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INFRASOUND FROM THUNDERSTORMS

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Abstract

The present work summarizes the results of infrasonic observations of thunderstorms recorded by the Swedish Infrasound Network (SIN). A lightning in the atmosphere is a source of cylindrical shock waves. When the distance from the source increases, more and more energy is transferred into the low-frequency range through the same mechanism as for shock waves from supersonic aircraft. It is difficult to estimate maximal distances at which infrasound from a single lightning may be detected. It is, however, clear that distances between the SIN arrays (250 – 600 km) are in most cases too large in order to identify the same lightning from at least two arrays. During the recent summer, at few occasions, the same thunderstorm cell, and even the same lightning, could be observed by two arrays. That means that intense lightning may be, during favourable meteorological conditions, observed at distances up to 300 km. The infrasonic data may be used to determine the angular extent of the discharge, as seen by the array, its radial extent (in kilometres) and its acoustical intensity. Recent results of these morphological studies are presented.

The Swedish Infrasound Network (SIN)

The Swedish Institute of Space Physics operates, since the beginning of 1970:ies, four infrasound stations: Kiruna, Jämtön, Lycksele and Uppsala (see Table 1). All original time series collected since 1994 are stored in a data base accessible for general public at the Internet home page of the Swedish Institute of Space Physics together with all standard software needed for data analysis. Each station consists of a tripartite microphone array located in corners of an isosceles triangle, oriented in NS-EW directions. Microphones used in the network are unique, high sensitivity Lidström-microphones, manufactured in Sweden. Time series from all three microphones are stored in a compressed binary format, in 30-minutes files. The recording equipment covers the frequency range 0.5 – 9 Hz.

Table 1: Stations in the Swedish Infrasound Network (SIN)

Name	Latitude (Degs)	Longitude (Degs)
Kiruna	67.8°N	20.4°E
Jamton	65.87°N	22.51°E
Lycksele	64.61°N	18.71°E
Uppsala	59.85°N	17.61°E

Infrasound from thunderstorms

A lightning in the atmosphere acts like a source of cylindrical shock waves. When the distance from the source increases, more and more energy is transferred into the low-frequency range through the same mechanism as for shock waves from supersonic aircraft The overview display presented on the SIN home page, showing the angle-of-arrival and the horizontal trace velocity of incoming infrasonic signals, may be used to view the development and movement of thunderstorm cells around each array, typically within a 100 km radius. An example showing, on a angle-of-arrival *vs.* time graph, three thunderstorm cells passing by the Lycksele-array.

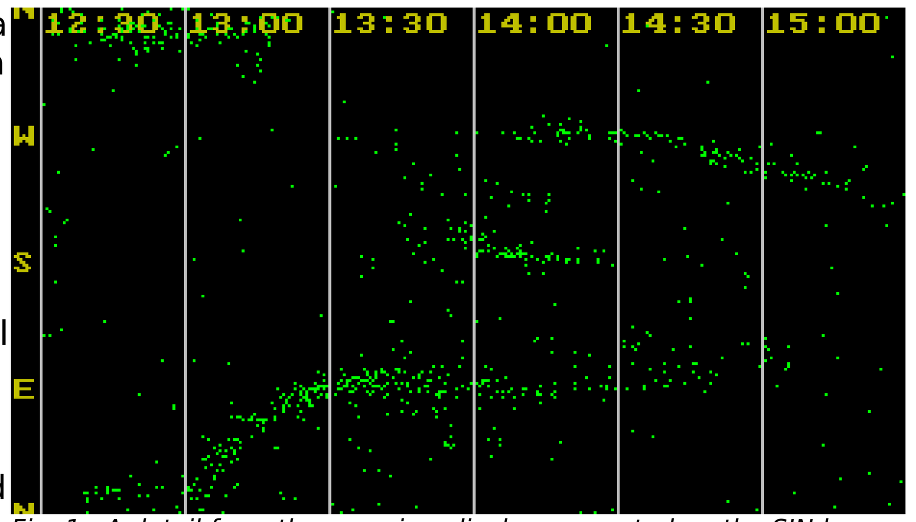

Fig. 1. A detail from the overview display presented on the SIN home page for Lycksele-array on July 8, 2005. The horizontal axis shows the UT (30-minute vertical marks) and the vertical axis shows the angle-of-arrival of infrasonic signals. A signal from each single lightning is shown as a bright dot. Three individual thunderstorm cells may be seen moving by the array (diffuse bright bands).

Occurrence of thunderstorms in Northern Sweden

During the past 10 years (1995 – 2005) large number of thunderstorms was recorded at infrasound stations of the SIN. As an example, the occurrence of thunderstorms observed by the infrasound station Lycksele is shown in Fig. 7.

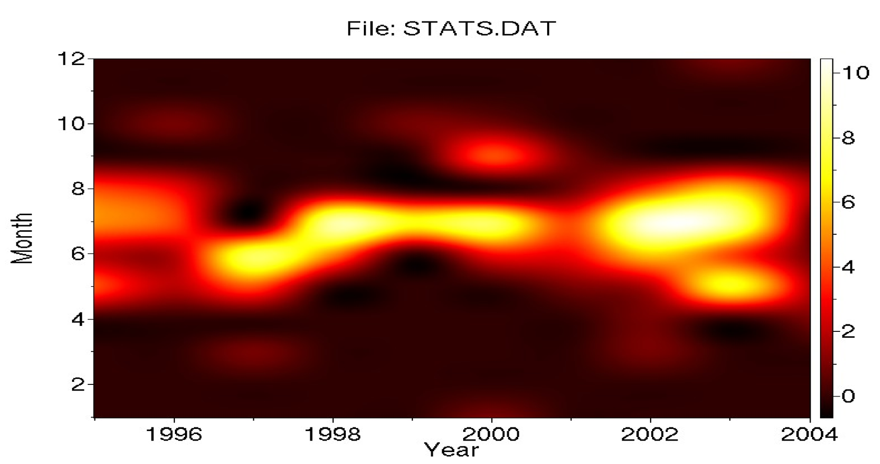

Fig. 7. Occurrence of thunderstorms at the infrasound station Lycksele as a function of year and time of the year. The vertical axis (colour) shows number of thunderstorms/month.

Frequency spectrum

Most of the acoustic energy from a lightning at distances of the order 10 – 50 km is located in the frequency range 1 – 10 Hz (0.1 –1 sec). It may be seen on the wavelet spectrum (scalogram) of infrasonic signals from few flashes during a thunderstorm of July 8, 2005.

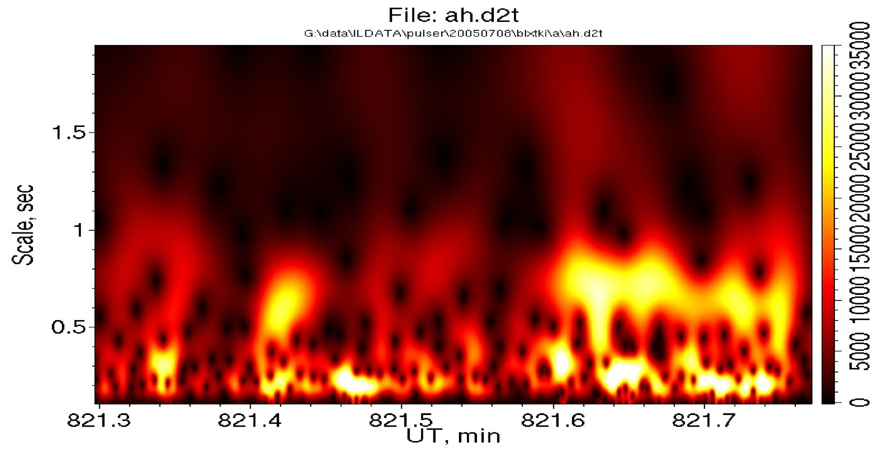

Fig. 10. Wavelet spectrum (scalogram) of infrasound from a CG flash (at 821.4 min UT) and of an IC flash (821.6 – 821.75 min UT), duration of the signal 9 sec.

High resolution analysis

In order to study the fine structure of individual signals, a high-resolution presentation has to be used. A small fraction of the period shown in Fig. 1, shortly before 1400UT, is shown in Fig. 2. Accumulations of points on the upper graph correspond to signals from distant flashes: short in time and limited in azimuth correspond to cloud-to-ground (CG) flashes, while signals extended in time, and often in azimuth probably correspond to intracloud (IC) flashes or CG flashes with substantial horizontal extents. IC flashes can produce spectacular infrasonic signals, often longer than 30 seconds. A longest observed infrasonic signal from a single flash lasted for 78 seconds! These long-duration signals may be easily distinguished on infrasonic recordings.

Sloping long-duration traces, as two first IC-traces in Fig. 2, correspond to flashes more or less perpendicular to the line-of-sight from the array. When the line-of-sight from the array coincides with the direction of the discharge channel, horizontal traces, as the third IC trace in Fig 2, are observed.

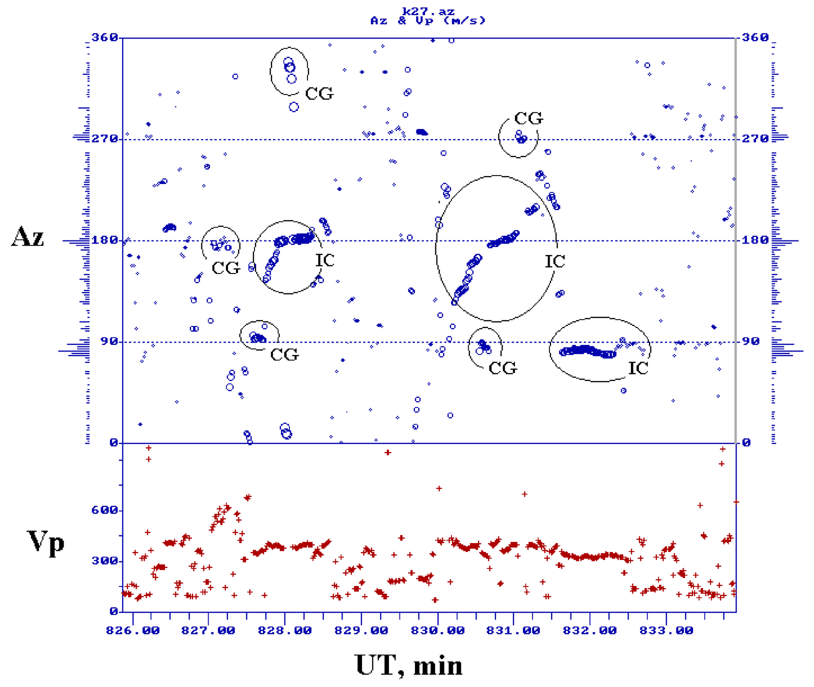

Fig. 2. High-resolution recording of infrasonic signals at the Kiruna-array between 1346 and 1354 UT. The upper graph shows the angle-of-arrival of infrasonic signals, the lower one shows the horizontal trace velocity. The size of the symbols on the upper graph is proportional to the cross-correlation across the array. Infrasonic signals from CG and IC flashes are encircled.

Examples of infrasonic long-duration traces

During the final part of a thunderstorm sequences of similar infrasonic long-duration traces are often observed. An example of sloping long-duration traces is shown in Fig. 3.

A sequence of long-duration infrasonic signals, corresponding to flashes with discharge channels oriented along the line-of-sight from the array, is shown in Fig. 4.

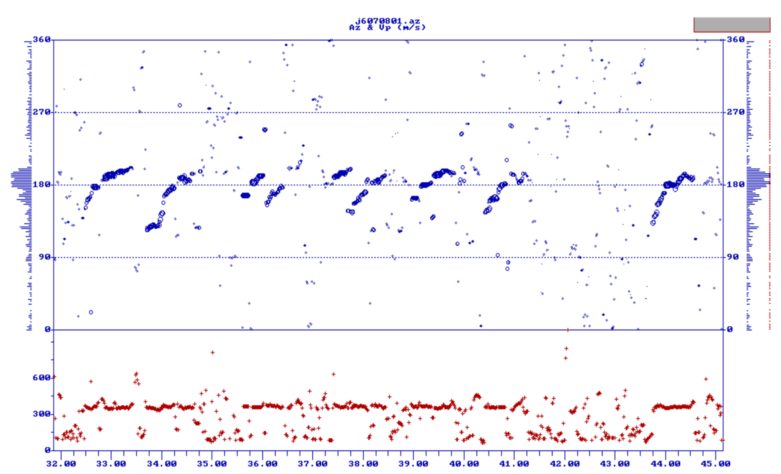

Fig. 3. A sequence of long-duration infrasonic signals, probably from IC flashes, directed more or less across the line-of-sight from the array.

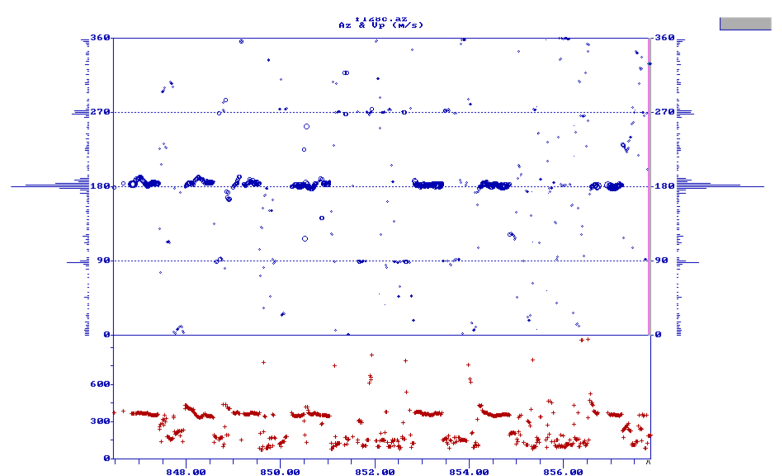

Fig. 4. A sequence of long-duration infrasonic signals, probably from IC flashes, directed nearly along the line-of-sight from the array.

Geometry of infrasonic traces

The long duration of infrasonic signals from IC flashes is due to their large horizontal extent. The geometry of IC signals is explained in Fig. 5.

The signal generated at both end points of the discharge channel arrives to the observer O at instants t_1 and t_2. The duration of the signal, t_2 - t_1, is thus proportional to the difference of distances r_2 – r_1. Knowing the angle between r_2 and r_1 and the inclination of the ray between r_2 and r_1, it is possible to estimate the geometrical extension of the discharge channel. Since at a close range the horizontal trace velocity is proportional to the inclination of the ray to the horizontal plane, measurements of the trace velocity and azimuth will uniquely describe the morphology of the discharge channel. Converting the trace velocity into the inclination of the ray, a "map" of flash-generated infrasound across the sky may be generated. Since the infrasonic signal may be polluted by the atmospheric background noise, it is practical to describe the signal using its average cross-correlation across the array, This quantity is closely related to the average signal-to-noise ratio across the array. The signal-map may be generated for each individual flash with substantial horizontal extent. An example of such a map for one single flash among those shown in Fig. 3, is shown in Fig. 6.

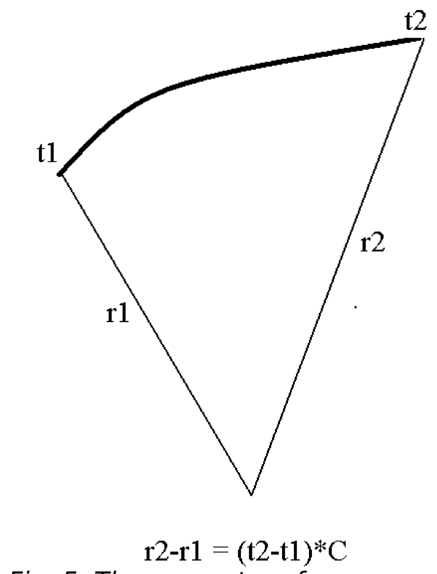

Fig. 5. The geometry of an infrasonic signal from an IC flash. C is the speed of sound.

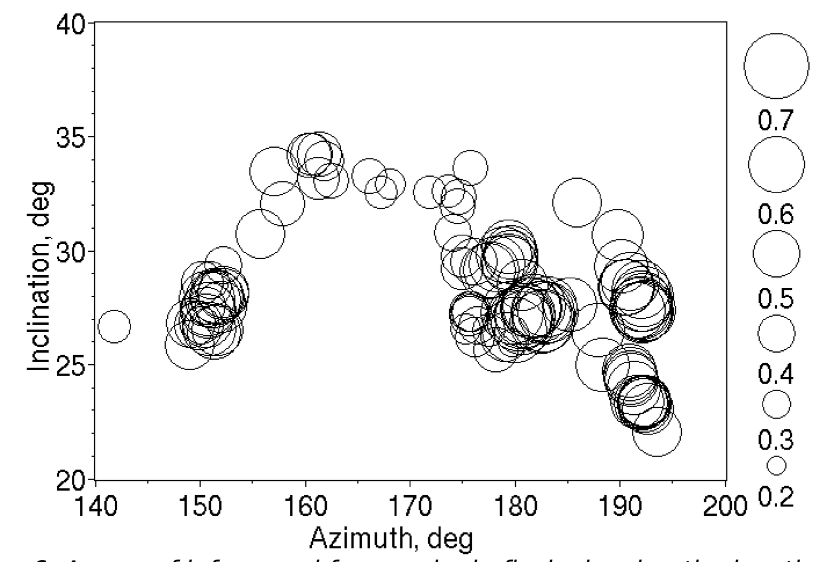

Fig. 6. A map of infrasound from a single flash showing the location of sound sources on the sky. The size of circles is proportional to the average cross-correlation between microphones of the array, and thus to the signal-to-noise ratio.

Localization of thunderstorms

The distance from which a single thunderstorm cell may be detected depends on its location with respect to the observing station and the atmospheric wind system. At large distances (> 100 km) a thunderstorm cell, with a large number of flashes per time unit, appears as a continuous source of infrasound. In spite of large distances (200 – 300 km) between arrays of the SIN, few thunderstorms each summer may be observed simultaneously by two arrays. The motion of the cell may then be followed, see example of Fig. 8.

In thunderstorms with a small number of flashes per time unit, it is sometimes possible to identify a single flash from a distance up to 300 km. Such a thunderstorm occurred on August 2, 2006, when single flashes over Northern Finland were recorded by the Jämtön-array at a distance of almost 300 km.

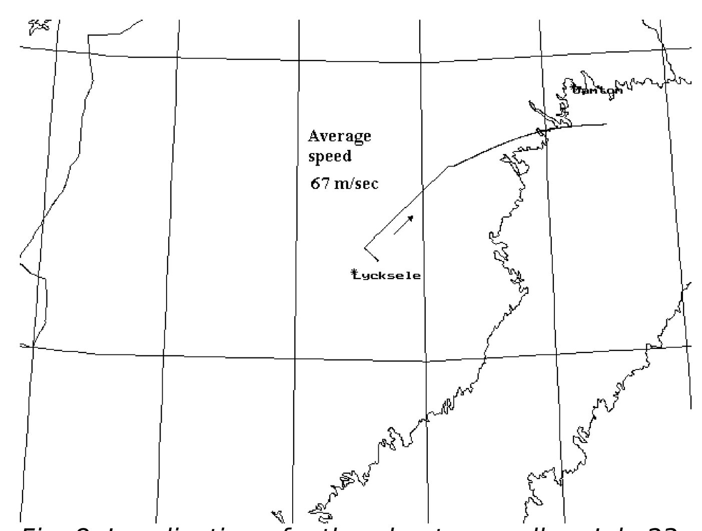

Fig. 8. Localization of a thunderstorm cell on July 23, 2006. Its average speed was 67 m/sec.

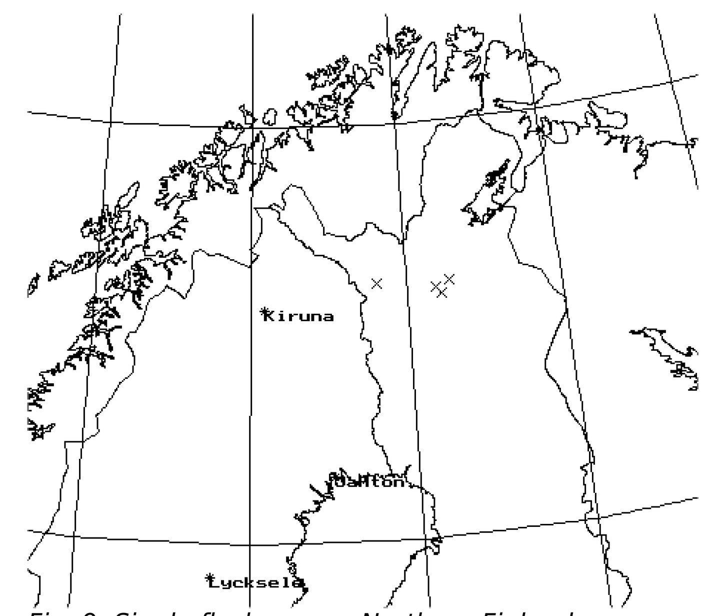

Fig. 9. Single flashes over Northern Finland on August 2, 2006, recorded by both Kiruna- and Jämtön-arrays.