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6.4 Analysis of infrasound data recorded at the Apatity array

6.4.1 Introduction

Kola Regional Seismological Centre (KRSC) of the Russian Academy of Sciences has for many years cooperated with NORSAR in the continuous monitoring of seismic events in North-West Russia and adjacent sea areas. This work has been based on a network of sensitive regional arrays which has been installed in northern Europe during the last decade in preparation for the global monitoring network under a comprehensive nuclear test ban treaty (CTBT).

As part of a project aimed at improving seismic and infrasound monitoring capabilities for the Arctic region, KRSC has installed a small-aperture infrasound array within the existing seismic array in Apatity. The Apatity infrasound array will in the future become an important complement to the planned infrasound array in northern Norway near the ARCES seismic array. This paper gives a brief description of the Apatity infrasound system and presents initial results from the infrasound array operation.

6.4.2 The Apatity seismic/infrasound array

Since 1996, Kola Regional Seismological Center (KRSC) has been engaged in infrasonic research and development. As part of this effort, a small-aperture microbarographic array was installed in conjunction with the seismic array near lake Imandra in the Kola Peninsula, with data digitized at the array site and transmitted in real time to a processing center in Apatity. A total of three infrasound sensors are installed in the innermost ring of the array, forming a triangle of approximately 500 m diameter. The sensors are differential microbarographs of model K-304-AM. The frequency range is 0.01-10Hz, and the sensitivity is 37.5 mV/Pa. The geometry of the combined seismic/infrasound array is shown in Fig. 6.4.1. Figure 6.4.2 shows the location of the Apatity and ARCES arrays, as well as some nearby mines from which explosion data have been analyzed in this study.

6.4.3 Data analysis

We have studied the background infrasonic noise level over extended periods (2-3 months), and have found, not unexpectedly, that the variation is considerable. During high-wind conditions the typical level is a factor of 100 (two orders of magnitude) greater than during quiet conditions. In the future, the performance during windy conditions could be improved by installation of additional noise-reducing porous hoses, and this will be considered. Figure 6.4.3 shows an example of noise (and signals) during 4 hours of "quiet" conditions. Infrasonic signals from four nearby mining explosions are clearly seen on these recordings. A combined view of the seismic and infrasound recordings from two of these explosions (both in Khibiny) are shown in Figure 6.4.4.

We have analyzed a number of infrasonic recordings of selected events in the Kola Peninsula and adjacent regions. Several large mines in this region generate explosions that are routinely detected by the seismic systems installed in northern Fennoscandia and NW Russia. Some of these explosions are also recorded by the infrasound sensors. We present analysis results from 19 such mining explosions, with a distance range from 38 to 220 km. The analysis includes frequency-wavenumber analysis of the array recordings, estimation of phase velocity and azimuth, and estimation of group velocity based on travel time calculations. We have analyzed 3-6 events from each of the following mines: Khibiny, Zapolarnyi, Kovdor and Olenegorsk (see Table 6.4.1 for details). We find that the azimuth estimates are quite stable, typically within a range of 5 degrees or less for events from the same mine. This is very satisfactory taking into account the small array aperture.

Another source of data has been a set of ammunition demolition explosions in Northern Finland, at a distance of 300 km from the array. In these cases, we have been able to identify three separate phase arrivals for each of the five analyzed events. Following the phase conventions used at the prototype IDC (Brown et. al., 2002, see also Armstrong, 1998 and Hagerty et. al.,2002), these phases are identified as the tropospheric arrival (Iw), the stratospheric arrival (Is) and the thermospheric arrival (It). An example illustrating these three phases for one of the explosions is shown in Figure 6.4.5. We note that the amplitudes of these phases are very different, and in fact (as can be seen from the table) the relative amplitudes of the phases vary also from one explosion to the next. Even the smallest phase (It) can be easily seen in an enlarged plot, as shown in Figure 6.4.6.

Figure 6.4.6 shows that the moveout of the signals are quite clear and the signal coherency is excellent. Similar features are seen for the other phases (although not shown here). As a result, reliable f-k analysis can be performed on each phase. Figure 6.4.7 illustrates the results of f-k analysis applied to the three phases for the event shown in Figure 6.4.5.

Table 6.4.2 shows details of the processing results for the entire set of Northern Finland explosions. Again, we find that the azimuth estimates from the (in this case) 15 total phases are very consistent, ranging from 278 to 288 degrees (true azimuth is 284 degrees). The observed group velocities (average travel velocities) range between 326-336 m/s for the Iw arrival, 300-305 m/s for the Is arrival and 244-254 m/s for the It arrival. The phase velocities (apparent velocities) range between 330-400 m/s, with the lowest values for the Iw phases and the highest values for the It phases. However, with this very small array (aperture only 500 m) the estimates of phase velocity are not quite stable enough to provide a confident indication of the phase type.

6.4.4 Future plans

We note that the detection of infrasonic phases is very dependent on the background atmospheric conditions, and that such phases are usually observed only during relatively quiet wind conditions. Our future plans include the installation of additional noise-reducing porous hoses to improve the detectability during windy conditions. After the projected infrasonic array in Karasjok, northern Norway, is installed, we plan to carry out joint processing of data from these two arrays. Further perspectives include cooperation with colleagues in Sweden, the Netherlands and Germany for more extensive joint processing.

An important task which we have not yet addressed is the development of an infrasonic real time signal detector. Several such detectors are available at various institutions, and we intend to build on this experience when designing the detector. Among the topics to be considered are which detection algorithm to select (e.g. Fisher detector, correlation detector, STA/LTA). We also need to find one or more filter bands for optimum processing, and define time windows for processing and f-k analysis.

The detector output will be similar to what is produced today for the seismic detectors. A phase association procedure will be implemented, attempting to associate the detected phases to seismic events detected by the regional network (Generalized Beamforming algorithm). We expect to have a number of unassociated detections, (i.e. detections by infrasound data only), and it will be a challenging task to associate these detections so as to define new events.

Finally, it will be important to establish an interactive analysis tool and integrate the analysis with that currently done for the seismic data. Our preliminary aim is to augment the existing NORSAR regional seismic bulletin (analyst reviewed) with infrasound observations.

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References

Armstrong, W.T. (1998), Comparison of infrasound correlation over different array baseline, Proc. 20th Annual Seismic Research Symposium, September 21-23, 1998.

Brown, D.J., C.N. Katz, R. Le Bras, M.P. Flanagan, J. Wang and A.K. Gault (2002): Infrasonic Signal Detection and Source Location ant the Prototype International Data Center, PAGEOPH 159, 1081-1126

Hagerty, M.T., Won-Young Kim and P. Martysevich (2002) Infrasound detection of large mining blasts in Kazakhstan, PAGEOPH 159, 1063-1079.

Table 6.4.1 List of 19 mining explosions from four separate mines analyzed in this study.

Location		Date 2002	Explo-sion time	Acoustic phase/arrival	Travel time, s	Dis-tance km	Gr. vel m/s	App. vel. m/s	Azi-muth, degrees	Amplitude, counts			Wind m/s	Wind dir. deg
68.06	33.16	07.06	11.49.53	Iw/11.52.21	148	51.3	347	350	6	1200	11340	7570	4	SE 160
68.06	33.16	12.07	11.03.34	Iw/11.06.08	154	51.3	333	334	6	34100	28500	17300	1	E 90
68.08	33.38	05.06	09.45.12	Iw/09.47.59	167	55.4	332	340	15	44100	48580	42450	2	SE 150
68.08	33.38	20.06	07.53.04	Iw/07.55.45	161	55.4	344	350	18	33500	21400	15200	2	N 360
68.08	33.38	26.06	08.42.28	Iw/08.45.13	165	55.4	336	335	14	2360	1200	950	3	W 280
68.15	33.20	11.07	12.30.18	Iw/12.33.21	183	61.4	336	350	6	15580	13680	10900	1	SE 130
67.62	33.90	14.05	11.54.53	Iw/11.56.47	114	38.4	336	337	85	417**	321**	253**	3	S 180
67.62	33.90	13.07	11.33.09	Iw/11.35.00	111	38.4	346	350	86	560	580	350	2	Sw 240
67.62	33.90	19.07	11.51.26	Iw/11.53.15	109	38.4	352	354	86	5120	5200	4590	4	SE 150
67.62	33.90	11.09	11.40.17	Iw/11.42.15	118	38.4	325	341	91	9650	8700	5960	3	Nw 340
67.62	33.93	13.09	11.41.52	Iw/11.43.55	123	39.7	323	337	86	1225	940	800	2	S 170
67.62	33.90	20.09	11.52.27	Iw/11.54.22	115	38.4	334	333	90	2621	1690	1500	3	NE 30
69.40	30.69	24.04	11.27.43	Is/11.40.12	749	220.6	295	342	338	2170	1570	1632	2	SE 160
69.40	30.69	24.04	11.34.38	Is/11.47.18	760	220.6	290	334	337	2615*	1890*	1518*	2	SE 160
69.40	30.69	30.10	12.07.06	Is/12.20.14	788	220.6	280	379	334	2450	1560	1690	2	Nw 330
69.40	30.69	01.11	12.10.48	Is/12.23.27	759	220.6	290	338	336	7400	5950	5000	3	N 350
67.56	30.43	20.07	10.18.15	Iw/10.24.04	351	109	311	334	268	5120	5200	4590	4	SE 160
67.56	30.43	28.09	10.51.38	Iw/10.57.17	339	109	322	340	273	2950*	2820*	2700*	3	S 180
67.56	30.43	12.10	10.09.17	Iw/10.14.48	331	109	329	334	272	560**	515**	521**	1	Nw 300

*) - filtered in 1-4 Hz band, **) - filtered in 2-6 Hz band. Is phases are marked with green color.

Table 6.4.2 List of 5 explosions from the ammunition demolition site in northern Finland analyzed in this study. Note that three infrasonic phases have been detected for each explosion.

Location		Date 2002	Explo-sion time	Acoustic phase / arrival	Travel time, s	Dist. km	Gr.. vel. m/s	App. vel. m/s	Azi-muth, degrees	Amplitude, counts			Wind m/s	Wind dir. deg.
Lat.	Lon									Bar1	Bar2	Bar3		
68.00	25.96	04.09	12.59.58	Iw/13.14.46	888	298	336	348	281	44800	33000	38300	2	Nw 300
			s-signal	Is/13.16.18	980		304	357	282	2000	1530	1850		
			t-signal	It/13.19.33	1175		254	390	286	2850	2500	2100		
68.00	25.96	05.09	13.30.00	Iw/13.44.44	884	298	337	360	281	4100	3600	3700	2	Sw 220
			s-signal	Is/13.46.16	976		305	365	284	6350	5200	5600		
			t-signal	It/13.49.50	1190		250	404	283	1500	1250	1300		
68.00	25.96	07.09	13.00.00	Iw/13.15.15	915	298	326	335	279	43450	35000	39800	3	N 360
			s-signal	Is/13.16.20	980		304	365	283	7000	6400	6800		
			t-signal	It/13.20.20	1220		244	399	288	1630	1310	1370		
68.00	25.96	08.09	13.30.05	Iw/13.45.02	897	298	332	350	281	29550	20900	23350	3	Nw 310
			s-signal	Is/13.46.22	977		305	357	282	11600	8800	11100		
			t-signal	It/13.50.02	1197		248	372	286	2750	2070	2260		
68.00	25.96	09.09	12.00.02	Iw/12.14.48	886	298	336	343	278	13170	10680	10700	3	Sw 210
			s-signal	Is/12.16.34	992		300	342	280	7350	5320	5480		
			t-signal	It/12.19.46	1184		251	364	285	670	490	470		

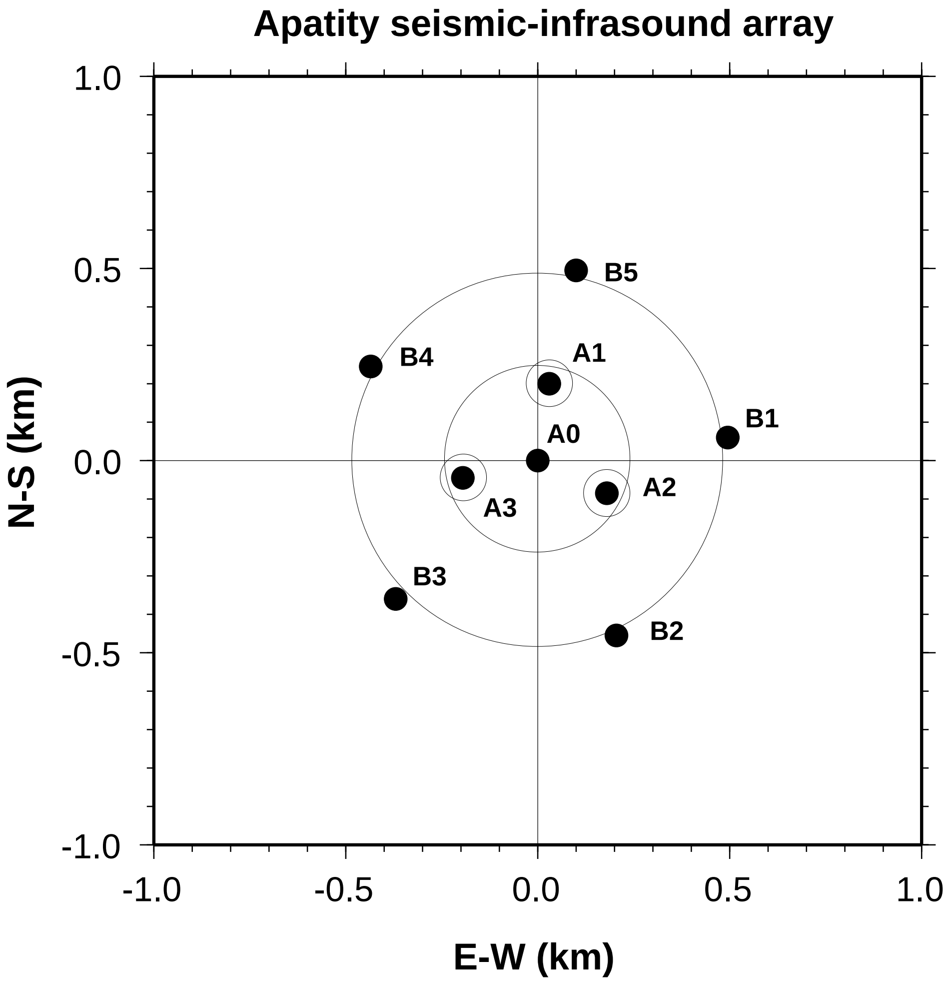

Fig. 6.4.1. Configuration of the Apatity seismic-infrasound array. Seismometers are shown as filled circles, with the location of the three infrasonic sensors (A1, A2 and A3) marked as small circles. The two concentric circles have diameter of 500m and 1000m respectively.

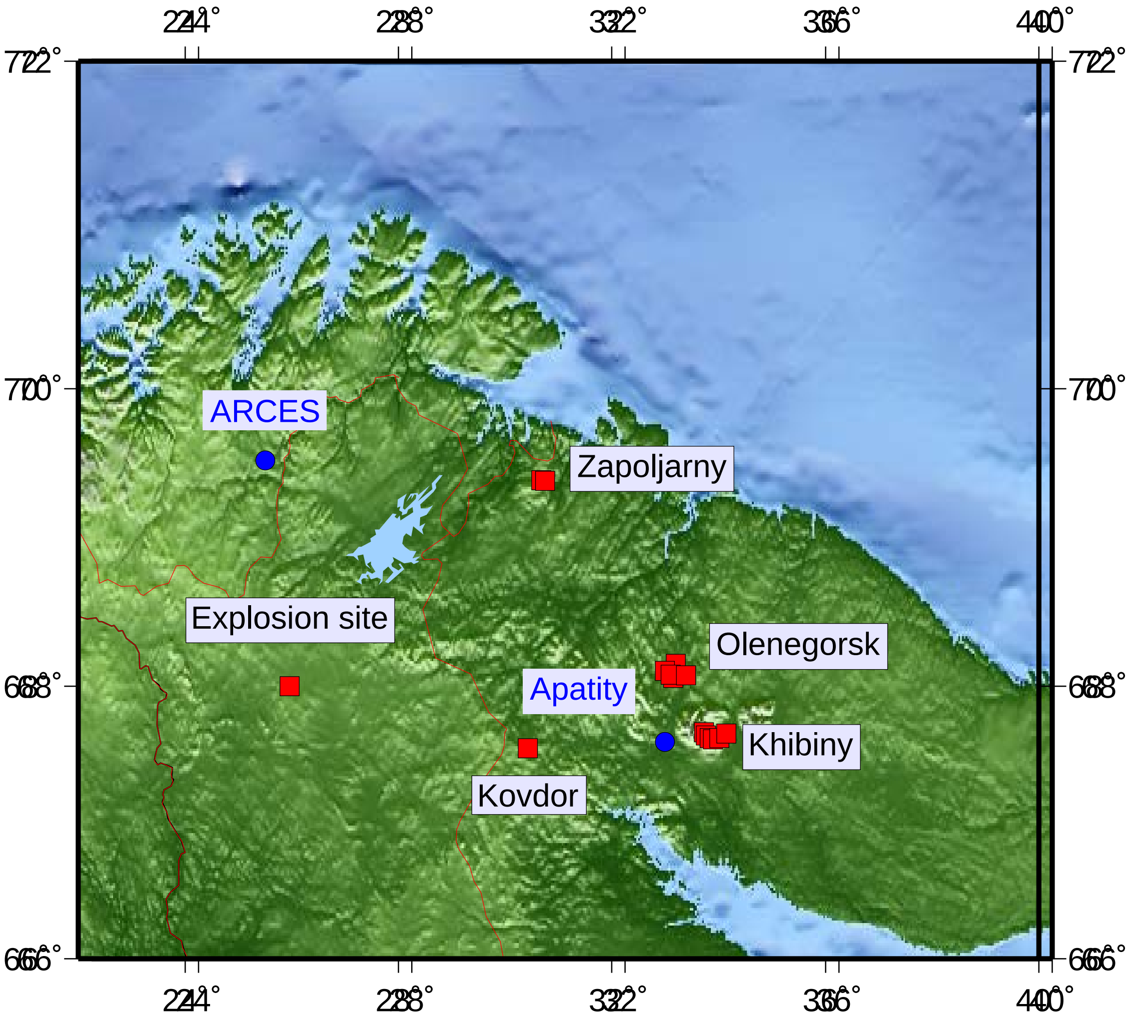

Fig. 6.4.2. Map showing the location of the Apatity and ARCES arrays (marked as blue), together with selected mines and the northern Finland site for ammunition demolotion (red squares).

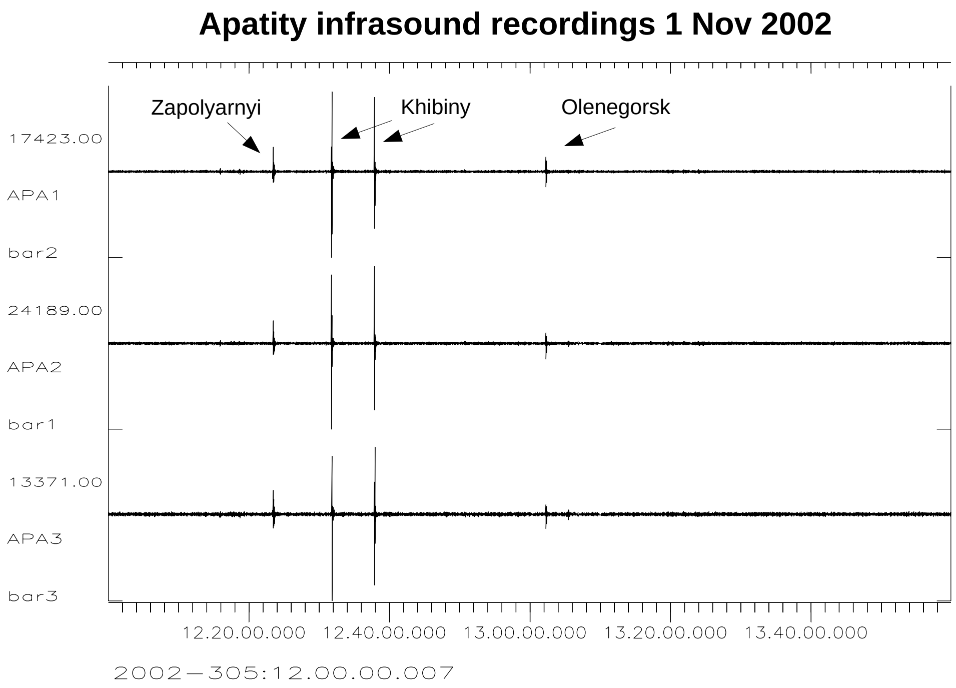

Fig. 6.4.3. Example of infrasound recordings at Apatity for a 4-hour interval on 1 November 2002. Infrasound signals from four mining explosions are marked.

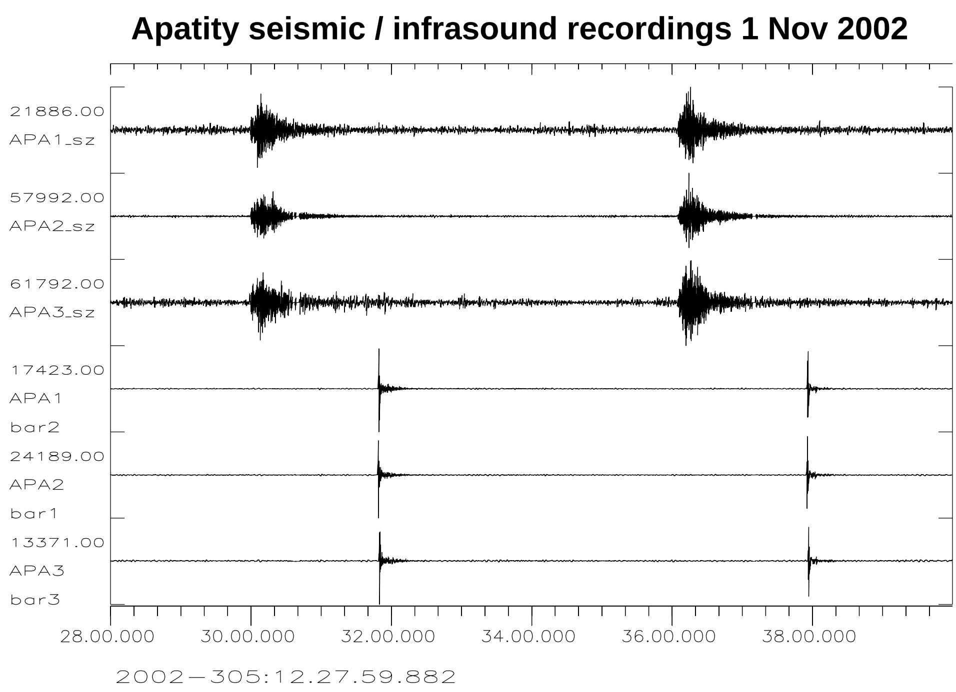

Fig. 6.4.4. Seismic and infrasound data for the two Khibiny explosions shown in Figure 6.4.3.

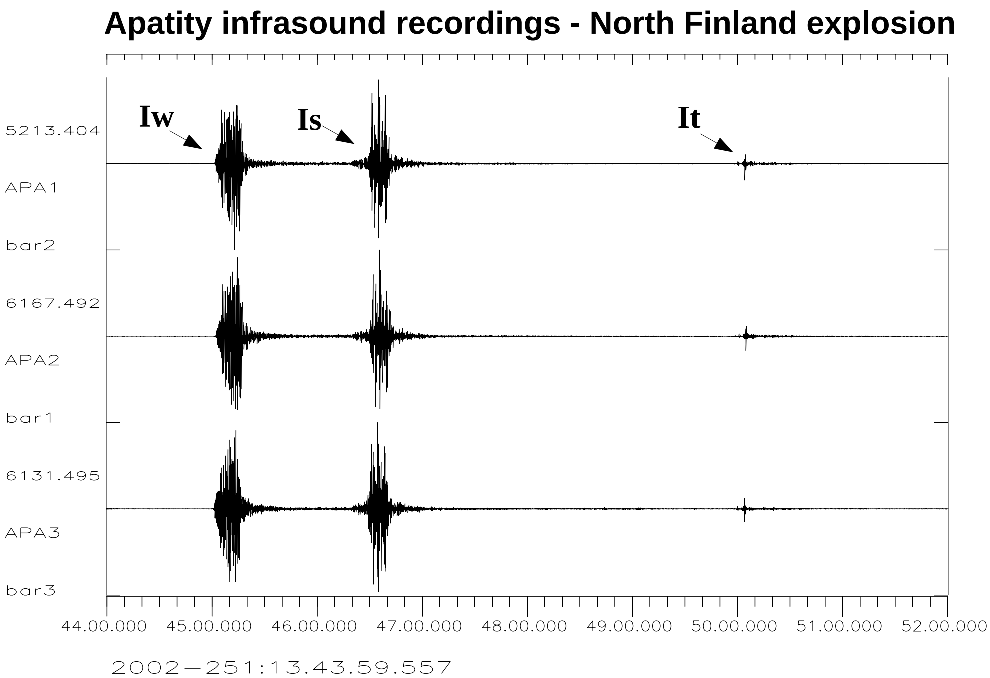

Fig. 6.4.5. Infrasound recordings of an ammunition demolition explosion in northern Finland at 300 km distance. Data are filtered 2-6 Hz. Three distinct infrasonic phases are indicated.

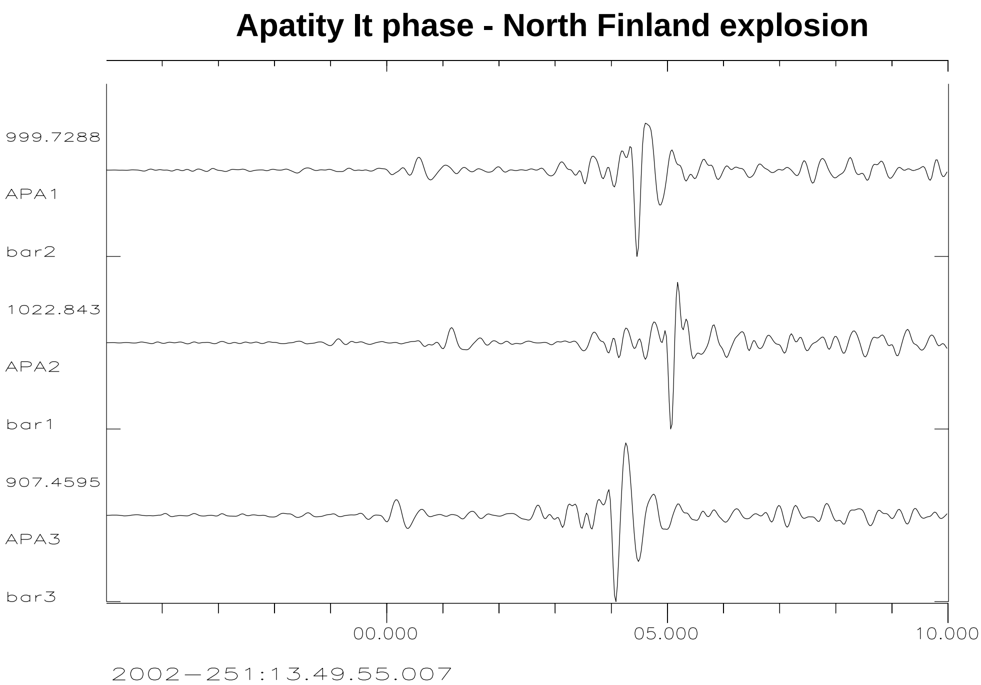

Fig. 6.4.6. Enlarged plot of the third (It) phase shown in Figure 6.4.5. Note the clear moveout as well as the good signal coherency. The It phase appears to have two distinct arrivals.

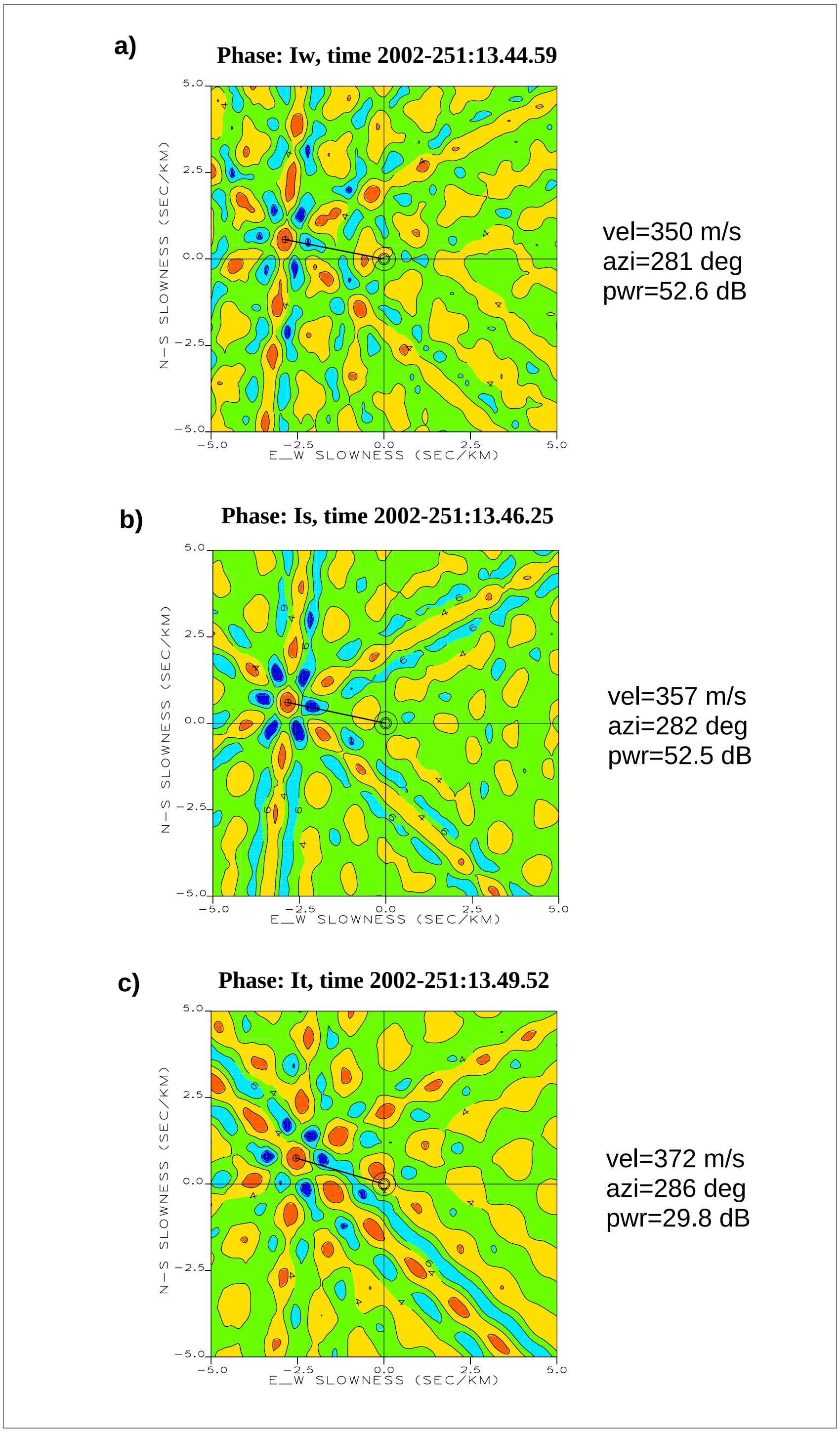

Fig. 6.4.7. F-K analysis results of the three phases shown in Fig. 6.4.5.