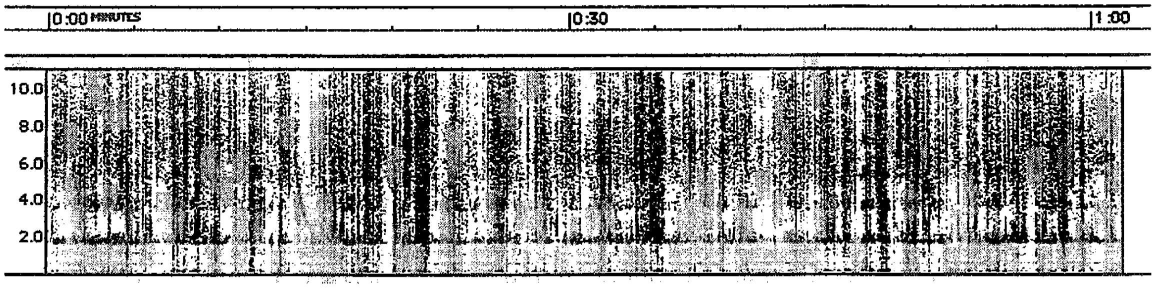
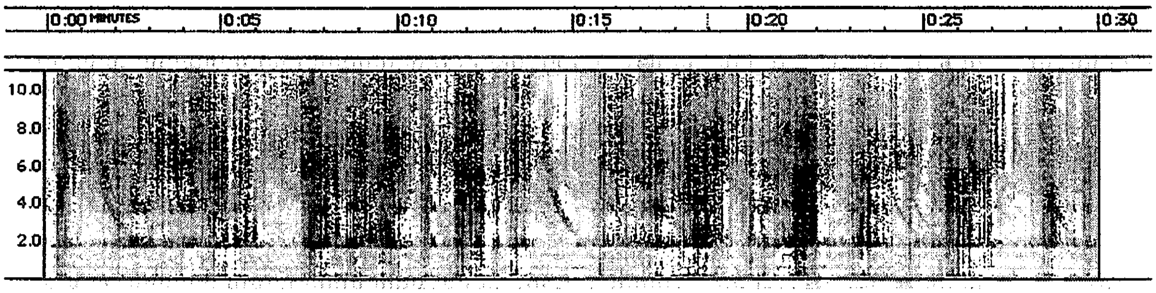
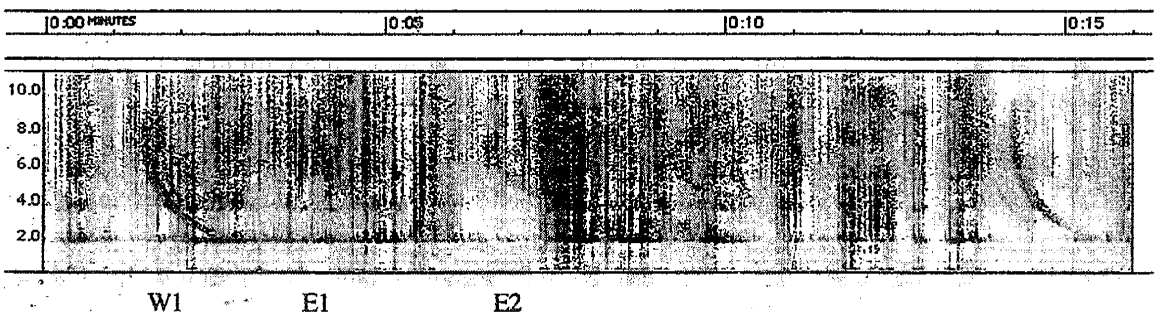


Spectrogrsam of the first minute after 1000 UT. Ten whistlers were logged during this interval.

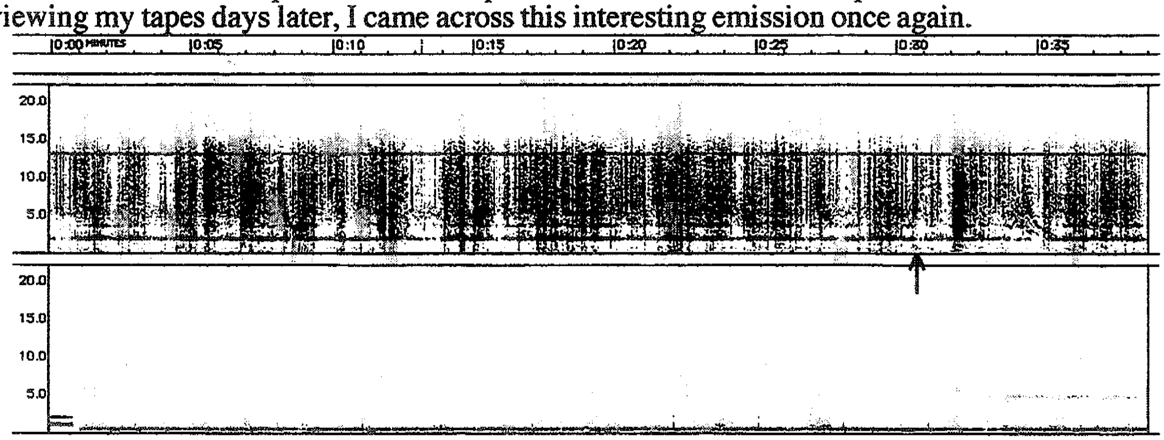


First 30 seconds. Six whistlers. The first is the strongest.



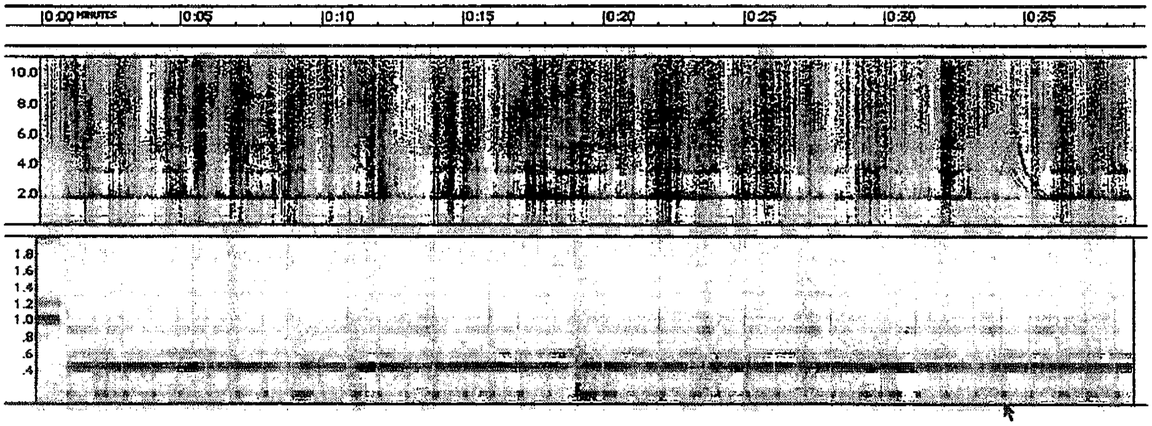
First 15 seconds. Two echoes (E1 and E2) follow the first whistler (W1).

Now let's back up to that event captured at 9:02:34 GMT on Sept. 17th. As I was reviewing my tapes days later, I came across this interesting emission once again.



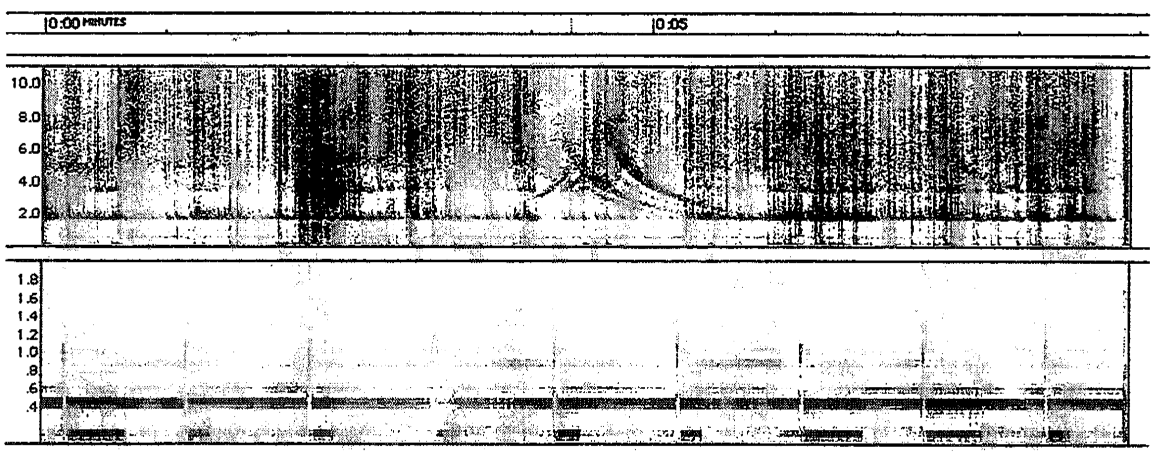
Spectrogram showing natural radio on the top track and WWV on the bottom track.
The dash at the beginning of the WWV track is the 0902 UT WWV tone.
The arrow points to the "interesting emission".

The event reminded me of how some of the triggered emissions sounded that I had heard previously on tape recordings created by the Navy's NAA transmitter in the 1950's. I listened a little closer and noticed that I could hear a faint bubbling sound around 1 kHz, beginning approximately 0.8 seconds before the "triggered emission" occurred. After taking a quick break to listen to this recording again, I can better describe this bubbling sound as being centered around 600 hertz instead of the assumed 1 kHz. Basically it sounds like a string of fast-rising and descending notes (around 10-15 per second) centered around 600 hertz. It almost sounds like someone yodeling way off in the background. (I had to throw that in - it's hard to describe exactly.)



The VLF spectrogram is shown with a 0-11 kHz frequency range;
the WWV track uses a 0-2 kHz range.
The arrow points to the location of the faint "bubbling" sound.

This faint bubbling sound that begins immediately before the triggered emission on Sept. 17th sounds very similar to the VLF emissions that were created by the NAA CW transmissions, which made them also sound nearly like a steady tone in the 1950's. This was proof enough to me already that this was indeed a triggered emission. I had an even bigger surprise awaiting me that would throw all doubt out of my mind that this was a triggered emission I had captured.



About 7 seconds centered on the triggered emission.
The dash at the bottom left of the WWV track is the 0902:30 tick

After arriving home from work later that same day, I decided I needed to create some logs of the activity I had heard from this day of coordinated listening sessions. Mike Mideke had already sent me his logs of the activity he had heard, and I wanted to pass along my logs as well. This time I was monitoring the WWV track alongside with the VLF audio track so I could mark down the exact time that whistlers were being heard for comparisons of our logs at a later date. I was in for a surprise when I arrived at the point where the triggered emission occurred. Not only did I hear the triggered emission this time, but I also heard a transmission on the WWV station I was monitoring. It keyed up at exactly the same time the bubbling sound begins in the VLF audio track (approximately 0.8 seconds before the triggered emission occurred.) This transmission consisted of an 8-second data signal followed by a CW identifier "WPC," which made the overall transmission time twelve seconds in duration. Now I found out I had not only the triggered emission on tape, but also the signal that triggered the emission with its Morse code identifier!

A little more research using audio filters and spectrographs showed that the signal was indeed transmitted by WPC. I thank Mike Mideke for the wonderful spectrographs he provided. A little research on the WPC transmitter showed they were licensed to 27 different frequencies in the HF radio spectrum. The station is run by the United States Coast Guard and sends out signals to commercial ships, military vessels and yachts worldwide. They boast about their "global coverage" using "very advanced proprietary technology" that relies on "using the earth's ionosphere" instead of "satellites" and their corresponding "mammoth capital investment." Again, from an email dated Sept. 26, "We provide commercial service on 27 frequencies for vessels all over the world using as our infrastructure nature's own ionosphere instead of a satellite structure costing many billions of dollars to put up." The station is located in Gladstone, New Jersey and transmits with one thousand watts of power. So, how did I happen to hear this signal on my WWV receiver?

That's easy to explain. All radios have mixers that mix different frequencies together to arrive at the signal you want to hear and to allow you to tune up and down in frequency. After being mixed, the signal is sent through filters to filter out the unwanted frequencies while leaving in place the desired frequency. If the unwanted signals from the mixing process are strong enough, they will bleed through the filter(s) and be heard along with the station that you are monitoring. A little research proves that this is what happened on Sept. 17th with my WWV receiver. My receiver has an IF (intermediate frequency) of 455 kHz. Usually, "images" (duplicates of the same signal which are heard elsewhere because of the mixing process of the radio receiver) occur at twice the IF (intermediate frequency). Looking at the frequencies licensed to WPC, one stands out in particular - 5910.5 kHz! Everything adds up now. I was monitoring WWV at 5000 kHz. Add to this twice the IF (910 kHz), and you come up with 5910 kHz. Further listening with this short-wave receiver used on Sept. 17th showed that all stations with any decent strength can be heard at their actual frequency and also at 910 kHz below their actual frequency. So, in summary, what I heard that night was the 5000 kHz WWV signal and the 5910.5 kHz WPC signal combining together into one signal at 5000 kHz in my receiver through the receivers' internal mixing process.

In closing, I would have to say that research is underway! If what was heard was in all actuality a triggered emission by an "HF" radio station, which very strongly appears to be the case, it could potentially mean another breakthrough in the field of research dealing with the ionosphere and the frequencies affecting the ionosphere. WPC uses a "log periodic antenna" to broadcast many of their transmissions. On the spectrographs, the triggered emission looks like two quick risers, which are then blended into two descending whistlers. One note that may be of interest is that on this particular night for several hours starting from the time of the triggered emission and continuing for several hours onward, the lightning crashes that appeared 5-10 dB louder in the WWV receiver while remaining at the same decibel strength as all the other crashes in the VLF receiver, seemed to be having really great affects on the VLF activity in the way of nice, loud-sounding whistlers. Again, I would have to say research is underway!

Instrumental Detection of Meteor-produced VLF Electromagnetic Radiation

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Abstract

In November 1998 a Croatian Physical Society expedition to Mongolia was undertaken. The goal was to try to record VLF emissions and electrophonic sounds (if any) of Leonids during the anticipated Leonid storm. We obtained some instrumental recordings of very-low-frequency electromagnetic radiation (VLF) which we attribute to a meteor. The detected VLF signals were coincident with the light maximum of meteors in question, and the meteors involved in these events were quite small (-5 mV and -8 mV) which implies much lower brightness limit (about –5 mv) for the VLF producing meteors than previously suggested. It is, however, not excluded that this limit depends on weather conditions. In the best recording (the -8m meteor), a 0.7 s long sequence of 8 short VLF impulses with amplitude of about 10-2 V/m, starting 0.1 s before the visual maximum of the meteor, was registered. The amount of gathered data is huge, and we are still at the analysis of it.

Introduction

The meteor--related electrophonic sounds are defined as sounds heard simultaneously with the appearance of a bright meteor. Although their existence and possible relation to "electric matter" (Bla1784) was recognized already in the 18th century, they are still a mysterious natural phenomenon. The fact that puzzled so many scientists is that any sound produced by the meteors would travel to the observer on the ground within a few minutes, as the meteors usually burn--out at heights of around 100 km. Moreover no audible sound from that height can reach the ground as the sound wave will be totally reflected back into the ionosphere on the denser layers of the atmosphere near the ground level. So the electrophonic sounds must have a different origin. A distinction to a normal sonic boom produced by very large meteors should be made here. The sonic boom is generated when a large and solid meteoroid, usually of stone or iron type, penetrates into the lower atmosphere, while the smaller meteors, to which our study is directed, disintegrate at heights between 80 and 100 km.

The first plausible mechanism of the origin of electrophonic sounds was suggested by Keay in 1980 (Kea80) and theoretically modeled by Bronshten (Bro83) (KB-theory hereafter). According to their theory, a bright fireball can under special conditions produce ELF/VLF radio waves The low frequency end of electromagnetic spectrum is divided into ULF (frequencies below 30 Hz), ELF (30--3000 Hz) and VLF (3 kHz--30 kHz) bands). This electromagnetic radiation can then be converted into sound by an ordinary object in the observer's vicinity. The main conclusions of this theory are that very bright bolides are needed to generate VLF, and they set the lover limit to -12 m (about equal to the brightness of a full Moon). Keay also tried to do some laboratory experiments on generation of sound by VLF fields on mundane objects that have clearly demonstrated the ability of VLF radiation to produce audible sound (Kea91). In 1991, he pointed to the first known detection of a meteor VLF by Japanese observers (Kea92a) which was published in Japanese (Wat88). Soon after, he refined the KB theory (Kea92b) and predicted that VLF can be generated in the moment of the explosive disintegration of a bolide, but also a little bit earlier. In cooperation with Ceplecha he tried to predict the average number of electrophonic sounds that should be heard by a single person (Kea94a). The calculation was based on data presented by Ceplecha (Cep92,Cep94). The results predict that a person who would spend every night outside has a once in a lifetime chance of hearing an electrophonic sound, with a comment that this is a very optimistic prediction as today many such events would be masked by man-made sounds and would so pass unnoticed. Recently Keay attempted to give a review of this field (Kea95) but misses some Russian references.

Expedition to Mongolia

To collect a significant sample of bright meteors, an exceptionally high meteor rate is needed. The predicted Leonid meteor storm of 1998 was expected to be such an event. The storm was predicted to happen over East Asia on the night of November 17/18 (Jen96). Historical records from the great Leonids meteor storm in 1833. suggest that large Leonids are capable of producing electrophonic sounds (Olm1833). Considering these facts, our observing campaign was located in Mongolia, lasting from Nov. 10 until Nov. 24, 1998. Here is a rather lengtly, but a very interesting recollection on the voyage itself, extracted from the diary of Dejan Vinkovic:

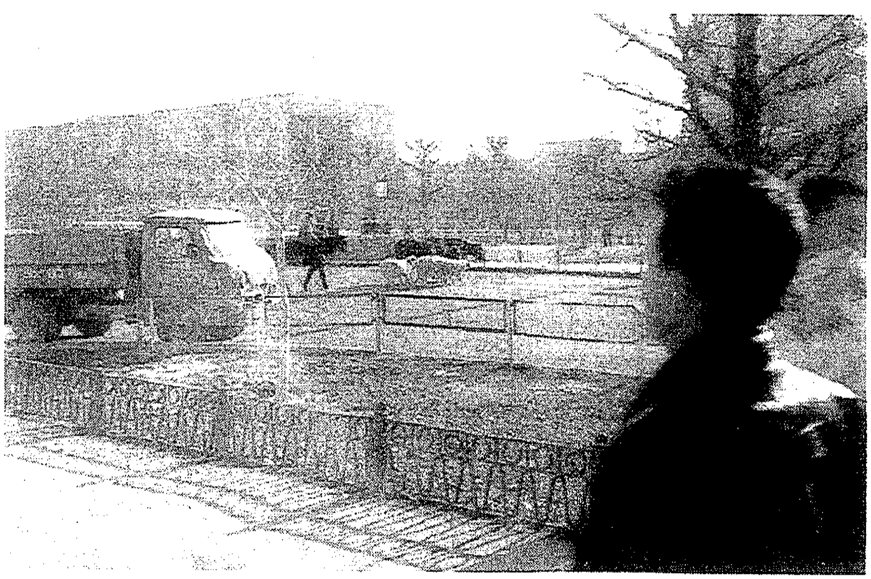

Figure 1:

Ulan-Bator has a lot in common with big towns of the former Soviet Union

"Imagine a huge land, empty land. Without people and roads, with deserts, mountains, wild animals, ... And one town in the middle of that. Small, smoggy town, mixture of people, cattle and cars... with nuclear power plants!! That's Mongolia and Ulan-Bator.

The first impressions of Ulan-Bator: streets are crowded and everything is strange and interesting. But people are friendly and curious on us. It is warm! Where is this "-30C"?! Is my investment into the low-temperature clothes a loss of money?
The first two days we spent in observing Ulan-Bator through the eyes of tourists: photo and TV cameras, getting excited about things which are ordinary for people there, talking with kids on the main square, etc.. At the evenings we were preparing the equipment, and had briefings about the current problems and how we would perform the experiments. Then we went to the astronomical observatory, where we supposed to have two gers, at least 2km away from the observatory to avoid electric installations because they are producing a ELF/VLF (extremely/very low frequency) radio noise. We would like to perform two experiments: detection of the ELF/VLF emission from the meteors, and detection of the electrophonic sound, which is probably somehow related to ELF/VLF electromagnetic waves. But, first we found that there was only one ger. Moreover, our Mongolian hosts thought that it would be nice for us to have electric bulb in the ger, so the ger was in the observatory complex, surrounded by electricity, impossible for any kind of experiments!

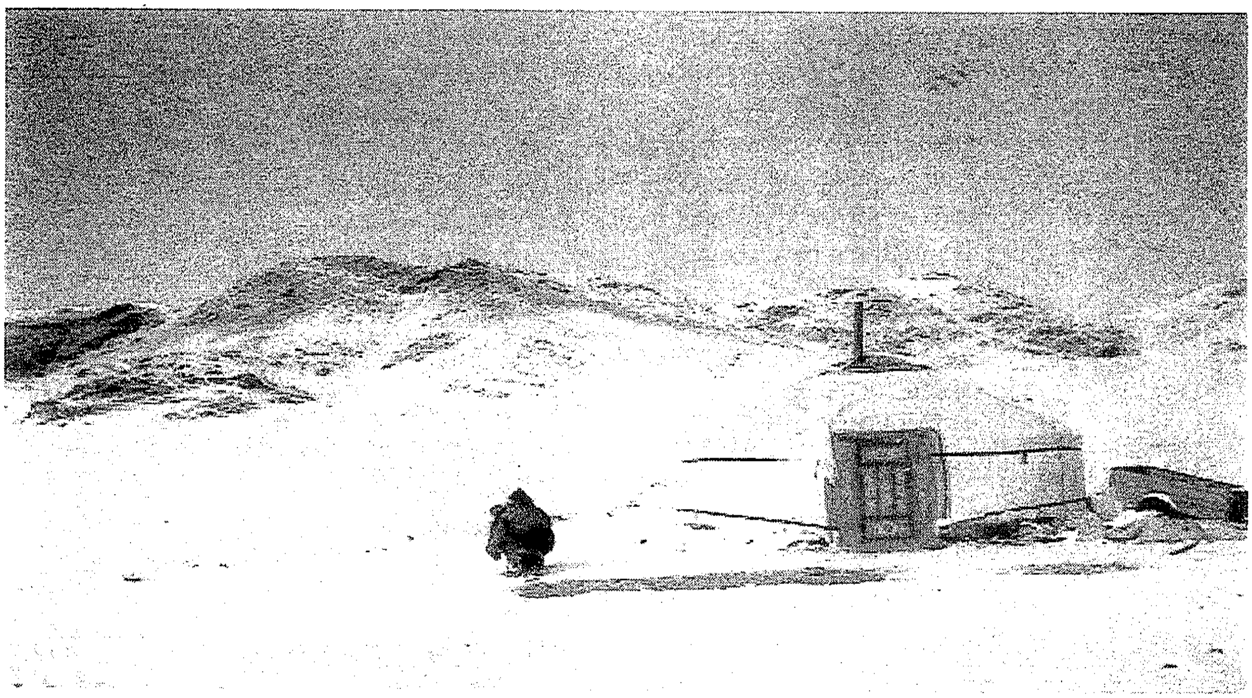

Figure 2: The first snow in the Mongolian wilderness. Believe it or not, people are driving cars there, even when there are no roads around. But the ground is smooth and frozen.

We thus had to move our gear somewhere where we wouldn't see civilization. During the day we found the place, and next day we were moving there. At least, we learned how to set up a ger. Weather is still nice, warm. But Americans at the observatory told us that a cold Siberian air was coming, with the snow in front of it. Americans are part of the large Canadian-American expedition. There is a German team ,too, and a few people from Slovakia and Yugoslavia. Crowded place!

The first night in countryside: snow storm! The ger is really overcrowded: 13 people all together! Mongols said that another ger should come in the following days. Anyway, everybody is in a good mood. But temperature is falling down ... fast. Sky is suddenly full of clouds and snow storm starts! Next morning everything is covered by snow. And it is cold ... now I do not regret spending money on warm clothes anymore... First tests of our equipment are carried out in days before the anticipated meteor storm. Temperature outside is -25C !! Cool!! Every night the sky is partly cloudy. We are worried about the sky at the night of maximum, although Americans are saying that weather will be good, and we relied on it. Then the last night before the predicted maximum came and we made the last tests of complete practice for tomorrow. There are two of us outside, freezing on almost -30C, and making visual observations and comments which are recorded with the video signal from a small camera. There are also two microphones specialized for electrophonic sounds, and two ELF/VLF antennas. Everything is going smoothly. Taurids are active. There is also a small activity of Leonids. But, the Leo constellation is still under the horizon, and activity will be probably a little bit larger after the midnight, when the Leo is rising. At about 11pm, we noticed a few very nice Leonids. Good. If we already see higher activity, then we can expect show tomorrow. Actually, the show has already begun! The number of Leonids is slowly increasing. All of them are bright. Magnitude zero or brighter. But, the Leo is rising and Leonids are flying more often.

Suddenly, we realize that something strange is happening! These meteors have become fireballs, and now we can see huge explosions every 10 minutes. And there are no small meteors!! The excitement is rising. At 3am we are watching incredible show: explosions every few minutes. The most of them have beautiful trails and colors. We are just standing and waiting for another flash from the sky. Sometimes they are so bright that you can see shadows on the ground. Slaven and Neven claim that they heard an elecrophonic sound. But we are skeptical. Until something turns night into day! A huge bolide appears on the north horizon, and we hear a "pop" sound! Now we are sure that they exist, and hope that everything is on tapes. This incredible show was going on and on ... We have a tape where we're dancing in front of camera, when the Sun and Moon are rising behind us, and meteor is falling near by the Moon! When the Sun rose, they were still falling on the blue sky! This was indication that they are visible in Europe, too.

The setup of the equipment

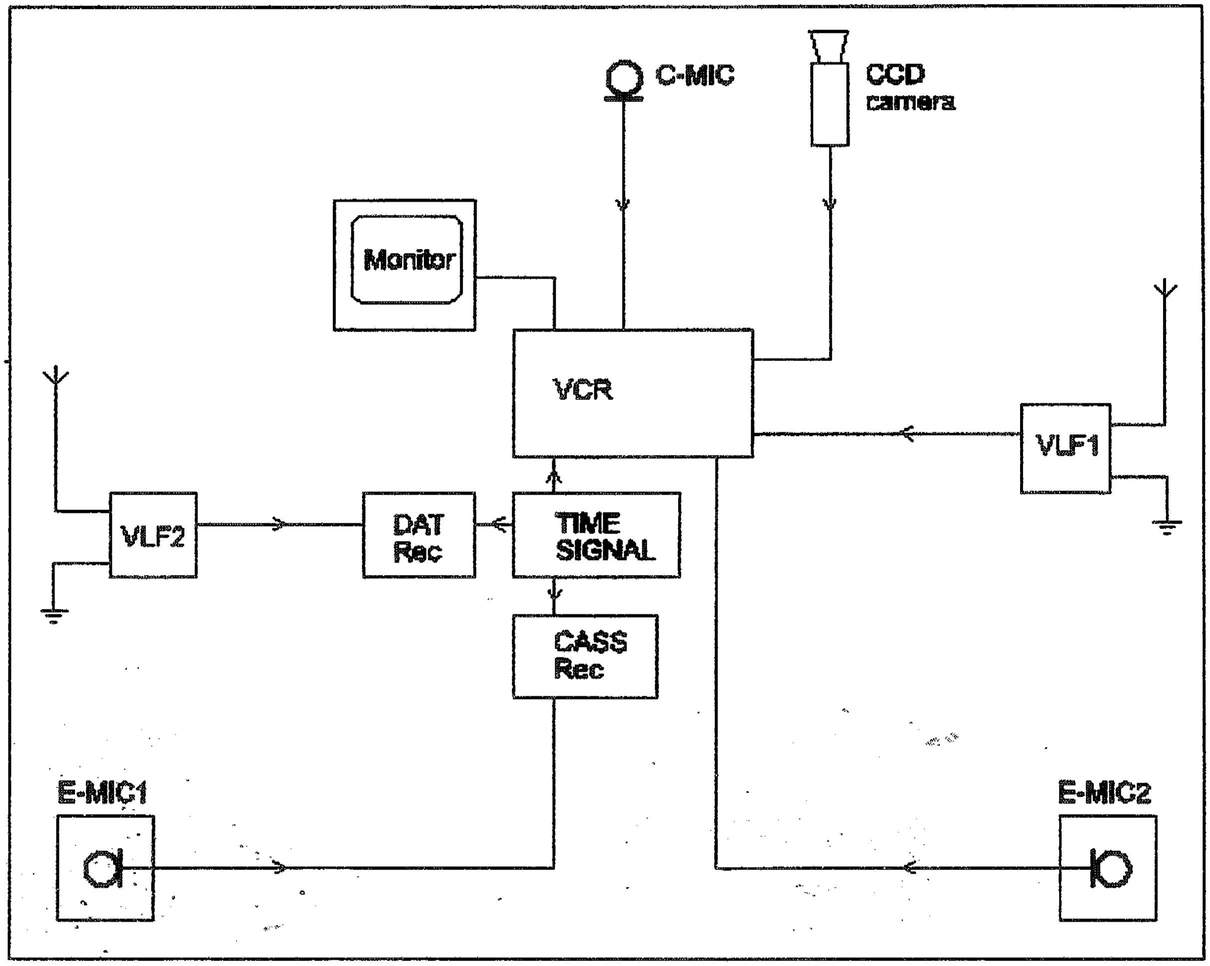

Figure 3: The schematics of recording setup used in our experiment. Video signal from a CCD camera is recorded on a professional VHS video-recorder with 4 sound channels. An accurate time signal is recorded on one of these channels to provide absolute time reference for other channels. The other channels are used for an VLF detector (VLF1), observers comments (C-MIC) and a separate environmental sound microphone (E-MIC2). A digital sound recorder (DAT) supported spare VLF detector and a cassette recorder supported a spare environmental sound microphone (E-MIC1).

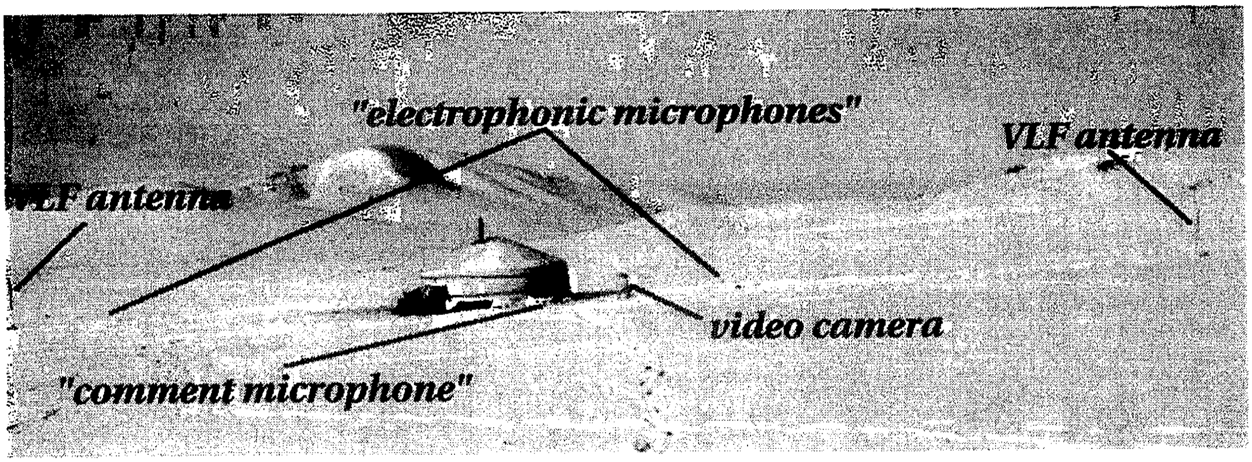

Figure 4: The observing site and the position of the microphones and the antennas around it. At the moment when this picture was taken, there was about 15 cm of snow and the temperatures were very low already.

On the observing site was almost no vegetation, and the relatively flat ground was covered with snow. The humidity was extremely low, and the temperature during the observations was between -20° C and -30° C. The scheme of experimental setup is shown on the Fig. 4. We used two separated and locally grounded VLF receivers (INSPIRE RS4) with whip antennas. To avoid local interference, the antennas were well separated from each other and from visual observers. Microphones in another part of experimental setup were used to monitor environmental sound. A CCD video camera with a sky coverage of 55% and a limiting magnitude of about 0 m was placed near the visual observing site. Absolute time signal from Taskent radio station at 5.000 MHz was recorded simultaneously with other signals on each recorder used. Simple photometry was performed on the video frames, each one with 0.04 sec exposition (25 frames/sec frame rate). A dark frame was created by averaging six frames at 0.5 sec before the frames with visible meteors. After the dark frame had been subtracted from the frames with meteors, a simple integration of the remaining pixel values was performed, and Sirius was used for calibration of magnitude scale. The two main sources of error associated with this procedure are the outermost contour used for the integration and the comparison of the resulting intensity with Sirius. Due to the low S/N of the Sirius image, this was the principal source of error which was estimated to about ± 0.5 m. Overall synchronization accuracy between different recording channels was found to be better than ± 0.02 s. In total, 5.5 hours of observations on the night of Nov. 16/17, 1998. were logged in. In addition to the two ELF/VLF signals from meteors known before, we obtained several new recordings, with an order of magnitude better time correlation with video and sound signals than before. No electrophonic sound was detected for these events. The most interesting VLF signal is shown on the Fig. 5.

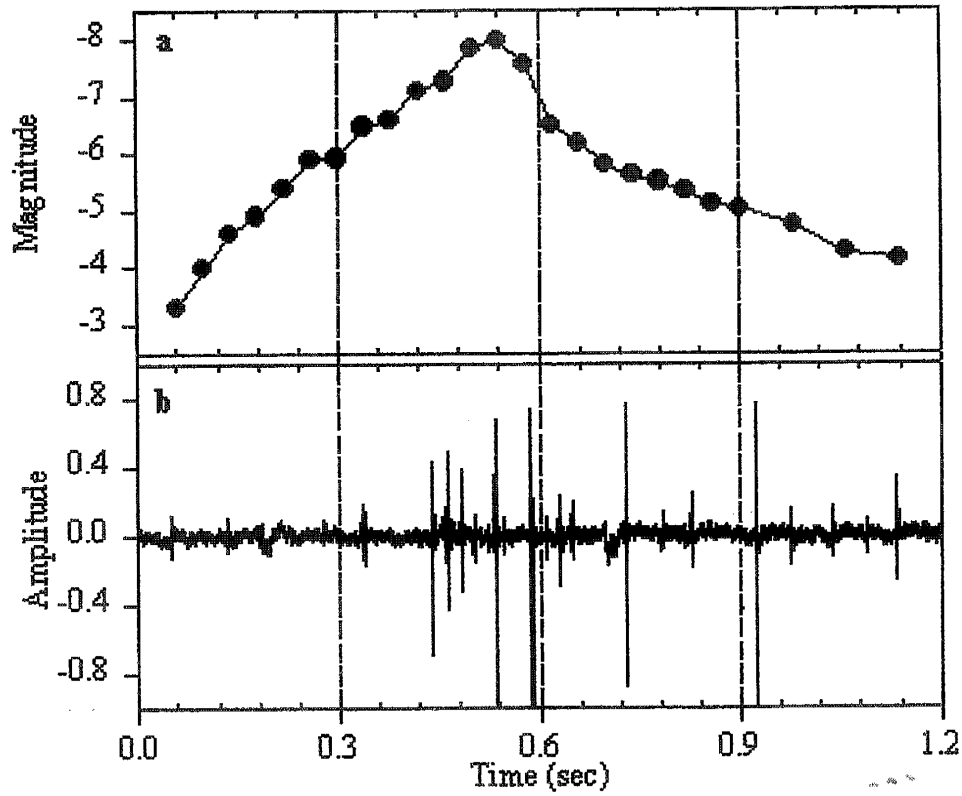

Figure 5: Recorded ELF/VLF emission from a -8 m (+- 0.5 m) meteor. Upper panel shows the meteor brightness recorded by video, and the lower panel is the signal at ELF/VLF channel during that event (amplitude is given in arbitrary units). Time 0.0sec = 21h 44m 35.1s UT (Nov.16.1998.). The synchronization accuracy between video and ELF/VLF channel is +- 0.02 sec.

A meteor with visual magnitude of -8 mv was observed close to the horizon and the final part of the trajectory is partially obscured by a hill, but the light maximum is clearly visible on the video. About 0.1 s before the visual maximum, a sequence of 8 short pulses of VLF radiation appeared, with a total length of 0.7 s and amplitude of about 10-2 V/m. More rigorous discussion of this first results can be found in our article published in Fizika (Gar99).

Conclusions

A vast amount of experimental data (the complete data set spans about 35 CD ROMs of video and audio data) was gathered the night before the anticipated Leonid storm. The preliminary analysis has given us some examples of VLF radiation from meteors and, for the first time ever, detections of electrophonic sounds The VLF observing group remains active and more observing sessions will be caried on on favourable occasions. An indication that electrophonic sounds are maybe produced by ULF instead by VLF waves exists, so we are planning to use receivers that are sensitive in the ULF region also. We recently expanded our activities by starting the Global Electrophonic Fireball Survey (GEFS, accessible at http://gefs.ccs.uky.edu) reporting network. The purpose of the GEFS is to collect these reports and provide a more systematic approach in the study of this phenomenon with a possibility for more extended activities.

Acknowledgements

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Whistler Analysis Using the TI-83+ Graphing Calculator

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ABSTRACT

This article covers three topics. First, a procedure for using the TI series of graphing calculators (specifically the TI-83 plus) to analyze whistler-generated data is presented. This process uses the curve fitting, data manipulation, and calculus capabilities of the graphing calculator to accurately analyze whistlers and to extrapolate data from the received whistlers outside of the frequency range that was audible and visible upon reception. A wide frequency range whistler is used to test the procedure to demonstrate the validity of extrapolating data from the "typical" whistler. Second, a process using the graphing calculator to analyze whistlers based on the dispersion models presented in Robert Helliwell's book *Whistlers and Related Ionospheric Phenomena* will be presented. Calculation of the time location of the source lightning strike of a whistler will be compared to actual received data. Finally, a graphing calculator program that produces predictions of low-frequency and high-density models of whistlers will be presented. Received whistler data is overlaid on the two models to illustrate how graphing calculator technology can be used to compare real world data to theoretical predictions. The article concludes with a few observations and generalizations about whistler behavior that resulted from this project and the author's novice study to date.

Introduction

I have been listening to whistlers for only a very short period of time. The experience has been very rewarding and the auditory beauty of the sounds generated by natural phenomena have generated a new appreciation for our complex world. I have been fortunate to hear examples of almost all of the various signals that are by-products of lightning strikes. Though many of my peers and acquaintances have looked at me with suspicious accommodation when I replay the "neat" things that come over the low-frequency airwaves, my enthusiasm to learn more about these audio pearls of nature has not been dampened.

I will freely admit that I became frustrated by the apparent superficial depth of coverage given to whistlers in contemporary publications. Fortunately an e-mail reply to a rhetorical question I posed in a recent article in the *Inspire Journal* proved to be the catalyst I needed to begin a serious study of the whistler phenomena. The e-mail hinted that I should seek out the book by Robert Helliwell, *Whistlers and Related Ionosheric Phenomena*. During an Internet search I found three copies of the book available, two in major university libraries and one in the Library of Congress. I live in a very rural, frontier county of California and my request for an inter-library book loan from the Library of Congress raised many doubtful eyebrows, and that was before the librarians even looked at the title of the book. The quest was well worth the effort and I would recommend that anyone serious about studying whistlers get their hands on this book.

I want to caveat the remainder of this article up front: there is nothing that follows that I would consider original research. All that follows is based on the content and work presented in Helliwell's book and I give him and other contributors to his book full credit. I hope that you will indulge this one, all encompassing footnote.

There are three parts to this article. First, a procedure for entering time and frequency data taken from received whistler plots into a TI-83 plus graphing calculator will be presented. Once the data is entered into the calculator's lists, curve fitting and discrete analysis of the curve can be performed to get a mathematical snapshot of the whistler. The whistlers that I receive at my latitude (38 degrees north) generally have a frequency range from 500 Hz to 5,000 Hz. I found this frequency range a little shy of the range I needed for a comprehensive analysis of a whistler and I was looking for a reliable way to extrapolate data from a whistler that was outside of the actual received range. I also needed a way to determine the slope of the whistler at a specific frequency (find the derivative of the whistler curve). This procedure allows me to do that.

The second part of the article builds on the process developed in the first part to apply the data received from a whistler to a mathematical model to determine the time of the lightning strike that created the whistler. The model was tested numerous times with collected data. In most cases the spherics were so numerous within a reasonable time of predicted strike that it was difficult to confirm with certainty that the predicted strike was in fact the strike that created the whistler. Fortunately I have had a few very quite days when I could determine a definite correlation between the predicted strike and an actual strike that preceded the whistler. These occurrences allowed me to validate the utility of the model.

The third part of the article tests two mathematical models for whistlers presented in Helliwell's book, the low-frequency model and the high-density model. A program that displays both models on the calculator screen is presented. Actual whistler data can then be overlaid on the models for comparison.

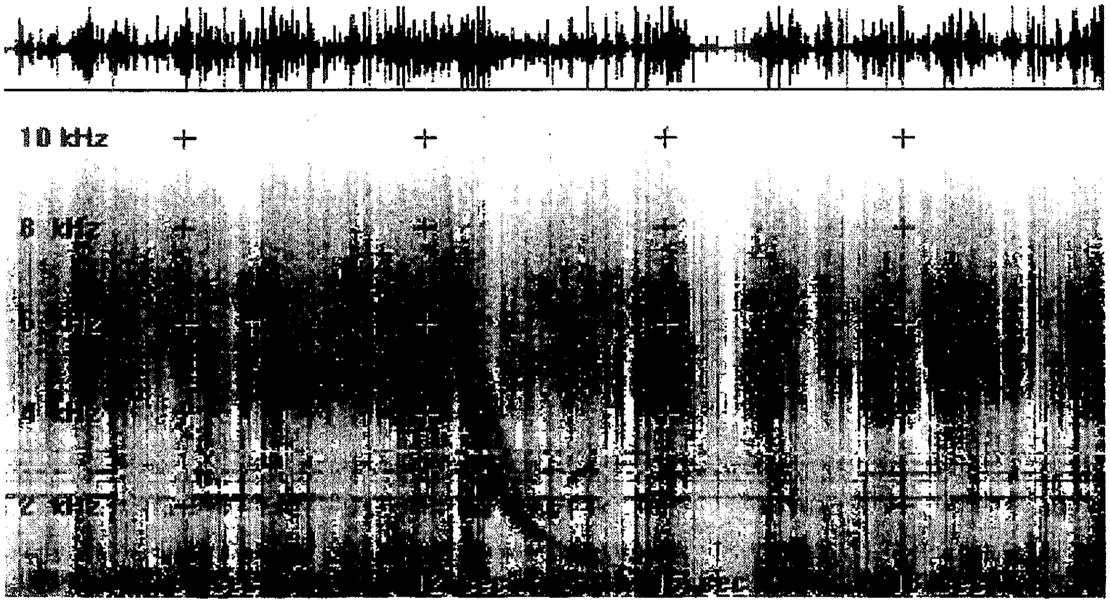
I have attempted to provide enough step-by-step procedures for the graphing calculator neophyte. The procedures could be readily adapted to other calculators than the TI-83 plus.

Part 1: Entering whistler data into the graphing calculator.

The overview of this procedure is as follows:

1. Extract time and frequency data from the whistler using the Spectrogram program.
2. Enter the data into the graphing calculator lists.
3. Normalize the time data to around 1 second.
4. Perform a curve fit of the data using the graphing calculator power curve fit function.

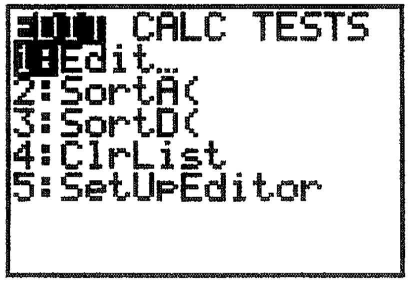
For demonstration purposes I have chosen one particularly good whistler that I collected that had a very distinct signature on the Spectrogram presentation that allowed me to precisely extract time and frequency data. This particular whistler also had a wider than the normal frequency range, from about 10,000 Hz to about 600 Hz, which allowed me to test the validity of the concept of extrapolating data from the fitted curve that was outside the range of the actual received time and frequency of typical whistler. The whistler being used is depicted in figure one. If you would like a copy of the wave file of this whistler please submit a request via e-mail.



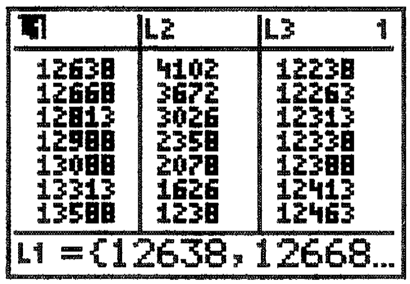
Step 1. The time and frequency data that I pulled from this whistler is listed in table 1. I have split the data extracted from this whistler into a high-frequency set (first two columns) and a low-frequency set (last two columns). The demonstration analysis will treat the low frequency data set first, do a curve fit using this data, then overlay the high frequency data on the curve to see how valid the curve fit using the low-frequency data is, and finally, the total data set will be used to provide a comparison of the curves.

Data Table for Whistler 04301130z at 12 seconds			
Time (ms)	Frequency (Hz)	Time (ms)	Frequency (Hz)
12238	10089	12638	4102
12263	9443	12688	3672
12313	8452	12813	3026
12338	7720	12988	2358
12388	7009	13088	2078
12413	6363	13313	1626
12463	5696	13588	1238
12488	5330	13963	937
12563	4641	14313	722
		14688	571

Step 2. After you have turned on your calculator press the **[STAT]** key, you should see the following screen:



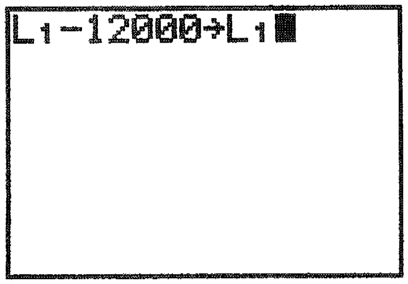
Press **[ENTER]** to select **Edit** and the lists will be presented. If the lists **L1**, **L2**, **L3**, and **L4** are not empty, you should empty them by using the arrow keys (**[◀] [▲] [▶] [▼]**) to highlight each list to be cleared in turn as shown here for **L1**, pressing the **[CLEAR]** key and then **[ENTER]**, will clear the list. Repeat this process for **L2**, **L3**, and **L4**.



Enter the time and frequency data that you extracted from the whistler into **L1** and **L2**, if you would like to follow along with my example, enter the low-frequency time in **L1** and the frequency in **L2** and the high-frequency time in **L3** and frequency in **L4** as shown here.

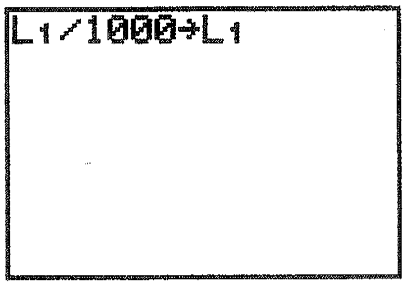
Step 3. I have developed the habit of normalizing the time data to a range that makes the remaining calculations more consistent. If you choose to use the actual time data from Spectrogram in milliseconds, the time numbers will get pretty large and may be outside of the capabilities of the calculator. I subtract some number that will normalize the time data to approximately 1 second (1000 milliseconds) (in this case subtract 12000 ms from each time list **L1** and **L3**) and then divide the time list by 1000 to convert the times into seconds as follows:

Press **[2ND] L1 [-] 12000 [STO→] [2ND] L1 [ENTER]**



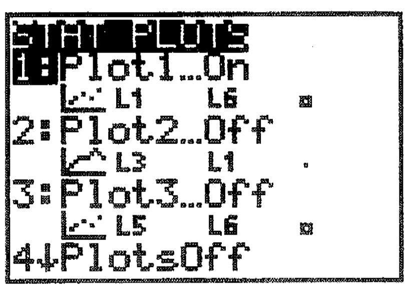
Repeat this process to normalize time list L3.
Now divide the time lists by 1000 to convert the time into seconds as follows:

Press **[2ND]** L1 [÷] **1000** **[STO→]** L1

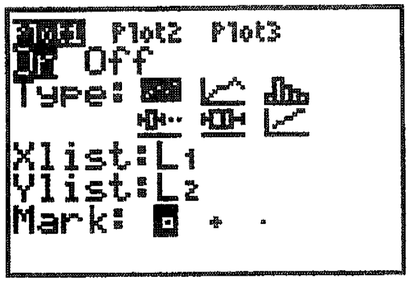


Again repeat this process to convert list L3 to seconds

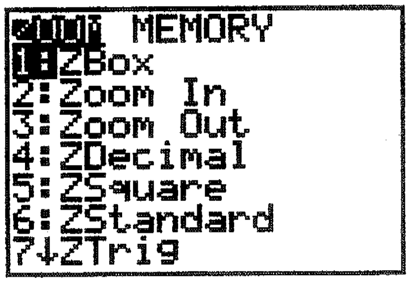
Step 4. Confirm that the data you entered into the calculator lists looks reasonable by displaying a plot of the data, your calculator plot should mirror the plot displayed by the Spectrogram software. Press the **[2ND]** **[Y=]** (for **STAT PLOT**) keys to obtain this screen:



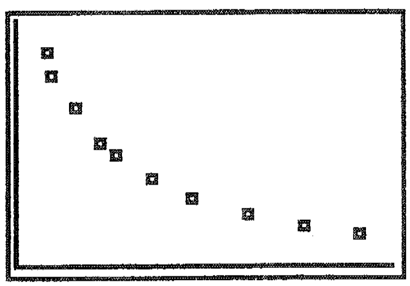
Select **PlotsOff** and press **[ENTER]** twice to turn off all plots (this avoids confusion later). Press the **[2ND]** **[Y=]** (for **STAT PLOT**) keys again and select **Plot1** (**[ENTER]**). Select the options as shown on this screen (**On**, **scatter**, **Xlist L1**, **Ylist L2**, **Mark** is the **square**).



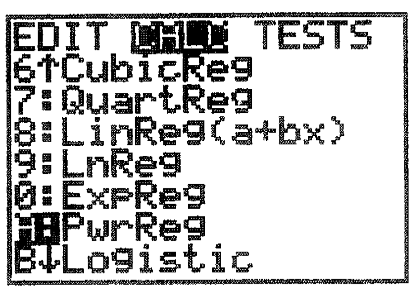
After the plot parameters are selected, press the [ZOOM] key to obtain this screen.



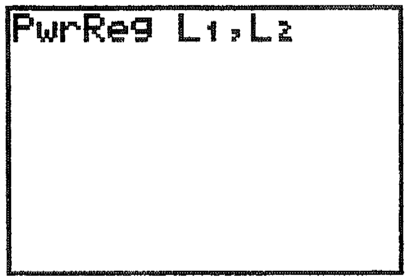
Scroll down with the [▼] key or press 9 to perform a **ZoomStat** operation. You should have a screen that looks like this, if the plot does not resemble the whistler presented by Spectrogram, check your data:



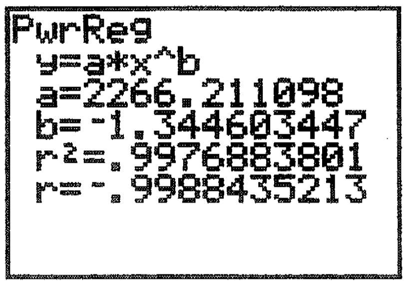
It is time to fit a curve to the data. Press the [STAT] key to obtain this screen and cursor over to CALC and cursor down to highlight PwrReg.



Press [ENTER] to call the PwrReg procedure and enter L1 for the independent, and L2 for the dependent variables as shown.

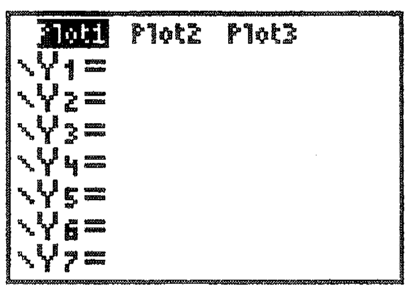


Press **[ENTER]** to obtain the algorithm for the curve that fits the data.

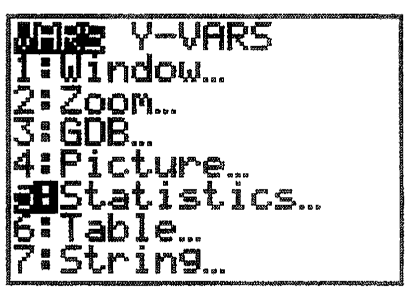


You can write this algorithm down but that would be very tedious and error prone. The following keystrokes will enter the algorithm into one of the functions automatically:

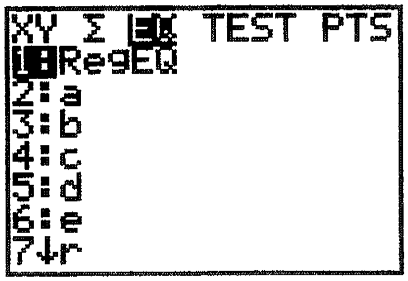
Press **[Y=]** and ensure the Y1 is cleared, if it is not press the **[CLEAR]** key and it will be cleared.



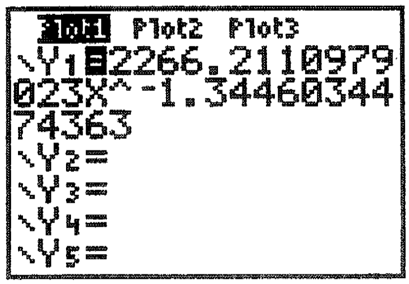
Press the **[VARS]** key and select **Statistics**:



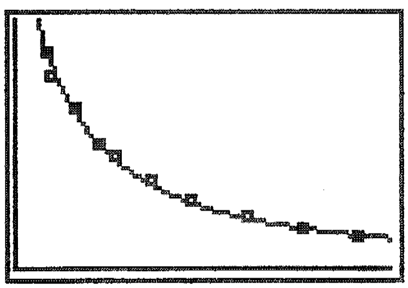
Press **[ENTER]** and select **EQ** and **RegEQ**:



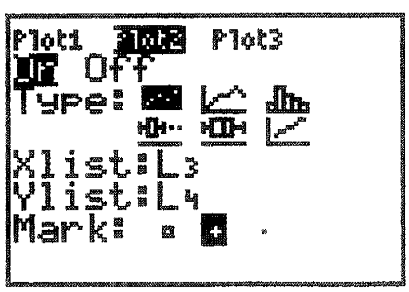
Press [ENTER] and the algorithm for the fitted curve will be entered into **Y1** and **Y1** will be turned on as shown (the = will be bold):



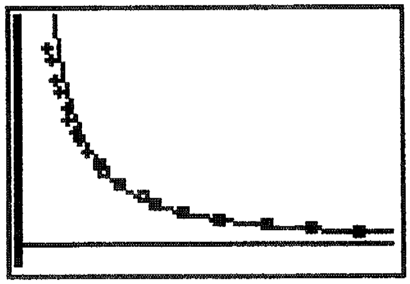
Now when you press [ZOOM] 9 (to display **Plot1**) the fitted curve will be overlaid on top of your data and you can confirm the quality of the fit.



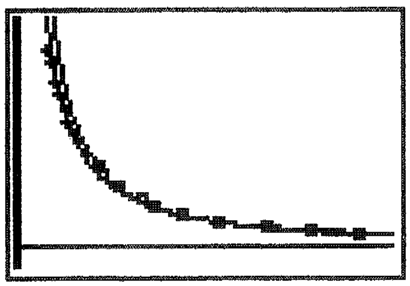
Now the high-frequency data will be added to the plot. Turn on the display of the high-frequency data by pressing [2ND] [Y=] and selecting the following parameters for **Plot2**:



Press [ZOOM] 9 to obtain the display of the combined high and low-frequency data points and the curve that is based on the low-frequency component of the data.



The curve derived from the low-frequency data seems to be a reasonable fit for the total data though there is some departure from the high-frequency data points. To take a more quantitative look at this departure, create a listing of the total data from table 1 in lists **L5** and **L6**, do a curve fit of that data following the same procedures as before except put the curve into **Y2**, and display the data and the two fitted curves:



There seems to be fairly good correlation between the curves developed from the low-frequency data alone when compared to the curve developed from using all of the data. The frequency of 5,000 Hz is of particular interest in part 2 of this article. This frequency was chosen by Stanford University researchers as the reference point for calculations and models to determine the time of the lightning strike that created the whistler and also for comparing the slope of various whistlers to help determine the whistler type. The frequency was chosen because whistlers are generally strongest and most pronounced at this frequency. Therefore we will use the frequency of 5,000 Hz to test the validity of this curve fitting process by taking a more detailed look at the two developed curves at this frequency.

Zoom in around the area of 5,000 Hz by pressing **[ZOOM]** and selecting **ZBox**: