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6.2 Infrasound observations from the meteor north of Norway on 15 January 2009 (sponsored by US Army Space and Missile Defence Command, Contract no. W9113M-05-C-0224)

6.2.1 Introduction

In the evening of 15 January 2009, light flashes and a fireball were observed over parts of Northern Norway. Figure 6.2.1 shows some locations with visual observations of the object, which was reported to propagate in a north-northwesterly direction into the Barents Sea. Based on newspaper reports, the time of the event is estimated to 19:40 GMT.
The signals from the meteor, recorded at the 4 infrasound arrays operated by the Swedish Institute of Space Physics (IRF) were analyzed within a short time after the event. Prof. Liszka of IRF estimated the signals to originate halfway between mainland Norway and Svalbard. For details see *http://www.irf.se/Topical/Other/?newsid=7&group=P2*.

We will in this contribution provide results from additional analysis of signals at the IRF stations (Liszka and Kværna, 2008), as well as at the infrasound station in Apatity (Vinogradov and Ringdal, 2003) and at an experimental infrasound deployment within the ARCES array (Roth et. al., 2008).

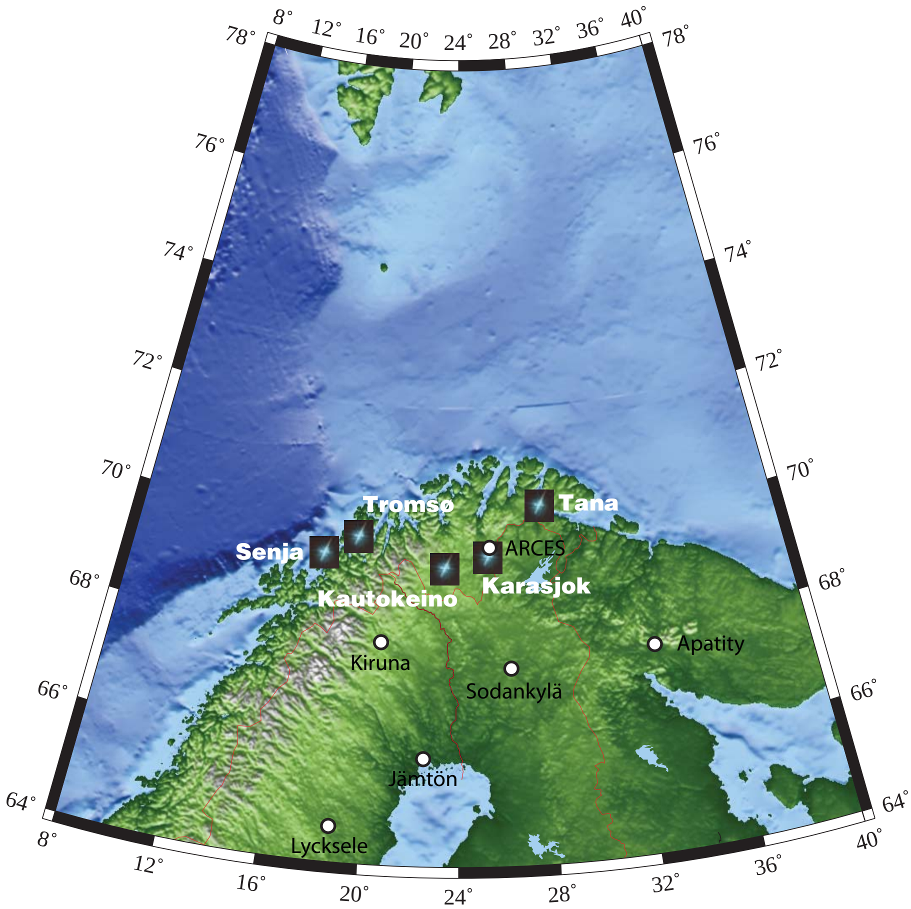

Fig. 6.2.1. The black symbols show some of the locations in Northern Norway (white text) with reported visual observations of the 15 January 2009 meteor. The infrasound stations in Sweden, Finland, NW Russia and Norway are shown as filled white symbols.

6.2.2 Data Processing and Location

For each of the stations (see Figure 6.2.1), we have processed the infrasound data using vespagram analysis. Using a fixed apparent velocity around 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. Because of the larger array apertures, the ARCES and Apatity infrasound data were processed in the 1 - 4 Hz frequency band, whereas the stations of the Swedish Infrasound network were all processed in the 2 - 5 Hz band. Figures 6.2.2-6.2.4 show the results from the vespagram analysis together with the raw and bandpass filtered waveforms,

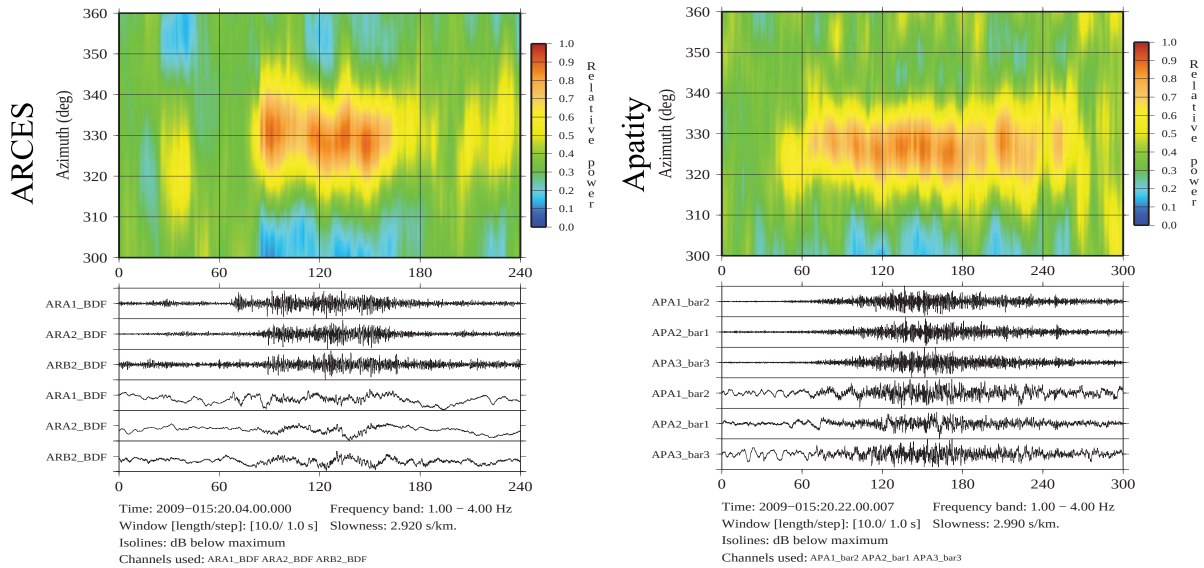

Fig. 6.2.2. Azimuthal vespagrams from analysis of ARCES and Apatity infrasound data for the time interval around the signals from the meteor on 15 January 2009. The upper three traces of each panel show the bandpass filtered waveforms, whereas the three lower traces show the raw data. Notice that different time scales are used for the two stations. A constant slowness close 3 s/km has been used when calculating the azimuthal vespagrams.

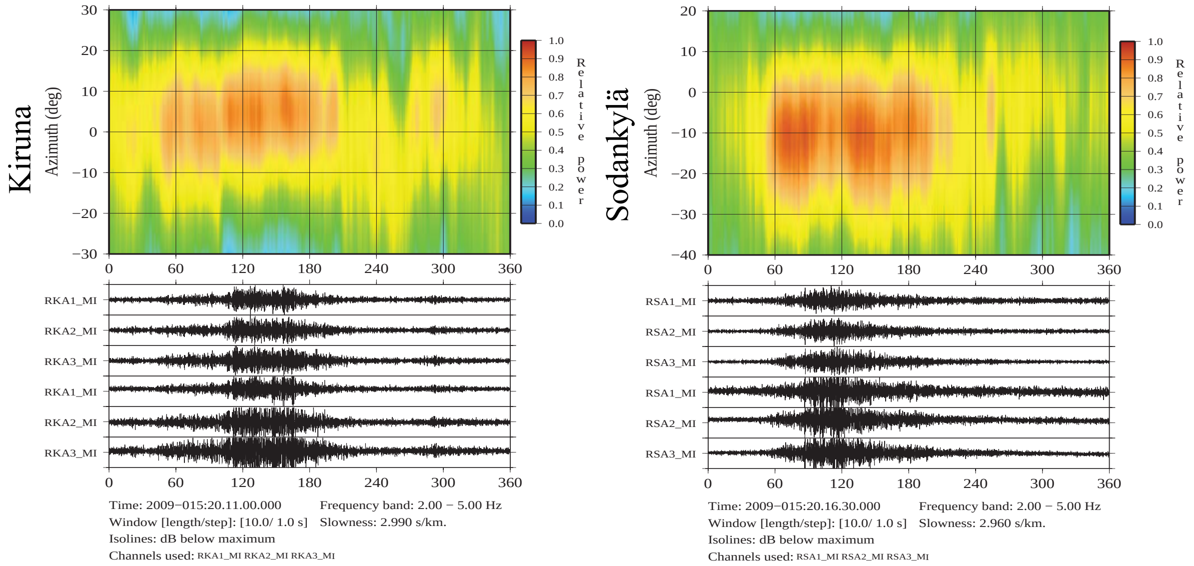

Fig. 6.2.3. Azimuthal vespagrams from analysis of Kiruna and Sodankylä infrasound data for the time interval around the signals from the meteor on 15 January 2009. For these two stations the raw data is clipped. See caption of Figure 6.2.2 for more details.

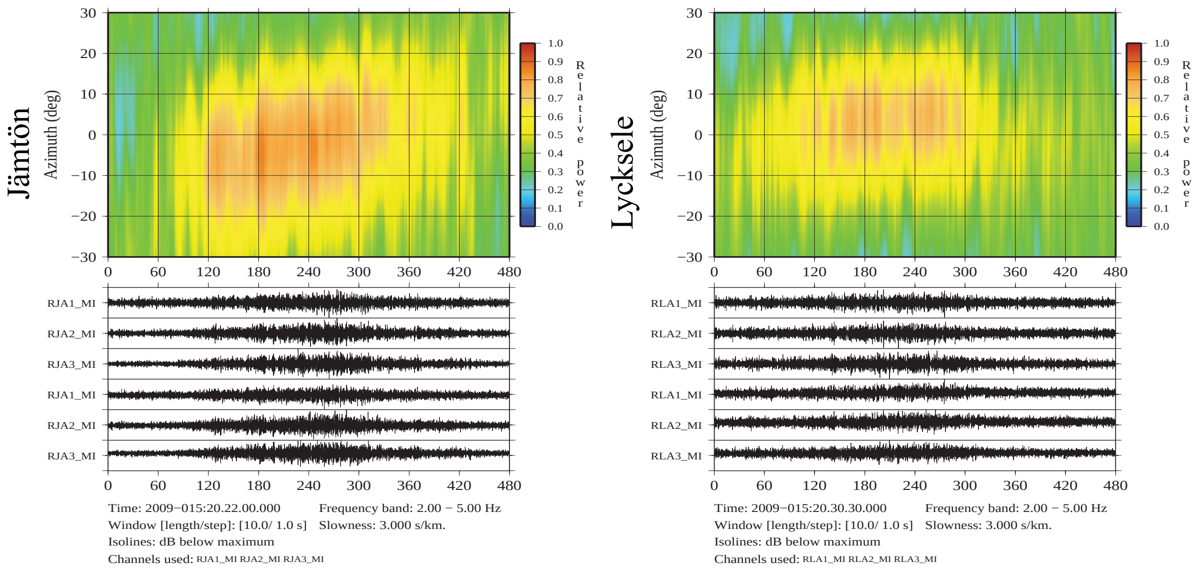

Fig. 6.2.4. Azimuthal vespagrams from analysis of Jämtön and Lycksele infrasound data for the time interval around the signals from the meteor on 15 January 2009. See caption of Figure 6.2.2 for more details.

Table 6.2.1 gives the back-azimuths and apparent velocities for different parts of the infrasound signals, estimated using standard wide-band f-k analysis. The 1 - 4 Hz frequency band was used for ARCES and Apatity, and 2-5 Hz for the IRF arrays. The time windows varied between 10 and 20 seconds.

Table 6.2.1. Estimated back-azimuths and apparent velocities of infrasound signals from the meteor on 15 January 2009

Station	Lat (N)	Lon (E)	Front part of signal			Back part of signal		
			Start time	Baz (°)	App. vel (km/s)	Start Time	Baz (°)	App. vel (km/s)
ARCES	69.55	25.51	20:05:27	330.88	0.34	20:06.30	329.94	0.35
Kiruna	67.86	20.42	20:11:50	6.18	0.29	20:13:50	8.44	0.30
Sodankylä	67.42	26.39	20:17:30	349.77	0.33	20:19:30	350.06	0.35
Apatity	67.60	32.99	20:23:20	328.05	0.33	20:25:20	327.66	0.34
Jämtön	65.86	22.51	20:24:00	353.54	0.34	20:27:10	0.85	0.35
Lycksele	64.61	18.75	20:32:40	2.43	0.32	20:35:00	5.34	0.33

Compared with analysis of a large number of infrasound signals from a military ammunition demolition site in Finland (Gibbons et. al. 2007), we have found a relatively large variability in back-azimuth estimates. This variability can be caused by several factors, like wind conditions, local noise sources, low SNR or data quality problems. In this study, we have assigned a variability of ± 8 degrees around the average back-azimuth estimates for each station, and the corresponding back-azimuthal sectors from each station are shown in Figure 6.2.5. As indicated in Figure 6.2.5, there is a small area of intersection in the Barents Sea, close to the Finnmark coast.This area is an indication of the source region of the infrasound signals, i.e., where the meteorite exploded.

15 January 2009

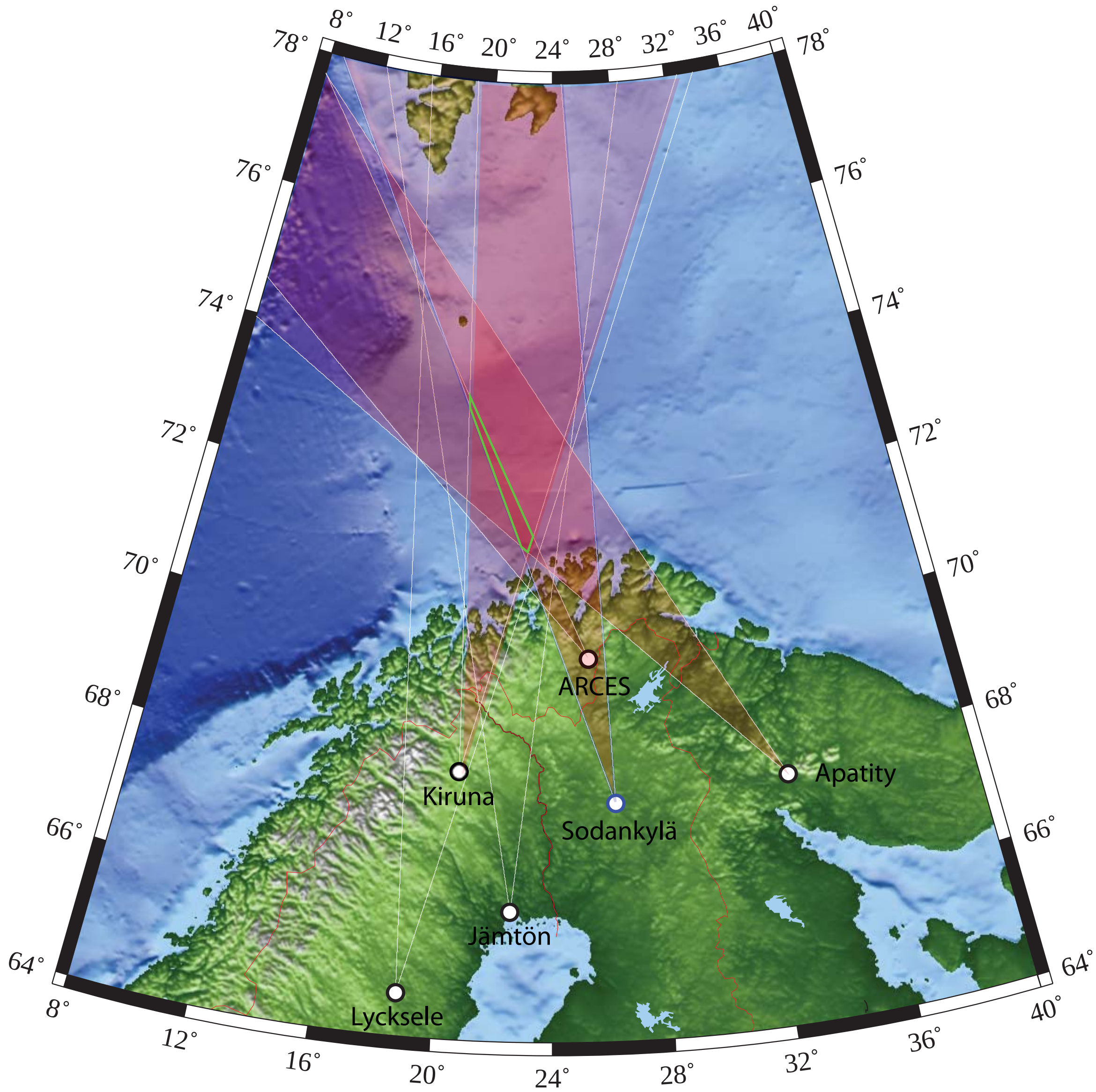

Fig. 6.2.5. Map showing the sectors of back-azimuths of infrasound signals from the meteor as observed at the infrasound stations in Sweden, Finland, NW Russia and Norway. For each station, a sector of ±8 degrees around the average back-azimuth estimate is plotted. The highlighted green polygon shows the area of common intersection. No corrections for the wind field are introduced to the back-azimuth estimates.

Another approach to source location is to use the reported origin time of the event. According to a newspaper report, the origin time of 19:40 GMT was read from the display of a cellular telephone at the time of the meteor observation. This gives us the possibility to calculate the travel-time to each station, which again can be scaled with a standard celerity for stratospheric arrivals of 0.29 km/s to obtain a distance estimate. Table 6.2.2 provide information about the arrival time of the main signal energy at the different stations, the corresponding travel-time and the estimated distance to the source using a standard celerity value of 0.29 km/s.

Table 6.2.2. Distance estimates to the 15 January 2009 meteor explosion at 19:40 GMT

Station	Lat(N)	Lon(E)	Main signal energy	Traveltime (s)	Distance (km) Celerity 0.29 km/s
ARCES	69.55	25.51	20:06:00	1560	452
Kiruna	67.86	20.42	20:13:00	1980	574
Sodankylä	67.42	26.39	20:18:30	2310	670
Apatity	67.60	32.99	20:24:30	2670	774
Jämtön	65.86	22.51	20:26:00	2760	800
Lycksele	64.61	18.75	20:33:30	3210	931

We have in Figure 6.2.6 plotted arcs of the estimated distances from each station, together with the lines of back-azimuth estimates given in Table 6.2.1. The intersection of the distance arcs provide indications of the location of the event, and the white ellipse, with center coordinates 72.1^{o} N, 20.3^{o}E, covers all intersections. In Figure 6.2.6 we have also plotted the area of common azimuthal intersections, also shown in Figure 6.2.5.

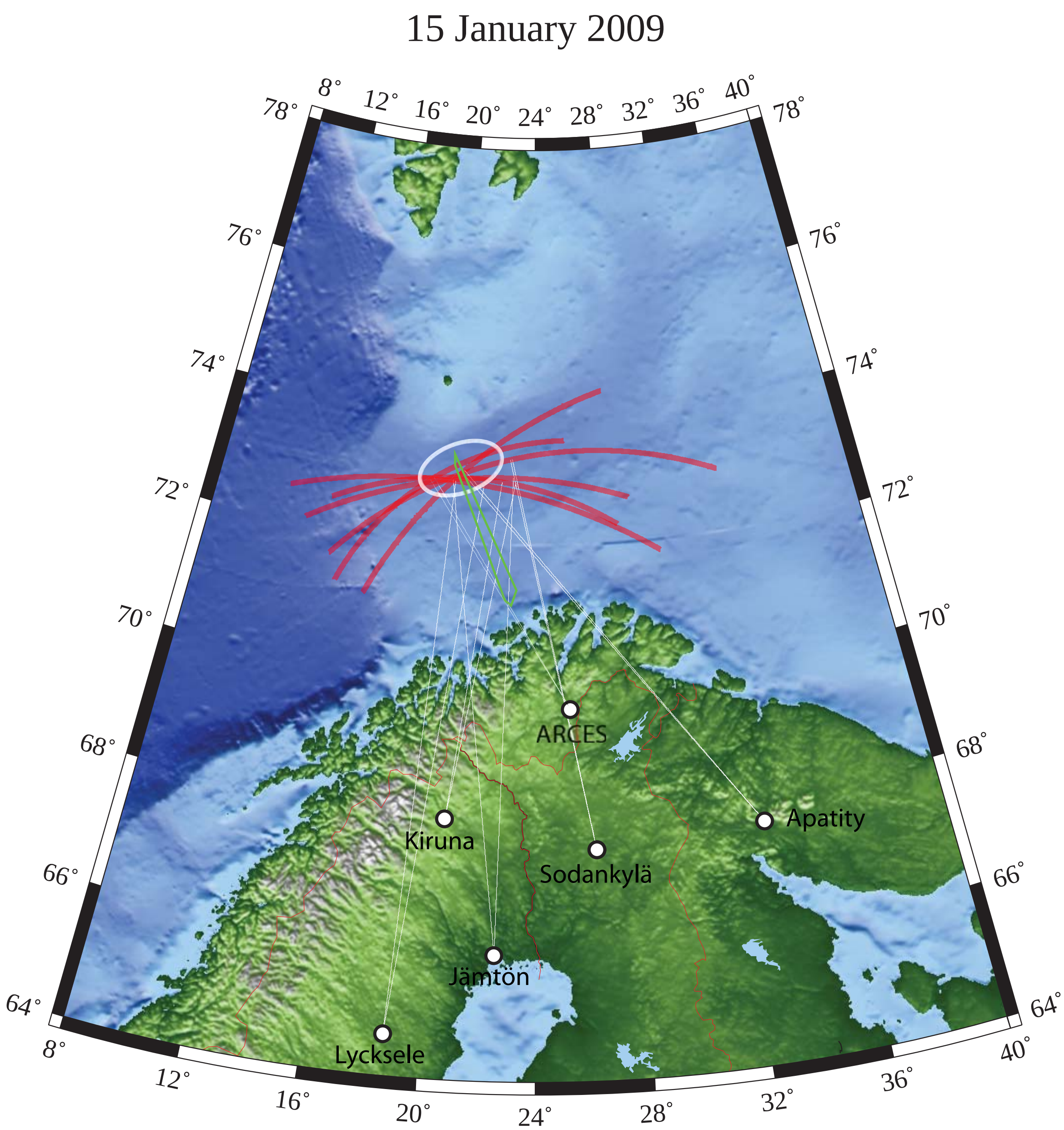

Fig. 6.2.6. Station-source distance estimates are shown as red arcs, and the white ellipse covers all intersection points between the different distance arcs. The center of the ellipse is at 72.1° N, 20.3°E, and indicate the location of the meteor explosion. The green polygon shows the area of common azimuthal intersections, also shown in Figure 6.2.5.

6.2.3 Conclusions

We have estimated the location of the meteorite explosion over the Barents Sea on 15 January 2009 to 72.1° N, 20.3°E. The semi-major axis of the ellipse covering all intersection points between the different distance arcs is approximately 35 km, and indicate the uncertainty of the location estimate. Smaller meteors usually disintegrate at an altitude around 20 km.

We have also demonstrated that several stations show significant deviations in the back-azimuth estimates as compared to the great-circle path to the source, and it is our plan compare these deviations with the observed wind field in the region. In this way it may be possible to correct for wind effects when applying the back-azimuths for location purposes.

It is also interesting to observe that a standard celerity value of 0.29 km/s provides quite consistent distance estimates to the different stations observing the signals.

This latest meteor explosion supplements two previous such observations in Norway during 2006 (Schweitzer and Kværna, 2006). Establishing a database of such events will be important for future studies of infrasound wave propagation.

Acknowledgements

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