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7.3 Generalized beamforming using a network of four regional arrays

The generalized beamforming method (GBF) for automatic phase association and event location (Ringdal and Kværna, 1989) has now been implemented for processing of data from the four regional arrays, ARCESS, FINESA, GERESS and NORESS. This method works from a list of phase detections for each array. For a large set of hypothetical event locations, GBF searches for a pattern of detections that fit the theoretically expected phase arrivals from the hypothetical locations. When a group of matching detections is found, the event location having the best fit to the data is chosen as the most likely epicenter.

In the following we present a brief report on our initial experience from applying GFB experimentally to the four-array network during a continuous five-day period.

Data analysis

A total of 600 beam grid points with an average separation of 150 km is used to span the geographical area of interest (see Fig. 7.3.1). This grid represents the initial (coarse) set of test locations, and whenever a match is found, a beampacking algorithm with a much denser grid is applied to refine the locations.

The GBF output from a typical 12-hour period is given in Table 7.3.1. For each associated event, the table lists the individual phase detections that either have defined the event or been associated as coda phases (p or s). Phase attributes (SNR, apparent velocity, dominant frequency, etc.) are also listed for each entry.

From Table 7.3.1 we find that the majority of the events are observed by one array only, whereas larger events have phase observations at two or more arrays. This is consistent with earlier studies of two-array and three-array networks.

It is interesting to notice that the incorporation of data from GERESS enables us to obtain more reliable event locations for events in northern Europe, as seen for the event in Poland with origin time 292:21.57.40 and epicenter location 51.70°N, 15.68°E. This event is presumed to be a rockburst in the Lubin mining area, and the location estimate is very close to that site.

In order to evaluate the performance of the method, we have analyzed GBF results from five consecutive working days (10/22/90 – 10/26/90). The results can be summarized as follows:

1. Several hundred regional events were associated, where the large majority were detected by one array only.

2. A total of 37 events had four or more associated phase detections, and the corresponding locations are shown in Fig. 7.3.2. After inspection we found that all but one of these events were properly associated and located. From Fig. 7.3.2 we see that the large majority of these events are located in the active mining areas of western USSR. We also notice a precise location of a nuclear explosion at Novaya Zemlya.

3. The occurrence of incorrect phase associations increases when we allow fewer than four phases to define an event.

Future work

From inspecting phase attributes, the analyst can in many cases identify erroneous phase associations based on inconsistencies among parameters like epicentral distance, apparent velocity and dominant frequency. Our next step will be to compile statistics on such attributes and make this kind of information available to the GBF program for use in the automatic computations.

We have also found that there is a need to refine the travel time models and also to improve the estimation of onset time for the different phase detections. Thereby, the automatic event locations will become even more precise.

Dynamic consistency checks using thresholds computed by the threshold monitoring method are also expected to help in identifying and removing unlikely phase associations. This will be particularly important at the time when detection data from the two three-component systems in Poland will be incorporated into GBF.

T. Kværna

References

Ringdal, F. and T. Kværna (1989): A multichannel processing approach to real time network detection, phase association and threshold monitoring, *Bull. Seism. Soc. Am.*, 79, 1927–1940.

Origin time	Lat	Lon	Azres	Timres	Wres	Nphase
1990-292:12.00.03.0	59.80	27.26	3.65	2.71	3.63	3

Sta	Dist	Az	Ph	Time	Tres	Azim	Ares	Vel	Snr	Amp	Freq	Fkq	Pol	Arid
FIN	194.4	160.1	Pn	12.00.33.3	-0.6	155.1	-5.0	6.4	18.4	752.9	6.07	3		115935
FIN	194.4	160.1	Sn	12.01.07.3	7.1	162.3	2.2	4.4	19.6	1474.2	3.45	3	-2	115936
NRS	874.8	90.0	Pn	12.01.57.9	0.3	86.2	-3.8	10.7	5.3	237.0	3.59	3		115940

Origin time	Lat	Lon	Azres	Timres	Wres	Nphase
1990-292:12.04.36.0	50.50	12.11	0.58	0.43	0.58	2

Sta	Dist	Az	Ph	Time	Tres	Azim	Ares	Vel	Snr	Amp	Freq	Fkq	Pol	Arid
GER	217.0	328.6	Pn	12.05.09.5	-0.6	327.6	-1.0	7.4	13.2	4020.5	9.03	3		181
GER	217.0	328.6	p	12.05.17.1		335.9	7.3	7.9	4.5	831.1	2.69	2		182
GER	217.0	328.6	s	12.05.30.5		330.1	1.5	3.3	12.3	2018.7	1.25	1	-2	183
GER	217.0	328.6	Lg	12.05.37.0	0.2	328.5	-0.1	3.9	3.8	1857.8	2.28	2		184

Origin time	Lat	Lon	Azres	Timres	Wres	Nphase
1990-292:12.06.12.0	59.50	24.04	3.52	0.32	1.20	3

Sta	Dist	Az	Ph	Time	Tres	Azim	Ares	Vel	Snr	Amp	Freq	Fkq	Pol	Arid
FIN	244.1	208.2	Pn	12.06.48.9	-0.6	203.1	-5.1	7.1	28.7	754.8	5.48	3	-1	115939
FIN	244.1	208.2	Lg	12.07.20.2	-0.1	206.2	-2.0	4.1	17.0	1227.7	3.23	3	-2	115941
NRS	708.0	95.7	Lg	12.09.29.8	-0.2	99.1	3.4	4.3	3.6	1032.6	1.50	1	-3	115946
NRS	708.0	95.7	s	12.09.32.7		96.0	0.3	3.7	2.7	834.6	2.12	2		115947

Origin time	Lat	Lon	Azres	Timres	Wres	Nphase
1990-292:12.08.49.0	59.20	27.52	2.89	0.35	1.07	2

Sta	Dist	Az	Ph	Time	Tres	Azim	Ares	Vel	Snr	Amp	Freq	Fkq	Pol	Arid
FIN	262.6	161.7	Pn	12.09.28.8	0.0	157.8	-3.9	7.3	6.1	306.5	9.90	3		115948
FIN	262.6	161.7	Lg	12.10.03.1	0.7	159.8	-1.9	3.8	4.7	708.1	7.40	3		115949

Origin time	Lat	Lon	Azres	Timres	Wres	Nphase
1990-292:12.28.03.0	67.60	32.68	2.05	1.11	1.63	3

Sta	Dist	Az	Ph	Time	Tres	Azim	Ares	Vel	Snr	Amp	Freq	Fkq	Pol	Arid
ARC	363.9	123.0	Pn	12.28.56.4	1.1	121.8	-1.2	8.0	90.0	3292.0	4.73	2		115970
ARC	363.9	123.0	p	12.29.04.5		125.5	2.5	7.1	9.6	1945.9	6.38	3		115971
ARC	363.9	123.0	Sn	12.29.35.2	-1.8	118.3	-4.7	3.7	2.5	1338.2	4.72	3		115973
ARC	363.9	123.0	Lg	12.29.44.3	-0.4	122.8	-0.2	3.2	3.8	2015.0	3.25	2	-2	115974
ARC	363.9	123.0	s	12.29.47.5		125.3	2.3	4.3	3.6	3113.7	4.44	2		115975

Origin time	Lat	Lon	Azres	Timres	Wres	Nphase
1990-292:12.28.38.0	50.20	14.30	1.97	3.22	3.72	3

Sta	Dist	Az	Ph	Time	Tres	Azim	Ares	Vel	Snr	Amp	Freq	Fkq	Pol	Arid
GER	156.8	15.7	Pg	12.29.04.3	1.0	16.6	0.9	7.5	4.6	2374.7	9.98	4		187
GER	156.8	15.7	Rg	12.29.22.5	-8.7	12.3	-3.4	3.1	22.7	650.6	1.01	1	3	188
NRS	1186.2	170.4	Sn	12.33.08.1	0.1	172.0	1.6	4.3	2.5	409.1	4.49	3		115982
NRS	1186.2	170.4	s	12.33.12.3		173.7	3.3	3.9	11.9	1522.1	3.95	2	-1	115985

Origin time	Lat	Lon	Azres	Timres	Wres	Nphase
1990-292:12.30.18.0	50.80	12.59	8.90	4.50	6.72	3

Sta	Dist	Az	Ph	Time	Tres	Azim	Ares	Vel	Snr	Amp	Freq	Fkq	Pol	Arid
GER	231.8	340.2	Pn	12.30.55.6	1.6	325.8	-14.4	6.3	7.7	3574.5	8.32	3		190
GER	231.8	340.2	Lg	12.31.11.1	-11.8	330.2	-10.0	3.0	8.6	1874.4	1.60	1	-3	192
NRS	1108.7	176.2	Pn	12.32.40.9	-0.1	173.8	-2.4	6.7	5.3	280.3	4.13	3		115978

Table 7.3.1. GBF output from a typical 12-hour period. For each associated event, the table lists the individual phase detections that either have defined the event (Pn, Sn, Lg, Rg) or been associated as coda phases (p or s). Phase attributes (SNR, apparent velocity, dominant frequency, etc.) are also listed for each entry. (Page 1 of 3)

Origin time	Lat	Lon	Azres	Timres	Wres	Nphase
1990-292:12.31.08.0	56.20	26.39	11.07	3.89	6.66	4

Sta	Dist	Az	Ph	Time	Tres	Azim	Ares	Vel	Snr	Amp	Freq	Fkq	Pol	Arid
FIN	584.9	178.1	Pn	12.32.28.5	1.2	155.4	-22.7	9.4	4.5	77.3	4.56	3		115980
FIN	584.9	178.1	p	12.32.56.1		185.0	6.9	7.1	32.1	1286.9	3.91	1		115984
FIN	584.9	178.1	Sn	12.33.24.0	-6.4	180.3	2.2	4.5	8.7	767.9	2.38	1	-2	115986
NRS	1000.7	113.8	Lg	12.35.55.0	7.1	99.4	-14.4	3.4	2.7	660.2	2.35	2		115991
GER	1185.3	41.6	Pn	12.33.39.4	-0.9	46.6	5.0	6.2	9.1	143.9	4.49	4		193

Origin time	Lat	Lon	Azres	Timres	Wres	Nphase
1990-292:12.31.45.0	67.60	33.47	2.34	1.17	1.75	4

Sta	Dist	Az	Ph	Time	Tres	Azim	Ares	Vel	Snr	Amp	Freq	Fkq	Pol	Arid
ARC	390.1	119.8	Pn	12.32.40.0	-0.5	122.5	2.7	7.6	202.2	18647.9	6.78	1		115977
ARC	390.1	119.8	p	12.32.46.3		121.6	1.8	8.5	4.2	1185.3	3.09	3		115979
ARC	390.1	119.8	p	12.32.50.5		117.8	-2.0	7.4	2.8	1568.1	8.43	4		115983
ARC	390.1	119.8	Sn	12.33.21.4	-3.2	124.8	5.0	4.5	6.9	5042.9	2.92	2	-1	115987
ARC	390.1	119.8	Lg	12.33.34.6	0.4	118.2	-1.6	3.2	7.8	11233.4	2.86	2		115990
ARC	390.1	119.8	s	12.33.39.0		120.4	0.6	4.8	5.4	10591.9	3.67	2		115994
NRS	1302.7	44.8	Pn	12.34.32.1	0.5	44.7	-0.1	8.4	4.0	265.2	3.35	3		115988

Origin time	Lat	Lon	Azres	Timres	Wres	Nphase
1990-292:12.35.44.0	61.00	29.03	4.27	2.23	3.29	8

Sta	Dist	Az	Ph	Time	Tres	Azim	Ares	Vel	Snr	Amp	Freq	Fkq	Pol	Arid
FIN	166.4	106.0	Pn	12.36.09.8	-1.1	117.9	11.9	6.6	29.3	3083.2	6.99	3	-1	115989
FIN	166.4	106.0	Lg	12.36.29.2	-1.3	102.0	-4.0	4.0	25.2	1883.8	1.85	1	-2	115992
FIN	166.4	106.0	Rg	12.36.37.7	-2.7	111.3	5.3	3.4	10.9	4734.5	1.24	1		115993
NRS	948.8	80.6	Pn	12.37.46.5	-1.0	83.3	2.7	11.4	8.9	730.2	6.35	2		115995
NRS	948.8	80.6	Lg	12.40.07.4	-2.0	80.5	-0.1	4.6	2.6	835.6	1.36	2		115997
NRS	948.8	80.6	s	12.40.12.6		77.5	-3.1	4.1	3.9	1353.3	1.90	1		116001
ARC	966.4	168.6	Pn	12.37.51.7	2.0	169.2	0.6	9.1	9.9	466.4	5.42	2		115998
ARC	966.4	168.6	Sn	12.39.27.9	1.2	162.5	-6.1	4.7	3.0	402.9	4.30	2		116000
ARC	966.4	168.6	Lg	12.40.07.8	-6.5	172.0	3.4	3.5	2.8	695.1	2.41	2	-3	116002

Origin time	Lat	Lon	Azres	Timres	Wres	Nphase
1990-292:13.18.05.0	59.50	27.85	0.83	0.19	0.39	2

Sta	Dist	Az	Ph	Time	Tres	Azim	Ares	Vel	Snr	Amp	Freq	Fkq	Pol	Arid
FIN	237.7	155.0	Pn	13.18.41.7	0.0	154.4	-0.6	6.8	7.1	204.3	8.91	3		116032
FIN	237.7	155.0	Sn	13.19.12.4	0.3	153.9	-1.1	3.8	5.0	563.3	7.06	3	-2	116033

Origin time	Lat	Lon	Azres	Timres	Wres	Nphase
1990-292:13.36.54.0	59.50	24.83	7.98	0.66	2.66	3

Sta	Dist	Az	Ph	Time	Tres	Azim	Ares	Vel	Snr	Amp	Freq	Fkq	Pol	Arid
FIN	227.4	198.1	Pn	13.37.30.0	0.6	191.0	-7.1	7.8	16.5	392.4	3.37	1		116045
FIN	227.4	198.1	Lg	13.37.56.3	-1.4	193.0	-5.1	4.0	23.2	1195.6	2.83	1	-2	116046
NRS	750.8	94.7	Lg	13.40.24.1	0.0	83.1	-11.6	4.1	2.5	533.1	2.58	2		116050

Origin time	Lat	Lon	Azres	Timres	Wres	Nphase
1990-292:13.49.09.0	60.40	29.68	1.23	0.47	0.77	2

Sta	Dist	Az	Ph	Time	Tres	Azim	Ares	Vel	Snr	Amp	Freq	Fkq	Pol	Arid
FIN	227.6	119.2	Pn	13.49.44.1	-0.4	118.6	-0.6	7.1	6.6	460.8	9.05	3	1	116071
FIN	227.6	119.2	s	13.50.06.4		121.2	2.0	4.1	5.8	769.0	5.57	3	-3	116073
FIN	227.6	119.2	Lg	13.50.12.1	-0.6	117.3	-1.9	3.1	3.9	444.4	1.14	1	-3	116074

Origin time	Lat	Lon	Azres	Timres	Wres	Nphase
1990-292:14.24.30.0	57.40	6.13	10.65	1.13	3.79	3

Sta	Dist	Az	Ph	Time	Tres	Azim	Ares	Vel	Snr	Amp	Freq	Fkq	Pol	Arid
NRS	484.2	222.2	Pn	14.25.36.3	-0.8	211.3	-10.9	9.0	10.8	635.0	8.20	1	1	116090
NRS	484.2	222.2	Lg	14.26.44.9	-0.5	224.7	2.5	4.0	3.6	909.2	2.13	1		116092
NRS	484.2	222.2	s	14.26.47.9		221.6	-0.6	4.1	3.2	954.8	2.56	1		116093
GER	1077.6	334.9	Sn	14.28.39.2	2.1	353.5	18.6	4.0	3.6	175.5	1.54	4	1	218

Origin time	Lat	Lon	Azres	Timres	Wres	Nphase
1990-292:14.33.35.0	48.40	30.42	5.87	0.22	1.69	2

Sta	Dist	Az	Ph	Time	Tres	Azim	Ares	Vel	Snr	Amp	Freq	Fkq	Pol	Arid
FIN	1478.5	167.3	Pn	14.36.43.0	0.0	155.6	-11.7	8.4	6.5	94.6	4.32	3		116095
NRS	1825.2	130.3	Pn	14.37.24.7	-0.4	130.3	0.0	10.1	5.8	197.2	4.71	3		116096

Table 7.3.1. (Page 2 of 3)

Origin time	Lat	Lon	Azres	Timres	Wres	Nphase
1990-292:14.44.52.0	64.60	37.82	4.45	0.29	1.41	2

Sta	Dist	Az	Ph	Time	Tres	Azim	Ares	Vel	Snr	Amp	Freq	Fkq	Pol	Arid
ARC	766.1	130.0	Pn	14.46.32.8	-0.5	131.8	1.8	8.3	5.5	131.2	8.81	3		116109
ARC	766.1	130.0	Sn	14.47.52.6	0.1	122.9	-7.1	4.2	2.8	285.2	8.16	3	1	116111

Origin time	Lat	Lon	Azres	Timres	Wres	Nphase
1990-292:14.56.29.0	49.90	12.11	4.25	0.48	1.54	2

Sta	Dist	Az	Ph	Time	Tres	Azim	Ares	Vel	Snr	Amp	Freq	Fkq	Pol	Arid
GER	164.9	316.0	Pn	14.56.55.2	-0.4	310.5	-5.5	6.9	3.0	1375.0	7.64	3		221
GER	164.9	316.0	Lg	14.57.15.7	0.6	319.0	3.0	4.2	7.2	1416.7	4.18	3	-2	222

Origin time	Lat	Lon	Azres	Timres	Wres	Nphase
1990-292:15.59.44.0	59.20	11.31	2.60	0.52	1.17	2

Sta	Dist	Az	Ph	Time	Tres	Azim	Ares	Vel	Snr	Amp	Freq	Fkq	Pol	Arid
NRS	171.7	184.5	Pn	16.00.11.8	0.2	185.3	0.8	7.0	13.6	462.6	4.38	1		116126
NRS	171.7	184.5	Sn	16.00.34.5	-0.8	180.1	-4.4	3.9	4.7	864.1	9.00	3	-3	116127

Origin time	Lat	Lon	Azres	Timres	Wres	Nphase
1990-292:16.09.58.0	49.60	11.64	5.55	0.29	1.68	2

Sta	Dist	Az	Ph	Time	Tres	Azim	Ares	Vel	Snr	Amp	Freq	Fkq	Pol	Arid
GER	171.9	300.0	Pn	16.10.25.2	-0.5	289.5	-10.5	6.5	4.0	800.7	9.71	4		228
GER	171.9	300.0	Lg	16.10.46.0	-0.1	300.6	0.6	4.0	3.3	758.0	4.95	3		229

Origin time	Lat	Lon	Azres	Timres	Wres	Nphase
1990-292:20.46.18.0	60.70	21.82	5.40	0.43	1.78	2

Sta	Dist	Az	Ph	Time	Tres	Azim	Ares	Vel	Snr	Amp	Freq	Fkq	Pol	Arid
FIN	244.7	252.1	Pn	20.46.55.3	-0.3	261.7	9.6	8.7	5.7	115.6	4.22	2		116244
FIN	244.7	252.1	Sn	20.47.27.1	0.5	253.2	1.1	4.6	3.8	241.1	4.66	3	-3	116245

Origin time	Lat	Lon	Azres	Timres	Wres	Nphase
1990-292:21.57.40.0	51.70	15.68	4.23	1.70	2.75	6

Sta	Dist	Az	Ph	Time	Tres	Azim	Ares	Vel	Snr	Amp	Freq	Fkq	Pol	Arid
GER	347.5	23.2	Pn	21.58.30.3	0.0	29.3	6.1	8.9	64.9	2858.7	2.75	1	1	253
GER	347.5	23.2	p	21.58.38.2		25.0	1.8	6.4	17.3	3017.5	2.64	1	1	254
GER	347.5	23.2	p	21.58.43.8		25.6	2.4	6.3	8.7	4004.7	2.49	3		255
GER	347.5	23.2	Lg	21.59.25.2	8.0	26.2	3.0	4.2	3.4	8589.2	2.27	1		257
GER	347.5	23.2	s	21.59.38.5		29.8	6.6	5.3	3.2	4114.4	1.00	1	3	258
NRS	1038.4	163.9	Pn	21.59.54.8	0.4	166.3	2.4	8.3	17.1	383.9	3.42	1		116282
NRS	1038.4	163.9	p	22.00.04.8		162.3	-1.6	9.7	4.5	245.6	4.02	1		116283
NRS	1038.4	163.9	Sn	22.01.38.5	-0.4	167.9	4.0	4.8	3.7	417.7	2.27	1		116284
FIN	1256.7	215.0	Pn	22.00.21.3	0.3	217.4	2.4	9.8	23.8	195.6	3.78	2	1	116281
FIN	1256.7	215.0	Sn	22.02.26.0	1.1	207.5	-7.5	4.9	2.6	202.5	2.84	1		116286

Origin time	Lat	Lon	Azres	Timres	Wres	Nphase
1990-292:23.36.38.0	67.90	19.99	7.23	2.29	4.09	5

Sta	Dist	Az	Ph	Time	Tres	Azim	Ares	Vel	Snr	Amp	Freq	Fkq	Pol	Arid
ARC	288.7	233.4	Pn	23.37.20.6	-0.4	225.4	-8.0	7.4	55.2	1175.6	6.11	2	-1	116311
ARC	288.7	233.4	p	23.37.25.5		221.6	-11.8	6.7	7.3	695.8	4.11	2		116312
ARC	288.7	233.4	p	23.37.46.9		221.7	-11.7	7.1	2.4	762.6	3.67	1		116313
ARC	288.7	233.4	Sn	23.37.53.4	-2.5	227.8	-5.6	5.0	15.2	2346.3	3.61	2		116314
ARC	288.7	233.4	Lg	23.38.03.4	4.7	225.3	-8.1	4.0	3.0	2834.8	1.42	1		116315
FIN	776.3	340.7	Lg	23.40.11.7	-3.4	346.2	5.5	4.1	3.0	198.6	1.79	1		116310
NRS	896.3	23.3	Pn	23.38.34.8	-0.4	32.3	9.0	8.3	5.4	114.1	3.45	3		116309

Origin time	Lat	Lon	Azres	Timres	Wres	Nphase
1990-292:23.42.32.0	67.30	20.04	1.54	2.52	2.90	3

Sta	Dist	Az	Ph	Time	Tres	Azim	Ares	Vel	Snr	Amp	Freq	Fkq	Pol	Arid
ARC	335.7	224.6	Pn	23.43.21.2	0.4	225.2	0.6	7.5	24.7	979.0	6.33	1	-1	116316
ARC	335.7	224.6	p	23.43.23.5		220.3	-4.3	7.3	6.1	470.3	5.04	2		116317
ARC	335.7	224.6	p	23.43.32.7		226.8	2.2	7.4	4.8	443.2	3.99	3		116318
ARC	335.7	224.6	Sn	23.43.53.8	-6.2	225.5	0.9	4.8	6.3	944.5	4.68	2		116319
ARC	335.7	224.6	Lg	23.44.06.9	1.0	221.5	-3.1	4.3	4.8	1896.3	2.90	1		116320

Table 7.3.1. (Page 3 of 3)

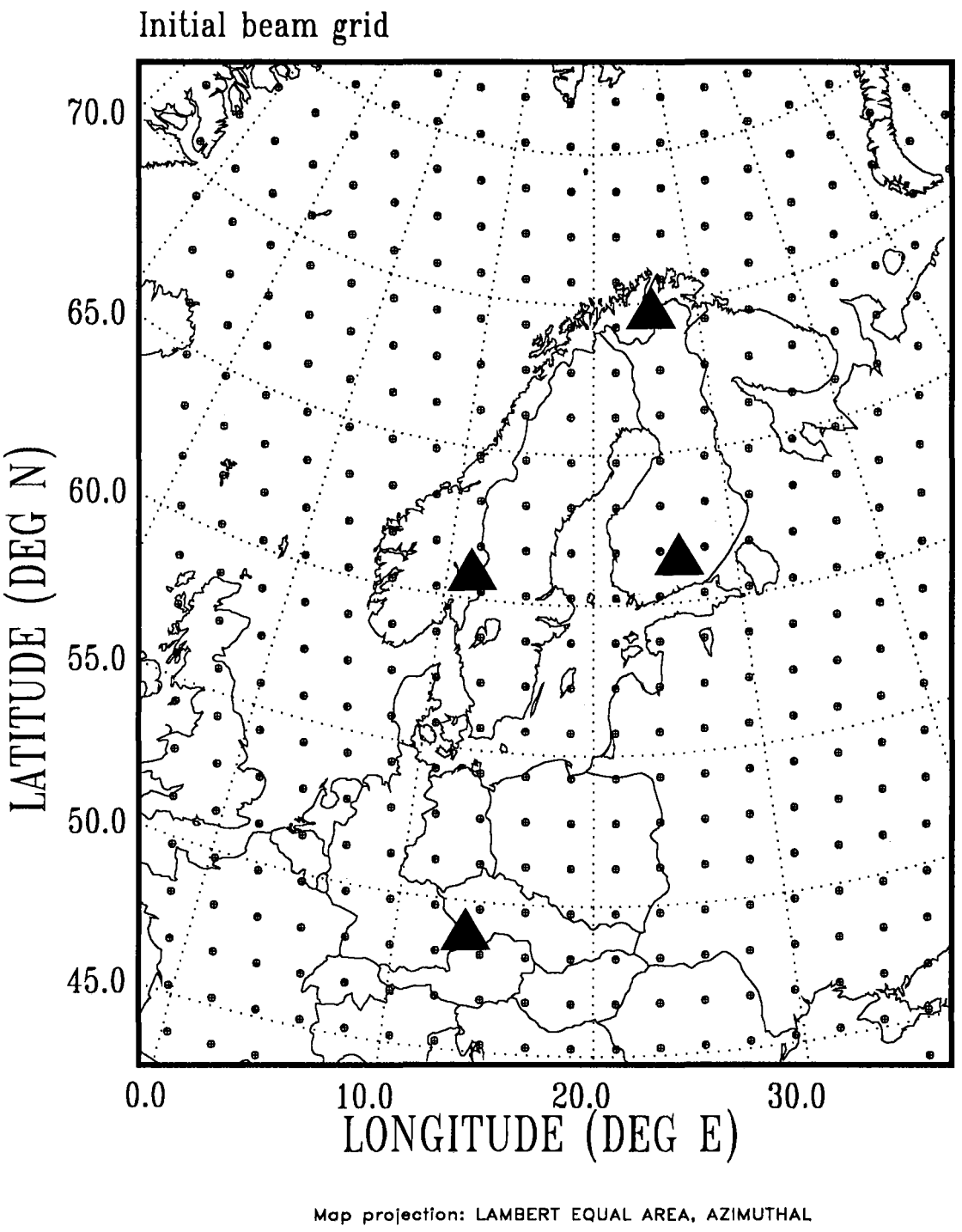

Fig. 7.3.1. Initial beam grid used by the generalized beamforming method when processing data from four regional arrays. ARCESS, FINESA, NORESS and GERESS are marked with solid triangles.

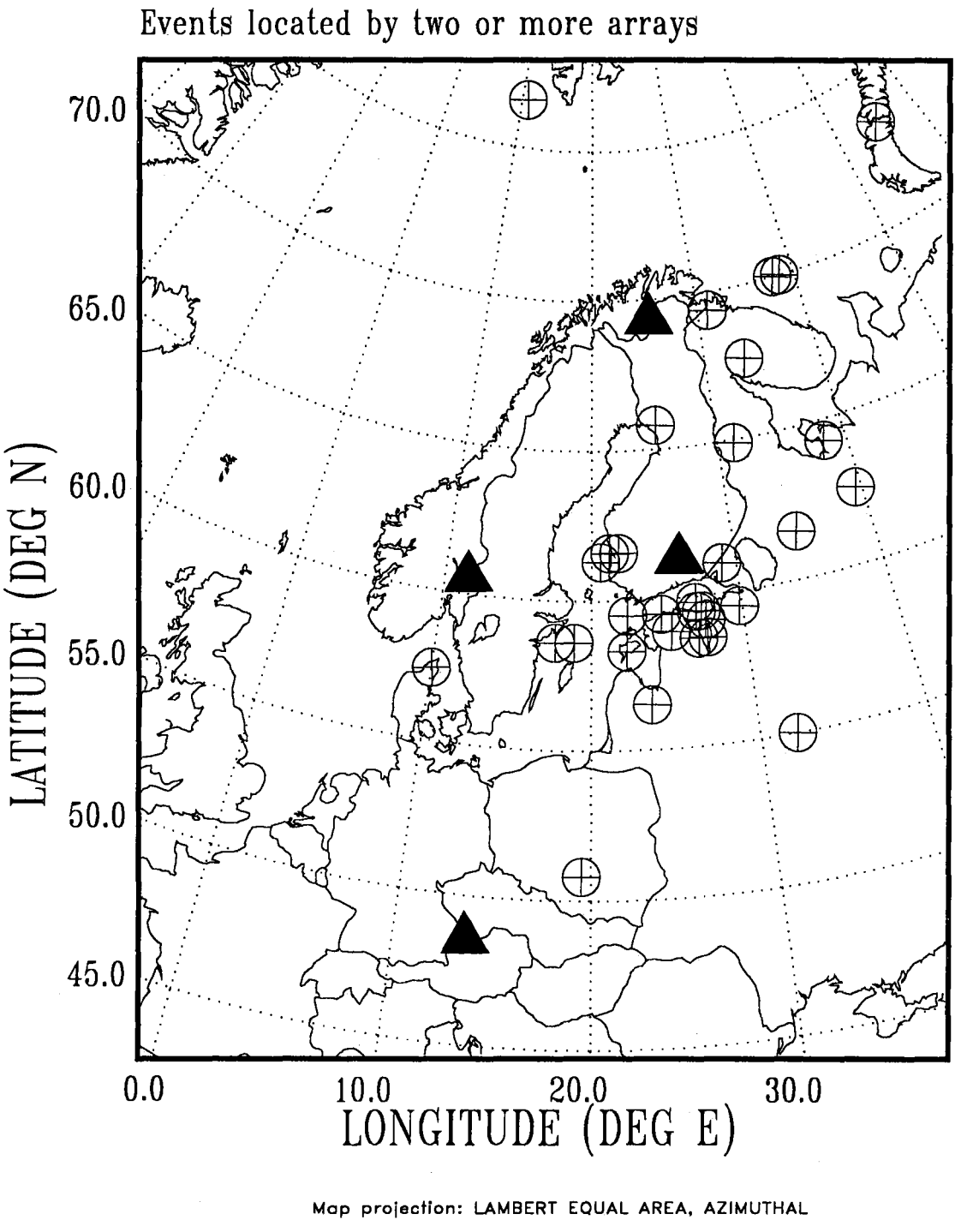

Fig. 7.3.2. Events located by GBF having four or more associated phase detections. The data cover the five-day period 22–26 October 1990. Out of a total of 37 events, 12 were located by two arrays, 22 by three arrays and 3 by four arrays. The four regional arrays, ARCESS, FINESA, NORESS and GERESS, are marked with solid triangles.