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THE DIURNAL AND ANNUAL VARIATIONS OF SPORADIC METEORS

Abstract: A number of visual and radar series of observations made in different geographical latitudes are examined for the two-dimensional diural—seasonal variation in the frequencies of sporadic meteors. Dealt with is the effect of streams on the determination by different techniques of the variation in the sporadic rate. It is seen that the half-year phase-displacement of the annual activity maximum of sporadic meteors on the southern sky is real.

A new method is used to examine the annual variation in the activity of the principal radiant sources of sporadic meteors (model: apex, helion, antihelion, background) in Springhill radar data. Assumed for the computations was the dependence of $f \sim \cos^n z$ of the frequency observed upon the radiant's zenith distance; from the three exponent values considered ($n = 1.0, 1.5, 2.0$), the results for $n = 1.0$ were the most consistent. Fig. 7 shows the variation in the activity of the individual sources. Considered is a possible explanation of the variation differing from that obtained by Keay for the southern hemisphere.

1. Introduction

Examining the problem of the origin of sporadic meteor component we must do better than roughly investigate meteor frequencies and their diurnal or seasonal variation. However, accurate orbits are known so far only for a limited number of relatively bright meteors. Thus it will be of advantage to use for an over-all investigation of sporadic meteors also the two dimensional diurnal—seasonal variation. This analysis is feasible in the available homogeneous and fairly abundant observational series obtained by different methods and techniques in different geographical latitudes.

The two-dimensional variation was already examined for telescopic meteors (Kresák, Kresáková 1961, 1966), meteorite impacts (Kresák 1963) and for radar observations of meteors from the southern hemisphere (Ellyett, Keay 1963). It also was determined for Olivier's material (Keay 1964) which, however, is rather non-homogeneous. Moreover, comparing the northern and southern hemisphere, a few inaccuracies occured to Keay which reduce the applicability of his conclusions or even invalidate them. For instance, comparing his material with Olivier's, he failed to tell the northern Perseids from the southern δ-Aquarids, which follow closely one after the other, so that his deductions on the age of the latter are unsubstantiated. Confronting his results with Kresák's meteor analysis, he shifted the scale of the distribution of meteorite impacts in time, which largely affects his conclusions as to an equal meteor activity on the northern and southern hemisphere.

A comparison of the two-dimensional frequency variation from the northern and southern hemisphere is especially valuable for determining the exact contribution of the individual principal factors to the variation, and thus also for establishing the actual distribution of the orbits of meteor particles over the different parts of the Earth's orbit. An analysis of sufficiently ample and homogeneous data may yield important particulars also of the yearly changes in the activity of the principal radiant sources of sporadic meteors.

The following is an analysis of the two problems set, that is of the variation in both the frequencies and activity of radiants. This analysis is based on visual and radar materials obtained on the northern and southern hemisphere. Some of the basic data are published in the preceding paper (Štohl 1967).

Table I

LT / ⊙	18	19	20	21	22	23	00	01	02	03	04	05
0			7.2	7.6	9.9							
10			4.5	8.4	11.9	10.0						
20			9.1	12.6	8.5	15.0	10.5	9.2				
30				9.4	9.3	11.9	7.8	9.1	10.4	19.4		
40				5.8	8.8	7.4	12.5	12.0	10.8			
50				6.4	7.3	8.2	7.7	6.4				
60					8.1	9.8	12.2	32.2				
70					7.1	7.9	5.9	3.7				
80					9.9	9.5	12.2	8.2				
90						26.4						
100					9.5	12.0	17.7	13.5				
110					9.8	15.6	14.5	17.4	7.7			
120				17.4	16.5	20.0	20.3	23.0	21.7			
130				14.3	13.5	18.7	25.7	25.2	27.5	23.4		
140			12.4	13.2	15.4	16.3	22.7	27.0	18.6	17.9		
150			13.5	11.7	16.2	14.3	16.4	21.3		13.2		
160			11.7	11.7	14.9	15.3	17.7	17.4	16.4	15.9		
170		8.8	10.5	12.1	13.3	18.8	16.2	24.9	25.1	22.3	17.1	
180			11.7	13.6	18.9	18.6	17.2	18.2	18.6	18.4	22.8	
190		12.7	10.5	10.3	19.4	17.2	18.5	20.0	20.5	20.4	25.9	
200	12.6	9.6	13.9	20.5	9.2	12.6	16.5	21.5	14.8	16.2	16.5	15.5
210	20.8	14.4	16.3	12.8	13.5	15.9	17.1	17.9	20.7	21.8	20.1	10.9
220	11.8	9.7	14.6	11.9	18.2	23.0	13.0	18.6	26.9	12.3	20.4	15.2
230	12.6	12.0	17.8	16.3	20.8	16.0	17.8	23.1	25.7	18.7	13.1	10.8
240	6.9	9.6		16.9	14.7			14.8	17.1		20.0	26.1
250			13.9	13.3	8.1	9.8			19.0	20.9	16.8	
260	9.0	6.3	6.2	13.8	12.5	10.0	11.0	15.9				
270	5.3	4.8	12.7	6.8	8.0	13.8	11.4	9.7	6.2	7.9		
280	9.2	10.2	10.4	8.3	8.5	12.4						
290			7.2	8.6	9.3	5.8	10.7	16.7	8.7			
300			9.7	9.4	8.7	9.5						
310		4.8	4.7	7.8	8.6							
320			7.3	6.3	11.5	9.2	10.6					
330			7.1	9.5	9.9	9.4	15.9			7.9	8.9	12.7
340		4.3	6.9	8.3			15.5					
350			10.1	5.2	7.0	6.8						

2. *Observational material*

Our analysis uses, on the one hand, visual meteor observations of the Skalnaté Pleso Observatory and from Olivier's catalogues and, on the other hand, radar recordings from Springhill, Jodrell Bank, Kharkov and Christchurch. The anabridged material of Skalnaté Pleso (geographical latitude 49.2 N) is given elsewhere in this volume. Tab. I lists the average frequencies f', reduced by the method of personal factors, for each hour of local time and each 10° of solar longitude ⊙. The corresponding number Σn of meteors observed and the total net observational time $\Sigma\tau'$, corrected for the coefficients of cloudiness and the personal coefficients (Štohl 1969), is given in Tab. Ia.

The visual material in Olivier's two catalogues (1960, 1964) comprises observations by a large number of observers, mostly members and collaborators of the American Meteor Society, from between 1901 and 1963. Although extraordinarily extensive, the material is rather heterogeneous. This is due especially to the largely differing qualities of the observers, whose frequencies, in addition, were not reduced to the standard observer, to the fact that observations from localities of different geographical latitudes were not distinguished from each other, and to the diverse method of selecting observations in different periods of the

Table 1a

LT ⊙	18	19	20	21	22	23	00	01	02	03	04	05
0			69 7	432 42	674 90							
10			296 18	897 99	661 98	279 36						
20			222 29	432 54	1450 171	235 33	388 63	156 23				
30				559 74	599 78	778 117	882 95	273 35	382 59	79 22		
40				36 3	321 31	96 10	98 16	525 94	807 123			
50				30 3	773 79	587 72	69 8	117 11				
60					168 20	260 35	223 36	36 16				
70					302 31	806 85	268 23	148 8				
80					244 26	708 90	388 67	89 11				
90						30 13						
100					199 21	611 98	612 158	345 68				
110					1364 183	2058 392	1336 245	676 143	84 8			
120				177 44	3027 638	5283 1306	5212 1344	5360 1563	2548 708			
130				293 49	1059 177	2163 468	3294 986	2767 801	2451 811	98 29		
140			82 14	1407 273	2296 486	2786 624	1277 381	1029 346	1237 315	273 64		
150			328 61	1733 291	1908 420	1010 206	1168 249	465 126		28 6		
160			341 58	1965 330	865 185	913 195	528 138	806 190	914 203	548 119		
170		81 11	1150 174	2658 482	1752 352	545 150	461 105	290 97	509 168	576 171	57 14	
180			669 111	1639 328	874 247	824 228	517 133	659 181	711 195	431 114	63 23	
190		466 93	720 117	222 39	222 52	395 98	664 177	265 72	251 73	551 167	256 84	
200	37 7	103 16	119 29	74 20	272 42	283 50	576 129	979 304	994 234	724 180	697 181	54 13
210	25 6	29 5	351 66	765 120	432 78	126 27	88 19	337 71	414 109	591 180	321 109	63 11
220	234 43	469 66	559 119	699 116	406 106	244 80	123 24	105 30	25 10	139 25	233 75	144 35
230	118 18	260 37	419 79	262 68	111 38	140 31	68 19	180 69	120 53	499 113	266 44	22 4
240	134 13	132 18		271 58	279 55			157 39	49 14		85 30	138 61
250			392 78	444 79	180 18	33 4			96 27	249 68	135 39	
260	99 12	160 15	76 7	495 55	1455 254	1124 168	556 96	578 116				
270	278 20	122 8	168 28	839 80	355 37	490 104	295 58	240 40	81 8	32 4		

Continuation Table Ia

LT ⊙	18	19	20	21	22	23	00	01	02	03	04	05
280	184 26	353 50	649 94	1209 133	365 40	135 26						
290			433 42	747 89	510 70	33 3	48 8	48 14	72 11			
300			233 36	632 88	382 53	222 34						
310		210 15	705 48	792 83	514 51							
320			279 31	228 22	180 20	117 16	63 10					
330			508 55	393 51	66 7	143 22	36 10			214 25	180 24	33 7
340		93 6	291 26	215 17			33 8					
350			292 39	493 35	980 91	279 26						

year. Using this material we have to bear in mind that it also comprises southern observations (about 3 %) which may contribute, in a certain degree, to enhanced activity during the period of southern streams, or affect the seasonal variation. The mean geographical latitude of the observational sites is 36° N on the northern and 39° S on the southern hemisphere.

The catalogue of the Skalnaté Pleso observations contains data only on sporadic meteors. For better comparison of this material with Olivier's data we eliminated, also from his material, all observations from the periods of activity of major meteor streams.

The preliminarily published radar material from Springhill (geographical latitude 45°.2 N) (Millman, McIntosh 1963) comprising a total of 4.4 million echoes recorded from October 1957 to December 1960 is the most abundant and at the same time most homogeneous material published so far. It is therefore well suited for both examining the form of the two-dimensional variation and analysing the activity of sporadic radiants. Unfortunately, the material has so far only been published in preliminary form and only gives frequencies in monthly averages, so that it does not indicate short-duration changes in seasonal variation. The same problem exists in the Kharkov (geographical latitude 50° N) material (Kaščeev et al. 1962). This should be remembered when comparing these materials with other data which permit investigations of the variation on a finer scale over the year.

The Jodrell Bank (geographical latitude 53° N) catalogue of radar observations (Evans 1960) unfortunately contains numerous inaccuracies which largely reduce its value (discordance between the data on the number of echoes and observational hours for individual hours and for their daily sums, especially for the period November 1956—March 1957). Data with the most marked disproportions were therefore eliminated from the treatment.

Particularly valuable is the material obtained by Ellyett and Keay (1963) at Christchurch (geographical latitude 43°.6 S). This material permits to evaluate the effect of the position of the observational place on the meteor frequencies observed, i.e. on the activity of sporadic radiants.

The two—dimensional frequency variation from Skalnaté Pleso is given in Fig. 1. The isopleths connect points with equal relative density F, determined with regard to the yearly weighed mean $\overline{f} = 17.2$ of Skalnaté Pleso. Fig. 2 shows the two—dimensional variation, for Skalnaté Pleso (SP) and for Olivier's catalogue (OL 1 and OL 2) plotted for the same values of densities.

The form of the two-dimensional variation in radar echoes is given in succession in Fig. 3 and Fig. 4 for the material of Millman (MI), Kaščeev (KA), Evans (EV) and, eventually, for Ellyett's (EL) southern observations. The isopleths connect points with equal relative density F (graduation by 0.4) determined in relation to average yearly unweighed frequencies. The corresponding absolute frequencies f are in Tab. II.

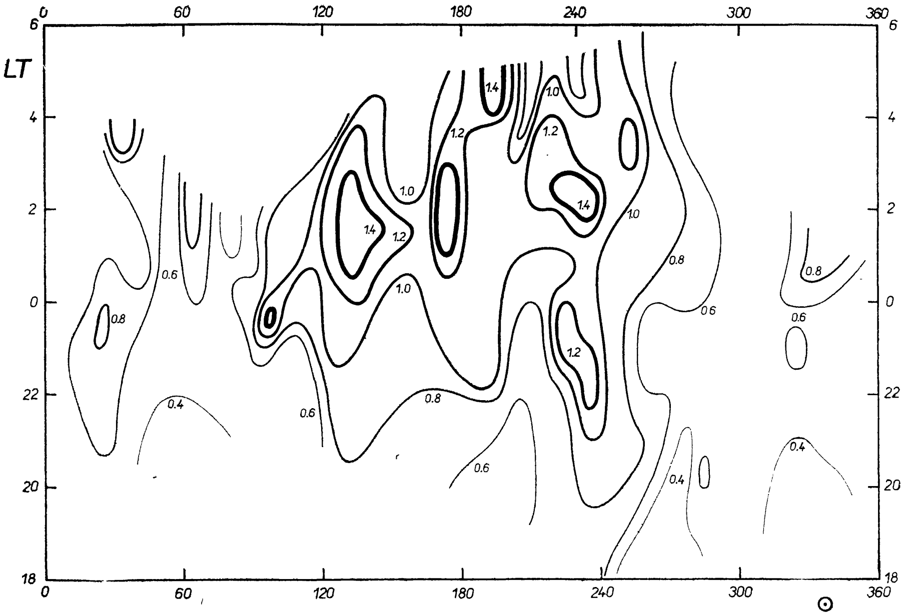

Figure 1.

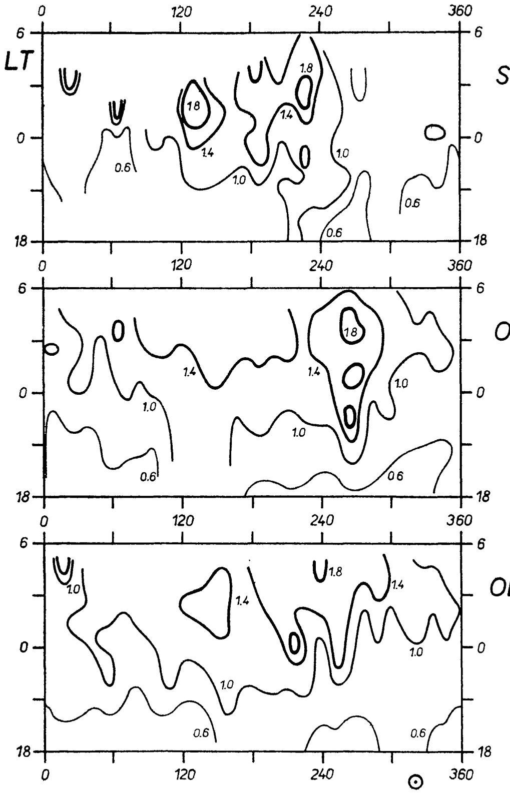

Figure 2.

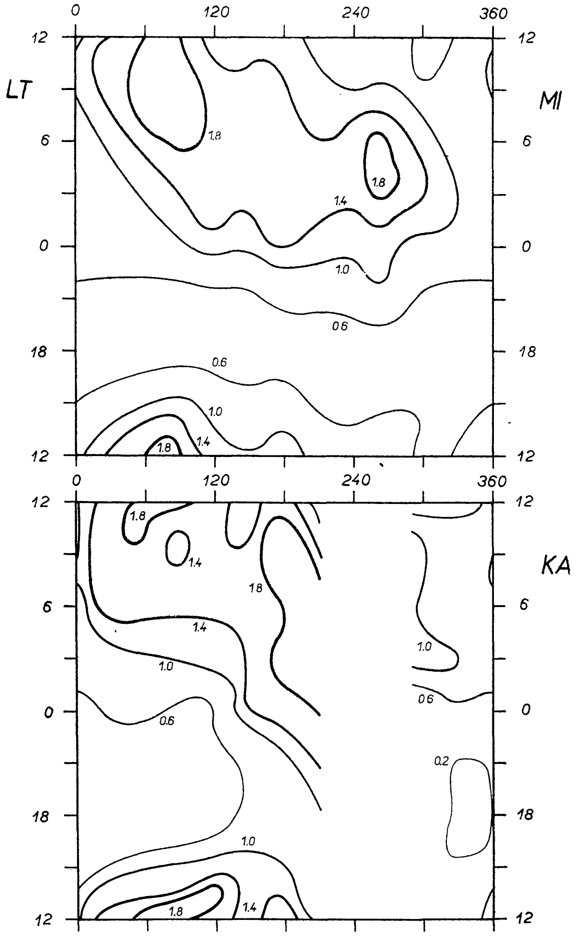

Figure 3.

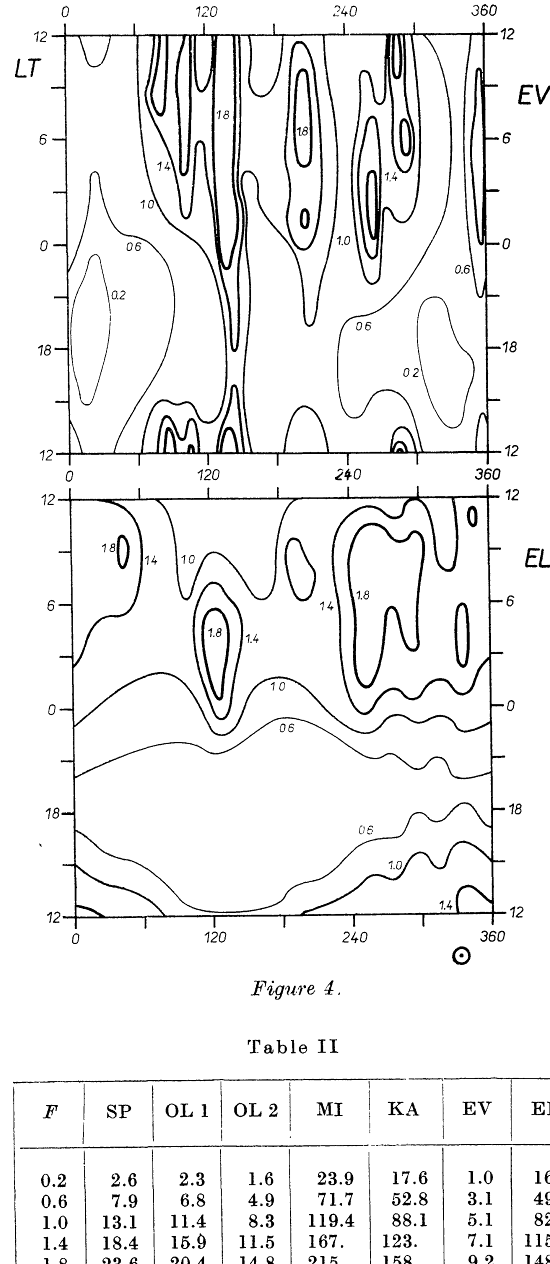

Figure 4.

Table II

F	SP	OL 1	OL 2	MI	KA	EV	EL
0.2	2.6	2.3	1.6	23.9	17.6	1.0	16.4
0.6	7.9	6.8	4.9	71.7	52.8	3.1	49.3
1.0	13.1	11.4	8.3	119.4	88.1	5.1	82.1
1.4	18.4	15.9	11.5	167.	123.	7.1	115.
1.8	23.6	20.4	14.8	215.	158.	9.2	148.

3. *Discussion of the two—dimensional variation*

The curve of the frequencies observed at Skalnaté Pleso (Fig. 2) has a prominent maximum in the autumn period between ⊙ = 160—260°. In the relatively continuously varying background, however, we may determine also local frequency enhancements which correspond to the major showers. Especially prominent is the activity of δ—Aquarids and Perseids (120—150°), Taurids and Leonids (210—240°), less pronounced that of the Lyrids. This is a surprising fact, since the shower meteors were eliminated from the material, just as was eliminated the sporadic background from the periods of maximum shower activity. This may evidently be accounted for by the fact that the rather scattered stream meteors which revolve in the wings of the streams are dificult to identify if frequency is low, and are classified by observers as sporadic meteors. This effect is not equal for all streams, however, it may largely distort the determined seasonal variation of sporadic meteors.

The contribution of meteor showers appears different in the frequencies given in Olivier's catalogues, where shower meteors have been eliminated by another method, mentioned above. In this connection it is worth noting that the differences are large even between Olivier's two catalogues. The Geminids, prominent in his first catalogue (OL 1, Fig. 2), are almost absent in his second catalogue (OL 2, Fig. 2). Their activity is completely absent also in the Skalnaté Pleso material (SP, Fig. 2). The activity of the August streams, on the other hand, is marked in catalogue OL 2. Both Olivier's catalogues suggest the activity of a minor stream between ⊙ = 20 and 45°, with the maximum shortly after midnight. The differences noted in the streams, except the effect mentioned above, may be largely due to the non-homogeneity of the material.

The visual data indicate quite an evident seasonal variation in sporadic meteor rates, irrespective of the effect of streams. It is much more marked in the daily minimum frequencies, which are not so largely influenced by streams as the maximum frequencies, in which the activity of the sporadic background may be masked by active streams.

All visual materials (SP, OL 1, OL 2) concur in that they show that the most prominent continuous minimum activity of sporadic meteors lies between ⊙ = 300 and 50° in the course of the year. The activity, however, is not sufficiently distinct, the observations having been made during night hours only. In this respect the radar material may give more information.

All northern radar materials are characterized by a prominent maximum in the daytime hours from May to July. It is due to a complex of summer day-time showers whose maximum activity is in June. The activity of this complex has the same form in both Millman's and Kaščeev's results. The activity begins to increase at ⊙ = 40° (beginning of May) and it continues until the first half of July, ⊙ = 100 to 110°. The course of the activity given by Evans is slightly different. The daily variation, however, in all three cases is equal, having a marked activity of the complex of day-time streams from the early morning hours until about 2 p.m.

Prominent in Millman's material is also the Geminid shower. Kaščeev has no data for this period. Marked are the Geminids also in Evans' material, but so are other showers, especially the δ-Aquarids and Perseids, the Orionids and the Quadrantids. These showers are not recorded in Millman's and Kaščeev's materials. This is easy to understand for showers of short duration, such as the Quadrantids, for they cannot appear in the monthly frequencies, as given by Millman and Kaščeev. In the case of abundant showers of long duration, however, such as the Orionids but especially the Perseids, the cause has deeper roots. Evans evidently recorded brighter meteors, and among them the Perseids are outstanding. In Kaščeev's and Millman's materials of much fainter meteors, the activity of the bright Perseids is lost in the sporadic background, which is in connection with the relatively low slope or kink of their magnitude function (Kresáková 1958). Such may also be the cause of the time lag in the activity of the summer day-time showers in Evans' material or, with regard to the steeper slope of their magnitude function, also of their occurence among fainter meteors.

The most outstanding complex of radiants in Ellyett's and Keay's material is the one pertaining to the Puppid and Velaid streams. It is active from the beginning of November till the end of January (Ellyett et al. 1961) in the morning hours. In this material, however, we see also other showers, such as the day-time Aquilids in the second half of February, the η-Aquarids in the first half of May, and the Sagittariids in May and June. Outstanding is the prominent maximum of the δ-Aquarids between $\odot = 105$ and 145°, they are the most abundant stream on the southern sky. The northern Perseids naturaly cannot show here.

The autumn maximum of sporadic meteors is almost completely lost in the shower activity in the northern radar materials. Much more distinct is the yearly minimum activity which is, for all these materials, in the spring months between $\odot = 300$ and 30°. In the southern material, the curve of the activity is completely reversed. The maximum of sporadic meteors occurs in the first half of the year, as also borne out by the marked drop in activity between $\odot = 100$ and 220°, that is from July to November, most prominently in September. This is another confirmation of the half-year phase displacement on the southern hemisphere.

An analysis of the two-dimentional diurnal-seasonal variation in different materials and their intercomparison permits certain conclusions as to the activity of sporadic meteors all through the year:

1. The activity of meteors gradually increases and extends on the northern sky from 0 to 180° in the direction from daytime trough the early morning to the night-time hours. The extension of the activity over night-time hours is seen in all materials and almost in the same form. The meteor activity drops abruptly between $\odot = 300°$ and 330°. The frequency minimum occurs in the evening hours of the period 300—30° and a secondary minimum occurs in the period 150—200°.
2. The frequencies of the southern sky are inverse to those of the northern sky. The maximum extends from $\odot = 230$ to 300°, and less continuously from 330 to 50°. A broad marked minimum lies between 100 and 220° in the second half of the year, a secondary minimum occurs in February and March (300—350°).
3. The frequency variation for the southern hemisphere is displaced by half a year in comparison with that of the northern hemisphere, and the apparent activity of sporadic meteors is thus primarily determined by the geometric conditions of the observations.
4. The complex of northern day-time streams in the spring and summer months is so markedly diffuse that it cannot be completely told from the sporadic background. Similar is the effect of the complex of the Velaid and Puppid streams on the southern sky during the winter months. Their activity may be considered a broad meteor flow comprising a large portion of apparent sporadic meteors. It is quite possible that both these complexes correspond to a single broad meteor stream.

4. *The seasonal variation in sporadic meteor rates*

We have seen that the seasonal variation in sporadic meteor rates determined from frequencies obtained by different procedures, for different intervals of the day, and in localities with different geographical latitudes, will necessarily be markedly distorted by the activity of shower meteors. It is not always simple to eliminate the activity of streams and so to obtain the variation in true sporadic meteors. One of the possibilities to achieve this separation is the analysis of the magnitude function in so far as we have the necessary data on it. The effect of streams may also be better assessed by examining the seasonal variation for different day- and night-time hours (Millman, McIntosh, 1963).

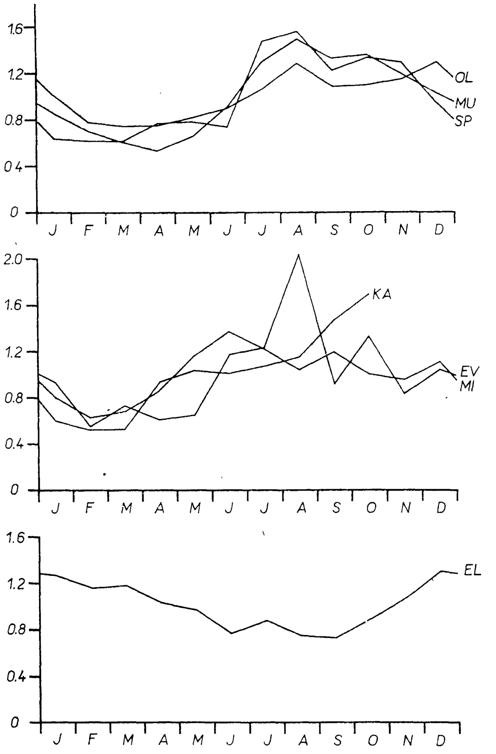

Figure 5.

Fig. 5 shows the trend of relative frequencies in the individual materials over the year, summarily for all hours of the whole day and night observed. Olivier's material (OL) is given summarily for both catalogues, and for comparison we give among the curves of the visual materials (above in Fig. 5) also Murakami's visual frequencies (MU 1955) determined from the observations made by the members of the Oriental Astronomical Society in the geographical latitudes about +35°.

The height of the maximum given in the visual materials, which show, on the whole, an equal course of activity, is to a certain degree influenced by the geographical latitude of the observatory. The frequencies in SP and MU, which were obtained within narrow intervals of latitudes (+48° or +35°), have a very similar variation curve. The variations in OL, including the data from the southern hemisphere, are less contrasting: the ratio of the maximum to the minimum is reduced.

The northern radar material yields, as expected, quite another curve form of activity in comparison with the visual curves, with a prominent contribution of major showers. This contribution is markedly distinct even in the radar materials themselves. Prominent is especially the activity of the day-time summer showers, as recorded by Millman, and of the Perseids in the Evans' material.

In order to facilitate the comparison between radar and visual frequencies, Fig. 6 gives the frequencies from materials MI and EL separately for different hours, namely for local midnight, for local noon, and for the evening hours (18 h. LT).

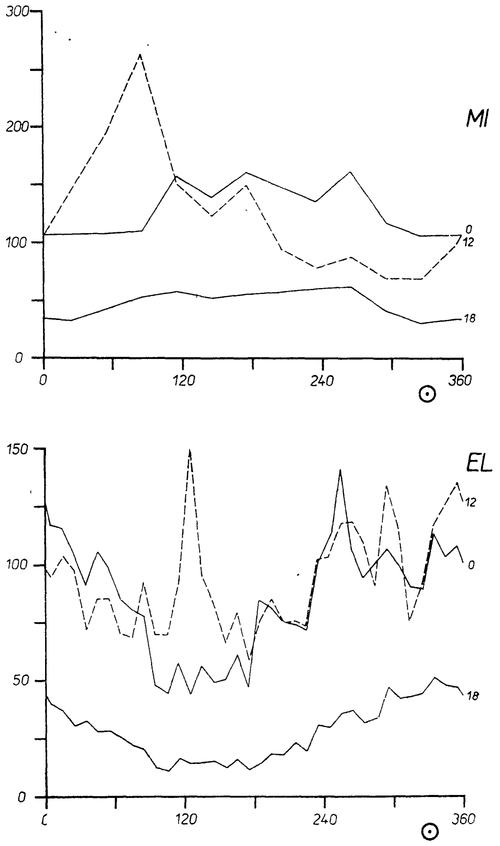

Figure 6.

The midnight variation in MI corresponds fairly well with the visual observations. The diurnal curve is prominently marked by day-time summer showers. The maximum of the evening frequencies is in the autumn months, but they are largely influenced by the δ-Aquarids and Geminids.

The variation in the southern EL material is more conform for the individual hours. Consistent in this case, are especially the day- and night-time curves, irrespective of the fact that the night-time curve shows a marked activity of the δ-Aquarids or Velaids—Puppids. Characteristic is the variation in the minimum frequencies during the evening hours which indicates quite unambiguously the southern maximum in March.

5. *Determination of the activity of sporadic meteors*

Observations only give the meteor frequency for a given locality and time. If we wish to reduce the meteor frequency observed to the spatial density of meteor orbits along the Earth's orbit we have to know the distribution of the radiants of sporadic meteors, which is closely connected with the frequency.

The distribution of the radiants of sporadic meteors may be considered symmetrical about the ecliptic plane. The radiants are known to be concentrated into several regions, mainly into two regions in the ecliptic, 60° to 70° to both sides from the apex, not so much into the region of the apex itself and into the toroidal sources in the ecliptical latitude circle of the apex, 60°—70° from the apex (Davies, Gill 1960; Weiss, Smith 1960).

Advantageous for statistical investigations is the schematic model of the distribution of apparent sporadic radiants with the following four components (Keay 1963): 1. apex source A with source strength 1 and radiant position in the apex ($\lambda_A = \odot - 90°$, $\beta_A = 0°$), 2. helion source H with source strength 2 and position ($\lambda_H = \odot - 30°$, $\beta_H = 0°$) 3. antihelion source AH with source strength 2 and position ($\lambda_{AH} = \odot - 150°$, $\beta_{AH} = 0°$), 4. source of sporadic background with uniformly distributed radiants on the sky and with integral source strength 1.

This model cannot be sufficient for closer investigations, as it does not consider possible seasonal changes in the relative contribution of the individual sources. As Keay (1963) showed, and as is seen in Davies and Gill's papers (1960), the relative strength of these sources changes markedly over the year. For southern observations, the source strength of the H-source changes between 0.8 and 3.7, that of the AH-source between 1.1 and 4.0 in comparison with the A-source as a unit.

In the following we shall design a method which will permit to determine the variation in the activity of presumed radiation sources from a sufficiently abundant observational series. This method will be also used to determine the seasonal variation in the distribution of sporadic radiants for the northern sky.

The frequency f_s of sporadic meteors observed in a certain time interval is given by superimposition of the activity of all radiants above horizon. Using a suitable model of radiant distribution, we may express this superimposition by the sum

$$f_s = f_0 + \sum_{i=1}^{k} f_i(z), \qquad (1)$$

where f_0 is the frequency of the uniform background and $f_i(z)$ the frequencies of the individual radiant sources in the total number k. Frequencies $f_i(z)$ are given by both the source strengths $f_i(0)$ of these sources and their zenith distances z_i. For the interval $22° \leqq z_i \leqq 90°$, within which vary the zenith distances of the three principal sources (the toroidal source is not considered so far) for Springhill, we shall adopt for the relation between $f_i(z)$ and z_i the formula

$$f_i(z) = f_i(0) \cos^n z_i \qquad (2)$$

The value of exponent n is not sufficiently certain, even for visual observations it is normally considered $n = 1$, in keeping with the simplified geometric conception. For a given observational site with the geographic latitude φ we may replace the zenith distance by the coordinates of the radiant sources

$$\cos z_i = \sin \delta_i \sin \varphi + \cos \delta_i \cos \varphi \cos t \qquad (3)$$

Substituting equations (3) and (2) into (1) we obtain

$$f_s = f_0 + \sin \varphi \sum_{i=1}^{k} f_i(0) \sin \delta_i + \\ + \cos \varphi \cos t \sum_{i=1}^{k} f_i(0) \cos \delta_i \qquad (4)$$

Although we take into account the seasonal variation in the activity of sporadic radiants, and thus also the variability of quantities $f_i(0)$, for a certain chosen, sufficiently short time interval we may consider these quantities constant. If the time interval chosen is one day, the observed frequencies $f_i(z)$ will vary according to (2) and (3) through that day. They will vary in dependence upon the hour angle given by local time T_L. Equation (4) may be designed for an arbitrary number m of T_L values, which gives us a system of m condition equations for k unknowns. The unknown quantities will be the source strengths f_0 and $f_i(0)$; frequencies f_s given by observation, and time T_L, given by the time interval will vary. Solving this system of equations by the method of least squares we obtain the values of source strengths f_0 and f_i (0). If we solve the system for more yearly time intervals, we obtain the seasonal variation in the presumed sources of sporadic radiants.

The foregoing consideration may be extended for the presence of active streams, which gives equation (1) in the form

$$f_s = f_0 + \sum_{i=1}^{k} f_i(Z) + \sum_{j=1}^{l} f_j(Z), \qquad (5)$$

where l is the number of active streams and $f_j(Z)$ their observed frequencies.

6. *Analysis of the variation in sporadic radiants*

The above method was used to determine the variation in the activity of sporadic radiants on the basis of the Springhill radar material, mentioned earlier. The published data of this material give the frequencies only in averages for whole months and for each hour of the day. Thus we shall have to compute 12 systems, each comprising 24 equations.

The Springhill radar material naturally also includes shower meteors, whose effect has to be eliminated from the results. This may be done by two methods:

A: We may ignore the showers in the computation itself, consider the frequency enhanced through their activity formally as activity of sporadic meteors, and evaluate the contribution, if any, of the showers only in the results for the source strength of the individual sporadic sources according to the position of the active-shower radiants.

B: We may solve the system of type (5) equations with the number of unknown quantities extended by the shower frequencies, f_{i0}, which eliminates the effect of the showers already in the computation.

In order to eliminate the shower activity as reliably as possible from the activity of sporadic radiant sources we shall use both methods. For the computation by method B we shall, for simplicity, only use the two most efficient showers in each yearly interval considered. These streams are summarized in Tab. III.

Table III

	Sh I	α	δ	Sh II	α	δ
I.	CrB	230°	+27°	Qua	231°	+50°
II.	Aur	75	+42	CrB	230	+27
III.	Boo	220	+10	Vir	190	0
IV.	Lyr	272	+32	η Aqr	336	0
V.	Ari D	45	+23	η Aqr	336	0
VI.	Ari D	45	+23	ζ Per D	62	+24
VII.	δ Aqr	339	0	β Tau D	87	+20
VIII.	δ Aqr	339	0	Per	46	+58
IX.	Aur	86	+41	Scl	80	—26
X.	Dra	262	+54	Ori	95	+15
XI.	Tau	54	+21	Leo	152	+22
XII.	Gem	113	+32	Urs	217	+80

For the computation itself we assume the model of sporadic radiant distribution given above. Thus, our equations will have four unknown source strengths f_0 for S, $f_i(0)$ for A, H, AH if we use method A, and 6 unknown source strengths (in comparison with the foregoing, $f_j(0)$ are added for two streams, R1 and R2) if we use method B.

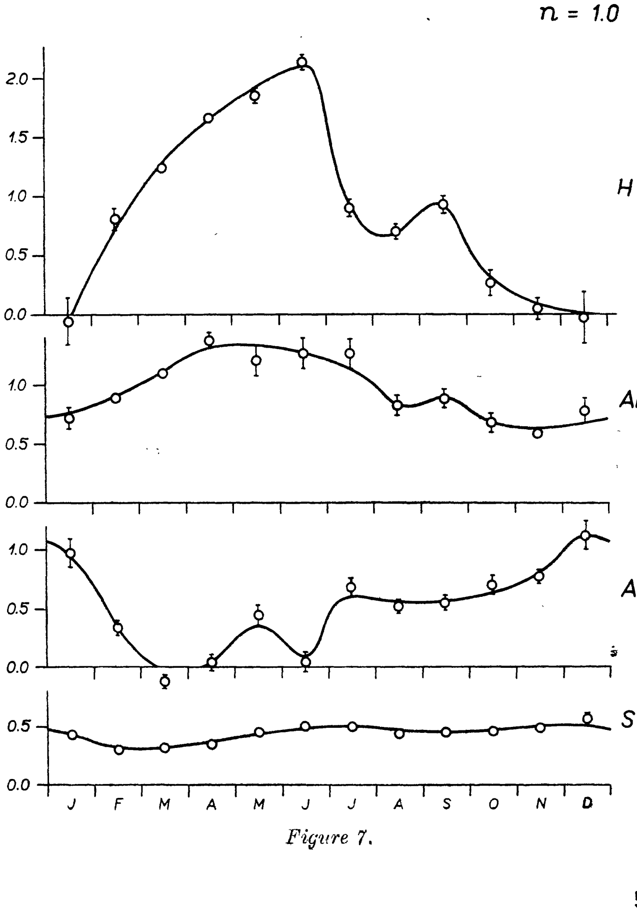

Figure 7.

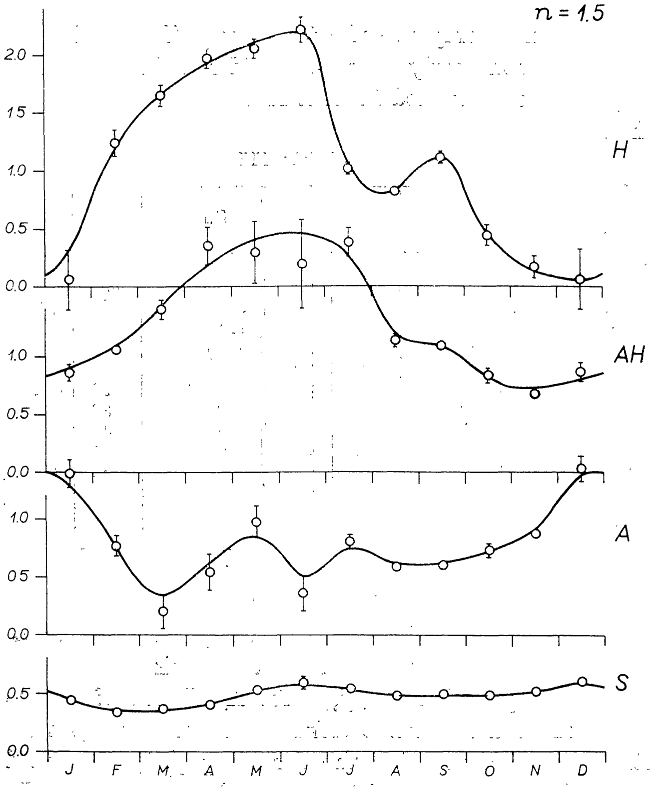

Figure 8.

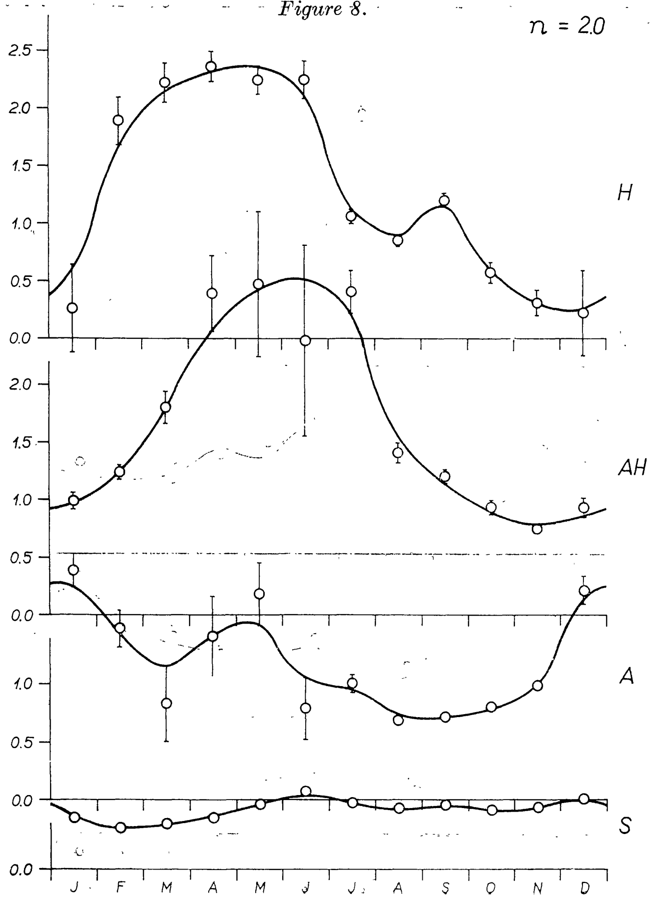

Figure 9.

All numerical computations were made on the ZRA-1 computer.

The results which were obtained by method A are given in Figs. 7, 8 and 9, respectively, for variants $n = 1.0$, 1.5 and 2.0. The strength of the individual sources is given in relative units, the unit being the mean yearly frequency $f = 119.4$ of Millman's material. Given for each monthly value are the mean errors computed from the residuals of the least-square solution. It is seen that the residuals are smallest for $n = 1.0$. The error in the determination of the source strength of the sporadic background is equal for all three solutions (± 0.03). The errors in the individual discrete sources for the solution using the exponent $n = 2.0$ are ± 0.18, for that using exponent $n = 1.5$ they reach the average of ± 0.11 and for that using coefficient $n = 1.0$ they are only ± 0.08. Thus the solution with the dependence of the frequency observed upon the first power of the cosine of the radiant's zenith distance is the best of all approximations to reality considered. In our further analysis we shall therefore only consider this possibility, that is the one for $n = 1.0$, as a reasonable approximation.

Fig. 10 shows the solution by method B in which two unknown frequencies of active showers are considered in addition. It is obvious that the solution by this method is much less reliable. The mean error in the strenght of the sporadic background is ± 0.33, the errors in the individual sources are, on the average, ± 0.28, which are values relatively higher than for method A. The poorer reliability of these results is also indicated by the very irregular variation in the source strength of sporadic meteors. The results are markedly distorted, evidently by the fact that the activity of a certain shower has formally always been extended over the whole month, regardless of the actual duration of the shower. This led to large overestimation of some showers and to a reduction of the frequency of the sporadic sources themselves: its values worked out negative in certain cases. The determined frequencies of the individual showers under consideration are given in Tab. IV., listing, for comparison, also the maximum frequencies f_M and duration d of the activity over the interval when the shower frequency should not drop below one fourth of the maximum frequency. These data have been taken from Millman and McIntosh's paper (1963) and are based, in the main, just on the Springhill observations. If conditions are favourable (position of the radiant and duration of activity) even a weak stream shows very prominently, while the activity of certain very abundant streams may almost completely disappear. The determined shower frequencies are evidently affected by other influences, since many abundant streams appear almost extinct (Orionids, Lyrids) or even have a formally negative frequency (Perseids), while a number of minor showers have a frequency unrealistically high (Ursids, Draconids), even higher than simultaneously active major showers (Ursids-Geminids). Decisive in this case is evidently also the fact that even the model of the four sporadic sources and the accepted dependence of frequency on the zenith distance of the radiant are no sufficient approximation to reality. Thus method B gives no satisfactory solution in our case, even though the results (with regard to the shower activity) do not differ too markedly from those of the more reliable method A.

Table IV

Shower	Month	f_c	f_M	d
Qua	I.	0.39	40	0.6
CrB	I.	0.71		
	II.	—0.09		
Aur	II.	—0.39		
Boo	III.	—0.18		
Vir	III.	0.07		(20)
Lyr	IV.	0.29	12	2.3
η Aqr	IV.	0.11	20	18
	V.	0.08		
AriD	V.	—0.08	60	22
	VI.	0.46		
ζ PerD	VI.	0.58	40	20
β TauD	VII.	2.49	30	14
δ Aqr	VII.	0.06	20	20
	VIII.	0.44		
Per	VIII.	—0.77	50	5.0
Aur	IX.	0.84	30	1
Scl	IX.	—0.52		
Dra	X.	1.14		
Ori	X.	0.17	25	8
Tau	XI.	—0.33		(45)
Leo	XI.	0.36		4
Gem	XII.	1.11	50	6.0
Urs	XII.	3.63	15	2.2

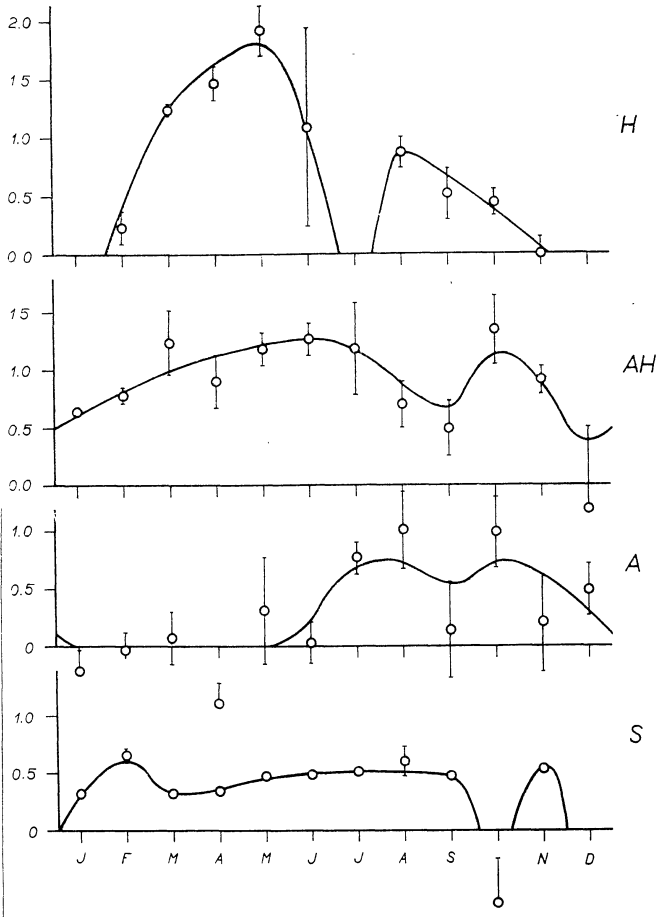

Figure 10.

We shall now discuss more in detail the activity of the individual sporadic sources in the course of the year.

1. Helion source. It has a prominent broad maximum in the first half of the year, and its activity completely vanishes in December and January. The activity is enhanced already in February, it gradually increases to reach its maximum in June, and to drop steeply afterwards. This activity is evidently due to a complex of radiants which comprises also the summer daytime showers and which, together with the Sun, moves along the ecliptic. The less prominent maximum in September also appears to be real. Method B gives, in principle, equal results.

2. Antihelion source. Similarly as in the case of the helion source, the maximum is in the first half of the year, however, it is flat and unprominent. In the second half of the year, the activity decreases insignificantly. The annual variation is also

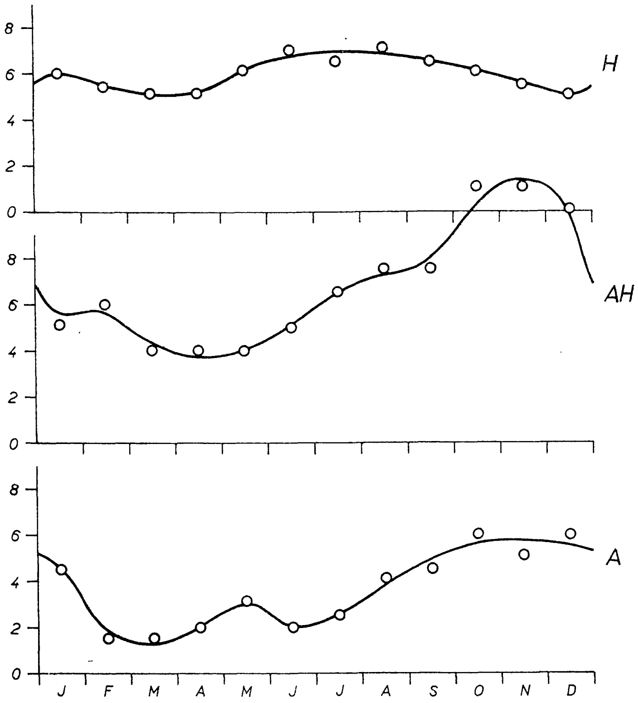

Figure 11.

slightly affected by the secondary maximum of September which occurs also in the helion source. Method B gives, in principle, the same results, with the only difference in October and November, which may be due, in the main, to the broad Taurid stream with radiants close to the antihelion.

3. Apex source. Its activity is maximum in the second half of the year, it is virtually inactive in the spring months of March and April. The shape of the curve is partially influenced by a number of showers, such as the Geminids and Leonids. The less marked local maximum in May may be due to the δ Aquarids. The B method gives virtually no activity over the first half of the year. On the other hand, the results obtained by this method are, in principle, the same as those of method A.

4. Sporadic rate. The activity of the backg-round is smooth, almost constant, throughout the year. The frequency decreases sometwhat in the first months of the year (February—March). Kresáková, Kresák (1955) found a frequency drop for telescopic meteors over this period. The agreement appears to be real. The effect of showers is less marked among the fainter meteors of the sporadic background recorded at Springhill, whose brightness is comparable to that of telescopic meteors. Thus, the yearly variation of this component may fully correspond to the frequencies of faint telescopic meteors where the effect of showers shows only slightly, due to the difference in the magnitude function of shower meteors.

The factors causing changes in the annual variation of the source strength of the individual sporadic sources are best seen if we check our results, obtained on the basis of northern observations, against the results from the southern sky, as obtained by Keay (1963b). The variation in the activity of the individual sporadic sources for Christchurch ($\varphi = -44°$) is in Fig. 11. A comparison of the northern and southern results leads to the following conclusions:

The annual variation in the activity of the apex source is virtually equal on the northern and southern hemisphere, with a marked minimum in the first half of the year. Both curves show also a secondary maximum in May. The corresponding yearly variation in the source strength of the apex source on the northern and southern sky may be explained by a real change in the density of meteors which fall onto the Earth. This change is most marked in the second half of the year and shows a real drop in February to April and in June.

The source strength of the helion and antihelion source in the northern hemisphere is the inverse of that on the southern hemisphere. Their activity is mutually exchanged and displaced in phase. The helion source on the northern sky has a prominent maximum from April to June, while its southern variation is almost smooth with a fainter maximum in the summer months. And, vice versa, the antihelion source has on the southern sky a prominent maximum from October to December, while it is relatively smooth on the northern sky, with a flat maximum in the spring months.

The northern helion source H_N and the southern antihelion source AH_S correspond therefore in the shape of their curve, but they are displaced by 180° in phase. Corresponding are also the curves of the northern antihelion AH_N and southern helion H_S sources, but they are shifted by 90° in phase. The mentioned activity of sporadic sources may be explained by assuming the activity of two extensive diffuse streams of meteor particles each of which touches the Earth twice. The activity of sources H_N and AH_S, displaced by 180° in phase, calls for a stream with an arbitrary inclination i of the orbit, but with a small perihelion distance q, approximately equal 0.5. The Earth would intersect this flow in its nodes with a half-year time interval. In the second case, in which the activity of sources H_S and AH_N is phase shifted by 90°, the orbit of the meteor stream ought to be inclined very slightly, while the perihelion distance q would have either to approach unity, approximately 0.9, or to be very small, about 0.1—0.2. In this case, to the slight inclination of the orbit would correspond also the small amplitude of the variation in sources H_S and AH_N.

The observed perihelion distances of the northern summer streams, which correspond to the maximum strength of the source H_N, reach values from 0.1 to 0.4. For the complex of the Velaid—Puppid radiants the orbit is not known so far.

Both these complexes of radiants differ in character from the sharply defined major streams of the Perseid or Geminid type, most likely also as to the magnitude function. They are diffuse systems of radiants which are not easily separable from the sporadic background. It is not excluded that both complexes form a broad stream. The enhanced activity of sources AH_N and H_S, which may be explained by the flow, with perihelion distance very small or approaching unity, reminds Hoffmeister's Taurids and Scorpio—Centaurids (Hoffmeister 1948).

In connection with the determined annual changes in the activity of sporadic meteors we may consider a new approximation of the model of these sources, in which the ecliptic latitude of the helion- and antihelion source would vary over the year. An explanation of the determined seasonal variation would require a displacement of the helion source towards northern latitudes in the spring months, with the maximum deviation in May, and of the antihelion source towards southern latitudes from the ecliptic in November.

It is worth noting that the relative source strength of the helion and antihelion sources on the northern and southern hemisphere is equal in the yearly average. Keay's paper does not show quite clearly to which extent the activity of the sporadic background has been eliminated from the activity of the individual sources. However, for the evaluation of the relative source strength we may assume that the strength of the apex source is always equal on both hemispheres. This is indicated by the fact that the variation curves coincide. If we put them equal unity, the yearly average strength of the individual sources on the northern and southern hemisphere is as follows:

	A	H	AH	S
N	1.00	1.73	1.91	0.86
S	1.00	1.67	1.91	

Taking into account this good agreement, we may consider as identical for the northern and southern hemisphere also the yearly contribution of the sporadic background. Total meteor activity is then divided among the individual sources as follows: A — 18 %, H — 31 %, AH — 35 % and S — 16 %.

In conclusion I wish to thank Dr. Ľ. Kresák for his valuable advice and comments. I am greatly indebted to Mrs. Ľ. Smíšková for helping me with the numerical computations.

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J. ŠTOHL

DENNÉ A ROČNÉ VARIÁCIE SPORADICKÝCH METEOROV

V práci sa skúma dvojrozmerná denno-ročná variácia frekvencií sporadických meteorov na základe pozorovacích radov z rozličných zemepisných šírok, a to vizuálnych pozorovaní zo Skalnatého Plesa (1944—1953) a Americkej meteorickej spoločnosti (1901—1963), severných radarových pozorovaní z Ottawy (1957—1960), Jodrell Banku (1954—1958) a Charkova (1958) a južných pozorovaní z Christchurch (1960—1961). Ukazuje sa, že chod frekvencií je silne ovplyvnený činnosťou rojov, a to aj vo vizuálnych materiáloch, z ktorých boli vylúčené všetky pozorovania z obdobia výraznej činnosti rojov. Ročná variácia sporadických meteorov sa tým môže celkom stratiť v prejave rojov. To vysvetľuje, prečo sa pri porovnávaní výsledkov zo severnej a južnej pologule dochádzalo často k protichodným záverom.

Po vylúčení vplyvu rojov a vyšetrením denných minimálnych frekvencií, ktoré nie sú natoľko ovplyvnené rojmi ako frekvencie maximálne, možno jednoznačne potvrdiť polročné fázové posunutie maxima ročnej variácie sporadických meteorov na južnej oblohe oproti chodu na oblohe severnej. Maximum na južnej oblohe nastáva v marci, minimum v septembri. Komplex denných severných rojov v jarných až letných mesiacoch a komplex južných rojov Velaid—Puppid je natoľko difúzny, že ho nemožno celkom oddeliť od sporadického pozadia, ale treba ho chápať ako široký prúd meteorov, do ktorého je sústredená veľká časť zdanlivých sporadických meteorov.

Pre predpokladané hlavné radiačné zdroje sporadických meteorov (model štyroch zdrojov: apexového A, helióonového H, antihelióonového AH a rovnomerného sporadického pozadia S) bola odvodená novou metódou ročná variácia výdatnosti. Výpočet sa uskutočnil na základe ottawského predbežne publikovaného materiálu (4 400 000 ozvien) pomocou samočinného počítača ZRA-1. Predpokladala sa pritom závislosť pozorovanej frekvencie od zenitovej vzdialenosti radiantu podľa vzťahu (2), pričom za exponent sa postupne volili hodnoty $n = 1{,}0$, $1{,}5$ a $2{,}0$. Najspoľahlivejšie výsledky sa dosiahli pri predpoklade $n = 1{,}0$, čo zároveň potvrdzuje, že pozorovaná frekvencia sa mení s prvou mocninou zenitovej vzdialenosti radiantu.

Zistený ročný chod činnosti jednotlivých sporadických zdrojov (obr. 7) sa značne líši od priebehu, ktorý odvodil Keay pre južnú oblohu. Zhodný chod v amplitúde však majú severný heliónový zdroj a južný antiheliónový zdroj, s maximami vzájomne posunutými o 180°, zodpovedajúci činnosti uvedených širokých komplexov rojov. Severný antiheliónový a južný heliónový zdroj sa zhodujú v menšej amplitúde, fázove posunutej o 90°. Tento efekt pripúšťa vysvetlenie v činnosti dvoch širokých difúznych prúdov s ľubovoľným sklonom a periheliovou dištanciou 0,5, resp. s malým sklonom a periheliovou dištanciou 0,1 až 0,2 alebo 0,9. Apexový zdroj má na severnej i južnej oblohe prakticky rovnaký priebeh s maximom v druhej polovici roka a so zreteľným minimom v marci—apríli. Vysvetliť ho možno reálnou zmenou hustoty meteorov dopadajúcich na Zem. Činnosť sporadického pozadia je počas roku celkom vyrovnaná s malým poklesom vo februári—marci, ktorý je v zhode s poklesom činnosti teleskopických meteorov. Výdatnosť jednotlivých zdrojov je v celoročnom priemere rovnaká pre obe pologule s nasledujúcim relatívnym podielom: AH 35 %, H 31 %, A 18 %, S 16 %.

Я. ШТОЛ

СУТОЧНЫЕ И ГОДИЧНЫЕ ВАРИАЦИИ СПОРАДИЧЕСКИХ МЕТЕОРОВ

В работе исследуются двухразмерные суточно-годичные вариации численностей спорадических метеоров на основании нескольких серий наблюдений на разных географических широтах, именно визуальных наблюдений, полученных сотрудниками обсерватории Скальнате Плесо (1944—1953) и американского метеорного общества (1901—1963), радиолокационных наблюдений из Оттавы (1957—1960), Джодрэл Бэнку (1954—1958) и Харькова (1958), и наблюдений из южного полушария в Кристчэрч (1960—1961). Оказывается, что годичный ход численностей находится под сильным влиянием потоков, что следует даже из визуальных данных, из которых были исключены все наблюдения с выразительной активностью метеорных потоков. Годичная вариация спорадического фона, таким образом, может совсем изчезнуть в активности потоков. Этим обстоятельством объясняются часто встречающиеся противоположные заключения при сравнении годичной вариации из северного и южного полушарий.

После исключения влияния метеорных потоков и после изучения суточных минимальных численностей, которые значительно меньше отяготены влиянием потоков по сравнению с численностями максимальными, подтверждается полугодичное смещение максимума вариации спорадических метеоров для северного и южного полушарий соответственно. Максимум на южном полушарии наступает в марте, минимум в сентябре. Комплексы дневных северных потоков и южных потоков Пуппид-Велаид являются настолько диффузными, что их невозможно полностью отделить от спорадического фона.

Новым методом была определена годичная вариация активности для предполагаемых главных радиационных источников спорадических метеоров (модель четырех источников: апексного A, солнечного H, противосолнечного AH и равномерного спорадического фона S). Вычисление проводилось на основании ранее опубликованного материала (4,400 000 радиэхо) из Оттавы с помощью электронной вычислительной машины ЗРА-1. При этом предполагалась экспоненциальная зависимость (2) наблюдаемой численности метеоров от зенитного расстояния радианта с последовательно принятыми показателями степени $n = 1.0$; 1.5; 2.0. Наиболее достоверные результаты были достигнуты при $n = 1{,}0$, что одновременно является подтверждением зависимости наблюдаемой численности метеоров от первой степени зенитного расстояния радианта.

Полученный годичный ход активности отдельных спорадических источников (рис. 7) значительно отличается от результатов, которые получил Кией для южного полушария. Совпадающий ход по амплитуде, однако, показывают северный и южный противосолнечный источники, с максимумами взаимно смещенными на 180°, отвечающими активности приведенных выше диффузных комплексов радиантов. Северный противосолнечный и южный солнечный источники тождественны в меньшей амплитуде, смещенной на 90°. Этот эффект можно объяснить действием двух широких диффузных роев с любым склонением и перигелийным расстоянием 0.5, или же с малым склонением и перигелийным расстоянием 0.1—0.2, или 0.9. Активность северного и южного апексных источников практически тождественна с максимумом во второй половине года и с заметным минимумом в марте-апреле. Это можно объяснить реальным изменением плотности метеорной материи вдоль земной орбиты. Спорадический фон в течение года практически постоянный, с незначительным понижением активности в феврале—марте, что согласуется с понижением активности телескопических метеоров. Средняя годичная активность отдельных источников одинакова для обоих полушарий с последующим относительным распределением AH 35 %, H 31 %, A 18 %, S 16 %.