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VII.7 P-wave Detectability Study of Existing World-Wide Seismograph Stations

A detailed knowledge of the event detection capabilities of existing seismograph stations is a prerequisite in order to accurately assess the existing capabilities for monitoring underground nuclear explosions. Such information can most reliably be obtained by actually measuring the performance of each station over an extended period of time, in terms of the number of reported teleseismic events. The method of Ringdal (1975) is well suited to this kind of analysis, provided an adequate 'reference system' (i.e., an organization reporting a comprehensive event catalogue and associated magnitudes) is available. In this respect, an analysis of the event detection capabilities of seismograph stations in Fennoscandia was undertaken by Pirhonen et al (1976), based upon ISC reported events during the years 1964-69. Fig. VII.7.1 shows the type of results obtained by this study, and the excellent fit of the detection curves shows that the resulting detectability estimates must be considered very reliable.

The objective of the present study, which is as yet in its initial stage, is to perform a comprehensive evaluation of world-wide P-wave detectability of existing seismograph stations in terms of ISC magnitude. The incremental probability G of detection, given event magnitude m , is assumed to be of the form (Ringdal, 1975)

$$G(m; \mu, \sigma) = \int_{-\infty}^m \frac{1}{\sqrt{2\pi} \cdot \sigma} \cdot \exp(-(x-\mu)^2 / (2\sigma^2)) dx \quad (1)$$

where the two parameters μ and σ characterize the detection capability. Assuming, for a given station, that the probability of 'false alarm' is equal to V_F , and the probability of the

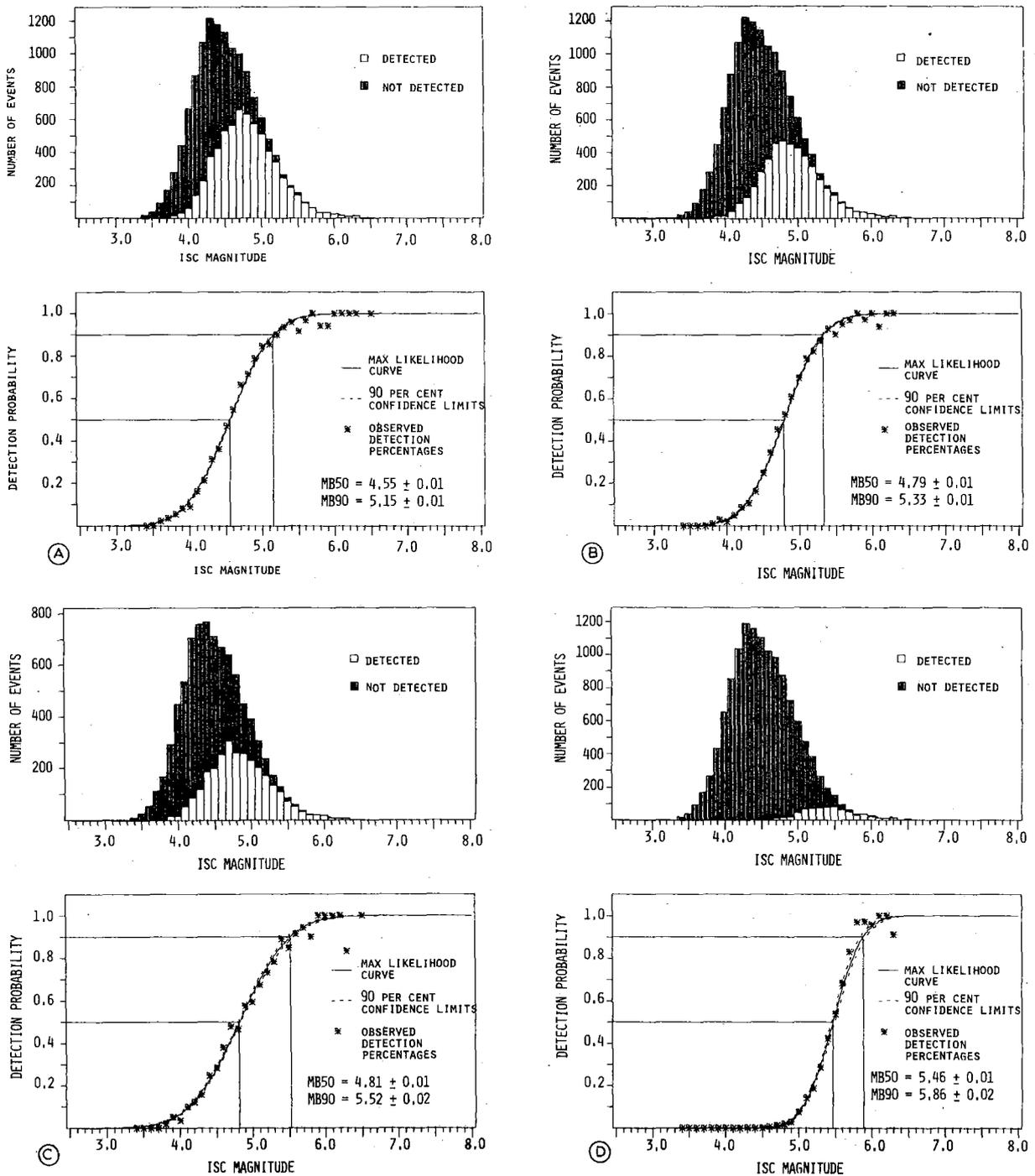


Fig. VII.7.1 Teleseismic (30° - 90°) P-wave detection statistics for selected stations based on the years 1964-69. The upper half is a histogram showing the reference event set and the number of events actually detected for each magnitude. the lower half shows the maximum likelihood detectability curve and its confidence limits. The actual percentage of detected events at each magnitude is also shown.

A. For station NUR (Nurmijarvi, Finland)
 B. For station UPP (Uppsala, Sweden)
 C. For LHN (Lillehammer, Norway)
 D. For COP (Copenhagen, Denmark)

station being out of operation is equal to V_D , it follows that the probability of finding a station detection that can be associated to a given event of ISC magnitude m is:

$$P(m) = P(m; \mu, \sigma, V_F, V_D) = (1 - V_D) \cdot [V_F + (1 - V_F) \cdot G(m; \mu, \sigma)] \quad (2)$$

For a given set S of reference events, denote by D the set of indices for which the station actually has a detection. The logarithm of the associated likelihood function then becomes (Ringdal, 1975)

$$\log L(\mu, \sigma, V_F, V_D) = \sum_{i \in D} P(m_i) + \sum_{i \notin D} (1 - P(m_i)) \quad (3)$$

This function may subsequently be maximized to obtain maximum likelihood estimates of the parameters μ, σ, V_F, V_D . In practice, V_F may reasonably be set to 0, since the chance of a 'random association' in the ISC bulletin can be considered very small. However, the 'downtime' parameter V_D cannot in general be ignored, and must be estimated on the basis of available data. We note in passing that Pirhonen et al (1976) estimated V_D directly from operational statistics obtained from the Fenno-scandian stations; however, this procedure cannot be used in the present case as no reliable operational reports are generally available.

Our initial detectability results, as presented here, have been obtained by, for each station reporting to the ISC, extracting those ISC reported events that have been located within 30-90 degrees epicentral distance of the station. Only events with an associated ISC computed m_b value have been used in this reference set. Table 1 summarizes the observed detection percentages and the estimated 50 and 90 per cent incremental teleseismic detection thresholds for a subset of 96 stations. This subset consists of those stations with an estimated 50 per cent threshold of $m_b = 5.0$ and better.

STATION NAME AND LOCATION	LAT	LON	DETECTION PERCENTAGE AT ISC MB							*****OBSERVED*****				***ESTIMATED***		
			3.5	4.0	4.5	5.0	5.5	6.0	6.5	DET	TOT	PC	MAVG	M50	M90	UPTM
AAB -TALGAR	KAZAKHSTAN	43.16N, 77.23E	0	4	22	56	80	89	79	2312	6069	38	5.07	4.80	5.41	85
ALE -ALERT	NORTHWEST TERRITORY	82.29N, 62.24W	2	8	29	68	94	94	89	1786	4310	41	4.95	4.73	5.36	95
ALQ -ALBUQUERQUE	NEW MEXICO	34.56N, 106.27W	0	4	22	56	78	75	90	1282	3878	33	4.98	4.76	5.34	80
ARE -AREQUIPA	PERU	16.27S, 71.29W	0	1	13	47	85	85	100	307	1036	30	5.07	4.95	5.49	90
ASP -ALICE SPRINGS	NORTHERN TERRITORY	23.41S, 133.53E	24	23	49	81	95	96	82	2377	3832	62	4.92	4.44	5.16	95
BDF -BRASILIA ARRAY (W)	BRAZIL	15.39S, 47.54W	11	14	28	51	59	68	100	520	1485	35	4.84	4.63	5.56	70
BKR -BAKURIANI	GEORGIA, USSR	41.44N, 43.31E	4	3	20	53	81	84	78	1181	3411	35	5.06	4.89	5.53	90
BLC -BAKER LAKE	NORTHWEST TERRITORY	64.19N, 96.1W	0	5	19	52	80	90	80	1302	4275	30	4.99	4.90	5.58	90
BMD -BLUE MOUNTAINS	OREGON	44.50N, 117.18W	71	77	87	91	98	90	92	3939	4527	87	4.67	0.0	0.0	90
BNG -BANGUI	CENTRAL AFRICA REP.	4.22N, 18.34E	6	31	55	68	71	71	50	1083	1883	58	4.79	4.08	4.72	70
BOD -BODAYBO	CENTRAL SIBERIA	57.51N, 114.11E	0	4	19	45	73	73	73	1181	3310	36	5.10	4.89	5.60	80
BRG -BERGGIESSHUBEL	GERMANY	50.52N, 13.56E	0	1	13	34	42	49	50	685	3582	19	5.00	4.66	5.09	40
BRS -BRISBANE	QUEENSLAND	27.23S, 152.46E	0	3	15	47	80	96	88	1057	3184	33	5.12	5.00	5.66	95
BUL -BULAWAYO	RHODESIA	20.8S, 28.36E	0	7	36	76	96	98	100	1035	1943	53	4.96	4.67	5.28	100
CIR -CHIREZI	RHODESIA	21.0S, 31.34E	0	1	25	58	83	95	50	717	1757	41	5.02	4.81	5.42	90
CLL -COLLM BERG	GERMANY	51.18N, 13.0E	0	12	39	78	97	96	88	1785	3607	49	4.91	4.58	5.17	95
COL -COLLEGE OUTPOST	ALASKA	64.54N, 147.47W	16	29	56	84	93	91	94	3265	4994	65	4.88	4.29	4.97	90
CPO -CUMBERLAND PLATEAU	TENNESSEE	35.35N, 85.34W	4	19	37	71	92	94	88	1483	3122	48	4.87	4.62	5.41	95
CTA -CHARTERS TOWERS	QUEENSLAND	20.5S, 146.15E	0	8	28	61	92	95	88	1584	3596	44	5.02	4.78	5.45	95
DUG -DUGWAY	UTAH	40.11N, 112.48W	0	9	27	59	77	76	90	1600	4323	37	4.92	4.69	5.37	80
EDM -EDMONTON	ALBERTA	53.13N, 113.21W	4	14	44	77	90	89	90	2189	4368	50	4.86	4.51	5.13	90
EIL -EILAT	ISRAEL	29.33N, 34.57E	0	0	8	33	54	52	43	559	2918	19	5.11	4.90	5.38	55
EKA -ESKDALEMUIR ARRAY	SCOTLAND	55.19N, 3.9W	3	2	11	43	77	81	78	909	3732	24	5.10	4.99	5.57	85
ELT -YELTSOVKA	WESTERN SIBERIA	53.15N, 86.16E	0	6	27	58	79	79	77	1704	4188	41	5.03	4.70	5.31	80
EUR -EUREKA	NEVADA	39.29N, 115.58W	9	28	54	80	89	90	85	2691	4510	60	4.81	4.32	5.08	90
FAV -FAYETTEVILLE	ARKANSAS	36.7N, 94.11W	0	1	7	48	85	86	78	781	3272	24	5.14	4.98	5.44	90
FCC -FORT CHURCHILL	MANITOBA	58.45N, 94.5W	4	5	16	46	77	83	90	1173	4349	27	5.00	4.99	5.73	90
FFC -FLIN FLON	MANITOBA	54.43N, 101.58W	8	15	37	70	88	90	80	1898	4240	45	4.85	4.60	5.34	90
GBA -GAURIBIDANUR ARRAY	INDIA	13.36N, 77.26E	0	4	17	48	75	86	93	1269	3780	34	5.11	4.97	5.67	90
GIL -GILMORE CREEK	ALASKA	64.58N, 147.29W	4	12	39	71	87	95	100	2569	4985	52	4.96	4.58	5.25	90
GMA -GRANITE MOUNTAIN	ALASKA	65.25N, 161.13W	2	6	24	57	82	90	88	1986	4973	40	5.04	4.82	5.50	90
GOL -GOLDEN	COLORADO	39.42N, 105.22W	0	3	11	38	61	67	60	824	3918	21	5.03	4.98	5.65	70
GRF -GRAFENBERG ARRAY	GERMANY	49.41N, 11.12E	0	8	29	64	82	85	89	1399	3569	39	4.94	4.69	5.32	85
HFS -HAGFORS	SWEDEN	60.8N, 13.41E	37	46	60	82	96	94	88	2506	3762	67	4.76	4.16	5.41	100
IFR -IFRANE	MOROCCO	33.31N, 5.7W	0	3	11	42	73	72	75	592	2377	25	5.04	4.97	5.58	80
ILT -IULTIN	NORTH-WEST SIBERIA	67.54N, 178.42W	0	5	20	45	76	83	82	1614	4716	34	5.08	4.97	5.73	90
IMA -INDIAN MOUNTAIN	ALASKA	66.4N, 153.40W	0	8	16	34	42	51	47	1202	4929	24	4.98	4.74	5.59	50
INK -INUVIK	NORTHWEST TERRITORY	68.17N, 133.30W	0	12	29	58	83	84	70	1786	4452	40	4.94	4.77	5.58	90
JAS -JAMESTOWN	CALIFORNIA	37.56N, 120.26W	0	3	19	63	96	97	92	1805	4770	38	5.05	4.82	5.34	95
JCT -JUNCTION CITY	TEXAS	30.28N, 99.48W	6	3	13	41	65	68	56	812	3374	24	5.03	4.91	5.54	70
KBL -KABUL	AFGHANISTAN	34.32N, 69.2E	16	23	44	68	74	78	64	2061	3973	52	4.90	4.39	5.27	80
KEV -KEVO	FINLAND	69.45N, 27.0E	0	4	15	50	87	98	88	1302	4273	30	5.07	4.99	5.65	100
KHC -KASPERSKE HORY	CZECHOSLOVAKIA	49.7N, 13.34E	0	10	38	77	97	95	89	1731	3548	49	4.93	4.60	5.18	95
KHD -KHOROG	TADZHIKISTAN	37.29N, 71.32E	0	3	15	42	68	75	57	1171	3995	29	5.10	4.91	5.54	75
KIC -KOSAN BOKA	IVORY COAST	6.21N, 4.44W	4	28	50	79	86	84	80	1438	2490	58	4.80	4.38	5.15	90
KIR -KIRUNA	SWEDEN	67.50N, 20.25E	5	10	31	68	92	95	88	1786	4129	43	4.94	4.70	5.37	95
KJF -KAJAANI	FINLAND	64.11N, 27.42E	11	20	50	83	96	96	88	2280	3888	59	4.87	4.44	5.10	95
KRA -CRACOW	POLAND	50.3N, 19.56E	0	1	10	53	89	96	86	949	3307	29	5.14	4.92	5.36	90
KRR -KAROI	RHODESIA	16.51S, 29.37E	0	2	26	61	84	95	100	690	1660	42	5.01	4.78	5.37	90
KRV -KIROVABAD	AZERBAIDZHAN	40.39N, 46.20E	0	3	14	41	66	84	70	939	3415	27	5.09	4.99	5.69	80

Table VII. 7.1

Teleseismic (30° - 90°) P-wave detection capability of selected stations reporting to the ISC during 1971-73. The following items are listed: (i) station code, (ii) geographical coordinates, (iii) percentage of detected reference events in magnitude bins of $0.5 m_b$ units centered at 3.5, 4.0, etc., (iv) total number of detected events, reference events and corresponding percentage detected, (v) average ISC reported m_b of the detected events, (vi) estimated 50 and 90 per cent incremental detection threshold, (vii) estimated percentage of total time when the station was actually reporting.

ISC STATIONS DETECTABILITY STUDY 1971-1973 NTFN/NORSAR

STATION NAME AND LOCATION	LAT	LON	DETECTION PERCENTAGE AT ISC MB								*****OBSERVED*****				***ESTIMATED***		
			3.5	4.0	4.5	5.0	5.5	6.0	6.5	DET	TOT	PC	MAVG	M50	M90	UPTM	
LAO -LASA CENTRE	MONTANA	46.41N,106.13W	91	90	83	77	81	74	80	3514	4247	83	4.50	0.0	0.0	80	
LBF -LES BUTEAUX	FRANCE	46.59N, 3.58E	0	2	12	50	85	82	70	959	3485	28	5.10	4.94	5.47	90	
LOR -LORMES	FRANCE	47.16N, 3.51E	0	2	13	54	91	89	80	1040	3503	30	5.10	4.90	5.39	90	
LPB -LA PAZ	BOLIVIA	16.31S, 68. 5W	11	17	50	77	93	89	100	611	1050	58	4.87	4.44	5.11	90	
MAT -MATSUSHIRO	HONSHU	36.32N,138.12E	0	4	20	59	93	97	92	1579	3412	46	5.13	4.85	5.40	95	
MBC -MOULD BAY	NORTHWEST TERRITORY	76.14N,119.21W	15	30	50	69	83	82	80	2287	4235	54	4.79	4.38	5.49	90	
MOX -MOXA	GERMANY	50.38N, 11.36E	3	7	31	75	97	96	88	1601	3595	45	4.96	4.67	5.22	95	
MTD -MOUNT DARWIN	RHODESIA	16.46S, 31.35E	0	1	18	37	56	62	0	425	1555	27	5.00	4.82	5.48	60	
NAO -NORSAR A	NORWAY	60.49N, 10.49E	45	59	50	45	47	55	63	1886	3756	50	4.60	0.0	0.0	50	
NDI -NEW DELHI	INDIA	28.41N, 77.13E	0	2	13	45	82	90	93	1241	3981	31	5.16	4.98	5.56	90	
NEW -NEWPORT	WASHINGTON	48.15N,117. 7W	0	6	24	65	95	96	91	1729	4546	38	4.98	4.78	5.36	95	
NIE -NIEDZICA	POLAND	49.25N, 20.19E	0	2	17	51	75	69	71	969	3301	29	5.04	4.80	5.30	75	
NIL -NILORE	PAKISTAN	33.39N, 73.15E	0	4	20	44	62	61	64	1206	3957	30	5.04	4.77	5.43	65	
NTI -NORDMAN	IDAHO	48.37N,116.57W	0	3	17	54	85	90	80	1402	4541	31	5.03	4.88	5.46	90	
NUR -NURMIJARVI	FINLAND	60.30N, 24.39E	9	24	51	83	98	99	88	2145	3601	60	4.86	4.46	5.22	100	
OBN -OBNINSK	CENTRAL RUSSIA	55.10N, 36.36E	0	2	20	63	92	93	88	1374	3547	39	5.07	4.79	5.28	90	
PMR -PALMER	ALASKA	61.35N,149. 7W	2	5	28	65	89	95	100	2309	5156	45	5.04	4.76	5.37	95	
PNS -PENAS	BOLIVIA	16.16S, 68.28W	11	24	54	81	92	89	100	646	1047	62	4.84	4.36	5.04	90	
PNT -PENTICTON	BRITISH COLUMBIA	49.19N,119.37W	2	3	16	53	89	92	91	1417	4620	31	5.05	4.89	5.46	90	
PRE -PRETORIA	SOUTH AFRICA	25.45S, 28.11E	0	1	14	46	78	80	100	613	1968	31	5.07	4.90	5.44	80	
PRU -PRUHONICE	CZECHOSLOVAKIA	49.59N, 14.32E	0	4	22	68	92	97	88	1344	3542	38	5.03	4.75	5.24	90	
QUE -QUETTA	PAKISTAN	30.11N, 66.57E	0	5	25	61	82	82	79	1592	3914	41	5.04	4.74	5.32	85	
ROL -ROLLA	MISSOURI	37.55N, 91.52W	0	2	9	24	34	38	33	457	3343	14	4.98	4.89	5.57	40	
SES -SUFFIELD	ALBERTA	50.23N,111. 2W	4	8	33	71	92	90	91	1873	4395	43	4.91	4.65	5.24	90	
SHI -SHIRAZ	PERSIA	29.38N, 52.31E	0	3	15	53	86	93	91	1182	3391	35	5.12	4.89	5.44	90	
SHL -SHILLONG	INDIA	25.34N, 91.53E	0	1	10	38	63	73	82	1075	4183	26	5.16	4.95	5.50	70	
SOD -SODANKYLA	FINLAND	67.22N, 26.37E	5	20	46	80	97	99	88	2293	4098	56	4.88	4.53	5.28	100	
SOP -SOPRON	HUNGARY	47.41N, 16.33E	0	1	7	25	42	46	50	488	3353	15	5.08	4.93	5.48	45	
SPA -SOUTH POLE	ANTARCTICA	90. 0S, 0. 0E	0	36	55	68	75	70	92	1752	2762	63	4.96	4.04	4.97	75	
SSF -SAINT-SAULGE	FRANCE	47. 3N, 3.30E	0	2	12	51	86	82	80	981	3475	28	5.09	4.93	5.46	90	
SVE -SVERDLOVSK	WESTERN SIBERIA	56.48N, 60.38E	0	1	14	45	71	81	90	1053	3640	29	5.13	4.93	5.51	80	
TAM -TAMANRASSETT	ALGERIA	22.47N, 5.31E	0	10	24	42	49	61	67	645	2093	31	4.88	4.68	5.58	60	
TCF -TOULX-STE-CROIX	FRANCE	46.17N, 2.12E	0	2	10	48	76	69	60	863	3418	25	5.09	4.92	5.44	80	
TIK -TIKSI	EASTERN SIBERIA	71.38N,128.52E	0	4	21	49	73	80	82	1438	4000	36	5.08	4.83	5.49	80	
TTA -TATALINA	ALASKA	62.55N,156. 1W	0	1	7	21	34	44	41	737	5056	15	5.12	4.97	5.61	40	
TUC -TUCSON	ARIZONA	32.18N,110.46W	0	5	22	62	93	89	90	1491	4055	37	5.01	4.78	5.33	90	
TUL -TULSA	OKLAHOMA	35.54N, 95.47W	0	13	35	70	88	92	89	1469	3274	45	4.89	4.62	5.29	90	
UBD -UINTA BASIN ARRAY	UTAH	40.19N,109.34W	45	47	55	60	58	51	60	2309	4216	55	4.66	0.0	0.0	60	
UME -UMEA	SWEDEN	63.48N, 20.14E	13	16	37	69	93	96	88	1843	3868	48	4.90	4.68	5.52	100	
UPP -UPPSALA	SWEDEN	59.51N, 17.37E	8	10	30	68	95	99	88	1617	3768	43	4.96	4.75	5.46	100	
UZH -UZHGOROD	UKRAINE	48.38N, 22.18E	0	0	7	41	79	80	86	756	3311	23	5.18	4.98	5.44	80	
VAN -VANNOVSKAYA	TURKMENIYA	37.57N, 58. 6E	0	0	3	18	33	34	18	390	3464	11	5.20	4.98	5.44	35	
WRA -WARRAMUNGA ARRAY	NORTHERN TERRITORY	19.56S,134.20E	20	27	51	76	92	92	82	2337	3828	61	4.90	4.36	5.17	90	
YAK -YAKUTSK	EASTERN SIBERIA	62. 1N,129.43E	0	1	13	34	55	72	40	941	3460	27	5.14	4.96	5.63	65	
YK -YELLOW KNIFE	NORTHWEST TERRITORY	62.28N,114.28W	2	8	20	52	81	80	80	1321	4228	31	4.96	4.90	5.66	90	
ZAK -ZAKAMENSK	CENTRAL SIBERIA	50.23N,103.17E	0	4	19	52	76	81	79	1443	3911	37	5.09	4.82	5.43	80	

Table VII.7.1 (cont.)

For four stations (NORSAR, LASA, UBO, BMO) no estimates have been given due to the fact that these stations detect essentially all ISC events in the appropriate distance range, hence ISC is not suitable as a reference network in these cases. Otherwise we note that stations of high detectability are found worldwide; e.g., Africa (BNG; $m_{50}=4.1$, KIC -4.4), South America (PNS - 4.4; BDF - 4.6), Antarctica (SPA - 4.0), Asia (KBL - 4.4; ELT - 4.7), Australia (ASP - 4.4; WRA - 4.4), besides several sensitive stations in North America and Europe.

Future work on the detectability study will concentrate on evaluating the potential bias in ISC m_b estimates and its effects on our detectability computations. Also, a possible regionalization of detection thresholds will be studied. Moreover, an analysis will be undertaken in order to determine to what extent the detection of a given event by stations within a close distance of one another are correlated. This is important since global detectability studies (e.g., Snell, 1976) generally assume statistical independence in this context.

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