MEASUREMENTS AND ANALYSIS OF AURORAL SOUNDS

IN FINLAND 2000-2001

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ABSTRACT

Two years ago informal research cooperation began between three Finnish university and research units with the common goal of collecting and analyzing data related to auroral sounds. Up to now audio and VLF recordings are collected during 40 nights, most of them being reference nights without any significant geomagnetic activity. In this paper we present the results of the interviews of Finnish auroral sound observers, remove some of the mysteries related to these sounds and describe the first results of the most successful measurements.

INTRODUCTION

Auroral sounds have long eluded scientific explanation. The most comprehensive study of this topic is [1]. It was concluded that the most probably source of the auroral sounds "seems to be brush discharge" and in order to solve the problem many physical parameters have to be monitored and recorded simultaneously. One of the mysteries related to the auroral sounds has been that even if many observers have heard them no-one has been able to make recordings. The basics of electro- and psychoacoustics helps to understand also this problem. The primary goal of our project has been to find answer to the question: do the auroral sounds form a real physical entity or are they just malfunctions of the human perception. The new results speak for the objectivity of these sounds.

OBSERVATION REPORTS

In order to gain background information for acoustic measurements we arranged a survey of observations of auroral sounds by the general public in Finland. Over 200 reports on auroral sounds were collected during the years 2000-2001 and covered observations made by individuals over their lifespan. The analysis of the reports by the public confirmed the results of earlier similar surveys performed elsewhere: auroral sounds are heard only when the aurorae are very bright and active, clear rays are visible and in most observations the auroral corona is above the head of the observer. The sound is weak and dissimilar to other natural sounds of the observation environment, however distinct and clearly recognizable. Most observers find it difficult to depict the direction or location of the sound source, but note that variations are in relation to the motion of the active aurora. Descriptions of the sound varied from hissing and swishing to crackling and noise like whistling, as revealed by earlier surveys. Approximately half of the observers heard hissing-like sounds and the other half heard crackling-type discrete sounds.

Although accurate timing of the observations proved to be difficult, two new important findings emerged from this recent survey: 1) the age distribution of the observers at the moment of observation shows a peak for an age below 15 years, with a decreasing tail for increasing age. Similar distributions were found for men and women. 2) The average temperature for a sound observation was -20 degrees Celsius. (The last result may however be biased by the generally adapted language to describe and recall temperatures.) Surprisingly, no latitude dependence was found in the distribution of observations. They were evenly distributed from the southernmost tip of Finland up to the northernmost point, i.e., from ~60° to ~70° north. However, public observations from the last two years have peaked more to the southern latitudes.

Human Ear Beats Most Microphones

The sensitivity of young healthy ear is at least 20 dB better than that of the best measuring microphones of the 60's and 70's. Also the noise level of the microphone preamplifiers and analog tape recorders has been too high. Sounds which probably were masked by the noise of the instruments can be detected by the ear. There is no mystery hidden in this. In acoustics the use of human observers is still a valid scientific method. There is no reason to underestimate the observations reported. The coherence of the Finnish observations to those made around the world speaks for the objectivity of the auroral sounds. Similar sounds are heard in different environments. Thus the sound producing process should be independent of the listening environment and its structures. To summarize: earlier failed attempts to make recordings of auroral sounds were at least partially due to the high noise level and low sensitivity of the instruments of that time.

METHODS

A small portable measurement and recording system with audio and VLF instrumentation was developed for outdoor use. The system is fully battery operated and can be easily carried to places where the ambient noise and weather conditions are favorable.

High quality measuring condenser microphone B&K 4179 able to measure SPL down to 0 dB in the frequency band 7 Hz – 12.5 kHz was used. The microphone and its preamplifier are mounted in metal tubes and permanently connected with a wire of one meter. The output impedance of the preamplifier is 50 Ohm. In order to improve the acoustical sensitivity the microphone was mounted in the focus of a parabolic satellite antenna with 80cm of maximum diameter. The directivity pattern and frequency dependent gain of the acoustic reflector have been measured by Klaus Readerer at HUT. The reflector does not amplify the sound below 20 Hz. The acoustical gain increases towards the higher frequencies and is about 20 dB at 1 kHz. In the same time the directivity improves.

The microphone and its preamplifier are insensitive to variations in the ambient magnetic field. The whole magnetic field of the Earth should oscillate with periodicity of, e.g., 50 Hz before an erroneous sound pressure level (SPL) of 18 dB could be measured. Even the strongest geomagnetic storm causes only 2% variation in the Earths magnetic field. Thus it is impossible that any geomagnetic variation could give an effect able to exceed the noise caused by the acoustical environment or the electrical noise of the preamplifier and DAT.

During a typical measurement session the microphone with its battery operated preamplifier and acoustic reflector are located on an open field about 12 meters from a car where the audio signal is digitally stored on one channel of a DAT-recorder. The microphone preamplifier and the DAT are connected with a coaxial cable. The recording of the sound is monitored with headphones meanwhile the sky and the environment are observed.

Four meters high vertical VLF antenna is mounted about six meters from the car. A passive lowpass filter is connected between the antenna and the coaxial cable leading to the car. The filter helps to damp possible RF signals. The VLF signal is led directly to the DAT player without any additional active preamplifier. The VLF signal level is left low in order to minimize its possible leakage to the audio signal on the other channel of the DAT.

The audio and VLF signals are stored digitally with 48 k sample/s (16 bits). This leads to a relatively high data rate of 360 M sample/h and 1.44 G samples per a typical night of four hours of recordings. The data is moved from the DAT tapes in digital form to a computer in which different analyses, e.g., one-third-octave analysis is performed.

MEASUREMENTS

The nights of measurements are chosen based on the geomagnetic and weather prognoses. The years 2000-2002 have been the period of double peaked solar max with many relatively strong geomagnetic storms. The preliminary measurement was carried out 6.-7.4.2000. The recording contains possible auroral noise, some pops and other acoustical events with similar character as described by some observers. However, the measuring system was not the best possible and the recordings do not have exact timing.

One interesting night with relatively strong geomagnetic storm and interesting sound material occurred 27.-28.3.2001. However, the analysis of that material is not yet done. In the following we concentrate to the most interesting case up to now which occurred 11.-12.4.2001. The place of measurements was at Lake Pielinen in eastern Finland close to a hill called Koli. The closest place for geomagnetic measurements was in Hankasalmi, about 210 km SW from Koli.

The mean deviation of the geomagnetic field components averaged over hours 19, 20, 21 and, 22 UT (11.-12.4.2001) are depicted in Fig. 1.

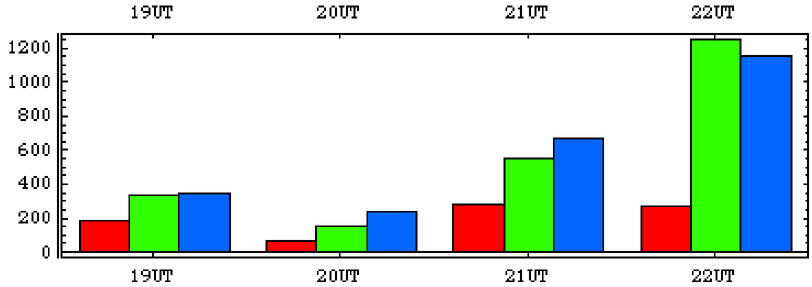

Fig.1. Mean deviation of the geomagnetic field at Hankasalmi 11.4.2001.

The lowest activity (geomagnetic fluctuation) occurs during 20 UT, the moderate activity during 19 UT and the high during 21 UT. During 22 UT the fluctuation in y- and z-components is high meanwhile the activity of the x-component has degreased.

Average acoustic energies measured in one-third-octave bands during these four hours are shown in Fig. 2. where the mean acoustic energy is plotted on an arbitrary dB scale (blue) together with the mean deviation from the mean energy value (red). All curves are averaged over 7200 data points.

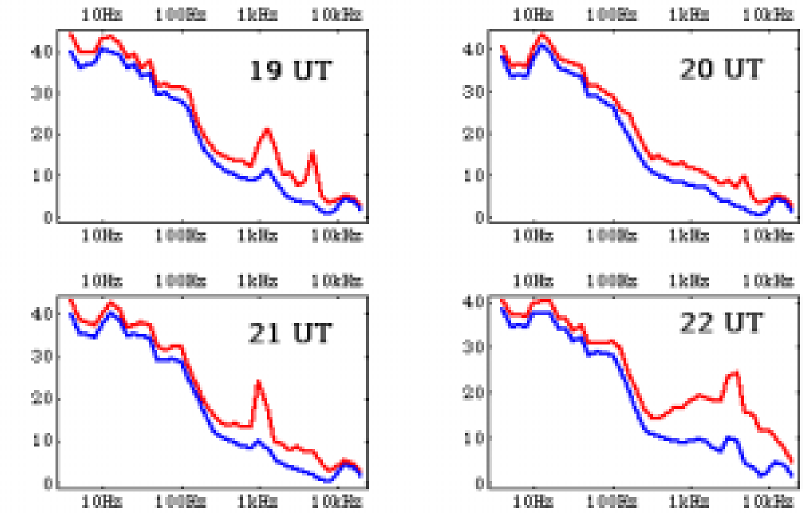

Fig. 2. One-third-octave analysis of acoustic energy and its fluctuation

Relatively little fluctuation is seen during the low geomagnetic activity hour (20UT). The moderate geomagnetic activity (19UT) clearly increases the acoustic energy and its fluctuation around 5 Hz, 100 Hz, 1 kHz and, 4 kHz. The situation is about the same in the case of high geomagnetic activity (21UT). Data of 22 UT shows broad-band energy fluctuation on the frequency range 1 kHz – 10 kHz.

Fig. 3. Mean acoustic energy differences between the active hours (19 UT left, 21 UT right) and the reference of 20 UT.

Figure 3. shows how the activation in the geomagnetic conditions increases the average acoustic energies about 2-4 dB in three frequency band with center frequency: 5-10 Hz, 100 Hz, and 1 kHz.

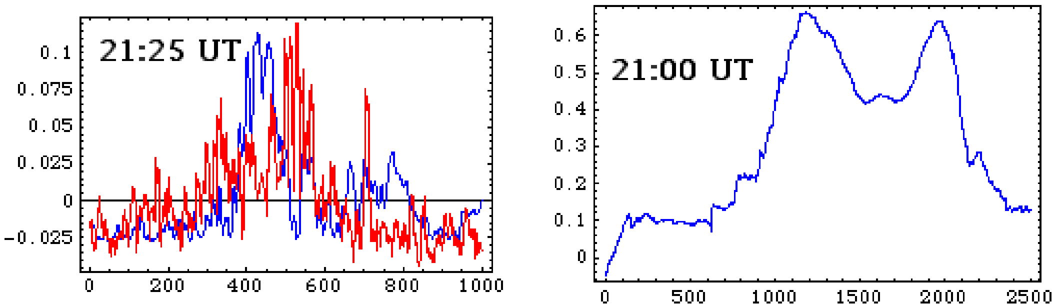

Fig. 4. Left panel: Comparison of the normalized highest geomagnetic activity (blue) and the highest acoustic energy (red). Right panel: Cross-correlations between the geomagnetic activity (x-component) and the acoustic energy in windows of 15 min (x-axis: starting point of the window, time in seconds).

The highest correlation between the geomagnetic and the acoustic data around the time instant of their highest activity is achieved when the geomagnetic data is delayed about 66-81 s. This shows that the dominating sound source must locate approximately at the distance of 25 km. Note that the infra sound components (below 20 Hz) are dominating the total acoustic energy.

The cross-correlation between the acoustic energy and geomagnetic activity was studied in frames of 15 min starting from 21:00 UT. The starting point of the frame was moved in steps of one second. Together 2500 frames over this one hour were studied. Each frame var correlated with 240 frames of geomagnetic data picked up 1-240 seconds earlier than the corresponding acoustic data. The delay corresponding to the highest correlation and the correlation value were stored for each acoustic frame. The result is depicted in the right panel of Fig. 4. The highest cross-correlation is about 0.63 achieved by the frame starting 21:20. When both audio and geomagnetic data sequences are low-pass filtered and down sampled to reduce the time resolution to 10 s the highest correlation found in a window of 15 min was 0.83. Thus the higher time resolution leads to some degradation in the cross-correlation.

The preliminary comparison of the VLF (electric field) and acoustic energy has shown smaller time differences as in the case of the geomagnetic activity. The acoustic events are often indicated in the VLF signal 2-24 seconds earlier. This means that some of the sound sources are located just 600-700 m from the microphone.

SUMMARY

The performed and analyzed acoustical measurements described above show that the acoustic energy close to the Earth surface varies during geomagnetic storm. Relatively high cross-correlation between the geomagnetic activity and acoustic energy was found. Four interesting frequency bands with clear correlations with the geomagnetic activity were found: 5 Hz, 100 Hz, 1 kHz and the range 1-10 kHz. The delay between the geomagnetic activity and the acoustic energy shows that the system has not worked as a magnetic or electric field sensor. Closer analysis of the data is needed in order to reveal further details.

The most successful measurements up to now have been carried out in the southern and eastern parts of Finland. The recorded material is rich in acoustical events, many of them quite strange and astonishing in character but still comparable to the testimonies of listeners around the world. In order to fully solve the mystery of auroral sounds in the near future additional analysis of the present data and theoretical work to pinpoint relevant possible mechanisms of sound generation, as well as more comparison with other geophysical data, is necessary. We are currently continuing the acoustical recordings with improved support from other instruments.

REFERENCES

[1] S. M. Silverman, T. F. Tuan, “Auroral audibility”, *Adv. Geophysics*, vol. 16, pp. 155-266,1973.