RADAR SPORADIC METEOR RATES AND SOLAR ACTIVITY

M. ŠIMEK and P. PECINA
Astronomical Institute of the Academy of Sciences of the Czech Republic, CZ-251 65 Ondřejov, Czech Republic
(E-mail: simek@asu.cas.cz; ppecina@asu.cas.cz)

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Abstract. The correlation of sporadic meteor rates from radar observations in January, August, and December non-shower periods in 1958–2000, and relevant solar activity represented by the solar relative number, R, is investigated. Similar analysis of the December sporadic period was already presented by Šimek and Pecina (1999), and Pecina and Šimek (1999). Complete analysis indicates high correlation of both phenomena with sporadic meteor counts curve following that of solar activity after 1.5–2 years in the mean eleven year solar cycle with the correlation index exceeding 70%. This result supports the large volume of observing material of the Ondřejov meteor radar in the above mentioned span covering almost four solar cycles.

Keywords: Correlation, meteor rates, solar activity

1. Introduction

The results of the study of the correlation of sporadic meteor rates from radar observations at Ondřejov observatory performed in January, August, and December non-shower periods from 1958 to 2000, with the relevant solar activity represented by the solar relative number, R, are presented. The December period has already been analysed by Šimek and Pecina (1999) and Pecina and Šimek (1999). We present it here again because of adding 1998 observation, and also the January and August periods. Combined correlations of all 3 periods as well as the correlation of echo duration group $T \geq 0.4$ s are also shown.

The parameters of Ondřejov meteor radar operating at 37.5 MHz were maintained constant during the whole observing period. Another parameters as the solar radio flux, R_f, usually at the wavelength of 10.7 cm, the geomagnetic C_p index, and others, could also be used as a measure of the influence of solar activity on the Earth's atmosphere. The application of R_f as a measure of the correlation with solar relative number, R, was also considered. Because of a high degree of correlation of R vs R_f reaching $99.7 \pm 0.2\%$ the application of R_f would yield almost identical result and, therefore, R_f was not considered in the analysis.

Bumba (1949) was the first who examined possible connection of visually observed meteor counts to the solar activity. He analyzed 2441 observations of meteors in the period 1844–1943 and concluded that maximum of visually observed rates occurred five years after the solar maximum while the minimum rates ap-

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peared two years after the minimum sunspot number. Lindblad (1976) found a similar dependence from radar observations of the Perseids from 1953 to 1972 at the Onsala Space Observatory. In later studies Lindblad (1978) and (1980) arrived from an analysis of the same observational data at an inverse correlation between meteor radar hourly rates and the geomagnetic C_p index position within the interplanetary sector structure.

2. Observation and Analysis

Full 24 hours daily rates based on observed hourly rates in non-shower periods were used for present study. Mean hourly rates were determined for every period and echo duration group using an iterative method described by Šimek (1985) and Šimek and McIntosh (1986). It should be emphasized that equal day-time hours of observation in all years in particular sample of data must be used for the analysis. Meteor hourly rates depend strongly on a method of observation and sensitivity of recording instrument. Not to avoid further exploitation of primary data hourly rates were normalized in all separate months and echo duration groups so that average value of sporadic counts (or activity level coefficient), S_n, is always equal to 1. Since the procedure of determination of the correlations depends on mutual ratios of data sets, the result is not affected by the normalization. The data used by Pecina and Šimek (1999) have now been extended adding observation in January and August 1958–2000, and December 1998. Distribution of monthly data is seen from Table I. Meteor echoes having duration, $T \geq 0.4$ s, were also taken into account. January period consists of 38400 sporadic meteors resulting from 1728 hourly intervals, August period contains 134400 meteors from 4800 hours, and December period is represented by 141800 meteors from 6288 hourly intervals. Analyzed data were divided into three duration categories containing normalized 24 hour sporadic counts, S_n, which are summarized in Table I for every month in particular year together with the relevant relative sunspot number, R (Waldmeier, 1961, Preliminary Report and Forecast of Solar Geophysical Data, Sunspot Bulletin). Analyzed data cover partly second half of solar cycle No. 19, cycles 20, 21, 22, and first half of No. 23.

Since the duration of the solar cycle is not exactly 11 years but varies mostly from 10 to 12 years, a sliding weighted means of three consecutive values of R in an 11-year cycle starting in 1958 were calculated and are presented in Table II as R_c. The weights 1-2-1 were used. For more details see Table II in Šimek and Pecina (1999). The same procedure was carried out with the activity level coefficients, S_n, resulting in S_c, which are included in Table II. The variation of R_c was correlated with the variation of S_c. The correlation coefficients, C_r, and their standard deviations resulting from the correlation procedure in each phase, SAP, of a virtual 11-year solar cycle, are shown in Table III.

TABLE I

Basic mean monthly relative sunspot number, R, and normalized sporadic activity index, S_n, for three radio echo duration groups (i.e. $T \geq 0.4$ s, $T \geq 1$ s, and $T \geq 8$ s) in January, August, and December periods in all analyzed years

Year	R	January S_n			R	August S_n			R	December S_n		
		$T \geq 0.4$	$T \geq 1$	$T \geq 8$		$T \geq 0.4$	$T \geq 1$	$T \geq 8$		$T \geq 0.4$	$T \geq 1$	$T \geq 8$
1958					200.2	1.395	1.339	1.852	187.6	0.805	0.805	0.748
1959					199.6	1.340	1.210	0.961	125.0	1.021	1.226	1.741
1960					134.1	2.575	2.209	1.360	85.6	1.277	1.439	1.780
1961	57.9	0.620	0.767	1.144	55.8	1.602	1.707	1.795	39.9	0.604	0.843	0.827
1962	38.7	1.051	1.331	0.885	21.8	1.183	1.075	1.113	23.2	0.824	0.965	0.821
1963	19.8	1.700	1.560	1.654					14.9	0.886	0.884	0.728
1964	15.3	0.664	0.600	0.493					15.1	0.665	0.742	0.420
1965	17.5	1.064	1.399	1.023					17.0	0.878	0.901	0.710
1966	28.2	1.045	1.008	0.906					70.4	0.851	1.045	1.412
1967	110.9	1.136	1.027	1.056					126.4	0.805	0.865	0.845
1968	121.8	0.818	0.929	0.988					109.8	1.272	1.026	1.185
1969	104.4	1.504	1.555	1.668					97.9	0.718	0.746	1.302
1971									82.2	0.527	0.639	0.731
1972	61.5	0.376	0.436	0.845	76.8	1.211	0.996	0.967				
1973	43.4	0.390	0.385	0.184					23.2	1.215	1.068	0.970
1974	27.6	1.213	0.952	0.862					20.5	1.202	1.199	1.221
1975	18.9	1.071	1.153	1.258					7.8	1.354	1.296	1.075
1976	8.1	1.038	1.187	1.429					15.3	1.476	1.201	1.097
1977	16.4	0.701	0.549	0.579					43.2	0.992	0.893	0.867
1978	51.9	0.921	0.862	0.750					122.7	1.584	1.342	1.290
1979	166.6	1.161	1.040	0.839								
1980	159.6	0.750	0.845	1.172	135.4	0.626	0.615	0.735	174.4	1.995	1.989	1.968
1981	114.0	2.436	2.367	2.643	158.7	1.412	1.277	1.226	150.1	1.787	1.553	1.287
1982	111.2	1.983	1.886	1.476	107.6	1.536	1.499	1.515	127.0	1.686	1.598	1.603
1983	84.3	1.121	1.131	0.938	71.8	0.806	0.833	0.828				
1984					25.5	1.049	1.058	1.020	18.7	0.809	0.835	0.792
1985	16.5	0.644	0.654	0.646	11.1	0.753	0.785	0.804	17.3	0.799	0.802	0.766
1986	2.5	0.672	0.749	0.916	7.4	0.629	0.694	0.745	6.8	0.700	0.753	0.730
1987	10.4	0.746	0.828	0.905	38.7	0.807	0.896	0.919	27.1	0.695	0.809	0.681
1988	59.0	0.854	0.946	1.295	111.6	0.688	0.810	0.894				
1989					168.9	0.536	0.593	0.659	165.5	0.671	0.625	0.524
1990	177.3	0.465	0.502	0.305	200.3	0.696	0.771	0.979	129.7	0.638	0.615	0.703
1991	136.9	0.746	0.745	0.802	176.3	0.664	0.709	0.847	144.4	1.313	1.180	1.273
1992	150.0	1.008	1.046	1.490	64.5	1.142	1.164	0.866	82.6	0.941	1.086	1.378
1993	59.3	1.053	1.081	1.344	42.2	1.003	1.042	1.028	48.9	1.235	1.114	1.140
1994	57.8	1.227	0.882	0.728	22.2	1.004	0.930	1.040	26.2	1.125	1.177	0.957
1995	24.2	1.604	1.196	1.104	14.3	0.945	1.026	1.032	10.0	0.394	0.373	0.423
1996	11.5	0.889	0.820	0.696	14.4	0.530	0.601	0.795	13.3	0.663	0.771	0.808
1997	5.7	0.552	0.547	0.607	24.4	0.413	0.495	0.351	41.2	0.895	1.007	0.773
1998	31.9	0.795	0.813	0.629	92.2	0.704	0.753	0.553	81.9	0.696	0.588	0.415
1999	62.0	0.780	0.857	0.849	93.7	0.957	1.058	1.000				
2000	90.1	1.203	1.381	0.893	130.5	0.792	0.855	1.118				

TABLE II

Mean solar relative number, R_c, and relevant mean sporadic activity level, S_c, in eleven phases of virtual 11-year solar activity cycles, SAP

SAP Years	R_c	January S_c $T \geq 0.4$ s	$T \geq 1$ s	$T \geq 8$ s
0	122.2	1.436	1.438	1.636
1	86.7	1.286	1.256	1.343
2	61.5	0.982	0.947	0.861
3	39.2	0.991	0.930	0.847
4	20.0	0.968	0.929	0.878
5	14.3	0.875	0.894	0.899
6	21.5	0.852	0.929	0.930
7	43.5	0.912	0.948	0.884
8	87.5	0.950	0.952	0.858
9	132.1	0.929	0.946	0.884
10	142.7	1.081	1.030	1.232
SAP Years	R_c	August S_c $T \geq 0.4$ s	$T \geq 1$ s	$T \geq 8$ s
0	136.8	1.299	1.226	1.120
1	93.7	1.442	1.355	1.191
2	57.1	1.253	2.203	1.166
3	31.3	1.022	1.014	1.047
4	16.0	0.784	0.791	0.829
5	27.5	0.610	0.677	0.652
6	62.4	0.714	0.794	0.742
7	105.1	0.766	0.854	0.880
8	143.5	0.714	0.791	0.918
9	173.1	0.772	0.807	1.027
10	164.7	0.996	0.975	1.090
SAP Years	R_c	December S_c $T \geq 0.4$ s	$T \geq 1$ s	$T \geq 8$ s
0	118.8	1.218	1.231	1.382
1	85.5	1.149	1.157	1.208
2	45.9	0.952	1.001	0.986
3	19.9	0.840	0.868	0.809
4	17.4	0.872	0.897	0.816
5	21.8	0.908	0.922	0.776
6	33.4	0.925	0.910	0.818
7	71.2	0.954	0.928	0.921
8	118.2	0.987	0.924	0.951
9	136.2	1.064	0.981	1.067
10	138.9	1.178	1.150	1.298

TABLE III

Coefficients of correlation, C_r, for particular number of years shift, SAP, of the mean sporadic activity index, S_c, with the relevant mean solar relative number, R_c

SAP	January C_r		
Years	$T \geq 0.4$ s	$T \geq 1$ s	$T \geq 8$ s
0	0.548 ± 0.211	0.522 ± 0.219	0.567 ± 0.204
1	0.838 ± 0.090	0.760 ± 0.127	0.790 ± 0.113
2	0.811 ± 0.103	0.703 ± 0.153	0.670 ± 0.166
3	0.437 ± 0.244	0.312 ± 0.272	0.231 ± 0.285
4	-0.066 ± 0.300	-0.185 ± 0.291	-0.260 ± 0.281
5	-0.466 ± 0.236	-0.526 ± 0.218	-0.558 ± 0.208
6	-0.701 ± 0.153	-0.657 ± 0.171	-0.635 ± 0.180
7	-0.741 ± 0.136	-0.607 ± 0.191	-0.552 ± 0.209
8	-0.561 ± 0.207	-0.395 ± 0.254	-0.358 ± 0.263
9	-0.239 ± 0.284	-0.113 ± 0.298	-0.104 ± 0.298
10	0.141 ± 0.295	0.186 ± 0.291	0.210 ± 0.288
SAP	August C_r		
Years	$T \geq 0.4$ s	$T \geq 1$ s	$T \geq 8$ s
0	0.109 ± 0.298	0.122 ± 0.297	0.425 ± 0.247
1	0.587 ± 0.198	0.575 ± 0.202	0.794 ± 0.111
2	0.886 ± 0.065	0.855 ± 0.081	0.917 ± 0.048
3	0.905 ± 0.055	0.868 ± 0.074	0.771 ± 0.122
4	0.622 ± 0.185	0.588 ± 0.197	0.376 ± 0.259
5	0.132 ± 0.296	0.108 ± 0.298	-0.156 ± 0.294
6	-0.396 ± 0.254	-0.403 ± 0.252	-0.645 ± 0.176
7	-0.784 ± 0.116	-0.767 ± 0.124	-0.922 ± 0.045
8	-0.910 ± 0.052	-0.873 ± 0.072	-0.893 ± 0.061
9	-0.762 ± 0.126	-0.717 ± 0.146	-0.578 ± 0.201
10	-0.391 ± 0.256	-0.356 ± 0.263	-0.089 ± 0.299
SAP	December C_r		
Years	$T \geq 0.4$ s	$T \geq 1$ s	$T \geq 8$ s
0	0.829 ± 0.094	0.634 ± 0.180	0.796 ± 0.111
1	0.908 ± 0.053	0.866 ± 0.076	0.942 ± 0.034
2	0.685 ± 0.160	0.812 ± 0.103	0.794 ± 0.112
3	0.224 ± 0.286	0.473 ± 0.234	0.370 ± 0.260
4	-0.311 ± 0.272	-0.034 ± 0.301	-0.190 ± 0.291
5	-0.730 ± 0.141	-0.496 ± 0.227	-0.657 ± 0.171
6	-0.887 ± 0.064	-0.764 ± 0.125	-0.890 ± 0.063
7	-0.763 ± 0.126	-0.797 ± 0.110	-0.854 ± 0.081
8	-0.439 ± 0.243	-0.622 ± 0.185	-0.582 ± 0.199
9	0.004 ± 0.302	-0.272 ± 0.279	-0.125 ± 0.297
10	0.480 ± 0.232	0.199 ± 0.290	0.396 ± 0.254

TABLE IV

Maximum correlation, C_m, for three echo durations groups with duration, T, in seconds, in January, August, and December periods, and shift, S_r, (years), of relevant sporadic activity index. All data were derived from Table III when maximum correlation indices within the limits of resulting errors were considered

	January		August		December	
$T \geq$	C_m	S_r	C_m	S_r	C_m	S_r
0.4	0.79 ± 0.11	1.1	0.90 ± 0.06	2.5	0.88 ± 0.07	0.6
1.0	0.71 ± 0.15	1.1	0.86 ± 0.08	2.5	0.82 ± 0.09	1.1
8.0	0.73 ± 0.14	1.0	0.88 ± 0.07	1.8	0.94 ± 0.03	1.0

TABLE V

Global correlation factor, C_g, when the parameters for all three months shown in Table II entered the analysis

SAP	$T \geq 0.4$ s	$T \geq 1$ s	$T \geq 8$ s
Years	C_g	C_g	C_g
0	0.321 ± 0.156	0.313 ± 0.157	0.544 ± 0.123
1	0.645 ± 0.102	0.635 ± 0.104	0.776 ± 0.069
2	0.741 ± 0.079	0.734 ± 0.080	0.725 ± 0.083
3	0.565 ± 0.119	0.554 ± 0.121	0.399 ± 0.146
4	0.193 ± 0.168	0175 ± 0.169	-0.059 ± 0.173
5	-0.230 ± 0.165	-0.240 ± 0.164	-0.460 ± 0.137
6	-0.579 ± 0.116	-0.567 ± 0.118	-0.700 ± 0.089
7	-0.755 ± 0.075	-0.723 ± 0.083	-0.742 ± 0.078
8	-0.708 ± 0.087	-0.672 ± 0.095	-0.583 ± 0.115
9	-0.466 ± 0.136	-0.445 ± 0.140	-0.264 ± 0.162
10	-0.095 ± 0.172	-0.094 ± 0.172	0.147 ± 0.170

The results of the analysis for three echo duration groups at January, August, and December periods are presented in Table IV. In all cases maximum correlation, C_m, exceeds 70%. While the winter periods, December and January, show the shift about 1 year (except for $T \geq 0.4$ s duration group in December), the August shift, SAP, is considerably higher and reaches 2.5 years for the echo duration group of $T \geq 0.4$ s as well as of $T \geq 1$ s. The combinations of R_c and S_c for all three months are summarized in Tables V and VI, analogical with Tables III and IV.

TABLE VI

Maximum global correlation factor, C_{gm}, resulting from Table V, and corresponding shift, SAP, (years), for particular duration group

$T \geq$	C_{gm}	SAP
0.4	0.69 ± 0.09	1.97
1.0	0.68 ± 0.09	1.97
8.0	0.75 ± 0.08	1.46

3. Conclusions

Present analysis of the dependence of observed sporadic meteor rates on solar activity represented by the relative sunspot number shows high correlation of both phenomena with sporadic meteor counts curve following that of solar activity after 1.5–2 years in the mean eleven year solar cycle. A degree of correlation of both events exceeds 70%. Histograms of cumulative number of sunspots, medium solar flares, and proton flares from satellite data published in the Preliminary Report and Forecast of Solar Geophysical Data indicate two years shift of prominent solar flares and proton flares occurrence after solar cycle maximum which affect the physical conditions in the upper atmosphere controlling the creation of ionized meteor trails as well as the changing heights of radio reflecting points. Higher levels of reflections correspond with the occurrence of shorter radar echoes. This can be in agreement with presented position of maximum correlation between observed sporadic meteor rates and relative sunspot numbers in the mean 11-year solar cycle. This result is supported by large volume of observing material of the Ondřejov meteor radar in the span of 1958–2000 covering almost four solar cycles.

There is no agreement between presented results and those of Bumba (1949) and Lindblad (1976). Due to the small amount of observing material in Bumba's work the main contribution of his work seems to be in introducing into the problem without sufficient reliability of his conclusion. Lindblad's work is based on 18 years of observations within incomplete two solar cycles. Moreover, his data set contains well known extraordinary meteor activity in 1963. Since the solar activity was almost at its minimum in that year, it could lead to the coincidence of both events. Lindblad did not search for the correlation of both events in the course of the whole solar cycle, he examined only mutual positions of their maxima and minima. We think that these are the main reasons for the difference between our and his results.

We are convinced that the used method of correlation of two periodic events is independent on their periods and, therefore, different length of solar cycles does not affect particularly resulting correlation index.

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