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The capability of three-component substation FIA1 at local and regional distances. Comparisons with FINESA and Helsinki bulletins

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Abstract
The automatic analysing capability of the three-component substation called hereafter also FIA1 (coordinates: 61.4444°N, 26.0793°E) is studied. The detections and daily bulletins of FINESA (renamed as FINESS since August 1993) are used as a basis of the study. At the three-component substation FIA1 a detector-bulletin producer of type Husebye-Ruud was used to detect events and after forming a single station daily bulletin the common detections with FINESA were taken into a more detailed examination. From 689 detections of FINESA (also referred to as FIA0) the three-component substation could associate 258 events. The main part of events were mining and quarry explosions in Estonia, Russia, north of St. Petersburg and Finland, at distances up to 250 km. The diurnal distribution of events was studied and the connections to certain mines were attempted to be determined. It is found that certain mining areas have very specified shooting times, thus making it possible to monitor this kind of areas under predefined procedure. The median difference of azimuths obtained from the three-component station compared with FINESA azimuths was 5° and the median difference of distance was as small as 6.2 km. In these comparisons the siting of the three-component sensor was not taken into account, even though it is not located in the centre of the array. The main sources of location differences are found to be the errors of azimuth and veiled later phases. Sometimes the phase pickings of the two different methods did not give any coinciding results, even though the *P*-detections occurred simultaneously. Also, the deviation of azimuths under poor SNR circumstances caused clear location biases. To investigate the detection and locating performance of the three-component substation FIA1 at local and regional distances, the results were compared with the preliminary weekly analysis and *Helsinki bulletins* of the Finnish National Data Centre (FNDC), which handled 480 events during the test period. Altogether 205 events located by FIA1 could easily be connected with the results of the Finnish National Data Centre. The median errors in azimuth and distance of these connected events were quite small, 8.9° and 9.1 km, respectively.

Key words *three-component – bulletins – local – regional – arrays*

1. Introduction

The location and identification of seismic events have been a challenge for seismologists for decades and still are. This fact is also stated by the *ad hoc* Group of Scientific Experts on seismic methods (GSE) of the Conference on Disarmament (CD). Numerous methods have been developed to determine the epicentres or locations of seismic sources, which are mainly based on the *P*-wave arrival times. Recently, event locations have been based on the applica-

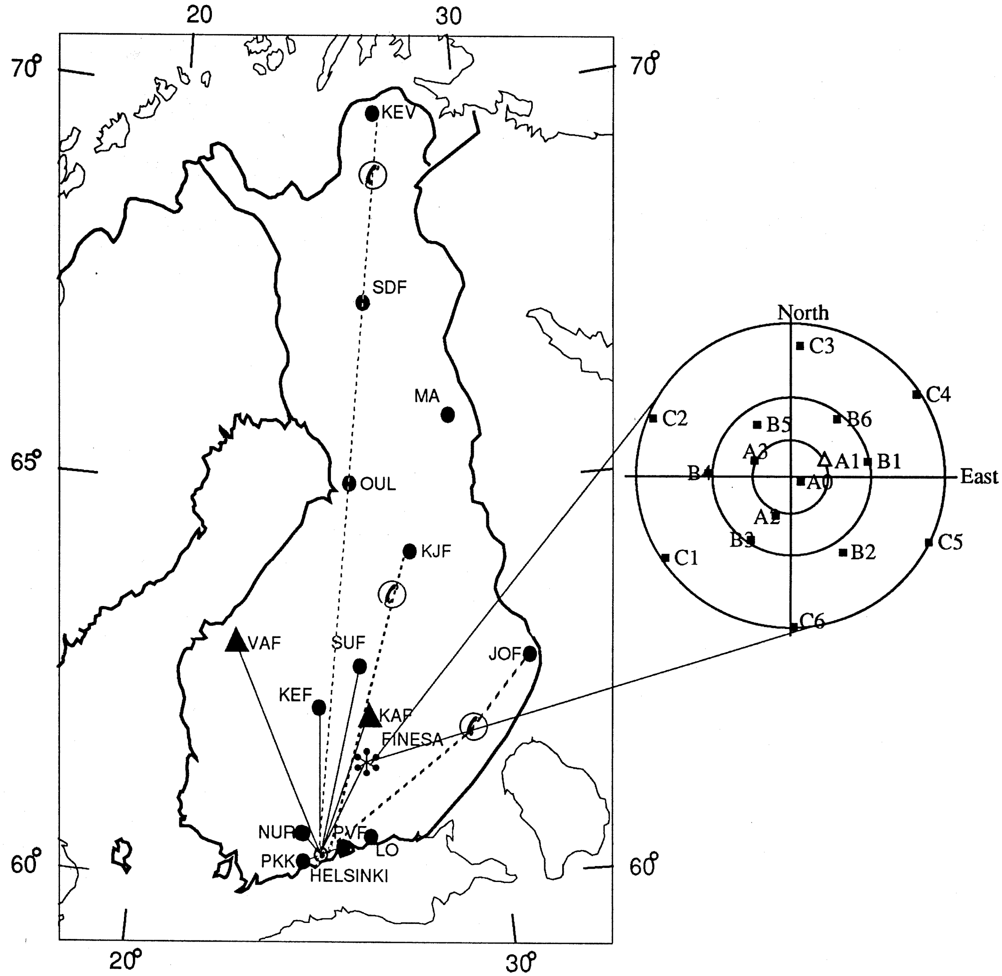

Fig. 1. The Finnish national seismic network (FINET) according to Teikari and Suvilinna (1993) and the configuration of the small-aperture array FINESA. Constant lines denote on-line stations, dashed lines with telephone are dial-up stations, triangles are three-component stations, respectively. The asterisk shows the location of FINESA array. The pop-up figure shows the configuration of FINESA array, and the single-component sensors are shown by black diamonds, while the three-component sensor FIA1 located in the ring A is shown by a triangle.

tion of arrays networks in terms of slowness vector estimates. The deployment of small-aperture regional arrays has risen a new effective tool for monitoring and locating small events at regional distances.

In Europe small-aperture arrays form a comprehensive monitoring assemblage from Southern Europe up to Spitzbergen. In the last years the arrays have proved their efficiency in the monitoring tasks, and tests – such as GSETT-2 in 1991 (Bratt 1992), initiated by GSE. The FINESA small-aperture array was established in 1985 as a joint project with NTNF/NOR-

SAR Norway. The array was upgraded in 1993 with more modern data acquisition and registration equipment, whose work is supported by ARPA. Accordingly, the array has been renamed FINESS.

During the last five years the location procedures for one three-component station have become more and more commonly used. The basic concept to locate seismic events with registrations of one three-component station was published by Magotra *et al.* (1987). After that many more studies concerning the topic have been published (Christoffersson *et al.* 1988; Ruud *et al.* 1988; Ruud and Husebye 1992; Saari 1991; Tarvainen 1992a,b). One station, having three-component registration can be used to locate seismic events at any distances (Cassidy *et al.* 1990), but the estimation of slowness vector from the angle of incidence may sometimes fail to produce satisfactory results, when dealing with teleseismic events. This problem is studied by Lokhstanov *et al.* (1991). According to them, the structure below the station plays an important role in the accuracy of the slowness estimation.

This study deals with the registrations of the three-component substation FIA1 of the small aperture array FINESA. Also, the analysis data of the Finnish National Data Centre (FNDC) are used. The Finnish National Network (FINET) is shown in fig. 1, where the configuration of the FINESA is shown, as well. The three-component sensors of FINESA are located into the ring 1, not in the centre of the array as in NORESS or ARCESS in Norway.

Different temporal and spatial analysis were done to characterise the detections of different analysis methods.

2. Data and results of the study

During the test period from April 10 to May 16, 1993 the FIA1 three-component station made 2287 detections/epicentre determinations using the Ruud-Husebye detector-bulletin production method (Ruud and Husebye, 1992). This «preliminary bulletin list» contained more than 50 daily locations and also many unassociated detections in average. So, it is evident that it had several later phase, coda or false detections. The initial detection input parameters, which are very similar to those used by Ruud and Husebye (1992), are shown in table I.

From the preliminary detections of FIA1, 874 were classified as local or regional ones. In the same period FINESA array reported 689 local or regional epicentres. Further, when the detections were merged, FIA1 and FINESA bulletins had 258 common or very close local or regional epicentre solutions. Consequently, 37% of FINESA locations got reliable three-component location, too. To become accepted as a common event the solutions of the two epicentres had to fulfil the equation

$$\varepsilon \leqq \sqrt{(\mathrm{lat}_0 - \mathrm{lat}_1)^2 + (\mathrm{lon}_0 - \mathrm{lon}_1)^2} \quad (2.1)$$

where lat_0 and lat_1 are the latitudes and lon_0 and lon_1 longitudes of FIA0 and FIA1, respectively. Further, ε is a predetermined accepted deviation, which was set in this study at 50 km. Some strongly deviating epicentres were also included in the analysis, if the *P*-phase detections differed less than 1.5 s and both bulletins assumed that the event was a regional one. Table II shows the data of the day number 111 of 1993, which was Tuesday April 21. In fig. 2a-c the events located by the entire FINESA and its substation FIA1 are shown. The strong concentration is clear near the oil shale mines on the Estonian coast.

During this test period the Finnish National Data Centre (FNDC) analysed 480 events at regional distances. From these events 205 locations were common or close location determinations with FIA1 three-component station. These events have the median error 9.1° in azimuth and 8.5 km in

Table I. The parameters used to form the preliminary station daily detections are read in the detection input file. The parameters are quite well understandable: start time is the beginning of the first detection block of length Segment length. No of segments determines the total number of detection segments. If this value is 720, a whole 24 of data are analysed, when using 2 min long segments. No of filters defines the number of filters and filter type tells the type of filter, 0 = no filtering, 1 = 2nd order Butterworth filtering in one direction and 2 = two direction filtering is used to avoid phase shift. KF is the number of filter, Delta is the step length of moving window in seconds, *L* wind length of the moving time window (in number of deltas). Ishift is the shift of long-term-average relative to short-term-average. Sigma is the number of windows used to calculate LTA. Thresh 1 is the lower snr (signal-to-noise) threshold combined with Cohmin, Thresh 2 the upper snr threshold for pure sta/lta detections. Cohmin is the minimum coherence threshold combined with Thresh 1. Ndmin is the minimum number of successive triggers. Svel is the *S*-wave velocity used in calculations of apparent velocity. Flow and Fhigh are lower and upper cutoff frequency, respectively.

Station: FINESA

Sampling rate (Hz): 40.0

Start time (year)	day of year	h	min	s	ds
1993	110	00	00	00	0

Segment length (s)	No of segments	No of filters	Filter type
120	720	4	2

KF	Delta	*L* wind	Ishift	Sigma	Thresh 1	Thresh 2	Cohmin	Ndmin	Svel	Flow	Fhigh
1	0.300	4	15	6	1.60	2.30	0.6	3	3.30	1.5	3.5
2	0.175	4	15	6	1.70	2.45	0.6	3	3.10	3.0	6.0
3	0.100	4	15	6	1.80	2.60	0.6	3	2.90	5.0	10.0
4	0.075	4	15	6	1.90	2.75	0.6	3	2.70	8.0	16.0

distance, respectively. The numerous explosions in Estonia and Russian Karelia form the big majority of detections in the Finnish seismic network (FINET). The event distribution of the FIA1 station is very different from the entire small-aperture array location map. Events in Norway and Sweden are almost missing in the FIA1 event list.

At distances around 200-300 km the whole national network (FINET) and the three-component station (FIA1) made very similar number of locations, while the small-aperture array made some 40% more detections (fig. 3a-c). Because the coherency limit in the three-component detections was set reasonably high, it may explain the coinciding results between national network and the three-component station. Certainly, this may also be due to the poorer monitoring capability of a single station beyond 500 km, because up to 300 km the number of locations of different methods coincides well with each other. Further, signals coming from longer distances can be contaminated by background noise or signal generated noise and high coherency demand rejected such kind of detections, even though they could have had high STA/LTA values. Still, many of the FINESA detections can be seen as pure spurious noise detections – because the event distributions between FINET and FIA1 have certain similarities. Strong noise burst with low coherencies (*e.g.* < 0.5) were rejected from the final three-component event lists.

This fact may become clear when the distribution of listed azimuths are studied. The main directions of FIA0 are from azimuths close to 160° and 340° (fig. 4a). The first mentioned direction points to Estonia and Karelia and the latter directions to the Norwegian coast. The azimuth distribution of FIA1 is different from FIA0 distribution. Most of the directions of approach point to 160°, which roughly presents the direction toward Eastern Estonia. The distribution of the entire FINET differs from both of the previous distributions. The Helsinki bulletin (Heikkinen *et al.*, 1993) locations seem to have maximum in Karelia (directions 135°). If the effects of strong cyclones on the Norwegian coast are taken into account, it is possible that many of the locations found in FINESA bulletins, have only hydrometeorological origin (Tarvainen, 1989). Consequently, many of those detections may not originate on any real event, because the azimuth distributions of FIA0 and the entire FINET network have different azimuth distributions (fig. 3b,c). The number of false detections could be minimised by using the continuous magnitude monitoring (Husebye and Mendi, 1993).

Because the main part of the events

Table II. The locations on 21th April 1993 provided by the entire array (FIA0) and the three-component substation (FIA1). Asterisks denote events, which were not found in the three-component station bulletins.

Day and origin time	FIA0					FIA1			
	Azim.	Dist.	m_b	Lat.	Lon.	Azim.	Dist.	Lat.	Lon.
111:08:50:21.9	221.6	425.6	1.6	58.485	21.214	*	*	*	*
111:09:23:21.6	187.8	149.8	0.9	60.108	25.710	187.9	129.0	60.29	25.76
111:09:59:35.7	192.5	830.4	2.3	54.115	23.323	*	*	*	*
111:10:03:22.6	163.4	256.2	1.3	59.227	27.362	158.9	252.1	59.32	27.62
111:10:18:43.2	161.6	245.0	1.1	59.344	27.439	169.0	253.7	59.20	26.92
111:10:52:26.3	306.0	196.6	1.4	62.451	22.983	308.2	184.8	62.44	23.35
111:11:00:22.0	167.4	234.1	1.7	59.385	26.978	163.3	229.1	59.46	27.24
111:11:07:04.3	162.8	123.0	0.9	60.385	26.741	152.8	102.1	60.62	26.94
111:11:29:13.1	156.4	116.6	0.8	60.480	26.930	162.8	113.2	60.47	26.69
111:11:41:09.1	222.9	127.1	1.3	60.597	24.492	208.9	102.5	60.63	25.17
111:11:47:47.5	74.2	95.7	1.3	61.668	27.823	70.5	93.6	61.72	27.75
111:12:10:41.6	171.7	231.4	1.0	59.382	26.666	166.6	233.3	59.40	27.03
111:12:12:36.9	163.7	242.6	1.1	59.343	27.280	152.4	271.3	59.26	27.29
111:12:14:56.5	244.8	215.4	1.2	60.570	22.507	236.3	224.0	60.28	22.69
111:12:39:39.0	44.2	214.2	0.9	62.795	29.019	36.6	238.7	63.14	28.91
111:13:12:03.7	77.4	249.9	1.3	61.854	30.734	84.0	275.8	61.61	31.28
111:13:15:41.9	116.7	172.6	2.2	60.717	28.916	104.1	181.0	61.01	29.34
111:13:28:59.4	271.2	122.7	0.7	61.447	23.767	274.5	115.2	61.51	23.91
111:14:10:17.5	28.5	199.1	1.5	63.005	27.963	23.2	217.1	63.23	27.79
111:15:16:40.2	163.5	102.0	0.6	60.563	26.609	150.7	102.1	60.64	27.00
111:15:27:41.2	281.2	163.4	1.0	61.696	23.034	*	*	*	*
111:16:56:18.0	168.9	976.2	2.5	52.789	28.872	*	*	*	*
111:18:37:04.4	87.5	171.3	0.3	61.474	29.302	*	*	*	*
111:18:43:14.2	30.3	544.6	1.8	65.558	32.063	*	*	*	*
111:19:25:14.6	356.9	226.8	0.9	63.482	25.830	*	*	*	*

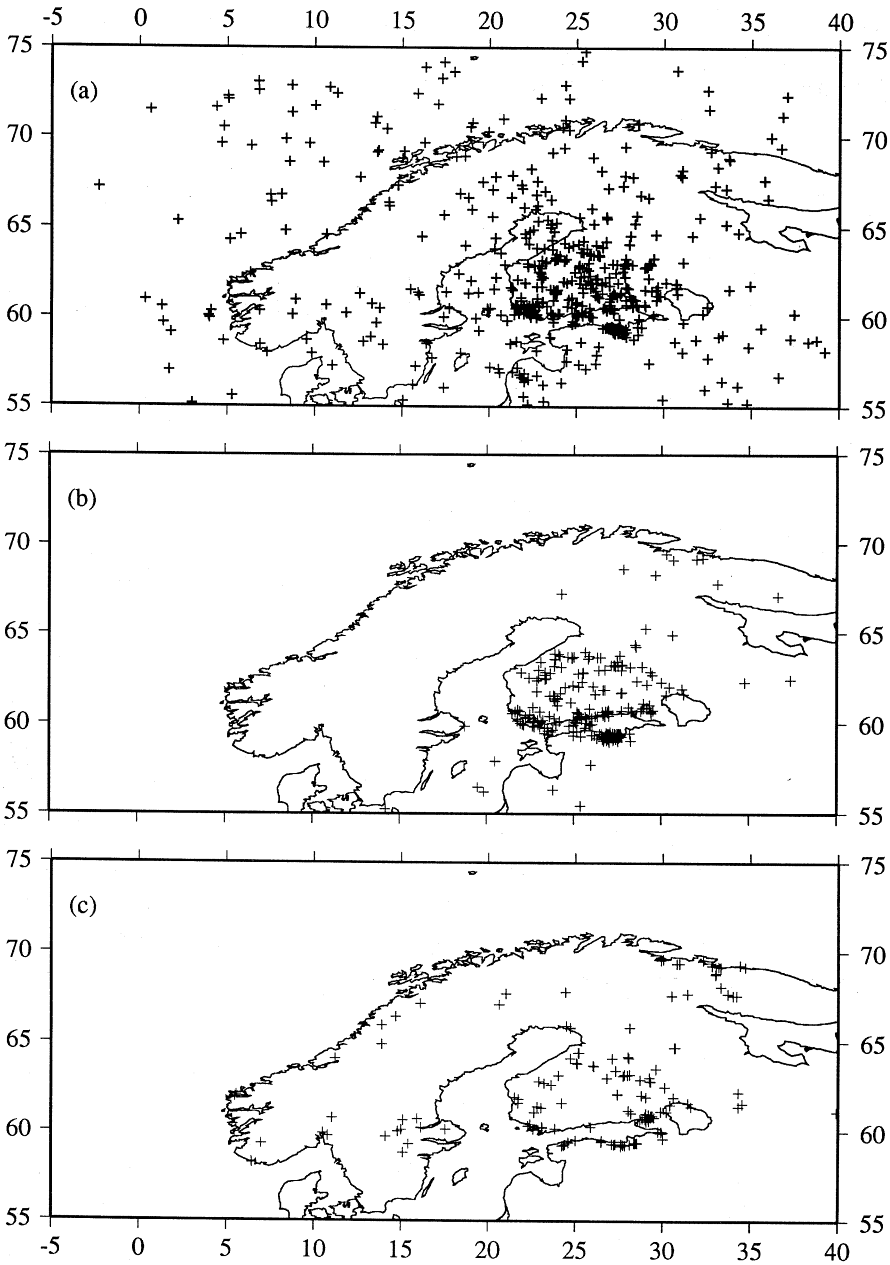

Fig. 2a-c. The locations reported by the daily bulletins of FINESA from 10th April to 16th May 1993: a) and corresponding locations of the FIA1, three-component substation, b) respectively. FINET locations are shown in c). The strong concentration of detections on the Estonian coast is clearly visible. FIA1 detected very few events beyond 300 km, *e.g.* no events can be seen in Northern Sweden. The locations in the Norwegian sea may be spurious noise detections made by FINESA. Those events were seldom found in the Helsinki bulletins.

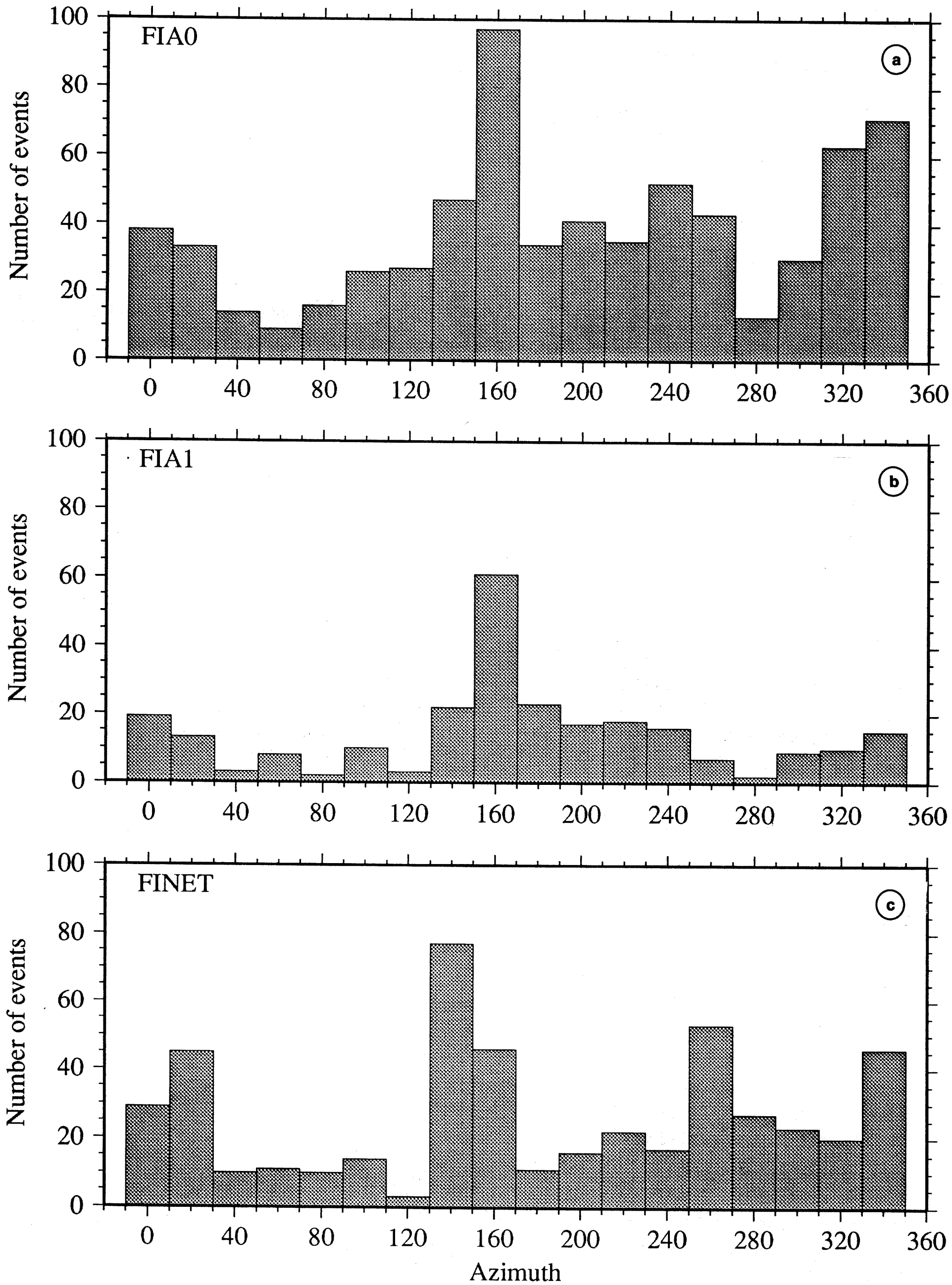

Fig. 3a-c. a) The azimuths of all the detected events of the entire array. The strongest bins point toward south-east and north-west. North-west and south-west directions may contribute many false alarms, because they are not dominating directions in three-component results; b) the directions of FINET network; c) have also wider distribution than FIA1.

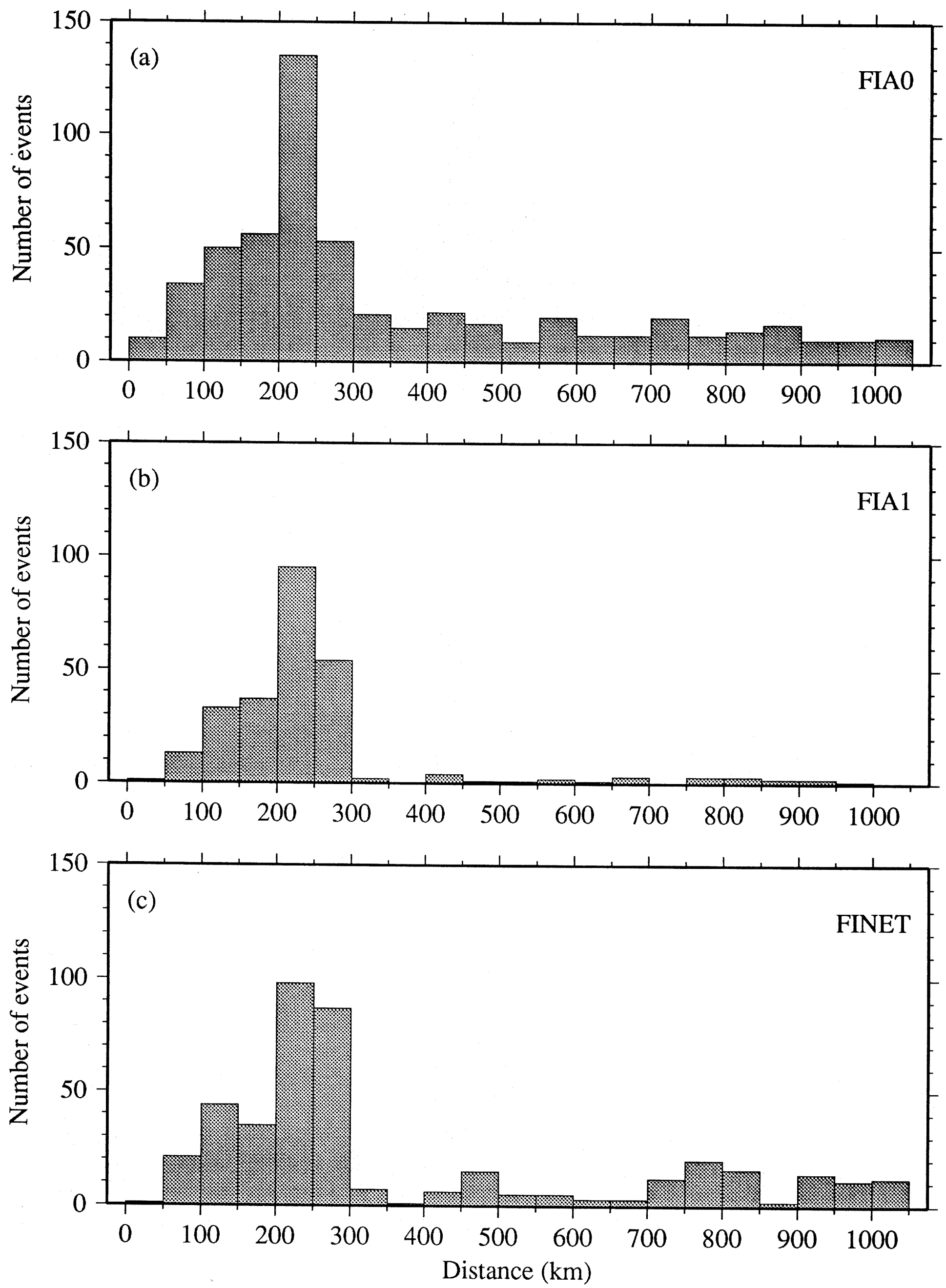

Fig. 4a-c. The distance distribution of three different analysis methods. The FINESA array (a) made around 40% more detections and epicentre locations than FIA1 three-component station (b). The main part of locations concentrates at distances from 200-300 km. FIA1 seldom detected beyond 300 km. The FINET analysis found many detections also at distances over than 500 km (c).

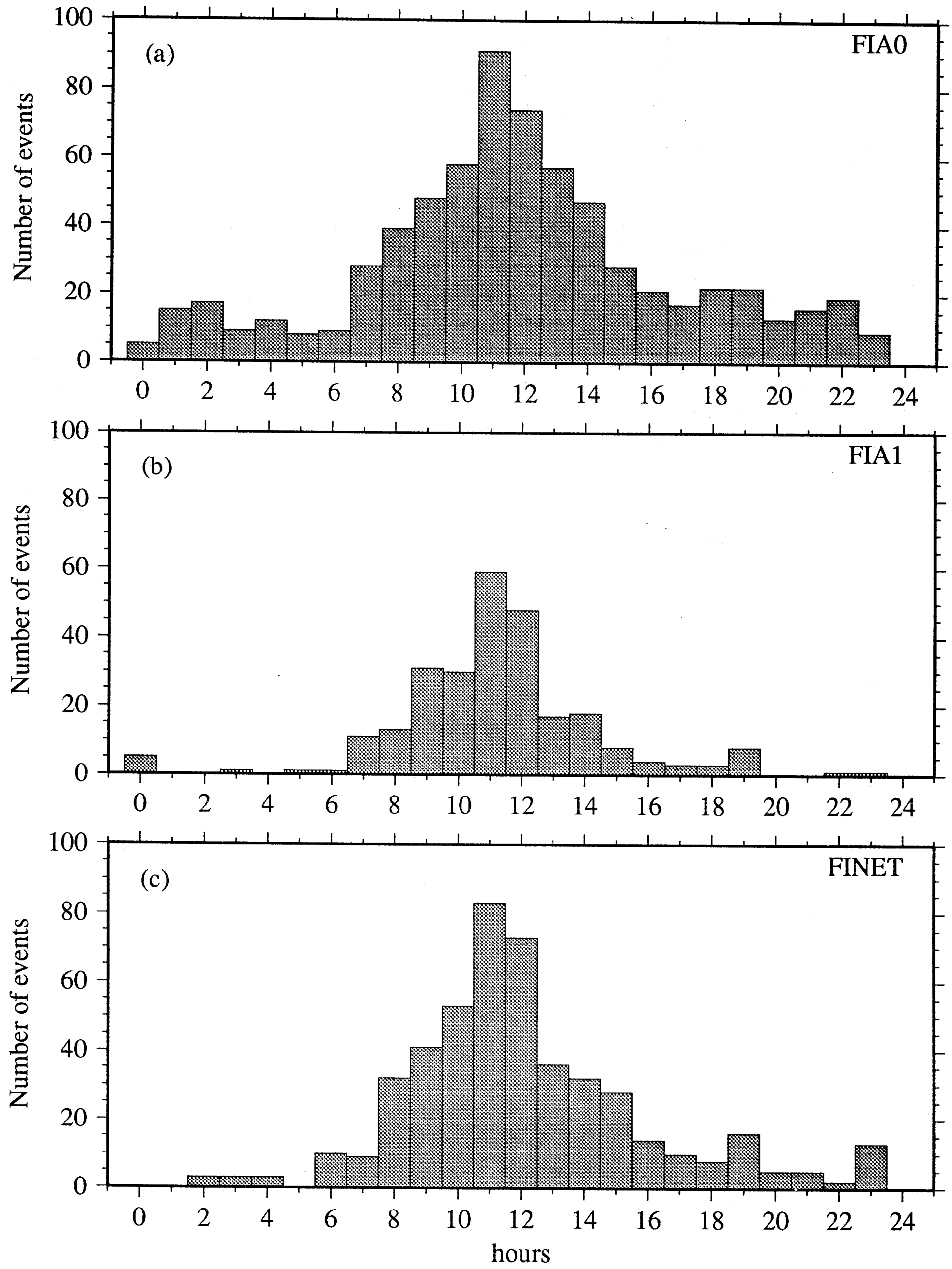

Fig. 5a-c. The diurnal distribution of detections. Time is in Greenwich mean time. Because the majority of the seismic detections made in Finland are industrial explosions in Fennoscandia and adjacent areas, it is expectable that detections concentrate in working hours. The most widely spread detections occurred at FINESA array processing (a), while events obtained from FIA1 (b) and FINET (c) readings concentrate more in the active time.

recorded by FINESA, FIA1 and FINET in general are industrial explosions in Fennoscandia and adjacent areas, the origin times of the events should occur during working hours. If the origin times are studied, they will concentrate around noon hours. The diurnal distributions of FINESA entire array, FIA1 three-component station and the whole national network are shown in fig. 5a-c. The highest bins of detections occurred at 11 h, which meant early afternoon local time. The events detected by the three-component substation seldom occurred outside active hours. The event location distribution of the FINESA array and the entire network remind more each other than the distribution of the three-component station. Consequently, the three-component station lost some events – evidently beyond 500 km. If the detection threshold were lowered for night time, the three-component diurnal distribution would have looked different, because it would have caused more detections during working hours mainly caused by risen noise level.

If the common locations of the three-component station FIA1 and the FINESA array are compared, it is found that the events match well with each other. Azimuth errors are shown in fig. 6. One can see that the azimuth values of FIA1 differ from values of the entire array mainly less than ± 20°. The distance difference of the main part of events is less than 20 km. In fig. 7 the errors of distance estimation are studied as a function of the distance obtained from FINESA daily bulletin. Some

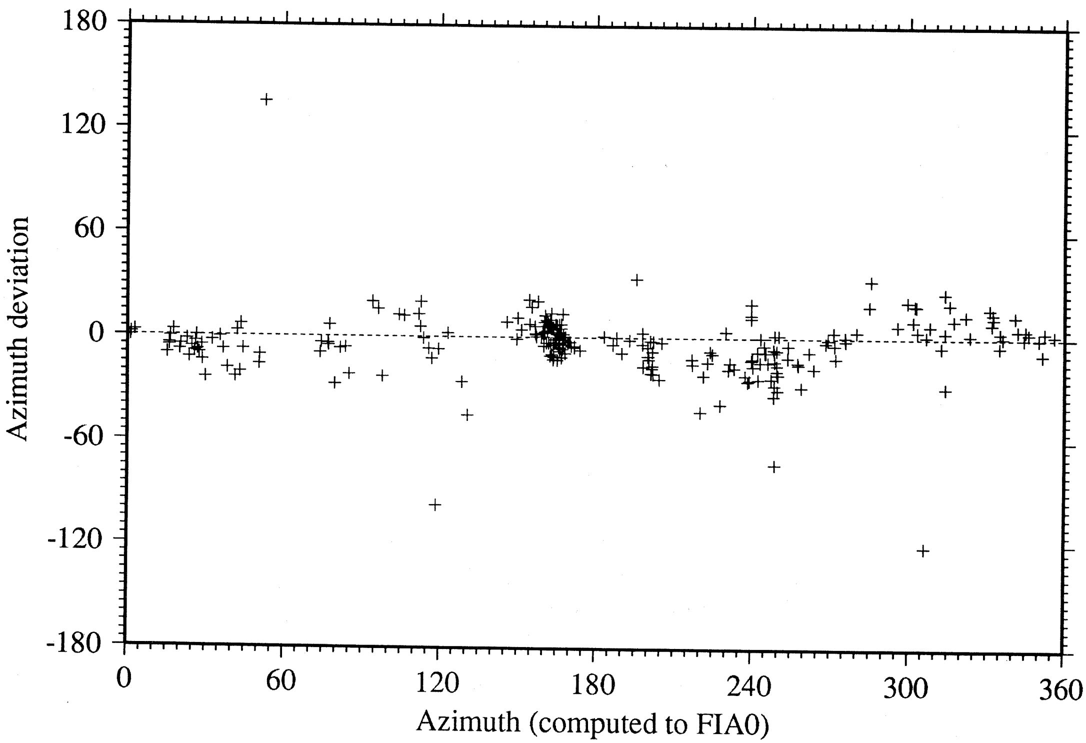

Fig. 6. The azimuth differences between FINESA and the substation FIA1. Excluding some extreme deviations the azimuth values coincide well with each other. The average difference was 5°. The strong concentration around 160° denotes directions towards Estonia.

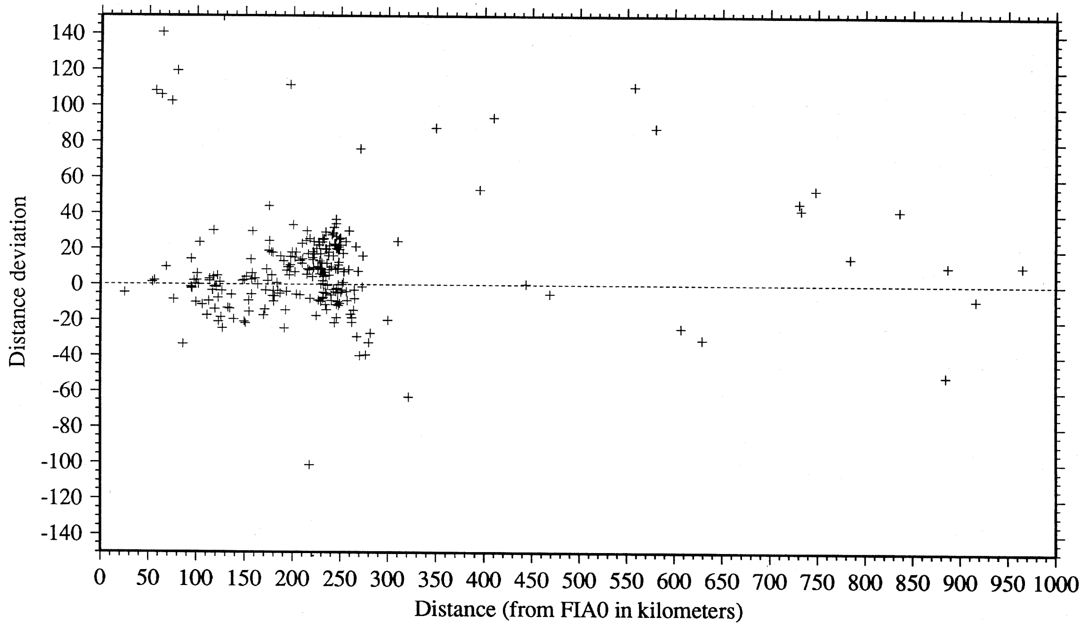

Fig. 7. Distance differences as a function of the distance from the FINESA centre element (FIA0). The errors stayed within 30 km. Some drastically differing distance values occurred occasionally, when FINESA array solution failed to pick the correct later phases. If only the connected events are analysed, the onsets of the three-component analysis are preferable – especially in events of very close *P*-, *S*-notations.

drastic errors occurred at distances less than 100 km, when FIA1 obtained very great distance values when compared with FIA0 values. The median value of the distance differences was 6.2 km. Tarvainen (1992b) found that at distances from 180 to 250 km the wrong phase notation could cause distance errors up to 30 km.

There are many sources of locating errors or differences, when using one station of three-component recordings.

The first is the error of azimuth estimations; this error being ± 5° may cause location errors, more than 20 km at the distance of 250 km. This is the distance approximately from FINESA to Estonia. Hence, it is not possible by seismic method only to connect the recordings to the correct mine of the area with high mining density. The deviations from the azimuth are reported by FINESA, where it can be seen that the azimuth deviations seldom exceed 20 (fig. 6).

The possible sources for the azimuth errors at one three-component station include such sources as:

— ripple fired explosion caused long and slowly rising emergent *P*-onsets. This is the situation with strong mining explosions made in Northern Sweden (Aitik) and Kostamuksha mine in Russia;

— some arriving *P*-phases at azimuths from approximately 45° to 80° have steep incidence angles of *P*-waves. Consequently, the signal-to-noise ratios in horizontal components tend to reduce;

— some phases like *Pg*-phase soon after *Pn*-phase or some surface converted waves having SV- or SH-polarised components produce great scattering in the azimuth estimations.

Tarvainen (1992a) found that the best backazimuth estimations were found within a moderate short data window starting very close to the first onset.

The second source for location errors are the misinterpreted later phases. Gomberg *et al.* (1990) studied the location error caused by this kind of error. The distance errors of the events common with FIA0 and FIA1 are shown in fig. 7. Because two different automatic phase pickings systems have different sensitivity to later, sometimes strongly masked phases, some events had very great distance deviations, also at close field distances.

One problem may rise also at FINESA, when the maximum secondary phase identification fails to find either *Lg* or *Rg* phases. At distances beyond 500 km *Lg* phase loses its amplitude and the maximum secondary phase is found to be *Sn*-phase. This fact may explain the lost events from Northern Sweden, when signal must cross the crustal fracture barrier. The locations from there are so scattered that no coinciding locations were found between FIA1 and FINESA.

The third error of location may be due to the crustal model used to compute the distances. This effect was not found to affect much the locations. At certain distances some closely approaching phases *Pg*, *Pn* may sometimes cause wrong phase definitions and further wrong distance estimations. The distance biases in this study were studied with different crustal models, but no significant changes or improvements were found.

The fourth possible source for errors is low signal-to-noise ratio (SNR). If we are dealing with very weak signals under noisy conditions, the estimated onsets of phases may be delayed sometimes even seconds, so causing unbearable distance errors. Tarvainen (1992a) found that when SNR is less than 2, the onset time errors rose fast, a situation which occurred particularly when the automatic phase picking was used. Also, in similar circumstances the three-component azimuth estimation accuracy will drop. When the signal-to-noise ratio rises reasonably high (*e.g.* > 5) the locations obtained from the data of a single station are comparable with array or network results up to 300 km distances.

3. Comparing the results of FIA1 with the national seismic network bulletins

As mentioned the Helsinki data centre determined 480 local and regional locations during the test period. The *Helsinki Bulletin* (Heikkinen *et. al.*, 1993) is widely used as a reference data base to study the accuracy of some analysing system. Next, the events detected and located by the three-component station are compared with these data. Since many of the locations reported in the bulletins stem from known mines, the well-known template system, established more than two decades ago by the Institute of Seismology, was applied to determine the locations simply by recognising the wave train visually. The mines having a specified shooting practice have received «coded» site markings. This was done to ease the daily analysis work load, locations are based on the preliminary pattern recognition rather than tedious phase readings. These locations have been stamped *«manual locations»* and are obtained without any waveform inspection. Also, the intelligent monitoring system (Bratt *et al.*, 1988; Bache *et al.* 1990) has a similar data base, but it is preferably based on satellite imagery studies. The events, having the coded locations, had very seldom any information of *P*-wave arrivals, so causing rejection, even though the locations would have been very similar to FIA1. The azimuth and distance deviations of the common 204 events of FINET, which could be associated with FIA1, are shown in figs. 8 and 9. The deviations are computed from the locations provided by FINET to FIA1. The azimuth deviations are remarkably small at any di-

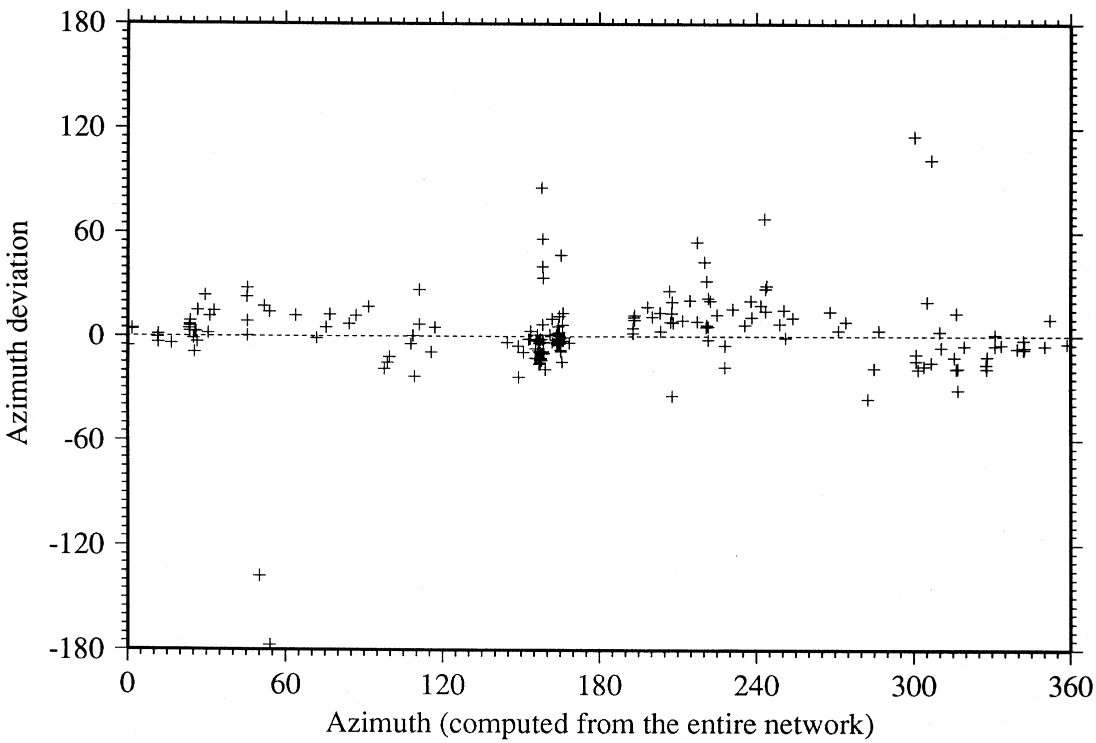

Fig. 8. The azimuth deviation of the common events with FIA1 and the entire network. The main part of errors stays within ± 20°.

rection. Only few connected events had over 30° error.

Distance deviations in turn had a great scattering, and they did not have any distance dependence. The greatest distance errors are evidently those events having very close *P*-onsets, but strongly different later phase picking. A very strong concentration of detections at distances around 200 km is caused by the numerous explosions in Estonia and Russia.

3.1. *Searching the clustering behaviour of the events*

This part of the study concentrates on the study of the clustering of events in Fennoscandia and surrounding territories. Next, some areas having repetitious shootings were chosen for analysing the locating and detecting capability of the three-component station FIA1.

Estonia – The oil shale mines along the Estonian coast form a band of mines shooting frequently. For example, in 1991 the Finnish National Data Centre analysed 1419 events, which occurred in that area (Tarvainen and Husebye, 1994). During this test period 114 FINET locations were connected into the Estonian mining sites, while FIA1 three-component station made 71 locations in the same area. Some events extended also into the Russian site, where also some activity exists. The detections of FIA1 coincide well with the detection times of the entire national network. The main

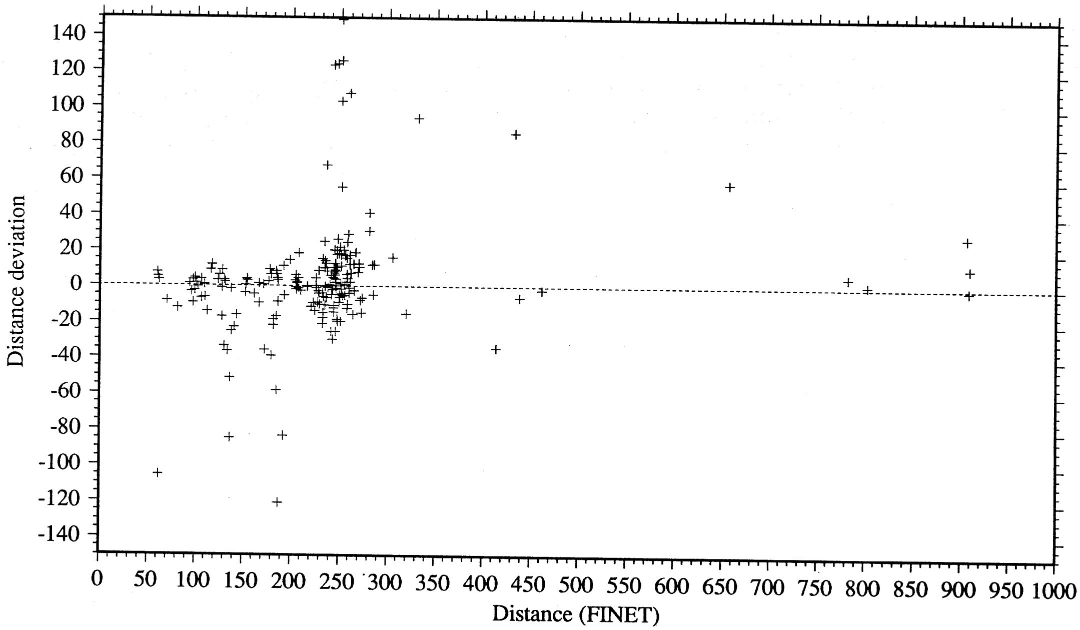

Fig. 9. The distance errors of FIA1 as compared with the locations of the entire network. The errors even long distances are acceptable. This may be due to the size of the events detected at longer distances. The signal must be moderately strong to have sufficiently high signal-to-noise ratio to be detected.

part of detections occurred during working hours (fig. 10).

When the distribution of FIA1 locations is compared with FINET locations, they coincide well with each other (fig. 11). Because, the locations obtained from Helsinki bulletins are mostly determined by analysts using the predetermined template and coding them as «manual location», the epicentres stem from those sites in Estonia. Only separate events can be found outside the mining sites. The locations provided by the three-component station have a little wider areal distribution.

Karelia – In Russian Karelia the mining activity is also considerably high. During the six weeks of study, the national data centre analysed 29 events within an area from 59° to 62°N and 28° to 32°E. The concentration bins of FINET analysis and the reported FIA1 locations are presented in fig. 12. The locations obtained by FIA1 three-component station concentrate nicely around the FINET locations. Only few events located by the FINET on the Gulf of Finland, are missing from the locations of FIA1.

The events in Karelia stem from the mining area north of Viborg and are sometimes separated from each other only one km or so. Consequently, one three-component station in this region needs extra «pinpointing» to find the right connection to mines under consideration. This can be done by using some known master event correlation method (Joswig and Schulte-Theis, 1993).

Siilinjärvi mine in Finland – Siilinjärvi mine in Finland is known for its very frequent and very characteristic shooting practice. Explosions there, are carried out in early afternoon and shot sizes are remarkably large, causing strong *P*-onsets at Finnish seismograph stations. Also, the mine in Nilsiä is located very near Siilinjärvi, and misidentifications between these two mines can occur, if data from only one station are used. The behaviour of the Siilinjärvi mine was studied by Tarvainen (1992b) using the network of three-component stations of the Finnish National Network.

The locations near Siilinjärvi and Nilsiä obtained from FINET and FIA1 are shown in fig. 13. The explosions in these two mines are usually determined and located by visual inspection of seismograms, without any waveform screening. Consequently, the co-ordinates of epicentres are only simply known code co-ordinates, without any possible scattering caused by phase reading errors by analysts. The events found in the bulletins of the three-component station have some east-west oriented

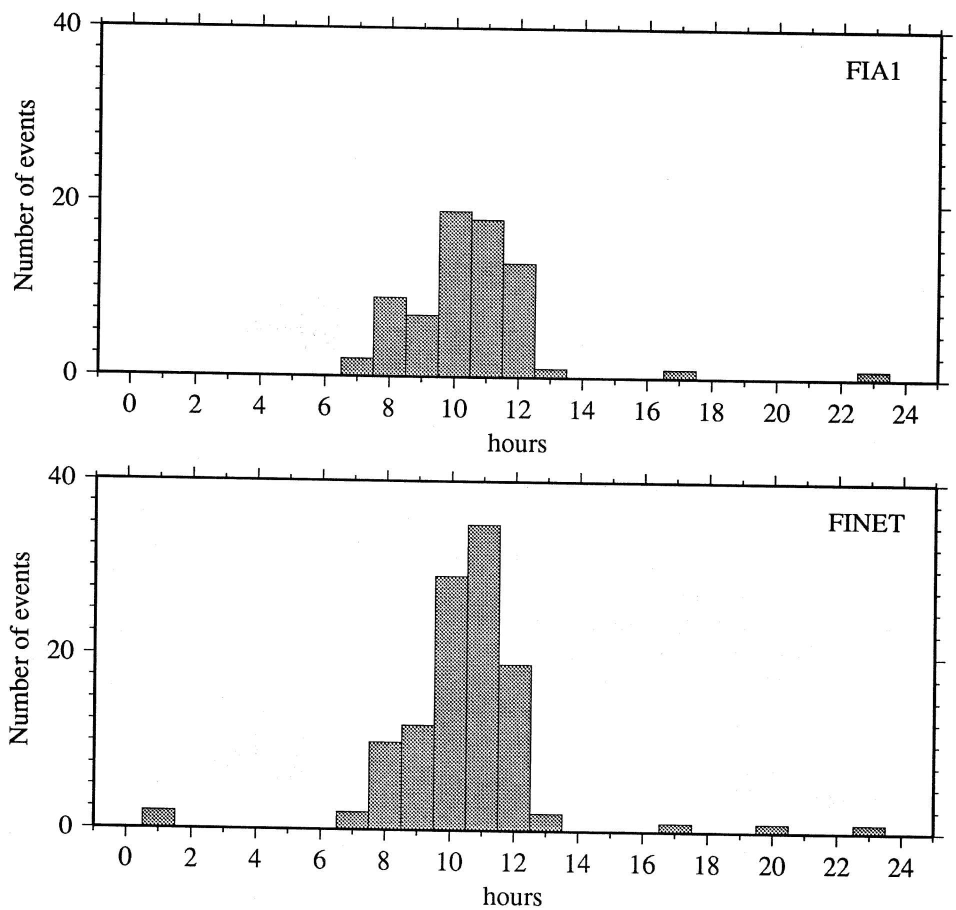

Fig. 10. The diurnal distribution of detections originating in Estonia. The main part of events occurred during the working hours. The time is Greenwich mean time, which differs from the local time by – 3 h. Consequently, the events happened mainly in the afternoon.

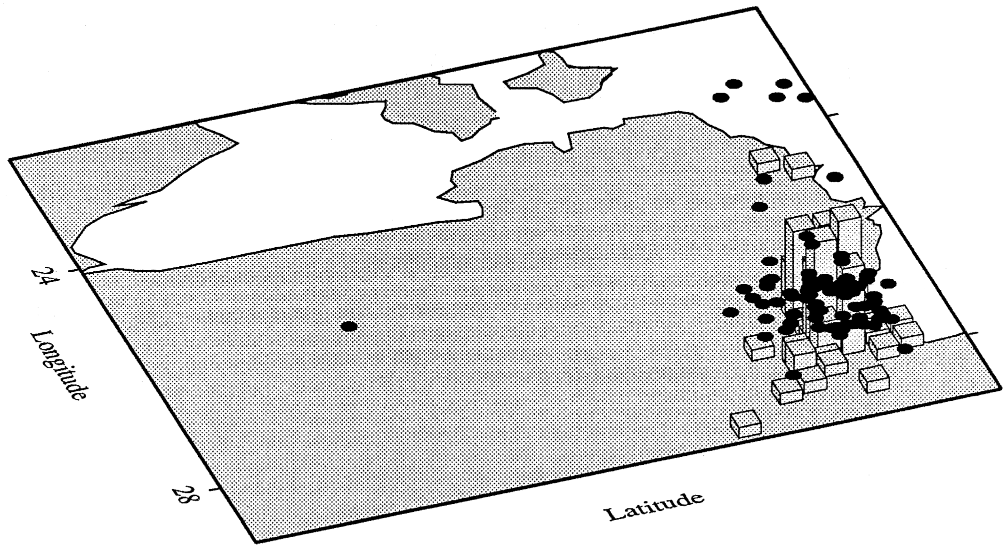

Fig. 11. Epicentres determined by the three-component station FIA1 (black circles) and locations of FINET within squares of 0.1°*0.1° (bins), respectively. Because many of the locations found in the Helsinki bulletins are determined according to predetermined pattern recognition, these locations are concentrated in the coded mines on the Estonian coast. The locations of FIA1 can be found in a wider area, even though strong concentration close to the mines can be seen.

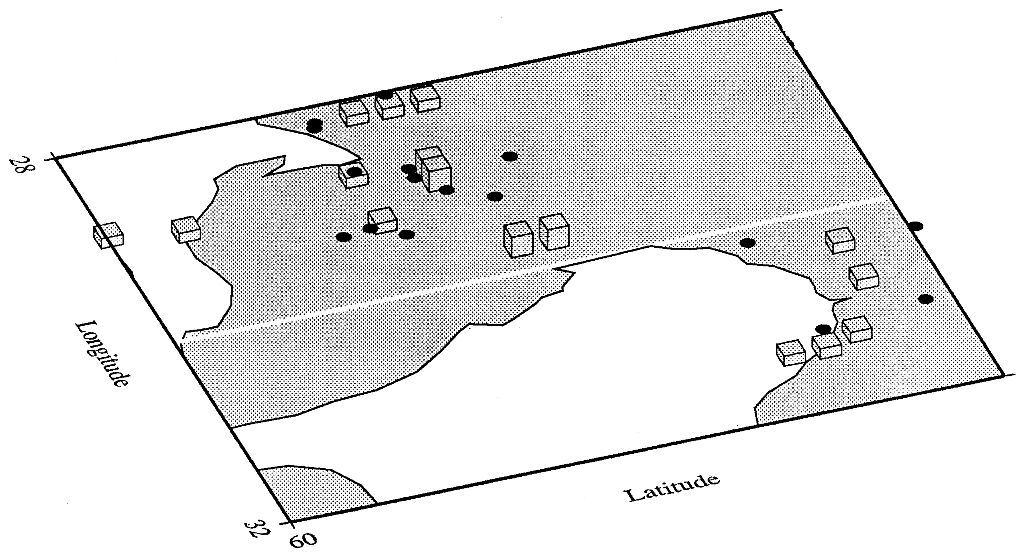

Fig. 12. Events in Karelian during the test period. The three-component locations are concentrated near mines or frequent explosion sites. The location bins of the national data centre are not remarkably high, because only 29 events were found in the area. As one can see, using only seismic locations of events at areas of high mining activity, it is not possible to connect seismic events to specific mines in the area.

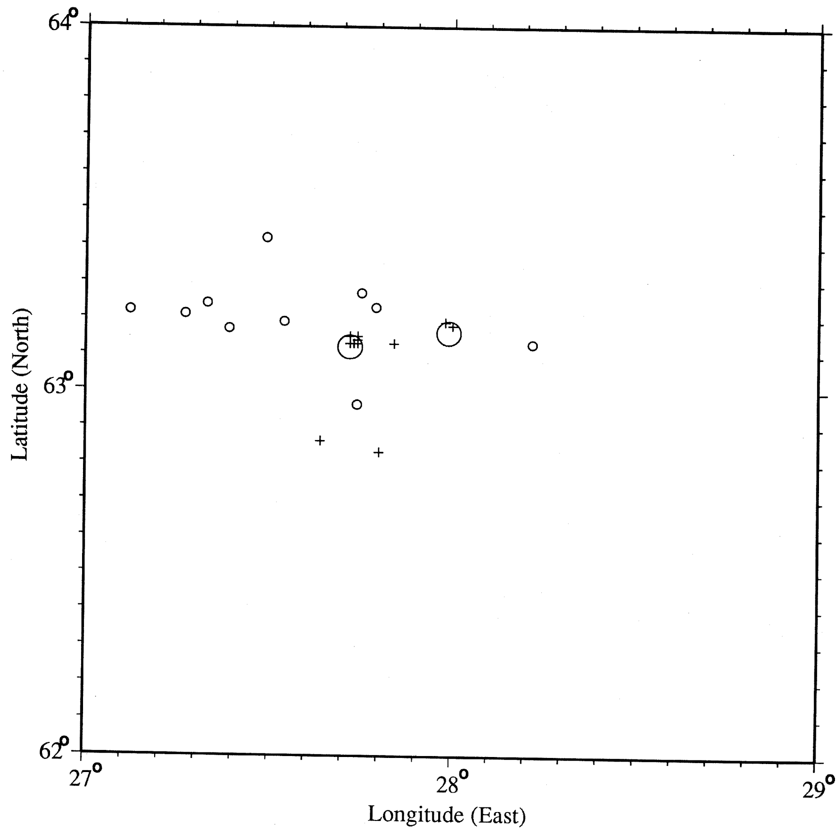

Fig. 13. The epicentres around Siilinjärvi and Nilsiä mines (great circles). The crosses denote epicentres provided by the national data centre analysis, while the small circles represent the epicentres obtained from the FIA1 three-component station bulletins. The three-component epicentres show strong east-west oriented biases. During the test period, the national data centre analysed 12 seismic events from which FIA1 found 10. The number of crosses mismatches the announced number of events, because many locations in Siilinjärvi are based on the analyst template and the reported epicentral data have a «manual location» note-meaning that a fixed epicentre is used.

scattering of epicentres, a phenomenon found also by Tarvainen (1992b) in the recordings of the seismograph station KAF, which is the closest station to FINESA.

During the registrations for this study FINET detected 12 events in Siilinjärvi and Nilsiä mines. The three-component station FIA1 detected and located 10 events in the area.

4. Discussion

In this paper it has been demonstrated how to apply an automatic three-component detection-bulletin production analysis to control automatic array bulletin quality. The capability of a three-component station to locate epicentres is not much inferior to the results of an array data, when only local and regional distances are taken into account. The ability to detect and identify *P*- and *S*-phases depends on the SNR of the event at the station and the set detection parameters, as well. Also, when strong man-made ripple-fired explosions are analysed, the later phases are occasionally masked by the codas of *P*-phases.

With more operational experiences coupled with software upgrading the accuracy of the phase picking can be improved. For example the data-adaptive onset estimator (Pisarenko *et al.*, 1987) might be applied to the signal screening process, so helping to fine-tune and improve the correct phase onsets.

The main contribution to this study is the examination of known mining explosions in Finland and Russia. Some problematic errors occurred at distances of approximately 250 km. Some known mining sites at distances close to 250 km were mislocated owing to wrong phase notation. At those distances different *P*- and *S*-phases arrive very close to each other, thus causing sometimes distance determination errors. Also, the errors in *S*-phase readings can cause distance errors (Gomberg *et al.*, 1990). The errors do not very much depend on the crustal model used.

The fracture zone from Lake Ladoga to Bothnia Bay may cause strong scattering of the signals arriving from north-east directions and from distances around 200 km. At longer distances, if the signal is available, the scattering was not found to cause much azimuthal biases. This may be caused by moderate shallow fracture extension of the Fennoscandian shield along the zone. Also, wavetrains of some close events arriving to FINESA and its substations across that fracture zone have steep incidence angles, and consequently cause decreasing SNR and further strong biases in the azimuth estimates.

5. Concluding remarks

The monitoring method based on the three-component station is a versatile tool for improving and confirming the usefulness of automatic array bulletins. A single substation may be used for fast confirmation of a detection found in bulletins and, when using manual screening controlled by an experienced analyst, even improve the contents of the bulletin.

The accuracy of three-component station locations depends primarily on two factors. First, when signal-to-noise ratios are below 2, the accuracy is strongly reduced, because the error of the determined backazimuth is strongly increased. Another source of errors is the misidentification of later phase. Strong *P*-phase codes sometimes distort the *S*-phase onsets.

Because the array beam-forming process suppresses the incoherent noise, it is evident that the entire array configuration can detect and locate more events than a single three-component station. In general the locating procedure can comprise observations from one or more three-component stations (Cassidy *et al.*, 1990; Ruud and Husebye, 1992). Based on the experience from this study multistation or array locations should give more accurate locations than reported here for individual stations. If the three-component station can be tuned by using some pre-defined knowledge like master event dynamic waveform matching, its monitoring capability may be risen remarkably. For example, some master event mapping of certain later phases could be used to improve the location ability of the three-component sensors.

The event locations based only on small-aperture array readings and one three-component station can be used to form a «ground truth» basis for the locating scheme. Further, some finer tuning may be done on some peculiar, curious or suspicious events to dig out their true nature.

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