Swedish-Finnish Infrasound Network – The Research Program

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Continuous observations of infrasound started in Sweden 1972. Three arrays in Northern Sweden were later completed with an array in Uppsala. The Uppsala-array was moved in 2006 to Sodankylä, Finland starting the Swedish-Finnish Infrasound Network (SFIN), a co-operative project between the Swedish Institute of Space Physics and the Sodankylä Geophysical Observatory. The data collected by the SFIN are displayed on the Internet, accessible for the scientific community.

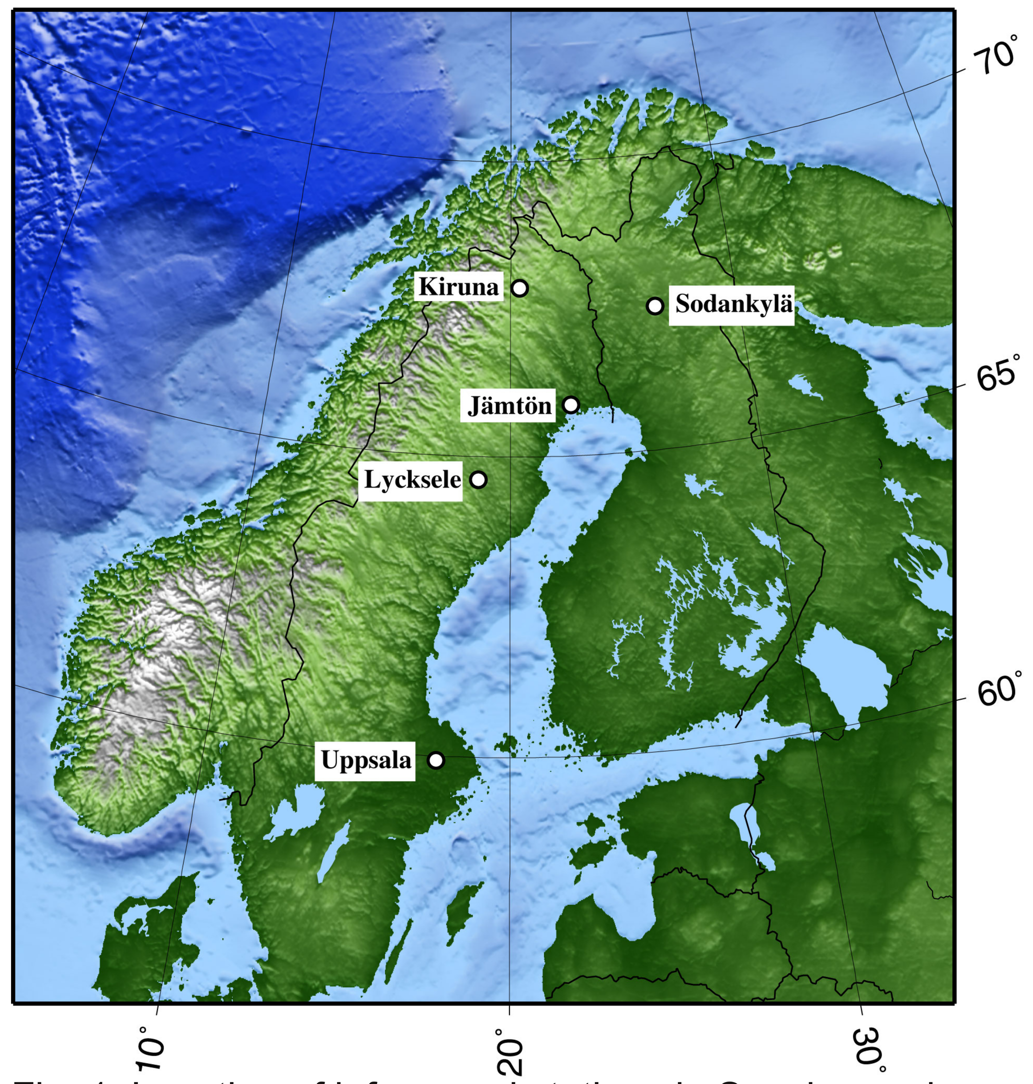

Fig. 1. Location of infrasound stations in Sweden and Finland.

The infrasound project at the Swedish Institute of Space Physics covers three main topics.

1. Source detection and identification

Detection of natural and man-made infrasonic sources. During more than three decades infrasound from numerous natural and man-made sources, like meteoroid entries, supersonic aircraft and explosions were recorded, and in many cases localized. Major achievements:

- In 1974: discovery of long-distance propagation of infrasound from Concorde
- In 1995: identification of infrasonic chirps, generated by sprites, high altitude electric discharges occurring at heights up to 90 km.

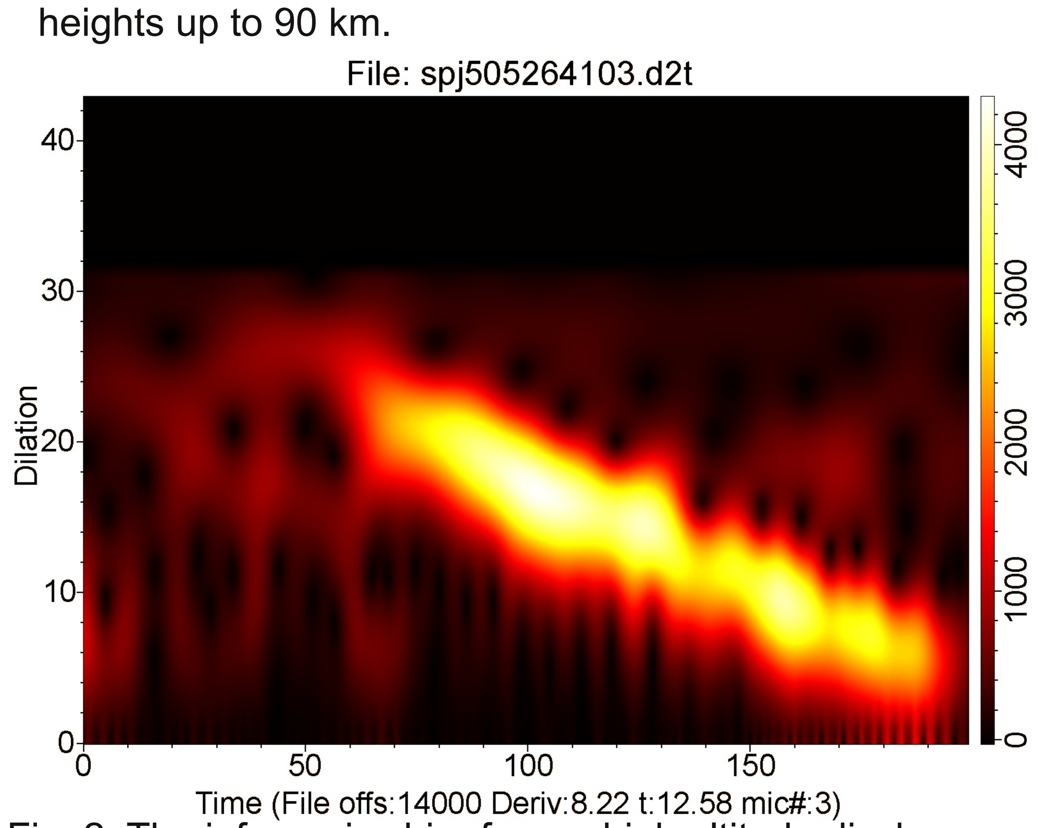

Fig. 2 The infrasonic chirp from a high altitude discharge, sprite.

2. Data mining

Since 1994 the Swedish Institute of Space Physics maintains a database containing digitised time series from all infrasonic arrays operated by the Network. The immense amount of infrasonic data requires efficient methods for data search and event identification.
Monitoring of complex systems is connected with collecting large quantities of, what we think is, relevant data (variables). These variables are usually sampled time series. Each state of the system is associated with a set of values of the system variables (a multidimensional feature vector). The variables are either the system's attributes / features, or a source of information about the attributes. Since, as a rule, we do not know causal relations between variables, the components of the feature vector may be a mixture of independent and dependent variables. The objectives of system monitoring is, both to identify the known states of the system and to detect new, earlier unidentified, states of the system. These procedures are known as *pattern recognition*. It is also important to determine possible relations between variables and between the different states of the system. The amount of data describing the system is often immense and its study time consuming. The extensive exploration of such data is known as "data mining". A particular group of methods, which try to emulate the human cognition processes and may be used in data mining have been described in an earlier book (Liszka, 2003).
During the recent decade numerous data mining methods were adapted for studies of infrasonic data and tested. One of major projects was the search for unknown meteroid entries in the surroundings of Northern Europe, occurring during the past 10 years.

Feature extraction – the multiple indicator model

It has been found by the present author that the infrasonic data are most efficiently described by a number of distribution parameters (indicators) of relevant variables. The method of representing a process through descriptive indicators is frequently used in social- and behavioural sciences, so called Multiple Indicator Method.
Indicators are distributions of variables within a given analyzing window:

- **Angle-of-arrival, A:** a distribution of angle-of-arrival is constructed using 10-degree bins. Then the distribution's entropy is calculated. The entropy value is used as one indicator. When looking for events within a particular area also the maximum value of A may be used as an indicator.
- **Horizontal trace velocity, Vp:** a distribution is constructed using 50 m/sec bins. The distribution counts between 300 and 700 m/sec are used as indicators (8 values).
- **Cross-correlation across the array:** a distribution is constructed using 0.1 bins. The distribution counts between 0.15 and 0.85 are used as indicators (7 values)
- **Spectral slope:** the average spectral slope (in A/D units per Hz) of the FFT spectrum between 0.4 and 1 Hz. The slope is mostly determined by the high-pass filter of the microphone, but is also influenced by the shape of the low frequency part of the spectrum. A distribution is constructed using 1000 A/D unit bins. The distribution counts between 0 and 6000 are used as indicators (6 values).

On a total, the signal is described by a vector of 22 indicators (1 + 8 + 7 + 6).
The reference information (time, date, eqipment settings etc.) are also a part of the vector, but are not used in the analysis itself. The next step of the analysis is to establish a set of reference data which will be used to calibrate the method.

The Neural Network Model

It has been found that a back-propagation type of neural networks is adequate enough to model properties of the meteoroid entry signal. The development software NW2v530 was used. The network configuration used here is shown in Fig. 3.

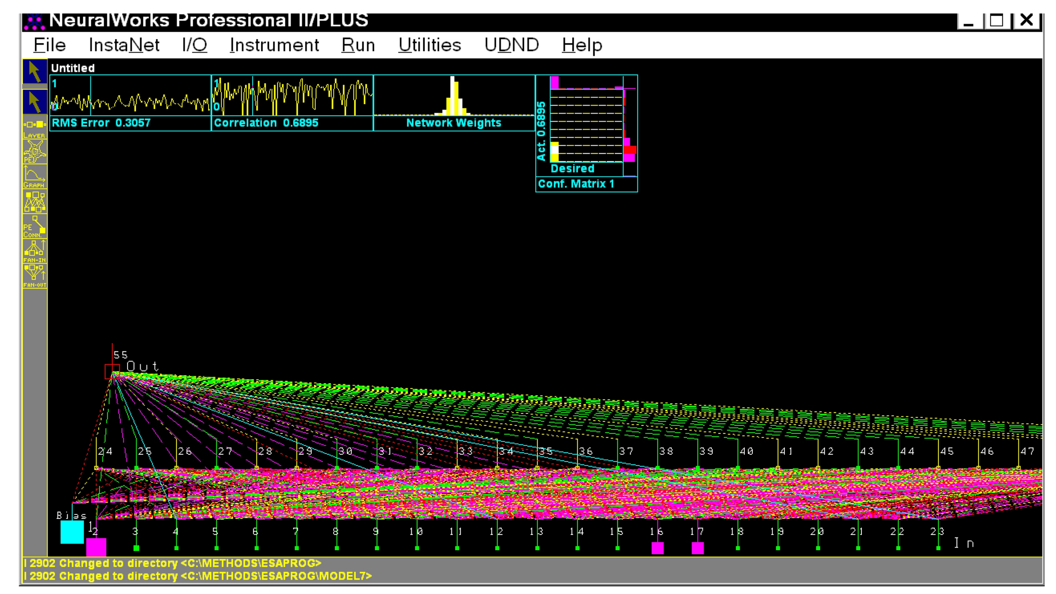

Fig. 3. The back-propagation type neural network used to develop a model of infrasonic signals from meteoroid entry events. The network has 22 input elements, 31 elements in the hidden layer and one element in the output layer.

During the training phase, 22 components of the multiple-indicator vector are placed in the input and the corresponding 23rd value (0 or 1) is placed in the output. The operation is repeated randomly 500,000 times until the network weights and hidden layer elements approach stable values. Training of the network is assumed to be

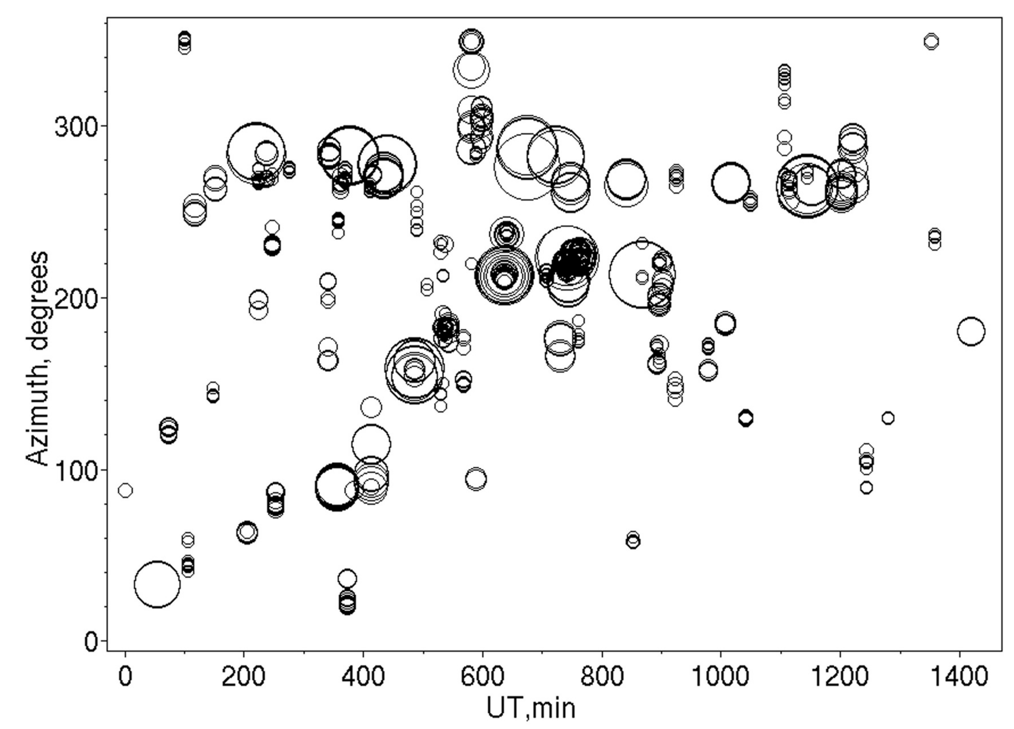

Fig. 4. An example of a daily plot showing validated infrasonic signals. The angle-of-arrival for each signal is plotted as a circle, whose diameter is proportional to the average weighting factor.

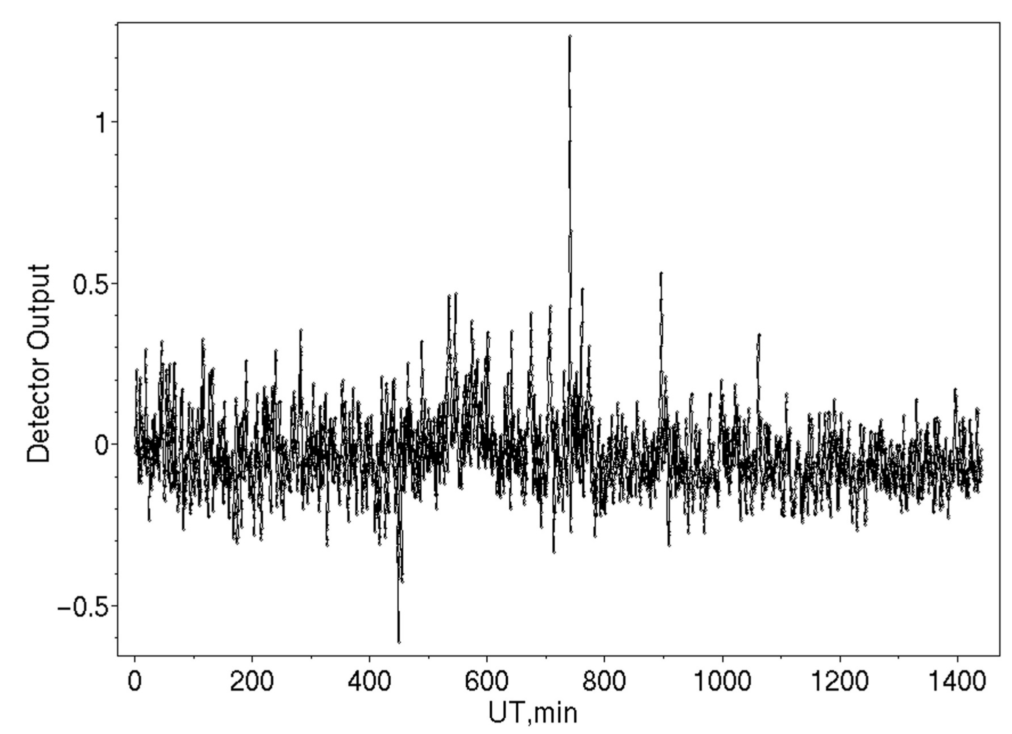

Fig. 5. An example of the event detector output for the same date as shown in Fig. 4.

completed and it may be used in the recall mode. In this mode, arbitrary values of the 22-component vector are placed in the input. The network then calculates the corresponding output. If the vector is similar to those recorded during an entry event, an output close to 1 will be obtained. If the output is close to 0, the analyzed signal does not show any similarity with the reference entry events. The ready model is extracted in a format of so-called flash-code, which may be converted into an executable file. The model, an event detector, generates a single output for each given value of the 22-component vector.
Unfortunately, some other supersonic objects, like aircraft and rockets, may occasionally generate signals very similar to those produced by meteoroid entries. These signals will also produce large event-detector outputs. For this reason, the list of event-detector outputs was manually reviewed to investigate the plausibility of the detection. The following criteria were used:

- A long-lasting infrasonic signal, which sometimes produces the detector indication, is most likely some other kind of supersonic object.
- For distant objects, a nearly constant trace velocity indicates a supersonic aircraft rather than a meteoroid entry.
- During the analyzed 10-year period, it is possible to check if possible entry events repeat at the same position of the Earth with respect to the Sun (day number).
- When the object's velocity can be measured, additional information may be drawn about its nature.

Also the continuous, automatized search for infrasonic chirps from sprites is carried on.

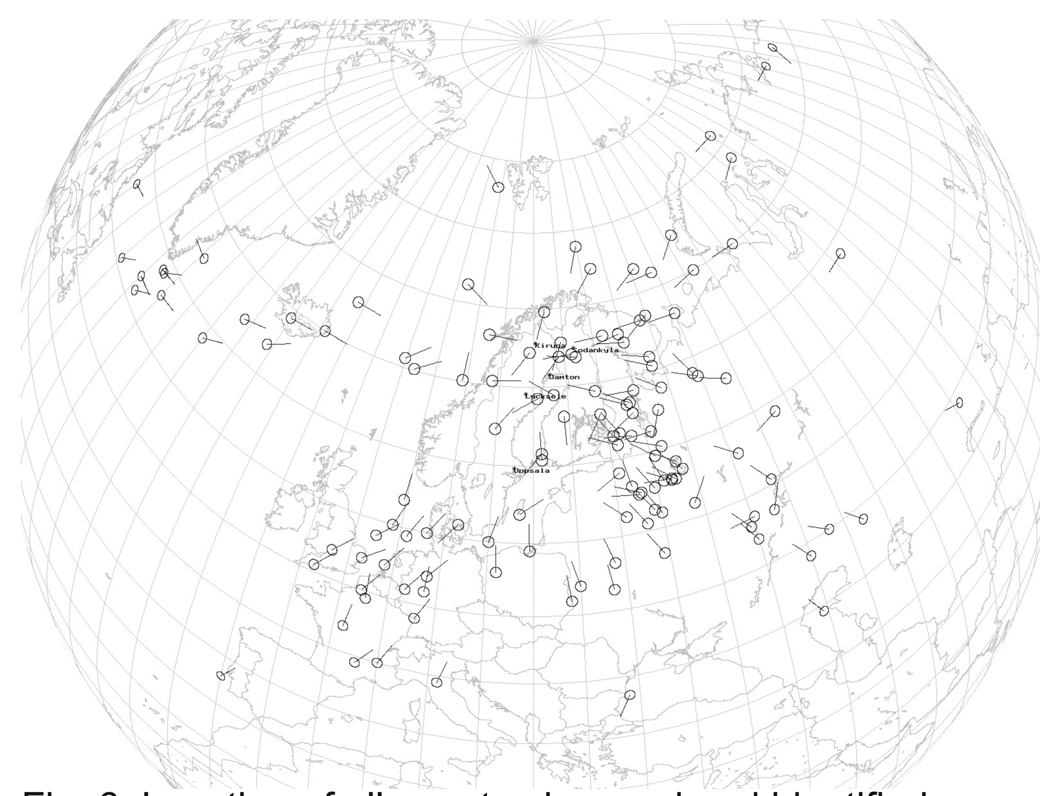

Fig. 6. Location of all events observed and identified during 1995-2005 for which the heading was determined. Headings marked by line segments.

3. Infrasonic signals from explosions

The proximity to the site of regularly occurring explosions in Northern Finland facilitates the access to high-accuracy propagation data. The influence of factors like the occurrence of atmospheric irregularities, non-linear effects around the explosion site, the contribution of tropospheric propagation, etc., is studied. The aim of this research project is to develop a probabilistic propagation model, which would improve the interpretation of infrasonic observations the determination of the true source location.

In November 2006 one of arrays was moved to Sodankylä in Northern Finland, only 62 km from the location where the yearly campaign of destruction of explosives takes place. Already in summer 2007 it has been found that, during certain meteorological conditions, the arrival of intense infrasonic waves from the explosion site is associated with the simultaneous occurrence of atmospheric vortices overhead of the array. As an example the explosion at 0730 UT on September 4, 2009 is shown in Fig. 7.

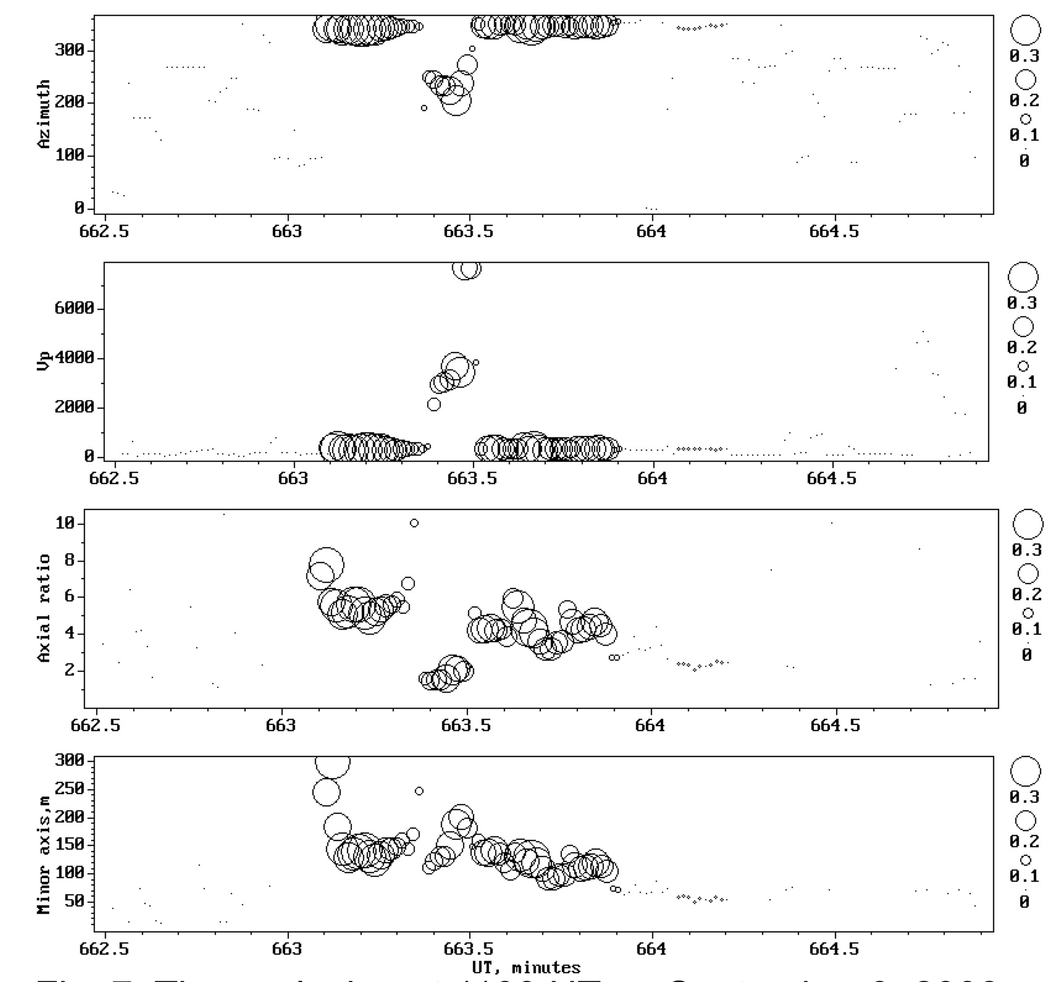

Fig. 7. The explosion at 1100 UT on September 3, 2008 recorded at Sodankylä, 62 km from the explosion site. The two uppermost graphs show the angle-of-arrival (graph 1) and the apparent trace velocity (graph 2) across the array. It may be seen that the explosion signal arriving from the true direction of 338 degrees is interrupted by the stronger signal coming from above (very high trace velocity). The frequency content and statistical properties of that signal are identical with, frequently observed, infrasonic signals from atmospheric vortices. The two lower graphs describe statistical properties of the signal: the axial ratio of the correlation ellipse (graph 3) and the minor axis (in meters) of the correlation ellipse across the array (graph 4). The size of the symbols is proportional to the product of crosscorrelation coefficients across the array.

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