An Analysis of Radio Meteor Detection

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Overview

Meteors have three stages to their lives. They start as rocky or metallic bodies in space, where they are known as meteoroids. Once a meteoroid enters the Earth's atmosphere, it is heated by friction and this extreme heat ionises the air around the meteor, creating a visible streak which is commonly known as a 'shooting star'. If any of the meteor makes it to the ground, it becomes a meteorite. The ionised air around the meteor reflects radio waves. This is the fundamental principle behind radio meteor detection. The detection starts with a transmitting antenna sending out a signal into the upper atmosphere. The signal reflects off of the ionised trail left by the meteor, and is received by another antenna. The way this signal is visualised is typically as a 'waterfall' plot (figure 1). Alternatively, software is used to count meteors from the signal.

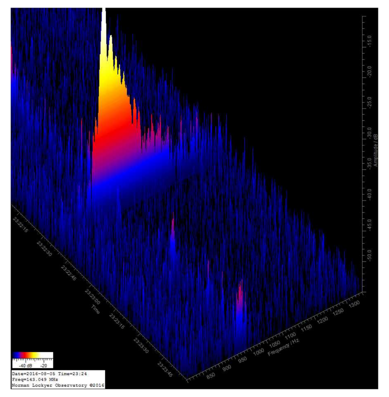

Figure 1: 3D Waterfall Plot

What data am I using?

For each study I present, the source of my data is the RMOB organisation [1]. Started as a group of radio observers hoping to communicate meteor shower results more easily, this group has grown into a worldwide network of radio meteor observation, with each observers' results available for use. The data itself is an hourly detection count. This data is available in one month long sets, as images (figure 8) or text.

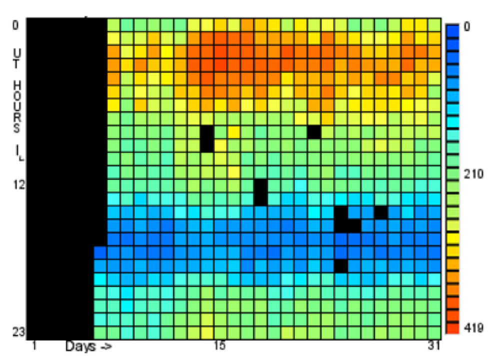

Figure 8: RMOB data in image format

Figure 9 shows the number of observers contributing for each month since RMOB text records started. Apart from a sudden drop in 2005, the number of observers is constantly increasing - good news for radio meteor detection analysis!

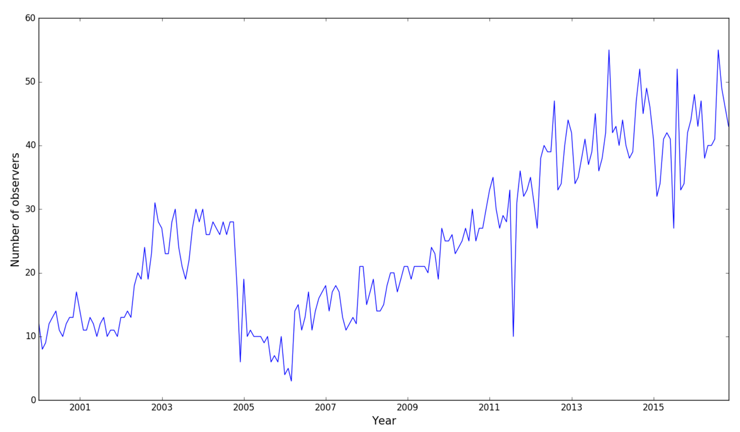

Figure 9: Number of observers contributing each month

Figure 10 shows the global reach of the RMOB data. It is clear that most data is from Europe. Overall, there are 3.8 million hourly counts, from 345 observers.

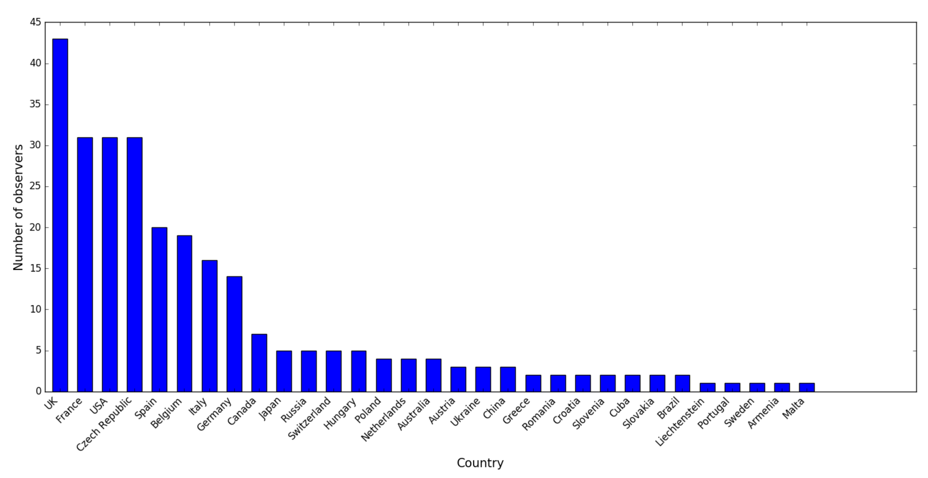

Figure 10: Locations of observers (where known)

Detection By Image Analysis

The idea of detection by image analysis is to identify areas of the image with a distinct signal, which are considered to be meteors (note the large yellow area in figure 1). Root mean square difference is a method of identifying distinct signals, which works by calculating a measure of the difference between corresponding pixels in two images: the signal image, and a 'baseline' image. In order to test how well this method works, I tested for correlation with a set of data that is known to work: hourly detection counts (from RMOB), as used in my other studies. The result is a correlation coefficient (using Pearson's Moment) of $r = 0.6165$, with a p-value of $p = 4.05 \cdot 10^{-214}$, suggesting a good correlation between the two data sets (figure 2).

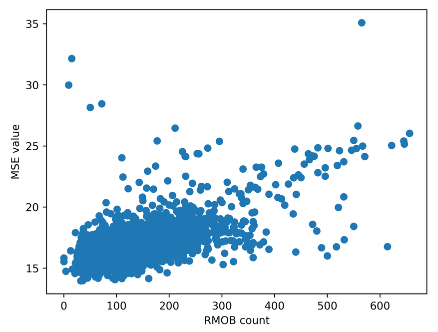

Figure 2: RMS difference vs. RMOB count

Zenithal Hourly Rate

Formula

I have modified the formula for Zenithal Hourly Rate to be used for radio meteor detection. The formula used for visual detection is equation 1, where F is a correction factor for field of view, $r^{6.5-m}$ corrects for the limiting magnitude, and $\overline{HR}$ is the actual visual hourly rate. The equation has a flaw: the $\sin(h)$ function is used to correct for the height of the radiant (where the meteors 'appear' from) above the horizon. This would result in a negative hourly rate with a radiant below the horizon, though meteors are still seen.

$$ZHR = \frac{\overline{HR} \cdot F \cdot r^{6.5-m}}{\sin(h)} \quad (1)$$

$$ZHR = \frac{N - b}{\left(\frac{1}{2} + \frac{h}{\pi}\right)} \quad (2)$$

My own correction to this is shown in equation 2, where b is the background hourly rate, N is the actual hourly rate, and h is the angular height of the radiant above the horizon. F and $r^{6.5-m}$ are no longer needed since I assume a field of view covering the whole sky, and the population index model is not valid, since an incredibly large number of meteors would be detected by radios, but aren't.

Validity

In order to test the validity of equation 2, I used it to calculate the theoretical ZHR for 6 common meteors showers for each observer, for years between 2007 and 2016. Most of the results correlate well with the expected visual data. The results do not all have values similar to those expected, though they correlate well since an increase in the visual results is reflected by an increase in radio results – the offset is likely due to an absent correction factor. In order to determine this, I used the results to calculate a theoretical field of view and limiting magnitude. The results show that the theoretical limiting magnitude of the antennas used is ~ 6.75, and the theoretical field of view is $\sim 30\%$. This field of view should be larger, as should the limiting magnitude. This indicates that there is an offset that is not present as a correction factor. This is expected, however, since I had no data available for field of view and so it was not included. The field of view is highly dependent on the antenna, as is the limiting magnitude.

Temporal, Spatial & Antenna Type Variation

Temporal Variation

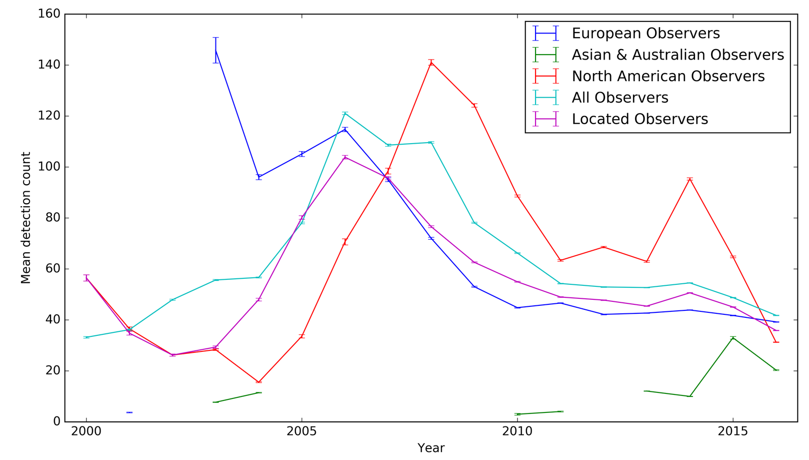

Figure 3: Variation in mean hourly detection count since 2000 by year

I have analysed the variation of detection counts and other descriptive characteristics of the data over time. There is a significant increase in detection counts between 2005 and 2011 (see figure 3), which links to the minimum of the solar cycle. This indicates that the activity of the Sun (and most likely the solar wind) prevents some radio meteor detection, since when the solar wind has a greater intensity, there is a greater electron density in the upper atmosphere, influencing radio signals.

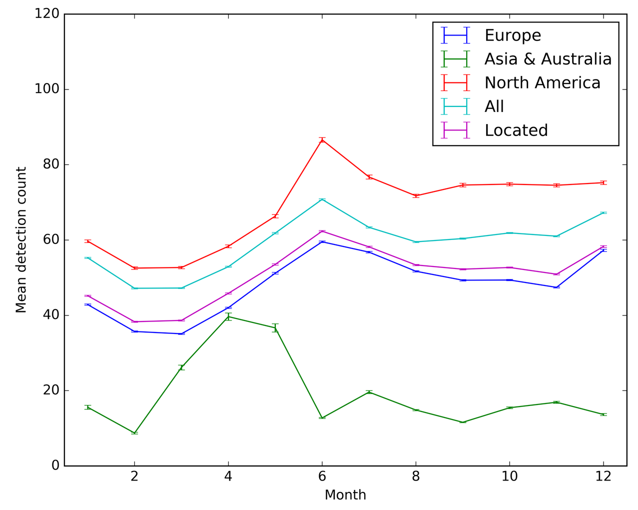

Figure 4: Variation in mean hourly detection count over a year

The results (figure 4) also show an increase in detection counts in the middle of the year, which persists for the rest of the year. This could be due to an increased number of meteor showers, or other effects which I have not studied. I have found little variation of detection counts during each month, as expected, since there are few effects that vary on a monthly basis. With a 1% significance level, there is no difference between daytime and night-time detection rates.

Spatial Variation

Most data characteristics do not correlate well with latitude or longitude, implying the location where a detection takes place has little impact on the resulting detections. As expected, there is a correlation between longitude and peak hour of diurnal shift. Other studies [2] have noted a correlation between latitude and the intensity of diurnal shift, though my results do not clearly support this. The implication of these findings is that, across the globe, the quality and quantity of radio meteor detection doesn't change, which in itself suggests a uniform distribution of sporadic meteors in space.

Variation by antenna type

Overall, there is little variation between antenna types, and a large degree of variation between observers with the same antennas, implying that the choice has little effect on the results of radio meteor detection. However, J-pole, log periodic and turnstile antennas appear to produce the most extreme results. However, this is likely due to anomalous readings.

Diurnal Variation of Meteor Flux

Diurnal shift is an observed increase and decrease in detection counts over a day. Some models explain this as the Earth 'intercepting more sporadic meteors at Sunrise than Sunset', though this is inconsistent. I propose that the incident velocity, added to Earth's orbital velocity at Sunrise ($\sim$ 6am observer's local time), results in a higher intercept velocity, meaning more detections occur since more meteors reach the atmosphere (see figure 5).

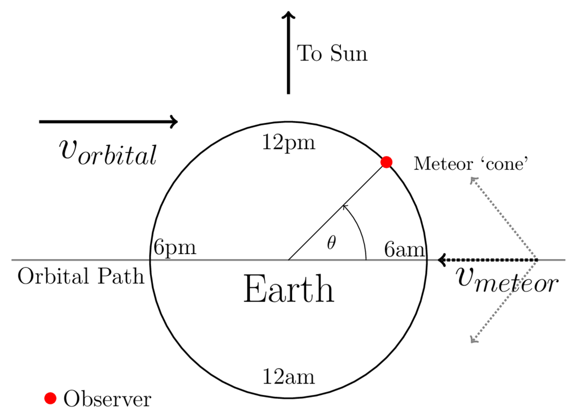

Figure 5: Diagram of diurnal shift model

A sinusoidal function fits the mean diurnal shift of each category well (see figure 6), indicating that my model, which is based around a cosine function, is consistent. It is apparent that the diurnal shift occurs worldwide, and varies in amplitude between locations, supporting other studies.

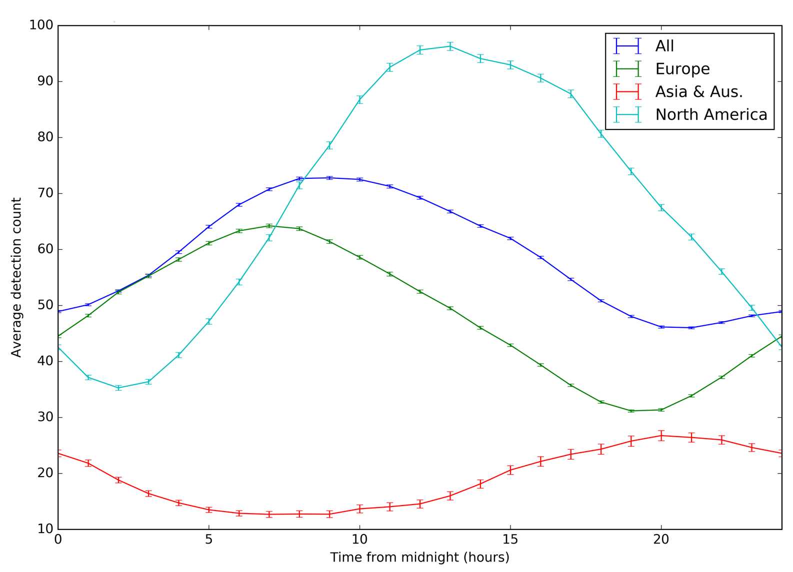

Figure 6: Diurnal shifts for various locations

Spatial variation of diurnal shift

Figure 7 shows the peak hour of an observer's apparent diurnal shift in their local time, based on their longitude, not timezones. My model predicts that the peak hour occurs at 6am, and this is seen in the histogram, indicating that my model fits the data. There is some spreading out from this time, as expected by any set of data, though there is also a large number of peak hours at 7am. This is potentially due to changes that occur in the Earth's rotation throughout a year.

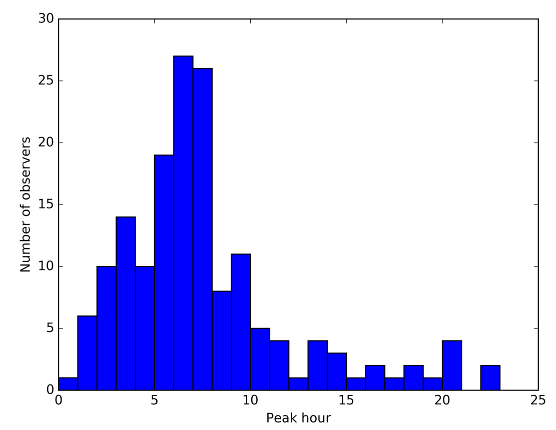

Figure 7: Histogram of peak hour of diurnal shift in observer's local time

Temporal variation of diurnal shift

Over time, the peak hour of diurnal shift does not appear to increase or decrease, which also supports my model since I provide no reason for the diurnal shift to change with time. Around the time of increased detection rates between 2005 and 2011, diurnal shift appears to be less sinusoidal, indicating an increased background rate, supporting my conclusions from the temporal variation analysis.

References

[1] *Radio Meteor Observation Bulletin*. URL: rmob.org.

[2] W. Singer et al. "Diurnal and annual variations of meteor rates at latitudes between 69°N and 35°S". In: *17th ESA Symposium on European Rocket and Balloon Programmes and Related Research* (2005).

Future Work

For many results, there is yet a conclusion to be made. There are many variables that influence radio meteor detection in conjunction with one another, making isolation of a variable and consequent analysis difficult. A larger set of data, with a more uniform coverage of the globe, is the aim for the future, as well as extensions of the analyses in order to refine and validate conclusions.

Acknowledgements

I am indebted to the RMOB organization [1] for permission to use their data. Credit is also due to the Norman Lockyer Observatory, where I have worked on this project, utilised my detection method, and sourced data.