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Geospatial analysis of IMS infrasound records related to announced spaceflight activity

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ABSTRACT

Infrasound is one of International Monitoring System (IMS) technologies used to detect explosions which originate in the atmosphere. Many infrasound events are caused by moving objects like fireballs or supersonic speed anthropogenic sources.

Rocket launches belong to anthropogenic atmospheric sources of infrasound signals generated by events taking place along flight trajectory, such as lift-off or stage re-entries. Under favourable weather conditions these signals can propagate thousands of kilometres until they arrive at infrasound stations. Information about vehicle launch time, place and its trajectory may often be found in open source materials.

This study presents geospatial analysis of infrasound data related to announced spaceflight activity recorded at the IMS infrasound network. Analysis of signals detected at both regional and large distances is a complicated task considering a relatively small number of recording stations and changes in propagation and detection conditions.

The aim of this study is to explore the possibility of identification of spaceflight stages by examining signal appearance and comparing event location with open source information. Results of this study may facilitate analysis of signals generated by these complex infrasound sources.

IMS Infrasound network was designed to detect atmospheric nuclear explosions. It records natural and anthropogenic events, majority of which are related to man-made activity like sonic booms or rocket launches/re-entries .

This study concentrates on two space centres Plesetsk in northern Russia and Baikonur in southern Kazakhstan. Both are located in Eurasia. Flight trajectories of carrier rockets launched from both Plesetsk and Baikonur go above unpopulated areas (in eastward direction) or over Arctic Ocean (in northward direction), so that lower stages of rockets and debris from launch failures do not fall on human habitation or industrial zones.

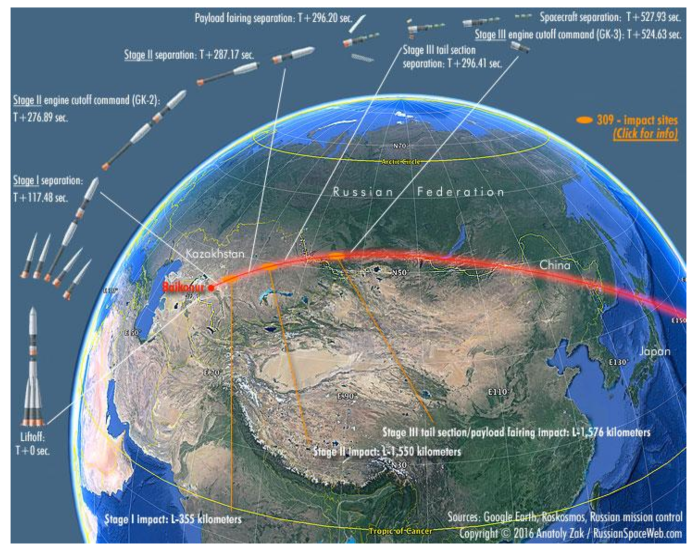

Fig. 1a Location of Baikonur Cosmodrome and a flight trajectory of Soyuz-U launched on July 16, 2016, at 21:41:46 GMT

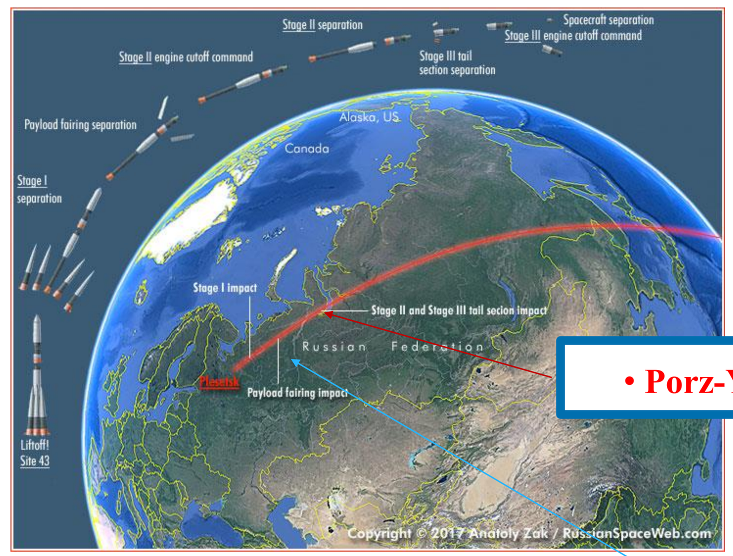

Fig. 1b Location of Plesetsk Cosmodrome and a flight trajectory of Soyuz-2-1b launched on Dec. 2, 2017, at 10:43 GMT

• Porz-Yaha/Khadyta region

•Ust-Tzilemsky region

After lift-off a number of launch vehicle (LV) fragments are separating and moving back to earth with a supersonic speed. These parts normally disintegrate in the atmosphere, only small debris may reach the earth surface. Under favourable conditions generated acoustic waves can propagate thousands of kilometres and are recorded at infrasound arrays of IMS network.

Authorities responsible for rocket launches are searching for downfall fragments of LV to protect the environment. This process is time consuming and technologically complicated. It may take at least several days to thoroughly search the steppe, taiga or swamps especially under low winter temperatures or harsh weather conditions.

Geospatial analysis of this type of infrasound events can be used for determining areas of LV fragments drop zones or searching for debris after an accident launch failure.

Detailed overview of events occurring after lift-off of certain LV families, i.e. different models of Soyuz provides helpful information in terms of their further identification and location of falling rocket stages.

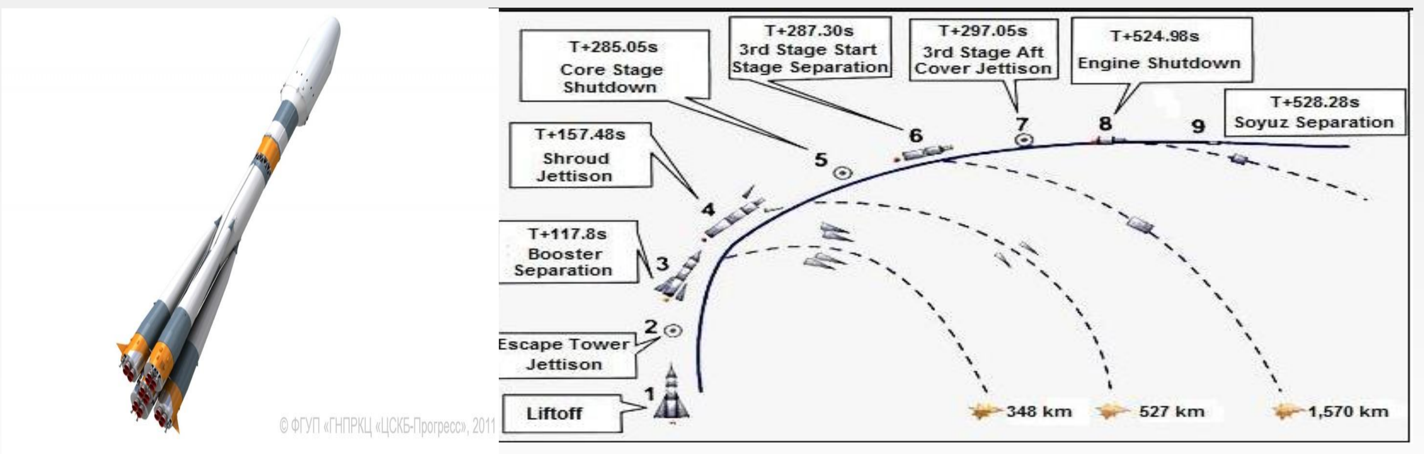

Fig 2 Soyuz 2.1b launch vehicle and Soyuz FG Flight Profile (Source: Roscosmos/TSUP)

FLIGHT TRAJECTORY AND LAUNCH EVENTS – PLESETSK SPACE CENTRE

LV of the same model carrying similar type of payload follow approximately identical ascent trajectories. Flight trajectories usually differ if models or payload are different.

Fig 3a shows location of events generated by launches of two different model LVs: Soyuz 2.1a with Bars-M satellite launched on 24.03.2016 and Rokot with three Gonetz satellites launched on 31.03.2015. Fig.3.b shows two Soyuz 2.1b launches with similar payload – Lotos satellites launched on 25.12.2014 and 02.12.2017.

Fig.3a Flight trajectories of two different models of launch vehicles

Fig.3b Flight trajectories of two Soyuz 2.1b launch vehicles carrying the Lotos payload

Flight trajectories may be approximated based on IDC location of events related to different launch and re-entry stages. They are very similar to flight paths found in open source materials (e.g. flight trajectories at fig.1.b and fig.4). In this case IMS stations recorded infrasound events related to three launch stages: the first stage, the payload firing and the second stage.

EXAMPLE OF LAUNCH FROM PLESETSK

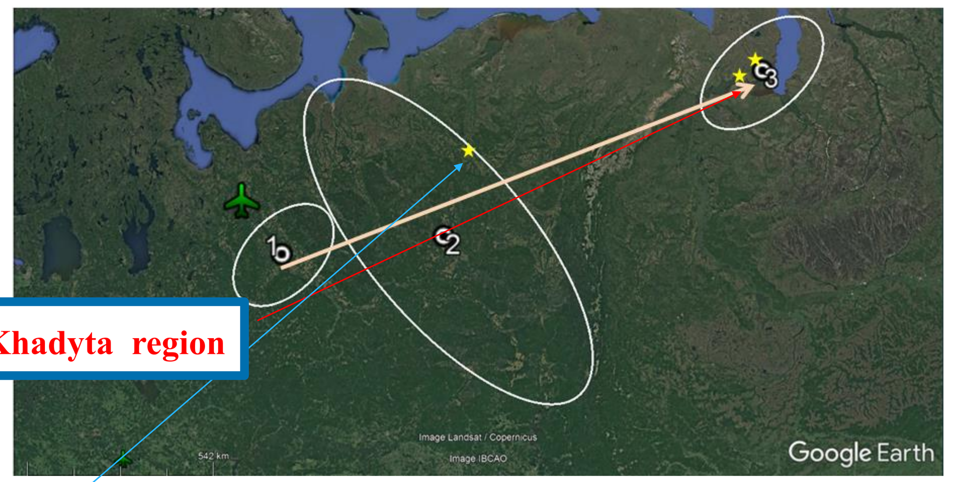

Fig 4. Flight trajectory of a launch from Plesetsk (02 December 2017). LEB events marked with circles, drop zones with yellow stars, 90% confidence ellipse marked with white, pink arrow – IDC calculated flight trajectory, green plane – Plesetsk space centre

Information about launch from Plesetsk on 02 December 2017 was found in the Russian media. Four boosters of the first stage separated after around two minutes and fell around 350 kilometers from the launch site. The payload fairing protecting the payload was probably dropped next, likely targeting the drop zone in Komi Republic (close to a yellow star in ellipse 2). Both, the second-stage booster and the segments of the tail section were aimed at the drop zone in Yamalo-Nenetsk Autonomous Region (www.russianspaceweb.com) (drop zone 3). According to the regional web portals, the expected areas of falling of LV fragments were :

- Ust-Tzilemsky region (www.bnkomi.ru) 65.43 N, 52.21 E
- Porz-Yaha/Khadyta region (www.interfax-russia.ru) 67.39 N, 71 E /67 N, 69.51 E

Geospatial analysis of infrasound events generated by rocket launches (Fig.3a,b, Fig 4) shows that events related to one launch were located in different places along the flight trajectory. It suggests that location of events related to different flight stages can be the key element for the launch stage identification. It can be achieved even with the relatively small number of sparsely distributed IMS infrasound stations.

LOCATION UNCERTAINTY

Location of each event is accompanied with a confidence ellipse, i.e. the actual source location should be within the ellipse area with the probability of 90%. The ellipse size depends on various factors, such as measurement errors, model bias or azimuthal coverage. Relatively small number of associated phases leads to a large error ellipse.

In case of Plesetsk launches confidence ellipse varied between $10^4\ km^2$ and $6*10^6 km^2$. Large confidence ellipse events located east of Plesetsk space centre. These events were located based on observations at two or three stations with poor azimuthal coverage.

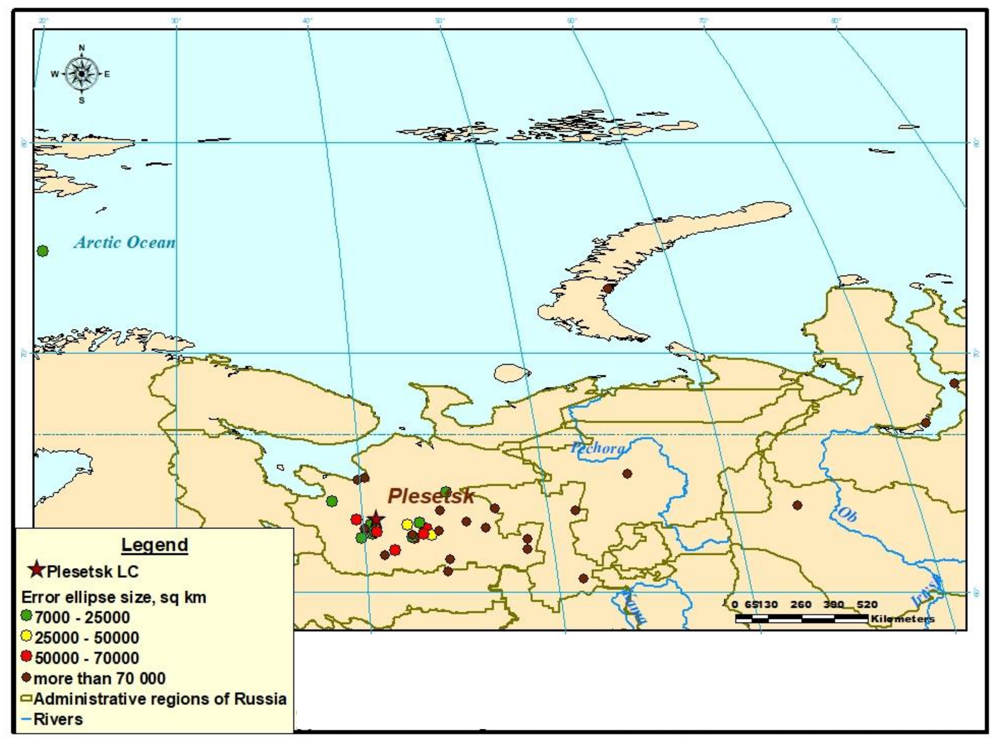

Fig.5. Infrasound events related to launches from Plesetsk ; years 2011-2018

DISTRIBUTION OF INFRASOUND EVENTS GENERATED BY LAUNCH VEHICLES BAIKONUR SPACE CENTRE

Baikonur space centre is the largest and oldest spaceport in the world. It is located in the southern Kazakhstan and mostly used by Roskosmos (Russian space agency). Almost all flights of LV launched from Baikonur have an eastward trajectory.

The number of launches from the Baikonur space centre is four times higher than number of LVs launched from Plesetsk. Infrasound events generated by different models of LV (Fig.6) are distributed within three clusters:

- between Kyzylorda and Karagandy regions in the vicinity of Baikonur space centre; this cluster contains most of infrasound events
- in Altaiskiy Kray with drop zones for the falling second stages
- Karagandy region with drop zones for the falling first stages and payload fairing

To show distribution of events in first two clusters (marked on the map) 68% standard deviational ellipses were calculated and shown in fig.6. Both areas are of similar size.

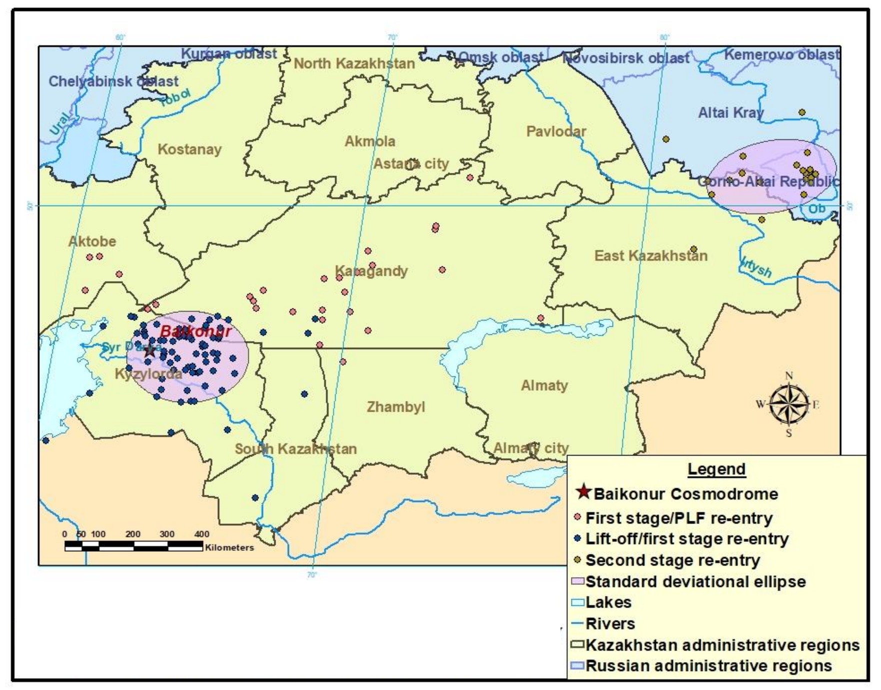

Fig 6 Distribution of infrasound events generated by rocket launches from Baikonur space centre (2011-2018)

EXAMPLE OF LAUNCH FROM BAIKONUR

A Soyuz-2.1a rocket carrying a Foton–M research satellite was launched from Baikonur on July 18, 2014, at 20:50 GMT. According to regional media, a number of fragments were expected to fall at the Bachkarsky and Parabelsky regions, the closest town to the drop zone was Kedrovy.

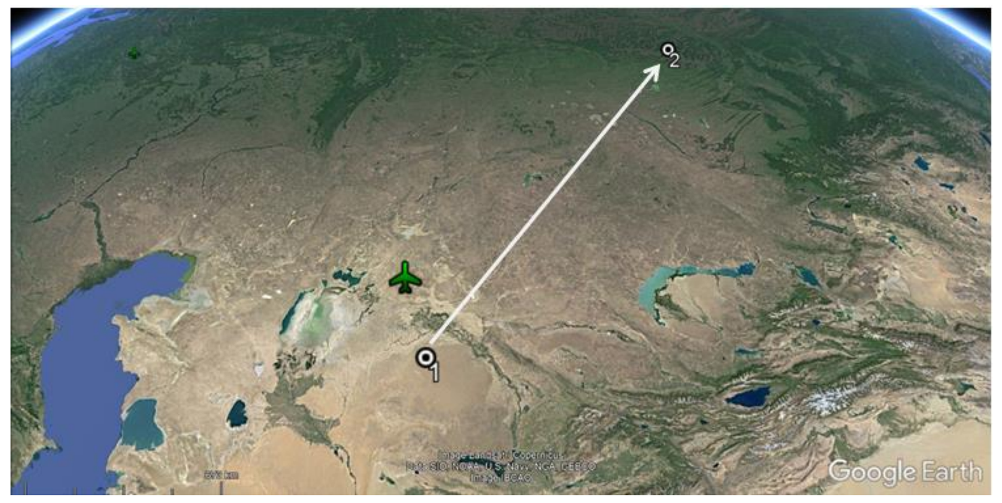

Fig.7. Soyuz 2.1 launched from Baikonur on July 18, 2014. Flight trajectory (marked with white); location of IDC infrasound events (white circles); green plane marks position of Baikonur space centre;

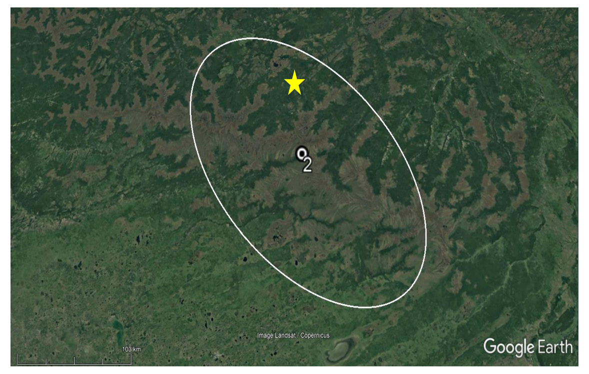

Fig.8. 90 % confidence ellipse of the second event from fig.7. Drop zone south east of Kedrovy marked with a star.

Two events related to this launch can be found in the IDC bulletin. A flight trajectory, reproduced based on IDC solutions (Fig.7.) is coincident with the one reported in the media (northeast direction). The first recorded infrasound event is located in the vicinity of Baikonur (around 240 km from the launchpad), the location of the second event is 70 km southeast of the of the town of Kedrovy (around 1850 km from the launchpad).

According to the media (www.riatomsk.ru): the second stage of the rocket fell southeast of the town of Kedrovy. It is within the 90% confidence ellipse of the second event (Fig.8).

CONCLUSIONS

IMS infrasound network deployed worldwide as a part of the CTBT verification regime gives an opportunity to record, identify and locate infrasound events generated by the jettisoned launch vehicle fragments.

Under favourable weather conditions these infrasound events were recorded by up to 6 IMS stations. Location uncertainty depended on the number of recording stations and the azimuthal gap.

REFERENCES:

Open Sources: spaceflight101.com/, www.russianspaceweb.com, www.interfax-russia.ru, www.riatomsk.ru, www.bnkomi.ru