INFRASOUND DETECTION OF LARGE MINING BLASTS IN KAZAKSTAN

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ABSTRACT

Since October, 1997, we have recorded infrasound signals at Kurchatov, Kazakstan, from large mining blasts in Kazakstan and the Altay-Sayan region, Siberia. Kurchatov is an ideal site for research on infrasound and application of synergistic (seismic and acoustic) methods of event discrimination. This is because it operates a 21-element short-period seismic array and a three-component broadband seismographic station and because of its close proximity to large (100+ ton) mining operations.

Several large mines in the region routinely carry out large explosions that are detected seismically and with infrasound. The mines range in distance from 80 to 750 km from the infrasound array. The Ekibastuz mine, 250 km west of the array, regularly produces 4-6 seismic detections per day. The corresponding number of infrasound detections is found to be dependent upon the season and the local winds. During the winter months, when the direction of the zonal component of the stratospheric wind is from west to east, a strong stratospheric duct develops between Ekibastuz and Kurchatov and the number of infrasound detections is high. During this period the infrasound signal consists of two arrivals separated by about 60 s. A preliminary interpretation of these signals is that the first arrival at 250 km distance propagates through the troposphere and is followed 60 s later by a stratospheric arrival. During the summer months, when the zonal winds reverse direction, the number of infrasound detections is low.

In March 1999, we installed a three-element infrasound array with about 2-km sensor spacing at Kurchatov. Two of the elements consist of Globe microphones connected to noise-reduction hose and pipe arrays, while the third is actually a small array comprised of several Soviet-built, low-frequency microphones (K-301A) connected to various noise-reducing pipe configurations. In the winter of 2000, we also installed a three-element infrasound array with about 2-km sensor spacing at Borovoye, northern Kazakstan. We have compiled infrasound signals from mine blasts since 1999 at these sites in Kazakstan in order to understand the character of infrasound signals produced by regional mine blasts and the nature of infrasound propagation at high latitudes. We are currently analyzing signals from 1999 recorded by the new large arrays. Preliminary analysis of signals recorded during spring, 1999, by the larger aperture array suggests that the larger array results in improved infrasound detection of Ekibastuz mine blasts and improved discrimination of non-acoustic noise. The data from the new large aperture arrays also confirms identification of infrasound signals believed to be produced by events in the Kuzbass mining region of Siberia, over 700 km away from Kurchatov.

KEY WORDS: infrasound, mining blast, Kazakstan

OBJECTIVE

The goal is to improve event location and screening for CTBT monitoring by using infrasound and seismic methods. To achieve this goal, we carry out ground-truth calibration studies in northern Kazakstan and southwestern Siberia, and quantify seasonal variations in infrasound characteristics at high latitudes.

RESEARCH ACCOMPLISHED

Installation of Kurchatov Infrasound System

Since October, 1997, we have conducted infrasound observations at the Kurchatov Geophysical Observatory in Kazakstan using available microphones coupled with existing noise reduction systems in order to address some of the infrasound monitoring issues outlined above. The Kurchatov Observatory (Figure 1) is an ideal site for research on infrasound and on the application of synergistic (seismic and acoustic) methods of event discrimination as it operates both a 21-element short-period seismic cross-array (Figure 2) and a three-component broadband seismic station, and because of its close proximity to several large (100+ ton) mining operations (Figure 1). In addition, conditions appear to be favorable for long-range infrasound propagation in Kazakstan, where infrasound signals have been detected out to 2,000 km distance [Al'Perovich et al., 1985].

A large aperture infrasound array with three elements is constructed in the spring of 1999 at the Kurchatov Geophysical Observatory. The infrasound noise reduction configuration utilized at each element of the large aperture array consists of six, 70 m long underground pipes extending radially from a central chamber and referred to as "spider" (Figure 2). There are two spiders at the central recording site, Ch26 and Ch27, in Figure 2. We presume that this system, which was constructed during the Soviet era, was designed to be functional during the severe local winters, when snow covers the ground for five months each year and prohibits the use of conventional plastic hoses. Two types of capacitor microphone - Globe and Soviet K301 - have been utilized with the pipe arrays described above. The K301s were originally installed at Kurchatov in the early 1970's by the Russian Ministry of Defense and recorded on paper. Since February, 1995, the analog signal from a K301 sensor has been digitized and recorded by a 16-bit A/D system together with the seismic channels from the cross array. Since spring of 1999, 1–2 microphones connected to the spider noise reduction system have been simultaneously recorded, forming a large aperture acoustic array.

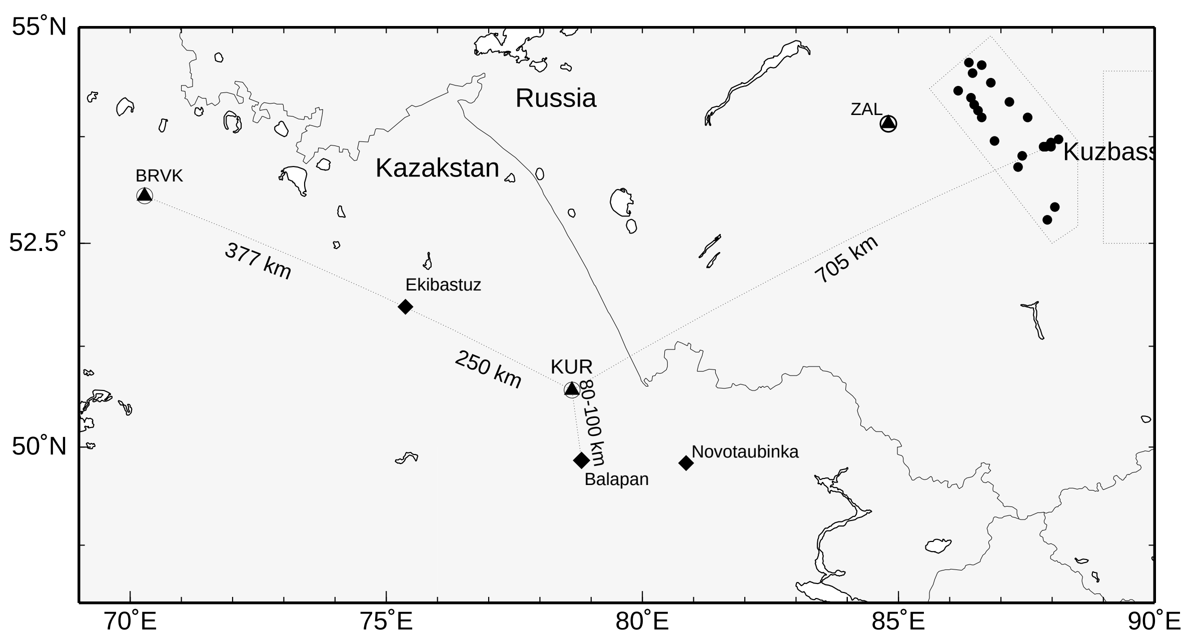

Figure 1. Map of Kazakstan and southwestern Siberia showing locations of broadband seismic stations (solid traingles), active mining areas (diamonds), Kuzbass and Abakan mining areas, and the Kurchatov Geophysical Observatory (KUR), where the seismic and infrasonic observations were made.

Spring 1999 Large Array Observations

Preliminary analysis of signals recorded since spring, 1999, by the large aperture acoustic array indicate an improved ability to detect mine events and to reject non-acoustic "noise" compared with use of the small array alone. An example one-hour window of data recorded during peak mining hours (07:00-10:00 GMT) is shown

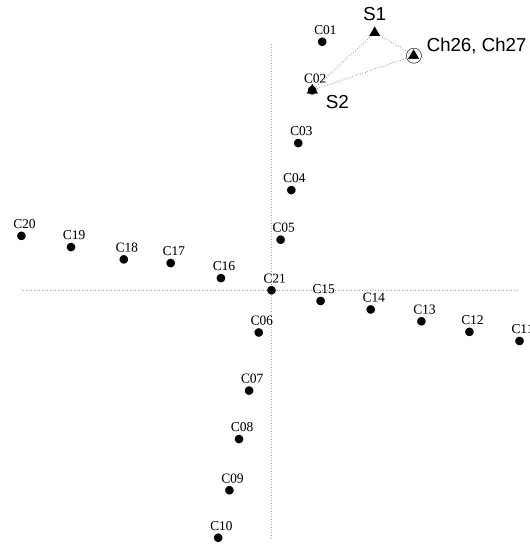

Figure 2. Plan view of the 21-element seismic borehole array (cross array) at Kurchatov and locations of the infrasound array elements (S1, S2 and Ch26). Notice that the spacing between the seismic array element is constant and 2.25 km.

in Figure 3. During this hour we are able to identify 7 Ekibastuz events in the seismic channels; for all but one of these we can also identify associated infrasound signals. The first infrasound arrival for each event has a travel time of 760 s and is followed 90 s later by a second arrival that consists of two pulses separated by 10 s. The estimated back-azimuth for these arrivals is 302°, close to the expected value. The character of the infrasound arrivals is so regular on this day, that we are able to identify two Ekibastuz events (one of these is indicated by the "?" in Figure 3), for which no seismic detection was made, solely on the basis of the infrasound detections. During this period we are also able to identify infrasound signals generated by mine explosions near the Kuzbass region in Siberia (Figure 1), over 700 km away. Example data from the large-aperture infrasound array for the infrasound records (band-passed) and corresponding spectrograms of Ekibastuz explosions and for infrasound arrivals from a Kuzbass event is shown in Figure 4. Note that since August, 1998, we have operated a broadband seismometer near the town of Eltsovka, close to the Kuzbass region, in order to aid identification of Kuzbass events.

Ekibastuz comprises a number of coal mines centered about (51.67N, 75.40E) as determined by satellite photographs [Thurber et al., 1990]. The infrasound wavetrain generated by Ekibastuz explosions can be classified into two categories. The first, shown in Figure 5, consists of 1 or 2 simple pulses, with travel times of approximately 740 and 810 s with respect to the seismically estimated origin time. The second arrival is observed in about 60% of the events from Ekibastuz; when present, it generally follows the first by 50-70 s, though this can range anywhere from 24 to 85 s (see Figure 5). The travel time of the first arrival exhibits great variation and probably reflects varying atmospheric conditions such as transient propagation ducts. The second type of infrasonic wavetrain associated with Ekibastuz events consists of a series of pulses of growing amplitude lasting some 20–30 s. There is no evidence for multiple cast firing within these blasts, hence, the multiple phases observed in the infrasound data must be produced by propagation effects. We applied a beamforming procedure to the acoustic traces shown in Figure 5 to estimate the apparent phase velocity (0.23 km/s) and back-azimuth (304°). The estimated back-azimuth is 7°off that predicted from the seismic location (297°) (see Figure 6).

Table 1: **Large Mining Blasts in Kuzbass and Abakan Region with Groundtruth Data**

Date year-mo-dd	Time (hh:mm:sec)	Lat (°N)	Long (°E)	K	Yield (ton)	name
1999-07-07	08:54:02.9	53.65	87.82	8.7	473	Mezhdurechinsk
1999-07-10	09:51:31.8	53.73	91.03	9.4	297	Chernogorsky
1999-07-14	07:29:27.0	53.66	87.84	9.5	430	Sibirginsky
1999-07-23	08:04:13.6	53.72	87.82	8.8	209	Sibirginsky
1999-08-11	08:06:33.3	53.62	87.85	9.5	550	Sibirginsky
1999-08-18	07:32:48.6	53.71	87.79	8.8	203	Mezhdurechinsk
1999-08-18	08:46:48.0	53.73	91.01	9.0	138	Chernogorsky
1999-08-20	08:20:34.6	53.74	87.88	8.6	222	Mezhdurechinsk
1999-09-01	07:31:14.3	53.69	87.88	8.2	173	Krasnogorsk
1999-09-03	08:37:16.6	53.77	91.02	9.9	378	Chernogorsky
1999-09-10	07:16:14.5	53.64	87.79	9.0	278	Mezhdurechinsk
1999-09-10	07:21:00.1	53.62	87.80	8.8	241	Krasnogorsk
1999-10-18	08:57:31.3	53.67	87.81	9.4	231	Krasnogorsk
1999-10-19	06:49:08.6	53.74	87.92	8.6	335	Tomusinsky
1999-10-29	05:26:01.9	53.69	87.93	8.8	284	Krasnogorsk
1999-11-15	08:59:50.5	53.80	88.02	8.9	257	Sibirginsky
1999-11-23	09:47:19.7	53.70	87.90	8.2	403	Mezhdurechensk
1999-11-23	10:28:40.4	53.67	87.83	8.3	403	Mezhdurechensk
1999-11-24	09:58:29.6	53.67	87.98	8.5	107	Sibirginsky
1999-11-29	09:40:10.4	53.67	87.85	9.7	458	Sibirginsky
1999-12-07	09:01:20.3	53.64	87.86	8.9	235	Krasnogorsky
1999-12-10	08:33:09.0	53.70	87.79	9.1	109	Sibirginsky
1999-12-17	09:01:09.9	53.60	87.49	8.6	161	Krasnogorsky
1999-12-17	09:17:19.8	53.68	87.85	9.2	300	Mezhdurechensk
1999-12-17	09:41:55.8	53.61	87.71	8.6	300	Mezhdurechensk
1999-12-30	05:59:56.5	53.61	87.75	9.0	319	Krasnogorsky
1999-12-30	07:05:02.2	53.90	88.16	8.9	17	Olgerassky
2000-01-17	08:46:19.1	53.70	87.91	8.7	210	Krasnogorsky
2000-01-18	09:53:44.3	53.66	87.85	8.7	122	Sibirginsky
2000-01-20	08:46:45.9	53.61	87.73	8.8	419	Mezhdurechinsky
2000-02-11	08:46:23.1	53.84	88.18	9.2	144	Olzherassky
2000-04-14	06:14:57.0	53.84	88.16	8.8	114	Olzherassky

Ground Truth Data from Large Mining Blasts in Southwestern Siberia

The Kuzbass and Abakan region in southwestern Siberia, Russia are very unusual in being the site of blasting activity that includes numerous explotions which can be detected teleseismically (Figure 7). In terms of size of seismic signals, these may be the largest routinely conducted blasting operations in Eurasia. This extensive mining region, which is close to the tectonically active Altay-Sayan, is also subject to frequent earthquakes. During July, 1999 – April, 2000, we obtained groundtruth data (date, location and total charge size) for several hundred large mining blasts in Kuzbass-Abakan region. 32 of these blasts are also located by Altay-Sayan Experimental and Methodical Seismological Expedition (ASEMSE), Siberian Branch of Russian Academy of Sciences in Novosibirsk, Russia from its local network which consists of about 15 stations with short-period seismometer (SKM) and analog recording. The events located by ASEMSE have location errors ranging from about less than 5 km to up to about 10 km (Table 1).

Table 2: **List of Mines in Kuzbass and Abakan region**

Id	Name	Type
a	Kolmogorovsky-1	open pit coal mine
b	Kolmogorovsky-2	open pit coal mine
c	Kiselevsk	includes Bachatsky, Krasnobrodsky & Novosergeevsky open pit coal mine
d	Taldinsky	open pit coal mine
e	Badaevsky	open pit coal mine
f	Oldgerasky	open pit coal mine
g	Mezhdurechensk	includes Mezhdurechensky, Tomusinsky, Krasnogorsky & Sibirginsky open pit coal mines
h	Kaltansky	open pit coal mine
i	Listvyansky	open pit coal mine
j	Tashtagol	open pit coal mine
k	Abakan-1	
l	Abakan-2	includes Chernogorsky and Izychsky open pit coal mines

CONCLUSIONS AND RECOMMENDATIONS

We have presented here an initial interpretation of the characteristics of infrasound propagation observed in northern Kazakstan and Siberia. During the winter, the infrasound signals associated with Ekibastuz events can be classified into two types. The first type consists of two pulses spaced 50–70 s apart, while the second type consists of multiple pulses arriving within about a 20–30 s window. Infrasound arrivals from both Ekibastuz (Δ=250 km) and Kara-Zhyra (Δ=80 km) explosions support the existence of a tropospheric duct, produced by a temperature inversion and/or a westerly jet in the troposphere. The multiple arrivals characteristic of the second type of infrasound wavetrains likely result from strong positive sound speed gradients in the troposphere and, especially, in the upper stratosphere. The large variability in the character of infrasound signals generated by Ekibastuz events over short time scales (hours to days) is indicative of the rapidity of atmospheric fluctuations.

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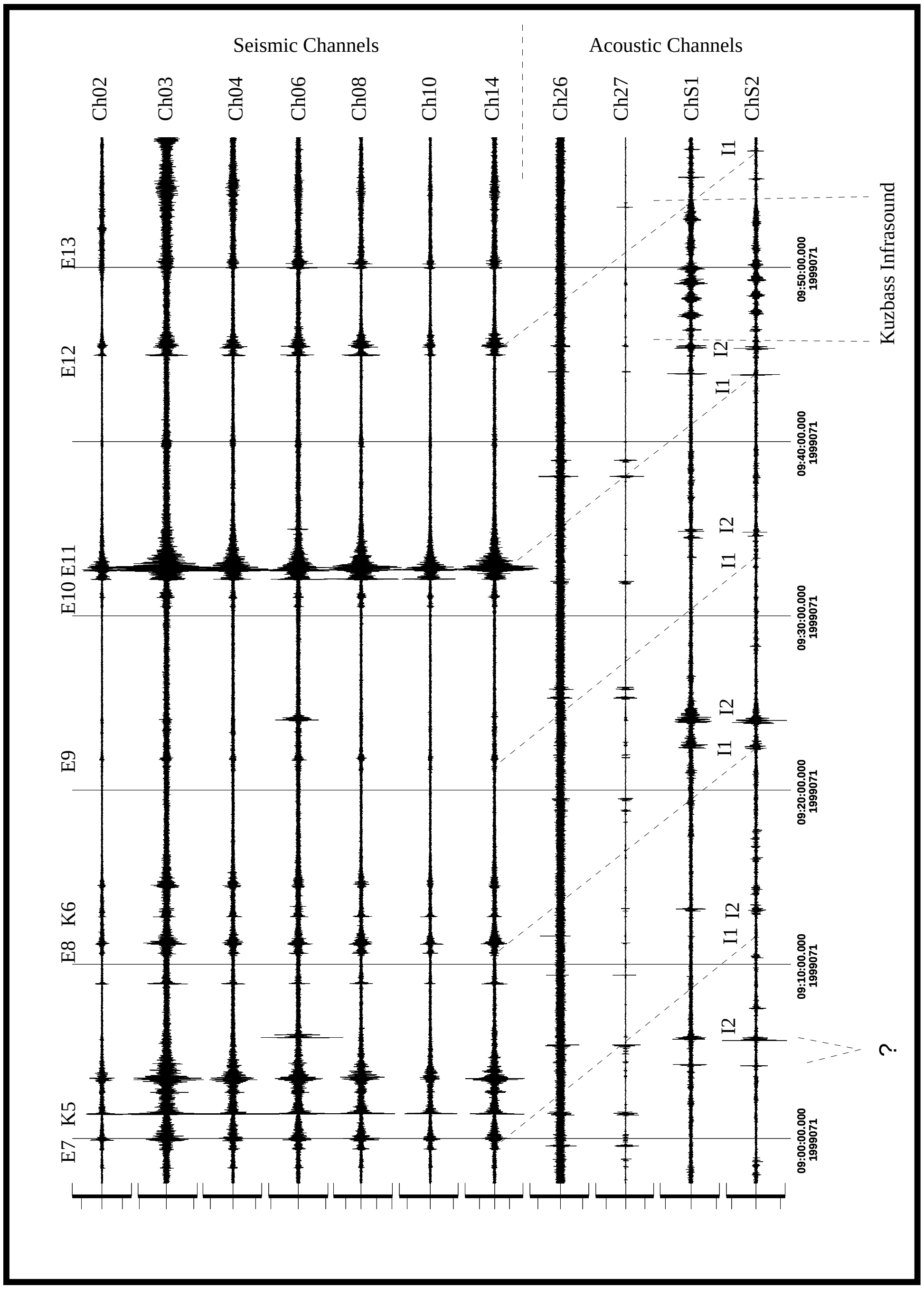

Figure 3. Example data from the Kurchatov seismic cross-array and acoustic triangle array for spring, 1999. During the one hour period shown are 7 Ekiabstuz events with associated infrasound arrivals, infrasound arrivals (?) believed to be produced by an Ekibastuz event that did not generate a seismic signal, and infrasound arrivals from a Kuzbass mine event, 700 km away.

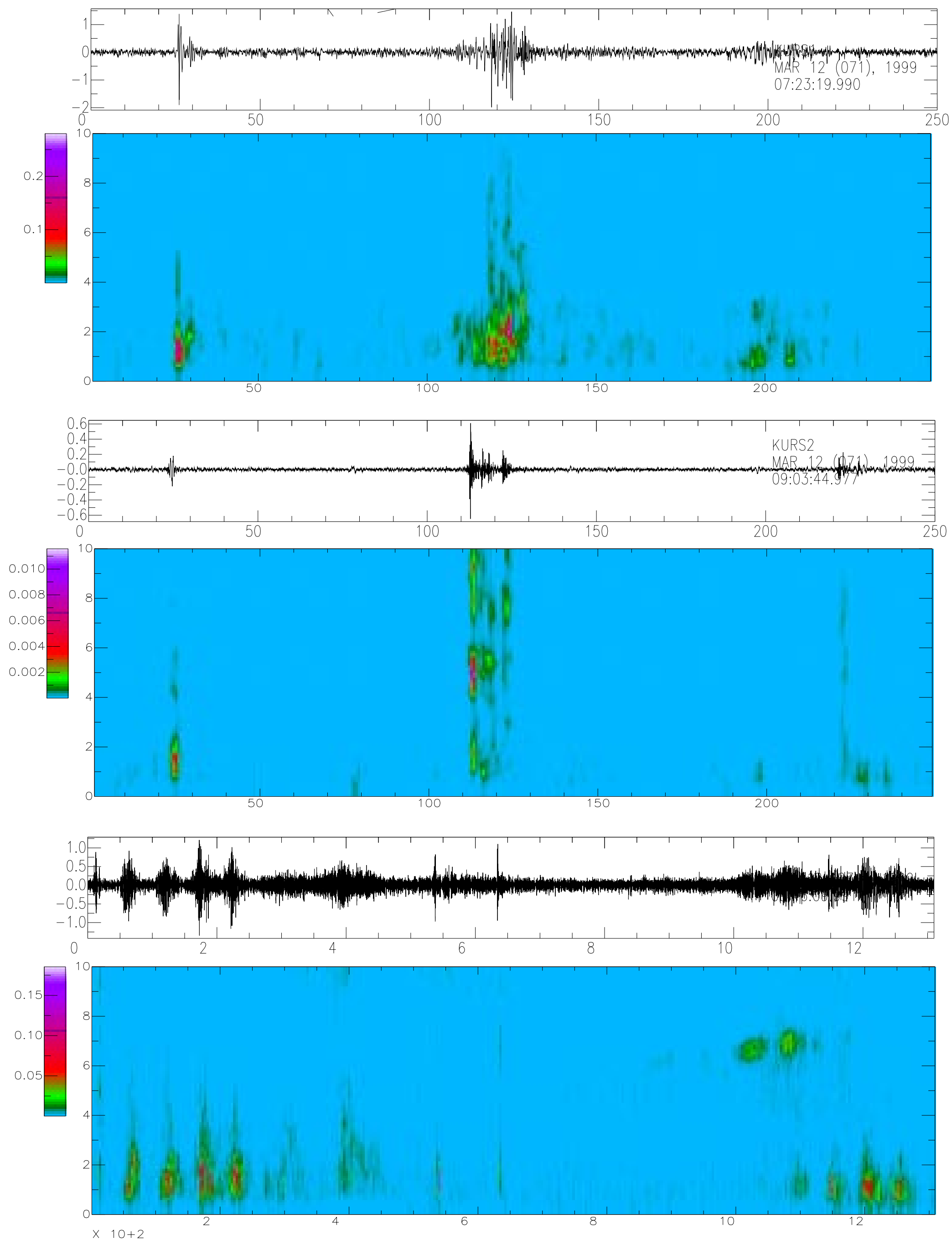

Figure 4. Example data from the large-aperture infrasound array for spring, 1999. Top panel: Infrasound record (band-passed) and corresponding spectrogram of an Ekibastuz explosion. Middle panel: Same for another Ekibastuz explosion. Bottom panel: Same for infrasound arrivals from a Kuzbass event. Note the larger time scale for the last event.

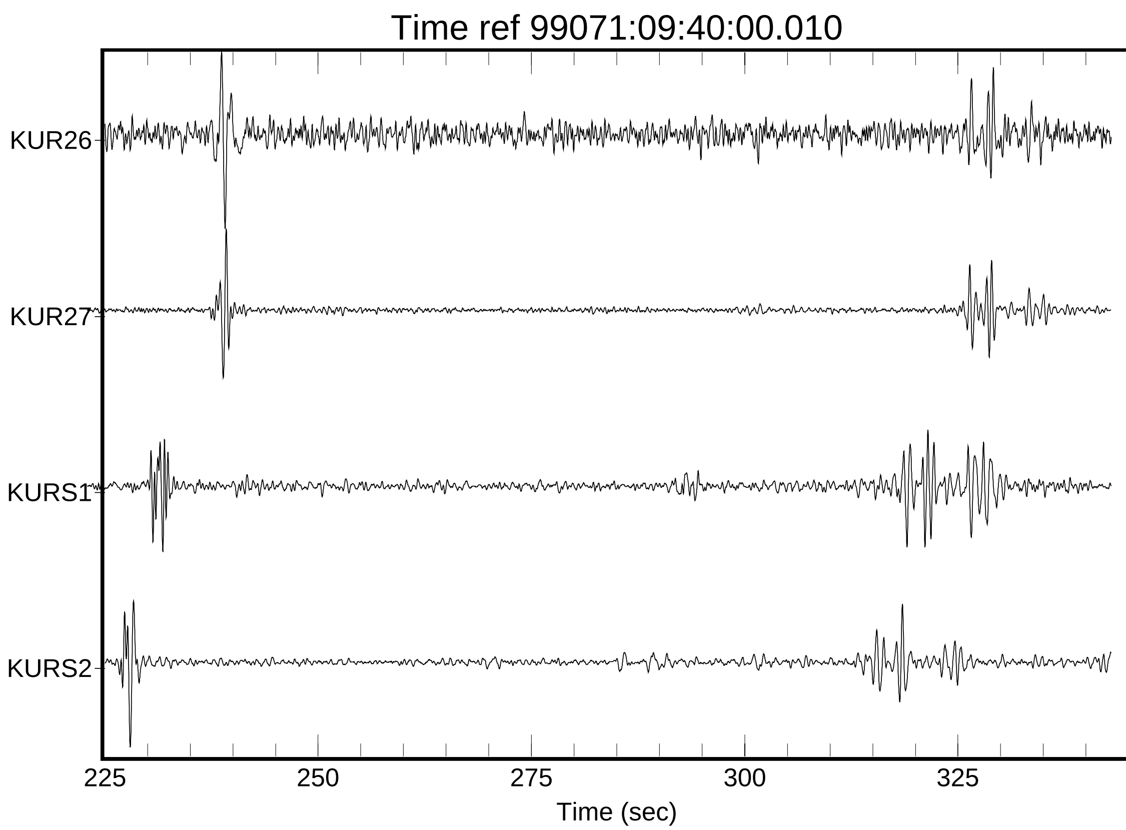

Figure 5. Infrasound signals from an Ekibastuz explosion on 03/12/1999 at 09:40. Notice the second arrivals about 85 s after the first arrivals.

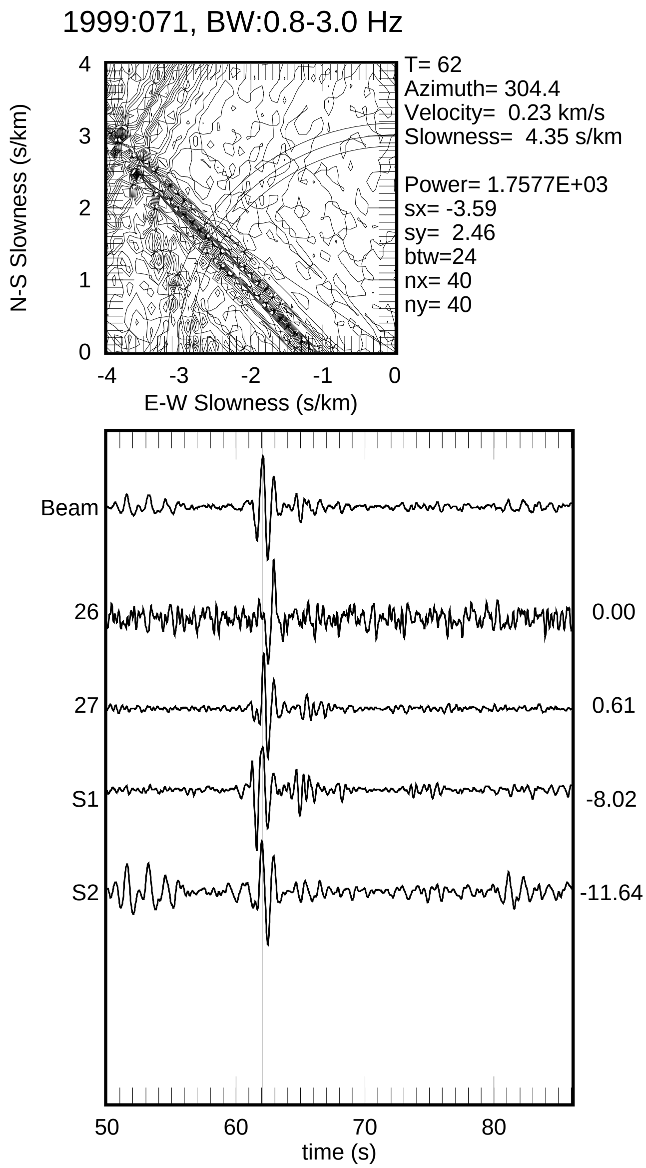

Figure 6. Beam forming of the infrasound signals from the Ekibastuz explosion on 03/12/1999 at 09:40 shown in Figure 5. Notice that the beam is calculated for the first arrivals.

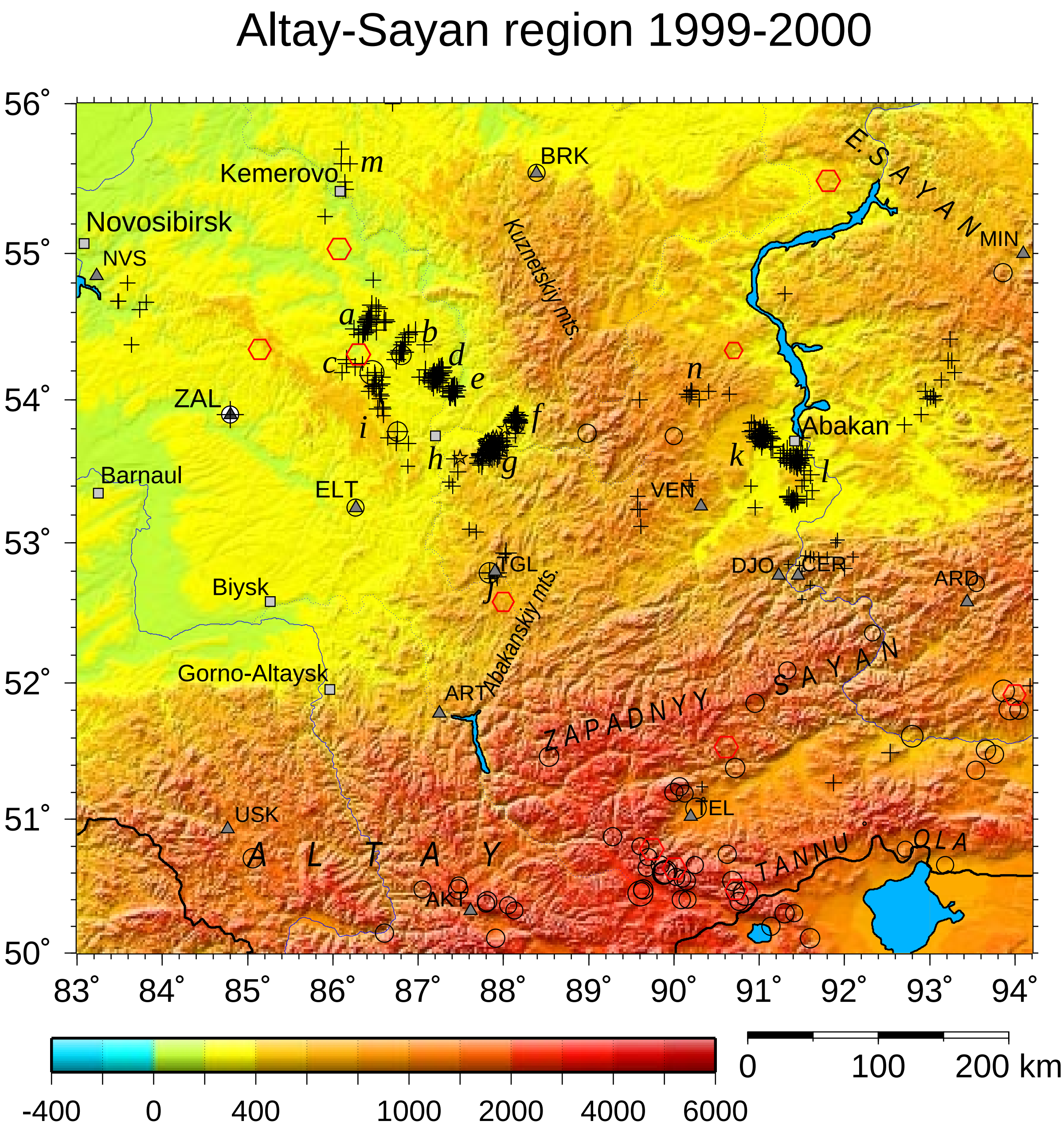

Figure 7. Locations of REB events in Southwestern Siberia during 1995–1997 and mining blasts in 1999–2000. Mining areas in Kuzbass-Abakan region are indicated by cluster of events. Primary IMS network station, ZAL and other local seismic stations in the region are indicated for reference.