DENOISING AND ANALYSIS OF AUDIO RECORDINGS MADE DURING THE APRIL 6-7 2000 GEOMAGNETIC STORM BY USING A NON-PROFESSIONAL *AD HOC* SETUP

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ABSTRACT

An unpredictably strong geomagnetic storm took place on April 6-7 2000. A scientific study on aurora related sounds and acoustical effects had just been started. There were two possible choices: to perform audio recordings with a non-professional *ad hoc* setup, or, to miss a promising possibility to study the phenomena. The first choice was selected and it produced over seventy-five minutes of data, corrupted with impulsive noise from a DC/AC-inverter used to power recording equipment in the field. The data consists of ten successive recordings.

This paper describes a novel method to cancel the impulses found in data without affecting the microphone signal significantly. Next, the power of the cleaned signal is computed in 1/3-octave bands. The spectral comparisons of the different recordings showed a clear increase in the average power in recording #5 that was sampled somewhat after the peak of geomagnetic activity. Specifically, the frequency band around 100 Hz showed an increase in power and also in its fluctuation during the most active geomagnetic periods. This new result supports those obtained earlier [4]. Also, the role of related infrasounds is preliminary discussed.

1. INTRODUCTION

"*IN the time of the Cimbrian warres (120-101 BC), we have been told, that Armour was heard to rustle, and the Trumpet to sound out of Heaven. And this happened very often both before and after those warres. But in the third Consulship of Marius (103 BC), the Amerines and Tudertes saw men in armes in the skie, rushing and running one against another from the East and West; and might behold those of the West discomfited. That the very firmament it selfe should be of a light fire, it is no marvaile at all; for often times it hath been seene, when clouds have caught any greater deale of fire.*"

Caius Plinius Secundus, *Historia Naturalis* [1].

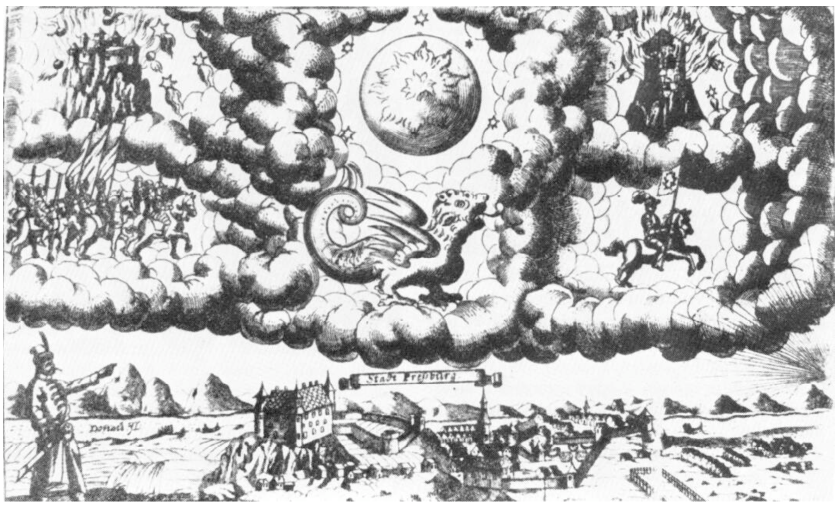

Figure 1. *Aurora Borealis above Pressburg, Hungary on February 10, 1681 [2].*

Through the history of mankind, Aurora Borealis has evoked fear and other strong feelings among the observers. In earlier times it was interpreted as a bad omen, a messenger of gods or even angels of heaven (in Greek *angelos* means a messenger). Many historical myths are inspired by auroral displays [2]. Fear had to be subdued in society and myths were often created for that purpose. There are numerous historical, even ancient documents, related to auroral observations. Some of them also include descriptions of associated sounds. Figure 1 not only visualizes one dramatic auroral event but it also tells how little the associated beliefs changed during a period of 1600 years, from the days of Plinius the Elder. However, if there is "a big host" in the sky, should there not be associated sounds as well?

During the past few hundred years the discussions and arguments regarding possible sounds have continued. At the end of the 19th century a Finnish newspaper article on northern lights described the sounds as a natural part of the phenomenon. However, when the height of the optical aurora was measured with increasing accuracy, it was realized that no audible sound may travel the one hundred kilometers or so down to ground level. After this was understood, the sounds were officially more or less resolutely neglected and pushed aside towards the world of fantasy. The lack of a possible physical mechanism supported this skeptical attitude. However, this did not stop people from making observations. Just recently in Finland, about 300 observers of aurora related sounds were interviewed in a study [3, 4].

During the past few decades some attempts have been made to obtain evidence about these hypothetical sounds. One of the best-known projects took place in Alaska during 1962-1964. That work did not bring about new results nor did it essentially shine any new light on this age-old question [5]. Unfortunately, the study was performed close to a solar minimum when high geomagnetic activity was not frequently present [6].

In December 1999 the author became interested in the study of possible aurora related acoustical phenomena often called *auroral sounds*. The literature showed that even though many observations of these strange sounds had been performed, there was very little - if any - instrumentally collected evidence. Studying the question further also revealed that very few researchers had a background in acoustics, psychoacoustics, electroacoustics, and digital signal processing. This has perhaps led to some nonrealistic ideas regarding the difficulties of studying and understanding this probably objective phenomenon. The observation reports mostly revealed that quite similar sound effects had been perceived independently of the place of observation, the cultural background, gender and to some degree of the observer's age. This supports for the objectivity of the phenomenon. Among the observers were even some well-known geophysicists, musicians and many native people who had lived all their life in the vicinity of the observation place thus knowing well its typical soundscape [3, 4, 5].

There has been some skepticism related to these sounds, as well. Attempts have been made to explain that the sounds were of a different origin. Most often the sounds were associated to normal ambient noise and sounds made by the physical or living environment. Sometimes, the sounds were described to be purely subjective "experiences" caused by the vivid auroral display, or, the geomagnetic storm had directly affected the auditory system of the observer. Of course there may have been some problems related to the validity of the human observations. However, the reports indicate systematic similarities thus minimizing the possible miss-interpretations of the perceived sounds.

As more information about the problem and attempts to study the phenomenon was brought forth, the more interest the topic generated. The author contacted the Sodankylä Geophysical Observatory (SGO) at the beginning of 2000. This led to active co-operation where methodology and instrumentation were developed and the active collection of sound material was initiated. Our first international report described some features of the sounds measured during a strong geomagnetic storm April 11-12 2001 at Koli, Finland [4]. However, the first attempt to make audio recordings occurred one year earlier in Karkkila, Finland during another strong geomagnetic storm on April 6-7 2000. For a period of four years the author has performed simultaneous sound and VLF (Very Low Frequency electric field) measurements covering about one hundred nights in six different locations in Finland. Audio data has also been collected in the vicinity of Sodankylä by SGO. The solar max occurred in spring 2000 producing many strong geomagnetic storms thus this was an opportune time for the project. All main geomagnetic events have been monitored when permitted by meteorological conditions. The huge database is awaiting more detailed analysis **as** the task will be difficult and demanding. We are currently developing and searching for suitable methods for automatic analysis and event clustering. Up to now the main tool has been manual analysis of the material together with intensive listening.

The first recording (April 2000) was not well planned, or planned at all. The storm was exceptional with huge blood-red aurora [7]. The event led to thirteen reported sound observations around southern Finland where the weather conditions were favorable [3]. The event was not easy to forecast and there were no prior warnings. Thus, the author was forced to perform the recording attempt with an *ad hoc* audio setup constructed in fifteen minutes. Due to these circumstances it is understandable that the achieved data was not of the highest quality. Some technical problems already presented themselves during the recording session.

Due to the exceptional geomagnetic conditions, the collected material may contain important details able to illuminate the phenomenon in question. For this reason a large effort was made to clean up the signals corrupted by the problematic setup and to further refine, analyze and classify the sound material. Reference recordings were done at the same place during a quiet night ten days later by using exactly the same, still problematic setup. The idea was to create material comparable to that of the auroral night even though the system also corrupted the new recordings.

This paper discusses in general terms the ongoing *Auroral Acoustics* project [8]. The complexity and difficulty of the task, and even the hopelessness felt while in front of the huge amount of work required to gain any progress with this problem, is at least partially presented. A new denoising process used for cleaning the recordings is described. The audio signals collected during the auroral night are preliminarily analyzed and compared with the reference data. The comparison reveals a clear increase in the SPL especially in the infrasound area as well as in the low frequency audio range during the active aurora. Also, an informal listening of the audio signals collected during the auroral and reference night reveals a clear audible difference in the noise level and noise type. The soundscapes are quite different.

To summarize, the experience of the past four years of work with aurora related sounds now seems to indicate that the probability of proving or solving the related problems within a realistic time phase or a reasonable amount of work is quite low. The complexity of the problem and the ongoing difficulties of methodological questions are the two main points that hinders rapid progress. These facts have been gradually illuminated during this “journey”. Thus we agree with Robert H. Eather who says: “To prove scientifically that auroras sometimes generate a sound … is not an easy task” [4].

The final confirmation of aurora related sounds seems to be at the moment a very demanding task. According to present experience, the best way to proceed is to lay aside any attempt to “prove” that this or that particular part in an audio signal is related to geomagnetic storm. Instead, one should concentrate on collecting, organizing, and analyzing the data, and develop new descriptive methods, in the hope that this will shed more light on the problem. In other words, it is better to proceed with small incremental steps than to try something, which seems unrealistic. Only new, brilliant ideas and good luck may change this somewhat pessimistic view.

This paper is a small example of method development and audio data analysis, which hopefully brings the answers to a difficult problem a little bit closer together.

2. THE PROBLEM

The primary question is: “Are aurora related sounds real or are they just perceptual artifacts or malfunctions”. If current and new evidence speaks for true physical sounds, the next question is, what is their nature and how are they produced? From basic acoustics we know that the structure of sound may reveal its production mechanisms. Therefore, it is of primary interest to capture these sounds for closer analysis.

Suppose that we have succeeded in collecting aurora related sound material. The next and very complicated problem is how to point out from the large amount of collected data which events and structures are the best candidates for aurora related sounds, and, what are the proper scientific, widely accepted, convincing methods to show or even prove that these particular sounds cannot belong to any of the known ambient sounds.

How to point out and detect the true candidates, how to show or even prove that these cannot be any commonly known acoustic events of the observation environment, are the most important questions especially when dealing with the acoustic data alone.

Data can be associated with other simultaneous information sources like geomagnetic activity, electric field measurements, etc., as shown in our earlier paper [4], however, even these correlations do not solve the basic problem. At the best they just give a hint that some parts or components in the audio signal are somehow connected to geomagnetic activity. The search for aurora related sounds could be simplified if we knew what to look for. At the moment there are only verbal descriptions of the sounds and some acoustic signals recorded under active aurorae corresponding more or less to the given descriptions.

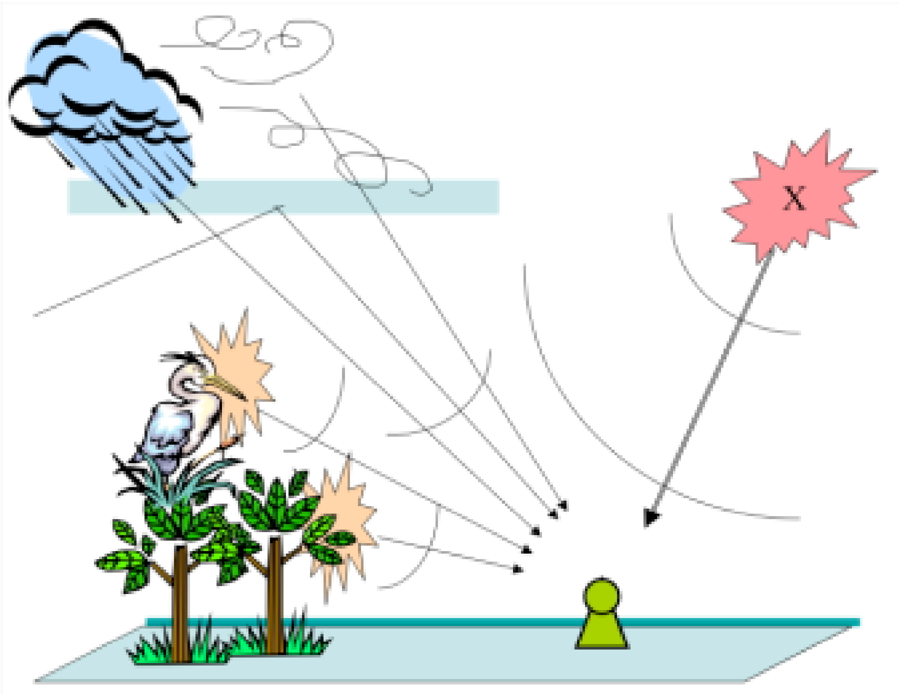

Figure 2. *The main problem in the study of aurora related sounds is how to separate them from common environmental sounds.*

The essential part of the problem is depicted in Figure 2. There are no absolutely quiet environments since some ambient noise is always present. Both physical and living nature produces sounds. Sometimes an inversion in the atmosphere reflects sounds down from distant sources. The sound may be ducted by two parallel layers, etc. If environmental sound sources are not well known they may be wrongly classified as aurora related sounds. On the other hand it may be that some of the aurora related acoustical events are similar to some well-known environmental sound causing a wrong classification in the other direction.

When working alone with acoustic information the problem needs efficient tools to detect, classify, and identify different sound sources. This methodology has clear connections to soundscape descriptions and Auditory Scene Analysis (ASA). Also, the methodology of source separation may be vital. More generally, the problems seem to need a kind of "listening machine", which automatically picks up exceptional events in the sound material, analyses them for some general *features*, and based on these also classifies them. Such an automated listener could be of great benefit especially when taking into account the large amount of data waiting to be analyzed and classified. Up to now we have only been able to make some preliminary steps toward these general goals. At the moment it is not well known what we are looking for and it is not easy to find efficiently features to help and strengthen the search and classification tasks.

3. THE *AD HOC* SETUP AND RECORDINGS

3.1. Setup

An aurora alarm occurred on April 6 2000 around 9:30 PM local time. The decision to make an attempt to record possible aurora related sounds was made immediately. During that time our research unit did not own any portable high quality measuring and recording system. The setup had to be assembled within a few minutes. The system had not been tested or even used before.

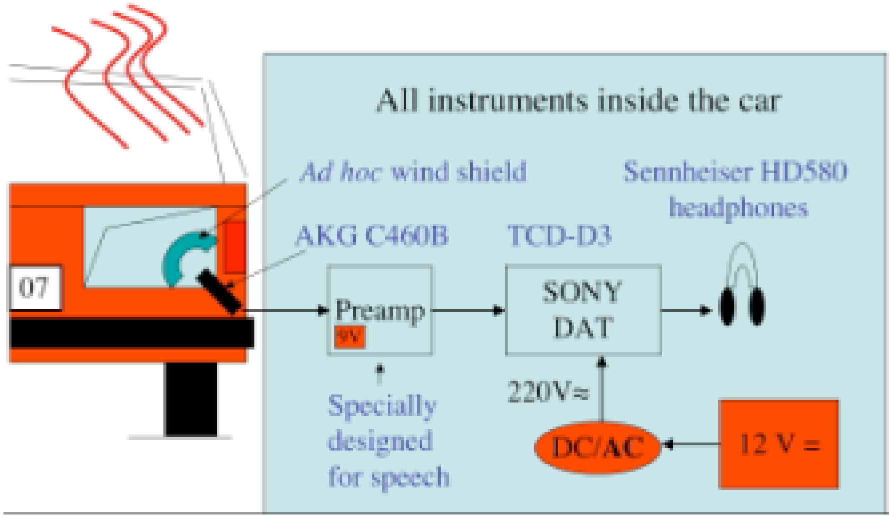

Figure 3. *The ad hoc setup for outdoors audio recording.*

The setup consisted of an AKG studio microphone (C460B), a preamplifier (designed at our research unit), a Sony DAT recorder (TCD-D3), a DC/AC power inverter (Genius PDA 150-12-230) to power the DAT, and a pair of headphones (Sennheiser HD580) for monitoring. The preamplifier was designed for speech research to produce a linear phase response above 50 Hz when used with the AKG-C460B microphone. The linear phase was achieved by designing a resonance below 20 Hz. Thus, the preamplifier somewhat emphasized the infrasound area and compensates for the low frequency roll-off of the DAT. Wind, as well as aurora, produce at times strong infrasounds that often form the largest components in the spectra. The system was able to record signal components down to 1-3 Hz. The sampling frequency was 48 kHz and the same signal was recorded on both channels (left and right). The inverter was not designed for use with sensitive audio electronics and it produced impulsive noise significantly corrupting the audio recording. Due to these impulses the estimated SNR from the differentiated signal was –18 dB. The noise also limited the maximum gain thereby reducing somewhat the dynamic range of the recording.

The microphone was fixed at the back of the car in a plastic pocket constructed from two pieces of plastic sheet (A4 size) bound together at two adjacent edges. This pocket was then opened up towards the sky and partially filled with acoustic damping material (see Figure 3). The purpose of this was to make a simple windshield, which also dampens the sounds coming directly from the environment. All electronics, aside from the microphone, were located on the right front seat of the car thereby providing some electromagnetic protection.

3.2. Problems

Due to the pioneering nature of the measurement experiment it is quite understandable that many things did not progress as planned, and as they would typically occur when the measurements are well planned beforehand and the system together with the whole methodology has been previously tested. The first problem was how to find a quiet location not very far from Helsinki. A couple of potential locations for auroral measurements were preliminary looked at from a map, however, these locations had not been examined firsthand more closely. In the darkness on unknown country roads it was easy to loose one's direction. The location on the map planned for the measurements was not found. The location was finally chosen quite randomly was neither the best possible nor the worst. In the evening there was no traffic on a nearby road beside which the recordings were made. Only two cars passed the recording location in the morning hours. This occurred during recording #8. The distance to the main road was about five kilometers and in the quietness some traffic noise from that road was detected. Also, air traffic ended a little after midnight. The sound of the first plane landing in the morning can be found on the last recording #10.

The worst noise problem in the audio signal was caused by the DC/AC inverter used to produce 220V power for the DAT. Also, wind was a disturbing factor during the first recordings. The designed windshield worked sometimes more like a wind detector. The plastic pocket in which the microphone existed bowed and vibrated during the strongest gusts thus generating its own noise. Luckily the wind calmed down during the most important moments of the night.

One more problem found in the data is the lack of exact timing. Since there were so many more important things to be taken into account and problems that needed to be solved quickly the whole question of how to document or indicate the time of the recording was not considered at all.

Finally, due to the large variation in the wind noise, the gain of the recording was manually controlled during the session in order to avoid clipping and also to maintain the signal level optimal for A/D –conversion (optimization of the dynamic range). The manual gain control was continuous (not stepwise) and not documented. This caused problems when trying to compare the material from different recordings or even at different places on the same recording.

These problems made the audio signals very difficult to be used for any scientific purposes. The situation was so bad that many times during this study the idea of altogether abandoning work with this material has arisen. However, the knowledge that this night was an exceptional one motivated the author to continue regardless of these obstacles.

3.3. Recordings

The recordings began around 20:30 UT (23:30 LT) and ended around 0:30 UT (3:30 LT). The task was paused many times due to the wind and also in order to make observations and photography outside the car. The material was divided into ten recordings based on the most prominent pauses found. The huge red aurora occurred during the fourth recording around 23:30 UT (2:30 LT). The period from the activating aurora (recording #3) to the end of the session (recording #10) was most intensively recorded.

#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
6:41	10:26	10:01	5:36	5:06	8:16	4:35	8:07	8:32 3:04 B	8:16
36.7 MB	57.3 MB	55.0 MB	30.8 MB	28.0 MB	45.4 MB	25.2 MB	44.6 MB	46.9 MB	45.4 MB
Wind	Wind	Some wind, events	**RED AUR.** Noise	Noise, events	Many events !!	Some events	Two cars passed	Dist. Cars, Wind	Cars, plane

Table 1. Summary of the ten recordings. From top down: recording number, duration in minutes and seconds, file size in MBs, and some comments regarding different audible events.

During the first hours the wind gusts and noise was too disturbing, and secondly, the most active auroral oval was far to the south from the location of the observations. During those hours the best places for observations were in Germany or even in France.

During the pauses the audio system was on and the soundscape was monitored through the headphones. Therefore, probably not very many important acoustical events were lost. Open fields surrounded the car except for a small hill with some trees to the south. Thus, the sky was well observable through the windows. Active visual and auditory monitoring was performed throughout the night even if the recording was not on. Table 1 summarizes the recording data.

The total duration of the recording is 75 minutes and 36 seconds. The material was moved from DAT- to wav-format on ROMs digitally without any additional cascaded D/A- and A/D-conversions.

4. DENOISING PROCEDURE

The main idea of the novel denoising method is to minimally affect the original microphone signal by the procedure. The corrupting impulsive noise component is assumed to be stationary. Ideally, the inverter noise can be modeled as a sequence of pure impulses. This means that due to the anti-aliasing low-pass filter of the DAT, these impulses will appear in the data as sampled versions of a sinc-function added to the microphone signal. Since the impulses are not in synchrony with the sampling oscillator the sinc-functions have random phase. Thus, they appear in the data in different shapes and in different time instances.

In order to study this in detail a new recording with the same setup was performed in a quiet anechoic chamber. This signal of "pure impulsive noise" was then carefully studied. Together over 2500 sinc-shaped pulses were collected from the recording. The frames of 32 samples including the impulses were power normalized for comparison and clustering. Before impulse extraction the signal was differentiated (a = 0.95). The differentiation is beneficial also in the cleaning of the auroral recording. It helps to flatten the spectrum of the measured microphone signal, which has strong infrasound and low audio range components thus protecting it during the impulse cancellation operation. Additionally, it emphasizes the impulses and makes their detection easier (see Figure 3).

The noise impulses were located, copied to a frame of 32 samples and correlated with the impulse library to be constructed. At the beginning the library was initialized by one random vector. If the correlation of a new impulse candidate with the library had a higher correlation than 0.95 with any of the items included in the library, the pulse was averaged with the best model. In other cases it was chosen to form a new model of the library. This stage compressed the 2500 impulses to a library of 40 models.

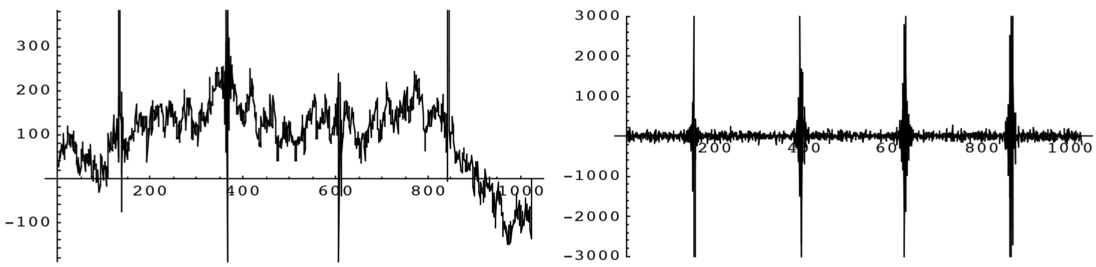

Figure 4. *Example of the corrupted signal and its differentiated form.*

The next step was to analyze how many times each model needed to be applied when fitting them to the material of the 2500 impulses. Since eight models were infrequently used they were removed. This caused only a minor reduction in the modeling quality when simultaneously improving the computational efficiency. Finally, it was noted that those pulse models with positive peaks had a strong negative correlation with those with negative peaks. This allowed the size of the library to be halved. Only models with a positive peak were left. Thus, the final library of impulses includes only 16 items.

The four highest peaks located approximately at the distance of 238 samples are first detected in frames of 512 samples. Then they are correlated with the library and cancelled by weighted subtraction. After this the signal is low-pass filtered to fully compensate for the primary differentiation operation. During the procedure a data file is created with all the important information: places of detected impulses, the fitting correlation, and the index of the library item used in denoising. The data file allows the monitoring of the process, and which is even more important, the modeling and automatic compensation for the gain variations in the recording (see 5.1). This way one problem can be used to solve another.

The denoising procedure works in general quite well. Only some residual audible impulses are left. The long-term spectrum may still show some of the harmonics of the impulse chain. It should be quite easy to compensate these with other tools if required. In some places groups of high amplitude impulses are for some unknown reason still remaining. They may be caused by some rapid and larger variations in the fundamental frequency of the DC/AC inverter. These details are awaiting closer analysis. Generally, the material can now be auditively examined and also it is ready for the 1/3-octave analysis.

5. 1/3-OCTAVE ANALYSIS

5.1. Gain normalization

It was noted that the amplitude of the impulsive noise produced by the DC/AC-inverter varies systematically with the level of the microphone signal, that means with the gain control of the DAT. Thus the impulses are leaked through the DAT input, possible through its preamplifier. This finding makes it possible to normalize the variable gain in connection with the 1/3-octave analysis in order to simplify the spectral comparisons. Figure 5 gives an example of a gain increase indicated by the amplitude of the detected impulses in the signal.

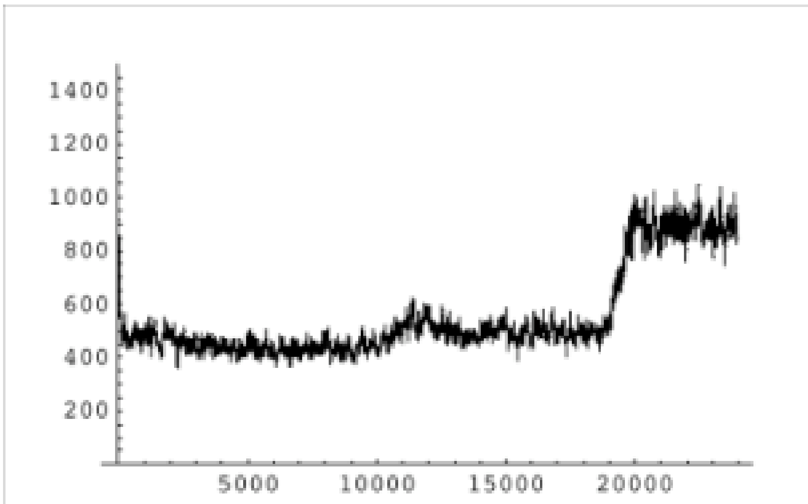

Figure 5. *Gain increase coded to the amplitudes of the noise impulses.*

5.2. Some Analysis Results

Segments of the lowest acoustic power were searched out of the nine recordings studied. Then the 1/3-octave data over the recording was averaged. In this way it is possible to avoid recordings with clear surface wind noise directly hitting the microphone. Figure 6 summarizes this comparison. It is most likely that a wind higher up from ground level and some distant traffic sounds increase the power around and below 1 kHz in the first two recordings. Similar problems are seen in the three last recordings (10, 9, and 7). Four recordings in the middle show a different trend. In these recordings the acoustic power increases smoothly toward the infrasound region.

The spectral slope of recording #5 is the steepest. It also has the highest value in the infrasound region. The power decreases about 10 dB/decade (also 10 dB per ten 1/3-octave band, i.e., 3 dB/octave) from the infrasound area of 12.5 Hz (band 1) to 100 Hz (band 10) and also from 100 Hz to 1 kHz (band 20). The 3 dB/octave roll-off means that the noise is equal to *pink noise.* As a working title for the aurora related noises with 2-4 dB/octave roll-off we have also used the name *amber noise.*

All nine spectra of the figure have about the same shape above 1 kHz. This is caused by the fact that the signals still have residual impulsive noise at the higher frequencies and this power dominates over the low-level microphone signal. For this reason the upper limit for spectral information is around 1 kHz. Possible improved denoising in the future may extend the bandwidth of the valid spectral information further.

By informal listening the increased noise of recording #5 does not sound similar to wind noise. It is surprisingly stationary noise without any clear fluctuation. The author heard this noise while remaining outside of the car. Some days later an informal characterization of the noise was given by the author in the Finnish TV news as: "*like the noise of a big, distant waterfall*." There was no noticeable surface wind, no clear traffic noise and there was no civilian nor military air traffic during those morning hours.

Often, when ground level wind disappears around the middle of the night it does not indicate that there is no more wind higher up in the atmosphere. However, if this increase in the noise level at lower-frequencies is caused by wind, the location of the turbulence should have increased rapidly in altitude. Simultaneously, the wind should have intensified when compared to the wind closer to the surface just some minutes earlier (recording #4), or some minutes later (recording #6). The author has no competence in evaluating whether this could be meteorologically feasible or not. In any case, this does not seem very probable.

The fine structure analysis of the clear wind noise of the first recordings and the different noise types of recording #5 is underway and may reveal further differences. In such a case the *pink noise* found might be a good candidate for a so called *auroral noise*.

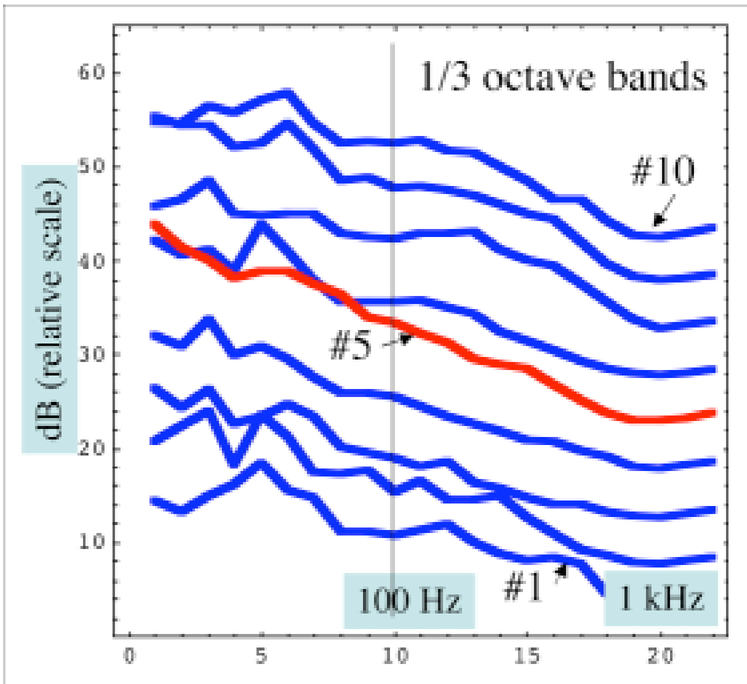

Figure 6. *1/3-octave analysis of the nine recordings (1, 2, 3, 4, 5 red, 6, 7, 9, and10). Recording 8 is not included due to the noise of two passing cars. Neighboring recordings are separated by an additional 5 dB level for clarity. Recording #4 was captured during the large red aurora at around 23:30 UT (2:30 LT). A clear increase of low frequency noise and infrasounds occurs in recording #5 (pink noise, see text).*

The reference recording was made with the same instruments at the same geographical location 10 days later (April 16, 2000). Figure 7 compares the spectrum of a segment of the noisy recording #5 (red) to the reference spectrum (gray and black). In one case (gray) the reference data is fitted based on the high frequency level, which leads to a good fit also in the 50 Hz band. In another case it is fitted based on the level and slope close to 1 kHz. These two fittings have a difference of 3 dB. The true level may lie somewhere in between.

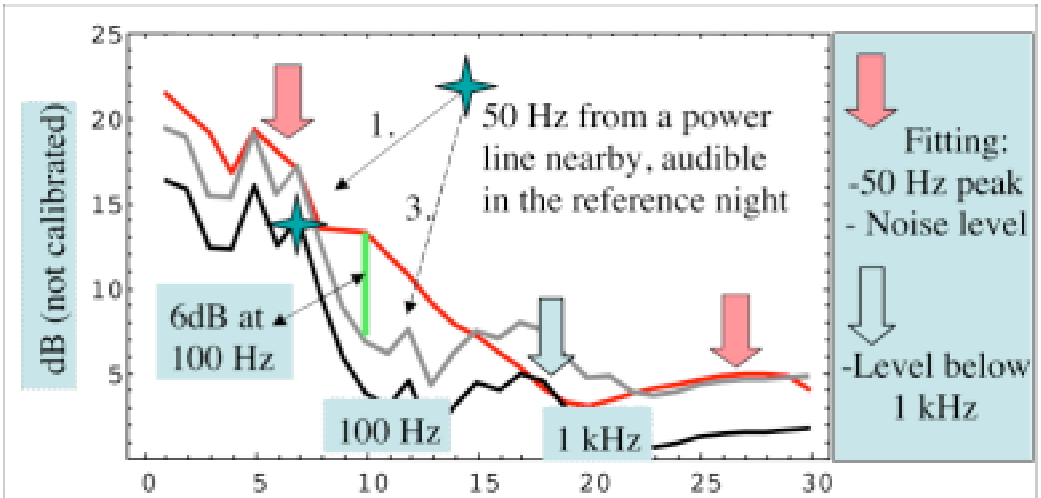

Figure 7. *Comparison of low power averaged spectra of recording #5 (red) and the reference signal (gray - fitted at high frequency range, black – fitted around 1 kHz).*

Even though it is not easy to decide which principle could lead to the most accurate fitting, the gray curve may be close to the right place. The reference night had less wind, however, the sample was taken earlier in the night and thus there may be more traffic noise (a power increase just below 1 kHz) in comparison to recording #5. However, the difference at 100 Hz (over 6 dB) may not be easy to explain.

During the auroral night the 150 Hz buzz produced by a power line nearby was not audible while during the reference night it was. The picture confirms this clearly. During the auroral night the buzz was masked by noise probably related to the geomagnetic storm. The informal listening and comparison of these two recordings makes it clear that the auroral night noise masked also many other environmental sounds. For example, some sounds produced by distant birds cannot be detected in the auroral night recording whereas they are clearly audible in the reference night. In other words, some noise dominated the soundscape of the auroral night, or at least during the most active period of the geomagnetic storm.

6. CONCLUSIONS

This paper presented a method to cancel impulsive noise in audio recordings. The procedure is based on a library of impulse models each averaging a cluster of impulses found in the recording. The first analysis of the auroral night recording of April 6-7 2000 was presented in the form of comparisons of 1/3-octave spectra. Variations in the averaged spectra taken out of periods of the lowest acoustic power were mainly caused by wind and other environmental noise. The period just after the highest geomagnetic activity exhibiting a large red aurora showed exceptional spectral structure. The power increased especially in the infrasound range and also systematically over the lower audio range. The comparison to the reference night recording showed a large, about 6 dB difference, in the 100 Hz band.

A closer analysis of this 1/3-octave band showed that there exists a larger fluctuation than in most of the other bands. The average level increase and fluctuation increase around 100 Hz simultaneously with the activation of the geomagnetic storm, fits earlier results well based on data measured with a high quality audio system in Koli, April 2001 [4].

The mechanisms of the sound source cannot yet be defined. Intense wind higher up from the ground can be one explanation. Two other preliminary, new hypotheses are related to flow dynamic and atmospheric electricity. Approximately laminar air flow (wind higher up in the atmosphere) does not produce much noise. The flow (constant velocity) layers are parallel with the ground. When a strong infrasound wave package 'shoots' through these layers of different velocities it may cause noisy turbulence. More detailed analysis of the noise will test this hypothesis in the future.

Another hypothetical possibility is that a strong geomagnetic storm is able to ionize the air, or with some other mechanism, able to form ionized clouds of opposite charges in the atmosphere. Ground level measurements of the electric field during bright aurora have revealed large variations. A strong infrasound wave package 'shooting' through these clouds may activate discharging mechanisms and acoustic noise is produced. In both cases the infrasounds, which alone are not audible, may catalyze audible noisy processes in the atmosphere.

The noise and infrasounds were noted to be activated simultaneously with some delay to the highest geomagnetic activity. This fits well with the hypotheses that infrasounds may be involved in noise generation. In both cases the sound source may be relatively close to the ground level, which makes them better audible.

The sounds associated with aurora are sometimes compared with the sounds heard in connection with meteorites. The infrasound hypotheses could explain also these sounds. The meteorite heats up a channel in the atmosphere that produces an infrasonic wave. The gas is ionized simultaneously and some electromagnetic waves are also produced. A known hypothesis is that these electromagnetic waves ionize air also close to ground and finally cause discharging and crackling [9]. This may be possible, however, all hypotheses need actual data and reliable measurements to be verified.

Also, other hypotheses have been created and discussed. However, they are still too speculative in nature to be discussed here. We have to continue the analysis toward structural details of the sounds in order to better illuminate the sound generation process. The data also contains plenty of quite strange acoustical events, such as: a rustling noise, a 'large flag in a wind'-sound, a crackling noise, loud claps, a popping sound, and a rumbling noise. It will be a very difficult task to show scientifically that these effects are or are not related to simultaneous geomagnetic activity. Presently a new methodology is under development and tests are being carried out.

Sounds, associated with aurora and geomagnetic storms, have been investigated during this study. Interestingly the central result coincides with our earlier results even though the measurements were performed essentially with different setups, in different environments and over one year apart. However, it is too early to state any "final" conclusions. We still face many complicated and unsolved problems.

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8. EPILOG

Why was this work performed? Why all these long years of effort? Some researchers in Finland have even asked, what does it matter if there exist aurora related sounds? So what if they exist? If these same people happen to hold a position where they can affect the financing decision it is understandable that a project like this has no chance in being supported.

The value of this effort and its results may not be large, however, why determine the possible meaning and value too much beforehand? Many current “less valued ideas” may after some years or decades gain importance. Similarly, many currently highly valued ideas may have vanishing value in the future. If the problem to be studied is relevant and interesting, the new knowledge and understanding possibly created by it should be sufficient motivation enough for it to proceed.

Nowadays, research goals and interests are increasingly directed by their immediately foreseeable applications and benefits. Creating new, universal, scientific knowledge as such is no longer a sufficient motivation for work. This means a strong narrowing in the breadth of the research “window”. In the end this may even hinder science, since its ability to creatively extend to new areas will be diminished.

Problems in our knowledge or in its relation to objective reality always means that knowledge is never maturated and needs further work. This is the case when dealing with the problem of aurora related sounds. Hopefully this study at its least opens up new relevant information and creates fruitful questions to work on.

I didn’t choose the topic – the topic chose me.

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