material on relevant experience from GSETT-3 will also be taken into account in the process of selecting a recommended IMS auxiliary network.

Much of the basis for the work of defining an IMS auxiliary station network was provided by the agreement reached in the Seismic Experts Group meetings held in Geneva during the week following the August 1995 GSE session. As a result of this work, there is already agreement in the NTB AHC on a specific 50-station primary seismic network for IMS (see CD/NTB/WP.269, pp. 4-9 and CD/1364, pp. 92-94). There is also agreement on the purposes of the auxiliary network, and on the basic principles/seismological procedures for selecting stations of an auxiliary seismic network to complement the IMS primary network in the best possible way (CD/NTB/WP.269, pp. 10-14).

Purposes of the Auxiliary Network

CD/NTB/WP.269 states that there are two principal purposes for the data that will be provided by the IMS auxiliary network:

- to improve the location accuracy of seismic events detected by the primary network
- to more finely characterize the seismic sources for purposes of event identification.

CD/NTB/WP.269 states that it is a goal to reduce the event location uncertainty to an area equivalent to less than 1,000 square kilometers, as a result of the combined use of primary and auxiliary station data at the IDC. CD/NTB/WP.269 also states that the auxiliary stations that are used to improve the event location, plus additional ones if full azimuthal coverage is lacking, will be used in the computation of source characterization parameters.

Station Selection Criteria and Procedures

CD/NTB/WP.269 states that

- auxiliary stations should primarily cover the seismically most active regions of the world, with emphasis on regions where earthquakes look explosion-like
- auxiliary stations should also be located in regions where there is extensive mining activity that produces large seismic signals
- auxiliary stations should further be located in areas where the azimuthal coverage of the primary station network is poor
- auxiliary stations should be selected from stations that are already available or can be adopted with a minimum of new investment.

Another factor to take into account in the selection process is the statement in CD/NTB/WP.269 that “stations in the auxiliary network should be able to act as a backup to stations in the primary network should an extended problem with a primary station arise”. This might be interpreted to mean that some of the auxiliary network stations should be especially selected so as to have signal detection capabilities similar to those of the primary network stations, so they could be useful substitutes for one or several primary stations in the same region.

Preparatory Work by the WGP

WGP has been compiling information on stations around the world that might be candidates for the IMS auxiliary network. As part of this survey, the WGP contacted all GSE delegations and asked for information on candidate stations in the various countries. In addition, updated lists of stations of the member networks of the FDSN have been obtained from various sources.

Information on worldwide mining activity has been obtained from various sources. This material shows that world minerals production is dominated by the United States, China, Chile and Russia. We have also obtained a list of eighteen other countries with major minerals production. Data on actual blasting practices are generally unavailable on a mine-by-mine basis. Therefore, regions having potential for large blast activity are best identified based on mine location and minerals production data. It must be noted here that we are only concerned with blasting activity that is detected and located by the primary seismic network. As an example here, this rules out some large, known shots in Canada, as it is known that these shots (of the order of 0.5 kt or more of chemical explosives) are not defined by the GSETT-3 Alpha network, and the IMS primary network will be even more sparse in the Canadian region.

The WGP has provided the WGE with four possible IMS auxiliary network designs; of 75, 100, 130 and 150 stations, respectively. According to the agreed division of labor between the WGP and the WGE, the WGE has made assessments as to which of these networks would be the most adequate for IMS. The WGE has focused on assessment of the expected event location uncertainties for the various designs, using different approaches, and on azimuthal coverage, using the so-called "octant approach". Their findings are presented in GSE/WGE/14, along with discussions of assumptions and limitations associated with this kind of assessment.

Network Recommendations

To accommodate all expert views expressed in CD/NTB/WP.269 regarding the number of stations in the IMS auxiliary seismic network, two possible designs are presented in the following (CD/NTB/WP.269, page 12: "Some experts expressed the view that up to 100 auxiliary stations would be needed, while others considered that between 100 and 150 stations would be necessary").

Table 7.5.1 lists 130 stations preliminarily proposed for the IMS auxiliary network, and in addition defines a subgroup of 100 stations, which in our view would be an optimum subset of this network. The two networks thus defined in this table are slightly revised relative to the 100- and 130-station networks that were provided to the WGE for their assessment, but the general capabilities of the corresponding networks are the same.

Table 7.5.1 provides details on the stations of these designs. The table gives the rationale for the inclusion of the various stations, in accordance with the station selection criteria and procedures outlined above. The meaning of the entries in the "Rationale" column of this table is as follows:

S : Station is in a seismically active region

M : Station is in an area of extensive mining

C : Station is in an area where the azimuthal coverage of the primary station network is poor

B : Station could serve as a backup for one or several primary stations (would then need to have continuous communications).

The "status" column of the table gives the operational status of the stations, with codes as follows:

ED : Existing digital station (note that communications link may not be in place)

PL : Planned digital station

PR : Proposed digital station

EA : Existing analog station

The proposed stations are shown as yellow triangles in Fig. 7.5.1, which also shows the IMS primary stations as dark blue squares. As seen in the figure, there is a distinction between the stations in the subgroup defining the 100-station network, and the additional 30 ones that are only in the proposed 130-station network (inverted triangles in the latter category). The stations are plotted against the background of world seismicity, here represented by 16,900 REB epicenters from 1 January 1995 through 11 November 1995.

Features of the 100-Station Design

- This design has 66 stations to cover the major seismic zones of the world. Some of these 66 stations also cover mining activity.
- 34 stations of this design are introduced to improve the overall azimuthal coverage, and/or located in regions of extensive mining activity.
- 13 out of these 100 stations have been assigned the role of providing backup for primary stations. These stations would need to have equipment for continuous transmission of data to the IDC.
- This design has a very limited coverage in ocean areas, and relies on synergy with the IMS hydroacoustic component for adequate performance in these areas.
- The location uncertainty area of this network design as simulated by the WGE is of the order of or smaller than 1,000 km^2 in the interior of all large landmasses except the Antarctica, but exceeds this number in the onshore parts of continental margin areas and in the oceans. It should be noted, however, that simulated network capabilities are generally on the optimistic side, due to several underlying idealistic assumptions made, one of which is that of a fully calibrated network.
- The worldwide octant coverage for this design is between 4 and 5. The WGE considers that a number of 5 or higher indicates good azimuthal coverage.
- Due to lack of digital stations in certain regions, some of the stations proposed to cover the seismically active regions are today analog stations (code EA in the table). These stations will need to be upgraded to comply with IMS standards.

Features of the 130-Station Design

- Relative to the 100-station design, stations have been added to improve the azimuthal coverage, and also to further improve the coverage of the seismicity zones. The coverage is especially improved in ocean areas by the addition of island stations. Some stations have also been added for better backup, in the sense discussed earlier.
- The event location uncertainties are further reduced (relative to those of the 100-station network), and nearly all of the landmasses are now inside the 1000 km^2 location uncertainty area contours, as shown in Fig. 7.5.2. Again, due care must be exercised in interpreting the simulation results.
- The average octant coverage for this design is above 5 globally.
- The WGE work has shown that the 150-station design has better performance than the 130-station design, but the improvements can be termed marginal, and thus perhaps not cost-effective.

Concluding Remarks

This paper has presented two options for an IMS auxiliary seismic network. Together with material that will be presented by others, this might facilitate the discussions in the GSE.

The question of redundancy in the auxiliary station network has not been considered explicitly in our work. Such redundancy might be needed to secure high data availability from all regions of the world.

The synergy with the hydroacoustic component of IMS has not been assessed quantitatively in this paper. It is expected that such synergy effects will be addressed in the expert meetings after the GSE meeting. Joint work by seismic and hydroacoustic experts may justify omitting some of the island stations from the 130-station design proposed in this paper.

Further work and discussion are needed to establish the exact locational capability of the networks and the operational status for the existing auxiliary stations proposed in this paper, and to check the progress of plans and proposals for the stations with status "PL" and "PR", respectively, in the table. Further work is also needed to estimate the costs related to bringing stations and communications arrangements in line with the required IMS standards.

S. Mykkeltveit
U. Kradolfer, Swiss Seismological Service,
ETH, Zurich, Switzerland

Possible IMS Auxiliary Seismic Stations

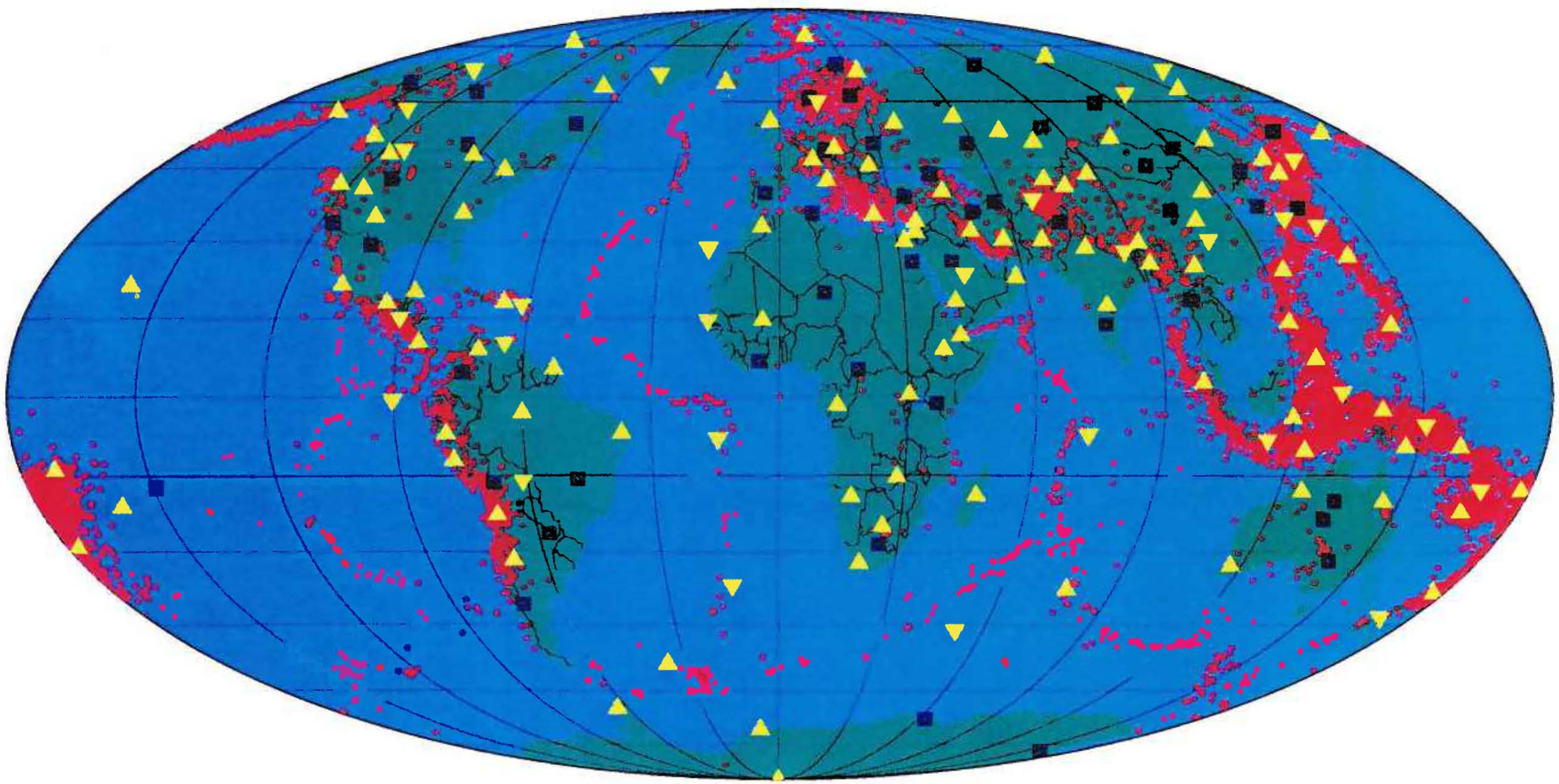

Fig. 7.5.1: The map shows the 50 IMS primary stations already agreed (dark blue squares) and the 130 auxiliary stations (yellow triangles) proposed in this paper.

Simulated event location uncertainty
Primary plus proposed 130-station auxiliary network

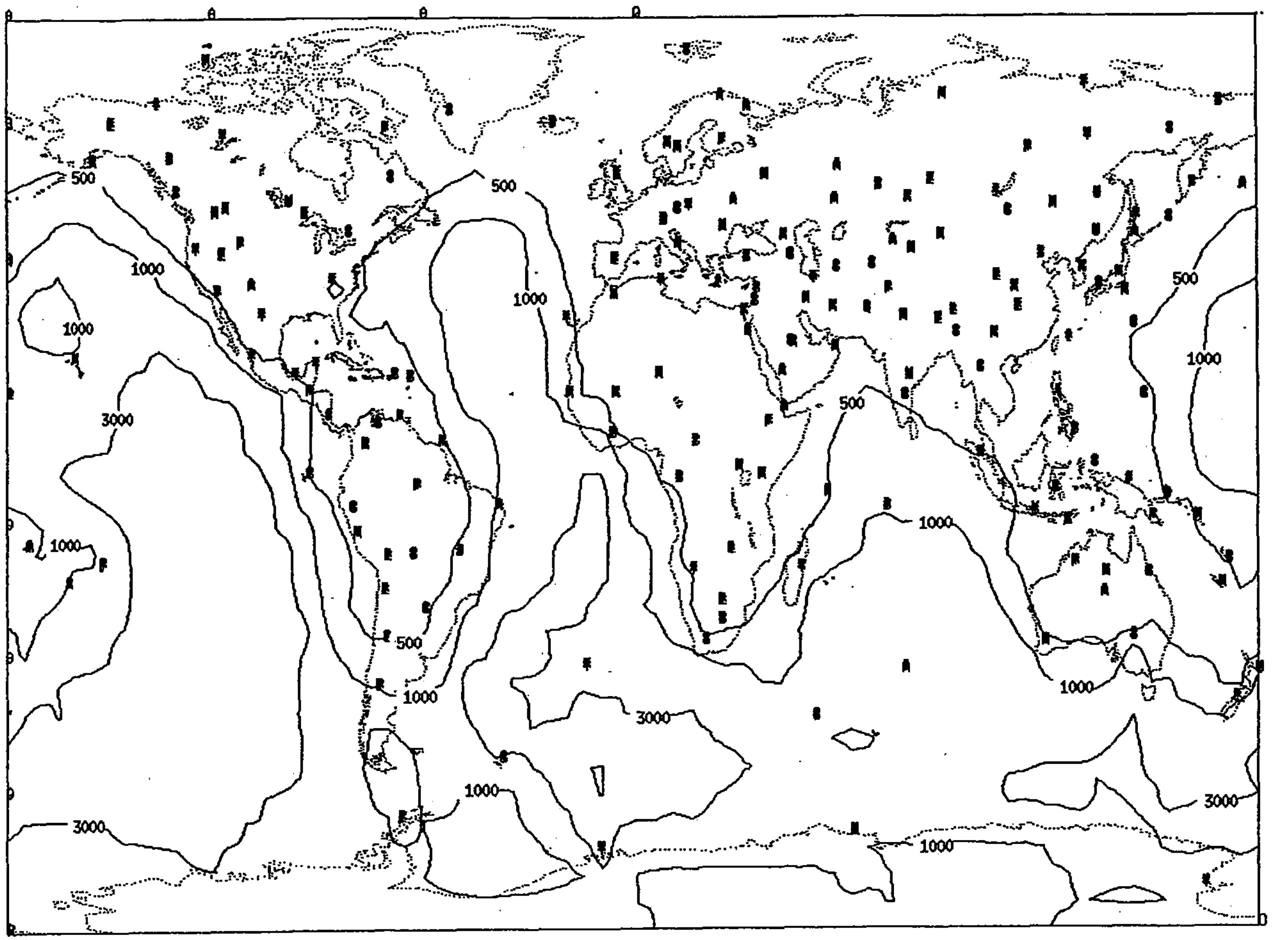

Fig. 7.5.2. This figure shows the simulated event location uncertainty of the network composed of the 50 primary stations already agreed and the 130 auxiliary stations proposed in this paper. The map was prepared by the WGE member Peder Johansson of Sweden.

Proposed IMS Auxiliary Stations

No.	Location	Station name and code	Station type	Lat	Long	Rationale	Status	100
North America								
1	Canada	Mould Bay MBC	3-C	76.242	-119.360	C	ED	x
2	Canada	Iqaluit FRB	3-C	63.747	-68.547	C	ED	x
3	Canada	Bella Bella BBB	3-C	52.185	-128.113	S	ED	x
4	Canada	Sadowa SADO	3-C	44.769	-79.142	M,C	ED	x
5	USA	Kodiac Island KDC	3-C	57.750	-152.490	S	PR	x
6	USA	Attu ATTU	3-C	52.800	172.700	S	ED	x
7	USA	Newport NEW	3-C	48.263	-117.120	S, M	ED	x
8	USA	Yreka YBH	3-C	41.730	-122.710	S	ED	x
9	USA	Elko ELK	3-C	40.745	-115.239	S,B	ED	x
10	USA	Albuquerque ALQ	3-C	34.946	-106.457	S,M	ED	x
11	USA	Ely EYMN	3-C	47.947	-91.508	M	ED	x
12	USA	Tuckaleechee Caverns TKL	3-C	35.658	-83.774	M,C	ED	x
13	Mexico	Islas Marias IMM	3-C	21.620	-106.580	S	PL	x
14	Mexico	Tepich TEYM	3-C	20.210	-88.340	C	PL	x
15	Mexico	Tuzandepeti TUVM	3-C	18.030	-94.420	S	PL	x
16	USA	San Juan SJG	3-C	18.110	-66.150	S	ED	x
17	Costa Rica	Las Juntas de Abangares JTS	3-C	10.290	-84.950	S	ED	x

No.	Location	Station name and code	Station type	Lat	Long	Rationale	Status	100
18	Canada	Dease Lake DLBC	3-C	58.417	-130.060	S,B	ED	
19	Canada	Inuvik INK	3-C	68.307	-113.520	S,C	ED	
20	Canada	Wateron Lakes WALA	3-C	49.060	-113.920	S	ED	
21	Guatemala	Rabir RDG	3-C	15.010	-90.470	S	EA	
22	United Kingdom	Barbuda BWI	3-C	17.665	-61.790	S	EA	
South America								
23	Venezuela	Santo Domingo SDV	3-C	8.890	-70.630	S	ED	x
24	France	Kourou KOG	3-C	5.207	-52.732	C	ED	x
25	Brazil	Pitinga PTGA	3-C	-3.060	-60.000	C	ED	x
26	Brazil	Rio Grande do Norte RGNB	3-C	-6.910	-36.950	C	PL	x
27	Peru	Cajamarca ?	3-C	-7.000	-78.000	S,M,B	New	x
28	Peru	Nana NNA	3-C	-11.990	-76.840	S,M	ED	x
29	Chile	Limon Verde LVC	3-C	-22.590	-68.930	S,M	PL	x
30	Argentina	Coronel Fontana CFA	3-C	-31.607	-68.239	S,B	ED	x
31	Venezuela	Puerto la Cruz PCRV	3-C	10.180	-64.640	S	EA	
32	Ecuador	Santa Cruz ?	3-C	-0.660	-90.230	S	PL	
33	Bolivia	San Ignacio SIV	3-C	-15.991	-61.072	S	EA	
Europe								
34	Iceland	Borgarnes BORG	3-C	64.750	-21.330	S	ED	x

No.	Location	Station name and code	Station type	Lat	Long	Rationale	Status	100
35	Norway	Spitsbergen SPITS	Array	78.178	16.370	S	ED	x
36	Russia	Apatity APAES	Array	67.610	32.990	M	ED	x
37	United Kingdom	Eskdalemuir EKA	Array	55.333	-3.159	C	ED	x
38	Switzerland	Davos ?	3-C	46.839	9.794	S,B	ED	x
39	Czech Republic	Vranov VRAC	3-C	49.308	16.594	M	ED	x
40	Russia	Michnevo MHV	3-C	54.960	37.770	M,C	ED	x
41	Romania	Muntele Rosu MLR	3-C	45.492	25.944	S	ED	x
42	Italy	L'Aquila AQU	3-C	42.354	13.405	S	ED	x
43	Greece	Anogia, Crete IDI	3-C	35.280	24.890	S	ED	x
44	Sweden	Hagfors HFS	Array	60.134	13.697	B	ED	
45	Denmark	Søndre Strømfjord SSGL	3-C	67.050	-50.300	C	PL	
Atlantic Ocean								
46	South Georgia Island	South Georgia ?	3-C	-54.000	-36.000	S	PR	x
47	Spain	Taburiente TRT	3-C	28.680	-17.910	C	ED	
48	United Kingdom	Tristan da Cunha ?	3-C	-37.000	-12.500	S,C	PR	
49	United Kingdom	Ascencion Island ASCN	3-C	-7.950	-14.380	S,C	ED	
Africa								
50	Morocco	MIdelt MDT	3-C	32.820	-4.610	S,B	ED	x
51	Egypt	Kottamya KEG	3-C	29.930	31.830	S	ED	x

No.	Location	Station name and code	Station type	Lat	Long	Rationale	Status	100
52	Ethiopia	Furi FURI	3-C	8.900	38.680	S,B	PL	x
53	Djibouti	Arta tunnel ATD	3-C	11.530	42.847	S	ED	x
54	Uganda	Mbarara ?	3-C	0.360	30.400	S	PL	x
55	Zambia	Lusaka LSZ	3-C	-15.280	28.190	S,M	ED	x
56	Namibia	Tsumeb TSUM	3-C	-19.130	17.420	C	ED	x
57	Botswana	Lobatse LBTB	3-C	-25.015	25.597	M,B	ED	x
58	South Africa	Sutherland SUR	3-C	-32.380	20.810	M	ED	x
59	Madagascar	Antananarivo TAN	3-C	-18.920	47.550	C	EA	x
60	Gabon	Bambay BAMB	3-C	-1.660	13.610	C	PL	x
61	Mali	Kowa KOWA	3-C	14.500	-4.020	C	PL	x
62	Senegal	M'Bour MBO	3-C	14.391	-16.955	C	ED	
Asia								
63	Russia	Arti ARU	3-C	56.430	58.563	M,C	ED	x
64	Armenia	Garni GNI	3-C	40.050	44.720	S	ED	x
65	Israel	Bar Giyora BGIO	3-C	31.722	35.092	S	ED	x
66	Lebanon	Bhannes BHL	3-C	33.900	35.650	S	PL	x
67	Saudi Arabia	Ab'ha ?	3-C	18.300	42.500	C	PR	x
68	Oman	Wadi Sarin WRAS	3-C	23.000	58.000	S	PL	x
69	Iran	Kerman KRM	3-C	30.280	57.070	S,B	PL	x

No.	Location	Station name and code	Station type	Lat	Long	Rationale	Status	100
70	Iran	Masjed-E-Solayman MSN	3-C	31.930	49.300	S	PL	x
71	Pakistan	Quetta QUE	3-C	30.190	66.950	S	PL	x
72	Kyrghyzstan	Ala-Archa AAK	3-C	42.640	74.490	S	ED	x
73	Kazakhstan	Kurchatov KURK	Array	50.715	78.621	M,B	ED	x
74	Kazakhstan	Borovoye BRVK	3-C	53.058	70.283	M,C	ED	x
75	India	New Delhi NDI	3-C	28.690	77.220	S	PR	x
76	India	Hyderabad HYB	3-C	17.420	78.550	M	ED	x
77	India	Shillong SHIO	3-C	25.570	91.880	S,B	PR	x
78	China	Baijiatuan BJT	3-C	40.020	116.170	M,C	ED	x
79	China	Kunming KMI	3-C	25.150	102.750	S,M	ED	x
80	China	Xi'an XAN	3-C	34.040	108.920	S,M,B	ED	x
81	China	Wulumuqi WMQ	3-C	43.820	87.700	S	ED	x
82	China	Lhasa LSA	3-C	29.700	91.150	S	ED	x
83	China	Wushi WUS	3-C	41.200	79.220	S	ED	x
84	Russia	Seymchan SEY	3-C	62.930	152.370	S,M	ED	x
85	Russia	Yuzhno-Sakhalinsk YSS	3-C	46.950	142.750	S,B	ED	x
86	Russia	Tiksi TIXI	3-C	71.660	128.870	C	ED	x
87	Russia	Talaya TLY	3-C	51.580	103.640	S,M	ED	x
88	Russia	Urgal URG	3-C	51.100	132.360	S	ED	x

No.	Location	Station name and code	Station type	Lat	Long	Rationale	Status	100
89	Japan	Aibetsu AIG	3-C	43.910	142.650	S	ED	x
90	Japan	Chichijima OGS	3-C	27.060	142.200	S	ED	x
91	Japan	Ishigakijima ISG	3-C	24.380	124.230	S	ED	x
92	Phillippines	Tagaytay TGY	3-C	14.100	120.940	S,M	ED	x
93	Phillippines	Davao DAV	3-C	7.090	125.570	S	ED	x
94	Indonesia	Sulawesi ?	3-C	-4.000	120.000	S	PR	x
95	Indonesia	Parapat PSI	3-C	2.700	98.920	S,M	ED	x
96	Indonesia	Jayapura JAY	3-C	-2.520	140.700	S	PL	x
97	Indonesia	Kupang KUG	3-C	-10.000	123.000	S	EA	x
98	Tadjikistan	Gissar ?	3-C	38.380	68.510	S	PR	
99	Saudi Arabia	Ar Rayn RAYN	3-C	23.600	45.600	C	PL	
100	Nepal	Everest EVN	3-C	27.960	86.820	S	ED	
101	China	Enshi ENH	3-C	30.270	109.490	S	ED	
102	Russia	Bilibino BILL	3-C	68.040	166.270	C	ED	
103	Russia	Yakutsk YAK	3-C	62.010	129.430	S	ED	
104	Russia	Simushir SIU	3-C	46.850	151.867	S	EA	
105	Japan	Hachijojima HCH	3-C	33.120	139.800	S	ED	
106	Japan	Shiraki SHK	3-C	34.530	132.680	S	ED	
107	Indonesia	Kalikatan KELI	3-C	-8.220	114.490	S	EA	

No.	Location	Station name and code	Station type	Lat	Long	Rationale	Status	100
108	Indonesia	Sarong SWI	3-C	0.860	131.260	S	EA	
Indian Ocean								
109	France	New Amsterdam Island AIS	3-C	-37.797	77.569	C	ED	x
110	France	Port Alfred CRZF	3-C	-46.430	51.861	C	ED	
111	United Kingdom	Diego Garcia ?	3-C	-7.30	72.40	S,C	PR	
Antarctica								
112	Antarctica	Palmer Station PMSA	3-C	-64.770	-64.070	C	ED	x
113	Antarctica	Georg Neumayer Base VNA	3-C	-70.610	-8.366	C	ED	x
114	Antarctica	South Pole SPA	3-C	0.00	115.000	C	ED	x
Oceania and Pacific Ocean								
115	Papua New Guinea	Port Moresby PMG	3-C	-9.410	147.150	S	ED	x
116	Australia	Narrogin NWAO	3-C	-32.927	117.233	M,C	ED	x
117	Australia	Fitzroy Crossing FITZ	3-C	-18.103	125.643	M,C,B	ED	x
118	Australia	Charters Towers CTA	3-C	-20.088	146.254	M,C	ED	x
119	USA	Guam GUMO	3-C	13.590	144.870	S	ED	x
120	Solomon Islands	Honiara HNR	3-C	-9.430	159.950	S	ED	x
121	France	Port Laguerre NOUC	3-C	-22.101	166.303	S	ED	x
122	Fiji Islands	Monasavu MSVF	3-C	-17.750	178.050	S	ED	x
123	New Zealand	Urewera URZ	3-C	-38.260	177.110	S	ED	x
124	Kermadec Islands	Raoul Island ?	3-C	-29.150	-177.520	S	PR	x

No.	Location	Station name and code	Station type	Lat	Long	Rationale	Status	100
125	Western Samoa	Afiamalu AFI	3-C	-13.910	-171.780	S	ED	x
126	Cook Islands	Rarotonga RAR	3-C	-21.210	-159.770	C	ED	x
127	USA	Kipapa KIP	3-C	21.423	-158.015	C	ED	x
128	Papua New Guinea	Bialla BIAL	3-C	-5.310	151.050	S	EA	
129	Vanuatu	Butte a Klehm BKM	3-C	-17.668	168.243	S	EA	
130	New Zealand	Rewhon EWZ	3-C	-43.512	170.853	S	ED	

Table 7.5.1. The table gives details on the 130 stations proposed for the IMS auxiliary network. The meaning of the colums "Rationale" and "Status" is explained in the text. The rightmost column labelled "100" identifies stations of an optimum 100-station subgroup of this 130-station network.