The population index of sporadic meteors

Jürgen Rendtel

Eschenweg 16, 14476 Marquardt, Germany

jrendtel@aip.de

Abstract

In this work we determine the population index r of sporadic meteors from visual meteor data. A sample of 301 499 meteor brightness estimates collected from 1196 observers in the period 1988 – 2003 and stored in the *IMO*'s visual meteor data base (VMDB) is used. Selection effects are discussed and annual as well as diurnal variations are discussed. Main results are derived from northern hemisphere data which comprise the major portion of the sample (278 724 meteors). The annual average value is $r = 2.95 \pm 0.06$. A minimum occurs in (northern) summer between 80° and 100° solar longitude (J2000) with $r = 2.80 \pm 0.05$, and a maximum is found between 200° and 220° solar longitude with $r = 3.10 \pm 0.05$. Similar variations occur in the respective seasons in the southern hemisphere.

1 Introduction

Sporadic meteors seem to be of little interest, particularly in a period with thrilling peaks of meteor activity such as the Perseids in the 1990s and the recent Leonids. There are rather few papers dealing with parameters of sporadic meteors.

Meteor observations yield a number of different meteoroid sources. The best known are dust trails released from comets or asteroids forming meteoroid streams appearing as major meteor showers. The observer has little problem associating meteors with their sources. Next, there is a number of meteor showers which produce only small numbers of meteors. Of course, this also holds for the outer regions of the major streams. Here the shower association becomes more important and requires more effort than in the vicinity of central regions of dense particle streams. But even with refined methods, a considerable part of the observed meteoroid influx cannot be associated with cometary or asteroidal sources with any certainty. Such meteors are called sporadic meteors.

Currently, there are several data compilations available. In this study we are interested in meteor magnitude data only. Meteor magnitudes can be determined from visual, photographic, video and radar observations. Photographic records mainly consider bright meteors and yield small samples. Video data reach basically the same magnitude range as visual data. So far the meteor magnitudes derived from video recordings are of limited accuracy and also show systematic deviations among video camera systems. Among other effects, the photometric calibration is rather difficult, and the spectral sensitivity of the video systems differs from visual data. Therefore we chose the huge data archive of the *IMO*'s Visual Meteor DataBase (VMDB). For all years available, the analysed sample contains 301 499 magnitude estimates of sporadic meteors, of these 278 724 from the northern hemisphere and 22 775 from the southern hemisphere.

2 Sporadic meteors — selection effects

It is obvious that the classification of a meteor as "sporadic" depends on the number of other, primary sources. The *IMO* working list of meteor showers is one reference; other compilations list more or less showers. The more showers are in the list, the smaller is the remaining sample of sporadic meteors. Subtracting only a few showers from the observed sample obviously leaves a portion of non-sporadic meteors in the data. This effect is also present if the observer does not appropriately apply the list of showers.

Another significant influence on the classification as a sporadic meteor is caused by the observing method. The limited accuracy of trail direction and length determination, combined with the observing errors of the angular velocity, cause a number of (true) shower meteors will be mis-classified as sporadic and vice versa (Koschack, 1995). This results in the assumption of certain radiant sizes which should compensate for these errors. While this compensation works for the rate determination (just numbers to correct), we also mix different particle size distributions. It is known from different observations that most showers include a larger fraction of larger meteoroids appearing as bright meteors. Consequently, we may expect to find a number of mis-classified brighter meteors in our sample of sporadic meteors. We may assume that the effect on the major shower's magnitude distribution at least close to its activity maximum is comparatively small, while it is largest on the sporadic magnitude data at the same moment.

Table 1: *Major showers of the year and minor showers active in the same period possibly contributing to the sample of sporadic meteors if not carefully associated. Abbreviations according to the IMO's working list of meteor showers.*

Major shower	Minor showers contributing to the "sporadic background"
QUA	DCA, COM
PER	CAP, KCG, NDA, SDA, NIA, SIA
ORI	NTA, STA, EGE
LEO	NTA, STA, AMO
GEM	MON, XOR, HYD, COM

Shower and sporadic meteor magnitude data become more uncertain if the shower association is done without carefully considering the trail (direction and length) and angular velocity information. This happens during "counting" observations, which are usually done near the activity maxima of major showers. This effect is further increased if observers just distinguish between the major meteor shower and "other meteors". In this case, the "sporadic" sample contains also data of all other minor showers. Table 1 lists the major meteor showers and the minor showers active at the same time. In the case of just distinguishing between major shower and "others" (then called sporadic), the largest error is expected during the activity of the Perseids, the Orionids, the Leonids and the Geminids. In the VMDB, the quality of a data entry is classified in the rate file. Unfortunately, this qualifier is not available in the magnitude file (which is independent). Therefore we have to take the magnitude data near major shower maxima with special care. For example, we can try with data of a few observers only for which we have ensured that they considered all meteor showers of the *IMO* working list.

3 Data selection

Since the sporadic background can be regarded as a flux of particles from all directions, we could just take all data into one sample. However, what we call sporadic meteors originate from several sources (apex, helion, anthelion, etc.; see Znojil, 1995) which have different strengths. Therefore it is necessary to separate the data.

First, we split the sample into two data sets including observations from the northern and southern hemisphere. Next, we want to find differences between sources of sporadic meteors which are above the local horizon during different intervals of the day. The latter split was only useful for the northern hemisphere data because the amount of southern hemisphere data is still not sufficient for such an investigation. The data sets are for the periods 18^{h}– 22^{h}, 22^{h}– 02^{h} and 02^{h}– 06^{h} local time (LT), centered at 20^{h}, 00^{h} and 04^{h} LT. As there are only very few regular meteor data from far northern locations, the remaining periods of the day are not accessible with visual or other optical observations. However, we can additionally check for annual variations in the northern data. The most significant differences could be expected between spring and fall, with the apex source appearing late in the night and remaining low (spring) and the apex source appearing early in the evening and being high in the sky after midnight (fall). For this purpose we selected the periods $310° - 10°$ (February – March) and $190° - 220°$ (October) which contain a sufficient sample of sporadic meteors. Because the fall period includes the Orionid activity, we considered plotting data only which should minimize the effect of shower meteors considered as sporadics.

4 Results and discussion

Only few papers deal with the question of the mass distribution in the sporadic complex. Some of these are summarized in Table 2. The population index r and the mass index s are related by the expression $s = 1 + 2.5 \log r$. Other authors give similar values, based on different types of data. Hruška (1956) gives an average $r = 2.93$ derived from visual data collected in 1232 hours between 1947 and 1949. Štohl (1976) analysed the variation of the average magnitude of visual sporadic meteors. He also finds the changes in the vicinity of major shower maxima as described in this paper, i.e. an effect of obviously mis-associated shower meteors to the sporadic complex. His average of $r = 3.5$ for sporadic meteors is higher than the result from other sources.

Table 2: *Mass index and population index (according to the equation given above) found from different data samples. The minimum and maximum values refer to the diurnal variation. The time is given as local time (LT).*

Reference and remarks	Average		Minimum		Maximum	
	s	r	s	r	s	r
Kresáková (1966) 21996 visual meteors (1944–55)	4.5	3.5				
Hughes & Stephenson (1972) 30 000 underdense echoes 1969 September 9–14, Sheffield	2.04 ± 0.04	2.60 ± 0.1	1.94	2.37	2.36	3.50
			$03^{h}00^{m}$ LT		$14^{h}30^{m}$ LT	
Hughes (1974) 10 287 visual meteors (1947–56) (Millman & Burland, 1957)	2.43 ± 0.02	3.73 ± 0.07				
Štohl (1976) 12867 visual meteors (1944–53)	2.42	3.70				
Babadzhanov & Bibarsov (1992) 200 000 echoes (1 mg – 100 g) 1965–1970, Dushanbe	2.1 ± 0.1	2.75 ± 0.25	1.96	2.42	$2.15 - 2.28$	$2.88 - 3.25$
			10^{h}– 12^{h} LT		18^{h}– 22^{h} LT	
This study 301 499 visual meteors (1988–2003)	2.17 ± 0.03	2.95 ± 0.06				

We find an average population index for the entire year and neglecting all temporal variations of $r = 2.95 \pm 0.06$. This is very close to the value of $r = 3.0$ used for all analyses based on the *IMO*'s Visual Meteor DataBase (VMDB). Of course, there are some obvious and systematic variations.

First, we look at the **diurnal variation**. As is already obvious from the data listed in Table 2, the results from various data sets differ significantly. Nevertheless, the values for the night intervals fit well, while they diverge for the 10^{h}– 18^{h} LT interval. However, Štohl finds a nearly constant r in the period between 18^{h} and 06^{h} LT. At least, the variation is smaller than the error margins, with an average of $r = 3.6$ (Štohl, 1976) Figure 1 shows our result for the spring and fall data. The population index r is generally lower in fall. Further, the decrease towards the morning is steeper in spring than in fall. Both these facts hint at a lower value of r particularly for the apex source: it occurs later in spring (after midnight LT) and reaches a lower altitude (fewer apex meteors visible). This aspect of an apex-effect is also described by Znojil (1995): meteoroids moving on long-period orbits are found to produce a higher proportion of bright meteors. That is, the apex source is expected to have the lowest value of r.

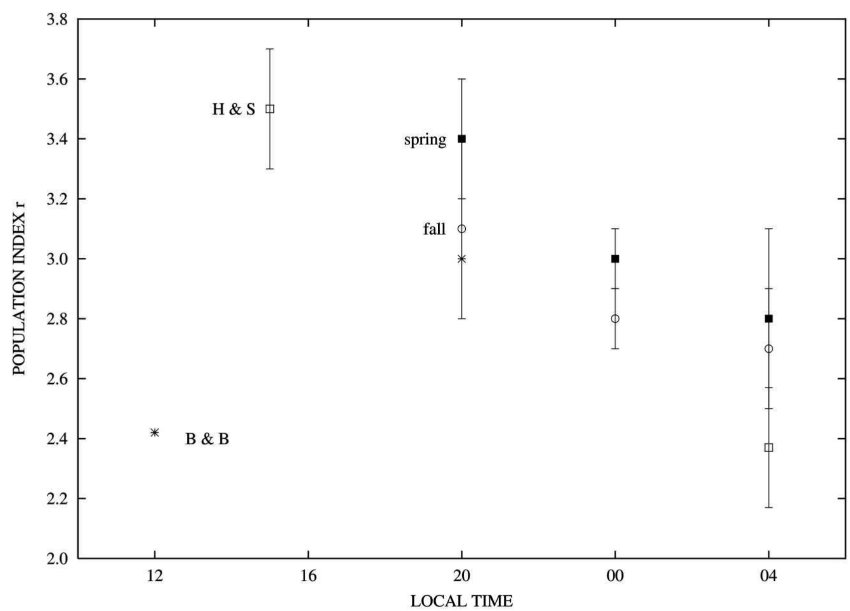

Figure 1: *Diurnal variation of the population index r of sporadic meteors. Asterisks (B & B) refer to Babadzhanov and Bibarsov (1992), with no error margins given; open squares (H & S) show the values found by Hughes and Stephenson (1972). Our results for the period 20^{h}– 04^{h} LT are shown with filled boxes (spring) and open circles (fall).*

Next, we look at the **annual variations** of the population index r. In this step of the analysis, we no longer distinguish between evening and morning meteors. If we assume that the diurnal variation can be represented by a linear decrease of r within all three periods, and further assume that the number of pre-midnight and post-midnight observations is roughly constant, the effect of the rising apex source should be negligible within the error margins.

For this step we also can use separate data sets for the northern and southern hemispheres. The results are shown in Figures 2 and 3 together with a simple sine fit which is primarily meant to identify longer periods deviating from the average. The larger sample from the northern hemisphere allows smaller binning intervals containing more meteor data. The limits were set to 140 sporadic meteors per interval and a binning interval of 15° shifted by 7.5° plus a minimum limiting magnitude of 6.0 for the northern data; the respective values for the southern sample are 60 meteors, 30°, shifted

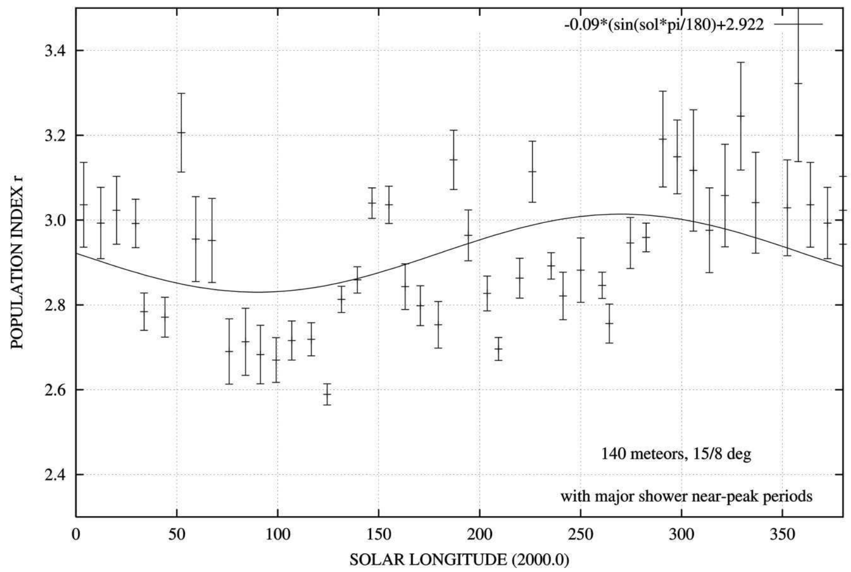

Figure 2: *Annual variation of the population index r derived from northern hemisphere data and a rough sine fit. Interval length* $15°$*, shifted by* $8°$*, minimum limiting magnitude 6.0. Note that the graphs shown in Figures 2 to 7 start at* $0°$ *solar longitude, i.e. the vernal equinox.*

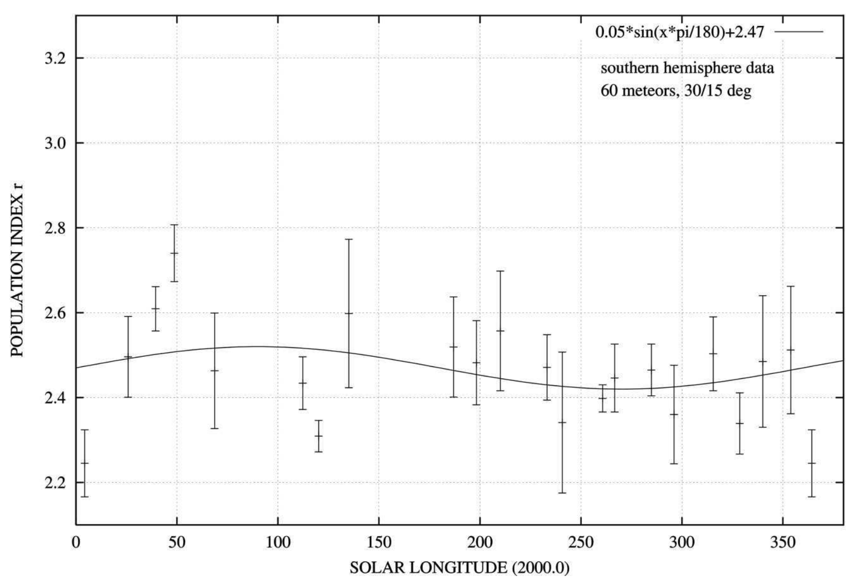

Figure 3: *Southern hemisphere annual variation of the population index r and a rough sine fit. Interval length* $30°$*, shifted by* $15°$*.*

by $15°$, with no limit on limiting magnitude. Consequently, we cannot resolve short-term variations (of the order of a week or shorter).

First, we find that the average r-value derived from the southern hemisphere sporadic data is about 0.5 lower than the northern annual average. There is no obvious astronomical reason for such a shift. Probably it is caused by systematic observational effects (perception or magnitude estimates). Since the northern hemisphere data sample is about five times the southern set, and a larger portion of the northern observers use the plotting method (which is supposed to allow better shower association),

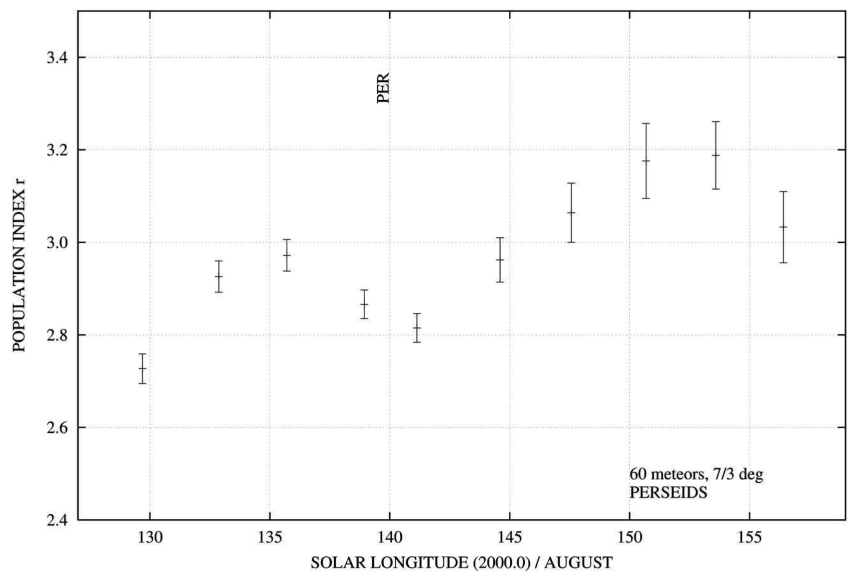

Figure 4: *Variation of the population index r during the Perseid activity period from the data shown in Figure 2. Perseid maximum near* $140°$.

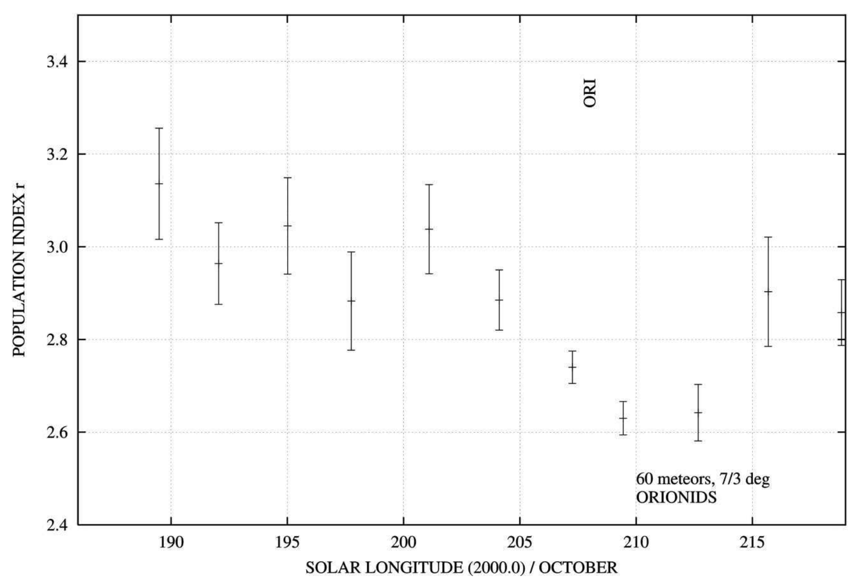

Figure 5: *Variation of the population index r during the Orionid activity period (maximum near* $208°$*).*

we may assume a shift of 0.5 to adjust both graphs. Despite the general shift, it is obvious that the variation in the two hemispheres shows an opposite variation with a minimum r in the respective summer months. Of course, the variation shows a large scatter between the individual intervals, and a closer look at the northern data shows that several minima of r correspond with the activity of certain meteor showers. Three Figures 4–6 illustrate this for the Perseids, Orionids, and Geminids. Similar effects have been found by Štohl (1976). Most if not all visual observers turn to counting techniques in such periods. Obviously, there is a significant "cross-talk" between the data, that is, mis-identified shower and sporadic meteors do not "compensate". While such a compensation may be achieved for the numbers, it is not possible for the magnitudes because the population indices

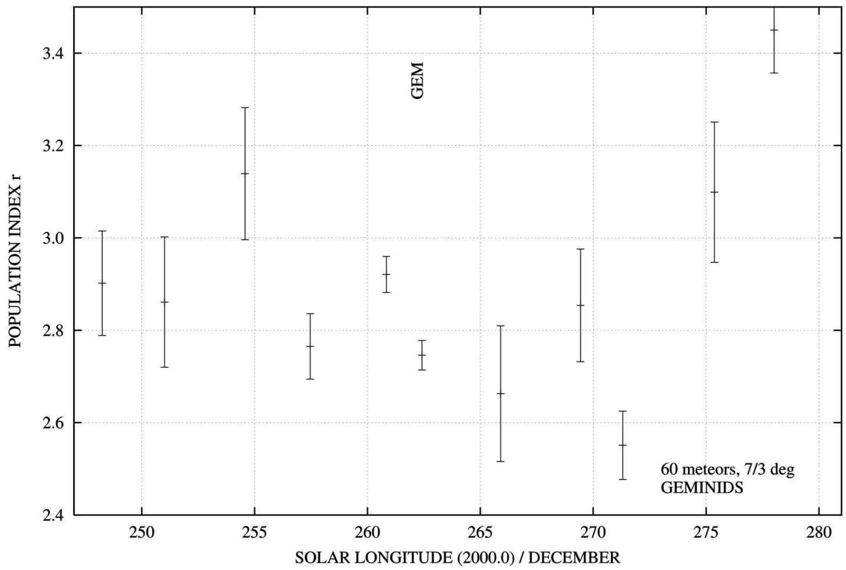

Figure 6: *Variation of the population index r during the Geminid activity period (maximum at 262°).*

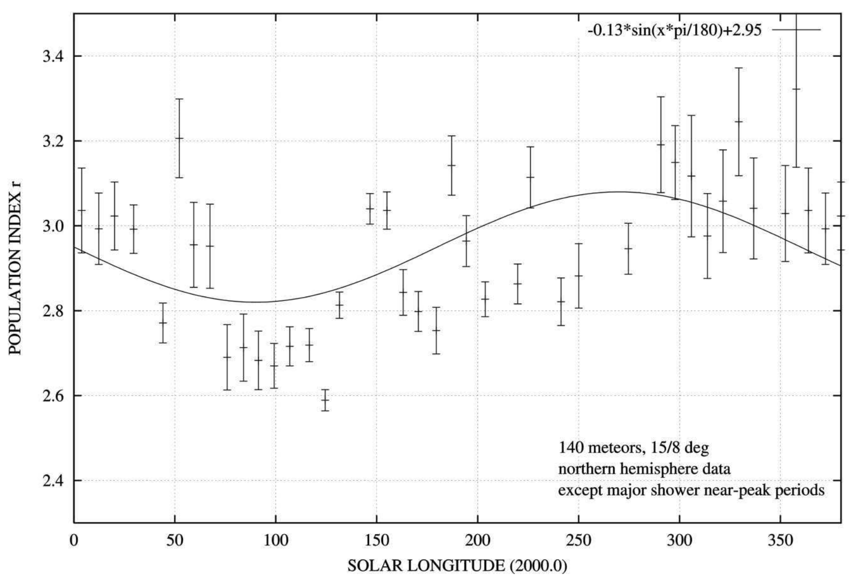

Figure 7: *Northern hemisphere annual variation of the population index r as in Figure 2 with the near-peak values of major showers omitted.*

of shower meteors are systematically lower than for sporadic meteors.

In order to obtain information about the sporadic meteors with less interference from shower characteristics, we omitted the intervals close to the peaks of major showers. The result is shown in Figure 7. We see that some of the minima disappear. Again, the fit is not meant as a description of the r-variation. The annual average from this sample gives an $r = 2.95 \pm 0.06$, again with a minimum in summer ($80° - 100°$, $r = 2.82 \pm 0.05$) and a maximum in winter ($260° - 280°$, $r = 3.08 \pm 0.05$).

Our previous look at the diurnal variation indicated a lower value of r for the apex source. The rough fit of the annual variation (opposite in in both hemispheres) could be interpreted as a general variation connected with the seasons, with a minimum of r in the respective summers and a maximum in the respective fall periods. Such a variation cannot be related to the apex source as is it almost opposite to the expected “apex effect”. Hence the apex cannot be the dominating source in terms of the magnitude data. Moreover, if we have a closer look at the annual values shown in Figure 7, we find significant and short-term variations (time resolution limits were discussed above). Such variations are expected to be caused by a passage of the Earth through different meteoroid populations. In our data we find a few features in both the northern and southern data. We have to keep in mind that the entire sample is collected over more than a dozen years with each year contributing in a very different manner. If such a structure occurs in the summarized sample, this may indeed indicate the Earth’s passage through different particle streams. We can detect maxima near $50°$ and $130° - 160°$ and a minimum near $240°$ solar longitude. On the other hand, near $330°$ and $353°$ we find a maximum in the northern r and a minimum in the southern r. If we also assume that these are real structures, those producing differing behaviour of r in both hemispheres are caused by sources in far northern/southern positions.

Table 3: *Annual variation of the population index r found by Štohl (1976) from Skalnaté Pleso data and from the VMDB data for the southern and northern hemispheres.*

Source	Average	Minimum	Maximum
Štohl (1976)	3.7	2.7 (80°)	> 4 (330°; 205°)
this study, North	2.95 ± 0.06	2.82 (95°)	3.08 (275°)
this study, South	2.47 ± 0.08	2.42 (280°)	2.52 (100°)

Assuming a variety of cometary and asteroidal parent objects and considering the long-term evolution of the individual orbital parameters, such differences in the unresolved “background” are not too much surprising. Some of them may be showers below the detection limit, or persisting structures close to resonant meteoroid populations. From the available sample it is not yet possible to study whether such suspected structures remain stable over several years. A comparison with Štohl’s analysis of 1944 – 1953 data (Štohl, 1976) shows no coincidence of extrema except the overall r-minimum between $80°$ and $100°$ and the maximum values in the range $280° - 30°$ (see Table 3). Štohl stated that the annual variations are mainly caused by “uncovered minor streams” or shower meteors erroneously included in the sample of sporadic meteors. Seeing the results from the two data sets from the periods 1944 – 1953 and 1988 – 2003, we have to conclude that there is no feature in the magnitude data which exists for decades. This is not surprising, because the strength of the sources is close to the detection limits, and furthermore typical evolution scales of Jupiter-system objects are of the order of < 10 years. Hence weak “meteoroid clusters” with peculiar characteristics which may occur in the r-profile are expected to have spread over large spaces and thus disappeared from the magnitude data.

5 Conclusions

Mainly based on northern hemisphere visual data, the average population index for the entire year neglecting all temporal variations is $r = 2.95 \pm 0.06$. This is very close to the generally adopted value of $r = 3.0$.

A decrease of the r-value from 18^{h} LT towards the morning (06^{h} LT) can be explained by the generally increasing portion of brighter meteors from the apex source in the course of the night. This is also supported by the steeper gradient in northern fall when the apex source reaches the highest altitude in the morning sky.

Annual variations are found in both hemisphere data sets. The southern average population index r is about 0.5 lower than the northern data average. Since the southern data are scarce, the temporal resolution is poorer (15°) than in the northern data (7.5°). A general trend shows an amplitude of the annual variation of $r \approx 0.15$ with a minimum in the early summer period and a maximum in the fall of both hemispheres. Close to the maximum activity periods of major meteor showers the values of r are obviously affected by misclassified shower meteors. Nevertheless, there are further distinct maxima and minima indicating either the existence of minor meteor showers below the detection limit or the presence of peculiar meteoroid groups with different size distributions. A comparison with a study of sporadic meteors in the period 1944 – 1953 (Štohl, 1976) reveals no coinciding features. This may be a hint of a rather short lifetime (presumably < 20 years) of such groups or a pure statistical fluctuation in the data.

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