Identifying VLF Transient Emissions produced by Meteors

Dr David Morgan

Part 1 Measurement Programme Planning

1 Programme aim

To make measurements of meteors and VLF signals necessary to determine if meteors can generate VLF transient pulses and if so, at what frequencies.

2 Experimental Variables

There are a number of physical variables that are presently unquantifiable and will need to be carefully controlled in order that the relationship (if any) between meteors and VLF transients can be isolated.

The variables include:

1. Expected frequency range of transients – papers[1-12] suggest around 1 kHz or from 6 to 10 kHz.
2. Variation in transient rates with time of day (ie. ionospheric condition)
3. Meteorological conditions - specifically lightning
4. Meteor Radar transmitter location and meteor trail echo geometry to the receiver. The Tx needs to be reasonably close to the receiver / observing location for echoes to be from meteors that are local to the area and which may be observed visually.
5. Optical visibility – clouds and phase of the moon + light pollution levels

3 Measurement Techniques

In order to understand the influence of each variable, the measurement programme must include techniques that monitor these over sufficient time in order to be able to remove these variable effects from the measurement data gathered during the Perseid meteor shower.

The required period of measurement during the shower needs to be from 8th to 15th of August 2015, with sufficient 'background' measurements made previously, when no influence from the meteor shower is expected.

3.1 Variable VLF Frequency

The uncertainty over the correct frequencies to monitor means that transients in both bands should be measured simultaneously. Each band should be measured alongside the meteor echoes to determine if any transients in either VLF band are correlated with meteors. This will require two PCs to be used.

PC1 – Meteor echo + 1kHz transients
PC2 – Meteor echo + 6 kHz transients

3.2 Variation with time of day

It will be necessary to establish a baseline for transients in both bands as function of time of day. Several days of measurements will need to be made during a period when no meteor showers are present. The baseline can then be used to recognise any day / night variation found in measurements during the meteor shower.

3.3 Meteorological Conditions

Several days of background measurements will also need to be made before the meteor shower for days / nights with lightning (in Europe) and without any lightning present. Again, the differences will help pin down any contribution from lightning impulses that may be seen when the meteor shower is occurring – if we are unfortunate and have lightning conditions.

3.4 Choice of Meteor Radar Transmitter

Most amateurs make use of the French GRAVES transmitter on 143.050 MHz when receiving meteor echoes. If we need to try and correlate meteor echoes with optical sightings however, we need echoes from nearby the receiving station. This would not be the case for Graves as it is located in central France and beams southward.

An alternative is to use the Belgian BRAMS transmitter on around 50 MHz as it is more local, but the Tx power is only 150 Watts on 49.97 MHz and 50 Watts on 49.99 MHz, so the number and strength of echoes is likely to be smaller than for the much more powerful Graves system.

It is necessary therefore to establish a detection threshold and echo rate for the two possible BRAMS transmitters to decide which one to use for the meteor shower measurements. This should be done in the period where only sporadic meteors are present – signals will be stronger and more frequent during the meteor shower.

3. 5 Optical detection

Ideally we should like to be able to correlate the meteor radar echoes with visual sightings. This can be done by the traditional manual method, recording count rates and brightness on paper forms by observers. A simple switched three level voltage source has been developed which has buttons for faint, medium and bright meteors. Each time one of these buttons is pressed the voltage reading is recorded on a laptop against time of day – replacing paper records. Later analysis can be performed on a spreadsheet to count / time each type of meteor.

It may also be possible to use low light TV cameras and low light webcams to make recordings of visible meteor trails. See Appendix B. The aim will be to time-stamp the recordings made using VHS or DVD recorders to enable post measurement identification with radar echoes and any VLF transients.

Some trial measurements should be made before the meteor shower to establish the right balance between system sensitivity and image integration time. Bright stars can be used for this purpose if the sky is exposed for a second or so to mimic a meteor. See Appendix B.

The suggested instrument configuration is shown in Figure 1 and Figure 2.

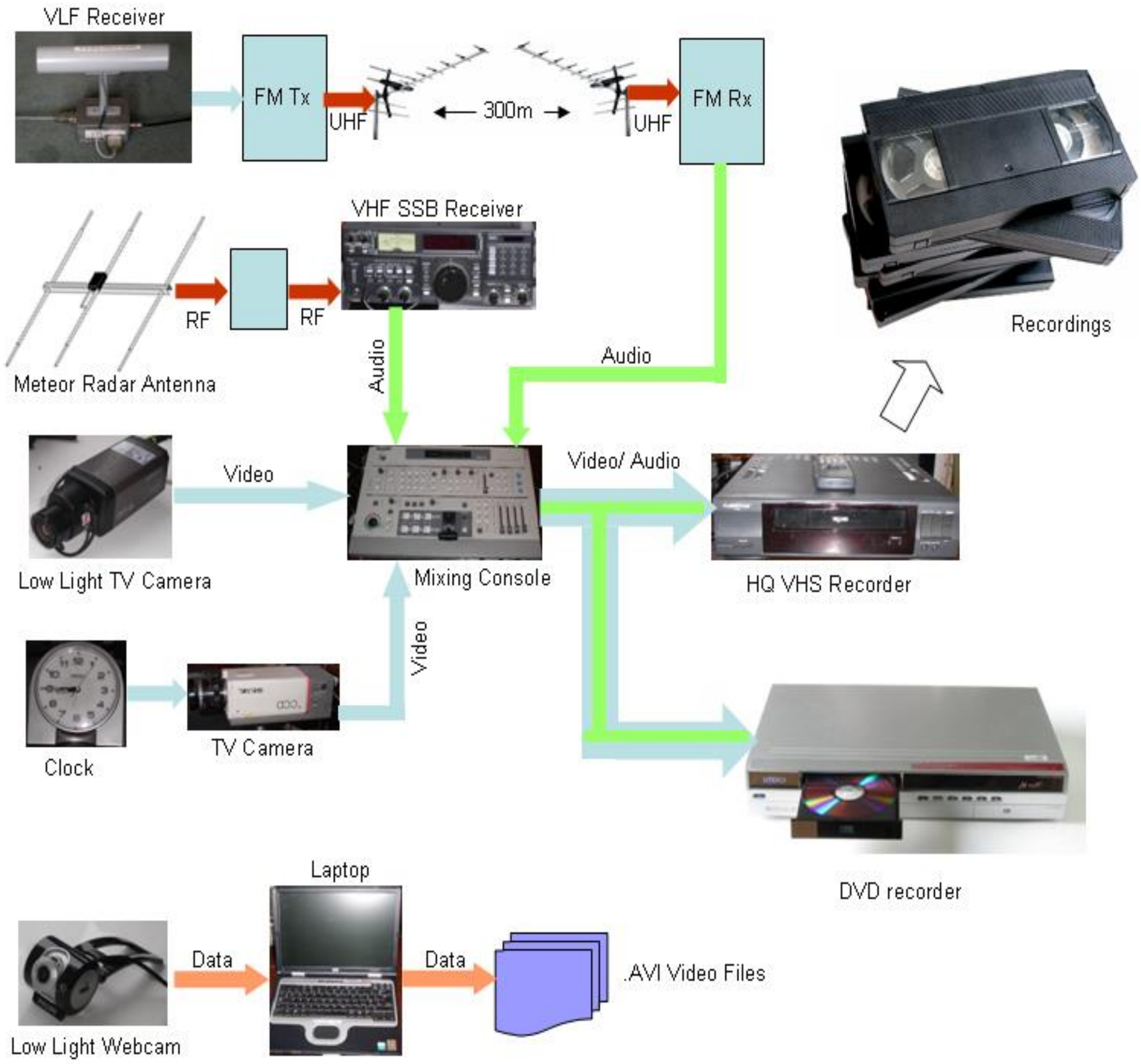

Figure 1 Proposed Measurement System - Optical /Meteor Echo / VLF

The PC based VLF transient and meteor echo recording configuration is shown in Figure 2.

Both PCs run the same version of Spectrum Lab with identical user configuration files – except for the digital filters applied to the VLF signals that provide band limited outputs for the 1 kHz Band (0.3 -2 kHz) and the 6 kHz Band (6 – 9 kHz).

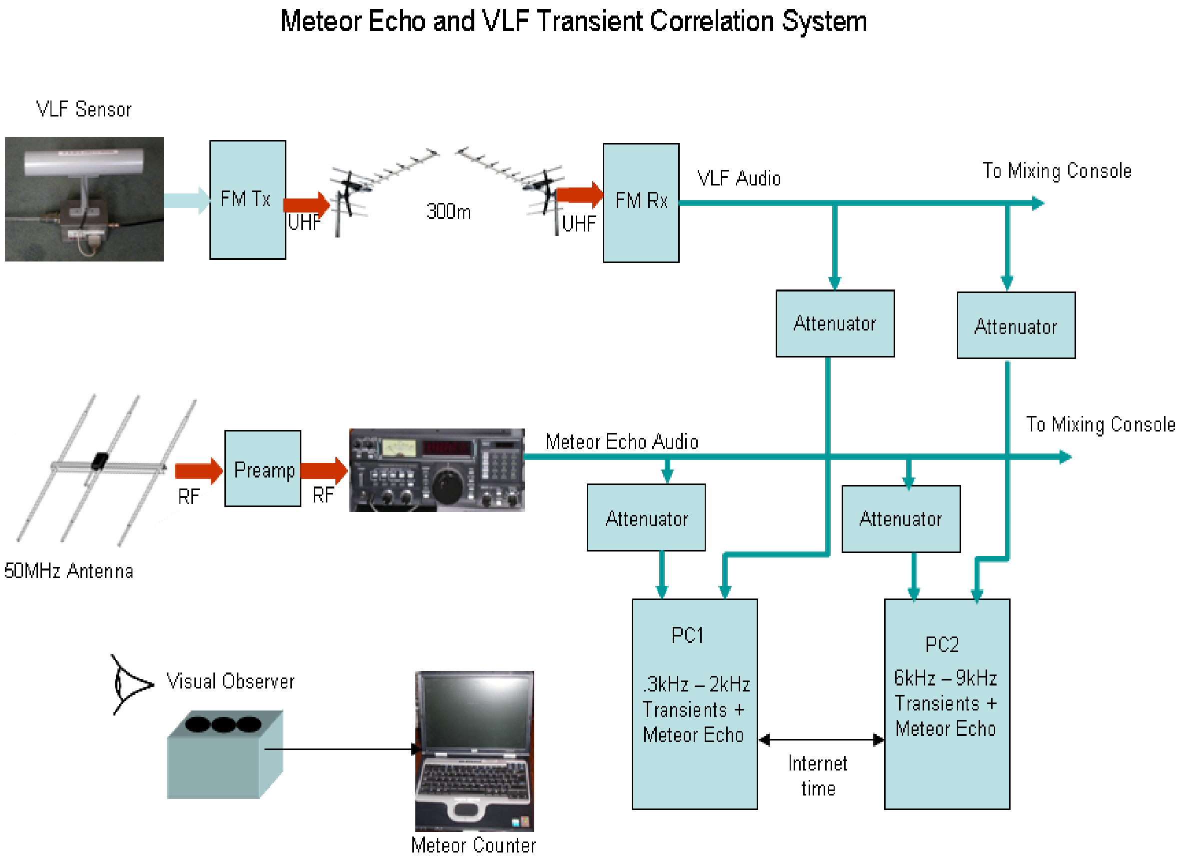

Figure 2 PC Based Recording Equipment

The intention to correlate a VLF spike emission with a meteor radar echo will not be easily achieved. Many baseline measurements will need to be made in order to understand what 'normal' conditions are like during non-shower periods. With this information we can hope to remove any 'normal' variations, with time of day or lightning activity from the data gathered during a meteor storm.

A number of experimental analysis techniques are suggested below that may show if there are more VLF spikes at around 1 kHz and 6 kHz than 'normal' during a meteor shower and if they can be correlated in time with either the optical appearance and / or the meteor radar echoes. These are discussed in the next section.

4 Potential Analysis Techniques

Readers should first be familiar with the way Spectrum Lab software is used to record Meteor Echo and VLF signals and to produce appropriate triggers when these signals exceed set values, as shown in Figure 5.8 of the article. Please see: Generation of VLF Emissions by Meteors[13] on the BAA RAG website.

4.1 Description of RAW data

Spectrum Lab Data display

In Figure 3 we have the usual Spectrum Lab data display showing the VLF pulses in the upper portion of the waterfall plot and the meteor echoes in the lower portion. The amplitude of the raw VLF signal is shown in red and that of the meteor echoes in white, in the lower section of the 'watch list window'. The echo trigger in yellow and the VLF triggers in green are shown in the upper portion. Setting trigger levels for both signals is difficult. They must be low enough for a reasonable number (100/ hr) to be logged at periods of low activity for the VLF spikes (predominantly in the day time and periods of low lightning activity), but high enough to avoid constant triggers at night and at high levels of lightning activity. For the meteor echoes, the trigger level is set to record a reasonable number per hour (~100) as background level during a period without a meteor shower.

It might be possible to analyse the raw data streams in real time using some advanced statistical methods for coincident echoes and VLF spikes, but this is not being undertaken in the first instance. A simpler approach is adopted using trigger events.

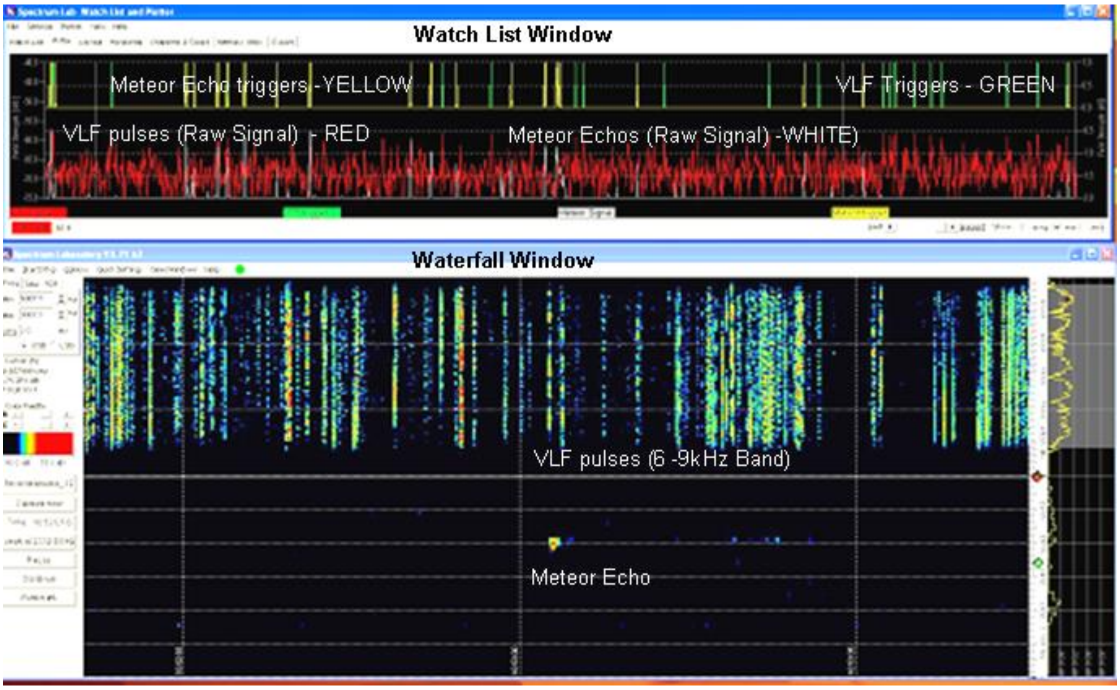

Figure 3 Spectrum Lab displays for VLF spikes and Meteor echoes

4.2 Trigger detection periods and Record Length

The detection time period for each trigger is set at 0.5 seconds. This is a compromise between capturing as much data as possible and limiting the record length. With this setting we generate around 28,800 measurements in a 4 hour period. This 4 hour period (28,800 points) is within the limit imposed in Microsoft Excel of a 32000 maximum record length for graphs. Spectrum Lab is configured to update the trigger data within the 0.5 second period every 50ms for the best peak detection.

4.2.1 VLF transient amplitudes

If we knew that meteor trails produced VLF signals of certain amplitude, especially if this was a high amplitude, it would be possible to use the trigger event analysis with a degree of certainty. Unfortunately at this stage we do not know what level of VLF transient (if any) is generated by the meteor.

If we inspect Figure 3 we can see that there is always a dense background of VLF spikes due to natural lightning and man made impulses. If any meteor VLF transients are low - or comparable with these levels – it will probably not be easy to identify and count those produced by meteors.

Initially we must simplify the problem by setting a trigger level that is slightly above this background transient level. If meteors produce VLF impulses with an amplitude greater than the background level, they will be picked out as VLF trigger events and timings can be compared with meteor echo triggers. In this way it is hoped that some temporal correlation can be established that will show a relationship between meteors and VLF transients.

4.2.2 Long Echo Issue

We also need to set a trigger point for meteor echoes, to establish two things:

- The time of the start of an echo
- To discriminate against long echoes that last for several seconds and cause multiple triggers.

If this were not done, the analysis of coincidences between echoes and VLF transients could be confused as many transients might be counted during the period of a long echo. An example a long echo (~15 seconds long) is shown in Figure 4.

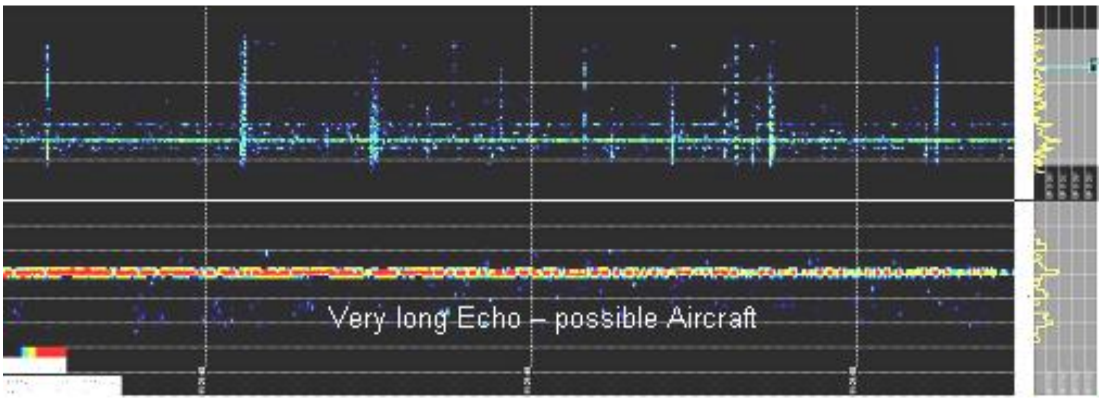

Figure 4 Example of very long Echo – possibly due to an aircraft ?

In this figure it can be seen that a simple count of VLF spikes during the period of the echo would return about a dozen coincidences. Such a conclusion would completely distort any sensible analysis of coincidence between short meteor echoes and VLF transients. It is therefore necessary to eliminate these long trains of echo triggers from the data. This is done during the spreadsheet analysis and before any coincidence tests are performed.

An example of long trains of echo trigger signals can be seen in Figure 5. We can see the raw signal level for the echo falling away over several seconds, leading to a constant period of triggers, before the signal level falls below the trigger threshold.

The spreadsheet analysis will eliminate these multiple triggers and mark only the time when the initial echo signal exceeds the trigger threshold, by generating a single trigger event.

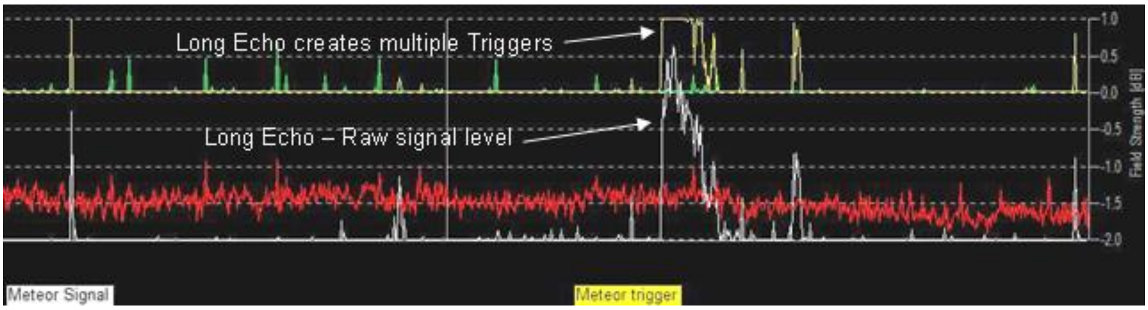

Figure 5 Example of Multiple Echo Triggers from a long Radar return (aircraft?)

4.3 Counting Trigger coincidences

It is not known if the VLF spike emissions from meteors and the radar echo are exactly coincident. From the expected generation mechanism, it might be thought that they are. However some meteor echoes can last for several seconds and this will produce multiple echo triggers, as triggers are evaluated every 0.5 seconds within Spectrum Lab. One option is to strip out multiple echo triggers for long echoes, as discussed earlier, leaving only the ‘single’ trigger at the start of the echo. See Appendix A for the means to do this.

If the VLF spike is generated at a time near the start of the echo, coincidence can be established between the VLF and meteor echo start triggers as shown in the example in Figure 6. In this case the condition using the ‘single’ trigger is NOT met as shown within the red box. However coincidence does exist if the RAW (unprocessed) meteor echoes are used as shown in Figure 7.

Extract from spreadsheet with single trigger (start trigger processing) showing NO coincidence with VLF trigger

YYYY-MM-DD hh:mm:ss	VLF signal	VLF trigger	Meteor Signal	Meteor trigger	Meteor Single triggers
14/06/2015 11:01	-73.5	0	-75.6	0	0
14/06/2015 11:01	-71.8	0	-67.6	1	1
14/06/2015 11:01	-57.3	1	-67.6	1	0
14/06/2015 11:01	-70.8	0	-75.1	0	0

Measurements are made every 0.5 seconds

Figure 6 Example of using processed Echo triggers ('single' triggers) – (coincidence is not achieved in this example)

To try to deal with this issue we can look for coincidences using both the raw echo trigger and the single echo triggers. It simply increases the analysis effort.

Option 1 Count VLF spike triggers coincident with 'single' echo triggers, then count VLF spike triggers around arbitrary time from echo, say 5 seconds after the echo. If spikes are produced in time with echoes there should be significant difference between the two counts.

Option 2 Count VLF spike triggers around the unmodified (RAW) echo triggers however long the echo lasts. See the example in Figure 7. The red arrow shows a coincidence between VLF and Raw (unmodified) echo triggers.

Extract from spreadsheet showing coincidence between VLF and Meteor Triggers

YYYY-MM-DD hh:mm:ss	VLF signal	VLF trigger	Meteor Signal	Meteor trigger
14/06/2015 11:01	-71.8	0	-67.6	1
14/06/2015 11:01	-57.3	1	-67.6	1
14/06/2015 11:01	-70.8	0	-75.1	0

Measurement every 0.5 seconds

Figure 7 Coincidence between VLF & RAW Meteor triggers

As before, we then count VLF spike triggers 5 seconds after raw meteor echo triggers. It will be interesting to see if there is a significant difference between the two counts- and if the trend follows that for the 'single' trigger results. Option 1 should be adopted first, only followed by 2 if there is no significant difference in the numbers counted.

4.4 Visual Inspection of Audio recordings

Spectrum Lab is set to automatically record the echo and VLF signals for 2 seconds before and 2 seconds after the generation of an echo trigger. Visual inspection of the .wav file records can be undertaken to determine if spikes are more likely to be present during a meteor echo than at another time, say 1 second later. It may be possible to determine when during the meteor echo VLF spikes are most likely to be seen. An example is shown in Figure 8. This process could be very time consuming and is unlikely to be undertaken until other more automated analyses have been completed.

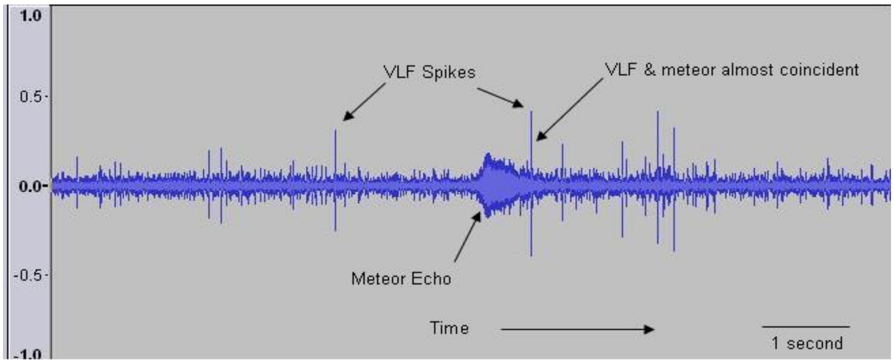

Figure 8 Example of VLF spikes superimposed on a Meteor Echo

4.5 Correlation of Visible meteor trails with Meteor echoes and VLF spikes
It is possible to visually inspect VHS recordings for coincidence of visible meteors and audio records of meteor echoes and VLF spikes. This could also be very time consuming. It will not be possible to make visual observation of meteor trails if there are cloudy skies.

4.6 Lightning Activity
From baseline measurements made prior to the date of the meteor shower it is known that lightning activity within Europe – and especially within the UK – generates a very large number of VLF spikes which may mask any additional spikes that may be produced by meteors. The Blitzortung .org website is used to monitor lightning activity. An example is shown in Figure 9.

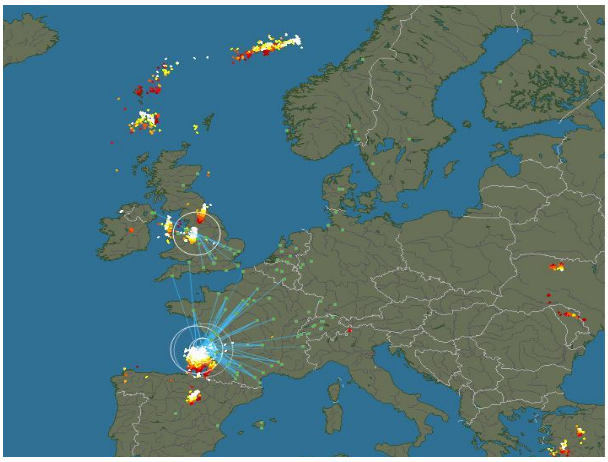

Figure 9 An example of the Output from Blitzortung .org website

The analysis task will be much more difficult if there is lightning activity during the Perseid shower and the measurement program may have to be abandoned.

Conclusions

- The physical variables that are involved in attempting to establish a causal connection between VLF transients and meteors have been identified and discussed.
- A measurement system has been proposed that should enable data to be gathered for subsequent analysis.
- Technical issues that will affect the interpretation of results for both meteor radar echoes and VLF transients are explored and methods for dealing with these are suggested.
- A number of experimental analysis techniques are proposed to uncover any causal connection between VLF transients and meteors. Initially these relatively unsophisticated techniques will be tried. It is possible that changes to both the measurement methods and the analysis techniques will be required following these initial results from the Perseid shower of 2015 if no firm conclusions can be drawn.

Appendix A Stripping out Multiple Triggers from long Meteor Echoes

In the excerpt from a spreadsheet recording typical meteor echo and VLF triggers we can see two instances where meteor triggers are generated. The first has only one trigger from a short echo, the second has two triggers from a longer echo.

By applying the formula shown above the red arrows to each line of data we set a condition where the 'single trigger' is only written if it is preceded by no trigger, thus stripping out multiple triggers.

In the second event we can see that there would be a coincidence with a VLF trigger (green circle) if the second echo trigger (blue circle) had not been removed.

The coincidence analysis will be conducted with both multiple triggers (raw data sets) which counts VLF triggers as long as there is an echo trigger – and using the single echo triggers which counts only coincidences present at the start of an echo, ie in a 0.5 second slot.

YYYY-MM-DD hh:mm:	VLF signal	VLF trigger	Meteor Sig	Meteor trigger	Meteor Single triggers	
14/06/2015 11:01	-68.9	0	-76.7	0	0	
14/06/2015 11:01	-79.5	0	-75.7	0	0	
14/06/2015 11:01	-77	0	-73.8	0	0	
14/06/2015 11:01	-74.8	0	-75.2	0	0	
14/06/2015 11:01	-66	0	-74.6	0	0	
14/06/2015 11:01	-71.3	0	-74.5	0	0	
14/06/2015 11:01	-71.2	0	-74.5	0	0	
14/06/2015 11:01	-67.8	0	-72.1	0	0	=IF(AND(E3=0,E4=1),1,0)
14/06/2015 11:01	-78.9	0	-60.8	1	1	
14/06/2015 11:01	-75.5	0	-69.7	0	0	
14/06/2015 11:01	-79.6	0	-73.9	0	0	
14/06/2015 11:01	-64.2	0	-73.9	0	0	
14/06/2015 11:01	-70.3	0	-74.3	0	0	
14/06/2015 11:01	-78.2	0	-75.7	0	0	
14/06/2015 11:01	-75.3	0	-74.7	0	0	
14/06/2015 11:01	-78.6	0	-75.1	0	0	
14/06/2015 11:01	-73.5	0	-75.6	0	0	=IF(AND(E3=0,E4=1),1,0)
14/06/2015 11:01	-71.8	0	-67.6	1	1	
14/06/2015 11:01	-57.3	1	-67.6	1	0	
14/06/2015 11:01	-70.8	0	-75.1	0	0	
14/06/2015 11:01	-70.7	0	-74.2	0	0	
14/06/2015 11:01	-73	0	-73.9	0	0	
14/06/2015 11:01	-76.4	0	-75.4	0	0	
14/06/2015 11:01	-73.4	0	-73.5	0	0	
14/06/2015 11:01	-78.5	0	-70.6	0	0	
14/06/2015 11:01	-71.6	0	-70.3	0	0	

Appendix B Setting up a Low Light Level TV Camera

The camera being used to monitor meteor trails must have a reasonable low light capability. It must be capable of detecting stars against a sky background, but it must also respond quickly enough to changes in the scene to detect transient meteor trails.

The camera used in this experiment is a Samsung SDC-435 with a 2.9 to 8.2mm zoom lens with auto iris control.

Samsung SDC-435 with a 2.9 to 8.2mm zoom lens

Trials were carried out prior to the Perseid measurements to establish the best camera electronic settings to give an acceptable low light and transient response performance.

An example (taken inside a building) is shown below.

Picture from video taken with Samsung SDC-435 Camera

The viewing angle is approximately 100 degrees

References

1 COLIN S**.** *L. KEAY Journal of Scientific Exploration,* Vol. 7, No. 4, pp. 337-354, 1993

2 Lamar, D. L. & Romig, M. F. (1964). Anomalous sounds and electromagnetic effects associated with fireball entry. *Meteoritics,* 2, 127- 136.

3 Astapovich, I. S. (1951). Acoustical phenomena occurring simultaneously with the flight of bolides. *Meteoritika,* 9,7 1 - 10 1.

4 LaPaz, L. (1958). The effects of meteorites upon the earth. *Adv. Geophys.,* 4,217-350.

5 Hawkins, G. S. (1958a). Radio noise from meteors. *Nature,* 181, 1610.
Hawkins, G. S. (1 958b). A search for radio emission from meteors. *Astrophys.* J., 128,724-726.

6 Astapovich, I. S. (1958). Meteoric phenomena in the earth's atmosphere. *Fizmatgiz,* Moscow (in Russian).

7 Romig, M. F. & Lamar, D. L. (1963). Anomalous sounds and electromagnetic effects associated with fireball entry. *RAND Memo.* RM-3724-ARPA.

8 Bronshten, V. A. (1983a). A magnetohydrodynamic mechanism for generating radio waves by bright fireballs. *Astronomischeskii Vestnik,* 17, 94-98; English trans: *Solar System Research,* 17,70-74.
Bronshten, V. A. (1983b). *Physics of meteoric phenomena.* Dordrecht, Reidel Publishing Company.

9 Colin Price & Moshe Blum, Department of Geophysics and Planetary Science, Tel Aviv University, RamatAviv 69978, ISRAEL

10 Martin Beech 1, Peter Brown 2, and J. Jones 2. 1 Department of Astronomy, 2 Department of Physics, University of Western Ontario, London, Ontario, Canada, N6A 3K7.

11 Anirban Guha. Barin Kumar De . Rakesh Roy, Earth Moon Planet
DOI 10.1007/s11038-009-9304-0 7 April 2009

12 S. Garaj, D. Vinkovic, G. Zgrablic, D. Kovacic, S. Gradecak, N. Biliskov, N. Grbac, Z. Andreic, FIZIKA A Zagreb 8, 91 (1999)

13 D Morgan Generation of VLF Emissions by Meteors
www.britastro.org/radio/downloads