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Infrasound monitoring of deorbiting Soyuz crafts on the territory of Central Kazakhstan

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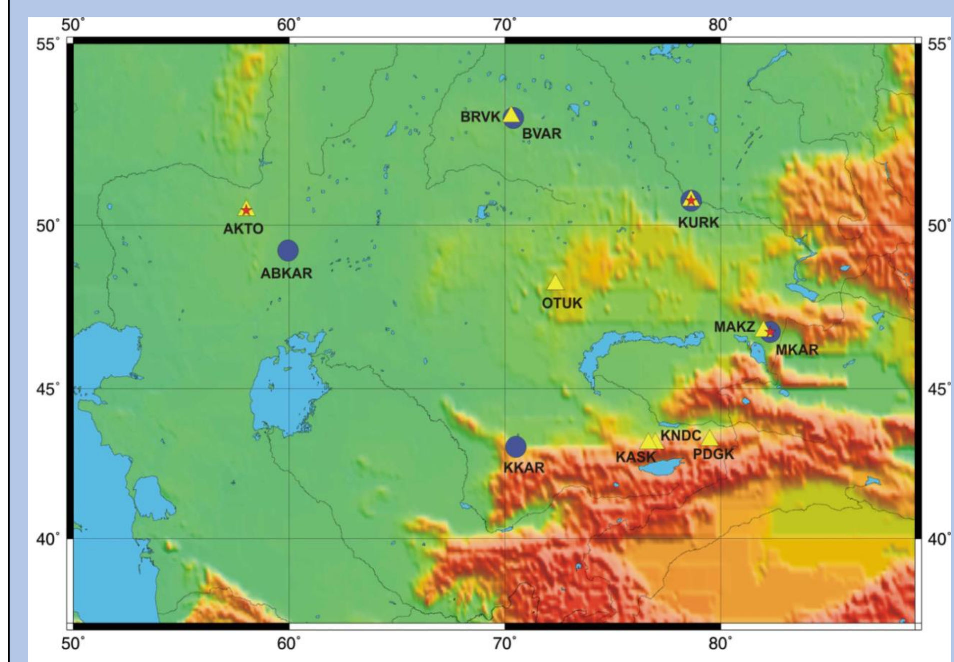
Kazakhstan has established and is successfully operating a contemporary digital network of seismic and infrasound stations located throughout the perimeter of the Republic (Figure 1). Currently, KNDC transmits in real time and processes data from 4 infrasound arrays: Aktybinsk IS31 (western Kazakhstan), Kurchatov KURIS (east Kazakhstan, on the territory of Semipalatinsk Test Site), Makanchi (east Kazakhstan), and Zalesovo IS46 (Russian Federation). This data allows for automated detection of infrasound events, and creating infrasound events bulletins on regular basis.

The station IS31 is a primary station of the IMS. It was constructed in 2001, and certified in 2002. The infrasound array IS31 "Aktyubinsk" represents a triangle of low-frequency elements L2 – L4 of 2 km on a side, and central point L1 surrounded by additional high-frequency elements array (H1-H4) in the form of square of ~200 m on a side (Figure 2) [1]. The sensors are microbarographs MB2000 – one per each element. The recorders are Aubrac, 24-bit, sampling rate – 20 Hz.

KURIS station was constructed in 2011 under the budgetary financing. The array consists of four elements – three of them are on the top of equilateral triangle, fourth is in the centre of the triangle (Figure 3). The array aperture is 1000 m. The station is equipped with microbarometers MB2005 and filters the same as those installed at IS31 station. The technical parameters correspond to the IMS requirements for infrasound stations. The station uses 24-bit recorders CMG-DM24S6EAM, sampling rate is 20 Hz.

In 2016 MKIAR infrasound station consisting of 9 elements was constructed at the premises of MKAR seismic array. The station configuration is similar to IS31 and KURIS, array aperture is 1 km (Figure 4). В качестве датчиков используются микробарометры Chaparral. The recorders are AIM24S-1, 24-bit, digitization rate – 40 Hz [1].



Circles – seismic arrays, triangles – three-component stations, stars – infrasound arrays

Figure 1 – The map of the IGR seismic and infrasound stations location.

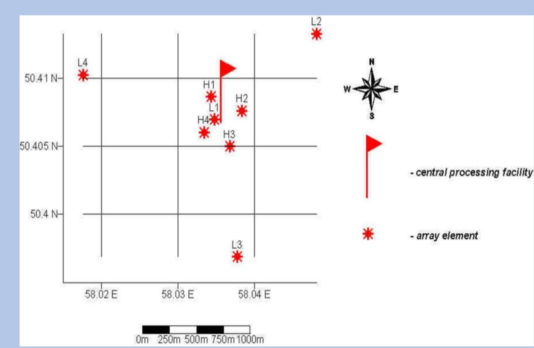


Figure 2 – The scheme of elements location of Aktyubinsk IS31 infrasound array

Figure 3 – The scheme of KURIS infrasound array elements location, Kurchatov

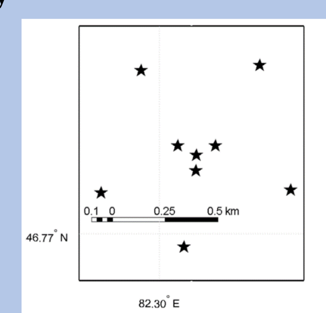


Figure 4 – The scheme of MKIAR infrasound array elements location, Makanchi

During almost ten years the CAPSSI has been calculating regularly and on daily basis the bulletins of infrasound detections by stations data using PMCC detector. Since May 2011, the bulletins of signals infrasound detections has been made for KURIS station, since March 2012 – for IS46 Zalesovo station, from 2015 for IS31 station, and from 2016 – for MKIAR.

At the end of 2013, French National Data Centre (NDC) transferred to the CAPSSI the adapted version of "Locinfra" software [2, 3] used by French NDC for location of infrasound events.

At the present moment the huge work is conducted on source type discrimination; most of recorded infrasound events are mining explosions, large earthquakes, bolides and other.

Another infrasound signal recorded by Kazakhstan network is launches and de-orbiting of spaceships. The infrasound sources at rocket-carriers flight at the active part of the trajectory are: turbulent pulsations of jet streams from propellant combustion products, "associated" shock wave at hypersonic velocity flight of the rocket, shockwave at carrier-rocket stages fall, and signals during emergency situations [6]. Among the sources of seismic oscillations at carrier rocket flight could be: shockwave from the carrier-rocket stages fall, fall of carrier-rocket stages, fall and blast of a carrier-rocket. IS31 records a lot of signals from spaceships launched at Baikonur spaceport (46.07°E, 62.97°E). The spaceport is located about 600 km south-eastward of the station. Figure 6 shows the waveforms and parameters of signals by data of the PMCC detector from Zenit rocket launch at Baikonur spaceport on June 29, 2007. The observed apparent velocity is equal to 0.3 – 0.37 km/s are typical for stratosphere phases. The azimuth to the source, by stations data, is 136.5± 0.6°, that coincides well with the true azimuth to the spaceport.

From May 2014 to April 2016 the bulletin contains about 3500 events (Figure 5).

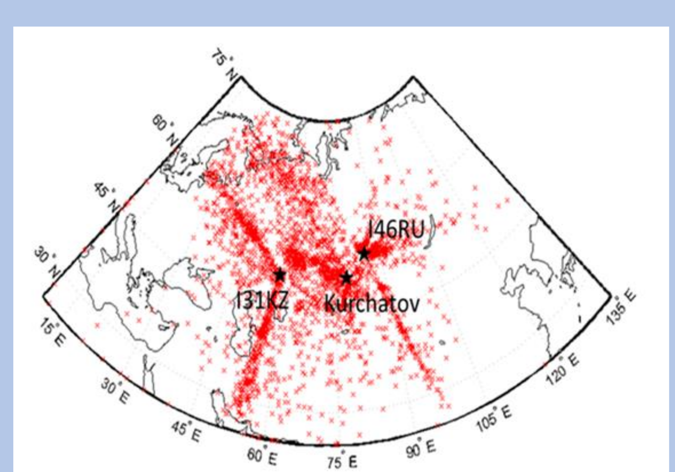


Figure 5. The map of infrasound events and bulletin location.

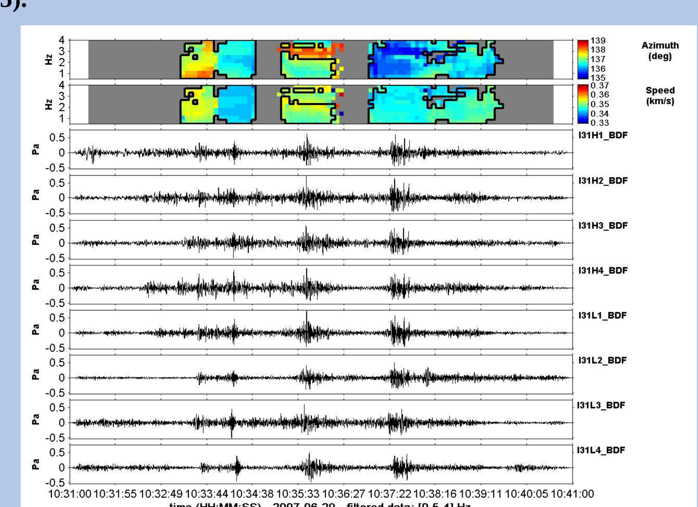


Figure 6. The waveforms and parameters of signals by data of the PMCC detector from Zenit rocket launch at Baikonur spaceport on June 29, 2007.

"Soyuz" is the name of the Soviet and Russian multi-seat transport manned spaceships. The development of the base model of the spaceship started in 1962 by OKB-1 and was guided by S.P. Korolyov for the Soviet lunar program. The contemporary "Soyuz" spaceships are able to transport up to three persons to low-earth orbit. The first launch was on April 23, 1967; to date there were 23 unmanned flights and 143 manned launches. The landing is usually at the region of Central Kazakhstan near Zhezkazgan, Arkalyk, Kostanay cities. From the beginning of the IGR monitoring network operation in 1994 to 2018 there were 69 landings, starting from 2010 there are 4 landings per year. The deorbiting is recorded by seismic stations: Akbulak seismic array and three-component Aktyubinsk (AS59) station, and by the infrasound IS31 station. Figure 7 shows the example of such landing record on 26.11.2010, 04-46-06 by SA Akbulak and IS31. The record by Akbulak SA shows low-frequency surface waves, and high-frequency infrasound signal consisting of one train. The records of IS31 station also show a clear signal. The signals recording is most probably related to spaceship entry into the dense atmosphere in several tens of minutes before landing.

The most clear signals were processed by the KNDC analysts, included into the seismic bulletins, and due to large surface waves were considered as mining explosions. Table 1 shows a catalogue of such events, the epicenters map is shown in Figure 8. The energy of such events is not high, the magnitudes range is mpva=1.2÷2.3, K=4.3÷6.4. Most often the localization is conducted by Akbulak SA data. The average time of these events is ~15 minutes before landing.

Figure 9 shows seismic and infrasound records of landing spaceship to the north of Arkalyk town on November 10, 2014, t0=3-58, Fourier spectrum for three-component element AB31, ABKAR SA, and results of signals detection from the deorbiting spaceship by IS31 station. The signal recorded by seismic stations is similar by its form with atmosphere explosion [5], the surface waves are domineering, P-wave arrival is not distinct; despite the borehole depth of 40-80 m at ABKAR SA the infrasound signal was recorded. Fourier spectrum for three components of AB31 station is almost the similar, peak amplitudes are observed for period T~0.7 s.

Table 1. The catalogue of seismic events related to de-orbiting spaceships.

Date, origin time	Lat	Long	mpva	K	AZ (ABKAR)	Δt, min
2006-09-29 00:57:52.2	49.729	59.639	1.7	5.7	274.9	15
2007-10-21 10:21:11.46	50.298	59.345	1.4	4.3	342.4	14
2009-12-01 07:00:03.48	49.508	59.599	1.2	-		15
2012-04-27 11:29:34.93	49.746	58.67	2.1	6.4	301.3	15
2012-11-19 01:37:18.64	50.341	59.073	1.9	5.1	327.6	19
2013-03-16 02:50:10.21	49.015	59.59	2.3	4.5	216.8	16
2014-11-10 03:43:09.86	49.157	59.283	1.5	5.4	265.1	15

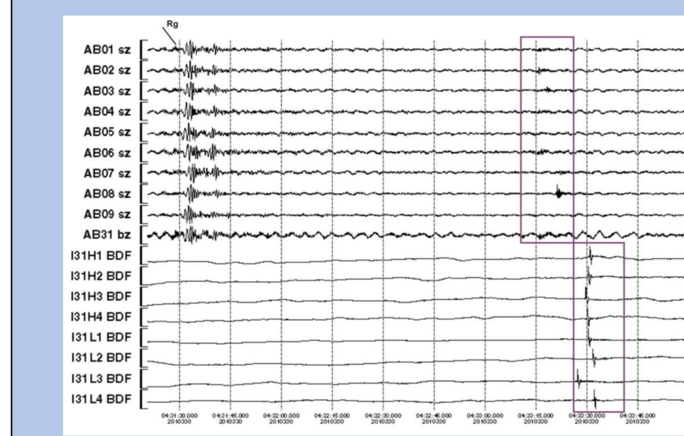


Figure 7. The landing of de-orbiting spaceship northward of Arkalyk town. 26.11.2010, 04-46-06. Akbulak SA abd IS31.

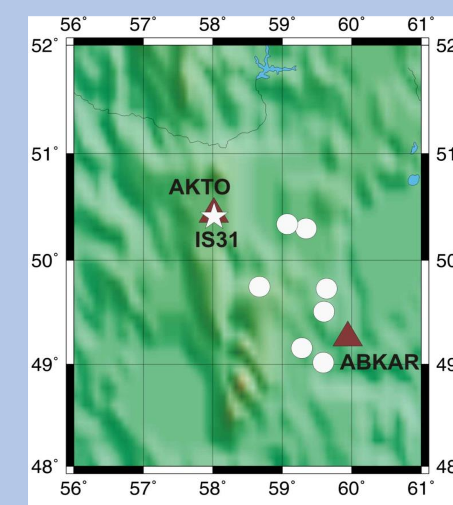


Figure 8. The map of events epicenters associated with spaceships landing (circles), triangles – seismic stations, star – the infrasound array.

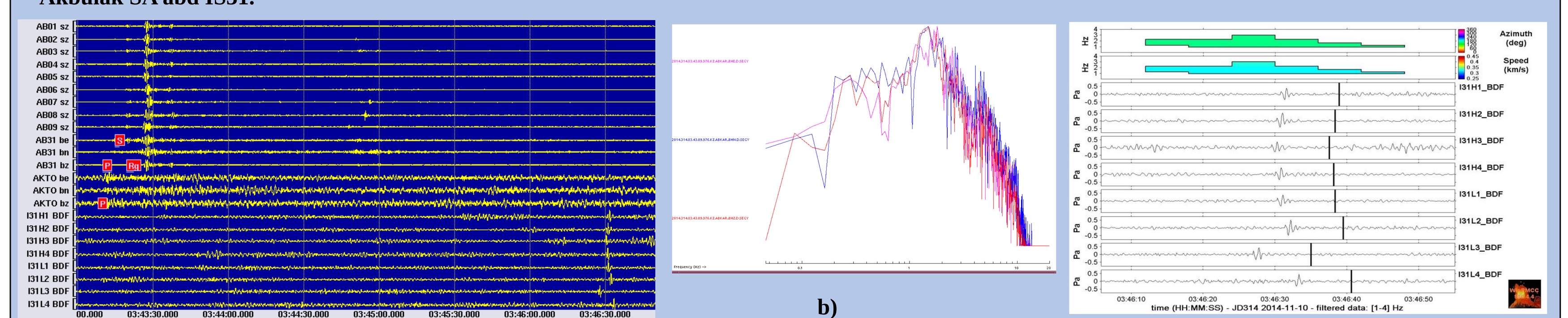


Figure 9. a- Seismic and infrasound records of the spaceship landing northward of Arkalyk town on November 10, 2014, t0=3-58, b- Fourier spectrum for three-component element AB31, ABKAR SA, c – results of signals detection from deorbiting spaceship by IS31 station.

To compare the features of the wave pattern of bolides recording by the IGR infrasound stations, the records of abnormal situation of a rocket launch from Baykonur launch site on October 11, 2018 were analyzed.

The piloted space ship Soyuz MS 10 with rocket Soyuz FG was launched from Baykonur launch site at 8:40 UTC, October 11, 2018 [6]. In about two minutes the launch was stopped, the cosmonauts were returned to the earth by ballistic path. Two of three infrasound stations of the IGR network – KURIS and MKIAR, and Russian station I46 (Figure 10) recorded the launch signals and supposedly the return of the second stage and the landing section.

IS31 station does not have signals from launch, de-orbiting and blast of the second stage (Figure 11).

All three stations recorded two groups of events; first the stations recorded signals of the return of the landing section and the second stage. These signals were first at all stations as the rocket flew toward the stations location with hypersonic speed. After that all stations recorded the launch signals. Figures 12 – 14 show the wave forms and detection results of signals using PMCC for stations KURIS, MKIAR and IS46, respectively.

Automated location at the KNDC allowed determining the assumed place of the second stage blast; Figure 15 shows a fragment of automatic bulletin with some parameters of this event.

Table 2 shows the epicentral distances and arrival times of the most precisely detected signal phases from the launch and return. The actual values of phase velocities show that the signals from the second group by each station are definitely the launch signals. For the location of the accident site the phase velocities are slightly lower of the expected 0.3 km/s. Nevertheless, this confirms well a hypothesis that the first group contains signals of the return; however, the actual automated location of the epicenter is slightly inaccurate, the true epicenter, probably, is eastward.

Figure 10. The mutual location of Kazakhstan infrasound monitoring stations, Russian infrasound array, Baykonur launch site, and assumed return place of the second stage of the rocket carrier Soyuz FG. The yellow lines show the directions of signal arrival from the first group (of return). The red lines show the directions of signal arrival from the second group (of launch). The directions were determined by stations data using PMCC.

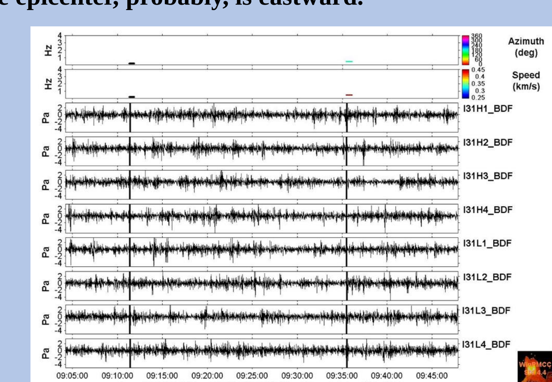


Figure 11. IS31 station does not have signals from launch, de-orbiting and blast of the second stage

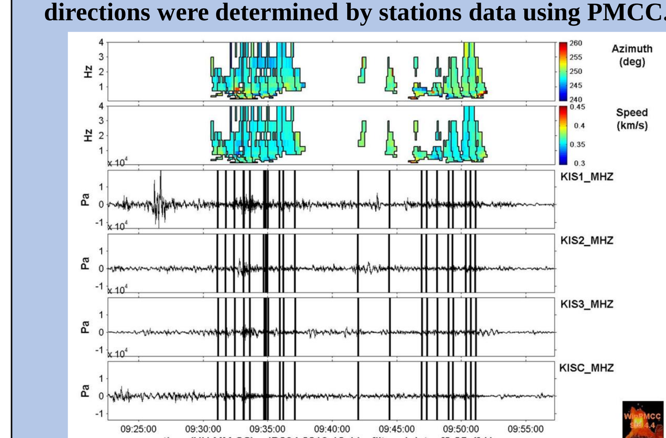


Figure 12 The waveforms and results of signals detection from launch and return of the landing section and blast of the second stage by KURIS station, Kurchatov.

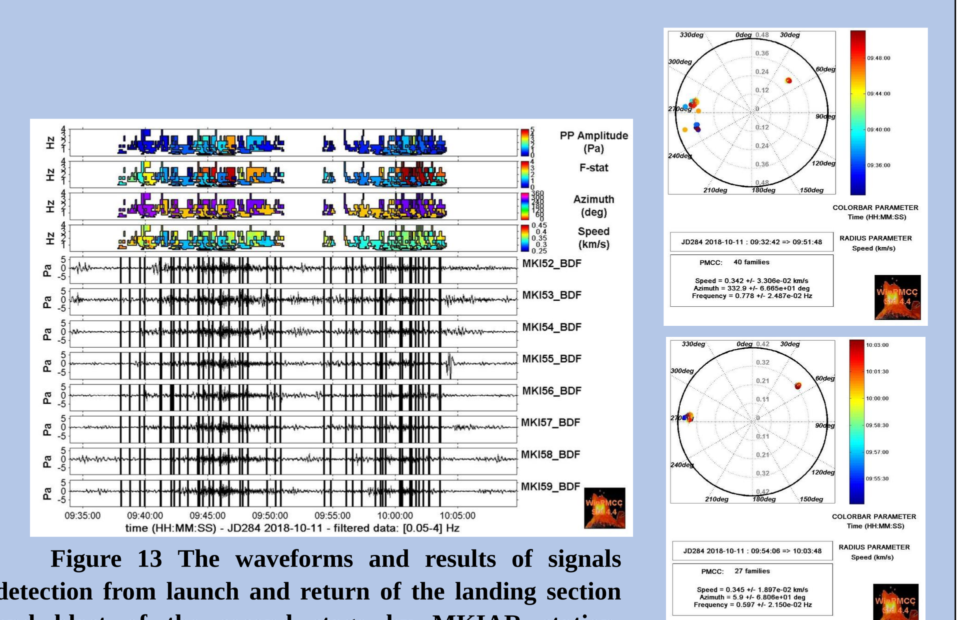


Figure 13 The waveforms and results of signals detection from launch and return of the landing section and blast of the second stage by MKIAR station, Makanchi

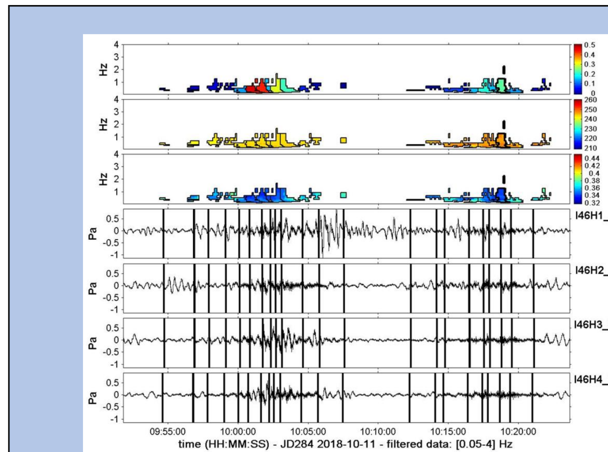


Figure 14 The waveforms and results of signals detection from launch and return of the landing section and blast of the second stage by IS46 station, Zalesovo, Russia.

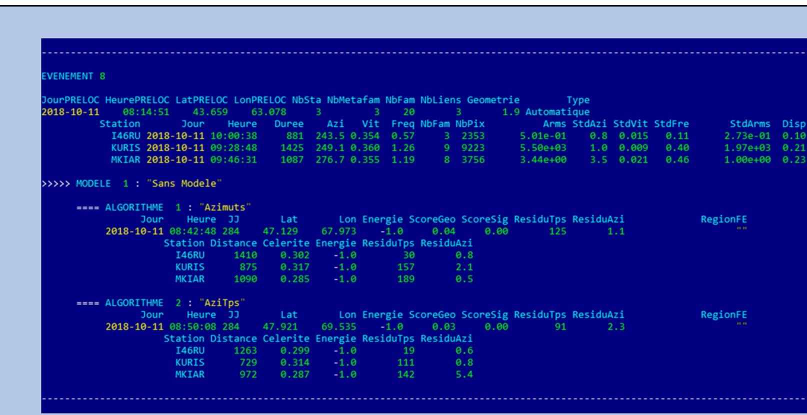


Figure 15 The fragment of automatic infrasound bulletin of KNDC, origin time by data of the solution with "Azimuths" algorithm coincides quite well with return time.

Table 2 Parameters of preliminary location

Station	Distance to Baykonur, km	Distance to the accident place by data of automated location, km	Launch time	Accident time by data of automated location	Time of phase arrival from first train with the best F-stat	Time of phase arrival from the second train with the best F-stat	Phase velocity at Baykonur – station site, km/s	Phase velocity at accident place – station site, km/s
IS46	1780	1400	8:40	8:42	10:01	10:18	0.30	0.30
KURIS	1250	870	8:40	8:42	9:33	9:50	0.30	0.29
MKIAR	1460	1080	8:40	8:42	9:45	10:01	0.30	0.29

It is interesting to compare the records of spaceship landing with bolide records. One of the examples is shown below.

On February 16, 2018, ~20-43 local time (14-43 UTC) the citizens of Ust-Kamenogorsk saw that bright blue light illumed the sky. There was one shot, and large fireball seen in the sky. After that there was a series of claps replaced with loud roaring. The bolide was seen not only in Ust-Kamenogorsk, but in Ridder, Serebryansk, Ayagoz, and Semey too.

The event was recorded and processed by the following infrasound stations of the IMS: I31, I43, I46. The epicentral distance ranged from 549 km (I46 station) to 3127 km (I43 station). REB location results are: 2018-02-16, t0= 14:38:35.8, φ=49.149°, λ=82.9856°, smajax=246.3 km (Figure 16).

At KNDC the event was processed by three stations: MKIAR (distance 315 km), KURIS (distance 333 km), I46 (504 km). Location results: 2018-02-16, t0=14:43:25, φ=49.574°, λ=82.923°. Figure 16 shows the map of location of the infrasound stations that recorded the bolide of 2018-02-16. The distance difference between the solution of IDC and KNDC is small δΔ=48 km. The wave forms and PMCC processing results of the meteorite fall of 2018-02-16 by MKIAR (Makanchi) infrasound station are shown in Figure 17.

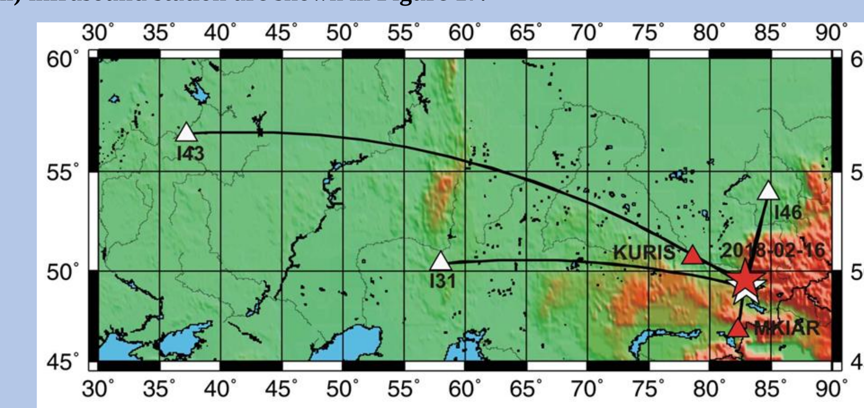
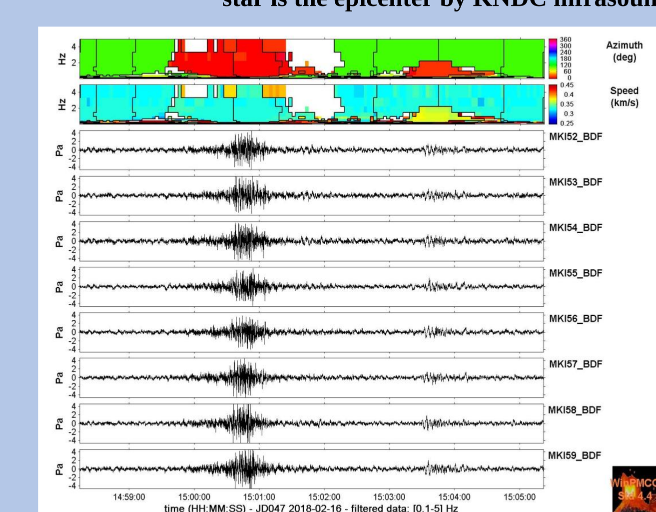


Figure 16. The map of location of the infrasound stations (triangles) that recorded the bolide of 2018-02-16 (star). White triangles are the IMS stations participated in the location, white star is the epicenter by REB, red star is the epicenter by KNDC infrasound bulletin.



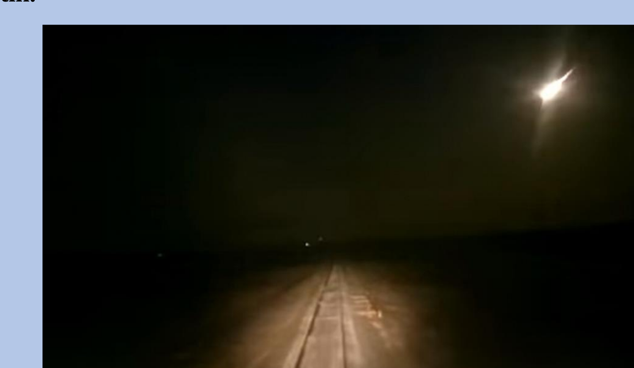


Figure 17. The wave forms and PMCC processing results of the bolide of 2018-02-16 by MKIAR (Makanchi) infrasound station

The obtained data can be used to improve the quality of KNDC infrasound and seismic bulletin and replenishment of the ground-truth events database.

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