GROUND-BASED OBSERVATIONS OF THE LEONIDS 1999-2000

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ABSTRACT

We present ground-based observations of the 1999 and 2000 Leonid showers. The 1999 shower was observed with image intensified video cameras at various sites around the world. Two station data were obtained in Israel, and heights were obtained for 233 double-station Leonids. The peak flux was also found from Israel data. The 2000 shower was observed with video and radar; both show an early peak much stronger than reported in visual observations. Video data from three sites, (Spain, New Mexico and Alabama) and radar data on two frequencies were used to define the two observed peaks.

1. INTRODUCTION

The purpose of the 1999 and 2000 Leonid observation campaigns was primarily to record the fluxes for the shower. The timing of the peaks is important in determining whether model predictions are correct, and the flux intensities can be used to calibrate models.

Double station video heights are very accurate, and of great use in determining the true height distribution of meteor populations. Video heights do not suffer from the biases that radar heights do, so give a better picture of the actual heights of ablation. In particular, it is interesting to look for bright Leonids with very high beginning heights like those recorded during the 1998 shower (Fujiwara et al, 1998). These extreme beginning heights cannot be explained by standard models of ablation and are therefore of great interest.

Observations for both years were carried out with image-intensified video cameras. To ensure that most of the shower would be observed, optical stations were placed at different longitudes. In 1999, the time of interest was just after 2UT on the night of 18 November, so the data from one site is of greatest interest. In 2000, there were several predicted maxima, namely near 8 UT on 17 November, 2000 and near 3 UT and 7 UT 18 November, 2000. The cameras were placed mainly to cover the predicted maxima, but cameras (the data from which is not presented here) were deployed to other longitudes to minimize the risk of missing any unpredicted activity.

2. EQUIPMENT AND DATA COLLECTION

2.1. 1999 Campaign

There were seven optical sites in the 1999 campaign, of which we present results only from one in this report. The main optical location was in Israel, which was well located to observe the peak of the shower around 2UT. Two stations were set up 48.5 km apart. The main site was located at the Wise Observatory near Mitzpe Ramon, Israel (34.76°E,30.60°N) and consisted of four MCP (microchannel plate) image intensified CCD cameras, two with Generation III intensifiers and two Generation II intensifiers. One of the Generation IIIs was equipped with a diffraction grating for spectral observations: the results from that camera will not be treated here. The remote site was located near Mitzpe Revivim (34.72°E,31.04°N) also consisted of four cameras, which were pointed so that they overlapped the fields of view of the cameras at the main site. The cameras had C -mount video lenses as objectives with focal lengths between 25mm and 75mm, producing fields of view between 35° and 9°, and the maximum limiting stellar magnitude on the most sensitive systems of nearly $+9^M$. Each camera pair was biased to a different height, to ensure that high-altitude Leonids would not be discriminated against in the study. The two pairs of cameras used in the analysis were cameras K and F, which overlapped at 160 km, and E and J, which overlapped at 110 km. While the cameras are biased toward a particular height, they have are still capable of detecting simultaneous meteors over a wide range of heights.

The video signal for all cameras was recorded on VHS video tape, at NTSC video rates (30 frames per second, two interlaced video fields per frame). The digitization was done directly from these tapes.

2.2. 2000 Campaign

Data from three optical sites from the 2000 shower will be presented in this paper. The sites were located in Spain, near Huntsville, Alabama and Socorro, New Mexico. The site in Spain had clear skies on the peak night, while New Mexico had some cloud problems and Alabama recorded during a few intervals of clear sky. The site in Spain consisted of four cameras, the New Mexico site three cameras and two cameras were deployed in Alabama. Cameras at all three sites were equipped with Generation III intensifiers, and lenses similar to those in the 1999 campaign were used, giving again a limiting magnitude for the most sensitive cameras of $+9^M$. No two-station work was done in 2000. The Leonids were also observed with a three frequency (17.45 MHz, 29.85 MHz and 38.15 MHz) radar, which was located near London, Ontario, Canada. Two of the frequencies (29 and 38 MHz) were operating at the time. Each radar has a seven-element interferometer which permits the altitude and azimuth of each echo to be measured with great precision.

3. ANALYSIS PROCEDURES

Meteors were detected by eye on several playbacks of the video tapes. The meteors were then digitized using a SCION LG-3 card to 640 × 480 × 8-bit resolution. Custom macros written for NIH Image 1.62 were used for the photometric and positional analysis. For each two hour tape, a calibration for both positional and photometric measurements was performed on a large number of stars. The positional calibrations used the ‘plate constants’ approach (Wray, 1967; Marsden, 1982; Hawkes et al, 1993). This essentially deals with any distortion in the field of view and can accurately place the elevation and azimuth of any meteor using background stars for calibration. The same stars are used in the photometric calibration: their apparent brightness on the video is compared to the actual visual magnitude of the star and the resulting curve can be used to find the apparent magnitude of any meteor. For details of the photometric calibration (used for calculating masses) see Hawkes et al (1993). The photometric analysis was complicated a little by the fact that the Generation III intensifiers are more sensitive in the infrared: class M stars in particular gave on average higher pixel intensities for similar magnitudes. This was corrected for in the calibration. The double station analysis procedures are described in detail in Hawkes et al (1993). The analysis involves finding the vector which matches the projection of the trail seen by both stations, and fitting a line to the observed points.

Echoes on the radar were found with Skiymet real-time detection software, and the time, amplitude, altitude and azimuth, range and height are recorded for each. While it is not possible to identify a single echo as a Leonid or non-Leonid, it is possible to get a statistical measure of the activity of a particular radiant. Since all echoes are specular (at right angles to the line of sight), the radiant of any echo must lie somewhere on a great circle 90° from the echo point. By counting the number of echoes at right angles to a particular radiant, one can get a measure of the number of meteors associated with that radiant.

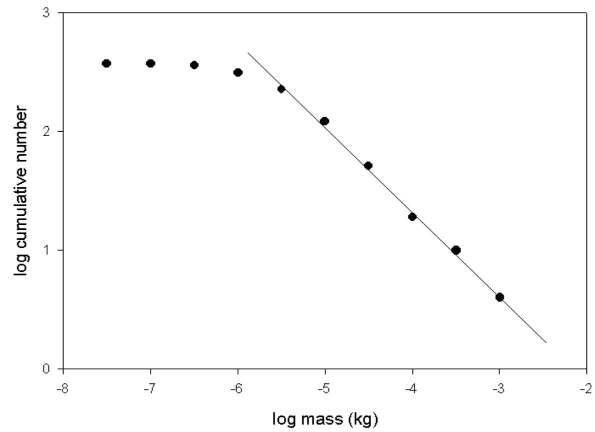

Figure 1. Mass distribution index for Camera F (1999 campaign)

4. RESULTS

4.1. 1999 Fluxes

In general, the mass distribution of shower meteors is of the form:

$$N_C = \frac{C}{1-s} m^{1-s} \qquad (1)$$

where N_C is the cumulative number of meteors larger than mass m, C is some constant and s is the mass distribution index. A larger value of s means a larger proportion of faint meteors, while a smaller value indicates that the number of meteors does not increase significantly at smaller magnitudes.

To calculate the mass distribution index, the mass of each meteor that was entirely captured by the camera was calculated by summing the intensities on each frame. Meteors which had only been partially observed, which either began or ended out of the field of view were rejected for this analysis. The log of the cumulative number of meteors was plotted against the log of the photometric mass, and the slope of the graph gives 1-s. Figure 1 shows the results for camera F. The data from fainter meteors are neglected because of incomplete coverage at higher magnitudes.

The mass distribution index was found to be 1.75 at the time of the Leonid maximum. The index was calculated at intervals, each containing 50-80 Leonids, in an attempt to determine if the mass distribution changed around the time of the peak. No significant variation was observed, either due to intrinsic lack of variation or because of the small numbers available.

The calculation of fluxes requires a limiting magnitude for Leonids for each camera, and the area of observation. Meteor limiting magnitudes are much lower than stellar limiting magnitudes since meteors are not point sources of light. The limiting magnitude for a particular shower can be calculated by (Hawkes et al, 1998):

$$\Delta_M = 2.5 \log \left(\frac{180 r_l V \tau \sin \xi}{\pi F_{ov} R} \right) \qquad (2)$$

where Δ_M is the difference in magnitude between the stellar limiting magnitude and the meteor limiting magnitude, r_l is the resolution of the detector in number of video lines (which for our systems is 300), V is the geocentric velocity in km/s (71 km/s for the Leonids), τ is the effective CCD integration time (0.033s at NTSC frame rates), ξ is the solid angle between the radiant and the pointing direction of the camera, F_{ov} is the field of view (taken as the average of vertical and horizontal fields of view) and R is the range to meteors in the center of the field (taken to be at altitudes of 100 km). This gives a limiting magnitude around $+2^M$ for the systems.

The collecting area of each system was calculated using basic geometry. It is essentially the area of the field of view when projected on a surface at an altitude of 110km. The simple calculation used neglects the curvature of the Earth, but is still accurate to better than 5% at elevations greater than $30_\circ$.

The fluxes were calculated in 15 and 3 minute bins. The 15 minute binning shows the peak clearly (Figure 2). The profile is asymmetric, the ascending branch being longer than the descending. The peak flux is 0.81±0.06 meteoroids km^{-2} hr^{-1} to $+6.5^M$. With the mass distribution index of 1.75, this corresponds to a visual ZHR of 4000±300. The full width at half max of the curve is 54 minutes.

The higher time resolution gives higher fluxes and higher errors. For the three minute binning, the maximum flux was found to be 0.99±0.11 meteoroids km^{-2} hr^{-1} to $+6.5^M$, which is equivalent to a ZHR of 4900±600 (Figure 3).

The peak time estimated from the lower temporal resolution data is 235.285±0.005°. The high resolution peak is less well defined, since the maximum is really a plateau lasting from 325.276° to 235.285°.

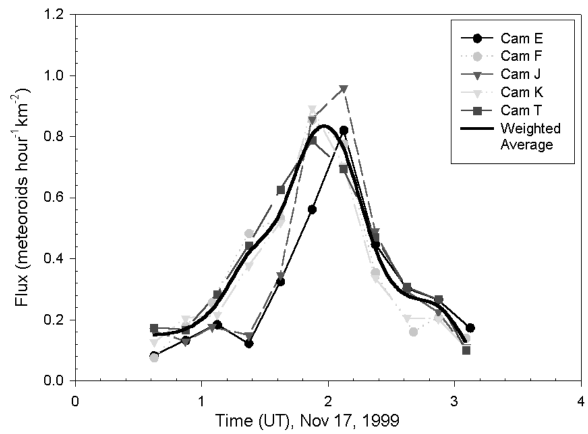

Figure 2. Individual camera and weighted average fluxes in 15 minute bins (1999 campaign)

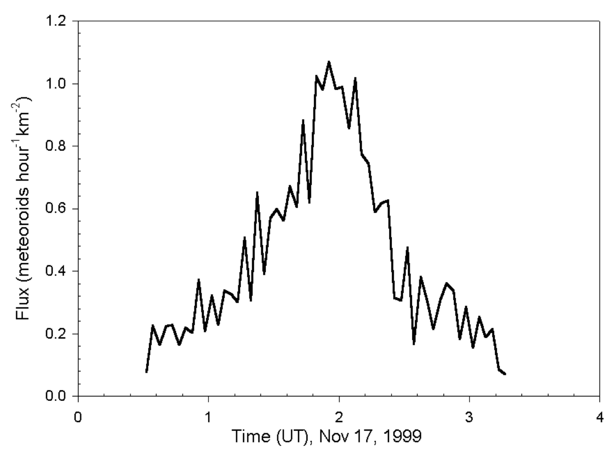

Figure 3. Weighted average of fluxes in 3 minute bins (1999 campaign)

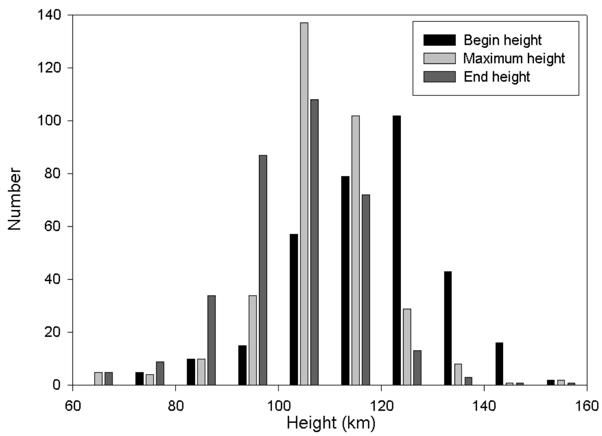

Figure 4. Two-station begin, maximum and end heights for Leonids (1999 campaign)

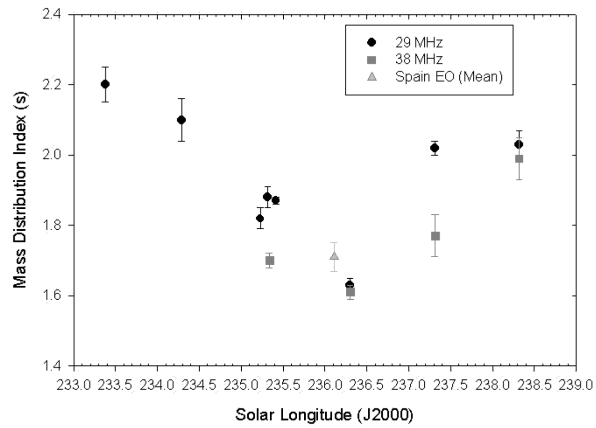

Figure 5. Mass distribution indices from radar and video observations (2000 campaign)

4.2. 1999 Heights

Double station meteors were found by comparing the times of appearance on both systems. False associations are readily identifiable from the unphysical trajectory solutions (heights over 250 km or under 40 km for example). Once the false associations were removed, the Leonids were isolated by comparing the radiant computed for each meteor to the Leonid radiant: anything less than 10° from the radiant was accepted. A total of 114 double station Leonids were obtained from the E-J camera pair and 118 from the F-K pairing. For each of these pairings, one camera was a Generation II and the other a Generation III. The average mean mass is that calculated from cameras E and F, the generation II cameras, since these cameras have the more visual response.

We calculated the number of meteor with beginning, maximum or end heights in 5 km bins. Neither camera pair showed any significant number of meteors beginning at unusual heights (>160 km). We do not expect any significant biases against high meteors, even on the pair with the lower intersection height, until 190 km. The meteors in this sample are smaller by several orders of magnitude from those in Fujiwara et al (1998); all high-altitude meteors recorded are very large meteors. The results for both camera pairs are shown in Figure 4.

4.3. 2000 Fluxes

The mass distribution index was calculated from the 2000 data in the same way as the 1999 data. Since the cameras in Spain yielded the most meteors, those give the most meaningful estimate of mass distribution index from the optical data: only one measurement, a total from all the meteors detected on the peak night, was possible. Since the radars collect much more data, it was possible to calculate the mass distribution index at several time intervals (Figure 5). The 29 MHz system collected more echoes, since it suffers less bias against high meteors than 38 MHz. The mass distribution index will be slightly contaminated with sporadic meteors.

The average sporadic mass distribution index is between 2.2 and 2.3. The general trend of the radar data is a mass distribution index which goes down from an initial value of 2.2 to 1.6 at the time of the predicted peak at 236.25°. This indicates that in the binning intervals shown, Leonids dominated the numbers at this time. At other times, sporadics were significant. The values of s at the November 18 peak agree well with the one calculated from the video data from Spain.

The collecting area for the radar is calculated as a combination of the physical area of sky where echoes from a given radiant can be detected, and the response function of the radar in that direction. It also takes into account the length of the ionized trails (as calculated from optical data) and the range of heights at which each system detects meteors.

The fluxes obtained with this method are then corrected for the initial radius effect. This frequency dependent effect occurs because of the finite radius of the ionized trails, which results in destructive interference at large heights. We have used the corrections derived from Greenhow & Hall (1960). It should be noted that this effect is poorly understood and this could be a significant source of error for the radar fluxes.

The radar and video fluxes are shown in Figure 6. The video data is from New Mexico and Alabama for the earlier peak, and Spain for the second peak. They are in good agreement, particularly the 38 MHz with the video data. Significantly, all three methods show a larger first peak at a solar longitude of 235.29±0.02. The flux at this earlier peak is 0.15 meteoroids km^{-2} hour^{-1} brighter than $+6.5^M$, corresponding to a visual ZHR of roughly 800. The second peak agrees with the one shown in visual observations, at 236.25±0.02, which had a calculated flux of only 0.07 meteoroids km^{-2} hour^{-1} brighter

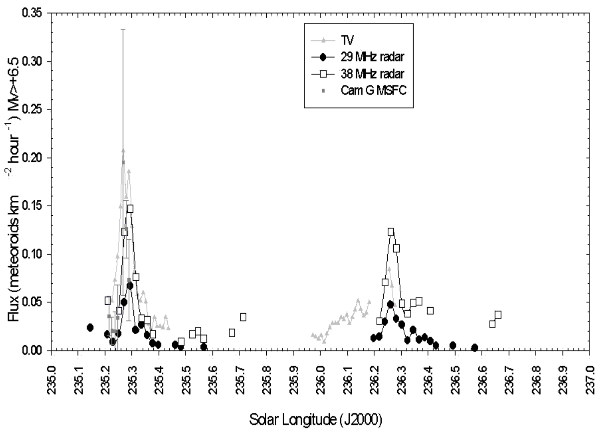

Figure 6. Radar and video fluxes (2000 campaign)

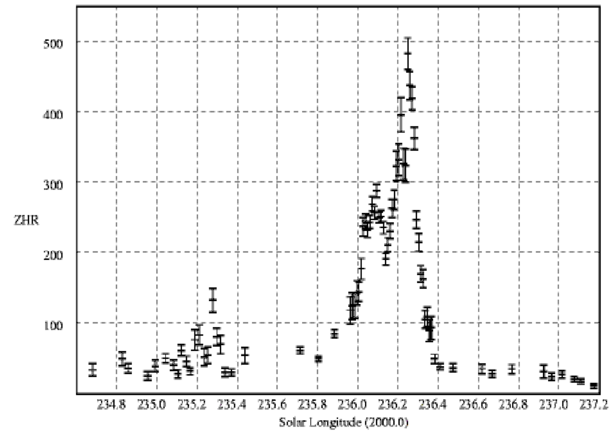

Figure 7. Visual Zenithal Hourly Rate (2000)(Arlt & Gyssens, 2000)

than $+6.5^M$ (ZHR of roughly 450). The second peak is broader than the first.

5. CONCLUSIONS

The heights in the 1999 campaign showed no evidence of the very high altitude meteors detected by other studies. This was in spite of the care that was taken to avoid biasing the results against high-altitude meteors. This is probably because of the relative faintness of the majority of the meteors detected during this campaign, compared to the previous year, when very bright Leonids were much more numerous. Very large Leonids may begin to emit radiation at very high altitudes due to interactions of volatile components (Hawkes & Jones, 1975) with the atmosphere. In faint meteors there may not be enough of this radiation released for the meteor to be visible.

The 2000 observations showed two peaks, with the first being greater than the second. This is not in agreement with visual observations (Arlt & Gyssens, 2000): the International Meteor Organization calculated ZHRs of 130 and 450 for the two peaks, in contrast with 800 and 450 for our results (Figure 7).

There are several possible reasons for this discrepancy. The mass distribution index was probably higher on the night of November 17, meaning more faint meteors: since visual observations were hampered by moonlight this would tend to decrease the number seen. There may also have been the psychological effect of the expectation (from model predictions) that the first peak would be weaker than the second.

There was no evidence of a significant decrease in mass distribution index for the first peak: this is probably due to an intrinsic property of the stream, but could also be partially due to the narrowness of the peak, meaning a greater number of sporadics were counted in the measurement.

This campaign shows the importance of careful observations off the times when the models show major peaks, since the strength of peaks is not well calibrated in the models.

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