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VII.5 Analysis of regional seismic events using the NORESS/ ARCESS/FINESA arrays

This contribution comprises two separate investigations related to analysis of events recorded on the three regional arrays NORESS, ARCESS and FINESA in Fennoscandia. The first investigation is an evaluation of the performance of the recently upgraded FINESA array in Finland, whereas the second investigation utilizes data recorded simultaneously on all three arrays in producing joint event locations.

An evaluation of the performance of the upgraded FINESA array

A description of the FINESA array is given in Korhonen et al (1987). In early 1988, the geometry of the FINESA array was expanded by adding five elements to the array, as shown in Fig. VII.5.1. The FINESA array geometry currently comprises 15 vertical only seismometers within an aperture of 2 km.

FINESA data are recorded on magnetic tape at the array site, and the tape recording is normally event triggered by a built-in voting detector. In order, however, to properly evaluate the performance of the upgraded FINESA array, data were recorded continuously for a 14-day period during March 8-21 of 1988. The tapes were played back and checked at NORSAR, and approximately 55% of the data for this 14-day period could be recovered and were hence subjected to detection processing. The remaining 45% of the data could not be read due to various problems with the tapes, like parity errors, etc.

A beam deployment comprising 72 beams (66 coherent, 6 incoherent) was used for the detection processing of the continuous FINESA data. The beam deployment used is in agreement with the recommendations by Kværna et al (1987) and Kværna (1988). The detection processing results in lists with attributes for each detected signal, like detection time, signal frequency, phase velocity and arrival azimuth. These lists were compared against the regional Finnish bulletin, issued by the Univer-

sity of Helsinki, and the results of the comparison are given in Table VII.5.1. Only those bulletin events occurring when the FINESA array was operating properly are included in the table.

Signals detected on FINESA were associated to the Helsinki bulletin events by requiring a reasonable match of FINESA detection parameters (arrival time, phase type from velocity, and arrival azimuth) with the corresponding ones predicted from the information in the Helsinki bulletin. From Table VII.5.1 we see that out of the 103 reference events listed, 99 had at least one detected P- or S-phase, i.e., 96 per cent. Two of the four events that were not detected, occurred at the Lahnaslampi mine in Finland (64.2°N, 28.0°E), at a distance of 322 km from FINESA. Most blasts at Lahnaslampi are quite small, and are not detected by FINESA. The two remaining events were both small ones (magnitude less than 2 for one event; magnitude not given for the other) at ranges more than 700 km from FINESA.

These results for the upgraded FINESA array are quite encouraging. An investigation based on 14 days of continuous FINESA data from 1986 (with the original array geometry) concluded that 84 per cent of the regional events listed in the Helsinki bulletin were detected by the array (Korhonen et al, 1987). The addition of the five extra sensors to the array geometry thus resulted in a considerable improvement of the array's capability to detect small regional events. It is evident that the FINESA array in its current configuration represents a valuable addition to the network of regional arrays in Fennoscandia. To fully exploit the FINESA data, however, it will be necessary to upgrade the on-site data acquisition system and also provide a communications link. This will allow real time transmission of FINESA data to the NORSAR data processing center at Kjeller for processing jointly with NORESS and ARCESS data.

Joint event locations from three-array data

Data recorded at FINESA were used together with NORESS and ARCESS data in assessing the capabilities of this three-array network in locating events in the Fennoscandian region. A set of 10 events, for which there was at least one detected phase for each array, was selected for an event location experiment. The events are listed in Table VII.5.2 and shown in Fig. VII.5.2. The event magnitudes range from less than 2.0 to 3.2. The origin times and geographical coordinates for the 10 events are taken from the Helsinki bulletin.

The continuous processing of data recorded at each of the three regional arrays in Fennoscandia provides estimates of arrival times and back azimuths. These parameters together with the associated uncertainties were used as input to the TTAZLOC program developed by Bratt and Bache (1988). TTAZLOC incorporates the arrival time and azimuth data into a generalized-inverse location estimation scheme, and can be applied to both single-array and multiple-array data.

Figs. VII.5.3a, 3b and 3c show ARCESS, NORESS and FINESA data, respectively, for event 3 in Table VII.5.2. The panels show on the top three P-wave beams for three different frequency bands. The beams were steered according to the phase velocity and azimuth of the peak of the fk-spectrum computed as part of the online detection processing. The three lower traces of the panels show data for a single channel, also for three different frequency bands. The detection times for the phases used in the location experiment are marked by arrows. The figures show that this event is recorded with a high SNR ratio at the closest array (FINESA), whereas it is marginal at the two other arrays, but is detected due to the SNR gain that is achieved through beamforming. Very simple rules based on phase velocity and relative arrival times and amplitudes are used in the phase assignment, and Pn, Sn and Lg phases only are considered. Another candidate would be the Rg phase, which is clearly seen in Fig. VII.5.3c, following the Lg phase (traces no. 4 and 5 from the top).

Table VII.5.2 gives the results of the location experiment. On the average, the joint three-array locations deviate from the network locations published in the Helsinki bulletin by 16 km. Two-array and one-array locations were computed for all combinations of events and array sub-networks, also using the TTAZLOC algorithm. The resulting average deviations from the network solutions are 26 and 68 km, respectively.

The results for one-array and two-array locations are in general agreement with what has previously been reported (e.g., Mykkeltveit and Ringdal (1988) found an average deviation of 34 km from the Helsinki bulletin locations, using data from seven regional events recorded at NORESS and ARCESS). The improvement in the location accuracy when invoking data from three arrays is significant, and we consider the results reported here as quite promising, when taking the following into account: The arrival times used were those determined automatically by the online processing. It is conceivable that human intervention for adjustment of arrival times and/or refinement of the automatic procedure would improve the location estimates. Only standard travel time tables for the phases Pn, Sn and Lg were used. The introduction of regionalized travel time tables is likely to result in improvements. Finally, master event location schemes of various kinds hold considerable promise and are expected to further enhance the capabilities of accurately locating regional events.

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Date	Time	Lat. (°N)	Lon. (°E)	Magn.	Dist. (km)	P-det.	S-det.
88/03/08	06.01.42	61.2	27.1	<2	61	-	x
88/03/08	07.50.57	62.8	29.1	<2	215	x	x
88/03/08	13.03.50	62.2	23.3	<2	169	x	x
88/03/08	13.29.02	64.2	28.0	<2	322	-	-
88/03/08	14.25.10	62.1	26.4	<2	75	x	x
88/03/08	15.02.39	60.3	24.8	<2	145	x	x
88/03/09	12.05.43	64.2	28.0	<2	322	-	x
88/03/10	08.47.04	59.3	27.2	<2	247	x	x
88/03/10	09.22.08	59.3	27.6	<2	253	x	x
88/03/10	09.57.40	59.2	27.6	<2	264	x	x
88/03/10	10.41.14	59.3	27.6	<2	253	x	-
88/03/10	11.07.37	59.2	27.6	2.1	264	x	x
88/03/10	11.14.23	59.3	27.6	<2	253	x	x
88/03/10	11.25.34	59.5	25.0	2.2	224	x	x
88/03/10	11.49.54	59.3	27.6	<2	253	x	x
88/03/10	12.05.20	59.5	26.5	2.2	218	x	x
88/03/10	12.07.05	61.2	28.9	-	154	x	x
88/03/10	12.10.50	59.3	28.1	2.1	264	x	x
88/03/10	16.03.30	64.3	24.0	<2	335	x	x
88/03/10	16.20.56	62.0	24.4	<2	108	x	x
88/03/10	18.16.15	65.8	24.7	<2	491	-	x
88/03/10	18.29.30	67.1	20.6	2.2	684	x	x
88/03/10	20.27.28	63.6	26.2	<2	240	x	x
88/03/11	08.18.59	62.9	25.9	<2	163	x	x
88/03/11	09.23.17.	67.6	34.0	-	783	-	x
88/03/11	09.24.26	67.6	34.0	-	783	-	x
88/03/11	09.25.40	67.6	34.0	2.7	783	x	x
88/03/11	09.48.06	61.4	34.3	2.3	439	x	x
88/03/11	10.21.09	62.2	25.9	<2	85	x	x
88/03/11	10.21.35	59.3	27.6	2.2	253	x	x
88/03/11	10.56.54	59.5	25.0	2.1	224	x	x
88/03/11	11.27.25	59.3	27.6	<2	253	x	x
88/03/11	11.46.58	69.4	30.8	2.3	913	x	x
88/03/11	12.03.37	63.2	27.8	2.3	215	x	x
88/03/11	12.17.09	59.5	25.0	2.1	224	x	x
88/03/11	12.33.24	60.8	29.3	2.3	188	x	x
88/03/11	12.57.59	59.3	27.6	<2	253	x	x
88/03/11	13.33.05	59.3	28.1	<2	264	x	x

Table VII.5.1. Results from detection processing of FINESA data for the period 8-21 Mar 1988. The table lists the 103 events of the Helsinki bulletin that occurred while the FINESA system was operating properly during the 14-day period. The distance from the FINESA array is given for each event. The table indicates whether or not a P- or S-phase was detected on FINESA, that can be associated with the event in question. (Page 1 of 3)

Date	Time	Lat. (°N)	Lon. (°E)	Magn.	Dist. (km)	P-det.	S-det.
88/03/12	09.12.28	59.4	28.4	2.1	261	x	x
88/03/12	09.59.59	64.7	30.7	2.9	431	x	x
88/03/12	10.43.17	59.5	25.0	2.2	224	x	x
88/03/12	10.48.21	61.8	36.1	2.4	533	x	x
88/03/12	11.03.58	68.1	33.2	2.1	815	x	x
88/03/12	11.11.12	68.1	33.2	2.9	815	x	x
88/03/12	12.25.01	59.3	27.2	2.3	247	x	x
88/03/12	12.40.45	67.6	30.5	-	718	-	-
88/03/12	12.41.07	67.6	30.5	2.4	718	x	x
88/03/12	14.15.38	67.1	20.6	<2	684	-	x
88/03/13	06.49.10	67.7	33.7	2.4	786	x	x
88/03/14	09.01.41	59.3	27.6	<2	253	x	x
88/03/14	09.13.21	62.8	22.6	<2	236	x	x
88/03/14*	09.22.16	59.3	27.2	2.1	247	x	x
88/03/14	10.32.41	59.3	27.6	<2	253	x	x
88/03/14	10.35.25	59.3	27.6	<2	253	x	x
88/03/14	12.41.49	59.6	30.0	2.1	298	x	x
88/03/14	13.10.52	59.5	25.0	2.6	224	x	x
88/03/14	14.07.27	59.3	28.1	<2	264	x	x
88/03/15	08.59.57	67.6	34.0	<2	783	-	x
88/03/15	09.06.42	67.6	34.0	2.4	783	-	x
88/03/15	10.31.30	59.2	27.4	2.5	260	x	x
88/03/15	11.34.36	59.5	26.4	2.5	218	x	x
88/03/15	11.41.57	60.5	25.9	<2	106	x	x
88/03/15	11.26.30	61.6	21.7	<2	234	x	x
88/03/15	12.10.38	59.2	27.6	<2	264	x	x
88/03/15	12.11.37	59.2	27.6	<2	264	-	x
88/03/15	12.19.15	59.3	27.2	2.2	247	x	x
88/03/15	12.33.35	62.5	21.7	<2	258	x	x
88/03/15	12.40.39	59.4	28.5	<2	264	x	x
88/03/15	13.16.45	59.3	24.4	2.3	256	x	x
88/03/15	13.22.14	61.9	30.6	2.0	245	x	x
88/03/15	13.51.30	59.0	25.8	<2	273	x	x
88/03/15	14.09.35	59.5	25.0	<2	224	x	x
88/03/15	14.20.59	60.9	29.2	2.4	179	x	x
88/03/15	14.36.30	63.1	22.2	<2	273	x	x
88/03/15	14.39.35	59.5	25.0	2.3	224	x	x
88/03/15	17.57.51	65.8	24.7	<2	490	-	x
88/03/16	08.37.13	59.2	27.6	<2	264	x	x
88/03/16	09.44.50	69.6	29.9	2.4	926	x	-

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* The origin time for this event is misprinted as 09.29.16 in the Helsinki bulletin

Table VII.5.1. (Page 2 of 3)

Date	Time	Lat. (°N)	Lon. (°E)	Magn.	Dist. (km)	P-det.	S-det.
88/03/16	10.25.03	59.3	27.6	<2	253	x	x
88/03/16	10.45.40	60.9	26.8	<2	72	x	x
88/03/16	11.26.47	59.2	27.6	<2	264	x	x
88/03/16	11.45.36	63.2	27.8	2.5	215	x	x
88/03/16	11.49.51	59.5	25.0	<2	224	x	x
88/03/16	23.04.26	67.8	20.0	<2	765	-	-
88/03/17	09.07.13	58.3	10.9	2.7	917	x	x
88/03/17	10.21.17	69.6	29.9	2.9	926	x	x
88/03/17	10.27.20	59.2	27.6	2.3	264	x	x
88/03/17	10.46.21	59.2	27.6	<2	264	x	x
88/03/17	11.18.48	59.3	27.2	2.3	247	x	x
88/03/17	12.02.23	64.2	28.0	<2	322	-	-
88/03/17	12.02.36	59.4	28.5	2.1	264	x	x
88/03/17	18.58.07	59.7	5.6	3.2	1135	x	x
88/03/18	05.16.20	69.2	34.7	2.6	952	x	x
88/03/19	10.04.08	61.1	30.2	<2	224	x	x
88/03/19	10.05.02	59.3	27.2	-	247	x	x
88/03/19	12.15.34	68.1	33.2	-	815	x	-
88/03/19	12.15.39	68.1	33.2	-	815	x	x
88/03/19	12.39.09	68.1	33.2	<2	815	x	x
88/03/19	13.03.39	67.6	30.5	-	718	x	x
88/03/19	13.03.54	67.6	30.5	-	718	x	x
88/03/19	13.07.00	61.9	30.6	2.6	245	x	x
88/03/19	13.42.33	67.6	30.5	<2	718	-	x
88/03/20	04.45.17	67.7	33.7	2.5	786	x	x

Table VII.5.1. (Page 3 of 3)

Event No.	Date	Time	Network Lat.	Network Lon.	Mag. M_L	No. of phases used	3-array 'error' (km)	Average 2-array 'error' (km)	Average 1-array 'error' (km)
1	88/03/12	14.15.38	67.1	20.6	<2	5	19	31	36
2	88/03/15	11.34.36	59.5	26.5	2.5	8	9	8	39
3	88/03/15	14.20.49.5	60.93	29.19	2.4	6	34	34	34
4	88/03/15	14.39.35	59.5	25.0	2.3	8	8	23	95
5	88/03/16	11.45.36	63.2	27.8	2.5	6	32	31	41
6	88/03/17	09.07.13.2	58.33	10.93	2.7	7	16	24	44
7	88/03/17	10.21.17	69.6	29.9	2.9	8	4	13	45
8	88/03/17	11.18.48	59.3	27.2	2.3	5	15	36	108
9	88/03/17	18.58.07.1	59.72	5.62	3.2	6	9	51	179
10	88/03/18	05.16.20	69.2	34.7	2.6	5	15	12	57
Average over 10 events							16	26	68

Table VII.5.2. Results from TTAZLOC location experiments using data from NORESS, ARCESS and FINESA. Epicentral location estimates are given as reported by the Helsinki bulletin for a set of ten regional events. The table gives the deviation from these reference locations, as inferred from the TTAZLOC experiments described in the text.

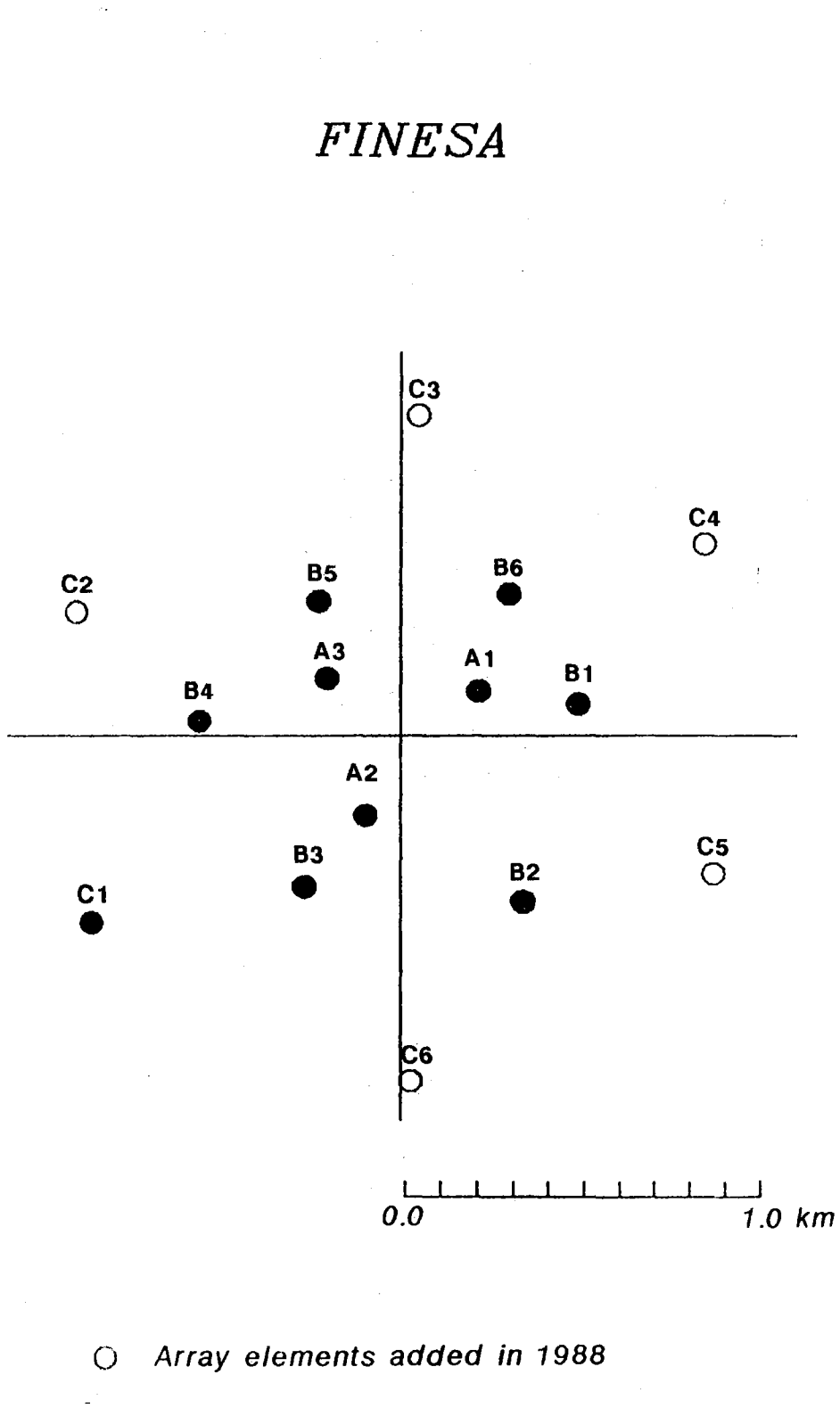

Fig. VII.5.1. The geometry of the FINESA array in Finland. Open circles denote array elements that were added in 1988.

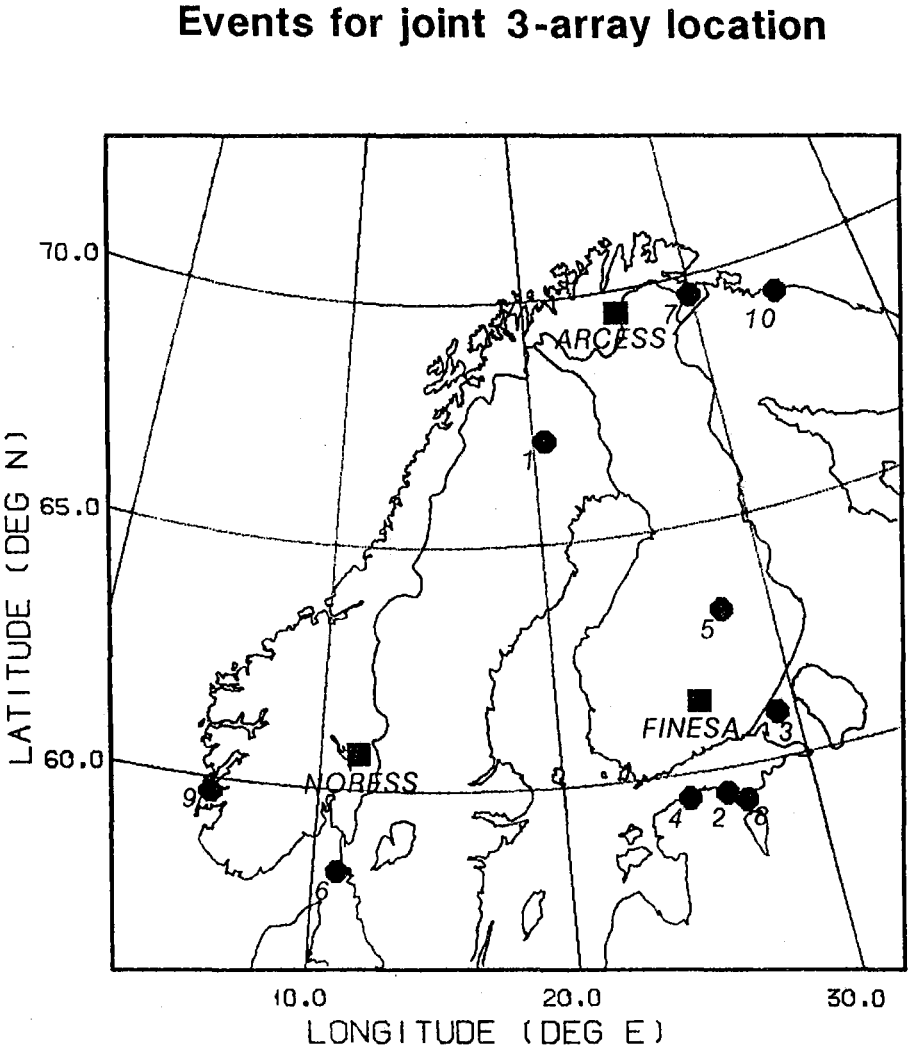

Fig. VII.5.2. The map shows the location of the three regional arrays NORESS, ARCESS and FINESA, as well as the location of ten events used in the TTAZLOC location estimation experiment.

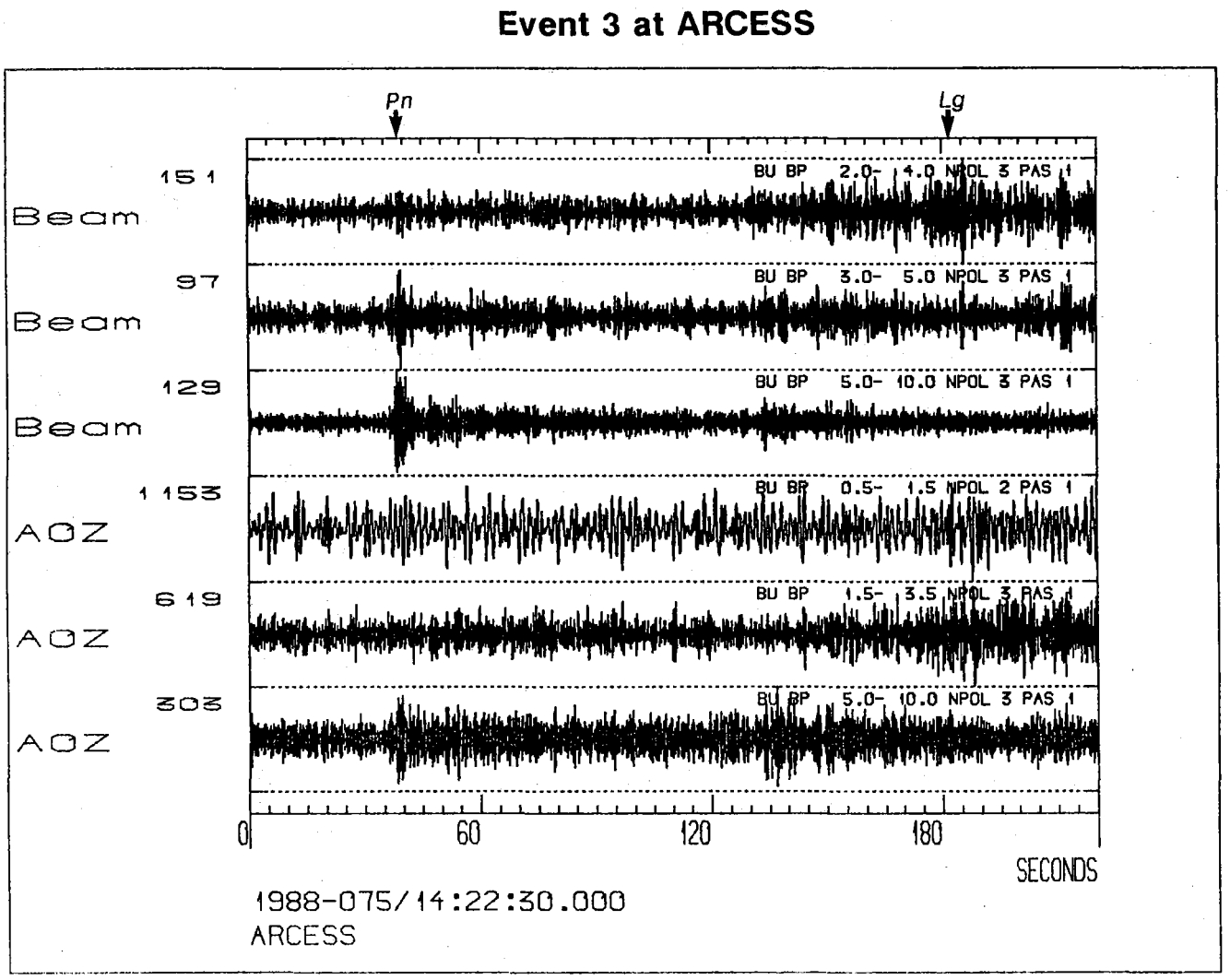

Fig. VII.5.3a. ARCESS data for event 3 in Table VII.5.2. The panel shows on top three P-beams steered towards the epicenter, for three different filter bands. The three bottom traces correspond to three different filters applied to the vertical sensor at site AO. The detection times (by the automatic online processor) for the phases Pn and Lg are indicated by arrows.

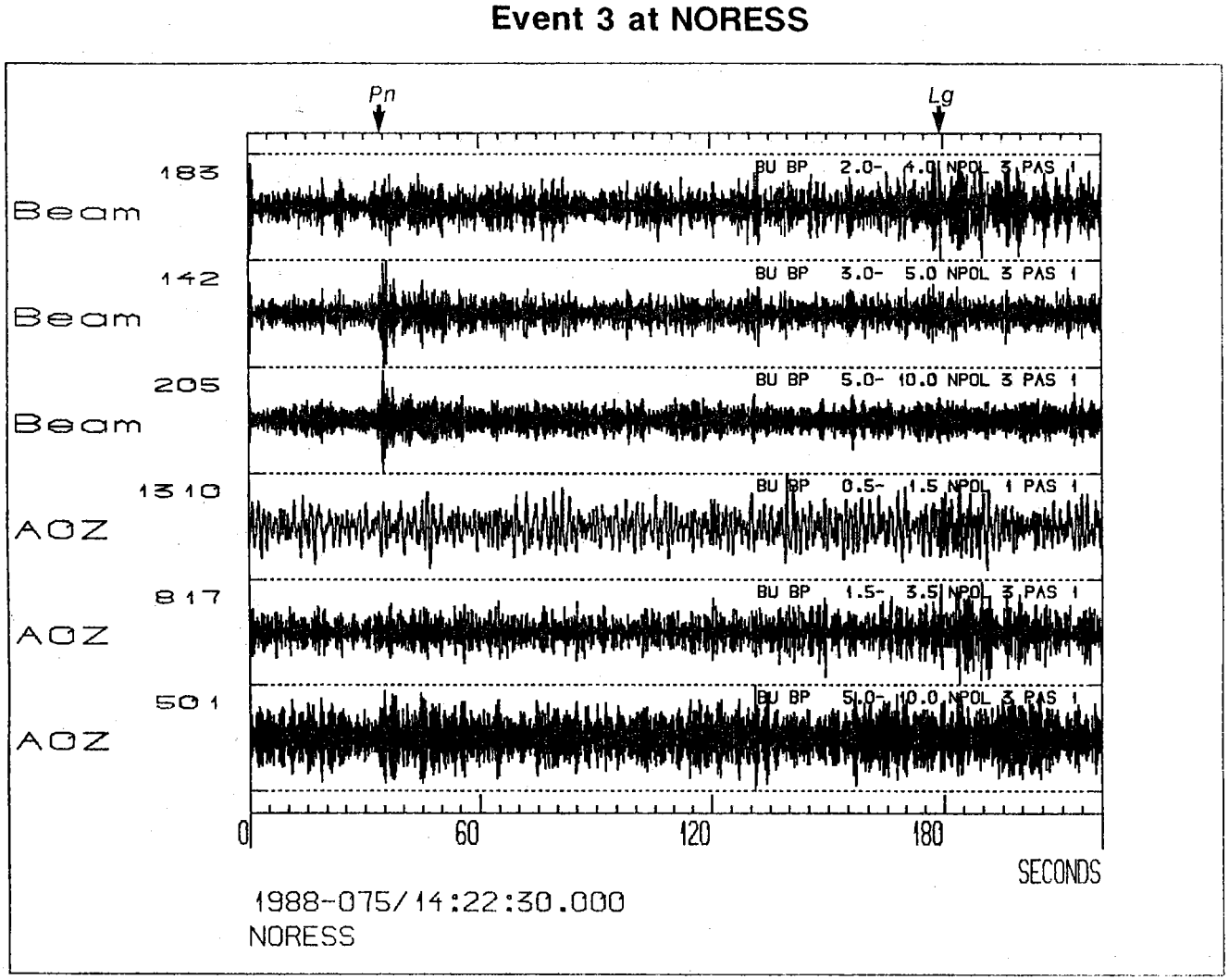

Fig. VII.5.3b. Same as Fig. VII.5.3a, but for NORESS data.

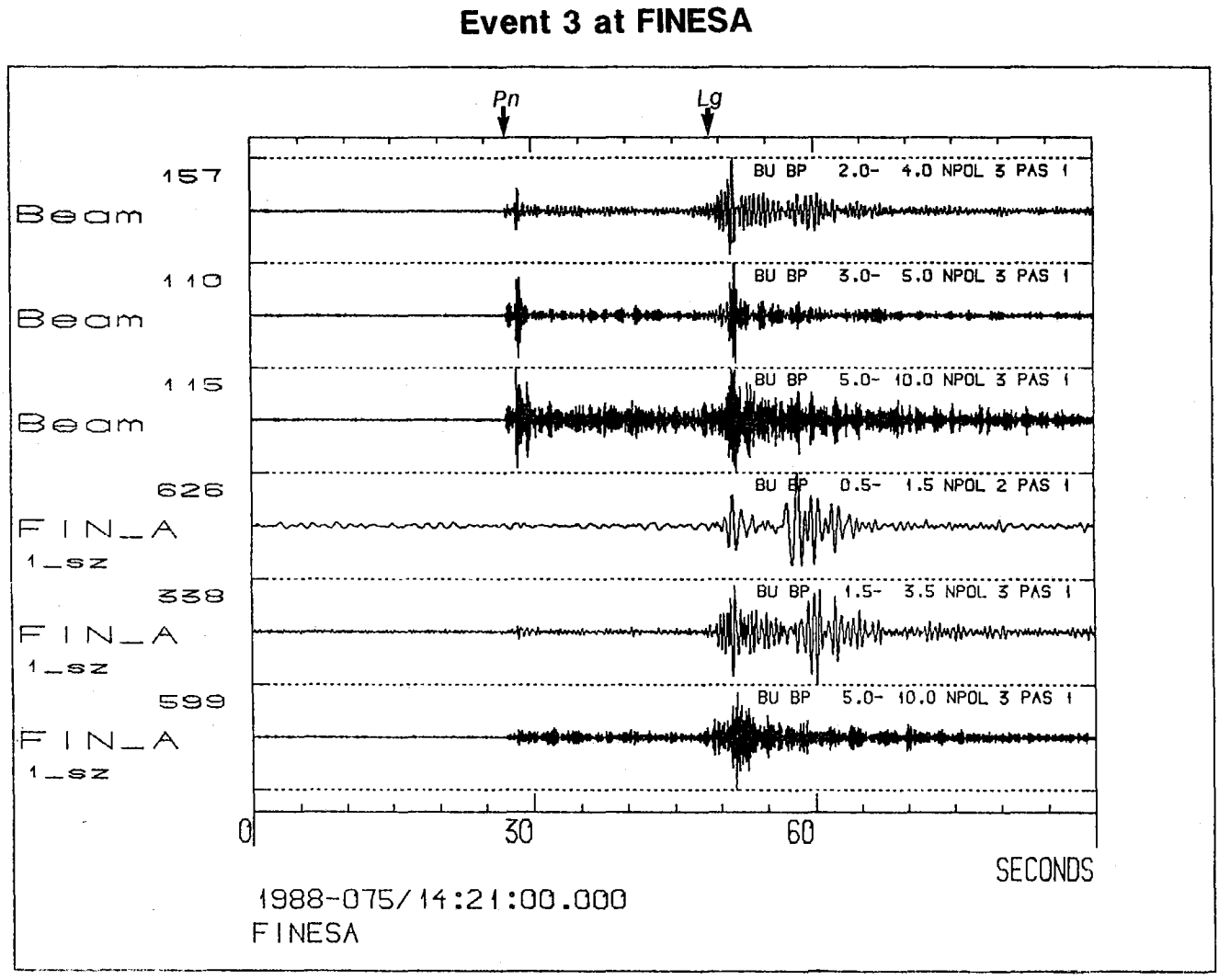

Fig. VII.5.3c. Same as Fig. VII.5.3a, but for FINESA data. The single channel data are taken from the sensor at site A1 (see Fig. VII.5.1).