TVZHR PROFILE FOR THE 1991 PERSEID SHOWER

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Abstract. Image intensified video detection systems were used to observe the 1991 Perseid meteor shower from two locations in eastern Canada. In 29.6 hours of total observing time a total of 668 meteors were detected, of which 403 were Perseids. We derived a profile of TVZHR (television zenithal hourly rate) values for the 1991 Perseid shower over the solar longitude (epoch 2000) interval 138°51′ to 141°01′. The apparent limiting stellar magnitudes of the observing systems were +9.4 and +8.8 (corresponding to limiting meteor magnitudes for our geometry ranging from +8.7 to +7.0). Within the observing period, the maximum TVZHR rate was approximately 1600, and occurred at solar longitude 139.9°. This is in good agreement with the second peak observed by visual observers. The data suggest that TVZHR values should be divided by a factor of approximately 5 to compare TVZHR and ZHR values.

1. Introduction

One of the most fundamental goals of meteor research is the determination of rate profiles for individual showers. Such studies yield valuable information about the initial ejection of meteoroids from cometary parent objects, and about the subsequent evolution of the stream by the combined action of differential planetary perturbation, erosional collision and radiative effects (e.g. the Poynting–Robertson effect and solar radiation pressure). The Poynting–Robertson effect is strongly size dependent, as is the initial aerodynamic ejection from the cometary nucleus, and there is ample evidence for separation of particles in streams according to size. Therefore there is significant value in extending shower rate observations to fainter meteors by using image intensified video systems. While both the sensitivity and diurnal coverage is preferable in radio studies, the effects of biases such as the initial trail radius and the echo height ceiling complicate interpretation of radio rate data.

With the return to perihelion of parent P/Comet Swift-Tuttle in 1992 (Kidger, 1993), and with increasing Perseid rates and occasional brief outbursts in recent years, the Perseid stream has been the subject of intense theoretical and observational scrutiny. While the predictions of a possible meteor storm in 1993 or 1994 lead to a wealth of observations during those years, the 1991 and 1992 Perseid shower has not been extensively studied at faint magnitudes. We present in this paper a preliminary analysis of observations of the 1991 Perseid shower as observed by

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image intensified video detectors which were capable of detecting meteors down to +8.7 corrected absolute meteor magnitude.

2. Theory

Hawkes (1990, 1992) has proposed a television zenithal hourly rate (TVZHR) which is similar to the visual ZHR which is widely used by the International Meteor Organisation (IMO) and other visual observers (e.g. Roggemans, 1987). We define the TVZHR as the number of shower meteors which would be detected by a video based observing system with a field of view of size 8655 square degrees, with the radiant were at the zenith, assuming a limiting sensitivity of $+6.5^{\mathrm{m}}$ and a cloudless night. The choice of a 8655 square degree field of view is based on the work reported by Koschack and Rendtel (1990) which suggests that the effective field of view of a visual observer is a circle of approximately 52.5°. While this is a very large field of view, and a somewhat poor sensitivity, for a video based meteor observing system, we have adopted it to maintain consistency with the visual ZHR.

We will provide here only a brief overview of the correction procedures which need to be applied to apparent rates in order to obtain the TVZHR, referring the interested reader to Hawkes (1992) for additional details. The TVZHR is given by:

$$\mathrm{TVZHR} = \frac{NCKV}{T} \tag{1}$$

where N is the unbiased number of shower meteors observed in an unobstructed observation interval of length T. The small field of view of most video systems means that one will encounter a large number of partial trails – meteors that meteors which originate within the field of view (or equivalently use only those which end on the field of view). In this work we estimate N by adding the total number of meteors which begin within the field of view to the number which end within the field of view, and then divide that number by two. One must use only those meteors whose radiant and apparent velocity are consistent with possible membership in that stream – see Duffy, Hawkes and Jones (1987) for a more sophisticated way of separating video meteors into different shower categories.

The correction C accounts for the limiting meteor magnitude of the observing system, and is similar to that employed in visual ZHR work except that the corrected limiting meteor magnitude M_m must be used.

$$C = r^{(6.5-M_m)} \tag{2}$$

In this equation r represents the population index for the shower, that is the ratio between the number of meteors of some magnitude and those of 1 magnitude brighter. The limiting magnitude for meteors will be somewhat brighter (up to several magnitudes for a meteor with a high apparent angular speed) that the apparent limiting magnitude for stationary stellar sources. The reason for this is that the light from the meteor will be spread out over several pixels during a single video frame time. Most detection systems have near linear response for the faint objects, and therefore the correction (in astronomical magnitudes) to be applied is given by 2.5 log n where n is the number of pixels traversed during a single picture integration time. One method is to use the single step VCR control estimate of the number of pixel resolution elements across the width of the viewing screen. An alternative method is to theoretically estimate the number of pixels traversed during a single picture video integration time from information regarding the meteor radiant, the expected mean height of ablation for meteors from this shower, and the pointing direction of the observing equipment. Hawkes (1992) obtains the following relationship:

$$M_m = M_s - 2.5 \log \left(\frac{57.3 v \tau \sin\theta \sin\epsilon P w}{H w} \right) \tag{3}$$

Here θ is the angle between the radiant and the centre of the observing field of view, v is the meteor velocity, τ is the picture integration time, H is the mean height of ablation (v, H must be expressed in consistent units), ϵ is the elevation angle of the observations and P_w is an estimate of the number of pixels of horizontal resolution and w is the width (in degrees) of the field of view. It should be noted that the procedure outlined here assumes that persistence in the video detection system can be ignored and that there is negligible real wake in the meteor so that it can be regarded as a point source (a good assumption for meteoroids of this size according to Robertson & Hawkes, 1992). Detection system blooming has also been ignored, since this is reasonable for the faint objects at the sensitivity limit. Usually the mean apparent speed will change significantly during a single tape, and it will be necessary to break the observing period up into several segments with different correction factors for each. In our case the data was broken into 30 minute segments for analysis, for the zenith angle of the radiant at the time of observations. This is because when the radiant is low to the horizon the meteors are distributed over a much larger effective area of the Earth's atmosphere. This geometric correction is simply given by sec Z, where Z is the zenith angle. However in the case of video based meteor observations a second dependence on zenith angle comes into play, since a meteor approaching the atmosphere vertically will have its mass ablation (and hence luminosity) spread over a shorter trail length than the same meteor approaching at a low angle to the horizon. This means that meteors with a low zenith angle are favoured, since the light will be spread over fewer pixel elements. It is argued by Duffy, Hawkes and Jones (1988) that to first order approximation this introduces a second sec Z factor, and hence (for video based observations) the total zenithal correction is given by:

$$K = \sec^2 Z \tag{4}$$

The final correction factor, V, is simply a geometric correction for the difference between the actual field of view of the video detection system and the assumed 52.5° radius field of view in the TVZHR standard.

3. Equipment

These data were obtained by two image intensified video detectors configured in a triangulation mode with a 56.9 km baseline. The triangulation analysis to yield trajectory and orbit information is still in progress, and we report only on the rate profile in this paper. One camera was located in Sackville, NB, Canada (64°21′38″ W, 45°55′30″ N, 15.2 m above sea level) while the other was located in Alma, NB, Canada (64°55′35″ W, 45°36′0″ N, 45.7 m above sea level). The Sackville camera used a 50 mm f/1.2 objective lens, a 25 mm Varo 3603-1 microchannel plate image intensifier, which was lens coupled (50 mm f/1.7 plus +3 diopter coupling lenses) to a Cohu model 4652 monochrome SIT video camera. The resulting system had a field of view of 15° by 20° with an apparent limiting stellar magnitude of $+8.8^{\mathrm{m}}$ and an effective resolution of about 200 line pairs horizontally. The Alma camera used a 110 mm/f0.95 objective lens, a 25 mm Varo 3603-1 microchannel plate image intensifier, which was lens coupled (50 mm/f1.7 plus +3 diopter coupling lenses) to a GBC low light level monochrome CCD camera. The resulting system had a field of view of 10.4° by 11.2°* with apparent limiting stellar magnitude of $+9.4^{\mathrm{m}}$ and an effective resolution of about 120 line pairs horizontally. In both cases the video signal was routed through a Panasonic WJ 810 video time/date stamper (each frame had a unique time code stamping) and then the data was recorded on VHS video (30 frames, 60 fields per second, interlaced). The motion and angular speed were used to isolate Perseid meteors. The raw rates of meteor detection by the two cameras, along with the observing duration, is given in Table I below.

4. Analysis

We used the correction formulae outlined in the theory section to convert the apparent meteor rates to Perseid TVZHR values. Observations extended from approximately 01:25 UT to 07:25 UT each night, although clouds precluded observations for part of the night on August 11/12, particularly from the Sackville station. The Alma camera was oriented at an azimuth of 95° and an altitude of 63°. The Sackville camera was oriented at an azimuth of 170° and an altitude of 68°. As the night progressed the radiant comes closer to each camera. The angle between the radiant and the Alma camera varied from 64° to 21°, while the separation between the radiant and the Sackville camera ranged from 87° to 43°. A mean height of ablation

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* The system did not have the standard 4 : 3 aspect ratio for NTSC video since the coupling lens resulted in part of the final video image comprising the inactive portion of the image intensifier.

TABLE I

Observing time, number of Perseid meteors, and total number of meteors for each station

	Alma			Sackville		
	Duration	Perseid	Total	Duration	Perseid	Total
August 11/12	4.34 h	36	98	0.75 h	8	12
August 12/13	6.18 h	110	187	6.18 h	137	180
August 13/14	6.00 h	52	97	6.17 h	60	94
	16.52 h	198	382	13.1 h	205	286

TABLE II

Television zenithal hourly rate (TVZHR) of Perseid meteors averaged over each night

	Alma mean TVZHR	Sackville mean TVZHR
August 11/12	244	306
August 12/13	700	678
August 13/14	254	287

for meteors of this size and velocity was assumed to be magnitudes varied from +7.7 to +8.7 over the observing period for the Alma camera, and +7.0 to +7.4 for the Sackville camera. We assumed a population index (r) value of 2.2 based upon the Perseid visual meteor analysis by Koschack, Arlt and Rendtel (1993), although it is quite possible that the index applicable to these fainter meteors is different. Some telescopic work by Currie (1994) suggests a very low Perseid population index of about 1.6. The mean TVZHR over each night is as indicated in Table II below. The agreement between the two stations is excellent.*

We divided the data into 30 minute intervals for purposes of determining a rate profile, the results being displayed in Figure 1.** The error bars are based upon the TVZHR for that interval divided by the total number of meteors observed in that time interval.

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* Although keep in mind that the cameras were configured in a triangulation mode, so much of the meteor region overlaps.

** Note that the displayed data is the mean TVZHR for the combined data from the two stations.

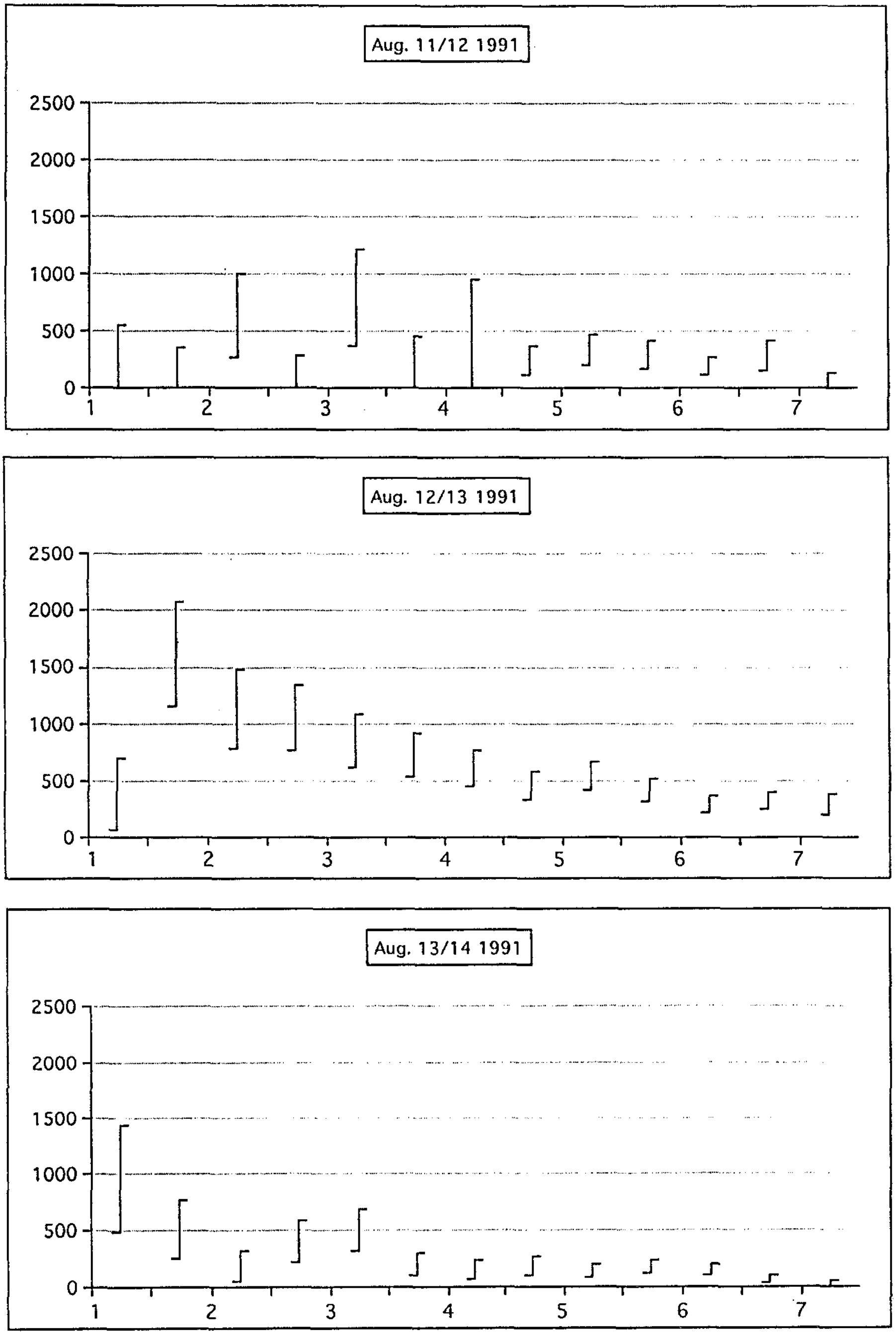

Fig. 1. Plot of mean (2 stations) TVZHR Perseid rate vs. universal time.

5. Conclusions and Discussion

It is clear that, at least over the interval under study, the peak rates were observed over the night of August 12/13, 1991, and that these TVZHR rates were more than 1000 during the interval 01:30 to 03:00 UT Aug 13, 1991, after which there is a very well defined (considering the number of meteors in this sample) decay that extended through the latter parts of that night and on the following night. The question naturally arises whether the significantly lower rate for the 01:00 to 01:30 UT Aug 13 1991 interval was a result of inadequate correction procedures for this early night, or a valid result. If valid, it would imply that there was a local peak at approximately 01:30 to 02:00 UT Aug 13 1991 (solar longitude 139.9, epoch 2000). The global analysis of the 1991 Perseid observations (Koschack, Arlt and Rendtel, 1993) finds that the second (lower) peak in activity closely corresponds (at solar longitude 140.00), and the decay curve from that point agrees broadly with that cited here. However, surprisingly, the enhancement seems to be significantly greater at these fainter magnitudes. For example, in the visual 1991 results Koschack et al. (1993) report a peak of about ZHR = 120 at solar longitude 139.9 falling to approximately 80 over the next 5 hours. In the case of our results the TVZHR falls from about 1300 to about 400 over the same interval. While the relatively small numbers in our sample lead to considerable uncertainty in the TVZHR rates, nevertheless it seems clear that there was a very marked decrease in rate at faint magnitudes over this interval. It is interesting that the ratio of decrease found here is similar to that found in radar observations for the 1992 Perseids (Simek, 1993), using a system with a limiting magnitude of about +7.5.

The stronger early Perseid maximum observed in recent years (at solar longitude 139.58) was, unfortunately, outside the observing period for this work, and the preceding night had been cloudy at both stations. The recent valuable paper by Lindblad and Porubcan (1994) in which they analyze the Perseid meteor stream based on photographic orbital data from the period 1937 to 1985 should also be mentioned. They find two distinct maxima in activity for the Perseid shower appears clearly in observations from about 1960 to the present, with the "new material" peak gradually increasing in prominence as the perihelion of Comet Swift-Tuttle is approached. A greater scatter in the orbital elements of meteors in the "old" branch reinforces the association of the two branches with material ejected during different comet returns. The rate of decay of rate with solar longitude after maximum (for the "old Perseids") is, however, significantly less (for these much brighter meteors) than that reported here for faint television meteors. Although additional data are necessary, it would appear from the present work that the small faint meteoroids are more closely concentrated than the larger photographic meteors. Simplistic ideas regarding relative ejection speeds from the comet would suggest that faint meteoroids should be more broadly spread. Additional modelling of the stream may help clarify the correlation between rate profile and meteoroid mass.

As a final point, these rates (preliminary analysis of observations made with similar equipment in 1993 and 1994 suggests slightly lower, but similar, rates) clearly illustrate the point that even experienced visual observers do not detect anywhere near all of the meteors over the 52.5° radius observing region. A closer examination of the work of Koschack and Rendtel (1990) suggests that approximately half of the cumulative total number of meteors observed by a visual observer are within approximately 16.5° of the centre of the field of view. This means, if one assumes that there is complete detection within this central region, that the apparent ZHR should be multiplied by a factor of approximately 5 in order to get the total number in the 52.5° radius field. If we apply this crude rule of thumb to the data presented, it suggests that the apparent ZHR corresponding to these TVZHR results would go from about 260 to 80 over the 5 hour period from 01:30 to 06:30 UT on 13 August 1991. The actual global ZHR data goes from 120 to 80 over this interval.

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