On the Possible Infrasound Generation by Sprites

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Energetic electrons accelerated by electric fields in thunderstorms are assumed to be responsible for generation of luminous phenomena at altitudes above 30 km, so called sprites. If the generation of light in these phenomena is associated with local heating, it may also be expected that low frequency acoustic waves will be generated. Due to the cylindrical structure of the source the most of the acoustic energy will be radiated close to the horizontal plane along the entire height of the source. The infrasound form these phenomena is therefore unlikely to be detected immediately beneath the source. The search for infrasonic signals from the high altitude luminous phenomena was carried out during the recent years using data from the infrasonic networks operated by the Swedish Institute of Space Physics. During the night of May 26-27 1995, when a severe thunderstorm area passed over the Golf of Bothnia, it was possible to identify signals, most probably generated by sprites. The infrasonic observations made during that night are described in the present report. Similar, chirp-like signals were observed during some other occasions at Swedish stations during the recent years.

1. INTRODUCTION

During recent years a considerable number of observations of high altitude luminous phenomena associated with thunderstorms have been reported (Franz et al., 1990; Winckler et al., 1993; Sentman and Wescott, 1993; Lyons, 1994; Sentman et al., 1995). There are probably two distinct groups of luminous phenomena associated with thunderstorms, the most common are the so-called red sprites (Sentman et al., 1995) occurring in the stratosphere/mesosphere (typically 70-90 km) above electrically active cumulonimbus clouds. These phenomena have been observed both from the ground and from aircraft. A second class of phenomena, "blue jets", which do not propagate beyond the stratosphere (Wescott et al., 1995) has also been identified. Also these phenomena have been observed from aircraft as blue or green pillars or columns over thunderstorms, up to about 45 km. According to present views (Mende et al., 1995; Wescott et al., 1995), these luminous phenomena are produced by energetic electrons accelerated by electric fields in thunderstorms. If the generation of light in these phenomena is associated with local heating, it may also be expected that low frequency acoustic waves will be generated. Due to the cylindrical structure of the source the most of the acoustic energy will be radiated close to the horizonthal plane along the entire height of the source. The infrasound from these phenomena is therefore unlikely to be detected immediately beneath the source. The problem will be discussed in a later section of this report using the ray tracing technique. The search for infrasonic signals from the high altitude luminous phenomena was carried out during the recent years using data from the infrasonic network operated by the Swedish Institute of Space Physics. During the night of May 26-27 1995, when a severe thunderstorm area passed over the Golf of Bothnia, it was possible to identify signals, most probably generated by sprites. The infrasonic observations made during that night are described in the present report.

2. THE METEOROLOGICAL SITUATION

It is essential to describe the specific meteorological situation during the observation period. This is provided in Fig. 1, where images taken by the NOAA satellites in the visual range before and

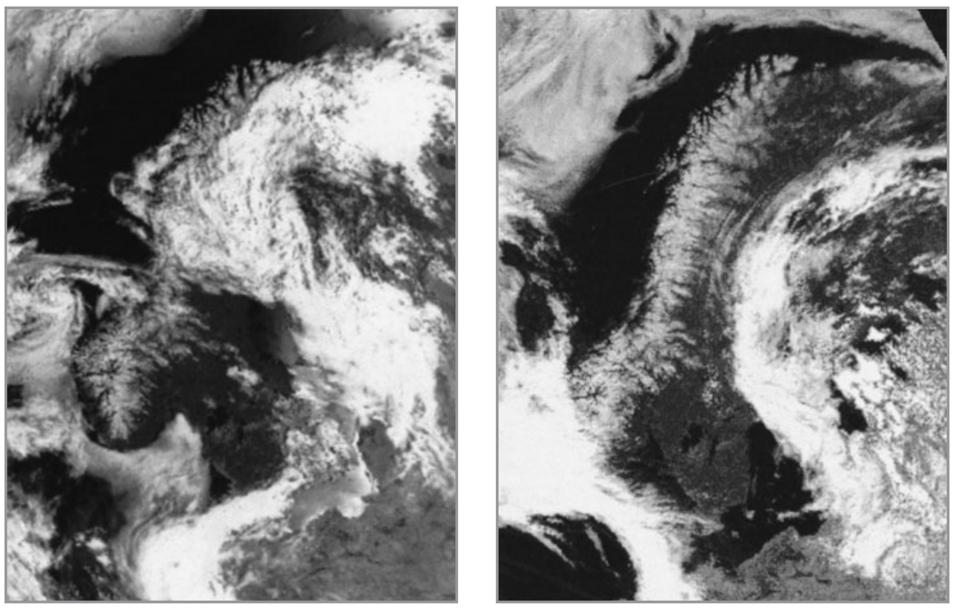

Figure 1 Visual satellite images taken by NOAA 14 on May 26 1995 at 1143UT (left) and by NOAA 12 on May 27 1995 at 0735UT (right).

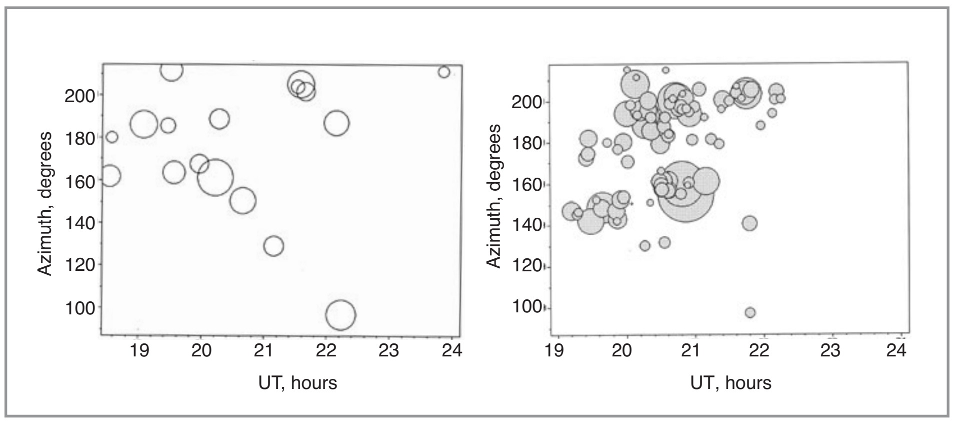

Figure 2 Azimuths to positive (left) and negative strokes (right) as those would be observed from the infrasonic station in Jämtön (Luleå).

after the actual night are shown. In the upper part of Fig 1 an image taken by the NOAA 14 satellite on May 26 at 1143UT is shown. The lower part shows an image taken by the NOAA 12 satellite on May 27 at 0735UT. On May 26 there is an arc-like cloud formation following the Golf of Bothnia and the Baltic Sea. On May 27 the weather system has been transformed it a S-shaped structure with its northern pat moving westward and the southern part moving eastward, indicating formation of a low pressure area over the central part of the Golf of Bothnia. During the night of May 26-27 a considerable thunderstorm activity was reported in the middle part of the Golf of Bothnia. Recordings of Cloud-to-ground lightnings performed by the Institute of High Voltage Research, Uppsala University, indicate a large number of lightnings at that time and location.

Observations of lightnings during the period 20-00 UT of May 26 are shown in Fig. 2. As the infrasonic signals were observed from only one station, locations of positive and negative strokes have been transformed to azimuths measured from the infrasonic station in Jämtön. It may be seen that numerous lightnings were recorded above the Golf of Bothnia and that there is a number of positive lightnings observed along the coast of Finland (azimuths between 100 and 170°).

It may be seen that there is a general agreement between the occurrence of positive strokes and the occurrence of infrasonic chirps. Four positive strokes (of 17 observed) are directly related, after correction for the propagation time to the observed infrasonic chirps.

3. INFRASONIC OBSERVATIONS

During the actual period two infrasonic stations could be of interest with respect to the thunderstorm activity: Jämtön (65.8N, 22.5E) and Lycksele (64.6N, 18.7E). During that night, the center of thunderstorm activity was located 90-130 km east of Lycksele, but 200-250 km SSE of Jämtön. The infrasound observations in Lycksele do not show any unusual features during that night, while the observations at Jämtön show very unusual signals from the SSE, beginning shortly after 20 UT. The signals, having a form of ascending chirps with frequencies varying between 1 and 6 Hz, are highly correlated across the microphone array (75 meters). The duration of the signal varies between 3 and 10 seconds. The most intense and best correlated signals were arriving from directions between 160 and 180°. Weaker signals were seen from directions down to 140°. The observed directions (Fig. 3) coincide well with the location where positive cloud-to-ground lightnings (Fig. 2) were recorded along the coast of Finland.

An example of an angle-of-arrival recording between 2030 and 2100 UT is shown in Fig. 4. The upper part of the diagram shows the angle-of-arrival marked by circles with a diameter proportional to the maximum cross-correlation between the microphones. In the lower part of the diagram the horizontal phase velocity of the signal across the array is plotted.

In order to show the frequency signature of the signals very short samples of the signal (only 16 samples corresponding to 0.89 seconds) were used for FFT analysis. 8 frequency channels were thus obtained, each corresponding to 1.125 Hz between 0 and 9 Hz. The spectra have a low frequency resolution, but a high temporal resolution. Two examples of 3-D spectra with a high temporal resolution are shown in Fig. 5.

In order to obtain a high time resolution a very short window of 16 points was moved along the time series.

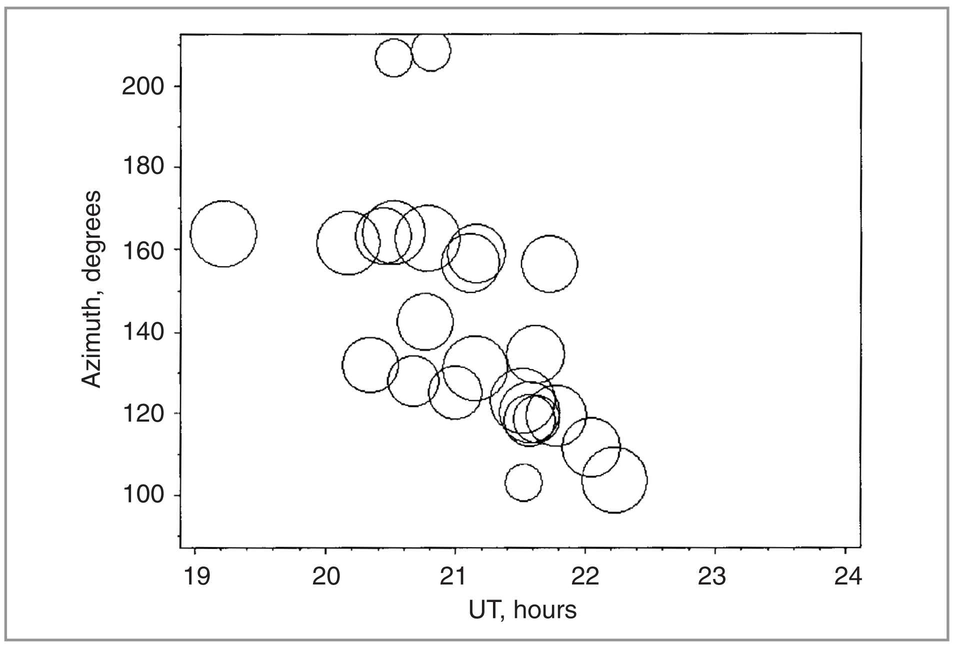

Figure 3 Measured directions of arrival of infrasonic chirps observed at the Jämtön station during the evening of May 26, 1995.

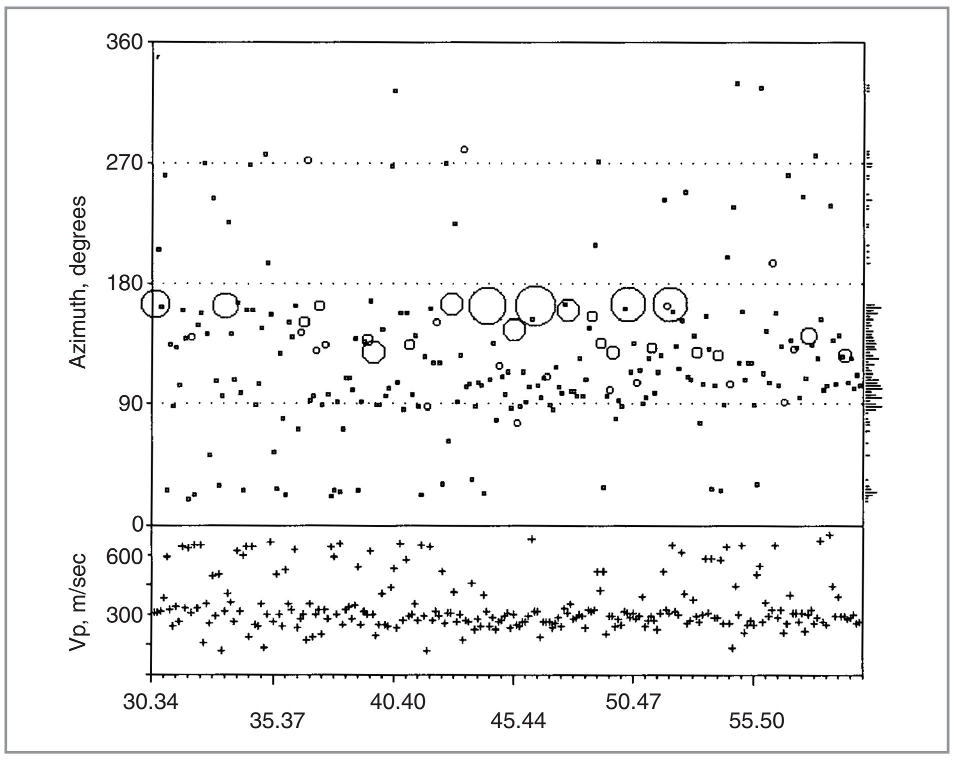

Figure 4 *An example of an angle-of-arrival recording (upper diagram during 2030-2100 UT when most of the chirps were recorded. The size of symbols is proportional to the maximum crosscorrelation between the microphones. The lower diagram shows the horizontal phase velocity of the signal across the array.*

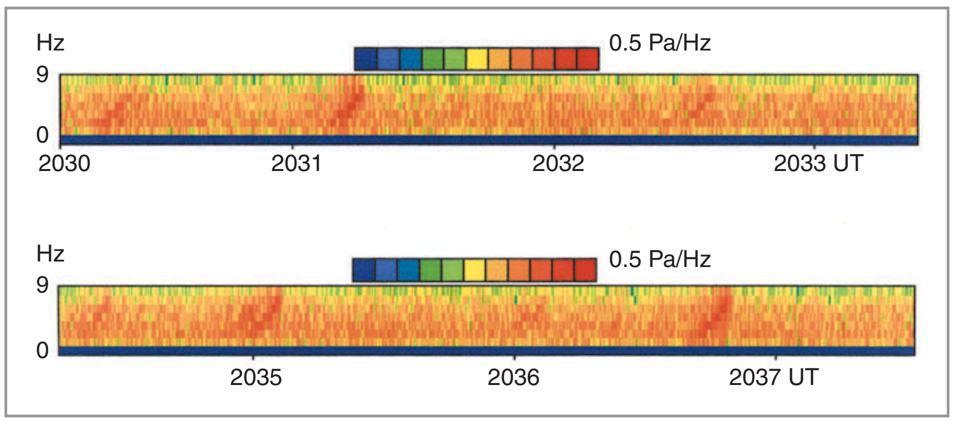

Figure 5 *Two examples of 3-D frequency spectra showing the ascending chirps.*

The FFT of each 16 point window results in an 8 points frequency spectrum covering the frequency range between 0 and 9 Hz. The effects of both the high-pass filter built into the microphone (0.4 Hz) and of the anti-aliasing low-pass filter with a 3 dB point at 6 Hz may be seen in the spectrum. In spite of the high damping of the low- pass filter (40 dB at 9 Hz), the chirps may usually be traced up to 9 Hz. In some cases, the chirps seem to bend at the highest frequencies (i.e. signal at 9 Hz arrives earlier than the signal at 7 Hz). Another interesting characteristic of the infrasonic chirps is that some of them occur in pairs; see e.g. Fig. 4 at 2035 and 2036 UT.

An example of a typical time series of the signal recorded by one of microphones is shown in Fig.6.

The above described signals essentially differ from those usually observed when thunderstorms are passing at distances of 20-100 km from the observing station. Those signals are usually nearly monochromatic bursts with frequencies around 1 Hz.

4. INTERPRETATION OF OBSERVATIONS

There may be different reasons why the signals were not observed at a station close to the thunderstorm area:

- The source of infrasound has a cylindrical radiation pattern, i.e. most of the energy is radiated within a narrow angle around the horizontal plane
- The local turbulence within the thunderstorm area and its surrounding generates high wind noise levels which obscure the signals
- The high altitude winds with a strong EW-component introduce an unisotropy into the infrasound propagation.

The infrasound propagating upwards from a source in the atmosphere may reach the ground after reflection at the thermospheric temperature gradient (see the sound velocity profile for the summer atmosphere in Fig. 7).

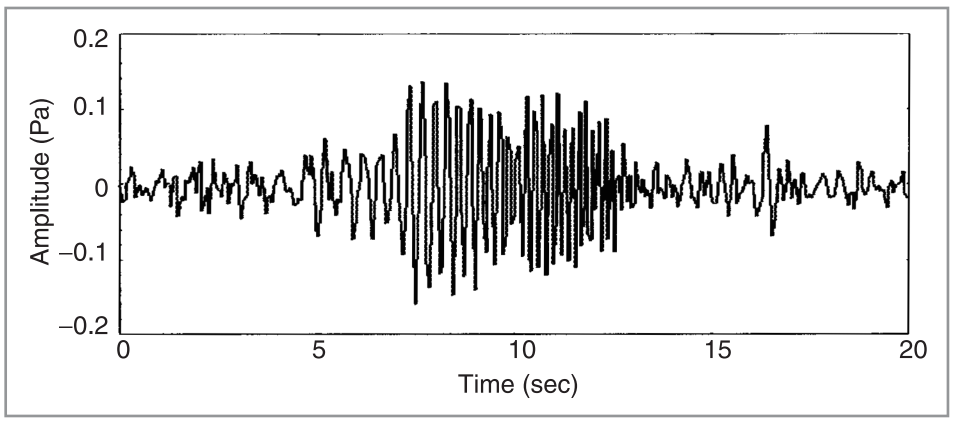

Figure 6 An example of the typical infrasonic signal, probably associated with the thunderstorm activity, recorded at one of microphones.

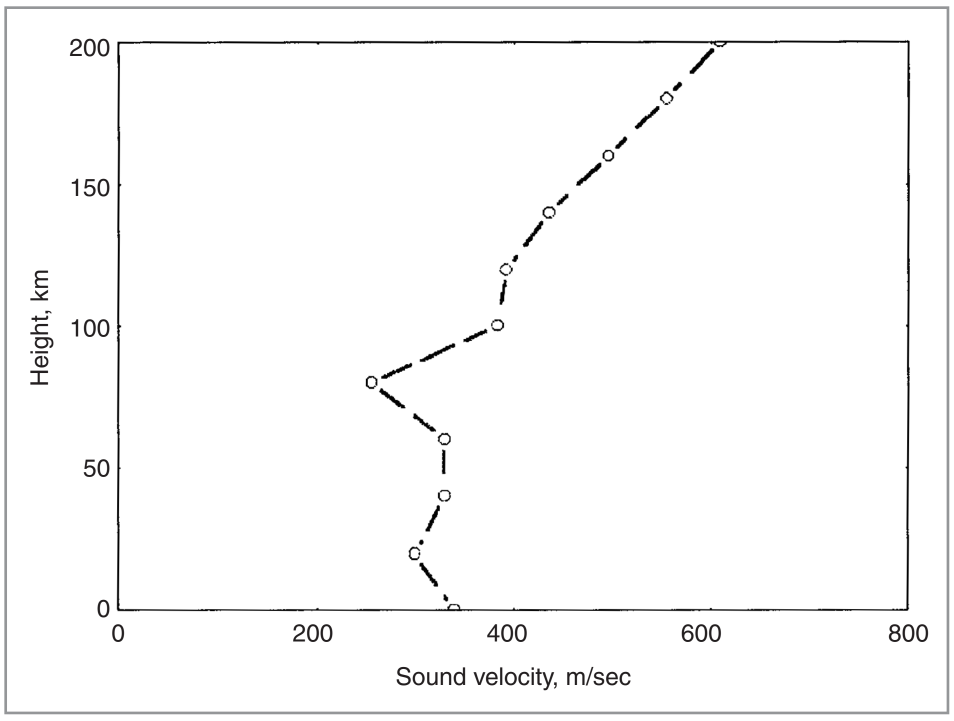

Figure 7 The sound velocity profile for summer atmosphere.

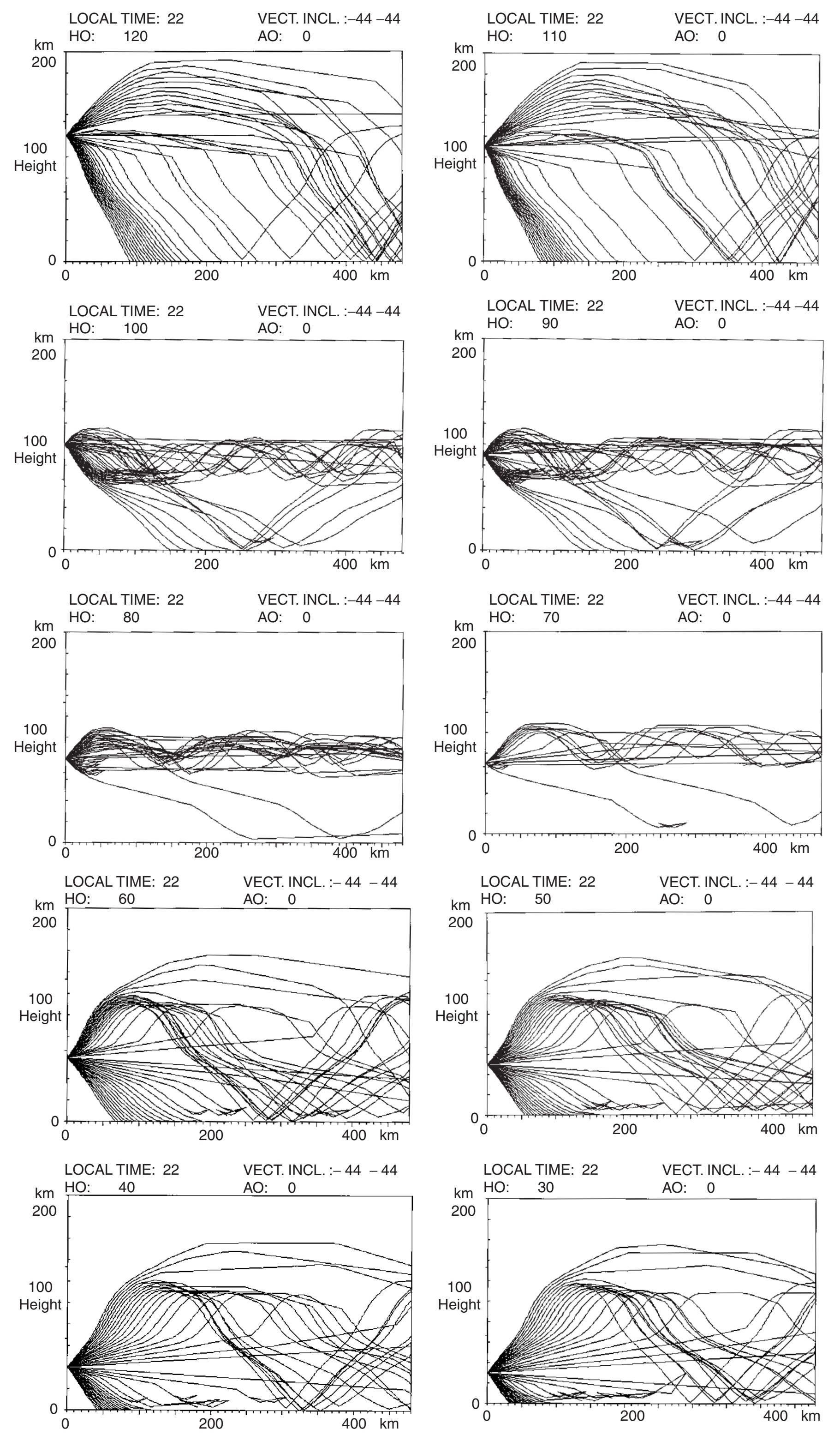

Figure 8 *Cylindrical vertical source. Rays propagating from points along the source between 12 (top left) and 30 km (bottom right) in the direction of 0° (towards north).*

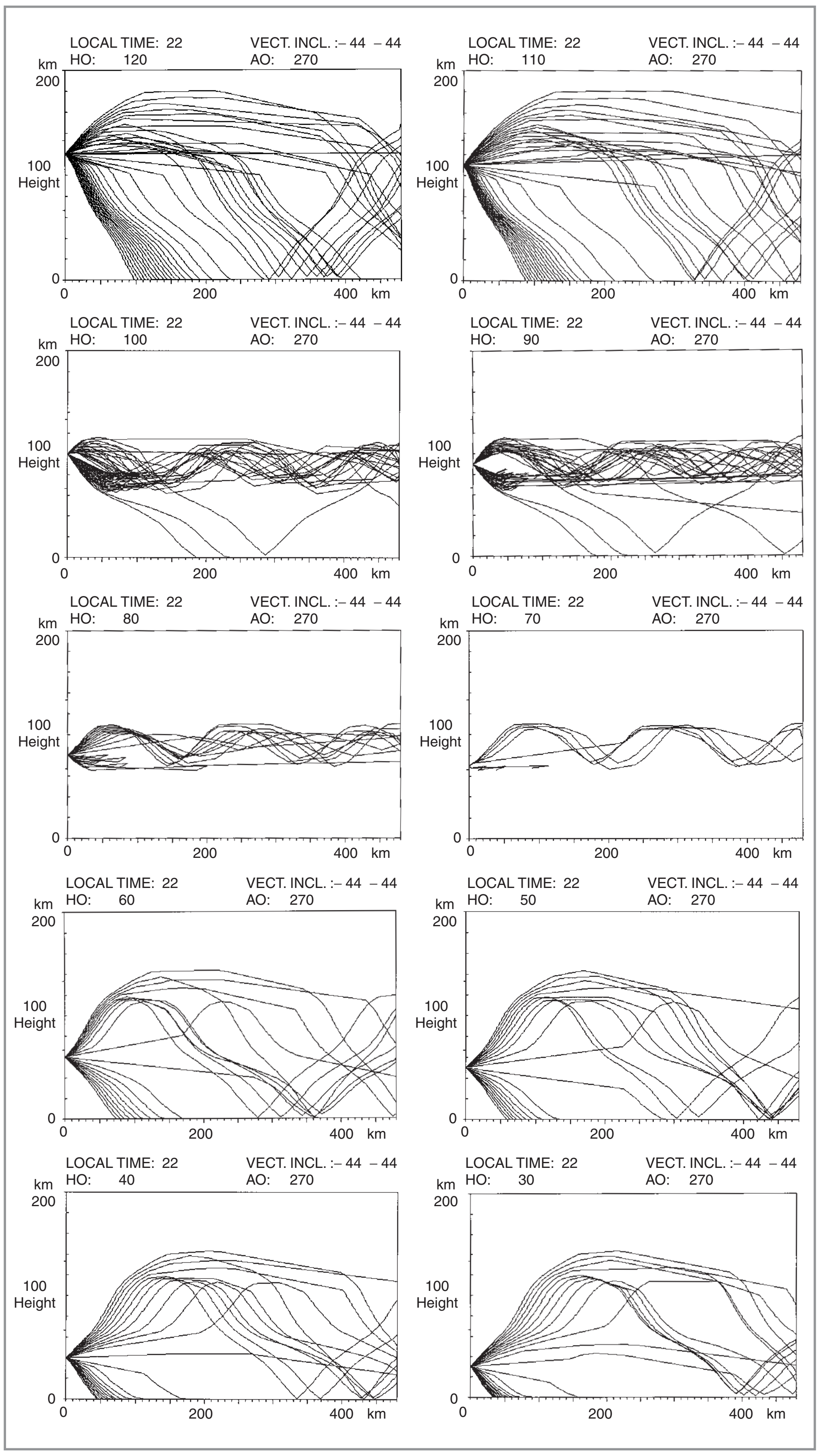

Figure 9 *Cylindrical vertical source. Rays propagating from points along the source between 120 (top left) and 30 km (bottom right) in the direction of 260°.*

In order to understand the propagation of the infrasound from a source in the upper atmosphere the results of ray tracing calculations for a source in the summer atmosphere are shown in Figs. 8 and 9. The height of the source varies at 10 km steps from 30 km (bottom right to 120 km (top left). Fig. 8 shows the propagation towards north (A = 0°), which corresponds to the Jämtön station and Fig. 9 shows the case of A = 260° from the source (Lycksele station).

The ray tracing results show that for propagation towards north (Fig. 8) there are no rays reaching the ground between 90 and 300 km from a source between 20 and 40 km (the altitude of blue jets). Not until there is a source at an altitude of 85 to 100 km, i.e. where the sprite events are observed, are there rays reaching the ground at distances between 150 and 300 km. Most of the rays generated at these altitudes are trapped between 80 and 100 km and dissipate in the atmosphere without reaching the ground.

When the propagation is towards the west, as in the case of the Lycksele station, there are practically no rays reaching the ground (see Fig. 9) at distances characterictic for the given location of the thunderstorm with respect to the station.

A detailed study of ray tracing calculations indicate that for a source, within the height interval where the sprite events are observed, the rays reflected highest up in the atmosphere arrive first to the observing site on the ground (see Fig. 10). This is due to the fact that the sound velocity increased rapidly with the height around 100 km. That indication coincides well with the

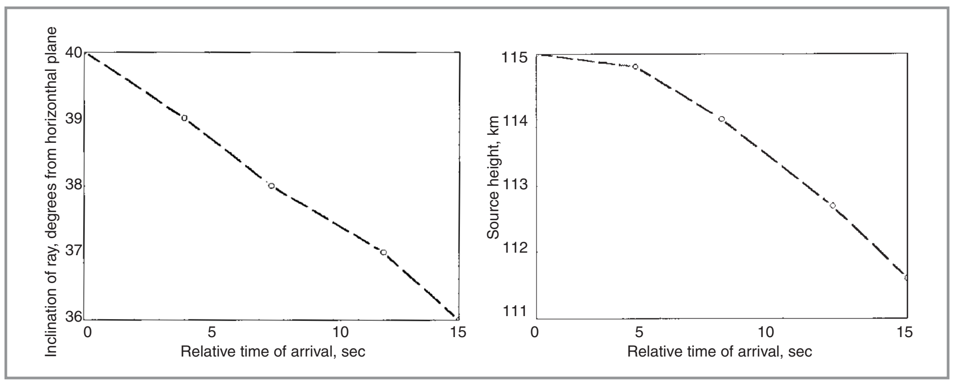

Figure 10 *A source at 100 km, recording station at 255 +/- km. Inclination of a ray at the source (left) and the reflection height of a ray (right) plotted against the relative time of arrival in seconds.*

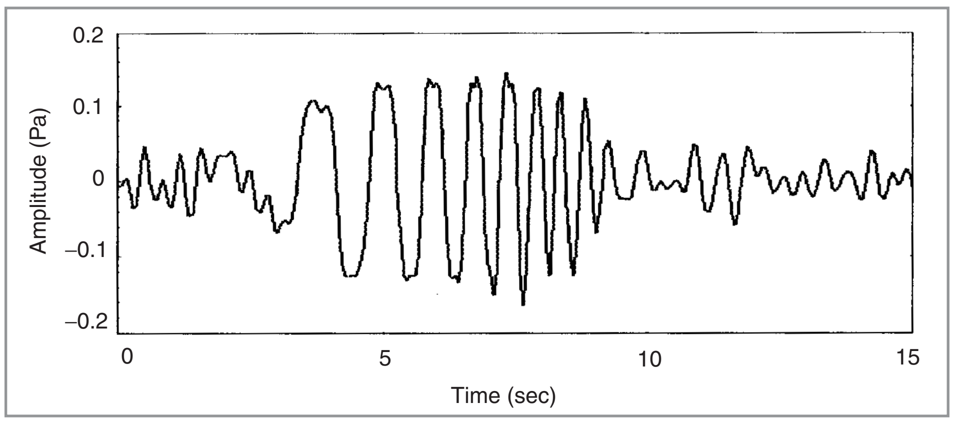

Figure 11 *An infrasonic chirp observed at Jämtön station, when there was no thunderstorm activity above Scandinavia.*

observed frequency signature of the infrasonic chirps. The slope of the frequency - time dependence of a chirp is probably related to the temperature gradient around 100 km altitude.

5. CONCLUSIONS

It may be concluded that the infrasonic chirps observed during the night of May 26, 1995 are very likely generated by the high altitude flashes (sprites) related to the thunderstorm activity. Since that particular storm infrasonic data from all Swedish infrasonic stations were screened through in order to find more periods when the infrasonic chirps occur. Suring following summers several infrasonic chirps were found during periods with severe thunderstorms above Scandinavia, however, never as numerous as during the storm described in the present paper. At one occasion a chirp (see Fig. 11) has been found at Jämtön infrasonic station on November 28, 1995 at 0930 UT, when there certainly was no thunderstorm activity above Scandinavia.

The generation of infrasound by sprites has been recently confirmed in France by Farge et al (2004).

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noise notes

TRUCKEE TAHOE AIRPORT

At Truckee Tahoe airport in Nevada, which is mostly used by private light aircraft owners and gliders, it has been observed that pilots stick to the correct noise abating flight paths for about 90% of the time in Summer, but only about 50% of the time in winter.

AUTISTIC CHILDREN

Early results of a study of noise in early education has found children with autistic disorders are among the most severely affected of any group of children in early education. "We wish to highlight the serious nature of early childhood centre noise and encourage everyone to think seriously about how we can improve the learning environment for these children," says Stuart McLaren, Senior Lecturer in Health Science based at Massey University, New Zealand. A wide range of groups of children with special education needs are being considered in the survey, along with young children in general. These include young children with autism, Asperger syndrome, Down syndrome, ADHD, global developmental delay and the hearing impaired. While all these children are seriously affected by noise, the effects on autistic children in general are far more severe. "While their hearing may be normal, autistic children process auditory information very differently from others. What others perceive as normal and tolerable can be extremely intense and painful to them. Noise can have two serious effects on these children. Firstly, it causes them pain, distress and confusion, and secondly, it further erodes their ability to communicate and learn," says Mr McLaren. "We intend to investigate a wide range of strategies to help these children. We have already seen some excellent individual strategies, which could be developed further. "Much of the present work is focused on these children being integrated into regular early childhood education environments. However we must look more closely at the learning environment too," he says. He asks why it is acceptable to expect autistic children to negotiate their way around any such environment when we never expect children with physical disabilities to negotiate their way up a flight of steps.

SCOTTISH NEIGHBOURS

Scotland is in the grip of a noise nuisance epidemic as complaints soar. A report by environmental watchdogs reveals that the number of noise-related complaints by feuding neighbours has increased by 50% in the past year. The Royal Environmental Health Institute Scotland (REHIS) says grievances found to be justified have doubled over the same period. REHIS believes much of the increase is due to Scots becoming less tolerant of noise, but lifestyle trends are also playing their part. The fashion for stripping a home back to the essentials and removing fitted carpets – largely prompted by TV home makeover shows – has become one of the biggest bugbears of tenement life in Scotland as thousands of feet clack over wooden floors. REHIS researchers found that in 2002 there were 3,099 complaints across Scotland about noise and vibration from domestic premises. The number of complaints investigated and found to be justified was 884. Environmental health officers served 20 enforcement orders threatening prosecution when people did not comply. In 2003 the number of complaints had risen to 4,584. But the number investigated and found to be justified had more than doubled to 1,727, and 50 enforcement orders had to be served.