

Radio Observations of Meteors: the 2004 Perseid Meteor Shower Etc.

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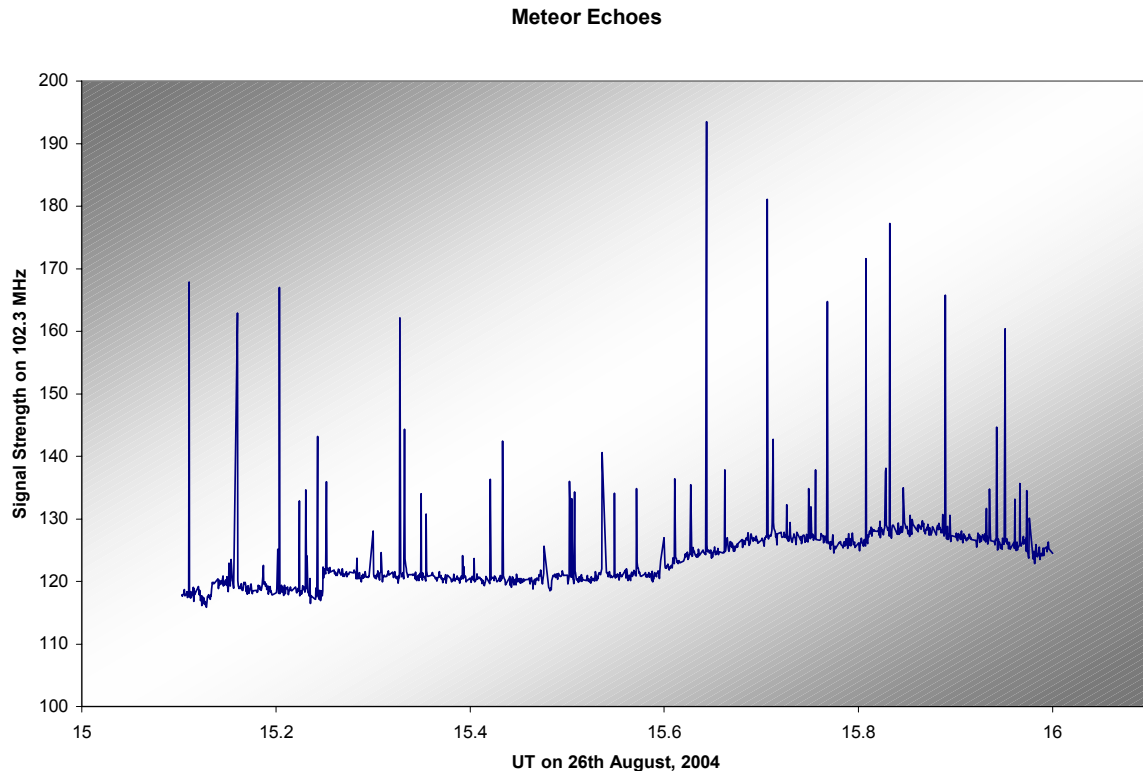


Figure 1: Each vertical spike in the figure is a radio echo from a meteor trail. These echoes, recorded in Penticton British Columbia, are of signals from one or more FM Broadcasting Stations on 102.3 MHz, observed on 26th August, 2004, between 1500 and 1600 UT, which is equivalent to 7:00 – 8:00 am Local Time (Pacific Standard Time).

The record above shows bursts of radio signals reflected from the ionization in meteor trails. The signals come from some FM radio broadcasting stations transmitting at 102.3 MHz, which are too distant to be received by other means. This technique provides a very easy and useful way to count meteors, and has the tremendous advantages of being automatic, and of being unaffected by daylight or cloud.

My introduction to radio observations of meteors was in the early 1970's. It was during one of my many visits to Ron Ham, an amateur radio astronomer and general radio enthusiast living in Sussex. He had a radio tuned to the frequency of a VHF broadcast transmitter in Gdansk, in Poland, connected to a small Yagi antenna, pointed halfway up the sky, in an northeasterly direction. It was fascinating to listen to the bursts of music or speech, knowing them to come via the ionization trails left by meteors. In addition to detecting the usual meteor

showers, he saw the normal diurnal variation in count rate, and also a slight drop in count rate when the Sun was very active. We attributed that to an increase in ionospheric (D-Region) absorption when the solar X-ray flux was higher. A couple of years ago, living at our current address in the Okanagan Valley, in British Columbia, I had an urge to try this for myself. This article describes the hardware, the experiment and discusses observations made of the 2004 Perseid meteor shower.

Radio Observations of Meteors

The tremendous amount of heat produced by friction as a meteoric body enters the atmosphere at many tens of kilometers a second does more than vaporize the body and leave a glowing trail. The heat also ionizes the air, producing a lot of free electrons. These do not last very long; the air cools and the electrons recombine with the ionized atoms, reproducing the neutral atmosphere that existed beforehand. However, while they exist, the presence of charged particles in the trail greatly affect any radio waves incident upon them.

Radio waves consist of oscillating electric and magnetic fields. The oscillating electric fields accelerate any free electrons so that they move with the waves. This occurs with the positive ions too, but since they are thousands of times heavier than the electrons the response is less. Therefore in comparison with the electrons we can ignore them. An accelerating electron radiates radio waves, so that the incident radio signals are re-radiated, but in all directions. This process is called scattering, and, if there are enough electrons, a significant amount of radio signal may be scattered.

If there are many more electrons per cubic centimeter, they cannot be considered isolated entities; they have to be treated as an electrically conductive fluid. They then act rather like an antenna, collecting radio signals as large-scale currents rather than motion of individual electrons, and re-radiating them. If the frequency of the radio signals is f , say, the number of electrons per cubic centimeter required for this situation to arise is given by:

$$N_e^2 = \frac{f}{8.1 \times 10^7}$$

where N_e is the number of free electrons per cubic centimeter. Or, putting it another way, there is a *critical frequency* or “plasma frequency” for any particular electron density:

$$f_0 = 9000 \sqrt{N_e}$$

For example, if a trail contains 10^8 electrons per cubic centimeter, the plasma frequency is 90 MHz. Radio signals with higher frequencies will be scattered; those with lower frequencies will be reflected.

The recombination of the positive ions and electrons in a meteor trail is very rapid, so if the electron density is only high enough to scatter the waves, this will

happen around the head of the meteor and part of the trail, and produce a short-lived echo that is not very strong, rising very quickly in intensity and decaying exponentially as the electrons and ions recombine. Trails where this happens are termed *underdense*.

If on the other hand, if the trail is sufficiently hot and large, the electron density could be large enough for the plasma frequency to be much higher than the frequency of the radio signals. If this is the case, recombination along the tail could proceed for some time and still have the plasma frequency higher than the frequency of the radio signals. In such cases, this condition may be met along a good length of trail. These trails are termed *overdense*. These produce longer-lived echoes that are much more intense. As the trail follows the meteor, the radio waves illuminating it hit at changing angles, and the line of sight from the trail to the receiver changes too. The result is wave interference, which causes the strength of the reflected signal to fluctuate. These echoes are strong, and may sometimes last as long as a minute, usually varying dramatically in strength. When counting by hand, there is no particular problem in distinguishing between the weaker, short-lived scattered signals from underdense trails, and the strong, persistent echoes from the overdense ones. However, if one is trying to count meteors automatically, something has to be done to minimize the chance that the echoes from over-dense trails are recorded as multiple meteors – distorting the count.

In general, radio methods allow smaller meteors to be detected than can be observed optically. Typically, the faintest meteors that can be seen optically come from the vaporization of particles with masses of about 10^{-2} grammes, whereas detectable radio echoes can be detected from meteors produced by particles with masses as small as 10^{-7} grammes.

The Experiment

A lot of information can be extracted from radio waves scattered or reflected by meteor trails. Options include using multiple antennas and clever signal processing to obtain directional information, and high-speed data logging to record the interference effects due to time-varying phase shifts along the trail. However, the objective of this experiment is much simpler, namely, to count meteors and look at changes in the hourly echo rate as a function of time.

A three-element Yagi antenna was mounted so that it looks in a vaguely easterly direction, at an angle of about 45 degrees elevation. A preamplifier brings up the signal level by about 15 dB before the signal is transferred back to the equipment shed via about 40 meters of coaxial cable. The cable is good, low-loss heliax, so the amplifier is not really necessary from the point of view of receiving the signals. The amplifier is there to ensure that the hash produced by several computers working near the receiver is always much weaker than the received signals, and cannot be heard when listening to the receiver output.

The receiver is an old FM radio tuner obtained from a TV repairman. It is completely self-contained, bearing just an antenna input and two stereo audio outputs. In the earliest experiments, attempts were made to use the audio outputs for automatic meteor detection. However, this proved difficult. The noise power coming from the output is pretty close to the signal power that comes out when a station is being received. Since the spectrum of noise is different from the spectrum of speech or music, Fourier spectrum analysis software was tried. This sort of worked but it seemed an overwhelmingly complicated way to do a simple thing. Comparing the levels through two audio band-pass filters to test for spectrum flatness sort of worked, but was again aesthetically unsatisfying.

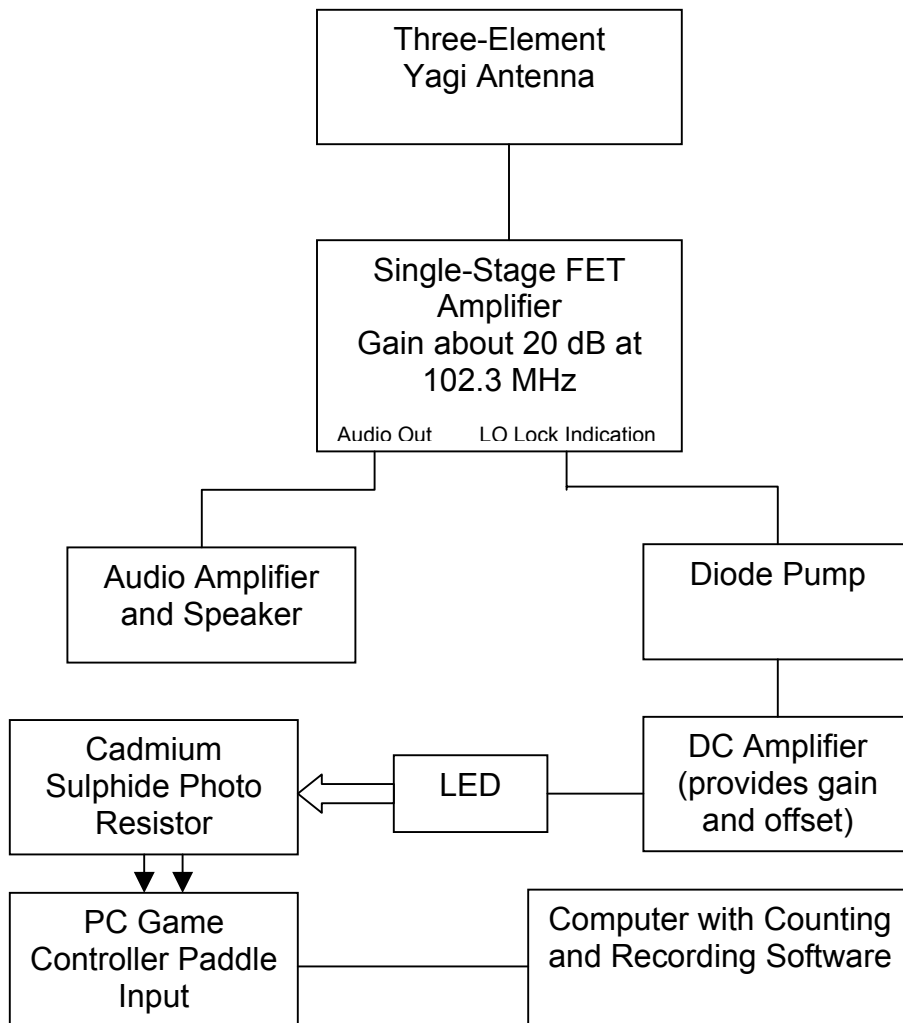


Figure 2: Block diagram of the hardware used for the experiment.

The method finally decided upon was to use the indication of signal lock on the FM tuner. When a proper FM signal is acquired, an indication appears on the panel display that the local oscillator system has locked onto it. All one needed to do would be to get a wire onto the lock indication circuit. This proved harder than

expected, because the tuner consists mostly of integrated circuits with unrecognizable numbers. The only identifiable access point was the ribbon connection taking the display signals to the front panel. To find which wire carried the "Quartz Lock" signal, the radio was tuned to a weak station where the lock was intermittent. A scope was used to look at the signal on each wire until the one was found that was changing with the indication on the panel. It was an unfortunate surprise that the signal was not a DC; it was a square wave with a changing mark-space ratio. This was changed to a DC using a simple diode pump circuit. A resistor (to limit the loading on the display drive – 10k Ω) and a diode (in series) were connected to a capacitor (10 μ F polycarbonate - the other end was grounded). A resistor was connected across the capacitor to allow the charge to drain away at a known rate (100k Ω). The voltage change between locked and unlocked were large enough to make amplification unnecessary. The voltage was buffered using a simple op-amp, which also had a voltage offset facility. The output from the op-amp was connected via a 10k Ω resistor to a red LED. The dome on the end of the LED was carefully filed and polished flat, and it was glued face-on to a cadmium sulphide photoresistor using a transparent acrylic adhesive. The LED/photoresistor combination was then embedded in a block of opaque epoxy. The changing level between the locked and unlocked local oscillator changed the brightness of the LED, and hence the value of the photoresistor. The photoresistor was then connected to one of the game paddle ports on a computer. The offset voltage applied to the op-amp was chosen to put the photoresistor in a part of its range that best suited the paddle circuit. The threshold for deciding upon a count was set in the software. To minimize spurious counts and avoid sampling problems the op-amp incorporates a time constant of about 0.5 seconds. To be detected with full sensitivity, a meteor echo has to persist for at least this long.

The main loop of the program takes 1s averages of the paddle value; if the mean paddle value has increased since the last average by more than a pre-decided trigger value the time of that event is noted, and a count is set. If the elapsed time since the last event is less than 2 seconds, the count is rejected, since this could be a case of multiple echoes from a single, overdense trail. On the other hand, if more than 2 seconds have elapsed, the count is deemed valid.

The software is written in the obsolete language Microsoft QB4.5. It is still one of the best general-purpose experimenting languages, without all those extras that more modern languages provide, whether we need them or not. The only issue that needed special attention was the need to minimize the chance that strong, long-lived, fluctuating echoes from overdense trails would not result in a dozen counts or so. The method used here is similar to the "dead time" technique used to ensure statistically understandable data from radiation counters; the local oscillator has to remain completely unlocked for two seconds after it was last triggered. If another trigger occurs within that two seconds that count is rejected, and another two seconds of dead time has to pass before the counter becomes active again. That means that the maximum counting rate the system can

accommodate roughly $3600/2 = 1800$ meteor echoes per hour. The system would therefore be saturated by a severe storm.

The counts over a day are accumulated in an array of 24 rows (one for each hour UT), and two columns. The first column is the UT hour of that row, and the second column is the total count for that hour. At UT midnight, which is detected because the UT time gets smaller, flipping from 23 to 00, the array is copied to a file and reset. The file is essentially a table of hourly count rates with the date in the left-hand column. The average hourly rate over a day is simply the average of the 24 values in a horizontal row. A sample is below from a data file is shown below. To fit onto the page, the rows have to wrap onto the next line:

```
08 08 000 000 000 023 033 041 058 068 087 094 086 098 079 054 065 049
069 058 041 046 026 033 037 021
08 09 000 000 000 021 020 044 061 063 066 096 089 075 074 058 061 075
055 073 070 051 035 040 032 027
08 10 000 013 017 019 032 040 063 077 085 092 093 080 071 051 066
060 078 061 069 053 044 050 029 027
08 11 023 028 022 029 038 040 076 080 079 093 090 070 059 068 063
071 078 081 106 107 097 074 056 059
08 12 081 042 068 061 085 097 093 124 153 144 136 116 091 088 181 220
114 127 115 097 090 077 048 076
```

The first two characters in each row are the month and day of the year. The year is in the filename. The 24 3-digit numbers following the date are the counts for each hour of that day. Any other processing is done off-line.

The Choice of Frequency

The highest frequency that should be used for meteor detection is one where the average meteor manages to produce, at least for an instant, an electron density sufficient to fully reflect the radio signal. Typically, electron densities are around 2×10^8 electrons per cubic centimeter, which, using the plasma frequency formula quoted earlier, gives a frequency of about 140 MHz. At much lower frequencies, such as 30 MHz, the trails will tend to be overdense and the echoes will last a long time, so that the maximum count rate will be limited.

Another requirement is a transmitter that is beaming its signals uniformly for 24 hours a day. An obvious possibility is one of the lower TV channels (where VHF TV broadcasting is still done), or one of the FM radio channels. The chosen station must not be receivable under usual circumstances at the meteor detector location.

To best serve its user community, the transmitter is usually designed to radiate its signal more or less horizontally, usually in all azimuths. We should point the antenna at a place in the sky where the beam of the transmitter passes through the height range where meteors typically occur. If we assume the transmitter is radiating at the horizon, the signals, moving in a straight line as the Earth curves away beneath, will pass through the meteor zone at a range (R) of about:

$$R^2 = (R_e + h)^2 - R_e^2$$

where R_e is the radius of the Earth (6378 km), and h the height of the meteor echoes. If we assume that the meteors are at 100 km, then the transmitter should be located roughly 1100 km away from where the meteor echoes are coming from. This is only a rough guide; a factor of two might not make too much difference, since the transmitter antennas do transmit significant powers at elevations of a few degrees.

The frequency used here is 102.3 MHz. No signal is normally detectable at Penticton, which has the additional advantage of being screened by mountains. There are several transmitters using this frequency, at distances scattered between 200 and 2500 km. It was assumed that the more transmitters the merrier, provided that none of them could be received other than via meteor trails.

A Matter of Time

Both Universal Time and Local Standard Time are important in the discussion of meteor count rates. The time of shower peaks is best expressed in Universal Time, to facilitate comparison with other observations, made elsewhere. However, there are also strong local effects, such as the diurnal variation in count rate due to the rotation of the Earth. Plots of this look meaningless in UT, unless one lives in the UT Time Zone. The observations discussed here were made at longitude 120 degrees West; the Local Standard Time – Pacific Standard Time, therefore lags UT by 8 hours. The canonical local times of the peak and minimum count rate, 6am and 6pm respectively, are therefore 1400UT and 0200UT respectively. In this article we use UT primarily, with references to PST as necessary. With an 8-hour time offset from UT, PST and UT dates are sufficiently different to give rise to confusion.

The Data

In the absence of identifiable shower activity, the dominant feature in a plot of hourly count rate against time is the diurnal modulation of the count rate caused by the rotation of the Earth. At 6am Local Standard Time one is on the side of the Earth facing forward along its orbit. At 6pm one is looking behind. In general one collects more insects on the windscreen of the car than on the rear window. Similarly, one sees more meteors when looking forward than when one is looking behind.

Figure 3 shows a polar plot of echo rate per hour against time for a day with no known shower activity, and the hourly count rates averaged over several days. Although the effect is more obvious if the x-axis were in Pacific Standard Time, to be consistent with the other plots, UT is used. The 6am and 6pm local times are marked, which are respectively the canonical times of maximum and minimum count rate. The peak at around 00:00UT in the averaged plot is due to a shower. In the plot, the minimum count rate occurs at about the right time, but although

the echo rate is high at 6am, it is even higher four or five hours earlier, in both the single day and the averaged plots.

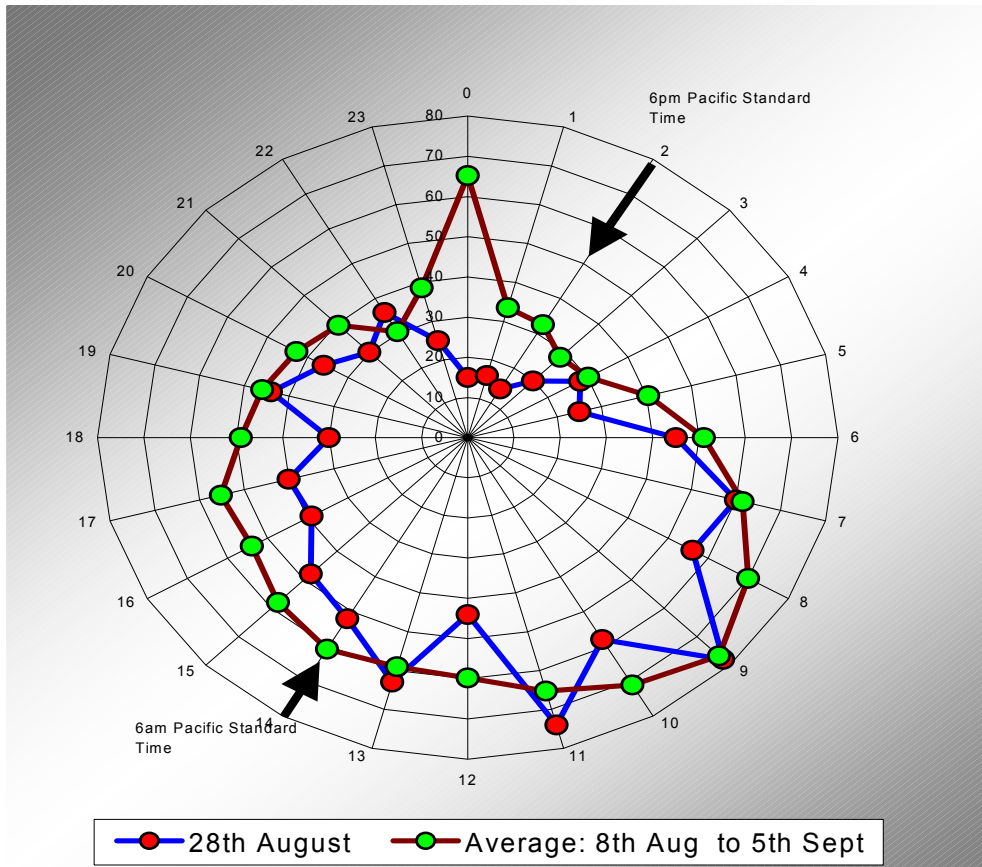


Figure 3: A polar plot of hourly count rates for 28th August alone (red/blue) and averaged over 8th Aug - 5th Sept (brown/green). The time scale is 0-24 Pacific Standard Time. The radius is proportional to count rate per hour. The arrows mark the local times of maximum and minimum count rate due to the diurnal variation.

The observed variation in count rate during the day is very robust, and shows clearly in all the data, as can be seen in the plots later in this article. It is likely that the explanation is geometrical, involving the lines of sight from the transmitter to the meteor trail and from the trail to the receiver, and of course the orientations of trail yielding the best reflection. Looking at this effect will be part of this continuing experiment. This is an illustration of the difficulty in relating radio measurements, which are of echoes in a localized patch or arc of sky, and a function of trail geometry, and optical counts, which are affected by completely

different criteria. This of course underlines the value of being able to relate them to one another.

The Perseids

Regular observations were made from a few days before the Perseid meteor shower, through the shower, and are continuing. The compilers of the Observer's Handbook of the Royal Astronomical Society of Canada predicted the shower would peak at 1100UT on 12th August. An article in Sky and Telescope predicted an auxiliary peak at about 2000UT, from material ejected in 1862. A contour plot of count as a function of Universal Time plotted against UT Date is shown in Figure 4.

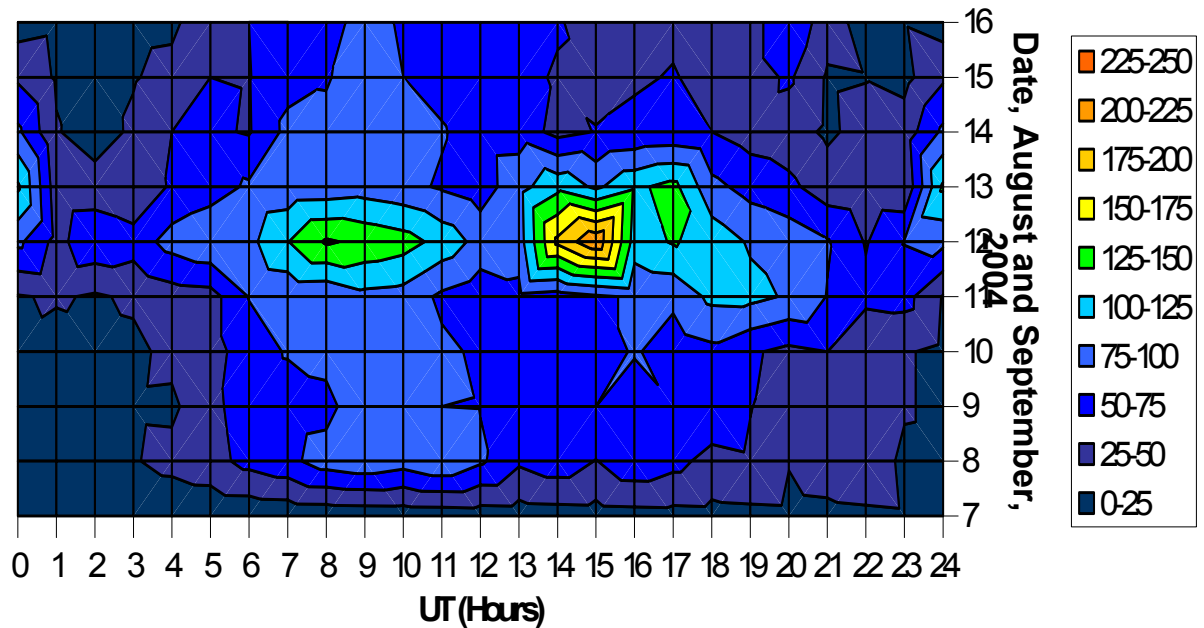


Figure 4: Hourly echo count rates over the period 7-16 August, 2004. The higher activity on and around the 12th due to the Perseids is clearly visible.

The data show a distinct peak, of 2-3 hours duration at about 0900UT, with a peak count exceeding 150 echoes per hour, and another at 1500UT, exceeding 200 echoes per hour. There can be little doubt that this method of detecting meteors works, although it is not clear what the relationship between radio meteors and the Zenith Hourly Rate for optical meteors happens to be, or whether it is even consistently quantifiable. The two peaks attributable to the

Perseids are clearly visible. The weak peak around 00UT may also be associated with them.

Showers are easily identifiable in observational sequences covering several days. However single-day observations are much less clear. A plot of hourly echo rate against time for 12th August shows the shower, but it is harder quantify the shower rates due to random fluctuations and the diurnal variation, as can be seen in Figure 5. For comparison purposes, a hourly rates for shower-free day (30th Aug) are also shown.

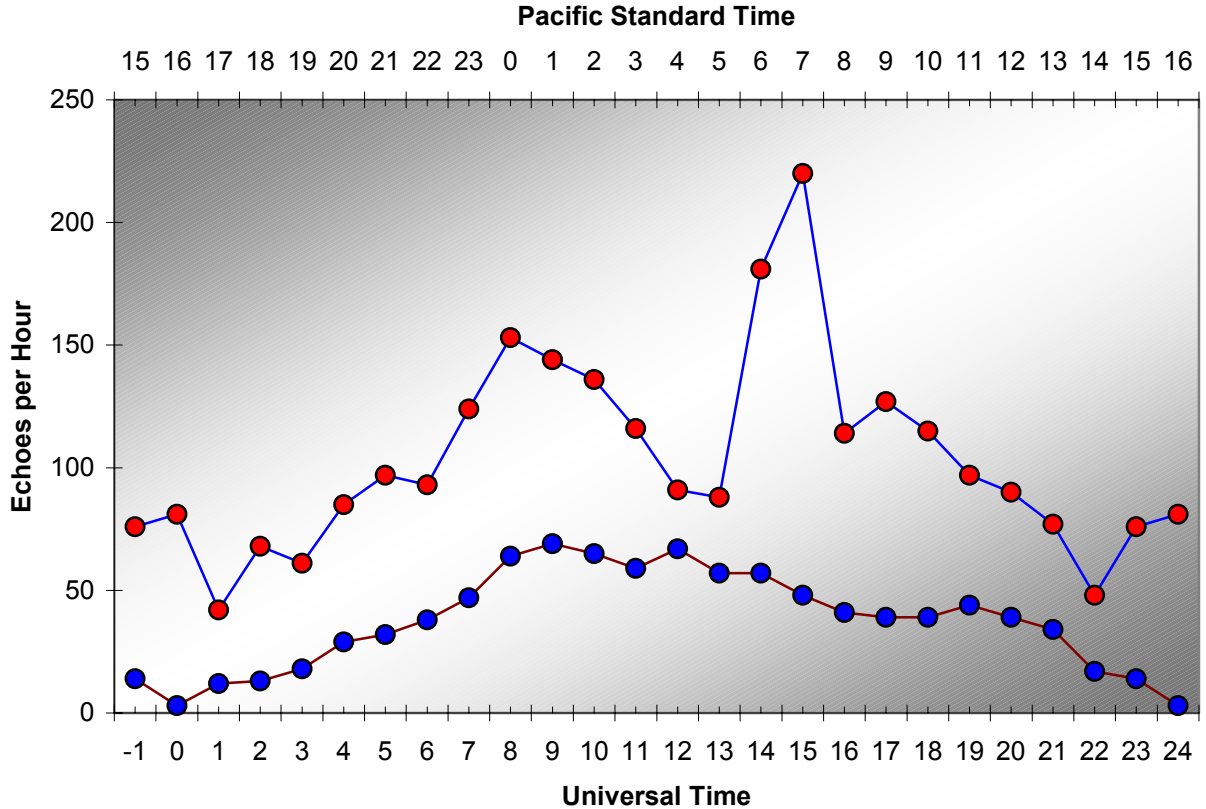


Figure 5: Hourly echo rates on 12th August (upper trace – red/blue), and on 30th August (lower trace – blue/brown).

Although the record of the 12th is distinctly peakier than that of the 30th, it is not easy to isolate the peaks. Moreover, the average level is also substantially elevated. To isolate peaks a long sequence of daily observations is really needed.

Longer-Term Observations

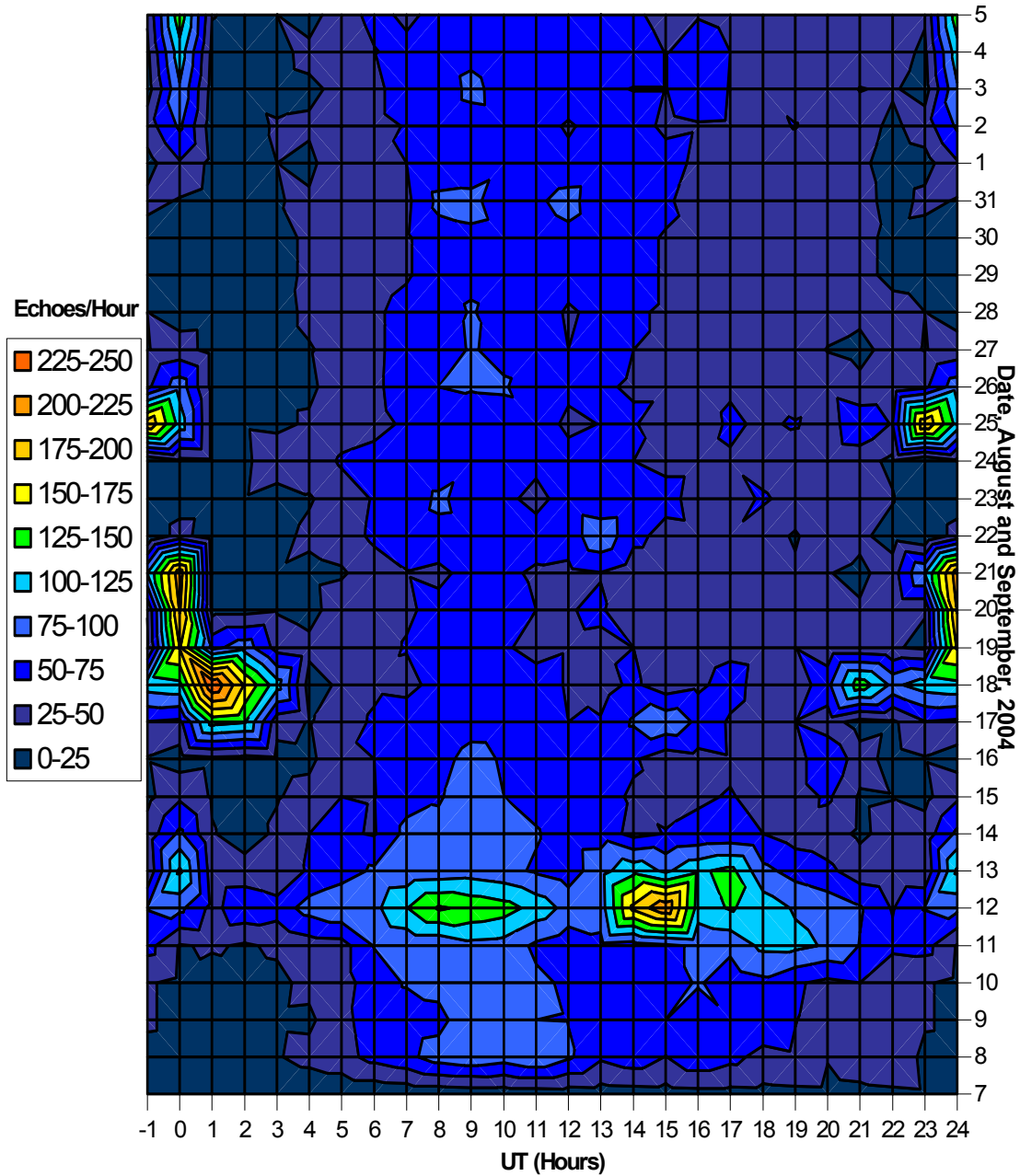


Figure 6: All the data to date (5th September), plotted as in the Perseid Plot in Figure 4. The Perseid event is near the bottom.

Following the Perseid observations, the equipment has been left running, recording hourly echo rates. The contour map in Figure 6 shows all the data to date, and puts the plot above into a broader context. The Perseid meteor shower(s) on the 12th are very obvious. There seem also to have been some shower activity around midnight UT 18-20 August, and on the 25th. Were these subsidiary Perseids? The diurnal variability is very obvious, as is the occurrence of the daily maximum echo rate at about 0900UT (1AM PST).

Comments and Discussion

Although the equipment being used in this experiment might look complicated, simply listening to meteor echoes is easy. During the Perseid week, it was possible to listen to Perseids on the car radio, tuned to 102.3 MHz. Meteor counting using FM radio broadcast transmitters is easy, providing one does not live in an area where there are strong or weak transmissions filling the dial, or if the unoccupied channels have strong signals next door.

Tremendous advantages of this method of meteor observation are:

1. it can be done at night, or in daylight, and it is unaffected by clouds,
2. it is automatic, so observations can be made over long-enough timescales, and continuously. This is necessary to get a clear picture of shower and other meteor activity.
3. once one has set the decision criteria for the inclusion of an echo in the accumulating count, there is no more need for manual decisions. The criteria will be applied absolutely rigidly,
4. it is very intriguing to listen to bursts of broadcast, and know that one is receiving it courtesy of a meteor.

The disadvantage is in combining the observations with other data. In optical meteor astronomy, the intensity of a shower is expressed in terms of the *Zenith Hourly Rate*, which is what one would hope to see on a completely clear night, with the meteors coming from the zenith. Turning real observations into this quantity is a bit empirical, but the procedures are well established. There are far more unknowns when using an FM broadcast transmitter to illuminate the trails.

When a trail is *underdense*, it can be treated as an array of scatterers with phases depending upon the phase of the illuminating wave. This is determined by the orientation of the trail with respect to the transmitter. However, the phase of each scattered signal at the receiver antenna depends upon the orientation of the trail with respect to the receiver. Therefore we have two unknowns: the electron density distribution in the trail, and the orientation of the trail with respect to the transmitting and receiving stations. The strength of the return is related to both these. In the case of a simple meteor counter, the meteors have to produce

a return at the receiver that is sufficient to make the local oscillator lock, and so cause a count to be registered. We would expect to receive a stronger signal from a meteor trail that is perpendicular to lines drawn from the transmitter and to lines drawn from the receiver.

Even at this level, this method of counting meteors is instructive and useful. However it does sound worth considering how the experiment can be improved.