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IMS Infrasound Records of Announced Rocket Launches

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ABSTRACT

Infrasound technology as part of the verification regime plays a significant role in monitoring compliance with the Comprehensive Test Ban Treaty (CTBT). Low frequency acoustic waves under favourable conditions can propagate thousands of kilometres until they arrive at infrasound arrays of the International Monitoring System (IMS). Recorded data are transmitted to the International Data Centre (IDC) and used for detection and characterization of atmospheric events. Underground events such as large magnitude earthquakes or surface explosions such as quarry blasts may also generate infrasound signals.

The aim of this study is to present a summary of infrasound records starting from mid 2016 related to publicly announced spaceflight activity that took place at the different spaceports, i.e. Baikonur Cosmodrome, Vandenberg Air Force Base, Guiana Space Centre, Xichang Satellite Launch Centre etc. Signals detected by the IDC were recorded not only at regional distances but also at several thousands of kilometres from the source. An overview of records from certain families of launch vehicles, i.e. Long March and Soyuz provides information helping to identify and locate events occurring along the trajectory. Results of this study may facilitate analysis of signals generated by these complex infrasound sources.

Rocket launches are anthropogenic atmospheric sources of infrasound signals generated by events taking place along a flight trajectory, such as lift-off, re-entry of the first stage or the second stage etc. Under favourable weather conditions these signals can propagate at large distances and be recorded at an infrasound array. (Fig.1)

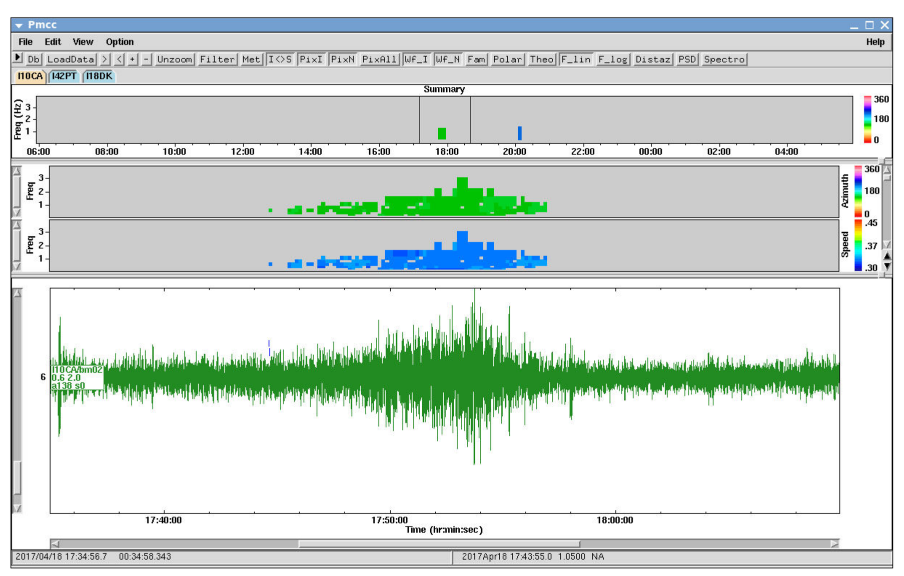

Fig. 1. Detection of infrasound signal associated to the Atlas V 401 launch on 18 April 2017 from the Cape Canaveral SLC recorded at the infrasound station I10CA (Canada). Distance from the event - 24.16 deg (2685 km)

CTBTO infrasound network registers long-range signals and also provides a unique opportunity to perform in-depth studies to better understand propagation of atmospheric signals.

DATA

From August 2016 till May 2017 there were 67 launches of carrier rockets from various spaceports around the world. The IDC registered 23 launches mostly from China, Kazakhstan and Japan that is around 30% from the total number (Fig . 2).

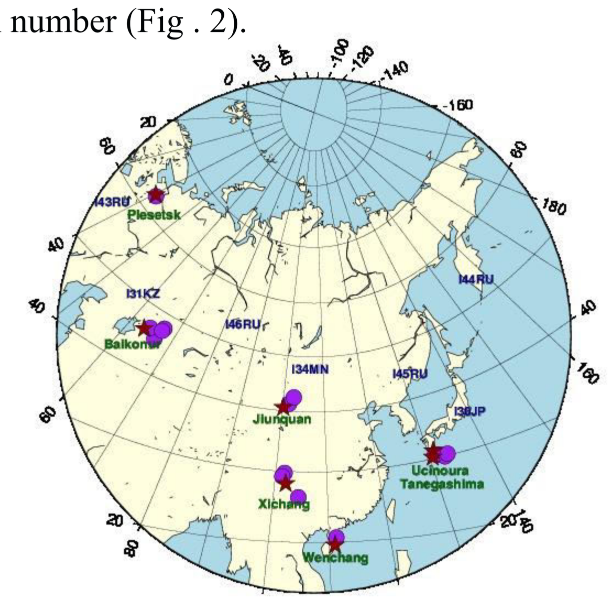

Fig. 2 Distribution of infrasound events related to launches of rocket vehicles (purple circles) from spaceports Xichang, Juinquan, Wenchang, Baikonur, Plesetsk, Uchinoura and Tanegashima (red stars), recorded by IMS network for the period August 2016 till May 2017

In 19 cases the launch pad was within the confidence ellipse (area in which an event takes place with probability of 90%) associated to event location, in 4 cases event time differed by more than 20 minutes from the actual time of the launch. Therefore the epicentre significantly shifted from the launch location. For 5 launches some distinct events along the flight trajectory were registered in addition to signals supposedly related to the liftoffs.

This study is aimed to inspect infrasound signal signatures and to define patterns related to launches of rocket vehicles from various spaceports that can later simplify the task of infrasound data analysis. Such factors, as flight trajectory, consistency of infrasound records and wind conditions, and their influence on infrasound records, are outlined below.

FLIGHT TRAJECTORY

Flight trajectory of a carrier rocket always goes above unpopulated area in a desert or in a ocean, so that lower stages of rockets and debris from launch failures cannot fall on human habitations.

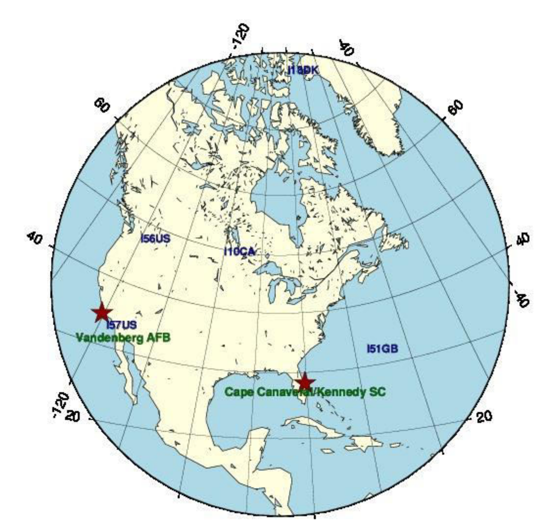

Fig. 3. Location of main American spaceports: Cape Canaveral SLC with adjacent Kennedy Space Centre (Florida) and Vandenberg Air Force Base (California)

A launch vehicle is moving in atmosphere source with the speed far exceeding the speed of sound, therefore the character of infrasound records depends on a flight trajectory.

When a launch vehicle goes away from an infrasound station, (i.e. a rocket launched from Vanderberg AFB recorded at I57US, Piñon Flat, California), the first observed phase at the records is a signal related to the liftoff, then to the first stage (Fig. 4).

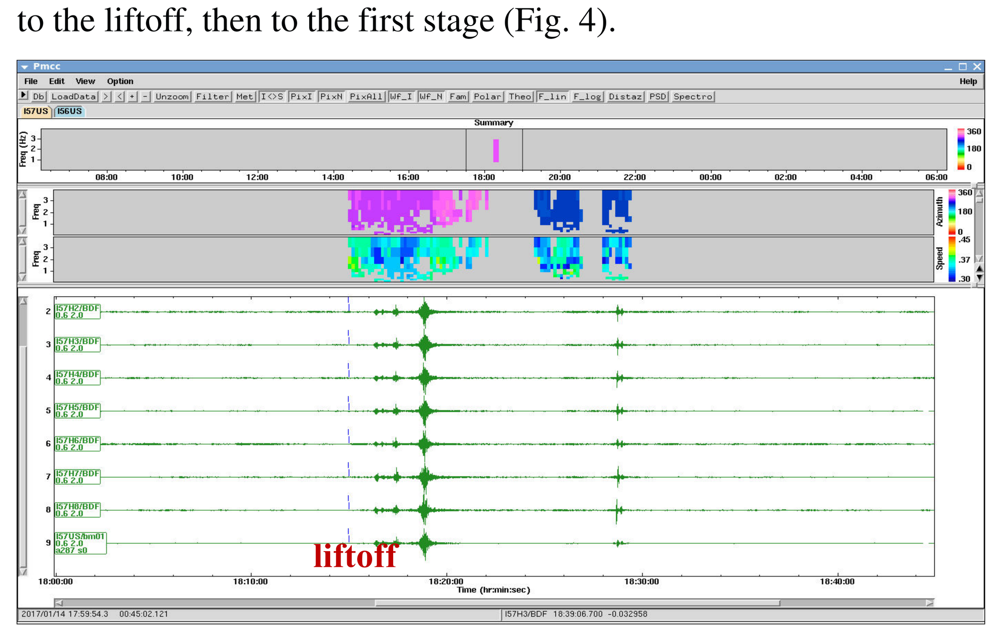

Fig 4 Infrasound signals related to the Falcon 9 Full Thrust launch from Vandenberg Air Force Base recorded at the station I57US on 14 January 2017 at 17:54:39 (UTC). Distance from the event – 2.05 deg (227 km)

When a launch vehicle goes towards an infrasound station, (i.e. a rocket launched from Cape Canaveral recorded at I51GB, Bermuda), infrasound signals related to the liftoff, the first stage are observed in the reverse order (Fig. 5).

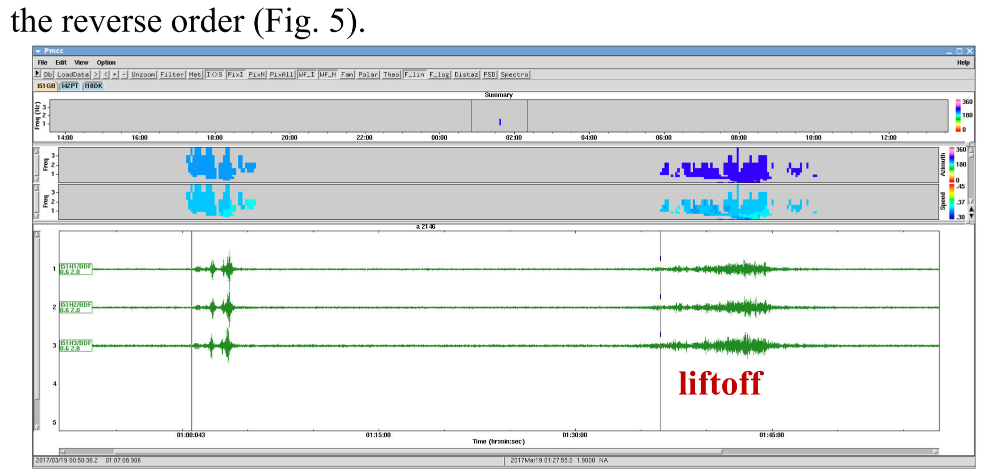

Fig. 5. Infrasound signals related to the DeltaIV launch on March 19 2017 from the Cape Canaveral SLC recorded at the closest to the launch pad station I51GB. Distance from the event - 10.28 deg (1142 km).

CONSISTENCY OF INFRASOUND RECORDS

To demonstrate consistency of infrasound signal signatures we checked IMS stations records of Soyuz rocket launches from Baikonur Cosmodrome. It is the largest and oldest spaceport in the world located at the southern Kazakhstan and mostly used by Roskosmos. The closest IMS station is I31KZ (Aktubinsk, Kazakhstan) at the west from the spaceport. The flight trajectory goes to the east towards IMS station I46RU (Zalesovo, Russia).

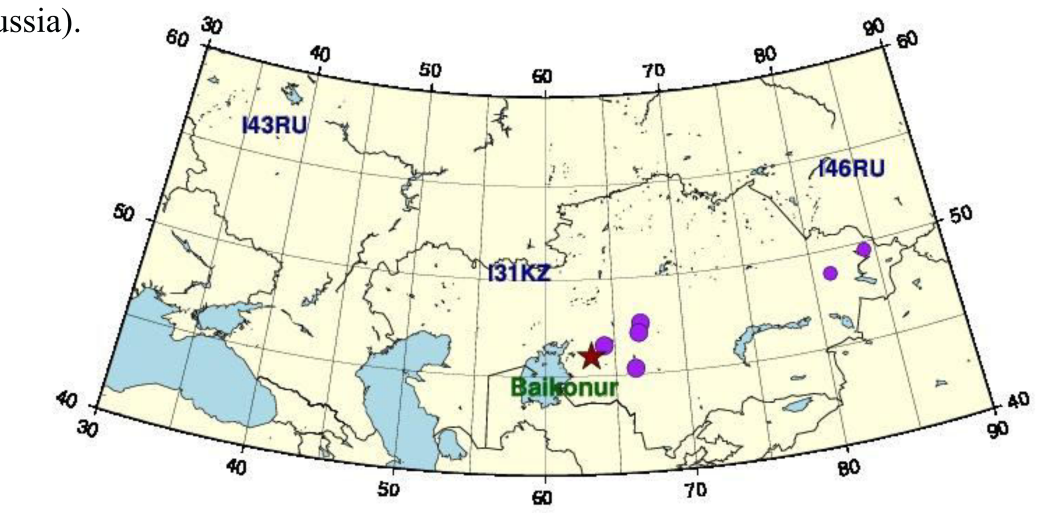

Fig. 6. Distribution of infrasound events related to launches and re-entries of Soyuz-family rockets from Baikonur Cosmodrome from 01.07.2016 till 31.05.2017

17 Nov 2016 – Soyuz-FG Launch time 20:20:14 (UTC)

1 Dec 2016 – Soyuz-U Launch time – 14:52 (UTC)

20 Apr 2017 – Soyuz-FG Launch time 07:13:44 (UTC)

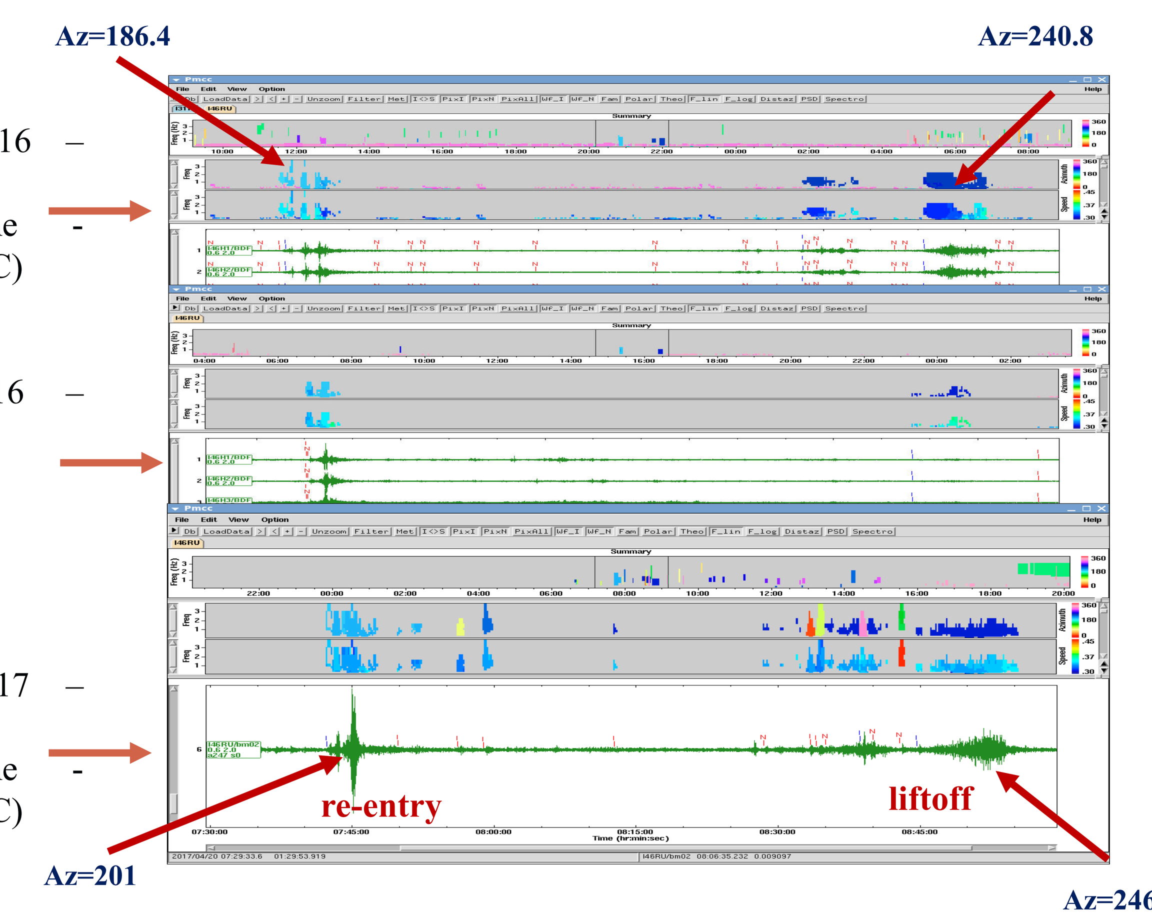

Fig 7. Infrasound signals related to launches of Soyuz –family rockets from the Baikonur Cosmodrome, Kazakhstan recorded at the station I46RU for the period November 2016 – April 2017

Infrasound signal patterns of Soyuz rockets launches registered at the IMS stations I46RU and I18DK (Greenland) (Fig. 8) during the winter period are consistent. The first observed I46RU records phase is supposedly related to re-entry of the second stage that always takes place in the vicinity of the I46RU. Back azimuth varies from 186 till 201. The last observed phase (back azimuth varies from 240 till 246) supposedly related to the liftoff. Time difference between these two phases varies insignificantly. Wind direction for both stations is West-East.

17 Nov 2016 – Soyuz-FG Launch time 20:20:14 (UTC)

1 Dec 2016 – Soyuz-U Launch time – 14:52 (UTC)

20 Apr 2017 – Soyuz-FG Launch time 07:13:44 (UTC)

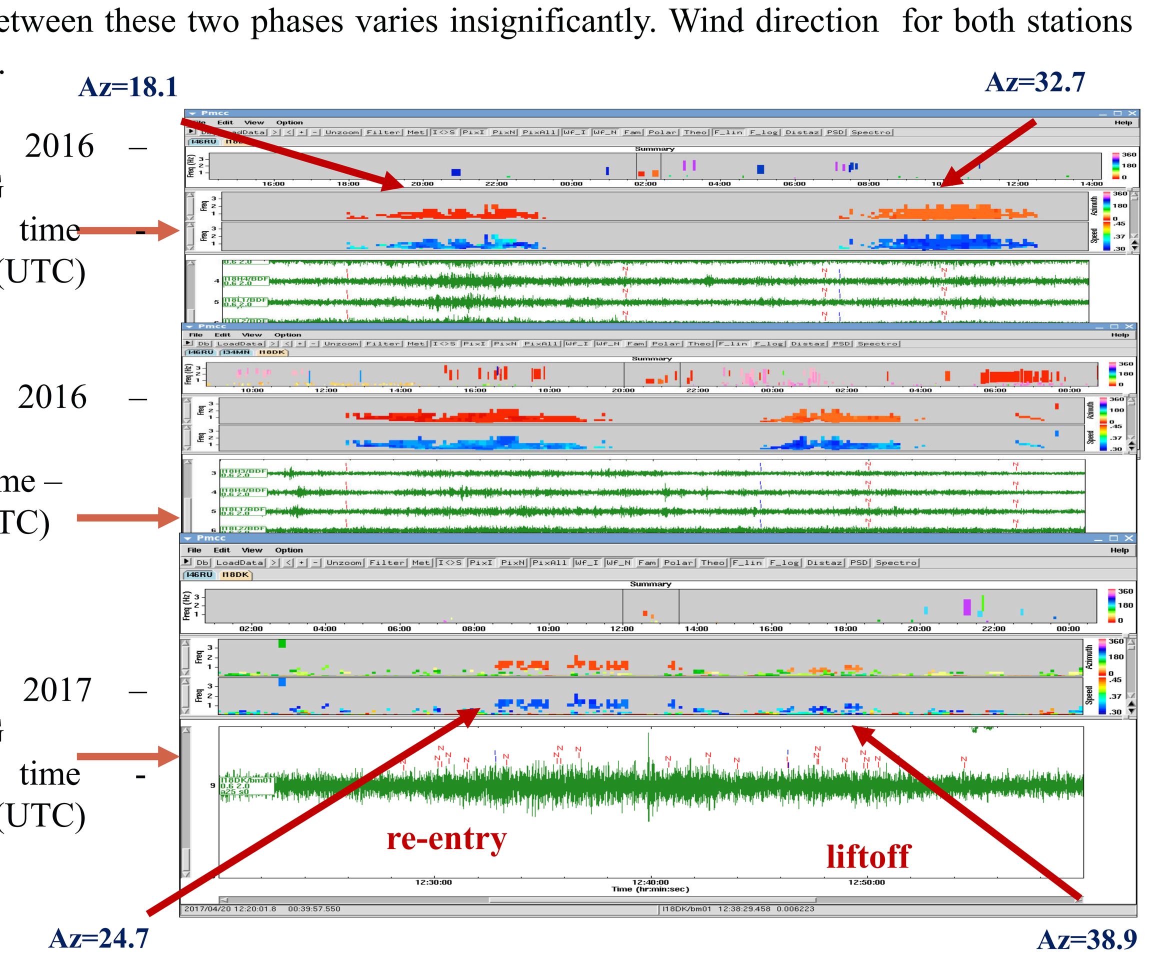

Fig 8. Infrasound signals related to launches of Soyuz –family rockets from the Baikonur Cosmodrome, Kazakhstan recorded at the station I18DK for the period November 2016 – April 2017

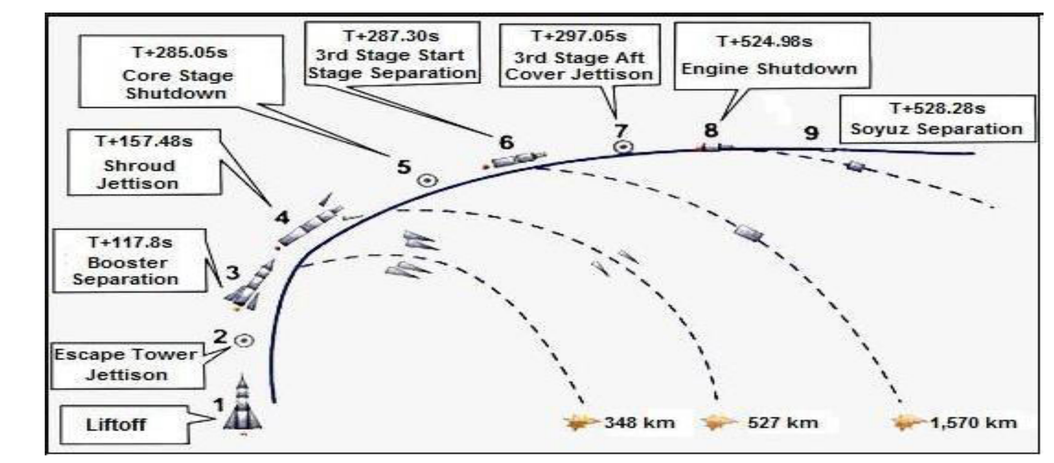

Fig 9. Soyuz FG Flight Profile – launched from Baikonur Cosmodrome (Source: Roscosmos/TSUP)

ATMOSPHERIC VARIATIONS

Long-range infrasound propagation is influenced by the general circulation of the stratospheric wind. Most spaceports are deployed in the Northern Hemisphere. North Hemisphere stratospheric wind direction (altitude of 40–50 km) is changing between westward direction in summer and eastward direction in winter.

08 June 2017 – Proton-M / Briz-M Launch time – 03:45 (UTC)

14 June 2017 – Soyuz-2.1a Launch time – 09:20 (UTC)

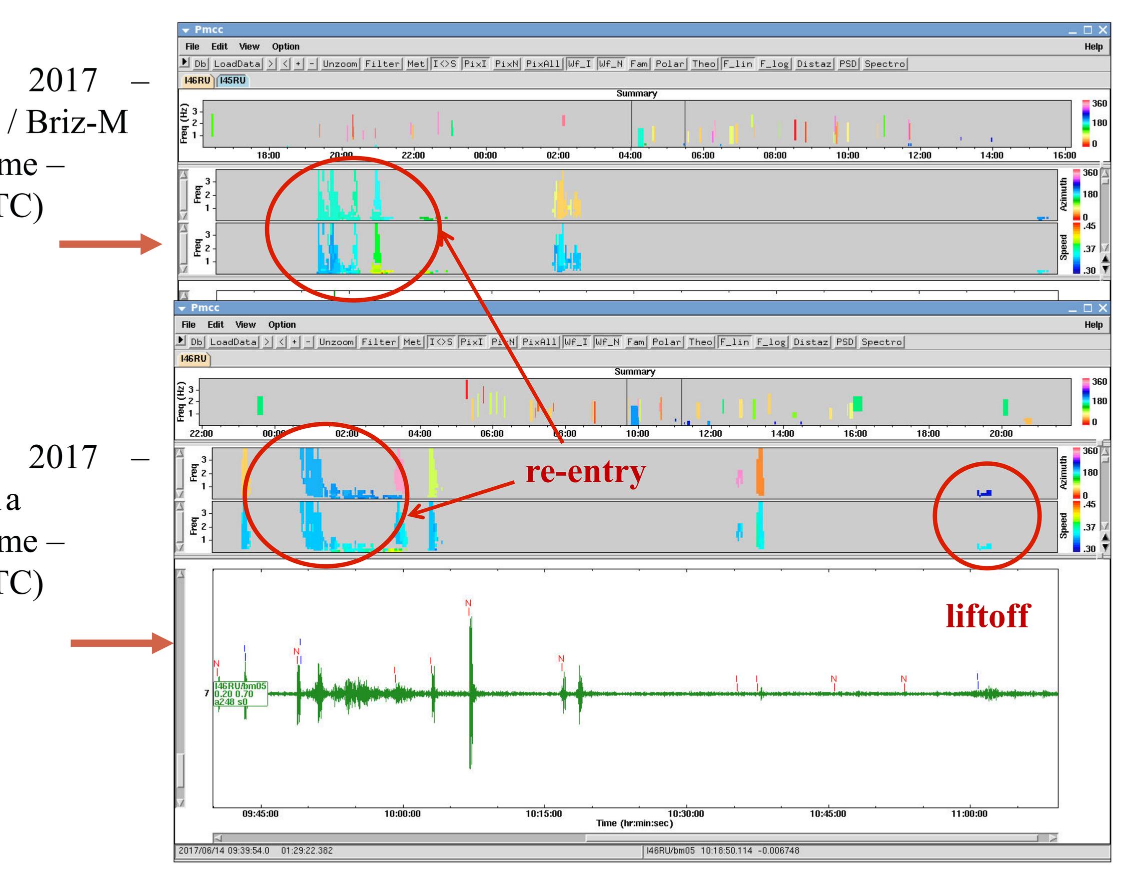

Fig 10.Infrasound signals related to launches of Proton-M and Soyuz -2.1a rockets from the Baikonur Cosmodrome, Kazakhstan recorded at the station I46RU in June 2017

In summer, when wind direction is East-West, infrasound signal patterns of rocket launches from Baikonur at the IMS station I46RU (Fig. 10) look different in comparison with the winter pattern from this station (Fig. 7). The first observed phase is still related to the re-entry of the second stage, but the signals related to the liftoffis strongly attenuated by the stratospheric wind and may not be detected at I46RU.

Concluding remarks

Analysis of atmospheric sources moving at a supersonic speed is a challenging and time consuming process as:

- Launch vehicles, as moving sources, may release energy in several places along their trajectory, i.e. more than one event may relate to one source; large time residuals, exceeding values expected due to varying propagation conditions may be observed
- Valid detections may be missed as signal to noise ratio for infrasound signals recorded at distant stations or propagating in unfavourable conditions may be very low; local sources as microbaroms, gas flares etc. may also interfere with signal of interest
- Relatively small number of associated phases leads to of big error ellipse (area in which the event took place with probability of 90%)

REFERENCES:

All infrasound recordings presented at this work have been routinely processed at the International Data Center (IDC) using the Progressive MultiChannel Correlation (PMCC) method [Cansi, 1995; Brachet and Coyne, 2006].

1. Sources of Infrasound events listed in IDC Reviewed Event Bulletin. P. Bittner, P. Polich, J. Gore, S. Ali, T. Medinskaya and P. Mialle. EGU2017-19462
2. Open Sources: http://spaceflight101.com/, http://en.roscosmos.ru/, https://en.wikipedia.org/wiki/2017_in_spaceflight