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6.2 Investigation of infrasound signals from rocket launches at the Plesetsk Cosmodrome, Northwest Russia

Introduction

Infrasound observations of Russian rocket launches has been demonstrated by Asming et al. (2008) who addressed both launches from the Plesetsk Cosmodrome as well as from submarines in the Barents Sea. In this study we will further extend the analysis of the infrasound signals from the Plesetsk rocket launches to obtain an understanding of the overall signal characteristics as well as the inherent variability among these signals.

The Plesetsk Cosmodrome is located about 800 km north of Moscow, with geographical coordinates 62.92 N 40.52 E. Plesetsk is used especially for military satellites placed into high inclination and polar orbits. However, global overviews on spaceflights, e.g., *http://en.wikipedia.org/wiki/2005_in_spaceflight* show that geosynchronous satellites also are launched from this site.

We have initially focused our attention on two launches, one on 19 June 2003 and another on 21 June 2005. See Table 6.2.1 for details.

Table 6.2.1. Rocket launches at the Plesetsk Cosmodrome observed at the infrasound stations in Apatity, Jämtön and Kiruna

Launch Year/Date/Time	Rocket	Orbit	Mission/Function
2003 19 June 20:00 GMT	Molniya M (R-7 8K78M)	Highly elliptical (Molniya)	Communications Satellite
2005 21 June 00:49 GMT	Molniya M	Geosynchronous	Communications Satellite

We have analyzed signals from these rocket launches recorded both at the Apatity infrasound array (Vinogradov and Ringdal, 2003) and by the stations of the Swedish Infrasound Network. The Swedish Infrasound Network (Liszka, 2007) has been in operation since the beginning of the 1970s. Operated by the Swedish Institute of Space Physics, the network has until the end of 2006 consisted of four infrasound stations: Kiruna, Jämtön, Lycksele and Uppsala. The station in Uppsala was moved to Sodankylä, Finland, during the fall of 2006. Figure 6.2.1 shows the location of the infrasound stations currently in operation and the Plesetsk Cosmodrome. Table 6.2.2 gives information on the distance and back-azimuth for the different stations to Plesetsk.

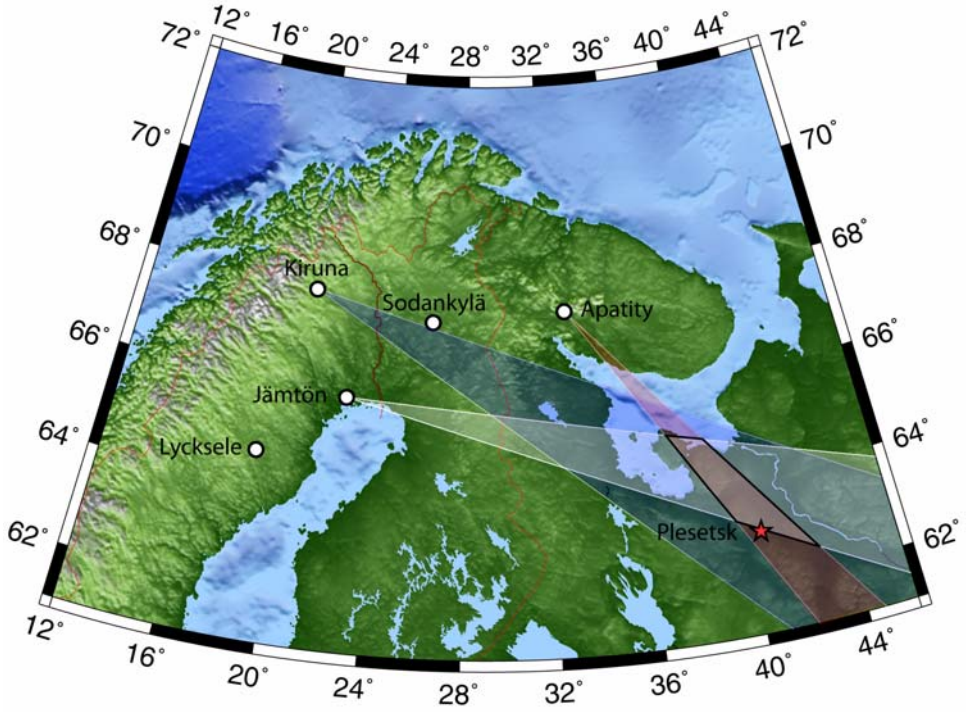

Figure 6.2.1. Map showing the location of existing infrasound stations in Sweden, Finland and NW Russia (filled white circles). The location of the Plesetsk Cosmodrome is shown by the red star. The azimuthal sectors from Kiruna, Jämtön and Apatity represent the range of back-azimuth estimates during the wavetrain of infrasound signals from the 2003 and 2005 rocket launches.

Table 6.2.2. Distances and back-azimuths from given infrasound stations to the Plesetsk Cosmodrome

Station	Latitude (N)	Longitude (E)	Distance (km)	Back-azimuth (^{o})
Apatity	67.60	32.99	628	142.6
Sodankylä	67.42	26.39	828	120.6
Jämtön	65.86	22.51	925	102.4
Kiruna	67.86	20.42	1077	111.1
Lycksele	64.61	18.75	1085	90.1

Data Processing

In order to get an overview of the signal characteristics we have processed the infrasound data using vespagram analysis. Using a fixed apparent sound velocity of 0.333 km/s, we have calculated the resulting normalized beam power for a range of back-azimuths, where the maximum represent an estimate of the back-azimuth of the arriving signal. In our calculations we have used a window length of 10 seconds and a window step of 1.0 second. The Apatity infrasound data were processed in the 1 - 3 Hz frequency band, whereas the stations of the Swedish Infrasound network were all processed in the 2 - 5 Hz band. Figure 6.2.2 shows the results for the 2003 and 2005 Plesetsk rocket launches, given in Table 6.2.1 for the stations Apatity, Jämtön and Kiruna. We observe the following general characteristics:

Apatity:

1) Some differences in waveforms between the 2003 and 2005 events.
2) Quite similar azimuthal vespagrams, with a trend of changing back-azimuths versus time. Such observations are indicative of a moving source.
3) Signal durations of almost 10 minutes. High SNR signals.
4) Back-azimuths ranging between 145 and 137 degrees

Jämtön:

1) Quite similar waveforms and vespagrams for the 2003 and 2005 events
2) Signal duration of about 5 minutes. Moderate SNR signals.
3) Back azimuths ranging between 91 and 102 degrees

Kiruna:

1) Quite similar waveforms and vespagrams for the 2003 and 2005 events
2) Signal duration of about 5 minutes. Low SNR signals with influence of local noise.
3) Back azimuths ranging between 101 and 118 degrees

For two additional Plesetsk rocket launches in 2005 and 2007 (see Table 6.2.3) we have also quite good recordings at the Apatity array. These are shown in Figure 6.2.3, together with the Apatity observations of the 2003 and 2005 reference events. We see that the 2007 event has a low SNR and is influenced by local noise at the station, and it is difficult to interpret the results. However, the 27 October 2005 signal has a characteristics similar to the 2003 and 2005 reference events, but with the exception that the trend of back-azimuthal change versus time is reversed. This may be explained by differences in rocket takeoff directions relative to the Apatity station.

In order to find how the direction estimates compare with the direction to the Plesetsk Cosmodrome, we have in Figure 6.2.1 plotted azimuthal sectors from Apatity, Jämtön and Kiruna spanning the range of azimuth estimates observed during the different infrasound wavetrains. It is interesting to notice that the area of overlap between the different sectors include the actual launch site. However, additional factors like atmospheric inhomogeneities, the wind field along the infrasound propagation path and the altitude and location of the infrasound source (the rocket) will most likely introduce biases in the azimuth estimates relative to the predicted Plesetsk direction.

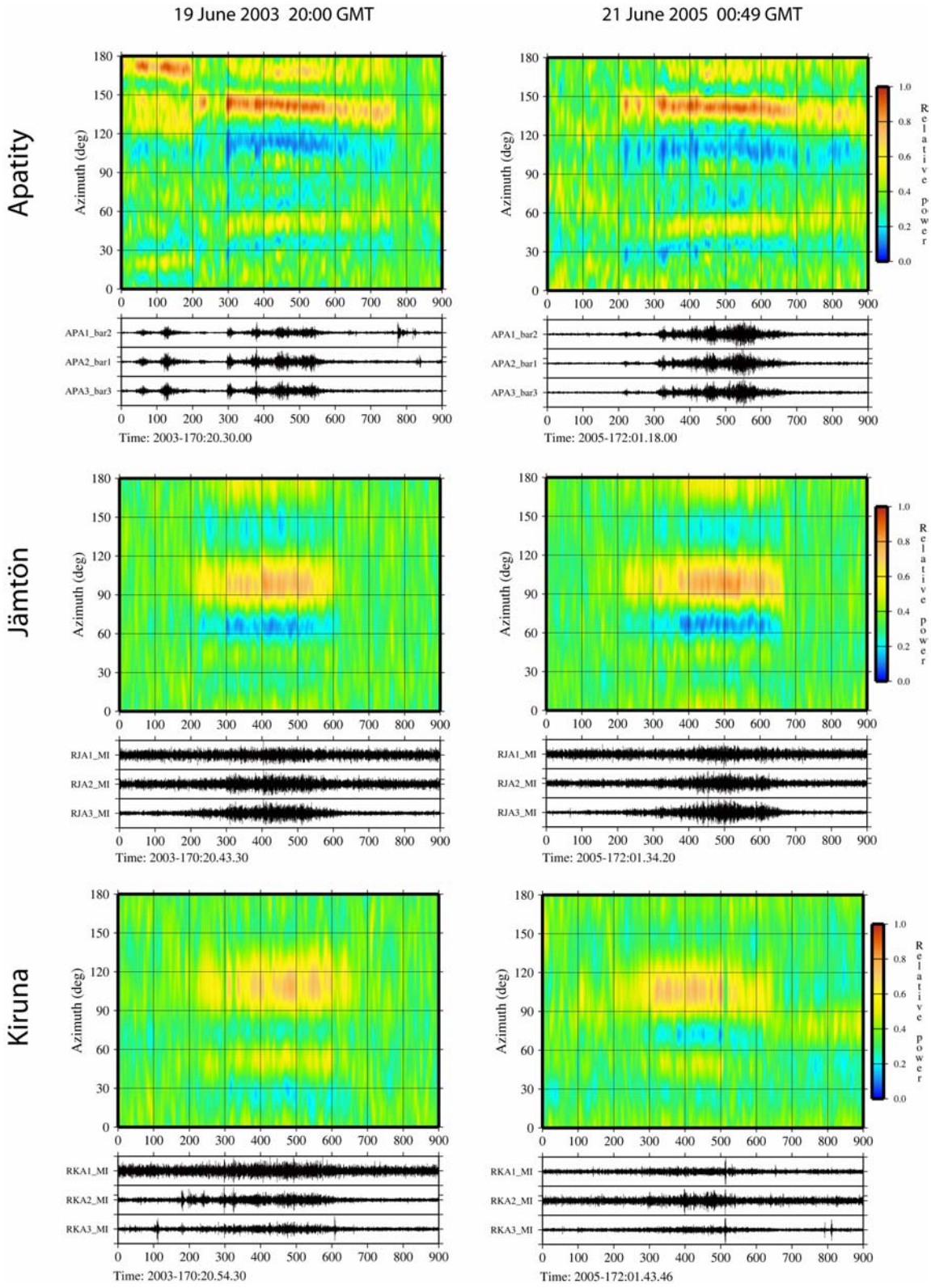

Figure 6.2.2. Each panel shows the infrasound waveforms from Apatity, Jämtön and Kiruna as well as the corresponding azimuthal vespagram of the signals from the 2003 and 2005 Plesetsk rocket launches given in Table 6.2.1

Table 6.2.3. Rocket launches at the Plesetsk Cosmodrome observed only at the Apatity infrasound station

Launch Year/Date/Time	Rocket	Orbit	Mission/Function
2005 27 October 06: 52 GMT	Kosmos-3M	Low Earth Orbit	Civilian mission, multiple payloads
2007 25 December 13:10 GMT	RS-24	Multiple re-entry vehicles	ICBM test

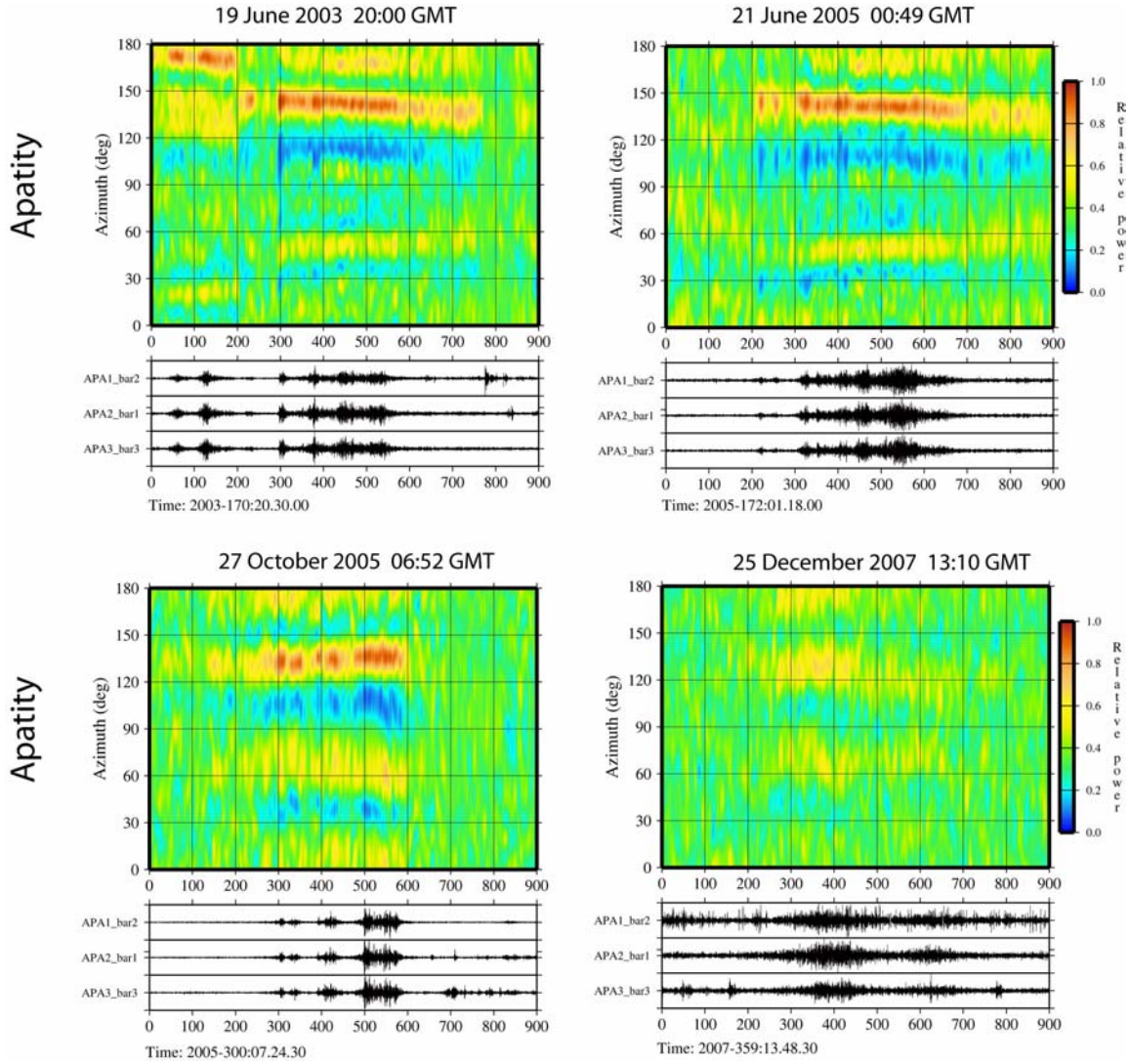

Figure 6.2.3. The two lower panels show Apatity data and vespagrams for the 2005 and 2007 Plesetsk rocket launches listed in Table 6.2.3. The two upper panels show similar plots for the 2003 and 2005 events listed in Table 6.2.1

Signals observed on 23 January 2007

During an exercise with processing of continuous data from the infrasound stations shown in Figure 6.2.1, we detected for 23 January 2007 a series of 5 very interesting signals. At the Apatity station, the waveforms had a duration of 5 - 8 minutes and time-varying back-azimuths. The directions were a bit to the south of the back-azimuth estimates obtained for previously analyzed Plesetsk rocket launches. The similarity with / difference between the 23 January 2007 signals and the reported Plesetsk rocket launches can be observed by comparing Figure 6.2.4 with Figure 6.2.3.

For two of the events (at 10:30 and 13:00) we had also detections at the Jämtön and Kiruna stations, and Figure 6.2.5 shows the corresponding panels with Apatity, Jämtön and Kiruna data. Figure 6.2.5 can be compared with Figure 6.2.2 in order to see how the Jämtön and Kiruna data compare with signals from known Plesetsk rocket launches.

During the fall of 2007 the Swedish infrasound station in Uppsala was moved to Sodankylä, Finland. Four of the 23 January 2007 events were also detected at this station, and the corresponding data and vespagrams are shown in Figure 6.2.6.

We were not able to find any reports on rocket launches from the Plesetsk Cosmodrome on 23 January 2007, but the signals has some striking similarities with those from the 2003 and 2005 verified rocket launches. In particular this concerned the duration of the signals (5-8 minutes) and the observation of time varying azimuths (in both directions) at the Apatity array.

The main difference were in the back-azimuth estimates, where the 23 January events were generally 10-15 degrees more to the south than those for the verified rocket launches.

We have in Figure 6.2.7 plotted azimuthal sectors from Apatity, Sodankylä, Jämtön and Kiruna spanning the range of azimuth estimates observed during the different infrasound wavetrains on 23 January 2003. Except for Sodankylä, the azimuth sectors are biased southwards relative to the Plesetsk Cosmodrome. As seen from the figure, there exists a small area of overlap between the sectors, but this cannot be confidently be interpreted as representative for the actual source location. Nevertheless, all the sectors contain the Plesetsk site, and it seems likely that they correspond to actual (unconfirmed) Plesetsk launches.

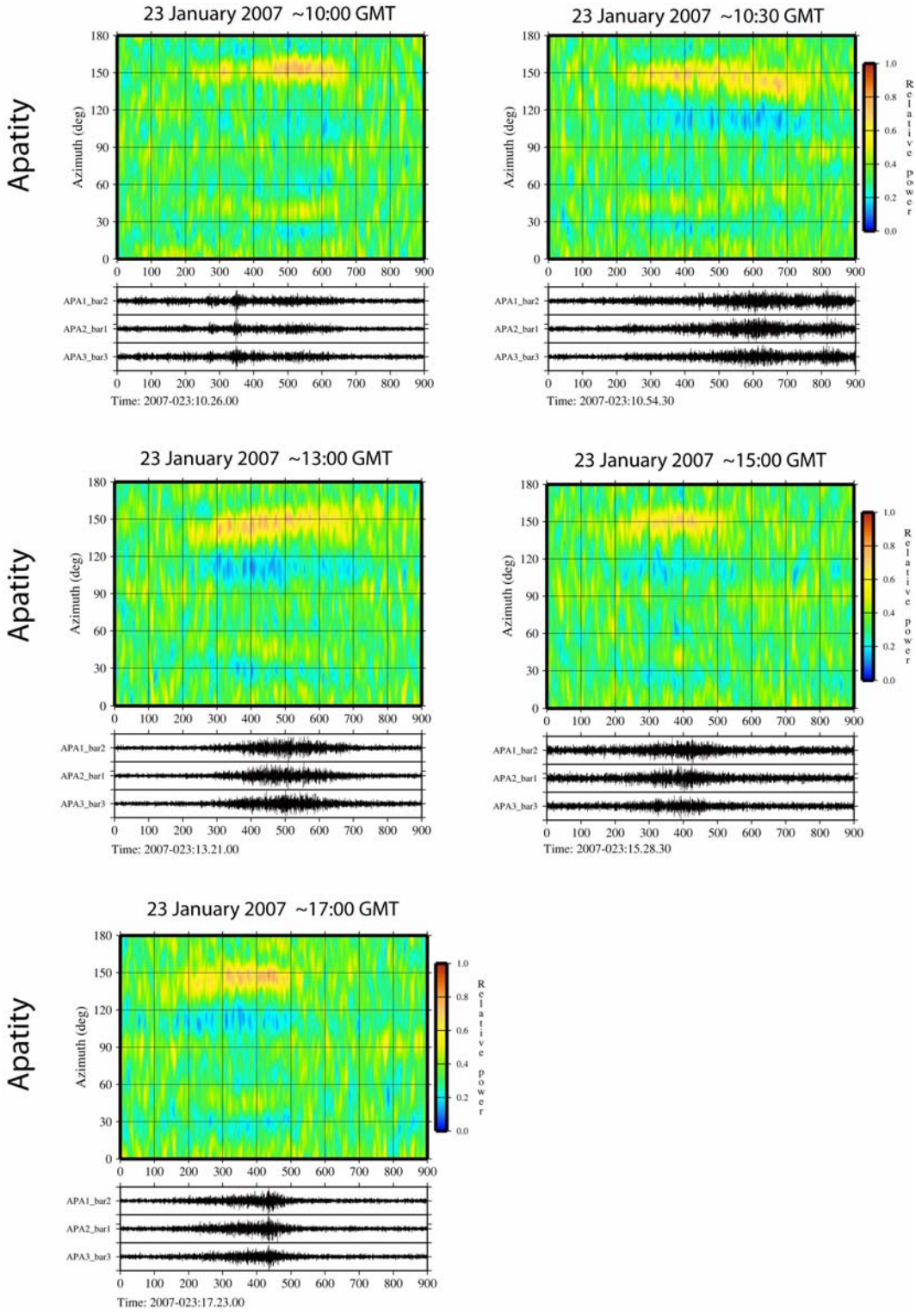

Figure 6.2.4. Apatity data and vespagrams for the 5 infrasound signal recorded on 23 January 2007. Approximate origin times (to the nearest half hour) are given above each event panel.

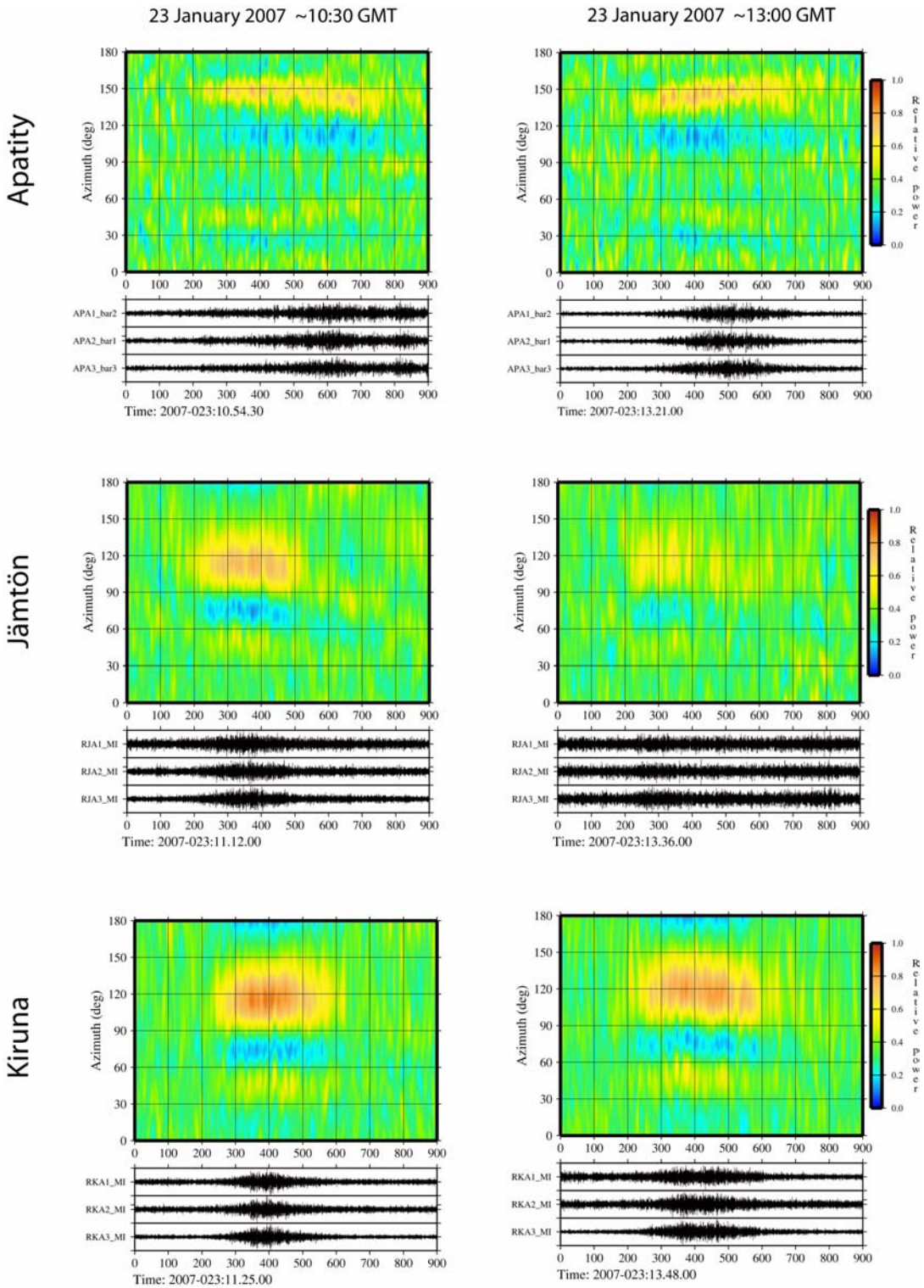

Figure 6.2.5. Each panel shows the infrasound data and azimuthal vespagram of the signals from two of the events on 23 January 2003.

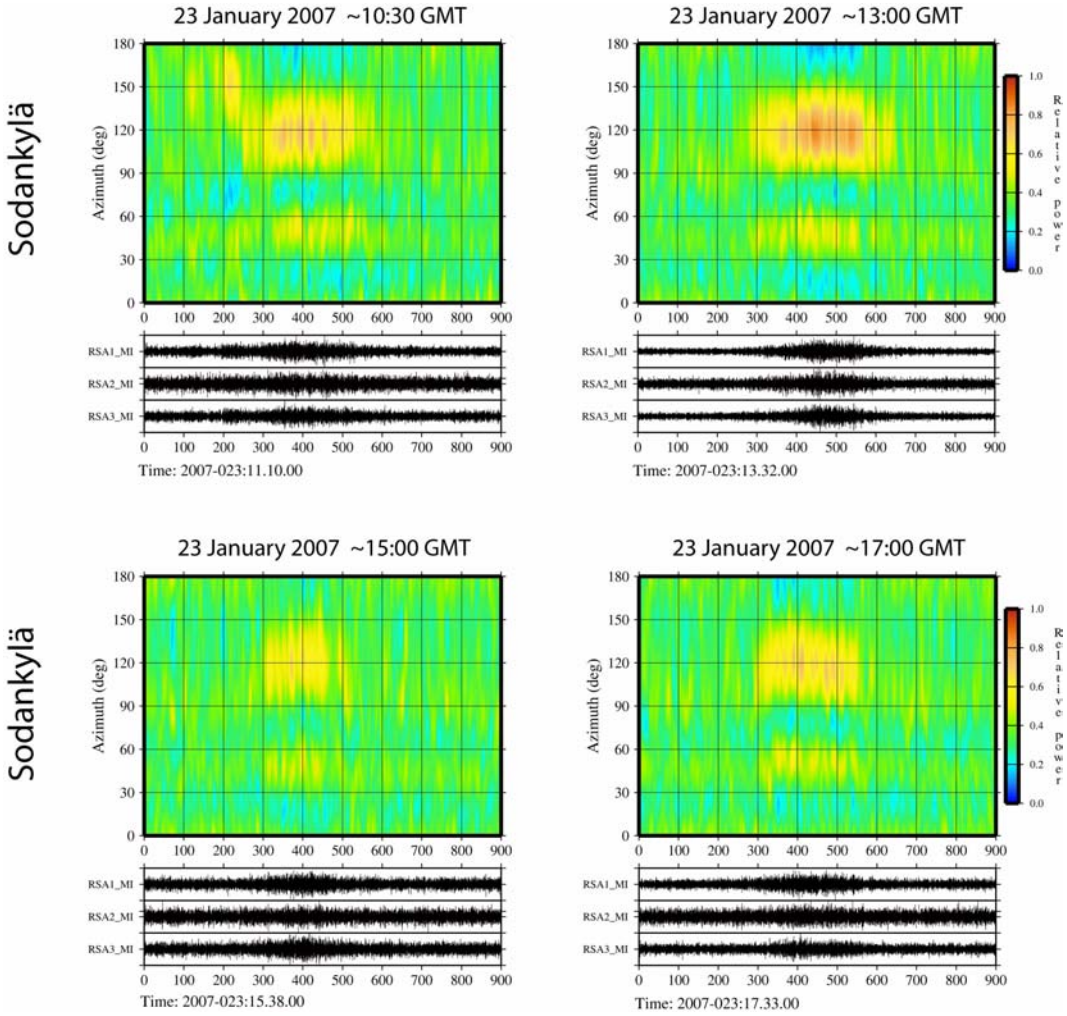

Figure 6.2.6. Sodankylä data and vespagrams for 4 of the infrasound signal recorded on 23 January 2007. Approximate origin times (to the nearest half hour) are given above each event panel.

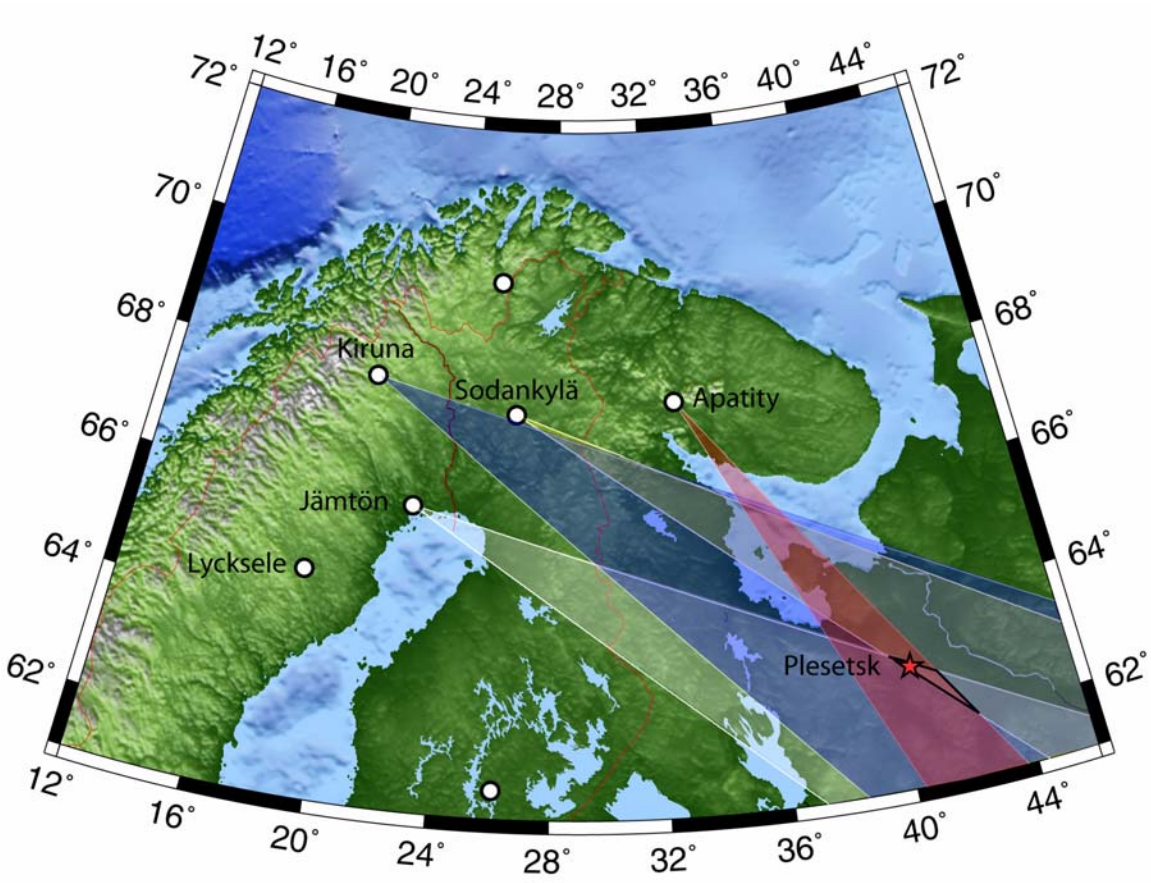

Figure 6.2.7. Map showing the azimuthal sectors from Kiruna, Sodankylä, Jämtön and Apatity that represent the variability of back-azimuth estimates calculated during the wavetrain of infrasound signals recorded on 23 January 2003.

Discussion

As a final step in our analysis we calculated differential travel-times for onsets of the infrasound signals at the Jämtön and Kiruna stations relative to Apatity. The onsets were read visually from the vespagrams, and had a rather high uncertainty. Similarities in the vespagram patterns were also used to infer the onsets. The results are given in Table 6.2.4, and we find that we cannot separate the source location for the unknown signals from the verified Plesetsk launches based on these differential travel times.

Table 6.2.4. Differential travel times relative to the Apatity infrasound signal

Event Year/Date/Time	Jämtön	Kiruna
Plesetsk launch 2003 19 June 20:00 GMT	13 min. 32 s (812 s)	25 min. 58 s (1558 s)
Plesetsk launch 2005 21 June 00:49 GMT	17 min. 50s (1070 s)	27 min. 6 s (1626 s)
Unknown origin 2007 23 January ~10:30 GMT	19 min. (1140 s)	30 min. 30 s (1830 s) Low SNR, most probably late onset
Unknown origin 2007 23 January ~10:30 GMT	15 min. (900 s)	26 min. (1560 s)

This study has provided us with very useful information on the characteristics of infrasound signals from the Plesetsk Cosmodrome in Northwest Russia. The signals exhibit significant similarities with respect to signal duration and overall back-azimuths. In particular the trend of changing back-azimuth versus time (both directions) at the Apatity station is a pronounced feature. There are large variability within the differential travel times and also within the back-azimuth estimates calculated during a given infrasound wavetrain.

We have not been able to locate the origin of the sources of the infrasound signals on 23 January 2007. Generally they have several characteristics in common with the Plesetsk rocket launches, indicating moving sources. For Apatity, Jämtön and Kiruna the general back-azimuths are 10-15 degrees to the south of those from the verified Plesetsk rocket launches.

Acknowledgements

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