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Solar activity and Perseid meteor heights

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Abstract. Photographic meteor heights of the Perseid meteoroid stream compiled in the IAU Meteor Data Center catalogue observed in 1939-1992, covering five solar activity cycles, are analyzed and their potential variation within a solar activity cycle is investigated and discussed.

Of the 673 Perseids selected from the catalogue, the variations of the heights for three independent sets: 524 Perseids with known information on both heights, 397 with known brightness and 279 with the geocentric velocity within a one sigma limit, were investigated. The observed beginning and end-point heights of the Perseids, normalized for the geocentric velocity and the absolute photographic magnitude correlated with the solar activity represented by the relative sunspot number R, do not exhibit a variation consistent with the solar activity cycle.

The result, confirmed also by the correlation analysis, is derived for the mass ranges of larger meteoroids observed by photographic techniques. However, a possible variation of meteor heights controlled by solar activity for smaller meteoroids detected by television and radio techniques remains still open and has to be verified.

Key words: meteor heights – Perseids – solar activity

1. Introduction

Changes in solar activity reflect also physical state of the upper atmosphere causing pulsation of its density influencing both the ionosphere and, to a certain degree, the meteor zone. Studies of various correlations between the changing upper atmospheric conditions and meteor parameters indicate short-term as well as long-term characters of some related phenomena.

Of the short-term variations, McIntosh and Hajduk (1977), analyzing radio observations of sporadic meteors, found that the proportion of persistent echoes rapidly increases after sunrise in the meteor zone. A similar effect of a variation of the mean sporadic meteor echo heights with respect to the local sunrise, with a minimum height occurring after sunrise, was observed by Porubčan and Cevolani (1983). Long-term and short-term variations of radio meteor rates associated with the solar activity were reported by Lindblad (1968, 1976 and 1978). The results led to an inverse correlation between the observed meteor rates and the solar cycle activity.

However, recent analyses covering several solar cycles based on both radio and visual observations led to contrary results. Pecina and Šimek (1999), from a series of radio observations of the Geminid meteor shower and sporadic background echoes in 1958-1997, found a direct correlation between the meteor hourly rates and the solar cycle activity. A similar result analysing sporadic background meteors from forward-scatter radio observations in 1996-2007 was obtained by Porubčan et al. (2009). These results were confirmed also by visual observations over two solar activity cycles in the period between 1984 and 2006 by Dubietis and Arlt (2007, 2010).

Possible variation of meteor heights within a solar cycle was investigated by Lindblad (1968, 1976) who in his analysis of long-term radar observations of the Perseids found that the endpoint heights varied opposite to the solar cycle activity. In order to verify the result, Porubčan and Getman (1992) have applied similar investigation to the precise photographic heights of the Perseids covering a period of four solar cycles and Porubčan et al. (2012) extended it to five solar cycles. However, no variation of meteor heights consistent with the solar cycle activity was identified.

Meteor heights depend as on the entry velocity, composition and structure of meteoroids so on the atmosperic density which is strongly influenced by the changeable solar activity. From this point of view, Sparks and Janches (2009) report to observe diurnal as well as seasonal variations in the micrometeors head echo heights detected by the Arecibo radar. Also Pellinen-Wannberg et al. (2010) report to record high altitude meteor trails around the solar activity maxima in 1990 and 1991, as well as in 1998, 1999 and 2001 by the Swedish EISCAT UHF and Israeli L-band radars, respectively. Similarly, recent TV observations (Fujiwara et al. 1998, Koten et al. 2006) indicate existence of very high trails of the Leonid meteors close to the peak of the solar cycle in 1998-2001. However, all these are individual results only, do not cover a complete solar cycle and desire verification by extended systematic observations.

In the present paper a more extended investigation, with respect to that made by Porubčan et al. (2012), of a possible influence of the solar activity variation within a cycle on meteor heights is presented and discussed. The analysis is based on heights of the Perseid meteoroid stream observed over five solar cycles compiled in the IAU MDC photographic database and partially also on television data from Japanese observations in 2007-2009.

2. Observational data

2.1. Photographic Perseids

The inference on an opposite correlation between meteor endpoint heights and solar cycle activity derived from a long series of radar observations at the Onsala Observatory (Lindblad 1968, 1976) was based on the heights derived from the combined radar-visual observations. Naturally, such observations can be biased by large observational errors and the inference has to be verified. Such a verification requires a homogeneous series of precise meteor heights which can provide photographic observations and data compiled in the IAU Meteor Data Center catalogue of photographic meteor orbits. The updated version of the IAU MDC catalogue (Lindblad et al., 2003) provides the orbital and geophysical parameters of 4581 meteors compiled from 17 different stations.

In order to select Perseids from the catalogue, an independent stream-search procedure applying the Southworth-Hawkins D-criterion (Southworth and Hawkins, 1963) for the rejection level of D_{SH}=0.20 with respect to the mean Perseid orbit listed by Cook (1973), was performed. The search enabled to separate 673 Perseids observed in 43 years between 1937 and 1992. Of this set, for 149 Perseids complete information on the beginning or endpoint heights was missing. Thus the final set of the Perseids was reduced to 524 meteors for which the mean beginning and endpoint heights in individual years were calculated and together with the number of meteors and the standard deviations are depicted in Fig. 1.

In the next step, in order not to bias the overall variation of meteor heights, only years with 5 or more recorded Perseids in a year were considered for further analysis. Application of this criterion reduced the number of years to 27 from the period 1951-1992.

The 524 selected Perseids were observed on 14 different stations utilizing various photographic cameras, which can be roughly divided into two qualitatively different groups: small cameras and Super-Schmidt cameras. The stations separated according to location into six groups of stations or networks, labeled by the catalogues used in IAU MDC database is together with the overall numbers of Perseids with known heights (Hb, He) and the number of Perseids with the absolute photographic magnitude (Mph) listed in Table 1.

As evident from Table 1, practically two thirds of the Perseids were recorded by the former Soviet Union stations operated with special meteor cameras with f/2.5 - f/3.0 (Dushanbe, Odessa and Kiev) between years 1952-1984 and the Dutch Meteor Society (NL network) operated with standard cameras with f/2. The numbers of the Perseids observed by individual stations and networks from Table 1 (column Mph) in particular years are depicted in Fig. 2.

2.2. Solar cycle activity

Variation of solar activity is represented by the relative sunspot number R with an average duration of the cycle of approximately 11 years. Durations of

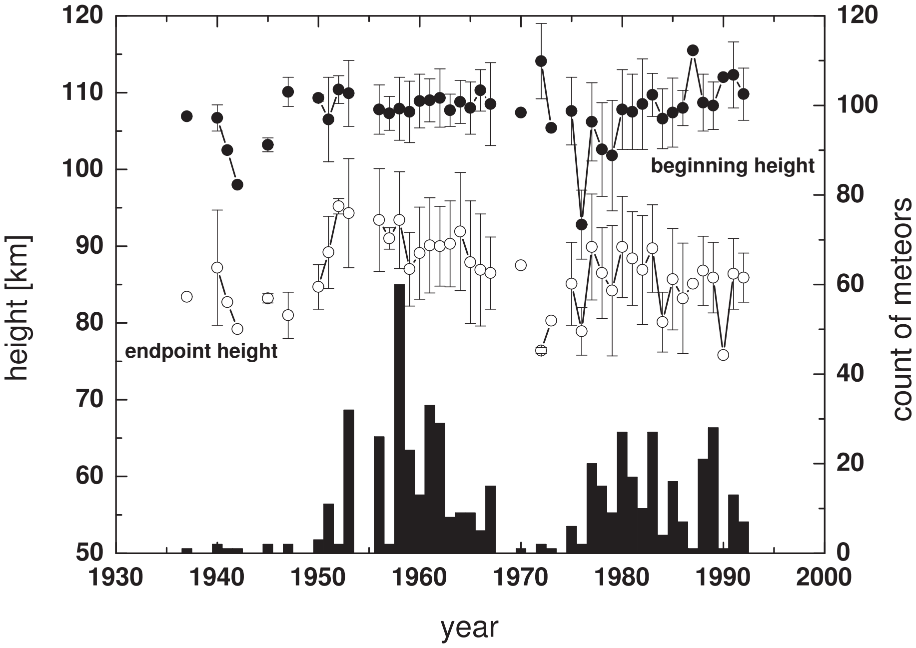

Figure 1. The mean beginning and endpoint heights of the Perseid meteors selected from the IAU MDC catalogue for the rejection level D_{SH}=0.20 with the corresponding numbers of meteors observed in individual years (histogram)

individual solar cycles can vary in a relative large interval. To estimate durations of individual solar cycles in the period covered by the analysed photographic Perseids 1950-1992 (five solar cycles), the smoothed monthly sunspot numbers R provided by SIDC, RWC Belgium, World Data Center for the Sunspot Index, Royal Observatory of Belgium (http://sidc.oma.be/DATA/monthssn.dat), were utilized. The estimated lengths of the solar cycles nos. 18-22 defined as the time between two successive minima are listed in Table 2. Taking into account that the activity of the Perseid meteor stream is peaking in August (at solar longitude L = 141°) and all Perseids selected from the IAU MDC database were recorded in August as well, for description of the solar activity to be correlated with the Perseid heights only the smoothed August data of R were used.

As evident from Table 2, the length of individual solar cycles vary from 9.7 yrs in cycle 22 to 11.7 yrs in cycle 20. In order to compare the Perseid heights in successive years with the corresponding phase of the solar cycle activity, a cycle of an average length from the five cycles covering the Perseids data was constructed. Consequently, the durations of all cycles were normalized to a cycle of the unit length and the mean "normalized" cycle was calculated. Due to different lengths of the cycles, individual years with the Perseids cannot

Table 1. Numbers of photographic Perseids selected from the IAU MDC database: (a) having both the beginning and endpoint heights (Hb-He), (b) with the photographic absolute magnitude (Mph), and (c) with the geocentric velocity (Vg) within the one sigma limit.

desig.	author	station	(Hb-He)	(Mph)	(Vg)
W	Whipple	USA	15	15	12
F	McCrosky	USA	3	3	3
I	Halliday	CAN	23	23	14
J	Jacchia	Super-Schmidt	10	10	9
H	Hawkins, Southworth	Super-Schmidt	9	8	6
P	Posen, McCrosky	Super-Schmidt	5	0	0
S	McCrosky, Shao	Super-Schmidt	12	0	0
K	Kiev	Soviet Union	24	23	16
O	Shestaka	Soviet Union	119	78	57
D	Babadzhanov	Soviet Union	155	125	77
C	Ceplecha	EU network	28	26	14
E	Ceplecha, Spurny	EU network	10	10	4
T	Ohtsuka	Japan	11	0	0
B	Betlem	Dutch network	100	76	67
	Total		524	397	279
TV	SonotaCo	Japan	1105	1105	756

Table 2. Durations of the solar cycles nos. 18-22 estimated from the relative sunspot number R.

Cycle no.	From	To	Duration
18.	1944.2	1954.3	10.2
19.	1954.3	1964.8	10.5
20.	1964.8	1976.5	11.7
21.	1976.5	1986.8	10.3
22.	1986.8	1996.4	9.7

correspond to the same cycle parts, therefore the cycles were divided into bins of the length of 0.1 and the mean cycle was calculated from the mean heights within a particular bin. The courses of normalized cycles nos. 18-22 and the profile of the mean normalized cycle are depicted in Fig. 3. As evident, the profile of the mean normalized cycle is close to cycles 18, 19 and 21, which are characterized by a rapid increase of activity in the first third of the cycle (maximum is between bins 0.3-0.4) followed by a moderate decrease of R continuing to the end of the cycle.

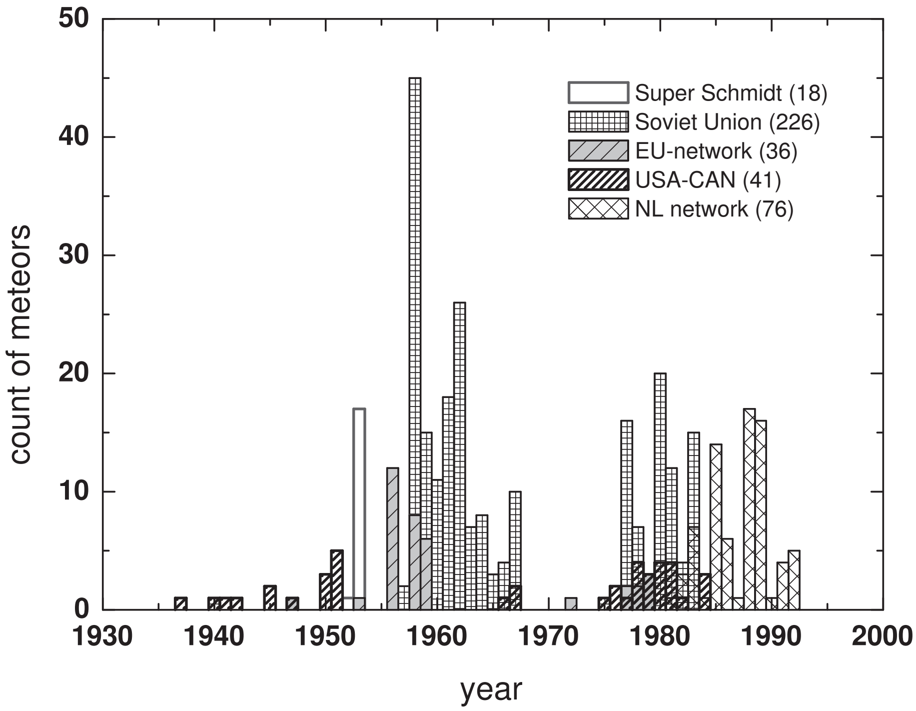

Figure 2. Counts of the Perseids with the known heights and brightness observed in particular years within the networks listed in Table 1 (column Mph).

3. Solar activity and variation of meteor heights

In case of existence of a real variation and positive correlation between the solar activity and meteor heights, we can expect to observe similar trends in the beginning and endpoint heights within the mean normalized solar cycle. For further analysis, the positions of individual years were assigned to the corresponding relative positions in the normalized solar cycle and the particular years were combined into the bins. The combined bins contain from 1 to 4 particular years, and consequently, the weighted mean beginning and endpoint heights based on the numbers of meteors with the standard deviations were determined.

As the meteor heights depend rather strongly on the velocity and mass of a meteoroid, in the next step the observed heights had to be corrected for these two effects. From the distributions of the beginning and endpoint heights with respect to the maximum photographic absolute magnitude, a strong dependence of the endpoint heights on the absolute magnitude (meteoroid mass) is evident (Porubčan et al., 2012), which at further analysis of the heights has to be taken into account. The regression lines derived from the distributions provide for the

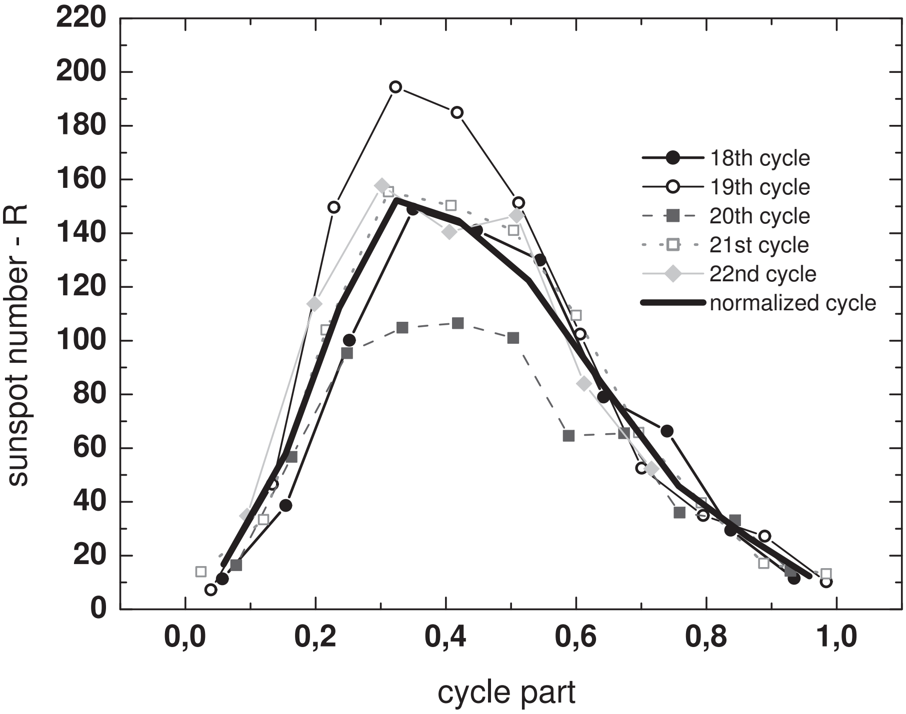

Figure 3. Solar cycles nos. 18-22 normalized to the unit length. The mean normalized cycle is marked by a thick line.

beginning and endpoint heights relations: H_B=109.1 + 0.24 M_{ph} and H_E=93.9 + 1.51 M_{ph}.

To minimize the influence of dispersion of velocities on meteor heights, only Perseids with the geocentric velocity close to the mean velocity of the stream (within one sigma) were considered for the final distribution of the heights. The geocentric velocity of the Perseids derived from the complete set of 673 orbits is V_g = 59.3±0.98 km/s and the one sigma condition reduced the number to 279 orbits (Table 1).

For the final distributions, three different sets of the Perseids listed in Table 1 were investigated: (a) a set of all orbits with complete information on the heights - 524 Perseids, (b) a set of orbits with the heights and the brightness - 397 Perseids, and (c) a set of orbits having complete information on the heights, the brightness and with the geocentric velocities within the one sigma limit - 279 Perseids. Furthermore, in order not to bias the observed variations of the heights, only years with 5 and more Perseids were in all three sets included into analysis.

Final results of the analysis are presented in Fig. 4, where the variation of the

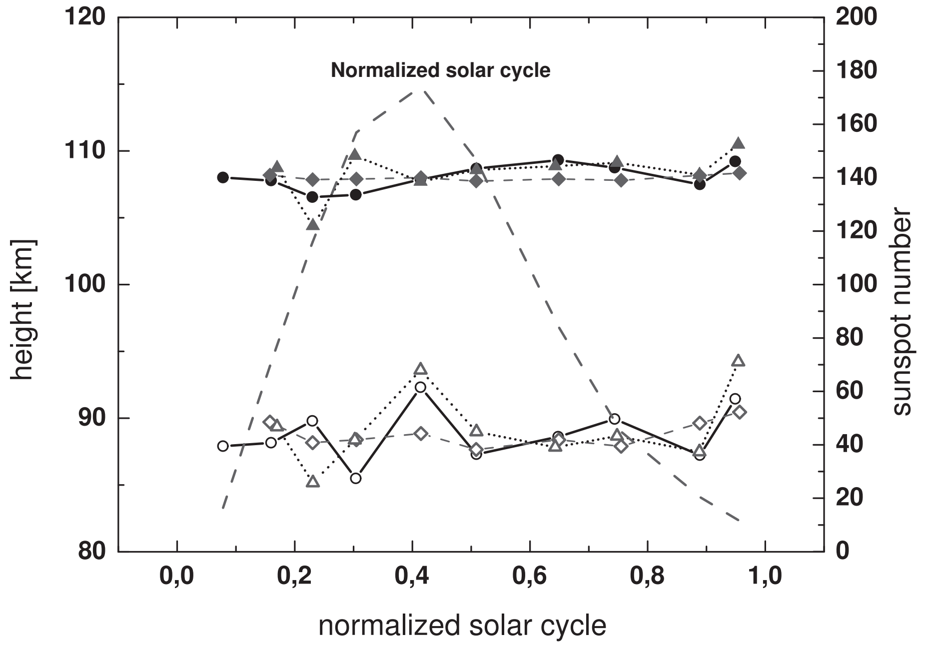

Figure 4. The mean beginning (full marks) and endpoint heights (empty marks) corresponding to the normalized solar cycle: (a) for all Perseids with the heights (thick line), (b) for Perseids with the heights and brightness normalized to the absolute photographic magnitude Mph=-4 (dashed line) and (c) for all Perseids with the heights, brightness and geocentric velocity within the one sigma limit (dotted line).

mean normalized solar cycle, derived from five cycles (nos. 18-22) is represented by the mean relative sunspot numbers R observed in August (dashed curve). Variations of the Perseid heights, for both the beginning and endpoint heights corresponding to the course of the normalized solar cycle were derived for all three sets of the photographic Perseids orbits (Table 1).

The course of the set (a) of all Perseids with the heights (524 meteors) in Fig. 4 is depicted by heavy lines. In the set (b) and (c) consisting of the Perseids with the known brightness, the observed beginning and endpoint heights were corrected and normalized to a common photographic absolute magnitude M_{ph}=-4^{mag}. The corrected variations for the set (b), i.e. all Perseids with the brightness (397 meteors) in Fig. 4, are depicted by dashed lines. The variations of the set (c), consisting only of the Perseids with the geocentric velocity very close to the mean velocity of the stream, within one sigma (279 meteors) are depicted by dotted lines.

As it can be seen from the resulting variations plotted in Fig. 4, the normalized variations of the beginning and endpoint heights of photographic Perseids

Table 3. Correlation coefficients and results of statistical test of correlations between the relative sunspot numbers R, and heights of Perseids. CC is the correlation coefficient, the p-value is the probability for testing the null hypothesis of no correlation (significance level based on the Student t-distribution), LBCC and UBCC are lower and upper bounds for 95% confidence interval for CC and DF is number of degrees of freedom (number of samples - 2). Abbrevations Hb-all and He-all refer to beginning and endpoint heights of all Perseids - set (a); Hb-M and He-M are beginning and endpoint heights of Perseids with the magnitude - set (b); Hb-M-Vg and He-M-Vg are beginning and endpoint heights of Perseids with the geocentric velocities within one sigma - set (c).

	R Hb-all	R He-all	R Hb-M	R He-M	R Hb-M-Vg	R He-M-Vg
CC	-0.361	-0.046	0.307	0.308	-0.319	-0.036
p-value	0.305	0.899	0.388	0.386	0.403	0.926
LBCC	-0.807	-0.657	-0.399	-0.399	-0.811	-0.684
UBCC	0.348	0.601	0.785	0.785	0.438	0.643
DF	8	8	8	8	7	7

do not exhibit any apparent correlation consistent with the solar cycle activity. This result is also confirmed by the correlation coefficients derived between the trends of the relative sunspot numbers R and the beginning and endpoint heights for all three sets of the Perseids, and by the results of statistical tests of correlation listed in Table 3.

4. Discussion and conclusions

In the present paper, so far the longest series of photographic meteor observations extending over five solar cycles (nos. 18-22), aimed at verification of possible variation of meteor heights consistent with the solar cycle activity, is analyzed. Variations in solar activity cause pulsations of the upper atmosphere and variations in its density, which should reflect also on the state of the ionosphere and consequently on the meteor zone, meteor heights and trails too (Brosch et al., 2001, Pellinen-Wannberg et al., 2010). Recent visual observations (Dubietis and Arlt, 2010) and radio observations (Pecina and Šimek, 1999, Porubčan et al. 2009) point out existence of a real relation between activity of sporadic meteors and solar cycle activity. However, a confirmation of the similar variation in meteor heights claimed by Lindblad (1968, 1976) from a long series of radar observations, is still missing. There are so far only a few indirect indications resulting from occational observations by high altitude radars from which existence of the variation of meteor heights consistent with the solar cycle is inferred.

The present analysis was based on precise photographic heights of the Perseids observed over 43 years (1939-1992). To minimize the influence of dispersion in velocities and masses of meteoroids on the observed beginning and endpoint heights, the relations between both heights, the geocentric velocity and the absolute photographic magnitude were derived and taken into account for the analysis. The analysis was extended to three sets of the Perseids: (a) all Perseids with heights (524), (b) Perseids with magnitudes (397) and (c) Perseids with velocity close to the mean velocity (279).

One has to take into account the fact that only larger and more massive meteoroids can be observed photographically and the changes in the atmospheric density initiated by the variations in solar activity may not be so effective on larger meteoroids and thus no variation in the heights of photographic meteors consistent with the solar cycle activity is observed.

On the other hand, there are several TV multi-station databases carrying out systematic observations of meteors operating at present, of which the SonotaCo database (2009) is the largest accessible compilation of TV meteor orbits of systematic observations from three years (2007-2009) with 64 650 TV orbits (http://sonotaco.jp/doc/SNM). As the database covers only three years of observation, it cannot be used for a separate analysis of the variation of meteor heights with the solar activity, only a partial analysis and comparison with the photographic heights in corresponding years could be made.

In order to separate only high quality orbits, multiple constrains to the database were applied and the set of orbits dropped to 16 804. Consenquently, Perseids were separated by employing a computerized stream search procedure for D_{SH}=0.20, and the final set of Perseids separated from the SonotaCo database is 1105 orbits (Table 1). In the next step, similar procedures as applied to photographic Perseids were applied also to the 1105 television Perseids. The mean beginning and endpoint heights normalized to the photographic absolute magnitude $M_{ph}=-4^m$ for each year were calculated and assigned to the normalized cycle according to their position with respect to the particular cycle considering the average duration of cycles nos. 18-23 (10.8 years). The mean geocentric velocity of the television Perseids is $V_g=58.85 \pm 0.82$ $km.s^{-1}$ and the one sigma limit eliminated additional 349 Perseids from the sample (Table 1).

The mean beginning heights of the Perseids derived from television observations in 2007-2009 are from a narrow interval 110.0-110.7 km. The corresponding mean photographic heights within 107.5-109.2 km are by about 2 km lower. Contrary to this, the mean endpoint television heights 84.5-84.6 km are by about 5 km lower than the photographic heights 87.2-91.4 km. The result shows that the trails of the Perseids observed by TV techniques are on average of about 7 km longer than the trails detected by photographic techniques. The fact is reflecting higher sensitivity of TV cameras with respect to photographic ones utilized in meteor research. Moreover, as the most recent TV systems and networks provide the orbital and geophysical data of meteors with the accuracy approaching to precise photographic observations, these are becoming still more effective and perspective.

Concluding present analysis, the observed distribution of the beginning and endpoint heights of photographic Perseids observed over five solar cycles does not exhibit a variation consistent with solar cycle activity. This conclusion is valid for larger meteoroids corresponding to photographic masses and not for smaller meteoroids observed by television and radio techniques. Therefore, for a more conclusive result, longer series of systematic TV and radio observations are desirable and could help to solve this problem more effectively.

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