NEMETODE: The Network for Meteor Triangulation and Orbit Determination. System Overview and Initial Results from a UK Video Meteor Network

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An overview is provided and first results presented from NEMETODE, The Network for Meteor Triangulation and Orbit Determination. This is a network of four low-light video cameras based in the North of England in the United Kingdom that use UFOCapture, UFOAnalyser and UFOOrbit to capture and analyse meteor data. NEMETODE is intended to supplement the increasing number of comparable teams around the world who are using similar networks. Many of these networks have been established to ascertain if the suspected meteor showers listed on the International Astronomical Union's Meteor Data Center actually exist and if so, determine if they can be associated with known parent bodies. This paper provides a detailed description of the equipment used and the techniques employed to collect and analyse the data. The results from the first full collaborative month of operation, 2012 August, are presented, with specific focus given to the 007 PER (Perseids) meteor shower. The Perseids are a well characterised shower and were selected to verify if the results from NEMETODE were consistent with currently accepted parameters.

Received 2013 January 29

1 Introduction

Using a network of cameras to simultaneously record the same meteor event from different geographical locations offers a number of advantages. Specifically the meteoroid's trajectory through the Earth's atmosphere can be triangulated, thus allowing characteristics such as the radiant and the beginning / end heights to be determined. Combining this information with timing data (when the event occurred, angular speed across the Field of View (FOV)) permits an estimate to be made of the meteoroid's original orbit around the Sun. From this an association may be made with a parent body. This is discussed elsewhere in greater detail (Jenniskens et al., 2011) and does not warrant further discussion here.

2 Network Overview

NEMETODE consists of three stations or nodes. The first is operated by William Stewart (WS) and is located in Ravensmoor, near Nantwich, Cheshire. The second is operated by Alex R Pratt (ARP) and is located in Leeds, West Yorkshire while the third is operated by Leonard Entwisle (LE) from Elland, West Yorkshire.

2.1 Ravensmoor Node

The Ravensmoor Node operates two similar camera systems. The cameras are Watec 902H units (1/2" sensor) coupled with Computar 8 mm $f/0.8$ lenses. The North facing camera has a Computar HG0808AFCS-HSP lens while the East facing camera has a HG0808FCS-HSP lens. Each yields a resolution of 3.63 arcmin per pixel. The instructions for this lens call for the supplied "B/W Aberration Compensation Filter" to be fitted between the lens and the camera but in the case of the Watec 902H, this is not possible as the filter touches the inside of the camera body before the threads on the rear of the lens are able to engage with those on the camera. Attempting to use a C/CS Mount adapter ring (which increases the distance between the lens and camera by 5 mm) allows the filter to be fitted. However when this is done it is no longer possible to focus the lens at infinity – as a result the filter is not fitted.

The lens has an auto-iris that, by default, is closed. The Watec 902H does not support auto-iris lenses so the Ravensmoor cameras operate with the iris opened fully by applying a voltage of 12 V DC across the red (+ve) and black (−ve) leads. The white lead is not required.

Focus is achieved by rotating the barrel of the lens. There is a screw that can be tightened to lock the focus position but repeated heating / cooling (hot days and cold nights) can result in the screw becoming loose and the focus drifting. A length of adhesive tape has therefore been affixed around the lens barrel to hold each focus ring in position.

Each camera is located in its own Closed Circuit Television (CCTV) Housing affixed to the gable end of a brick building (see Figure 1). The housings are weatherproof, have heated glass front windows and sufficient internal space for ease of fitting of / access to the cameras. Pointing and FOV details are as follows:

Ravensmoor	North	East
Azimuth (centre)	$18\overset{\circ}{.}5$	$90\overset{\circ}{.}8$
Elevation (centre)	$48\overset{\circ}{.}9$	$46\overset{\circ}{.}8$
Field of View	$43\overset{\circ}{.}5$ (H) × $33\overset{\circ}{.}3$ (V)	

The camera, iris on the lens and the heater on the CCTV housings all operate at 12 V DC. Laptop style power supplies were initially used to convert 230 V AC to 12 V DC but these were susceptible to intermittent problems with banding on the videos and images. The problem was traced to the push-fit electrical connections. Slightly twisting them temporarily cured the problem but it always came back after a few days. Replacements that made use of screw terminals (as opposed to the problematic push fit connectors) were required but during the specification phase it was deter-

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IMO bibcode WGN-413-stewart-nemetode
NASA-ADS bibcode 2013JIMO...41...84S

Figure 1 – Both cameras of the Ravensmoor Node permanently affixed to the gable end of a brick building. The unit on the left faces east while that on the right faces north. Note the black spacer block on the left hand unit between the camera housing and the mounting bracket. This modification was required in order to allow the appropriate elevation to be achieved without the rear of the housing fouling on the horizontal support bracket.

mined that a power supply that provided enough current to drive additional systems (for future expansion) would be desirable. A Sunpower 60 W 12 V DC 5 A Single Output AC-DC Enclosed Power Supply was selected and installed. This power supply is passively cooled and so no cooling fans are required.

All of the power is linked together, i.e. the power for the camera, iris on the lens and the heater on the CCTV housing all come from the same source (the power supply described above) and switch on / off together. Some meteor detection networks recommend having separate power supplies for the camera and the heater in order to avoid the potential of introducing noise to the system when the heater switches on and off. The Ravensmoor system has, as noted above, a common power supply and has not experienced any such switching issues.

In order to protect the camera and lens from damage, it is essential that the iris on the lens is closed and the camera powered off during daylight hours, particularly as one of the cameras is east facing. Direct sunlight falling on the fully operational system will quickly damage the sensor. Initially a simple rotary time-switch with the settings corresponding to the hours of nautical twilight was used. The times of nautical twilight can be easily determined for the observer's particular location by using the website of the US Naval Observatory.[1] This website allows the user to choose between civil, nautical and astronomical twilight. Settings for nautical twilight were initially chosen as this seemed to be the best compromise between not too bright to risk damage to the system and dark enough that there was the possibility of detecting a meteor. However two problems became apparent:

i. The settings on the rotary time-switch had to be regularly altered, particularly at times close to the equinox when the start / end of nautical twilight changed rapidly from one day to the next.

ii. As the power for the heater on the CCTV housing was activating at the same time as the camera and iris on the lens, initial video images were not good on occasions when there was condensation on the glass window at the front of the CCTV Housing – it took a few minutes for the heater to clear the condensation.

Images taken at sunset / sunrise were not saturating the sensor (the "shutter" switch on the rear of the Watec 902H camera is set to the "on" position) and so WS decided to have the switch activation coincide with sunrise and sunset. Although the sky would be too bright to detect meteors, it would give time for the heater to do its job and clear any condensation before the sky became dark enough for meteors to become visible.

The best solution found was to make use of a Theben SEL170 time-switch. This self contained device is able to switch 240 V AC, takes account of the observer's location and date and automatically adjusts the on / off times based on local sunset / sunrise times that it itself calculates. This solution has now been implemented at the Ravensmoor node and controls the power to all cameras, lenses and heaters.

Each camera is connected to its own dedicated desktop PC. A desktop was chosen as they are relatively inexpensive, powerful for the price, easy to repair and upgrade, have enough slots for extra RAM and space for additional Hard Disk Drives (HDDs). IBM M51 3.2 GHz P4 HT models were selected and upgraded from the standard specification to ones with 2 GB RAM and an additional 250 GB HDD. Under normal operation (resolution 762×576, 25 frames per second (fps)), the CPU load is in the region of 17 – 18%. The Operating System is Windows XP. The following lessons were learnt during the commissioning phase:

i. Disable HDD Power Saving. This can be done through the BIOS and / or via the Power Options menu in Windows. When a meteor is detected, the PC will need to transfer significant amounts of data from the memory buffer to the HDD in a very short period of time, while at the same time read (and monitor) the ongoing live video stream into the memory buffer. Prior to disabling the HDD Power Saving feature it was found that after a period of inactivity, frames were being lost from video clips while the HDD spun up from the auto powered down state.

ii. A reasonable size HDD (>100 GB) dedicated to the data (i.e. separate from the main HDD for the Operating System (OS)) avoids issues with the PC being occupied with normal OS issues when it needs to write video data. It also avoids the need for regular data transfer from one HDD to an archive. A minimum of 30 GB space is kept free at all times and the disk is regularly defragmented (circa once per week) – again, video frames can be dropped if the HDD Read / Write Head has to execute significant movements between sectors when writing to the disk. During nights of exceptionally poor seeing the detection software can

[1] `http://aa.usno.navy.mil/data`

interpret excessive scintillation as movement that should be recorded – some videos can then become a few minutes (as opposed to a few seconds) long, thus consuming considerable HDD space. UFOCapture provides the user with extensive tuning capabilities to minimise such occurrences but the preference amongst the NEMETODE members is to have the detection threshold as low as possible in order to reduce the likelihood of a missed meteor.

iii. Set the PC time to GMT and disable the "Automatically Adjust to Daylight Savings Time" feature. The timestamps for each file will then always be in UTC and won't suddenly jump by one hour twice per year when daylight savings starts / finishes. This is particularly useful when checking if the same event has been captured by another system – data-files can be compared automatically without the need for manual tweaking.

iv. The timestamp for each file is based on the PC's internal clock. This can drift by varying amounts each day and as a consequence each PC is set to auto-synchronise with an internet time server every 15 minutes using Dimension 4 software.[2] Typical corrections are of the order of 10–20 ms. Without this application running, the PC's internal clock would lose approximately 10 s every week. The aforementioned software is able to generate a text file that provides details of the timing corrections that have been applied to the PC's internal clock. This data is reviewed prior to each analysis to ascertain if large (>0.5 s) changes occurred during observing runs (and could therefore potentially affect the timing data). A review also helps highlight if there are avoidable scheduling issues (for example regular data uploads / downloads that could negatively impact bandwidth availability).

v. When running more than one system from the same internet connection, it is worth monitoring when the synchronisations occur. Sometimes they can end up simultaneously requesting a timing correction (for example if the internet connection goes down and then becomes available again, perhaps due to a power outage or maintenance work). For autonomous operation one can reduce the impact of this issue by having each PC synchronise after a different number of set minutes.

vi Auto-synching the PC clock does require a permanent internet connection. The Ravensmoor systems use AVG Free as a firewall and Malware Bytes for additional protection.

vii Ensure that security updates and scans using these or other programs, together with any Windows Updates, are scheduled for daylight hours when the PC will not be busy detecting meteors. It is also important to set the Windows security settings to not automatically install updates as these can, at times, trigger an auto-restart of the PC. It has also been found to be beneficial to restart the PC every so often, again during daylight hours, just to ensure that any cumulative memory issues don't lead to problems during the observing runs. For the Ravensmoor systems this is performed once per week.

viii Overall PC maintenance is essential and so it is important to monitor air inlets for the computer and vacuum them clean when they become dusty – if the PC runs 24 hours per day / 7 days per week then it may overheat and crash / lockup during warm weather. Keeping the cables at the rear of the PC neatly bundled away from the exhaust vents also helps with the airflow.

The initial selection of video cards to accept the signal from the cameras resulted in less than ideal performance. While they worked most of the time, a significant number of frames were being dropped. WS is indebted to Robert Cobain (Cobain, 2005) who operates a dual station meteor detection system in conjunction with Armagh Observatory in Northern Ireland (Armagh Observatory, 2009) for his recommendation to use an Osprey 210 Video Card. While these are slightly more expensive than other cards, they do have excellent performance characteristics and since switching to this card the system has worked perfectly.

The cable run from each camera to each PC is of the order of 10 m. Initially a combined video / power cable solution was implemented but this proved short-lived as part of the cable run is outside and is therefore exposed to the elements. The cable failed after a few months as repeated exposure to frost snapped the very fine inner cores of the power lead. The combined lead was replaced with separate dedicated lines for power and video. A double shielded RCA video lead (one with a central core, copper braid and a foil sheath) was selected both for its robustness (thicker wires) and in order to reduce the amount of noise on the video signal. The two core power lead has an exterior grade sleeve to protect it from the elements.

The whole system (PC, camera, iris on the lens, heater on the CCTV housing) all operate off an Uninterruptable Power Supply (UPS) so that in the event the mains power is interrupted, the system will continue to operate for up to 30 minutes. The system is located in an area that was prone to intermittent power outages lasting a second or two – just long enough to crash the PC. It should however be noted that since the investment in and the installation of the UPS, the local power lines have been replaced and the frequency of power outages has decreased from once per week to less than once per year.

The systems are very sensitive – on a clear, moonless night they are each capable of detecting, in real time, stars down to better than magnitude +5.5 though in practice the system struggles to detect meteors fainter than magnitude +4.

While UFOCapture does have excellent configurable settings to reduce the likelihood of non-meteor events resulting in a clip, some do on occasion slip

[2] `http://www.thinkman.com/dimension4`

through. Depending on the time of year and local lighting conditions, these can include birds, bats, insects, firework flashes, snowflakes, falling leaves and of course aeroplanes and satellites. On a regular basis (typically daily) the video clips from the previous night are reviewed and unwanted clips deleted. The data is copied to separate hard-drives for analysis and backup.

2.2 Leeds Node

The Leeds node operates a South-facing Watec 902H2 Ultimate camera (1/2" sensor) with a Computar HG3808 FCS-HSP 3.8 mm $f/0.8$ lens and B/W Aberration Compensation Filter, giving a resolution of 6.63 arcmin per pixel. The auto-iris is driven by the camera.

The camera and lens (and a large bag of silica desiccant gel) reside in the same model of CCTV housing as used by the Ravensmoor node. It is mounted on the southwest corner of the house. Pointing and FOV details are as follows:

Leeds	
Azimuth (centre)	184°.3
Elevation (centre)	49°.8
Field of View	89°.2 (H) ×68°.6 (V)

The camera and heater are powered by separate 12 V DC mains adapters. They are not triggered by a self-timer, so ARP manually switches them on / off at dusk / dawn. The Leeds system has not (yet) had problems with condensation so the heater is rarely switched on.

The Leeds node uses a dedicated tower PC, a Dell Dimension DXP061 running under Windows Vista Home Premium, with dual Intel 2.13 GHz CPUs, 4 GB RAM and a 300 GB HDD. The disk is defragmented every week and a separate HDD has not been necessary. Anti-Virus and Firewall protection are provided by Norton's software. Automatic Windows Updates are disabled, then checked manually and applied during the day.

As with the Ravensmoor node the Windows setting for HDD Power Saving was disabled. The PC was synchronised once per evening with an Internet time service. Some of the Perseids captures had to be time-corrected, using the method described in Section 3.1. Commencing 2012 October the PC is (just like at Ravensmoor) synchronised every 15 minutes with an NTP time server using Dimension 4 software.

Video capture is performed by a USB 2.0 device from ClimaxDigital and in normal operation (resolution 720×576, 25 fps), the CPU load is about 20%. The cable run is also 10 m, with a combined power/video cable for the camera and a separate cable for the heater. The cables have not caused any problems. Power cuts are very rare for the Leeds node so a UPS is not required although the equipment is connected to a mains surge protector.

The city sky is light-polluted with a video limiting magnitude of about +3.5. Captures often include many aeroplanes, so unwanted videos are deleted each day. Data backups are saved to external drives and to another PC on which the analyses are performed.

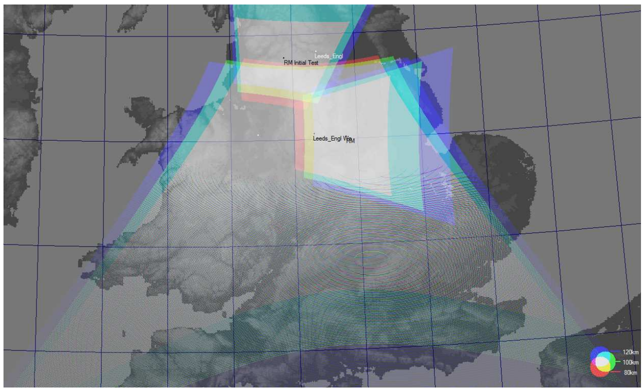

Figure 2 – Field of View (FOV) coverage of the NEMETODE cameras for Leeds and Ravensmoor for the period 2012 July – December. The different colours represent different altitudes. The red represents 80 km, the light blue 100 km and the dark blue 120 km. The almost transparent white is where there is single station coverage of a layer between 80 km and 120 km while the almost opaque white is where there is dual station coverage of a layer between 80 km and 120 km. While this shows the FOV, other factors such as local weather and the effects of atmospheric extinction limit the range over which meteors are detected

2.3 Elland Node

The Elland node is not a UFOCapture station. LE occasionally runs a tripod-mounted Watec 902H camera with an aspherical Computar 3.8 mm $f/0.8$ lens, facing South. Recordings are made to VHS tapes, with a manually synchronised time-and-date inserter. The video limiting magnitude is +3.

2.4 Overall Coverage

NEMETODE was created after an exchange of comments on a meteor forum relating to a fireball event that occurred over northern England at 2012 July 28, $00^h58^m47^s$ UT. While ARP and LE were aware of each other's work, they were not aware of WS's setup, or he of theirs. Following discussion of the July fireball it was realised that, fortuitously, the same volume of atmosphere was being monitored by different cameras and that as a consequence, triangulation could be performed using SonotaCo's UFOOrbit program.

The baseline between Leeds and Elland is relatively short (21 km) but between Leeds and Ravensmoor it is 107 km – a distance that is much more effective for triangulation work. Figure 2 shows the coverage plot for Ravensmoor and Leeds. It was obvious from the outset that overall coverage could be improved through simply re-aligning some of the cameras. However ARP and WS decided to leave their cameras on their original elevation / azimuth settings for the remainder of 2012 in order to ascertain the quality of data from their existing setups. As of the time of writing (2013 January) this initial commissioning phase has been completed and the cameras have been re-aligned and augmented with an additional camera in order to maximise dual station coverage. Further details of this enhanced coverage are available on the authors' website `http://www.nemetode.org`.

2.5 Software

The data from all NEMETODE nodes is captured and analysed using SonotaCo's UFO Suite. In addition, a number of custom spreadsheets are used to analyse timing corrections to the PC's internal clock, to provide an independent check of concurrence of event start times and to perform orbital parameter analysis.

3 Data Analysis

Members of NEMETODE adopt the same consistent approach when analysing their data and complete a shared checklist to minimise variation. Although UFO-Analyser has automated functionality for data reduction, the NEMETODE team has found that in a few cases (<10%), the assigned meteor trajectory is slightly misaligned but can be corrected by adjusting a number of software parameters as described in the UFO-Analyser manual. As a result the NEMETODE team perform a series of manual checks for each event.

3.1 Analysis Methodology

For each event the following checks are applied:

i. Timing corrections that have been applied to the PC's internal clock are reviewed to ascertain if there is an error of >1.0 s in any of the time-stamps associated with each video clip.

ii. The SonotaCo BBS Forum[3] is checked to verify if there are any software updates that need to be applied (e.g. updated software versions, leap second corrections).

iii. The assigned stellar background for a given profile is checked to ensure it is a good match for the stars visible in the composite image. If not, a new profile is generated.

iv. Each clip is reviewed to ensure the meteor commences within 1.0 s of the time-stamp assigned to the video clip.

v. The assigned meteor trajectory is checked to ensure it is a good match for the meteor trail on the composite image. If not, adjustments are made to the appropriate settings within the UFOAnalyser software (as detailed in the user manual) and the analysis re-performed until a good match is obtained.

As can be seen from Section 3.1 points (i.) and (iv.) there are occasions when the time-stamp attributed to an event may be incorrect. Examples of this include the PC Clock being incorrect or a video clip is triggered by a non-meteor event (e.g. excessive stellar scintillation or an aeroplane enters the FOV) but a meteor does subsequently appear and is recorded within the video clip. Under these circumstances, a timing correction needs to be applied and the following process is followed:

i. A copy of the original M.XML file (which contains details of the start time of the meteor event) is saved in a secure location (for archival purposes).

ii. The frames of the video clip are stepped through one at a time until the first evidence of the meteor appears. The start time of the meteor (from the time code at the bottom of the frame) ±0.1 s is noted.

iii. The original M.XML file (not the copied version) is edited to give the start time of the meteor noted in step ii. above.

iv. If it already exists (from a previous analysis), the MA.XML file is deleted.

v. UFOAnalyser is re-run for this particular video clip using the updated M.XML file.

vi. The new M.CSV file is saved and verification that the correct meteor start time has been written to the MA.XML and M.CSV files is performed (note that the filenames will remain unchanged and will still show the original start time of the video clip).

In a typical month each camera of the NEMETODE network will record a minimum of 100 meteors (often more, depending on shower season and weather) and so while this level of diligence may seem onerous, the authors feel it is essential in order to maximise the data-set with which further analysis can be reliably performed.

The resultant M.CSV files are then emailed between the members of the NEMETODE team. As an additional check however, the data is also compared in a custom spreadsheet to ascertain how many events have a common start time (±1.0 s) and thus may be different captures of the same event.

The data then undergoes an initial analysis using UFOOrbit and the number of events compared against the aforementioned spreadsheet. Any discrepancies are investigated and dispositioned at this stage and the spreadsheet that tracks the efficiency of NEMETODE network updated. A more detailed analysis is then performed.

3.2 Perseids Analysis

3.2.1 Preamble

The first likely Perseid candidate was recorded at Leeds on 2012 July 12, $01^h24^m56^s$ UT and the last on 2012 September 11, $23^h06^m20^s$ UT, again at Leeds. The magnitude distribution from 2012 July 11 to September 12 (measured by UFOAnalyser) is given in Table 1 (meteors from minor showers are not included). The activity profile of the Perseids is presented in the graph in Figure 3 (All dates are $00^h00^m00^s$ UT).

3.2.2 Multi-station Perseid Meteors

UFOOrbit provides three built-in Quality Assurance criteria:

Q1: minimum criteria for radiant computation; Q2: standard criteria for radiant and velocity computation; Q3: criteria for high precision computation.

[3] http://sonotaco.jp/forum/viewforum.php?f=17

Table 1 – Magnitude distribution of Perseid and sporadic meteors.

	−4	−3	−2	−1	0	+1	+2	+3	+4	Mean
Leeds										
Perseids	0	3	14	47	63	31	1	0	0	−0.3
Sporadics	1	3	11	25	38	20	0	0	0	−0.4
Ravensmoor East										
Perseids	2	3	13	38	56	23	0	0	0	−0.4
Sporadics	0	2	7	32	81	63	4	0	0	+0.1
Ravensmoor North										
Perseids	0	3	3	9	21	43	78	16	1	+1.3
Sporadics	0	1	2	13	21	71	96	18	0	+1.3

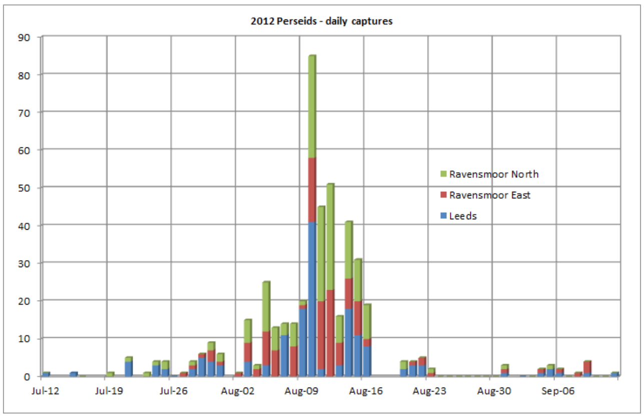

Figure 3 – Daily Perseid Video Captures. The histogram indicates that Perseid rates were low until there was a small increase around 2012 July 20/21. Activity picked up after 2012 August 04/05, with peak activity between 2012 August 08/09 to 13/14, although bad weather hampered observations on the nights of maximum. Rates declined rapidly after 2012 August 15/16. The activity profile is generally symmetrical, with a suggestion that it is skewed to the left.

Note that when grouping captures, Q1 includes level Q2 and Q3 data, Q2 includes level Q3 data.

Between 2012 July 30 and September 03 a total of 40 Q1 multi-station Perseids were captured by ARP and WS. ARP post-processed LE's tapes from the nights of 2012 August 08/09 and 09/10 via UFOCapture and UFOAnalyser but could not obtain an average star alignment error < 1.0 pixel (the UFOAnalyser Manual recommends a figure of <0.3 pixel). Almost all of the data were rejected at the Q1 level, except for a Perseid on 2012 August 08 at $23^{\rm h}07^{\rm m}43^{\rm s}$ UT, which is a tri-station capture. The ground tracks of the 40 Q1 multi-station Perseids (derived by UFOOrbit) are shown in Figure 4.

3.2.3 Radiant Drift

UFOOrbit was used to derive the radiant point for each multi-station Perseid, corrected for Zenith Attraction. The positions of the radiant points from 40 multi-station Perseid meteors between 2012 July 30 and September 03 were used to estimate the daily drift of the radiant in Right Ascension and Declination and the results are plotted in Figure 5.

3.2.4 Radiant drift in Right Ascension

The method of least squares gives a good linear fit:

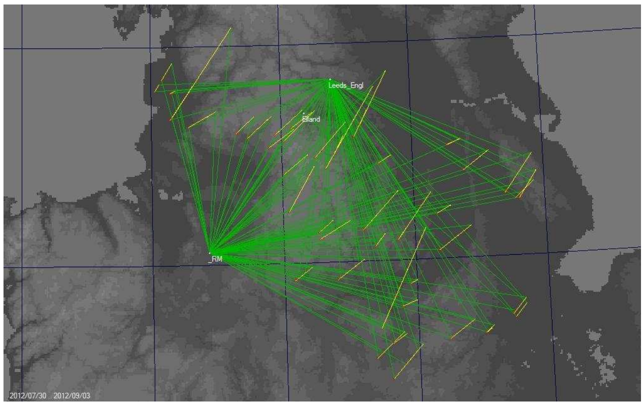

Figure 4 – Ground tracks of 40 Q1 Perseid meteors.

$$\alpha = 1.285 \times \lambda_\odot - 131\overset{\circ}{.}56 \quad (r = 0.937) \qquad (1)$$

The daily motion in RA during the observed period is estimated as $1\overset{\circ}{.}29$, which is close to the value of $1\overset{\circ}{.}35$ by Cook (1973) quoted in the 2012 British Astronomical Association (BAA) Handbook.

If the Perseid maximum occurred at solar longitude $140\overset{\circ}{.}0$ the estimated RA at maximum is $\alpha = 48\overset{\circ}{.}3$ ($3^{\rm h}13^{\rm m}$), as presented in Table 2.

3.2.5 Radiant drift in Declination

The method of least squares gives the linear fit:

$$\delta = 0.209 \times \lambda_\odot + 28\overset{\circ}{.}67 \quad (r = 0.576) \qquad (2)$$

There is a lot of scatter in the data, showing weak correlation, but the daily motion in Declination during the observed period is estimated as $0\overset{\circ}{.}21$, which is not too dissimilar from the value of $0\overset{\circ}{.}12$ by Cook (1973) quoted in the 2012 BAA Handbook.

If the Perseid maximum occurred at solar longitude $140\overset{\circ}{.}0$ the estimated Declination at maximum is $\delta = 57\overset{\circ}{.}9$, as presented in Table 2.

Table 2 – The Right Ascension and Declination of the Perseid radiant at maximum, and their geocentric velocities.

	$\lambda_\odot$	RA [°]	Dec [°]	v_g [km/s]
ARP/WS/LE	140.0	48.3	57.9	59.1
BAA	139.9	46	58	—
IAU MDC	140.19	48.33	57.96	59.38
IMO	140.0–140.1	48	58	59

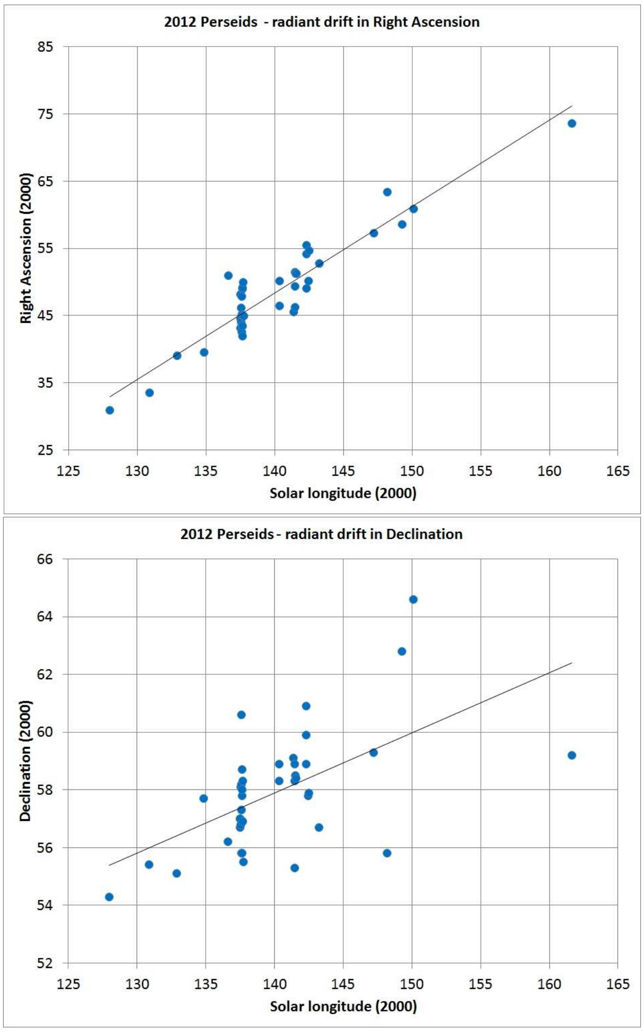

Figure 5 – Radiant drift in Right Ascension (top) and in Declination (bottom).

3.2.6 Meteor detection and extinction altitudes

UFOOrbit computed the start and end heights of 15 Q2 Perseid meteors, captured between 2012 July 30 and August 15 (see Figure 6). The method of least squares gives the linear fits:

$$h_b = 1.29 \times M + 113.0 \quad r = 0.447 \tag{3}$$

$$h_e = 4.24 \times M + 99.3 \quad r = 0.785 \tag{4}$$

where h_b is detection altitude, h_e is extinction altitude and M is absolute magnitude.

This suggests that Perseids burn up about 4 km lower in altitude for every 1 magnitude increase in brightness.

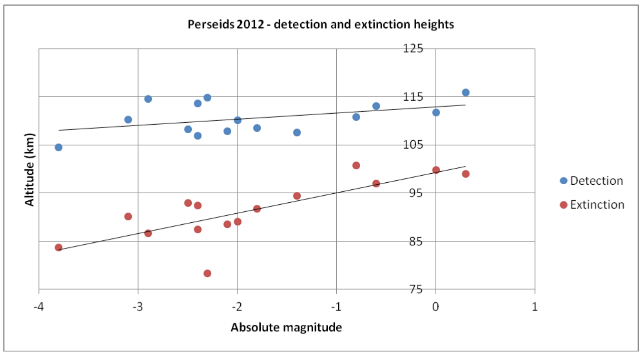

Figure 6 – Detection and extinction heights of 15 Q2 Perseid meteors.

3.2.7 Geocentric velocities

UFOOrbit computed the geocentric velocities, v_g, of the 15 Q2 Perseid meteors, which gave the following: $v_g = 59.1 \pm 0.96$ km/s. This compares well with the International Astronomical Union's Meteor Data Center (hereafter referred to as IAU MDC)[4] and IMO (McBeath, 2011) data (see Table 2).

3.2.8 Orbits of Perseid meteors

UFOOrbit computed the orbital elements of 6 Q3 Perseids. For each pair of observations it calculated 2 orbits and a Unified orbit. Key Characteristics of the Unified orbits are given in Table 3 while Figure 7 displays the "Top" view of the orbits.

3.2.9 Conclusions

The results derived from the video observations of the Perseids meteors by NEMETODE are consistent with the shower data catalogued by the BAA, IAU MDC and IMO. By applying Quality Assurance checks the authors now have confidence that NEMETODE equipment and methods should give reliable results for other meteor showers.

There is some variability in the Perseid orbital elements, especially the estimates of the semi-major axis a and period P, presented in Table 3. The authors' value of a is significantly different from that quoted by the IAU MDC and is nearer to the value of the Perseids' parent comet 109P/Swift-Tuttle (JPL SSD, 2013). A small error in the measured position and estimated geocentric velocity can give larger errors in the values of the orbital parameters a and P. As shown in Table 1, the

[4] http://www.astro.amu.edu.pl/~jopek/MDC2007/

Table 3 – Orbital parameters of 6 Perseid meteors with IAU MDC shower data shown for comparison.

$\lambda_\odot$	a (AU)	q (AU)	e	P (year)	ω (°)	Ω (°)	i (°)
137.5025	17.0	0.951	0.944	70.383	150.7	137.50	114.16
137.5710	15.6	0.941	0.940	61.581	148.3	137.57	114.10
137.6279	11.1	0.941	0.916	37.170	148.2	137.63	107.48
137.6401	37.0	0.958	0.974	224.789	152.8	137.64	112.15
137.7316	8.2	0.950	0.884	23.522	150.0	137.73	115.86
142.4478	14.3	0.958	0.933	53.829	152.7	142.45	114.38
Mean	17.2	0.950	0.932	78.545	150.5	138.42	113.02
Std. dev.	10.2	0.008	0.030	73.610	2.0	1.98	2.96
IAU MDC	71.4	0.953			151.3	140.19	113.22

authors' equipment is limited to detecting bright multi-station meteors (brighter than magnitude +2.0) so we are only monitoring and analysing a restricted sample of the meteor shower. SonotaCo (pers. comm., 2012) has confirmed that orbital analysis of meteors with high geocentric velocities is at the limits of the current equipment and it is anticipated that better results will be obtained from showers with relatively slower meteors.

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Handling Editor: Javor Kac

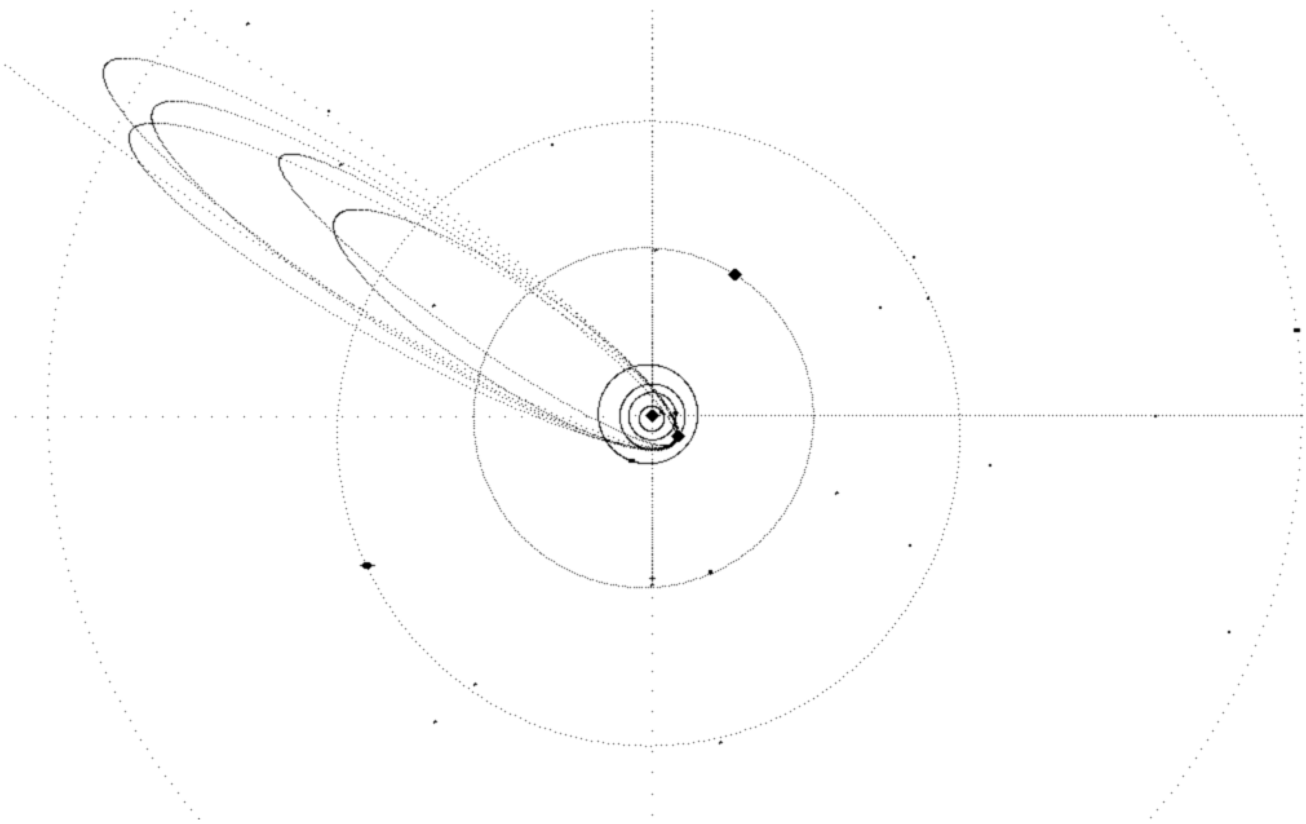

Figure 7 – "Top" view of the computed orbits of the 6 Q3 Perseid meteors.