Identifying VLF Transient Emissions produced by Meteors
Dr David Morgan

Part 2 – Results of measurements made during a Non Meteor Shower period (July 2015)

1 Introduction

The original article in this series – The Generation of VLF Emissions by Meteors [1] showed that professional researches had suggested a mechanism by which turbulence in meteor trails might give rise to a transient VLF emission. Some evidence was presented that showed an increase in VLF transients during a meteor shower.

A measurement programme was planned for the Perseid shower in August 2015, to replicate some of these professional measurements, with the aim of confirming increased VLF transient activity during the meteor shower.

As part of this process it was necessary to establish a set of baseline measurements during a non meteor shower period to act as a 'background' or control data set. A measurement protocol was established - Measurement Programme Planning [2] which discussed all the variables that might influence the number of VLF transients – lightning, time of day etc. A technical measurement scheme open to amateurs was suggested and an observing programme was established.

The technical scheme and observing program were put in place and used during the period 14/6/2015 to 17/7/2015 to generate sufficient 'background' data to establish a baseline with which measurements made during the Perseid shower could be compared.

The results of these background measurements are presented in this article.

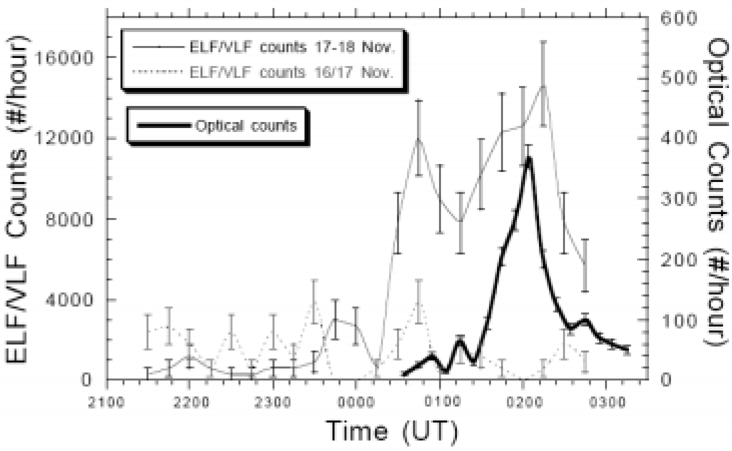

Figure 1. 1 Professional evidence of the connection between VLF Transients and Meteor Showers. (From Ref:1)

2 Measurement System

A schematic of part of the measurement system is given in Figure 2.1 – full details are to be found in Ref 2.

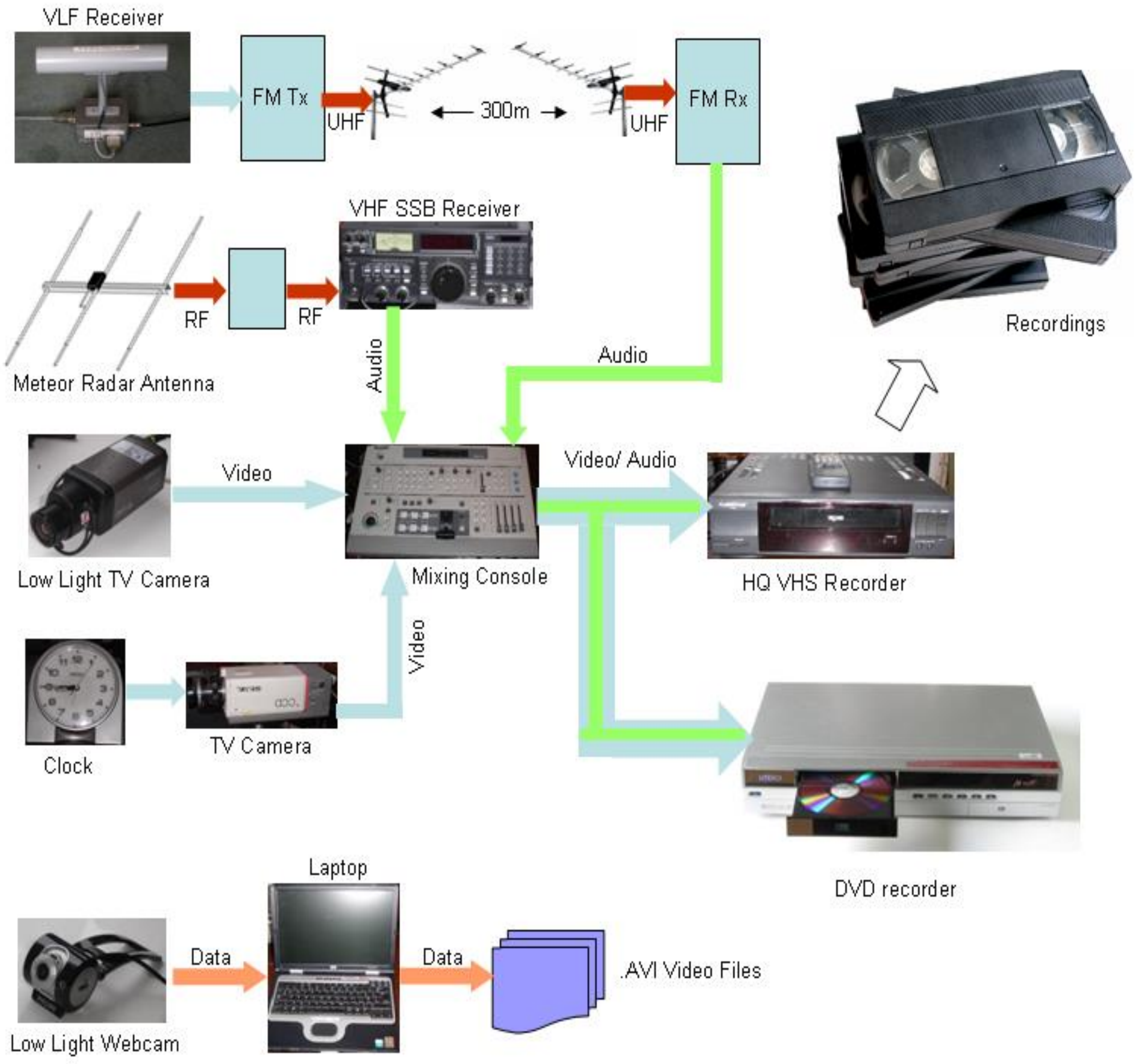

Figure 2.1 Schematic of Measurement System

The automatic meteor echo and VLF transient recording equipment configuration is shown in Figure 2.2. Spectrum Lab software was configured to count echoes and VLF transients, along with saving waterfall plots of both signals and .wav file recordings of both signals, for 2 seconds pre and post the meteor echo detection. A very large amount of data was therefore collected for later analysis.

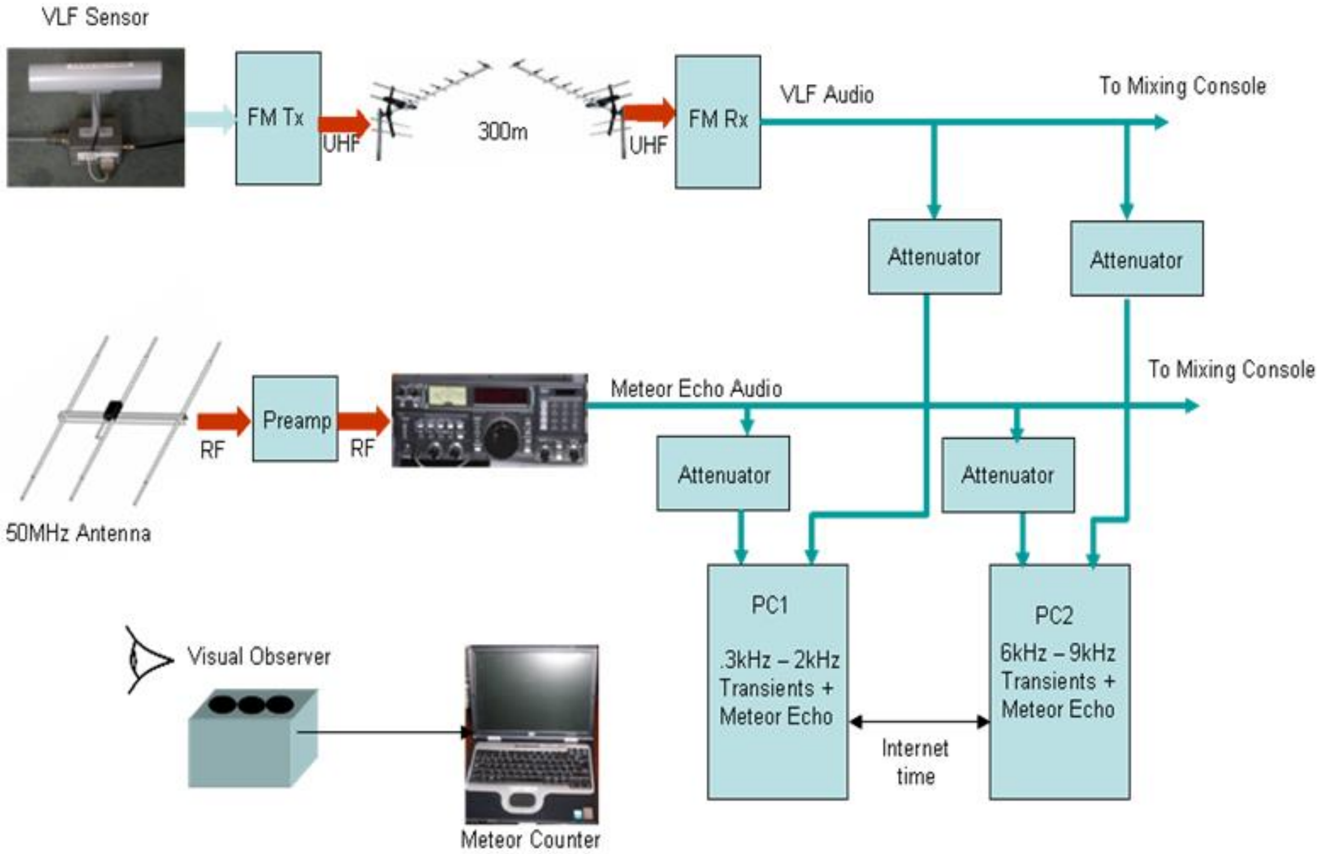

Figure 2.2 Automatic PC based recording of Meteor Echoes and VLF Transients

There are three options with regard to meteor echo detection from transmitters operating at:

143.050 MHz	Graves in France
49.97MHz	BRAMS Dourbes in Belgium
49.99MHz	BRAMS IEPER in Belgium

The Graves transmitter is likely to produce echoes from meteors above southern France which may not be seen from the UK.
The two Belgian transmitters are more local and therefore more likely to produce echoes from meteors that may be seen over southern England.

Initial meteor echo counting on both Belgian transmitters showed that the IEPR frequency of 49.99 MHz proved to be the most successful. Therefore this transmitter was chosen for the measurements.

3 Initial Measurements

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

3.1 VLF Transient Measurements

The aim was to understand the nature and causes of variability in the rate of VLF transients in two frequency bands: 1 kHz Band (0.3 - 2 kHz) and the 6 kHz Band (6 – 9 kHz). These frequencies were suggested in the professional research referred to earlier. The VLF and meteor echo information was collected in the form shown in Figure 3.1.

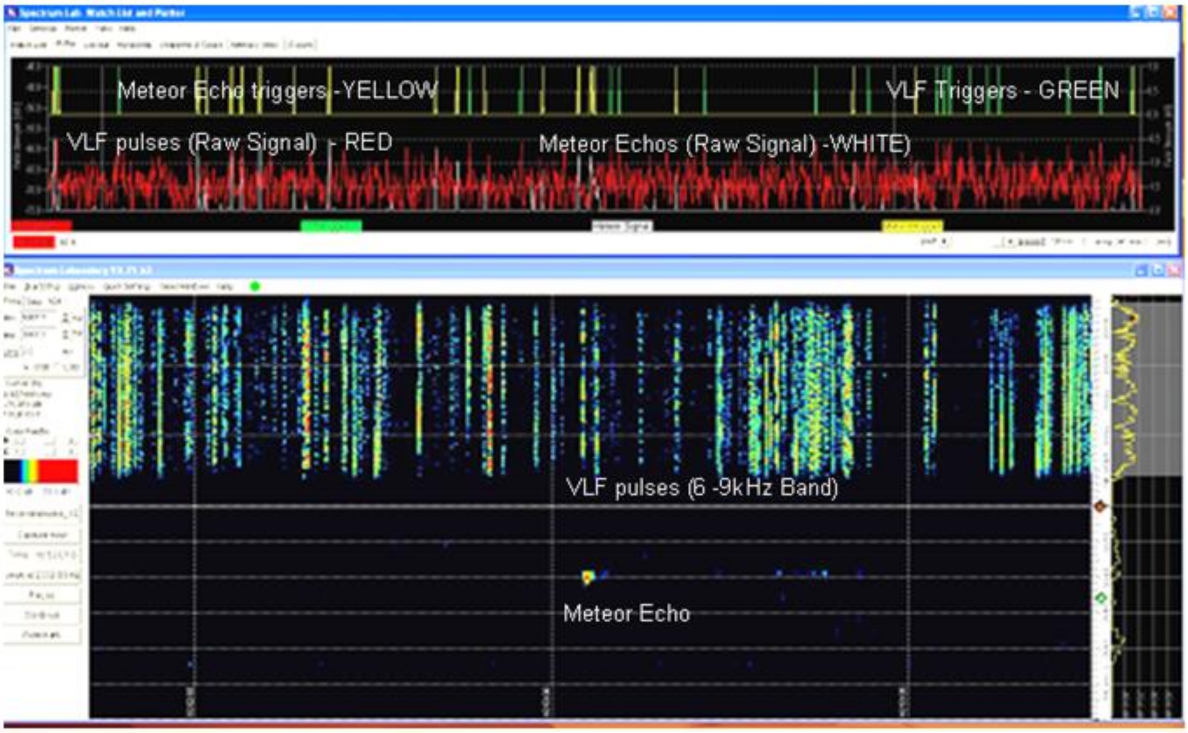

Figure 3.1 Meteor echo and VLF Transient waterfall plots with raw signal levels and triggers above defined thresholds shown in the upper panel.

The times at which VLF transients exceeded a certain threshold level (set by the operator and called “triggers”) were recorded in a spreadsheet over a period of some hours. The average rate of triggers can be calculated and displayed as shown in Figure 3.2 for both 1 & 6 kHz VLF bands. The example shown was from 19:00 to 02:23 hrs BST on the 25th -26th June 2015. There was no lightning activity in Europe during this period.

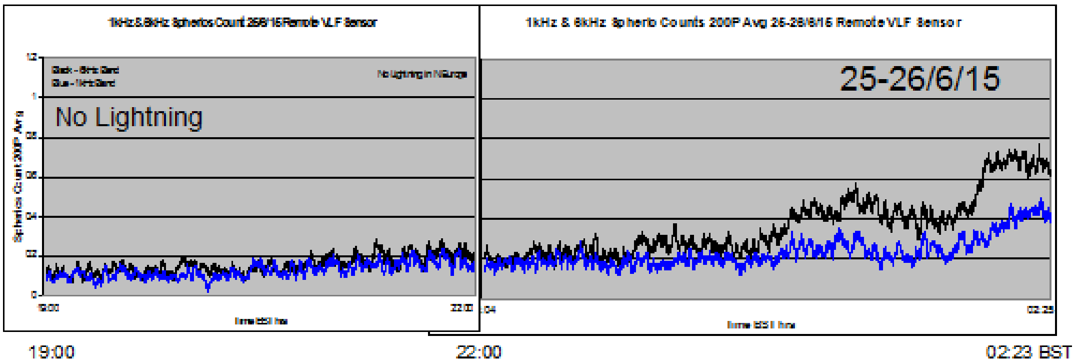

Figure 3.2 Rate of VLF transients during onset of evening

We can see an increase in VLF transient counts in both frequency bands as the day moves through evening into night time. This daily variation was confirmed in a number of subsequent measurements and is one of the fundamental factors that have to be recognised and removed from the VLF transient rates measured during a meteor shower, when measurements are made from daytime through to night-time.

A further example is shown in Figure 3.3 for a subsequent day / night and again with low lightning activity in Europe.

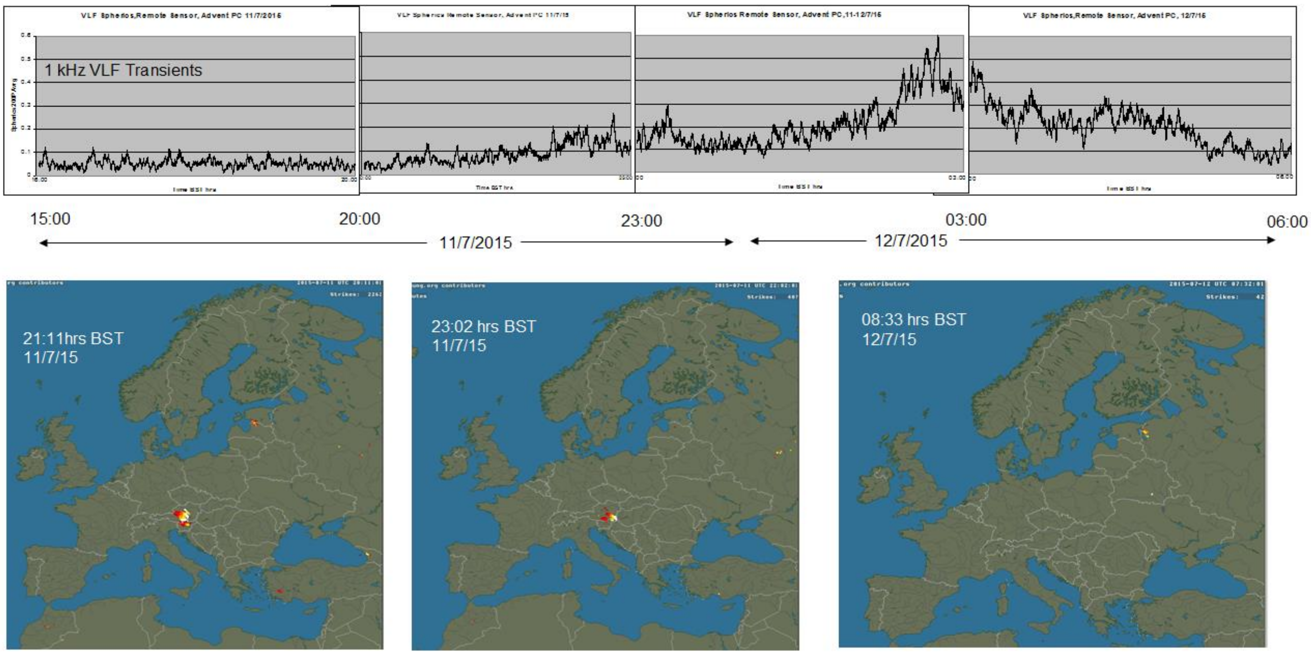

Figure 3.3 Rates of 1 kHz Band VLF Transients with low lightning activity

The next example in Figure 3.4 shows the rate of VLF transients (sometimes referred to as Spherics or S'ferics) with a lot of lightning activity within Europe. In this case, the increase in transient rate begins earlier in the day with the onset of the lightning and dies away later in the early morning. It is assumed that the usual day /night variation that is probably due to ionosphere changes is still present, but overlaid by the increased rates due to lightning.

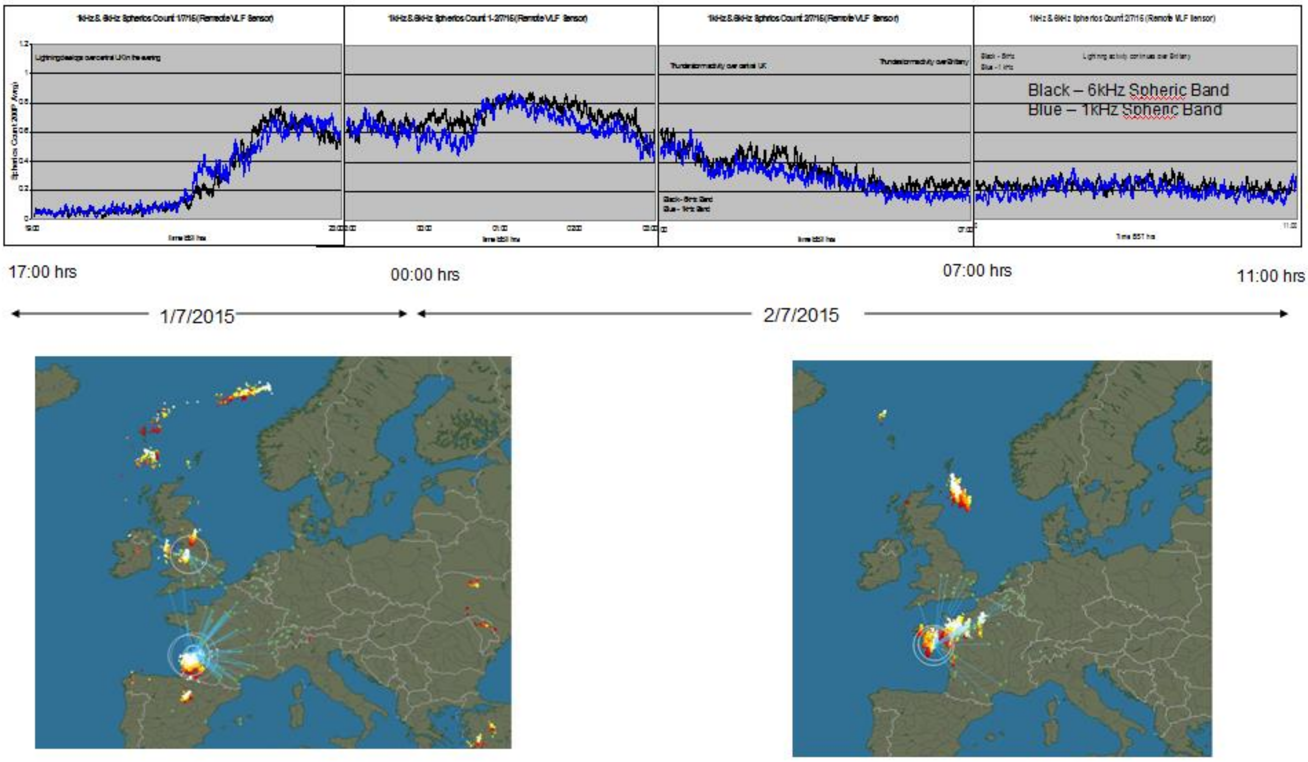

Figure 3.4 VLF Transient rates when there is lightning activity
(Rate scale is arbitrary – not counts / hour)

This suggests that it will be very difficult to remove any effects of lightning (if present) from the data gathered during the Perseid shower. It may be that useful conclusions about the relationship between meteors and VLF transients can only be made if there is NO lightning activity during the shower. It is noted that the data collected by professionals to produce Figure 1.1 had to be taken with no lightning activity on the continent where the measurements were made.

3.2 Sporadic Meteor Echo Rates on 49.99MHz

Between meteor showers there is still sporadic meteor activity that can be detected with VHF Radar. Many hours of measurements were made during late June and early July 2015 to establish a baseline rate for sporadic meteor echoes that would be used to compare with rates during the Perseid meteor shower.

The times of meteor echoes above a specified signal strength were recorded in a spreadsheet. An example of these echo triggers are shown in yellow, in the upper panel of Figure 3.1.

Initial measurements at a frequency of 49.99 MHz were made on 7^{th} and 8^{th} of July 2015 using a 3 element Yagi antenna as shown in Figure 3.4. It was directed toward the south east.

Figure 3.4 50MHz Yagi Antennas for Meteor Radar Reception

The receiver used was an ICOM IC-R7000 with SSB demodulation set to produce an echo 'ping' at a frequency of 1400 Hz. The signal is fed to both PC1 and PC2 running Spectrum Lab, producing the type of echo plot shown in the lower panel of Figure 3.1.

Examples of the meteor detection hourly rate are shown in Figure 3.5 for the initial measurements made on the 7^{th} & 8^{th} of July 2015. The average rate is 60 / hour.

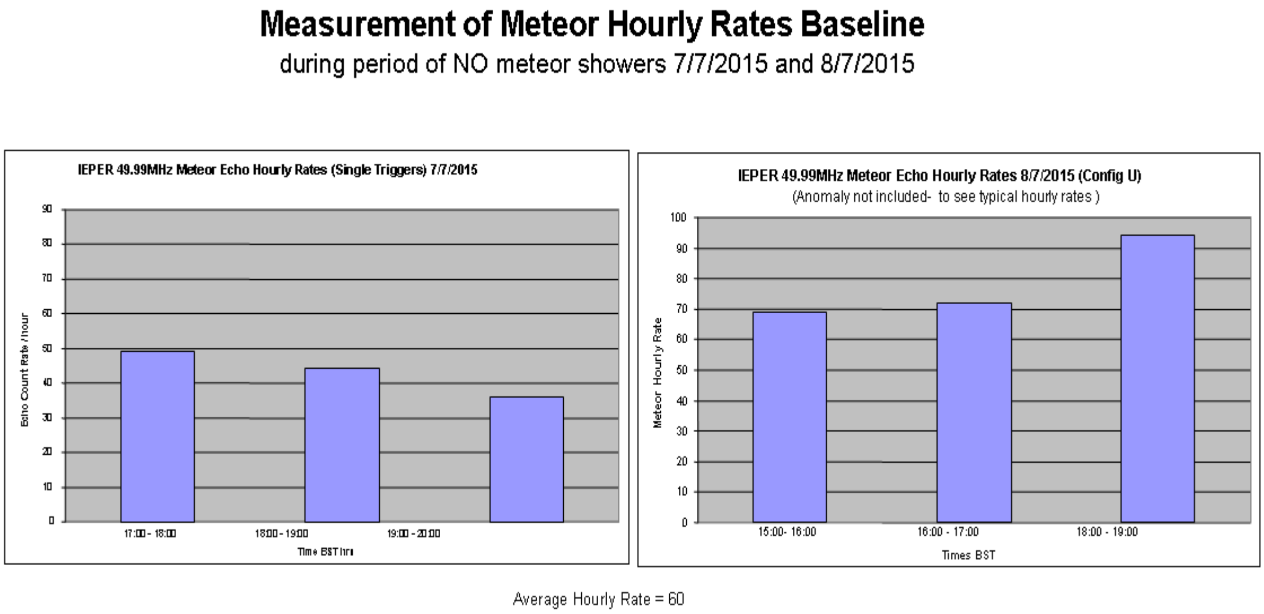

Figure 3.5 Initial Measurement of Meteor Hourly Rates

Further measurements were made at various times during days and nights from 7th to 9th of July 2015 resulting in 28 separate measurements of hourly rates as shown in Figure 3.6. The average value is 62 echoes/ hour.

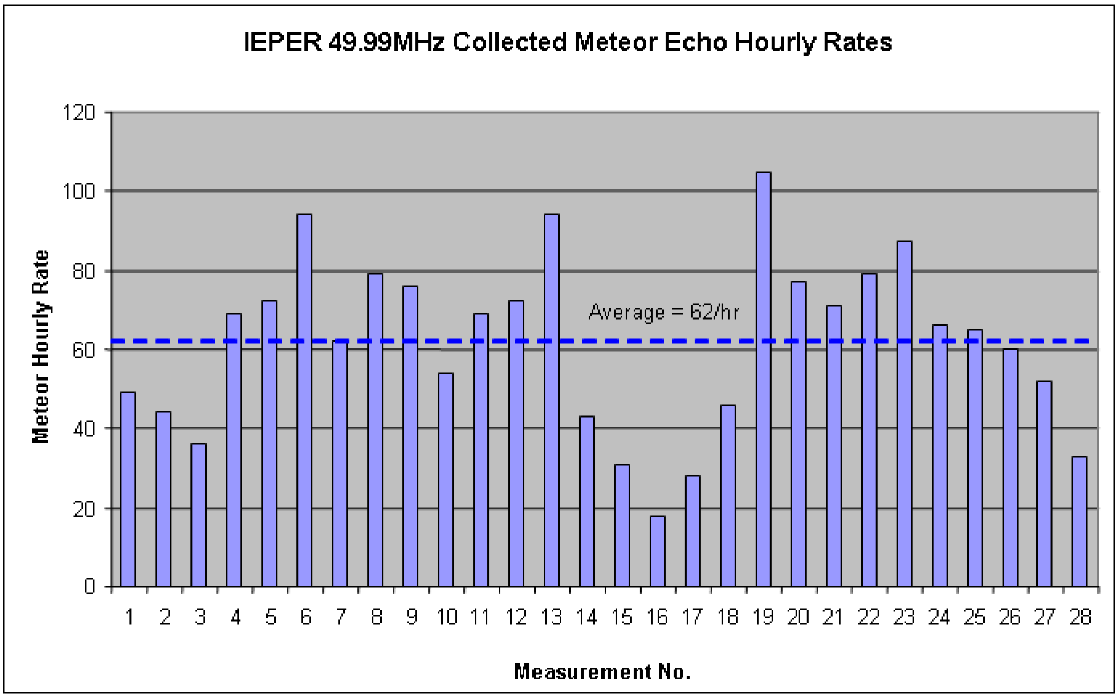

Figure 3.6 Measurement of Meteor Echo Hourly Rate

This establishes a baseline for echo reception during non meteor shower periods.

4 Analysis of the coincidence of Meteor Echoes and 6 to 9 kHz Band VLF Transients

The analysis is based on the idea of measuring the number of transients and meteor echoes occurring simultaneously, with the number of transients that occur 5 seconds after the echo has been received. The argument being that if meteor trails give rise to VLF transients, the number that occur simultaneously should be statistically greater than those with a 5 second delay – for which there is no causal process linked to meteors and therefore there should only be random matches. The analysis was carried out using the 6 - 9 kHz Band VLF data

A complication arises due to the fact that some echoes are quite long – over a second or two - and therefore produce multiple echo triggers (which are evaluated every 0.5 seconds). A technique is described in Appendix A of Reference 2 for eliminating multiple triggers from long echoes. The trigger point then refers to the start of the echo, where it is usually the strongest. There may be some risk in doing this as it is not known at what point during the echo any VLF transient may be generated. However this procedure is adopted as an initial analysis strategy.

To underpin the 'Single Trigger' analysis we also produce the results when all echo triggers – RAW data (including multiple triggers) - are taken into account. The aim is to see if any striking difference is evident. This analysis was undertaken for periods around midnight (when transient counts are high and more matches might be expected) on three days: 14/6/2015, 16/7/2015 and 17/7/2015.

The results for 14/6/2015 are shown in Figure 4.1.

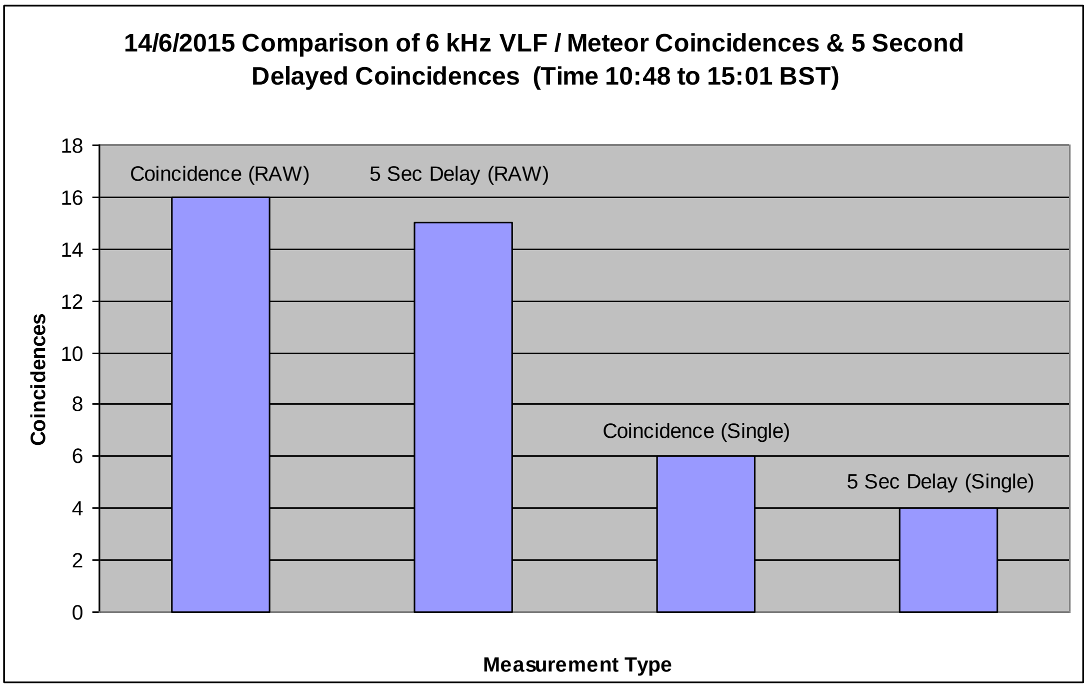

Figure 4.1 Coincidence of Echoes and VLF Transients

This shows that for both the RAW (multiple echo trigger) and single trigger echo coincidences, the delayed matches are slightly fewer than the actual coincidences. Random (5 second delayed matches) are 6% lower than actual matches for RAW data and 33% lower for actual matches. However the number of single trigger matches is low (as would be expected) and is probably too low for any significance to be attached to the 33% difference.

Analyses for the 16th and 17th of July have higher numbers of coincidences due to increased rates of sporadic meteor echoes and therefore the data may be considered to be more reliable. The analysis for 16th of July 2015 is shown in Figure 4.2.

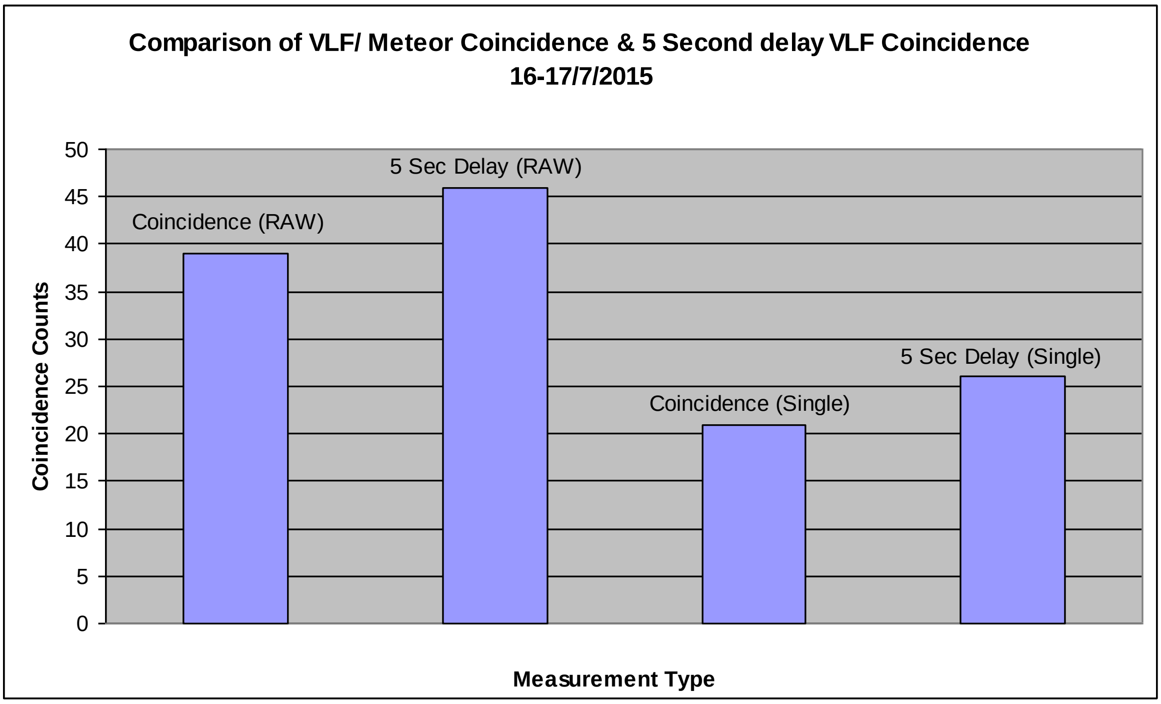

Figure 4.2 Analysis of Coincidence for 16th – 17th July 2015

In this analysis the 5 second delayed coincidences are greater than actual (real) coincidences for both RAW and single echo data sets, by 17% for RAW and 19% for 'single' echoes. These results are more likely to be significant as the overall number of echoes measured is greater than for the 14th of July 2015. This more or less confirms that there is NO greater chance of a real echo and VLF coincidence than a 5 second delayed – random one. The suggestion therefore is that there is NO evidence of VLF transients being generated by sporadic meteors. This will be compared with data gathered during the Perseid meteor shower when many more bright (high mass) meteors are expected.

Finally the analysis for the 17th of July 2015, shown in Figure 4.3 serves to confirm the above assertions.

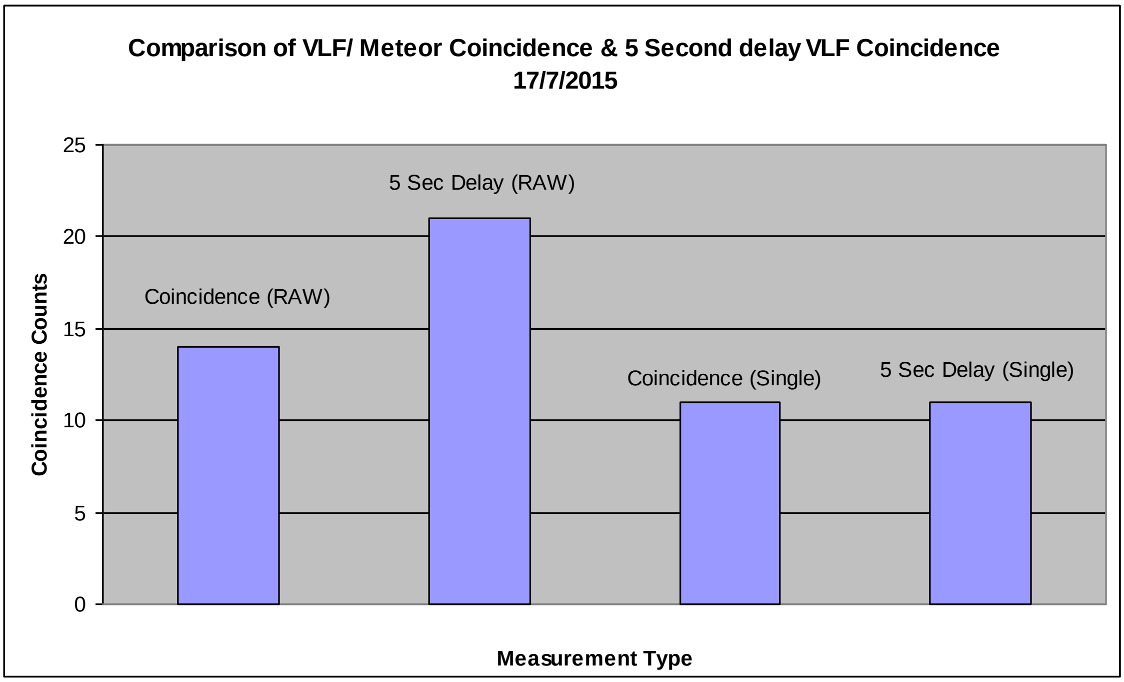

Figure 4.3 Analysis of Coincidence for 17th July 2015

The random matches (RAW set 5 seconds delayed VLF) are greater than the actual coincidences by 33% and are equal for single echoes.

The analysis presented here suggests that there is no clear evidence that supports the idea of meteors generating VLF transients during periods of low background levels of sporadic meteors.

5 Analysis of Signal Waveforms for Meteor Echoes and VLF Transients

The waveforms of the basic signals for both echoes and transients were captured using the Time Domain Scope function in Spectrum Lab V2.76.b8. This has a better functionality than earlier versions in respect of the record length available in the 'Scope' function.

This additional high time resolution examination of actual coincidences of VLF transients occurring during a meteor echo was undertaken to provide additional evidence to support or refute the conclusions made using trigger data.

An example of a time domain record is shown in Figure 5.1.

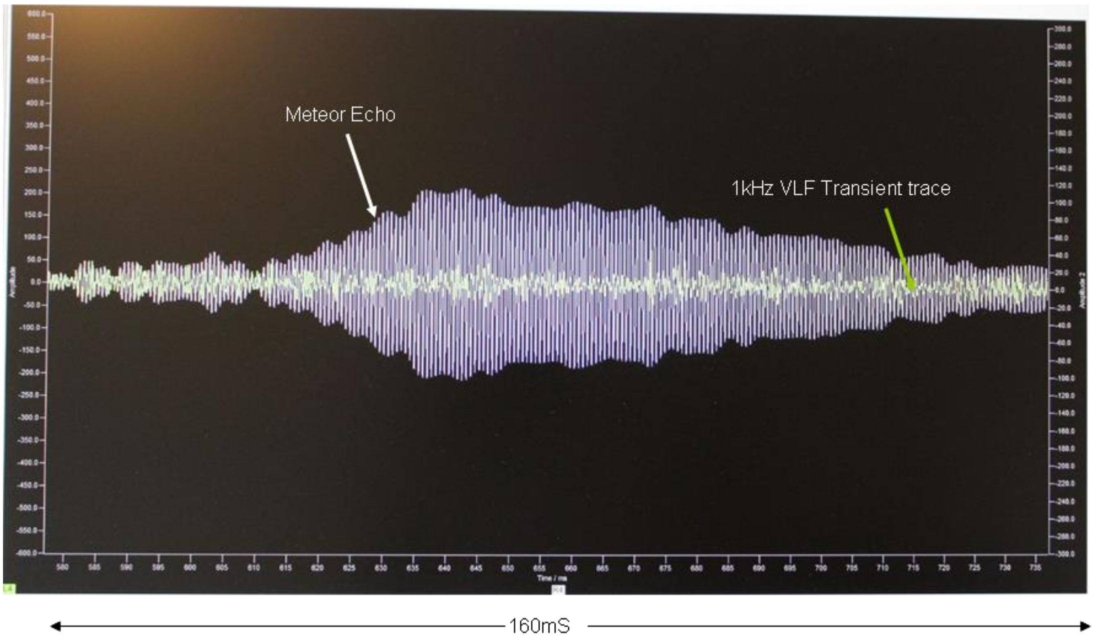

Figure 5.1 'Time Domain Scope' showing Echo and VLF signals

42 records were collected on the 17th of July 2015 and visually inspected to deduce any pattern in the existence and position of VLF transients during the period of a typical meteor echo. See Figure 5.2.

The results are displayed as a simple bar chart overlaid on the typical echo pulse. The high bar on the LHS represents the cases where NO transient was observed.

Distribution of 1kHz VLF Transients along a Typical IEPER Meteor Echo 17/7/2015
(The tall stack on LHS is the number of echoes with NO transient)

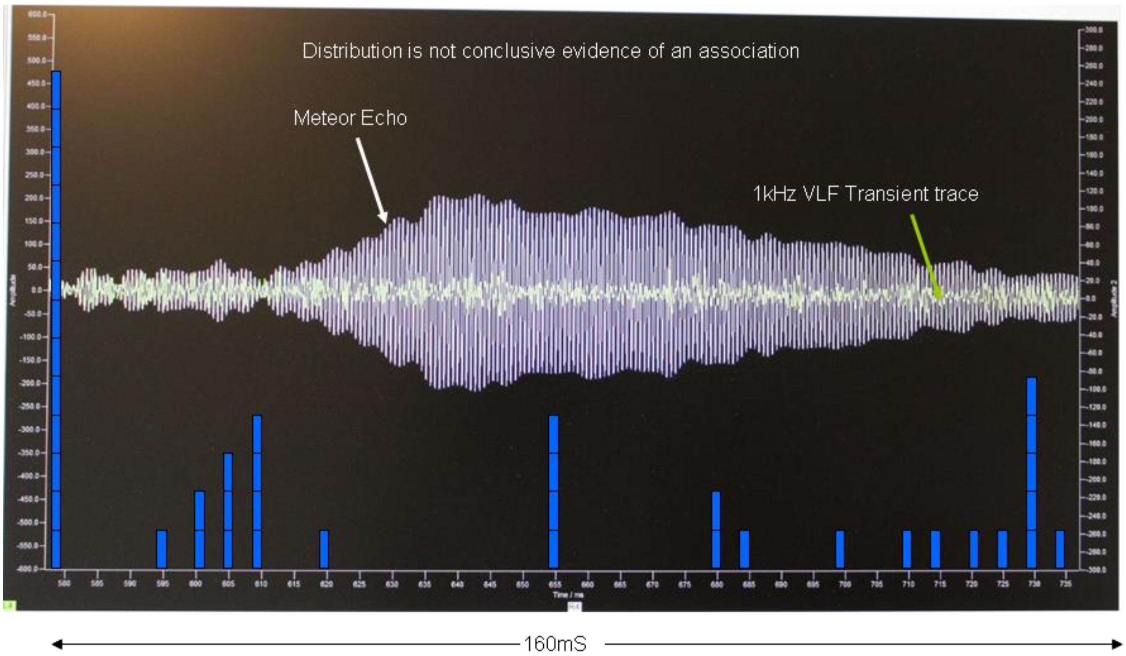

Figure 5.2 Number of VLF transients (in 5 ms windows) as a function of position through a meteor echo pulse

It was concluded that:

- There were 13 cases where NO VLF transient was present
- 29 cases where a transient was present
- The position of VLF transients over the period of a typical echo showed no clear pattern

The visual analysis of the limited sample of time domain records suggests that there is no clear linkage between the timing of VLF transients and a typical meteor echo over a period of 160 ms.

If there was a clear causal mechanism we might expect the distribution of transients to cluster around some point during the echo.

To examine the possibility that the VLF transients might occur at the tail end of the echo – or slightly later - the time base was increased to 630 ms. Of course, with this time spread many more unconnected transients will appear. See Figure 5.3.

No evidence was found of any transient position clustering.

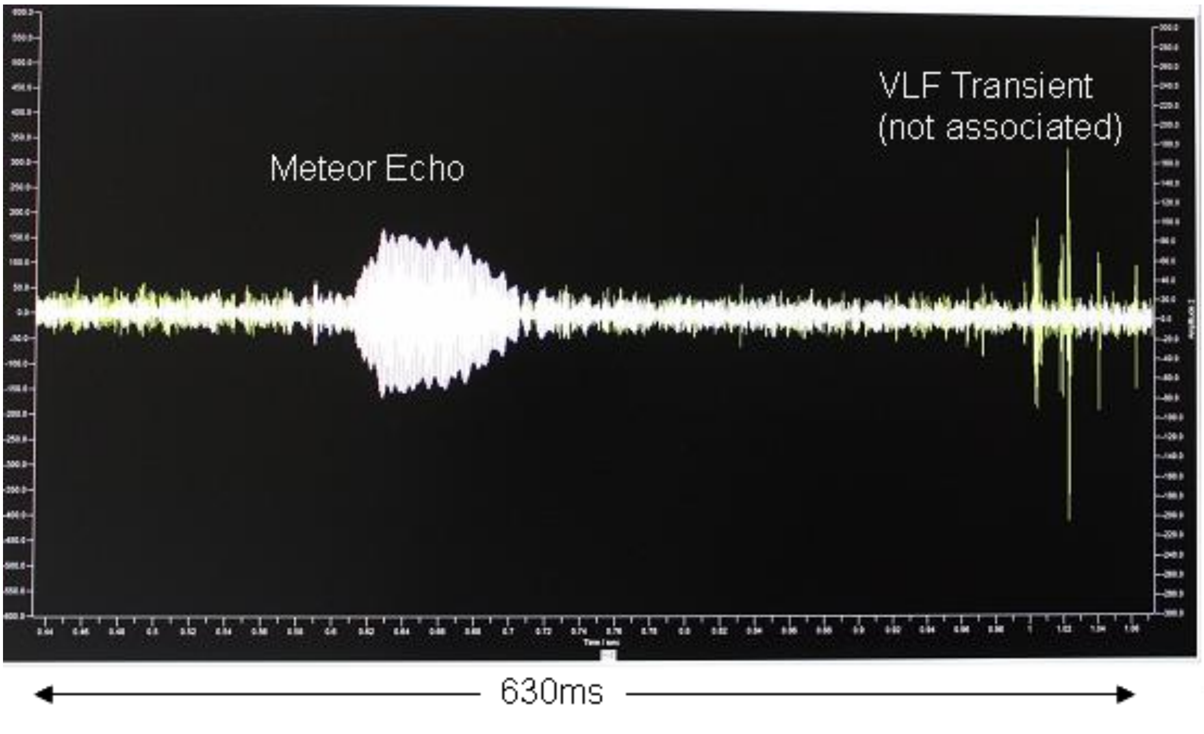

Figure 5.3 Meteor Echo & VLF Transient on long Time Base

6 Analysis of Recorded Meteor Echo and VLF Transient Audio Files

In this article several possible analysis methods have been suggested in order to find any association between meteor radar echoes and VLF transients. We will now look at the possibility of using automatically recorded audio files of both signals to add any information to the conclusions drawn thus far.

If there is a causal relationship between meteor trails and VLF transients it might be expected that the transients would be approximately coincident with the meteor echo. By automatically recording both signals at a sample rate of 48K samples / second, high resolution data can be saved from 2 seconds before to 2 seconds after the meteor echo. The signals have been added together in Spectrum Lab to overlay the VLF transients onto the meteor echoes.

Inspecting this data visually enables the times of transients to be measured with respect to the start of the echo signal with a view to examining the resulting distribution of transients to look for clustering at certain times. If no clustering is found, this would tend to support the conclusion thus far, that there is no causal relationship.

This is similar to the analysis carried out in section 5, but is performed over a much longer time-span to ensure that all transients that could realistically be associated with a meteor are examined.

The audio files of 10 meteor echo events recorded between 19:30 BST and 23:00 BST on the 16th July 2015 have been examined using the Audacity software package[3]. Two data sets each containing 5 audio files are plotted on Audacity's main window, as shown in Figures 6.1 and 6.2.

The start of each meteor echo is marked with a red arrow and the times of prominent VLF transients with black arrows. It is then possible to normalise the transient times to the start of the echoes by shifting them by a small amount so that all the red arrows coincide. This is shown in Figure 6.3.

The final step is to overlay the VLF Transient timings for both sets to reveal any clustering of black arrows around specific times relative to the start of the echoes.

None is found, confirming the conclusion that no causal connection between meteor echoes and VLF transients can be established – during non meteor shower periods when only sporadic meteors are present.

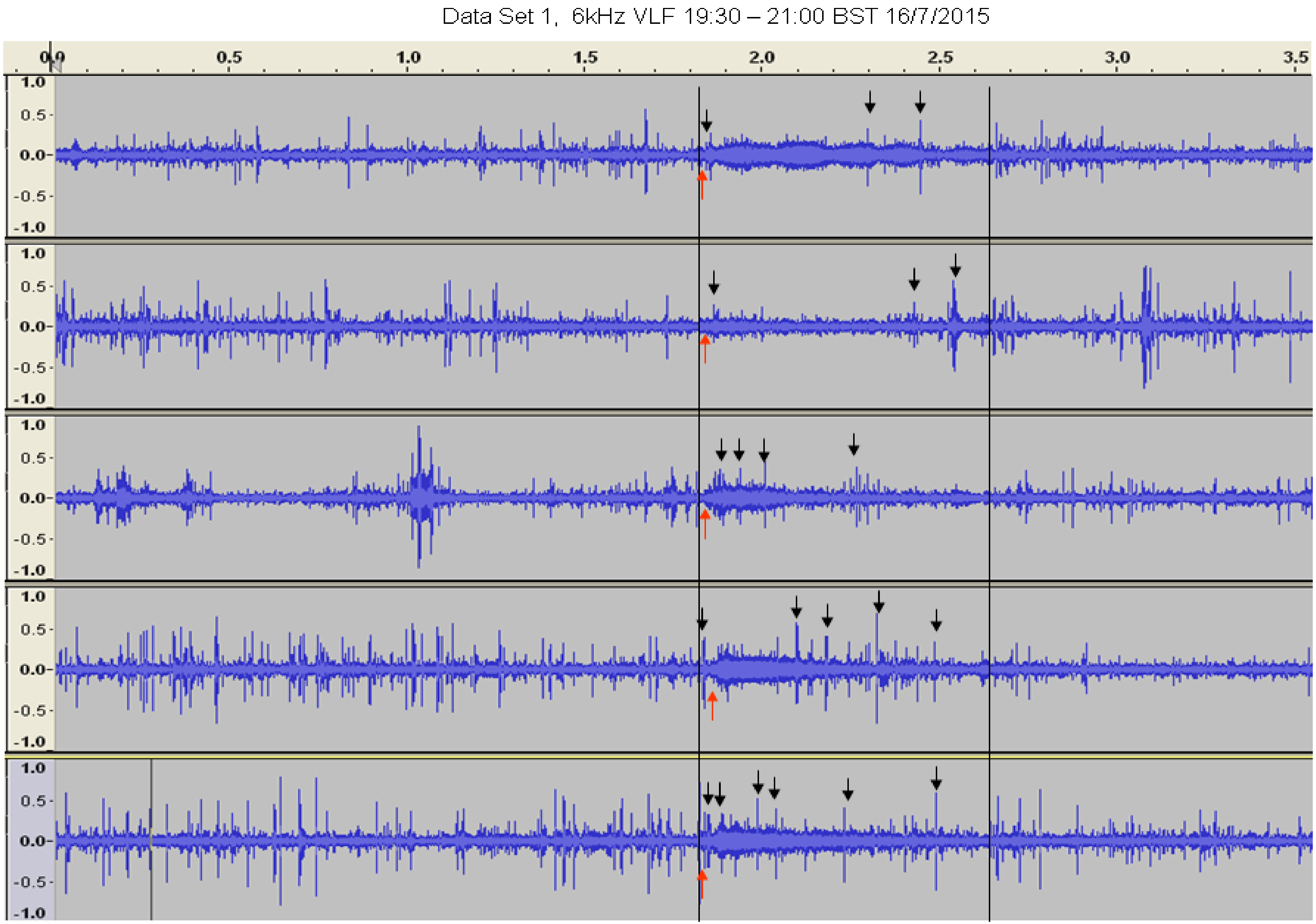

Figure 6.1 5 records of Echoes & Transients

Data Set 2, 6kHz VLF 19:30 – 21:00 BST 16/7/2015

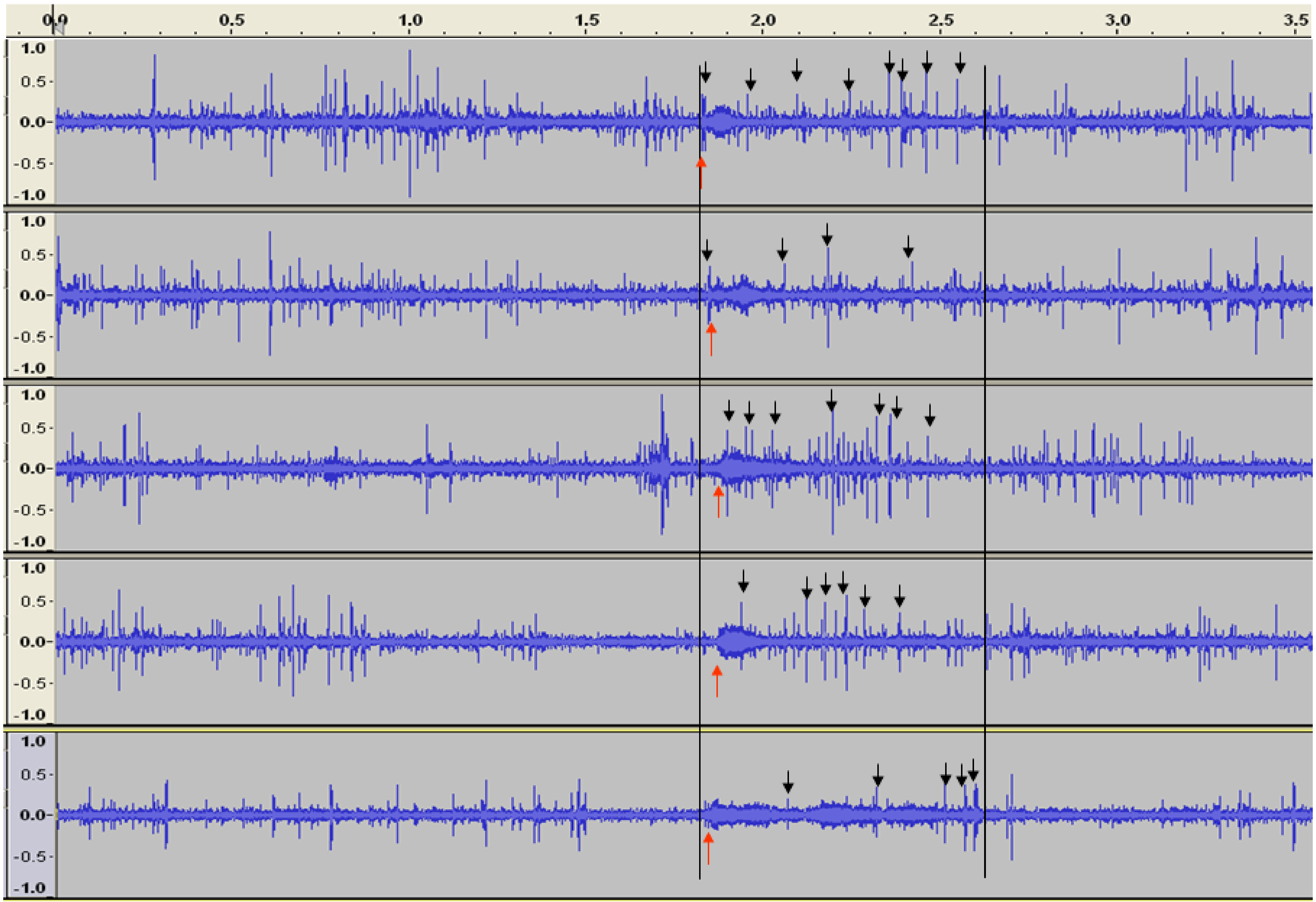

Figure 6.2 5 more records of Echoes & Transients

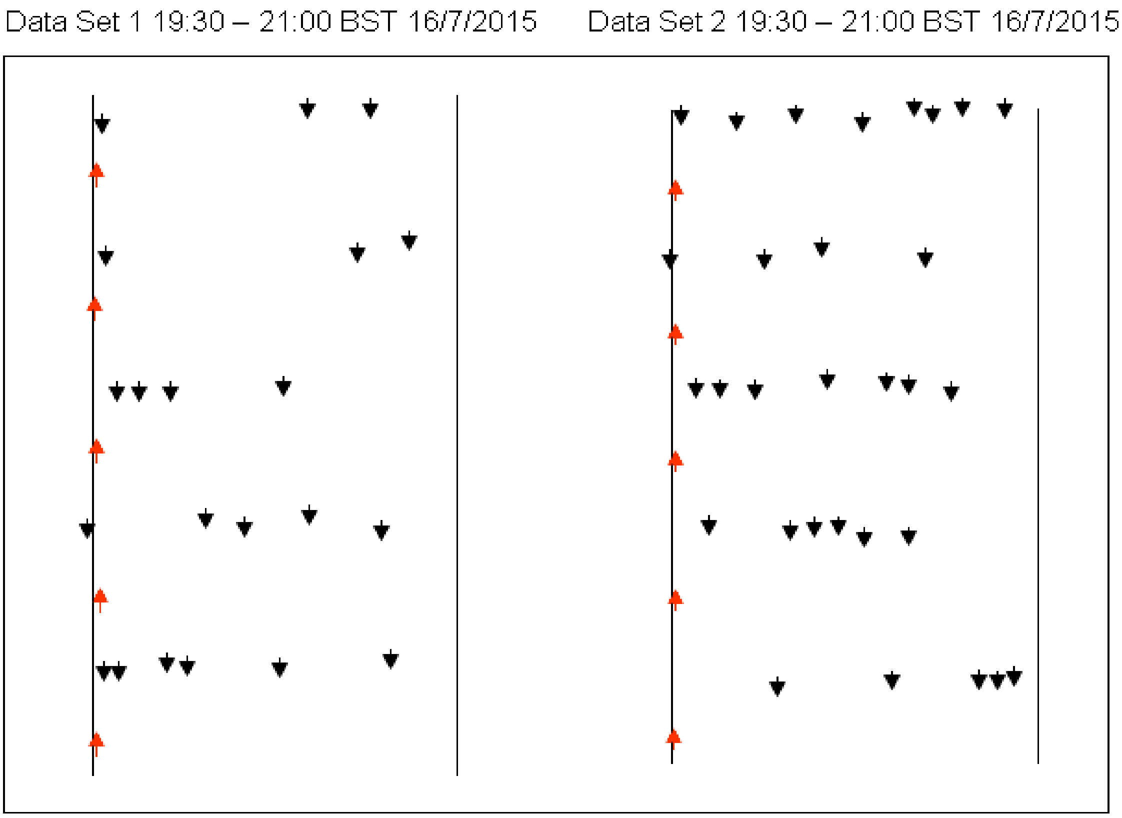

Figure 6.3 VLF Transient timing shifts for each Data Set

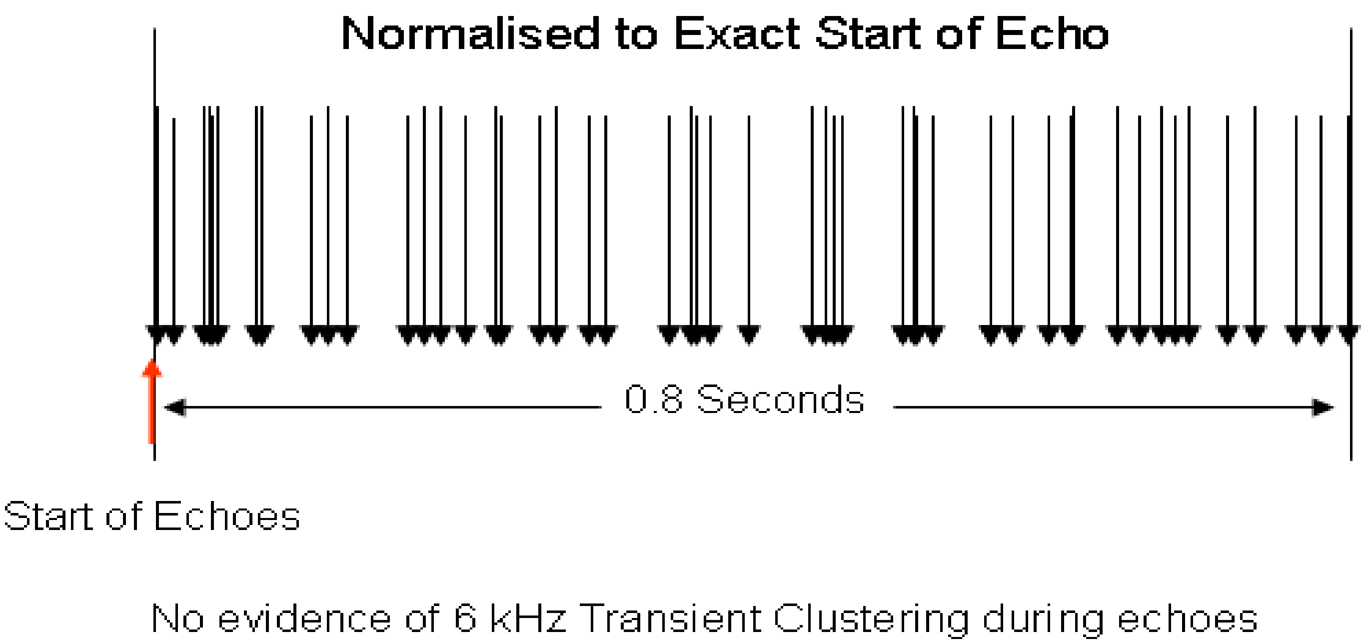

Figure 6.4 Summation of VLF Transient timings for both Data Sets

7 Conclusions

- Measurements have been made over a period of several days to establish a baseline against which results to be obtained during the Perseid meteor shower of 2015 can be assessed.
- A number of experimental analysis activities have been proposed that aim to uncover any causal link between VLF transients and meteor radar echoes.
- Dependencies have been observed between the number and intensity of VLF transients and time of day / night and the prevalence of lightning activity in the UK and Europe.
- If there is extensive lightning during the period of the Perseid shower it may be impossible to make useful measurements.
- 1,170,433 measurements were made during 0.5 second windows of any VLF transients and meteor echoes.
- 2,233 detailed .jpg waterfall plots of transients and echoes were obtained.
- 1,465 .wav 4 second long audio records were obtained of VLF transients occurring around the times of meteor echoes.
- No evidence has been found, using the experimental analytical techniques used in this note, of a causal relationship between meteors (meteor radar echoes) and VLF Transients.

References

1 www.britastro.org/radio/downloads/The Generation of VLF Emissions by Meteors.pdf

2 www.britastro.org/radio/downloads/ The Measurement Programme Planning

3 Audacity http://audacity.en.softonic.com/download?ab=2

Table of Background Data Collected from 14/6/2015 to 17/7/2015

The numbers in the Trigger Data, Waterfall Plot & Audio Record columns refer to the number of measurements made during the program.

DATE /ID	**TIME BST**	**TRIGGER DATA**	**WATERFALL PLOT**	**AUDIO RECORD**	**OTHER DATA**
1/6/2015	14:00-15:00	6698	129	179	
14/6/2015	10:48-15:01	28080	364	436	
23/6/2015	11:59-13:00	6758	108	137	
25/6/2015-T1	15:00-19:02	28404	0	0	
25/6/2015-T2	19:03-22:03	20880	0	0	
25/6/2015-T3	22:04-02:25	30407	0	0	
25/6/2015-T4	08:37-09:47	8078	0	0	
30/6/2015-TA	15:00-15:36	4298	0	0	
30/6/2015-TB	19:00-23:00	27992	0	0	
30/6/2015-TC	03:00-07:00	28072	0	0	
2/7/2015-TAA	19:00-23:00	27907	0	0	
2/7/2015-TBB	03:00-07:00	27975	0	0	Lightning
2/7/2015-TCC	07:00-11:01	27938	0	0	Lightning
2/7/2015-TAAA	19:00-23:00	27938	0	0	
2//7/2015-TBBB	23:00-07:003rd	55885	0	0	
4/7/2015	17:02-21:00	26417	0	0	
4/7/2015	21:00-01:005th	26750	0	0	
5/7/2015	01:00-05:00	26764	0	0	
5/7/2015	05:00-08:00	20061	0	1 @10:55	Lightning
6/7/2015-T1	17:00-21:00	26806	0	0	Lightning
6/7/2015-T2	21:00-09:007th	80228	0	0	Lightning
7/7/2015-T3	09:00-13:00	26632	0	0	
7/7/2015-T4	13:00-17:00	26735	0	0	Lightning
7/7/2015-T5	17:00-20:01	20117	0	0	
8/7/2015-T1	15:00-19:00	26732	0	0	Trigger
8/7/2015-T2/1	22:33-03:339th	33336	0	0	
9/7/2015-T2/2	03:33-06:28	19547	0	0	
9/7/2015-T3/1	06:30-10:30	26743	0	0	Lightning
9/7/2015-T4	11:30-15:30	26694	0	0	
9/7/2015-T5	15:30-19:31	26761	0	0	
11/7/2015	16:10-20:11	26852	0	0	
11/7/2015-S1	20:11-22:55	18380	0	0	
11/7/2015-S2/1	23:10-03:00/12th	25665	0	0	
12/7/2015-S2/2	03:00-06:10	21286	0	0	
12/7/2015-S3	06:10-10:10	26709	0	0	Lightning
16/7/2015 6k	06:02-10:00	26414	186	193	Lightning
16/7/2015 6k	10:00-14-19	28881	218	246	
16/7/2015 6k	14:19-17:33	21211	35	37	
16/7/2015 6k	17:37-18:56	8819	44	48	
16/7/2015 6k	23:00-06:00 17th	46670	181	188	
16/7/2015 1k	10:00-10:46	-	40	0	
16/7/2015 1k	15:34-18:38	22621	259	0	Lightning
16/7/2015 1k	19:01-23:00	26472	52	0	Echo /Li
16/7/2015 1k	23:00-03:00	26708	133	0	
16/7/2015 1k	03:00-06:00	19994	175	0	
17/7/2015 1k	06:04-10:00	26128	309	0	Lightning
17/7/2015 1k	08:01-09:41	-	--	-	Transients
TOTALS		1,170,443	2233	1465	