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Monitoring and Analyzing Regional Seismic Events Using a Network of Three-Component Stations

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Abstract

Seismic events at regional distances up to 1500 kilometers were studied using 3-component recordings from stations in Finnish National Seismic Network (FINET). The events were analyzed on a pseudo-real time basis using the continuous data streams from the two stations VAF (63.0°N, 22.7°E) and KAF (62.1°N, 26.3°E). Some events were also included from the dial-up station JOF (62.9°N, 31.3°E). The epicenter locations of the stations on a stand alone basis and as a group were studied and the results are compared with those listed in the FINET bulletins (also called Helsinki bulletins). Location errors were studied with some well established mining sites in Finland and Russia.

The median distance error regarding to network locations was 16 kilometers. Consequently the error of distance can be counted to be less than 5 % of the calculated distance. The error in latitude and longitude were 0.01° and 0.16° respectively.

The locations of 3-component stations differed from the locations given by Helsinki bulletins 52 kilometers in average. The main reason for location anomalies was due to the azimuth errors. The azimuth is found to deviate ±10° from the true value. That in turn means a location error of approximately 200 kilometers at a distance of 1000 kilometers.

1. *Introduction*

The location and identification of seismic events have been a challenge for seismologists for decades and still are. The fact which is also stated by the group of scientific experts (GSE) of the conference of disarmament. Classical methods for determining the epicenters of seismic sources are mainly based on the P-wave arrival times. More recently event locations have been based on the application of array in terms of slowness vector estimates. Very recently a single 3-component station has gained popularity in epicenter determination; using the same technique as for arrays (*Magotra et. al.*, 1987; *Christoffersson et al.*, 1988; *Ruud et al.*, 1988; *Saari*, 1989; *Thurber* et al., 1989). *Tarvainen* (1992) studied the location accuracy of the seismograph station VAF in western Finland using maximum likelihood method to determine the back azimuth (and slowness vector) and the data-adaptive onset estimator of *Pisarenko et al.* (1987) for P- and S-pickups. In this study

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the fast principal component technique (*Jurkevich*, 1988) was used to characterize the signal polarization state from which the azimuth was derived. The phase onset were picked in screening process.

A 3-component station can locate seismic events at any distances (*Cassidy et al.*, 1990), but the estimation of slowness vector becomes problematic for small teleseismic events as the signal amplitudes in the horizontal components can be weak (e.g. see *Ruud* and *Husebye*, 1992). Furthermore the structure beneath the station may bias the slowness estimations as demonstrated by *Lokhstanov et al.* (1991a).

The modern station practice makes possible to monitor seismic signal continuously using fast automatic detection algorithms on digital recordings. *Murdock and Hutt* (1983) published a detector which is widely used. *Tarvainen* (1991) developed a data-adaptive detector for weak regional seismic events. The analysis of detected signals can be automatic or manual. *Ruud* and *Husebye* (1992) introduced a three-component detector station bulletin production program. Their automatic method scans the seismic signal and forms according to preset parameters a station bulletin with phase analysis and locations.

This paper represents results from the establishment of a fast and reliable location tool in a sparse seismic network of 3-component stations. Also the needs of the compliance in detecting and identifying seismic events were considered to establish a network of three-component stations to use them alone or together.

In this study the location capacity of three-component stations is studied. They were used alone or all of them were used to establish a reasonable accuracy in location. The location analysis was done manually after use of detector of Murdock-Hutt type.

2. *Stations and data acquisition*

This study deals with analysis of recordings from 3-component stations in the Finnish national seismograph network (*FINET*). The location of the Finnish seismograph stations are shown in Figure 1, and the response curves of the instruments used in this study are shown in Figure 2. A complete technical description of stations is given by *Teikari* and *Suvilinna* (1992). Note, that KAF has smaller bandwidth than the other stations (cut-off at 5 Hz) so this station would be less useful for regional and local events for which higher frequency signals are dominant. Two stations VAF and KAF have continuous on-line recordings at the hub in Helsinki. JOF is a dial-up station from which the events, detected by the above on-line stations, are collected at 3 hour intervals. Even at JOF there is a station based disk loop for longer data storage capacity. In practice however only pre-detected events are transmitted automatically to the Helsinki hub.

The location analysis of the 3-component stations was done pseudo on-line basis. The analyst can select the events using a detector of Murdock-Hutt type and adjusting the detection threshold to maintain a reasonable false alarm rate.

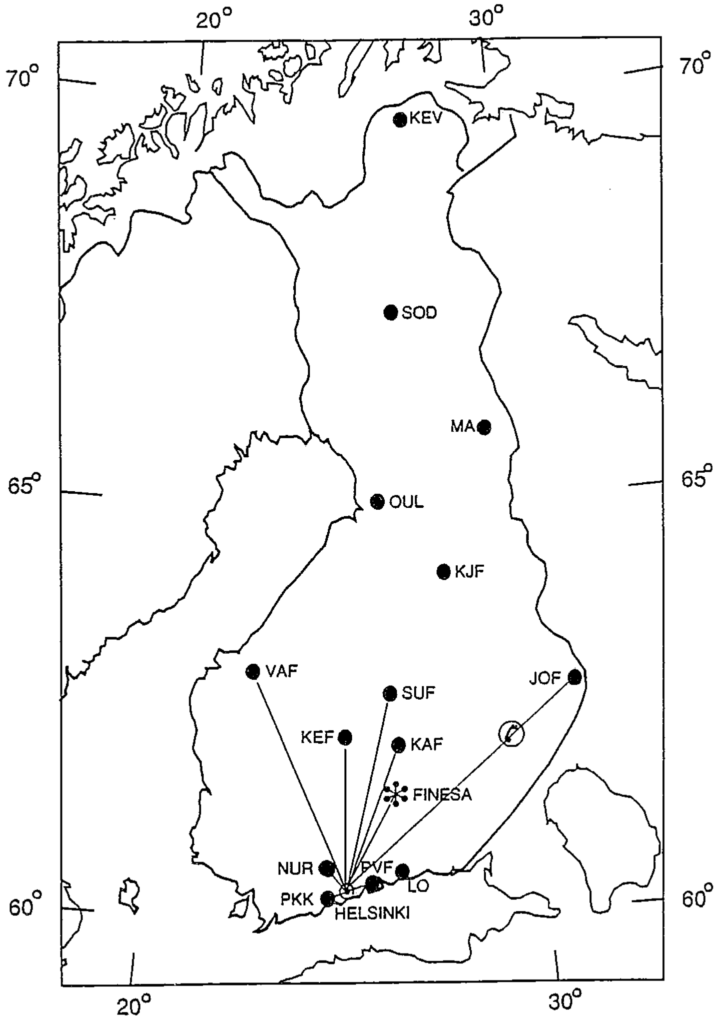

Fig. 1. The Finnish seismograph network. The solid lines present the on-line stations and the telephone symbolizes the dial-up link to the JOF station. The asterisk reflects the location of the FINESA small-aperture array.

3. *Seismic event recordings and their analysis*

The location analysis was performed interactively by manually picking P- and S-phase onsets from screen of the workstation and then starting the azimuth search with sliding windows. Distances were determined from P-S differences using crustal model

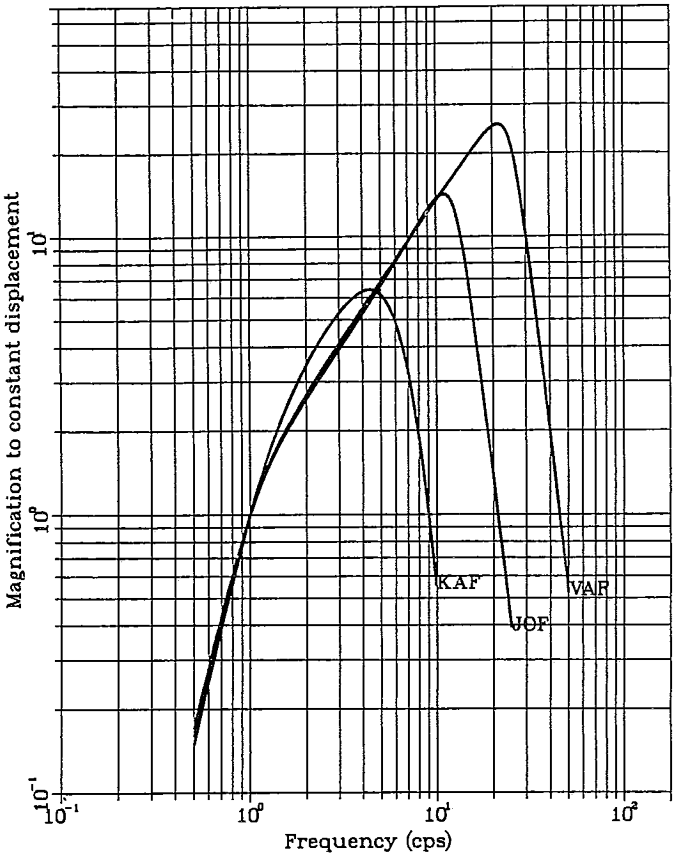

Fig. 2. The response curves of the seismometers used in this study. They are normalized to constant displacement at 1 Hz.

shown in Table 1. After that the solutions; azimuth, distance, location and origintime are given automatically and can be printed and archived. The depth of the events can be adjusted explicitly, but reasonable solutions could be achieved by setting it always zero. In modern workstations this location process takes less than 30 seconds/event/station.

Altogether 124 seismic events from Finland and adjacent areas occurring in 1991 and early 1992 were analyzed. The epicenter distances varied from 15 to 1480 kilometers and the magnitude range was 1.5 to 4.3. The majority of the events were man-made explosions. At Siilinjärvi and in the Russian Karelia the mining explosions are very numerous and were detected daily. In general, few explosions are recorded beyond 500 kilometers except for some strong explosions in the Kola district at $\Delta \approx 700$ kilometers.

These events were detected and also located by VAF. All the events are listed in Table 2. In Figure 3 all the epicenters obtained from VAF readings are shown. The VAF was preferentially used in this study, because of its superior detection capability in monitoring regional seismic events as compared with KAF and JOF.

Table 1. Crustal model used in this study. The same model is used also in preparing of the Helsinki bulletins.

Layer thickness (km)	P-wave velocity (km/s)	S-wave velocity (km/s)
15	6.07	3.51
25	6.64	3.81
40	8.03	4.64
*	8.50	4.75

Table 2. EX/EQ is discriminator between explosions and earthquakes. * in the magnitude means not measured magnitude. ML magnitudes from Helsinki bulletins. In stations K=KAF (Kangasniemi), J=JOF (Joensuu), V=VAF (Vaasa), * in station's code means missing location data of that station.

Known locations: 1) Siilinjärvi mine,2) Kostamuksha mine (Russian Karelia), 3) Öja quarry in Bothnian Bay region, 4) Kola mining area (Petsamo), 5) Pyhäsalmi mine, 6) announced depth charge explosions 7) Lahnaslampi mine.

Nro.	Date	Time	Latitude	Longitude	Magnitude	Expl. of Earhq.	Stations used
1	91-11-06	11:22	64.16N	31.90E	3.0	EX	*KV
2	91-11-06	13:24	62.01N	25.48E	*	EX	**V
3	91-11-07	20:52	68.44N	12.20E	*	EQ	JKV
4	91-11-11	12:14	59.23N	26.97E	*	EX	*KV
5	91-11-11	13:02	59.77N	29.41E	*	EX	*KV
6	91-11-13	10:17	58.82N	27.70E	*	EX	*K*
7	91-11-14	09:22	60.60N	29.47E	*	EX	JKV
8	91-11-14	12:56	61.21N	29.81E	*	EX	JKV
9	91-11-14	13:26	63.13N	22.42E	*	EX	**V
10	91-11-15	13:20	60.68N	28.06E	*	EX	JKV
11	91-11-18	09:13	58.26N	3.45E	*	?	**V
12	91-11-18	11:00	58.99N	25.69E	>2.0	EX	JKV
13	91-11-18	12:03	62.86N	28.04E	*	EX[1]	JKV
14	91-11-20	10:36	62.70N	22.79E	*	EX	*KV
15	91-11-20	11:34	61.57N	21.88E	*	EX	*KV
16	91-11-20	11:59	63.00N	28.06E	*	EX[1]	JKV
17	91-11-21	12:03	59.91N	33.93N	*	EX	JKV
18	91-11-21	14:07	60.76N	29.00E	*	EX	JKV
19	91-11-22	11:00	64.30N	31.33E	*	EX[2]	JKV
20	91-11-23	12:38	67.33N	31.76E	3.0	EX	*KV
21	91-11-25	09:15	57.39N	12.43E	*	?	**V
22	91-11-25	11:10	62.03N	25.54E	*	EX	JKV
23	91-11-25	11:50	59.59N	28.84E	*	EX	**V
24	91-11-25	14:09	62.53N	22.78E	*	EX	*KV
25	91-11-25	17:17	67.11N	20.86E	*	EX	JKV

Nro.	Date	Time	Latitude	Longitude	Magnitude	Expl. of Earhq.	Stations used
26	91-11-26	09:21	62.02N	23.42E	*	EX	*K*
27	91-11-26	10:53	62.75N	22.67E	>2.0	EX	*KV
28	91-11-26	12:33	63.76N	22.79E	*	EX[3]	**V
29	91-11-26	14:14	61.08N	29.07E	*	EX	JKV
30	91-11-27	12:03	62.93N	28.00E	*	EX[1]	JKV
31	91-11-27	12:06	59.97N	28.63E	*	EX	JKV
32	91-11-27	12:11	62.71N	23.05E	*	EX	*KV
33	91-11-27	13:01	63.13N	22.58E	*	EX	**V
34	91-11-27	14:07	61.17N	30.57E	*	EX	JKV
35	91-11-28	08:21	62.71N	22.93E	*	EX	*KV
36	91-11-28	11:36	63.13N	22.39E	*	EX	*KV
37	91-11-28	12:22	62.10N	25.59E	*	EX	JKV
38	91-11-28	12:46	59.91N	28.14E	*	EX	JKV
39	91-11-29	11:00	64.45N	30.94E	3.0	EX[2]	JKV
40	91-11-29	11:05	62.29N	30.93E	*	EX	JKV
41	91-11-29	11:33	62.52N	23.68E	*	EX	*KV
42	91-11-29	12:07	59.50N	26.48E	*	EX	*K*
43	91-11-29	12:53	59.45N	29.93E	*	EX	JKV
44	91-11-29	13:03	61.40N	29.40E	*	EX	JKV
45	91-11-29	13:32	61.30N	29.35E	*	EX	JKV
46	91-11-29	13:36	59.27N	27.97E	*	EX	JKV
47	91-11-29	14:13	69.41N	30.94E	3.2	EX[4]	JKV
48	91-11-29	20:25	63.68N	25.94E	*	EX[5]	JKV
49	91-11-30	09:45	57.24N	26.90E	*	EX	JKV
50	91-11-30	10:21	60.59N	29.50E	*	EX	JKV
51	91-11-30	12:02	66.97N	26.37E	3.0	EX?	JKV
52	91-12-02	11:15	59.15N	26.81E	*	EX	JKV
53	91-12-02	11:34	63.16N	27.81E	*	EX[1]	JKV
54	91-12-02	12:03	59.63N	29.08E	*	EX	*K*
55	91-12-02	12:09	61.66N	23.80E	*	EX	*KV
56	91-12-02	12.10	63.72N	22.45E	1.5	EX[3]	**V
57	91-12-02	12:14	64.17N	24.93E	*	EX	*K*
58	91-12-02	17:11	59.32N	24.63E	*	EX	JKV
59	91-12-02	18:06	65.79N	25.86E	*	EX	**V
60	91-12-03	08:53	59.91N	24.81E	*	EX[6]	*KV
61	91-12-03	11:18	58.74N	27.09E	*	EX	*KV
62	91-12-03	12:06	62.96N	28.03E	*	EX[1]	JKV
63	91-12-03	13:04	63.72N	23.30E	*	EX[3]	**V
64	91-12-04	11:57	63.68N	22.99E	*	EX[3]	**V
65	91-12-04	11:59	62.73N	34.42E	*	EX	JK*
66	91-12-04	12:02	62.93N	28.00E	*	EX[1]	JKV
67	91-12-04	13:18	64.35N	28.16E	*	EX[7]	JKV
68	91-12-04	16:40	66.95N	22.24E	*	EX	JKV
69	91-12-05	06:37	63.73N	22.76E	*	EX[3]	**V
70	91-12-05	10:49	61.58N	22.19E	*	EX	*KV
71	91-12-05	12:04	63.19N	28.14E	*	EX[1]	JKV
72	91-12-06	10:15	63.92N	31.19E	*	EX	JKV
73	91-12-06	10:37	64.44N	30.41E	3.2	EX[2]	JKV
74	91-12-06	11:47	58.72N	27.10E	*	EX	JKV
75	91-12-06	12:38	66.13N	14.36E	3.0	EQ	JKV
76	91-12-08	17.20	73.04N	19.06E	3.4	EQ	JKV
77	91-12-09	12:55	59.26N	17.34E	*	EX	*KV
78	91-12-09	13:10	57.85N	28.48E	*	EX	*KV
79	91-12-09	13:17	63.27N	27.91E	*	EX	*KV

Nro.	Date	Time	Latitude	Longitude	Magnitude	Expl. of Earhq.	Stations used
80	91-12-09	13:35	61.15N	24.15E	*	EQ?	**V
81	91-12-09	14:08	68.01N	26.37E	*	EX	*KV
82	91-12-10	09:15	59.62N	24.77E	*	EX	JKV
83	91-12-11	11:56	59.68N	26.47E	*	EX	*KV
84	91-12-11	12:01	58.75N	27.87E	*	EX	JKV
85	91-12-11	12:09	62.85N	24.02E	*	EX	*KV
86	91-12-11	16:01	61.68N	24.07E	*	EQ	JKV
87	91-12-12	13:47	67.03N	35.74E	*	EX	JKV
88	91-12-12	14:28	61.28N	29.28E	*	EX	JKV
89	91-12-15	15:19	60.58N	17.52E	*	EQ	JKV
90	91-12-16	15:35	62.17N	12.42E	3.2	EQ	JKV
91	91-12-17	12:53	68.15N	25.90E	*	EX	JKV
92	91-12-17	12:48	62.21N	27.98E	*	EX	JKV
93	91-12-18	14:50	60.39N	29.93E	*	EX	JK*
94	91-12-25	11:05	60.40N	31.08E	3.2	EX[2]	JKV
95	91-12-25	13:20	64.54N	29.45E	*	EX	JKV
96	91-12-25	14:26	61.17N	29.49E	*	EX	JKV
97	91-12-26	10:00	60.86N	29.72E	*	EX	JKV
98	91-12-26	12:04	60.61N	29.94E	*	EX	JKV
99	91-12-27	13:29	60.97N	29.45E	3.1	EX[4]	JKV
100	91-12-31	05:35	69:53N	5.42E	2.5	EQ	*KV
101	92-01-01	08:04	61.20N	15.49E	3.4	EQ	JKV
102	92-01-03	12:08	67.79N	28.01E	*	EX[1]	JKV
103	92-01-04	04:15	62.85N	16.73E	*	EQ	J*V
104	92-01-04	06:01	68.11N	16.46E	*	EQ	J*V
105	92-01-07	13:05	68.01N	22.98E	<2.0	EX	*KV
106	92-01-09	11:59	62.68N	27.96E	*	EX	JKV
107	92-01-09	14:04	62.94N	24.08E	*	EX	*KV
108	92-01-10	11:03	61.72N	30.93E	3.0	EX[2]	JKV
109	92-01-10	11:14	64.65N	28.30E	*	EX[1]	JKV
110	92-01-14	12:03	62.86N	28.01E	*	EX[1]	JKV
111	92-01-14	14:00	62.23N	29.27E	*	EX	*KV
112	92-01-22	10:01	60.65N	31.19E	3.2	EX[2]	JKV
113	92-01-22	18:58	64.54N	15.96E	3.0	EQ	JKV
114	92-01-24	10:19	67.82N	30.97E	3.0	EX[2]	JKV
115	92-01-24	11:01	64.79N	25.71E	*	EX	*KV
116	92-01-24	12:02	62.14N	25.53E	*	EX	*KV
117	92-01-24	12:13	58.54N	22.49E	<2.0	EX[3]	*KV
118	92-01-25	03:15	63.19N	27.40E	2.3ML	EQ	JKV
119	92-01-25	12:17	65.50N	16.70E	*	EQ	*KV
120	92-01-27	14:00	67.96N	29.33E	*	EX	JKV
121	92-01-30	12:02	61.34N	28.00E	*	EX[1]	JKV
122	92-01-31	10:00	63.12N	31.79E	~3.0	EX[2]	JKV
123	92-02-06	09:18	63.82N	30.27E	*	EX	JKV
124	92-02-07	12:12	61.01N	28.29E	*	EX[1]	JKV
125	92-02-07	12:30	63.16N	23.95E	*	EX	*KV
126	92-02-11	12:09	62.53N	27.98E	*	EX[1]	JKV
127	92-02-11	11:38	63.11N	30.15E	*	EX	*KV

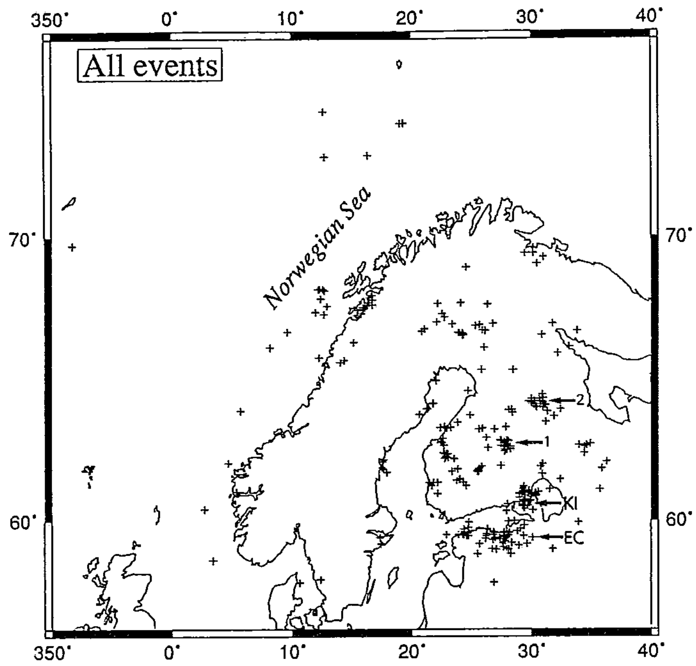

Fig. 3. The events detected and located using the recordings of the VAF station. The time interval of the events is from 6 November 1991 to 11 February 1992. "1" denotes the Siilinjärvi mine and "2" the Kostamuksha mine. The Karelian Isthmus (KI) and Estonian coast (EC) show also strong mining concentration.

4. Experiments in local seismic events using VAF, KAF and JOF readings

Some well located and identified mining sites with repetitious explosion activity are useful for assessing the location accuracies of these stations on a stand alone basis or as a group.

In Estonia and Russian Karelian Isthmus many mines and quarries are closely located, that is, their separation is of the same order as the accuracy in the epicenter determination. In such cases alternative approaches may be to introduce various types of wave form pattern analysis (*Joswig*, 1990; *Schulte* and *Joswig*, 1991; *Riviere-Barbiere* and *Grant*, 1991).

4.1 Siilinjärvi mining explosions in eastern Finland

In the Siilinjärvi mine the largest explosions are fired two or three times a week. The distance from the mine to KAF, JOF and VAF are 135, 177 and 260 kilometers respectively. A typical seismograms from an explosion in the Siilinjärvi mine is shown in Figure 4(a), while Figure 4(b) shows the epicenter locations estimated from the individual three station recordings. Locations achieved for VAF and JOF express the most stable location solutions, while those for KAF are scattered in SE-NW oriented vector.

The location errors of VAF are mainly due to the faulty distance of the station from the mine. Many different P- and S-phases arrive at this station with very short intervals and likely misreadings cause the eastward biased location errors, inasmuch changing the crustal model expressed by *Luosto* (1987) does not appreciably affect the location accuracy.

The locations achieved from JOF readings are concentrated in a small area. The distance values for JOF are correct. The azimuths in turn are clearly southward biased, causing the location errors.

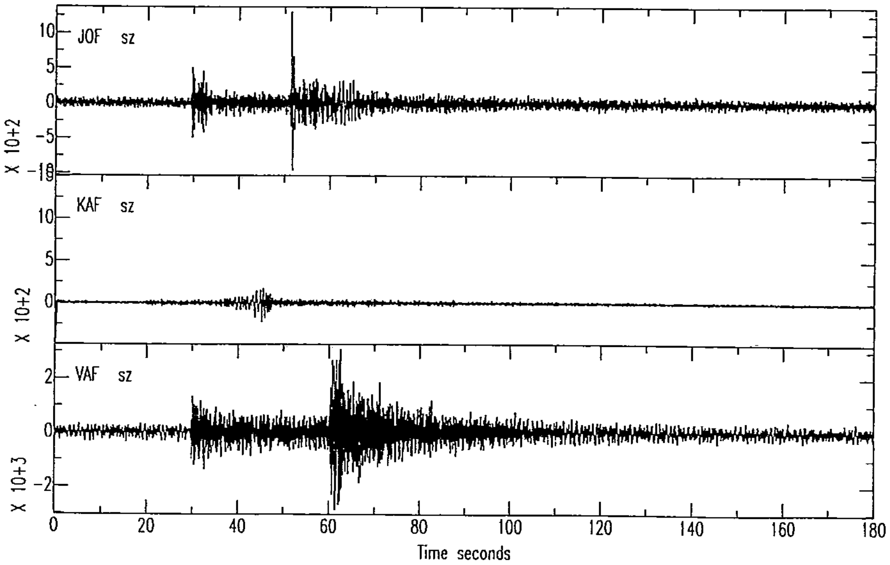

Fig. 4 (a). Seismic signal records from an explosion in the Siilinjärvi mine on the 18 November 1991. The signal is high-pass filtered lower cut-off at 1.5 Hz. The effect of lower signal sampling rate at KAF is cearly visible for high frequency signals from local and regional events. The P-wave is expectional weak.

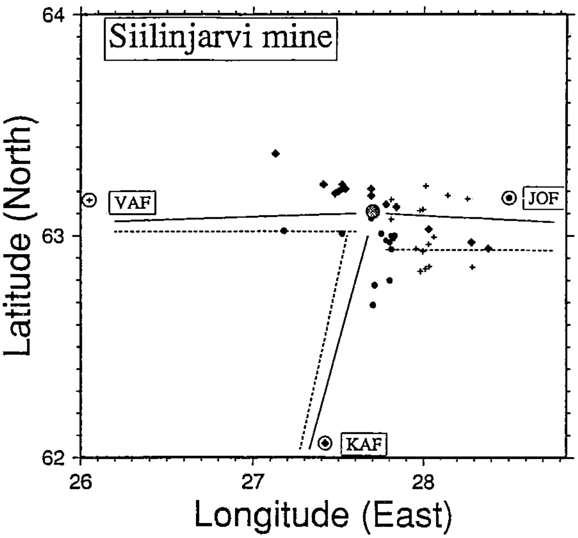

Fig. 4(b). Individual station locations of the Siilinjärvi explosions achieved from the recordings of VAF, KAF and JOF. The +'s and •'s present locations from VAF and JOF readings and ♦'s KAF readings respectively. The locations are biased towards South-East around the mine. The best groupings were achieved from VAF and JOF data. The solid line represents the correct direction from the station to the mine and the dashed line expresses the average direction azimuth computed from the records. The average distance errors at stations are: at VAF 9.6 km, at KAF 2.1 km and at JOF 0.6 km respectively.

4.2. Kostamuksha mine in Russian Karelia

The large open surface quarry Kostamuksha is located in the Russian Karelia. Strong ripple fired explosions there are characterized by emergent P-phases, being hard to detect at both VAF (Δ~450 km) and JOF (Δ~200 km).

In 3 months' time considered 9 explosions at Kostamuksha were detected and located. In Figure 5(a) strong explosion records are shown, while event locations achieved from VAF, KAF and JOF are presented in Figure 5(b). The location errors for VAF are dominantly due to too long distance estimates, which is mainly caused by erroneous phase pickings. The S-phases are partly masked by P-phase coda with the effect that the S-onset is picked too late. The station JOF, being closest to the mine, shows again well clustered locations, but too short and westward biased.

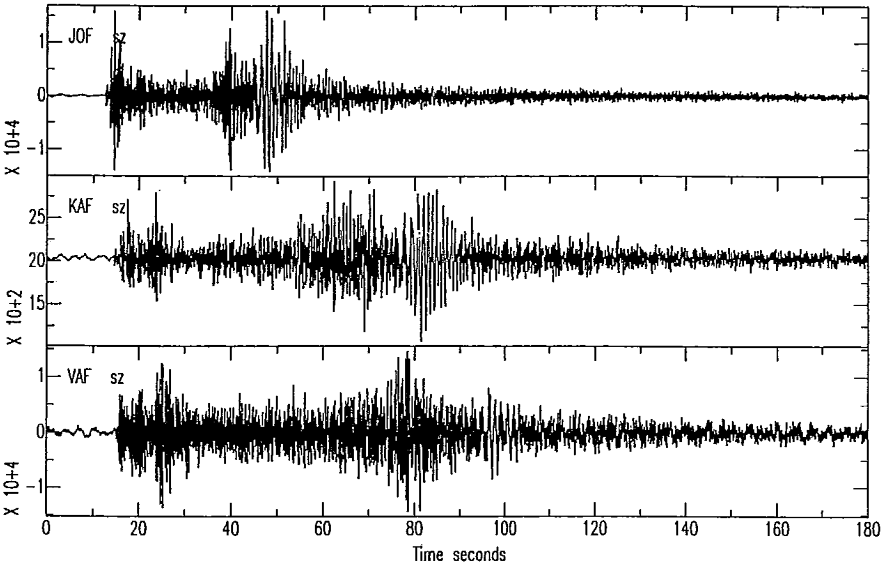

Fig. 5(a). A very strong explosion in Kostamuksha mine. For convenience the signals are shifted in order to ensure the same P-onset time.

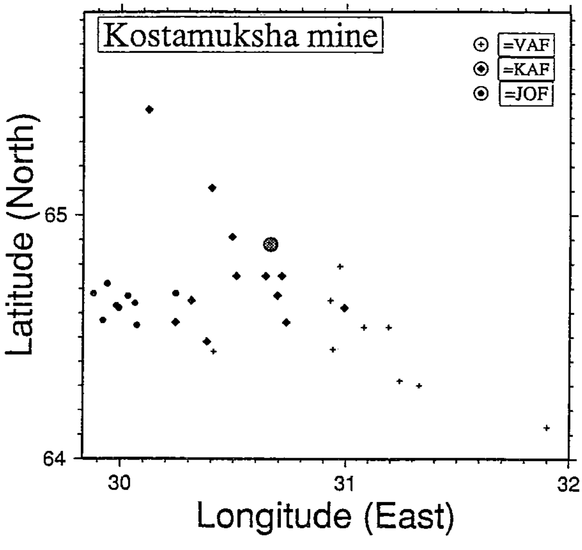

Fig. 5(b). Analyzed Kostamuksha mine explosions. The most stable location solutions were achieved from the JOF data, even though the locations are somewhat westward biased.

4.3. *Close spaced mines in the Russian Karelian Isthmus*

In Karelian Isthmus many mines and quarries are closely located. Owing to the short distance and frequent explosions, Finnish seismograph stations detect weekly numerous events in this area. Most of the mines are well located according to previous analysis. During the last few years also satellite data have been useful in improving the accuracy of the locations, details in Figure 6. Also 30 VAF event locations are included in the figure. Obviously any of the located event can be connected with almost any of the mining sites.

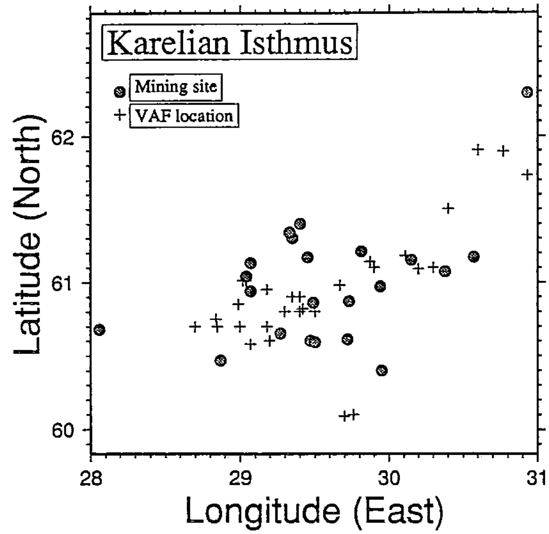

Fig. 6. The 21 identified mines in Karelian Isthmus together with 30 epicenters located using VAF data. Many of the locations might be "connected" almost to any of the mines. The location accuracy being the order of the spacing between different mines.

5. *Reanalyze of Fennoscandian earthquakes in 1991*

In Figure 7 the earthquake epicenters obtained from the *FINET* analysis in 1991 are reanalyzed using the VAF station readings only. The epicenters obtained via two different data sets (see Table 3 for details) coincide well with each other. The median of location deviations was 27 kilometers. The difference in latitude was 0.01° in longitude 0.16° respectively. In distances the median difference was 16 kilometers. The largest VAF location errors were found for the most distant events, which was expected, because azimuth errors scale with distance. The main error of location clearly is due to error in azimuth which is ±10°. The error in distance is found to be less than 5 % of the distance.

Table 3. Some reanalyzed Fennoscandian earthquakes which occurred in 1991. The results of FINET epicenter determinations are used as a reference.The deviation is computed from the epicentrum of VAF to the corresponding epicentrum achieved from FINET analysis. δΔ denotes distance error.

Date yy-mm-dd	Time hh-mm	Latitude	Longitude	Magnitude	δ Lat. degrees	δ Lon. degrees	δΔ kilometers
91-01-13	02:24	65.80N	5.50E	3.4	-1.45	0.25	12
91-01-19	18:50	66.20N	7.80E	3.1	0.88	1.83	47
91-02-13	21:53	65.80N	28.70E	1.8	0.75	-2.62	24
91-03-03	19:39	65.04N	24.40E	2.2	0.01	0.37	12
91-06-13	10:48	67.80N	19.60E	3.2	0.01	1.49	15
91-03-16	00:00	68.20N	10.90E	3.1	0.20	1.82	44
91-03-28	17:56	66.80N	7.40E	3.4	-0.23	0.78	40
91-03-30	13:00	71.00N	7.90W	4.3	1.23	0.34	19
91-04-13	21:20	69.30N	24.10E	2.5	-0.18	0.48	17
91-04-17	17:48	67.00N	24.60E	2.7	-0.04	-0.22	7
91-04-25	16:30	60.40N	2.20E	3.5	0.09	0.55	31
91-05-23	19:25	61.50N	25.00E	1.8	-0.07	-0.42	0
91-06-05	09:06	64.30N	20.80E	2.7	-0.09	-0.12	3
91-07-01	00:40	66.10N	11.80E	2.5	0.22	0.48	16
91-07-02	21:26	72.80N	13.50E	4.2	-0.48	-0.86	34
91-07-30	02:20	66.70N	33.00E	2.4	-0.13	0.16	0
91-08-22	18:04	67.70N	12.10E	3.3	0.05	0.59	23
91-08-24	10:57	65.70N	33.10E	4.0	0.66	-0.91	12
91-09-23	19:21	64.60N	21.40E	3.5	0.18	-0.13	7
91-09-23	20:54	64.40N	21.30E	2.0	0.02	0.08	2
91-09-25	23:28	64.40N	20.90E	2.4	0.02	0.35	14
91-10-05	06:20	64.42N	22.10E	1.9	0.20	0.25	25
91-11-08	22:08	65.24N	22.74E	2.2	0.19	0.69	24
Median:					0.01	0.16	16

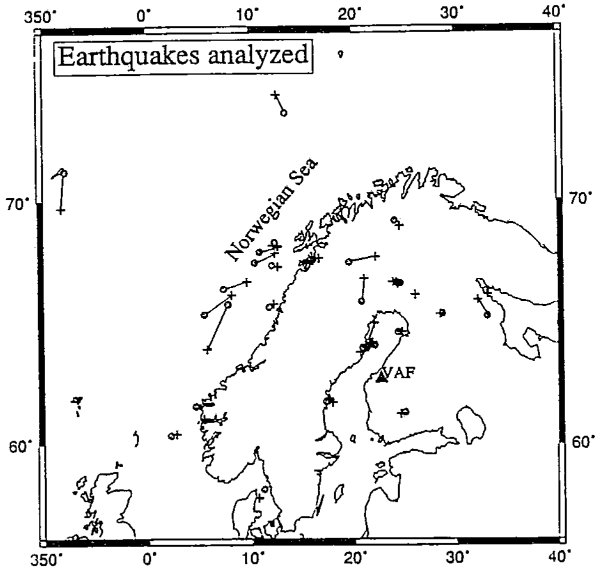

Fig. 7. Some Fennoscandian earthquakes which occurred in 1991. The hatched circles present the epicenters obtained from the Helsinki bulletins and the crosses are those obtained from VAF data. The most distant event analyzed in this study was an earthquake occurred near Jan Mayen on 30th March 1991 having a magnitude of 4.3.

6. *Discussion*

I have demonstrated a method how to detect and locate seismic events at local and regional distances. The operation was found to be fast and reliable for preliminary record screening and subsequent signal analysis and even for bulletin production. Its capability to locate epicenters is not much inferior to the results of an experienced analyst and network data. The ability to detect and identify P- and S-phases depends on the SNR of the event at a given station. When strong man-made explosions are analyzed, the later phases are occasionally masked by the P-wave coda.

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.

The main contribution of this study is the examination of known mining explosions in Finland and Russia. Some problematic errors occurred at distances approximately 260 kilometers. At those distances the mislocations was due to use of P_g-notation for the first arrival. Siilinjärvi mine locates 258 kilometers from VAF, so the first arrival may be analyzed as P_g or P_n. Also the distance estimations from Kostamuksha to VAF tended to be too long. This error probably is not due to the crustal model used, but the problematic S-phase readings (*Gomberg et al.*, 1990).

Location accuracy using epicenter locations, the Helsinki bulletins data showed some areal distribution. The greatest deviations were found at some "coded" mining sites, where the network locations were done according to some predefined criterion.

The configuration of the 3-C station network used in this study is not ideal. They form nearly a line from East to West, so the aperture of this triangle is not large enough if the stations are used as a group. To improve the parallel use of the 3-component stations a new station with 3-C registrations will be needed to North or South from the line JOF-VAF to give a larger network aperture.

7. *Concluding remarks*

The location method based on 3-component station is a new versatile tool for fast and robust location of seismic events. Older approaches, which are based on recordings from tripartite stations, small-aperture arrays and networks represent efficiently and exact locating schemes, but technical malfunctions (like telephone line breaks, thunder strikes, etc.) occasionally impair their operational efficiency. 3-component stations in turn are operated independently thus they are far less sensitive for this kind of operation failures.

The accuracy of 3-component station locations depends primarily on two factors. First, when signal-to-noise ratios are below 2, the accuracy is strongly reduced. Another source of errors is the misidentification of later phase. Strong P-phase coda sometimes distort the S-phase onsets. R_g-phases, which are an excellent diagnostic for shallow events or for structural mapping and attenuation studies (*Lokhstanov et al.*, 1991b), are seldom observed at Finnish seismograph stations beyond 100 km distances.

In general the locating procedure can comprise observations from one or more 3-component stations (*Cassidy et al.*, 1990; *Ruud* and *Husebye*, 1992). Based on the experience from this study multistation locations should give more accurate locations that reported here for individual stations.

The automatic detection and location procedure described here are convenient for producing a daily seismological bulletin.

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