Earth Moon Planets (2013) 110:41–66
DOI 10.1007/s11038-012-9409-8

The Method of Selection of Major-Shower Meteors Revisited

The Selection from the Photographic, Video, and Radio Databases

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Received: 17 May 2012 / Accepted: 26 November 2012 / Published online: 13 December 2012

Abstract We apply so-called break-point method to select the dense cores of 10 major meteor showers from the photographic, video, and radio-meteor databases. The major showers can well be selected from photographic and video data, in a lesser degree from radio data. The obtained mean characteristics of Quadrantids, Lyrids, η-Aquarids, α-Capricornids, δ-Aquarids N, δ-Aquarids S, Perseids, Orionids, Leonids, and Geminids are presented. A test to indicate the existence of a suspected shower in radio database is suggested.

Keywords Meteors · Meteor showers · Quadrantids · Lyrids · η-Aquarids · α-Capricornids · δ-Aquarids N · δ-Aquarids S · Perseids · Orionids · Leonids · Geminids

1 Introduction

Studies of real meteor streams are strongly dependent on the observational data. The data use to be concentrated in databases, where meteors belonging to various streams and sporadic background are mixed. This circumstance causes that a separation of meteors of a given meteor shower or, at least, a selection of its dense core is not trivial.

Several methods for separation/selection have been suggested. The first comprehensive study of the problem of separation was done by Sekanina in a series of papers (Sekanina 1970a, b, 1973, 1976). He used database of radio meteors consisting of 19,303 or, later,

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19,698 orbits. The Southworth-Hawkins (1963) D-discriminant was used to evaluate similarity of shower orbits and, consequently, to separate the orbits from the database. Specifically, Sekanina considered a fixed critical value of D, denoted as D_o, and separated all meteors having D-value between a given meteor orbit and mean orbit of a shower $D < D_o$. In the separation procedure, he assigned a larger weight, $w = 1 - D/D_o$, to the orbits being closer to the mean orbit in terms of orbital-element phase space. (The weight of orbits with $D \geq D_o$ was zero.)

Following the line of deduction made by Sekanina for radio meteors, we suggested the methods of selection/separation of shower meteors from the photographic IAU MDC database in our earlier work (Neslušan et al. 1995; Porubčan et al. 1995). The first method was aimed to select a dense core of a given meteor shower and, subsequently, determine reliable mean characteristics (Neslušan et al. 1995). This method is named as the "break-point method" (see Sect. 2 for a description). In contrast to Sekanina's method, the critical value of D-discriminant is not fixed, but determined, from the cumulative dependence of the number of selected meteors, N, on the threshold D, for each shower individually.

Our second method (Porubčan et al. 1995) is not based on the cumulative, but differential dependence $N = N(D)$. The critical D-discriminant determined using this method, D_{c2}, is a border between the orbital phase space from which a larger number of shower than sporadic meteors is separated (for a threshold $D < D_{c2}$) and orbital phase space from which a less number of shower than sporadic meteors is separated (for $D > D_{c2}$).

A new approach to meteoroid stream identification was further introduced by Valsecchi et al. (1999; Jopek et al. 1999, 2003). Their identification is based on a distance function involving four geocentric quantities that are directly linked to observations. The function is thus defined in a space that has as many dimensions as the number of independently measured physical quantities, at variance from the conventional orbital similarity criterion of Southworth and Hawkins.

In course to classify all meteors in a given database, to those belonging to a specific shower or to sporadic, we further suggested another method, so-called "method of indices" (Svoreň et al. 2000, 2001). The method assumes division of the entire phase space of five orbital elements (q, e, ω, Ω, and i) as well as equatorial coordinates of the geocentric radiant and geocentric velocity into appropriate sub-intervals. The strategy of the method is based on the fact that the parameters of a given shower or association fit the same combination of the sub-intervals.

A choice of the method of selection/separation of shower meteors from a database often depends on the purpose of the separation. In recent period, there have occurred some studies of theoretical streams associated with some potential parent bodies in orbits, which are situated far from the orbit of the Earth, but which can nevertheless have some filaments crossing the orbit of our planet and, thus, cause the meteor-shower phenomenon. Within these studies, the characteristics not only of night-time, but also day-time, and not only well recognized, but also weak, diffuse showers are predicted. To confront such prediction with reality, it is necessary to attempt to separate the shower with predicted characteristics from the databases available.

Since a prediction of existence of a shower should be reliably verified in the observational data available, the break-point method of the selection of dense core seems to be the most appropriate in this context. The method can also be highly automatized and, thus, fast to provide the intended confrontation.

In this paper, we extend our work about the method of break-point, already used for the older version of photographic IAU MDC database (Lindblad 1987, 1991; Lindblad and Steel 1994) and map the applicability of this method when selecting the meteors of major showers from the video and radio-meteor databases. Since the new, 2003-version of photographic IAU MDC database was meanwhile issued (Lindblad et al. 2003), we repeat the selection also from this new dataset to obtain the "reference" results.

Concerning the organization of the paper, the break-point method is briefly reminded in Sect. 2. In Sect. 3, we give a basic information about the databases used. The results are described in Sect. 4. The questionable separation and giving an indication of eventual existence of shower in the radio database is discussed in Sect. 5. Concluding remarks are written in Sect. 6.

2 The Break-Point Method

All methods of separation of meteors from a database, in which shower and sporadic-background meteors are intermixed, do explicitly or implicitly assume similarity of orbits of analyzed-shower members. The similarity of a shower meteor orbit to the shower mean orbit is not a constant phenomenon, but usually decreases[1] with time. Consequently, there is not any sharp border between the orbits of given stream and those of sporadic background. The methods of separation differ each other by the specific choice of discrimination between the meteors of the separated or selected shower and the other meteors. Usually, a critical measure of similarity, beyond which the orbits are not longer assumed to belong to the shower, is derived.

It appeared that the major showers have a well-defined "core", in which the diversity between the orbits of individual members and the mean orbit is relatively small (Neslušan et al. 1995; Paper I). The method of "break point" was designed to select just the meteors in this core. In the method, diversity between the orbit of meteor and the shower mean orbit is evaluated with the help of the Southworth-Hawkins (1963) D-discriminant. (However, a modification assuming other measure of the diversity is not excluded.)

In Fig. 1, the cumulative dependence of meteors separated from a database on the chosen threshold value of D is plotted. The dotted, monotonously increasing curve illustrates the behaviour of the number of sporadic meteors selected from the database with the increasing D. The number of selected meteors of the well-concentrated core of the shower, N, up to the appropriate limit of D (indicated with the arrow in graph) is illustrated by a dashed curve. At relatively small values of the threshold D, the number of shower meteors increases steeply, enough. Near the critical value, the slope of this increase changes to moderate and, finally, to almost flat. It is appropriate to choose the critical value of D just in the point, in which the apparent increase of the number of separated meteors is terminated. This point was named the "break point".

When constructing the $N = N(D)$ dependence from a real database, we obtain superposition of both shower and sporadic background numbers, only. In Fig. 1, the superposition is shown by the solid curve. In practice, the critical D corresponds to the lower-D border of a quasi plato in the dependence (see also Figs. 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 for more examples). The accounting of the critical value of D is subjective. So, the exact critical value can differ, a little, when accounted by various authors. However, the difference has only a negligible impact on the number of selected shower members, therefore this non-exact step of the procedure appears not significantly influencing the determined mean characteristics of the chosen set of shower meteors.

[1] If the particles of given meteor stream move in orbits in which they are in a resonance with a planet, the measure of similarity may not decrease in time, but oscillate.

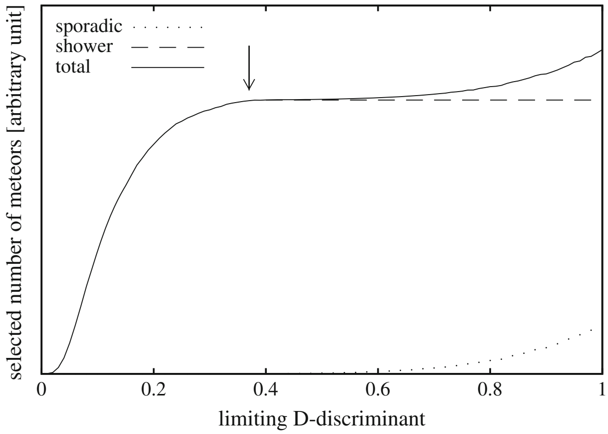


Fig. 1 The dependence of the number of meteors selected from a database on the threshold value of *D*-discriminant. Specifically, the *solid curve* shows the dependence for the selected number from a real database. This dependence is superposition of selected shower members (*dashed curve*) and sporadic background meteors (*dotted curve*)

To calculate *D*-value between orbits of a meteor and shower we need to know the mean orbit of the shower. In the break-point method, this orbit is determined in an iteration procedure. For an initial, low, threshold value of *D*, a mean orbit from an external source is used. It can be the orbit of the parent body, if known, or the orbit determined in previous studies (also by other method and/or using other database), or a theoretically determined orbit (from, e.g., a dynamical study of theoretical stream associated with a parent body considered). After a set of meteors is selected, the mean orbit can be calculated and is considered in further iteration step, in which entire selection for the given threshold *D* is repeated. Similarity of two successive mean orbits in the iteration can also be evaluated by the *D*-discriminant. The iteration procedure for given value of threshold *D* can be stopped, when the value of D_{orb} between two successive mean orbits becomes negligible ($D_{orb} \leq 10^{-6}$). The iteration procedure may not converge when a few specific meteors are included and then, in successive iteration step, excluded from the shower, repeatedly. In such a case, we suggest to stop the iteration after 100 steps. (There appears only a minute difference between the alternating mean orbits.) After finishing the iteration for a given threshold *D*, the process is repeated for another, higher, threshold *D*-value. The cumulative behaviour $N = N(D)$ should be determined for *D* from a value close to zero (e.g. $D = 0.01$) up to a relatively high value ($D = 1.00$ or $D = 1.50$ at maximum).

If a stream crosses the orbit of the Earth in both descending and ascending arcs (e.g. the stream of 1P/Halley), the break-point method selects the members of such stream as a single whole. To separate the meteors of corresponding two showers in this case, it is necessary as an extra step of the procedure, to divide the source data into two groups assuming, e.g., an appropriate date separating the expected periods of activity.

In contrast to the Sekanina's (1970a, b; 1973; 1976) approach, we do not assign any weight to the selected meteors. Steep increase of the selected number of meteors in the cumulative $N = N(D)$ dependence in the interval of relatively low threshold *D*-value (Fig. 1) should be sufficient waranty that just the mean orbits of reliable shower members is determined. A weighting would result in an unreasonable "inertia" of input mean orbit (which is taken from an external source and, thus, can be chosen diverse, enough, from the actual mean orbit). In addition, the showers usually consist of filaments (Perseids are a good example; see, e.g., Wu and Williams 1995; Kaňuchová et al. 2005; Svoreň et al. 2006) and contrary to expectations the weighting procedure can prefer a mean orbit in the orbital space between the filaments, where the number density of shower meteors can be relatively low.

3 Analysed Databases

As indicated in the Introduction, we investigate the applicability of the break-point method in three databases, each containing meteor orbits determined by different observational technique. The following datasets are considered.

(1) The photographic database of the IAU MDC, version 2003 (Lindblad et al. 2003). It contains 4581 meteor orbits from 35 partial catalogues linked together. The partial catalogues were created by 17 authors/observational stations in the period 1936-1996. The break-point method was for the first time developed using an earlier version of this database (Lindblad 1987, 1991; Lindblad and Steel 1994) with 3411 orbits. Thus, its upgraded version is considered again mainly as a reference.
(2) The video database published by the SonotaCo group (SonotaCo 2007). We use the part of the SonotaCo database from multi-station observations in 2007-2009. It contains 64,650 meteor orbits.
(3) The radio database (Hawkins 1963; Lindblad 2003; Sekanina and Southworth 1975). This dataset consists of 62,907 orbits. It is known that the orbits determined from the radio observations are less precise than photographic or video orbits, but the radio orbits provide still the only information about day-time showers.

Unfortunately, all three databases are collections especially from seasonal observational campaigns. The coverage during year is far from some uniform. The year variation in the number of detected meteors in the databases can be seen in Fig. 2.

4 Selected Cores of Major Showers

The method of break point was applied to select the well-defined members of 10 major night-time showers, the same as in Paper I, from all three databases. In order of their appearance in year these are: Quadrantids, Lyrids, η-Aquarids, α-Capricornids, δ-Aquarids N, δ-Aquarids S, Perseids, Orionids, Leonids, and Geminids.

The cumulative dependences $N = N(D)$ for showers selected from the databases are shown in Figs. 3, 4, 5, 6, 7, 8, 9, 10, 11, 12. In the plots, the arrow points to the position of the critical value of D-discriminant, D_B, at which the shower from given dataset is selected. It appears that in specific database some major showers have no dense core, the members of which can be undoubtedly selected. Therefore, no apparent break point in the $N = N(D)$ behaviour can be observed. From the radio database, only the Southern δ-Aquarids, Orionids, and Geminids using the break-point method can be selected (Figs. 8c, 10c, 12c). A densier core of the Northern δ-Aquarids is missing also in the video data (Fig. 7b).

The sporadic background meteors and of other showers can, sometimes, largely blur the phase space of the selected shower. This blurring and prevailence of meteors in a neighbouring phase space can be so high that the convergence of iteration procedure to the shower is interrupted and the procedure starts to converge to a highly different orbit, so far. An example of such a change in the convergence can be seen in $N = N(D)$ dependence for video-Geminids in Fig. 12b (at $D = 0.57$, the convergence to the mean orbit of Geminids

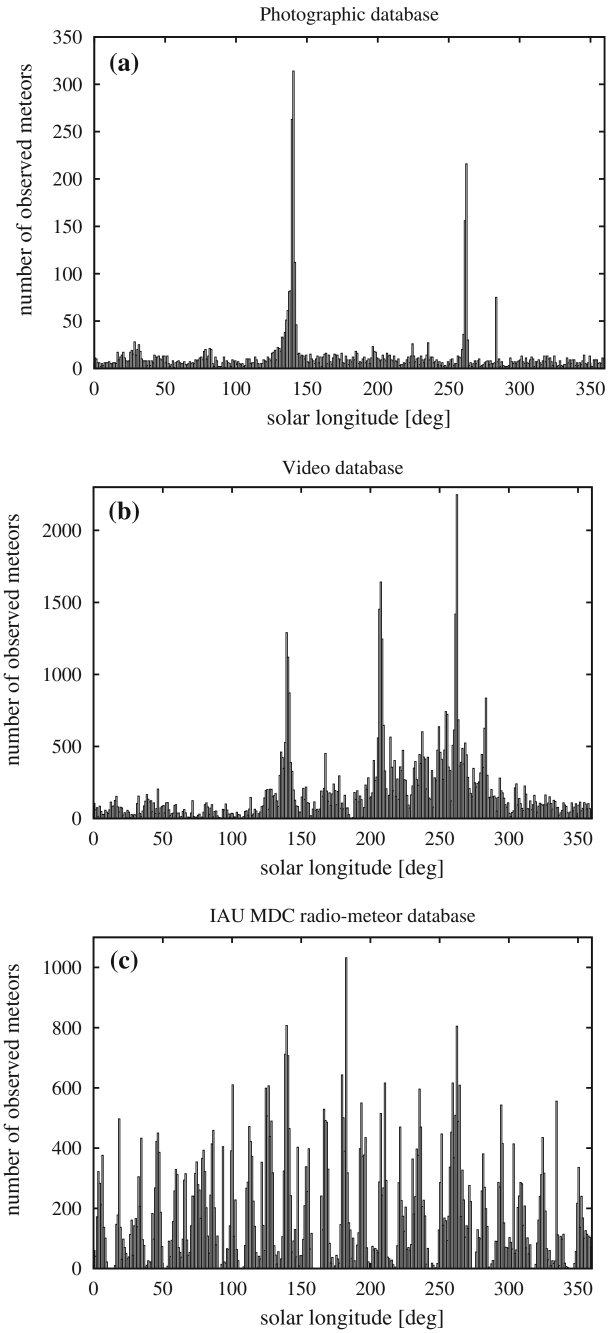


Fig. 2 The number of meteors detected during one-degree interval of solar longitude in three meteor databases considered. Specifically, the numbers are given for photographical (plot **a**), video (**b**), and radio-meteor (**c**) datasets

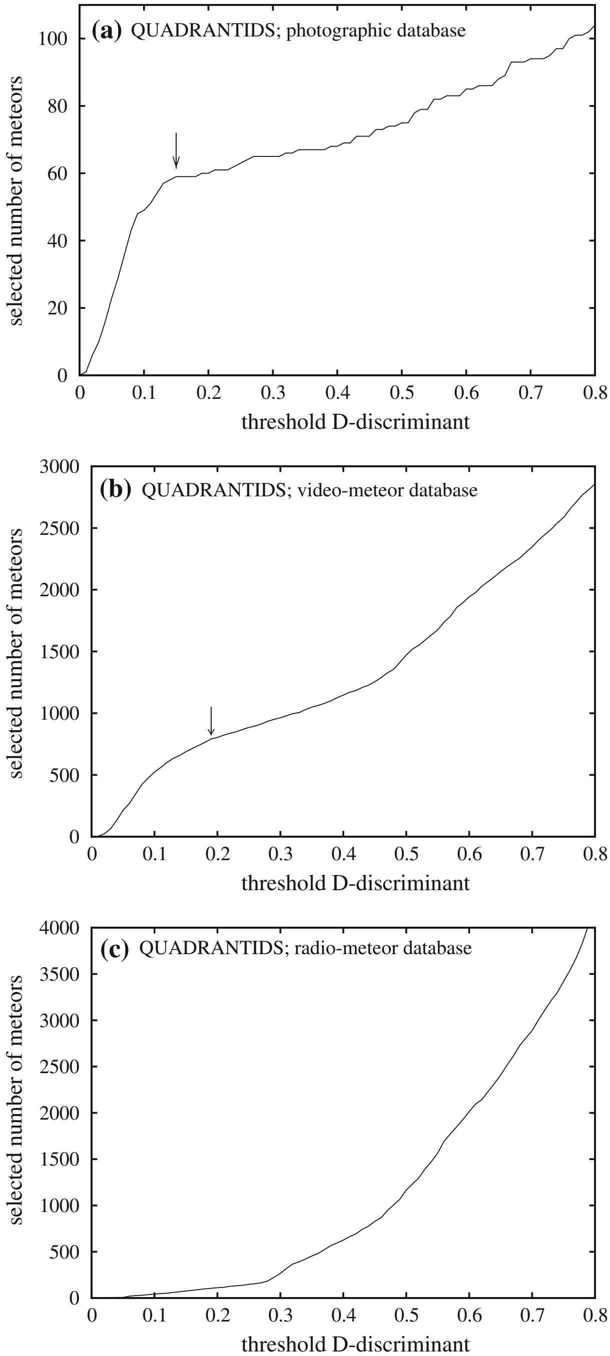


Fig. 3 The cumulative dependence of number of meteors, *N*, selected from the photographic (*upper plot*), video (*middle plot*), and radio (*bottom plot*) databases on the threshold Southworth-Hawkins *D*-discriminant for the Quadrantids. The *arrow* in the plots points to the position of the critical value of D_B (see Table 2) at which the shower in given dataset is selected

is inverted to that to the orbit with $<\lambda_\odot> = 148.9°$, radiant coordinates $\alpha_g = 289.3°$, $\delta_g = 22.9°$, and geocentric velocity of $V_g = 18.8$ km s^{-1} which is, likely, the "mean" orbit of a mixture of several showers and sporadic meteors). However, the

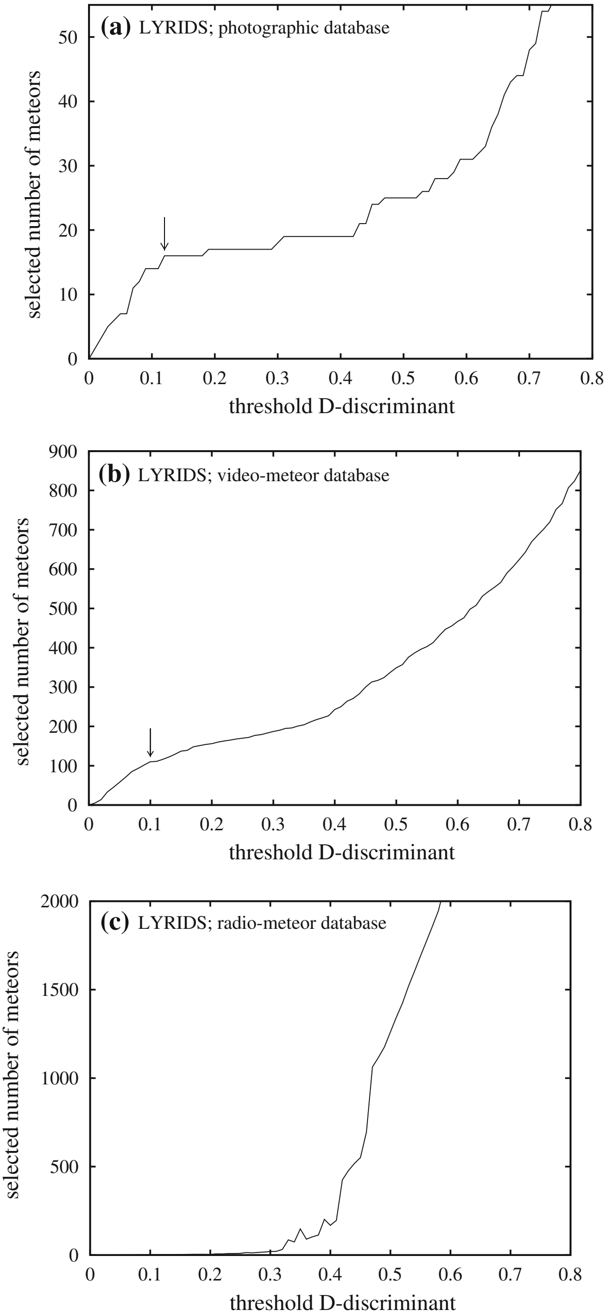


Fig. 4 The same as Fig. 3 but for the Lyrids

critical D_B uses to be much lower than the D-value corresponding to the change of convergence, therefore the change is no problem for the selection.

Sometimes, a diffuse shower in the neighbourhood of the selected one causes only a small deviation of the mean orbit from the previous convergence. Due to the deviation

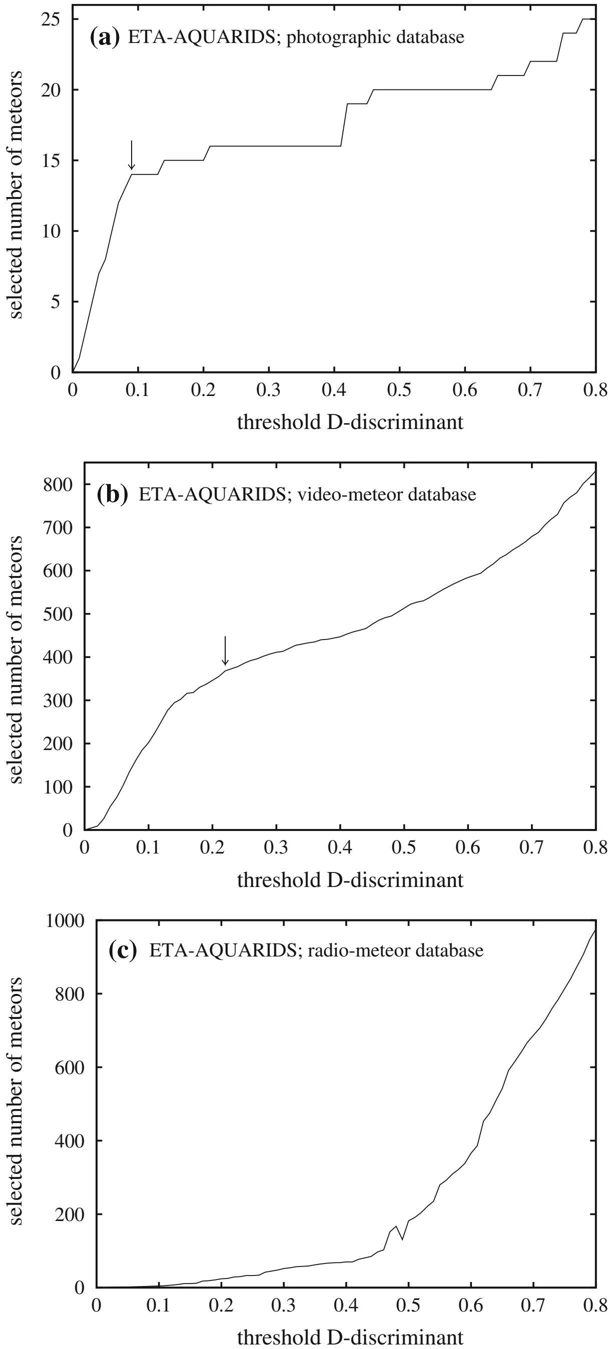


Fig. 5 The same as Fig. 3 but for the η-Aquarids

some members of the selected shower are omitted for a short interval of limiting D values and, thus, the number of selected shower meteors can episodically decrease. Such examples can be seen in $N = N(D)$ dependence of photographic α-Capricornids and

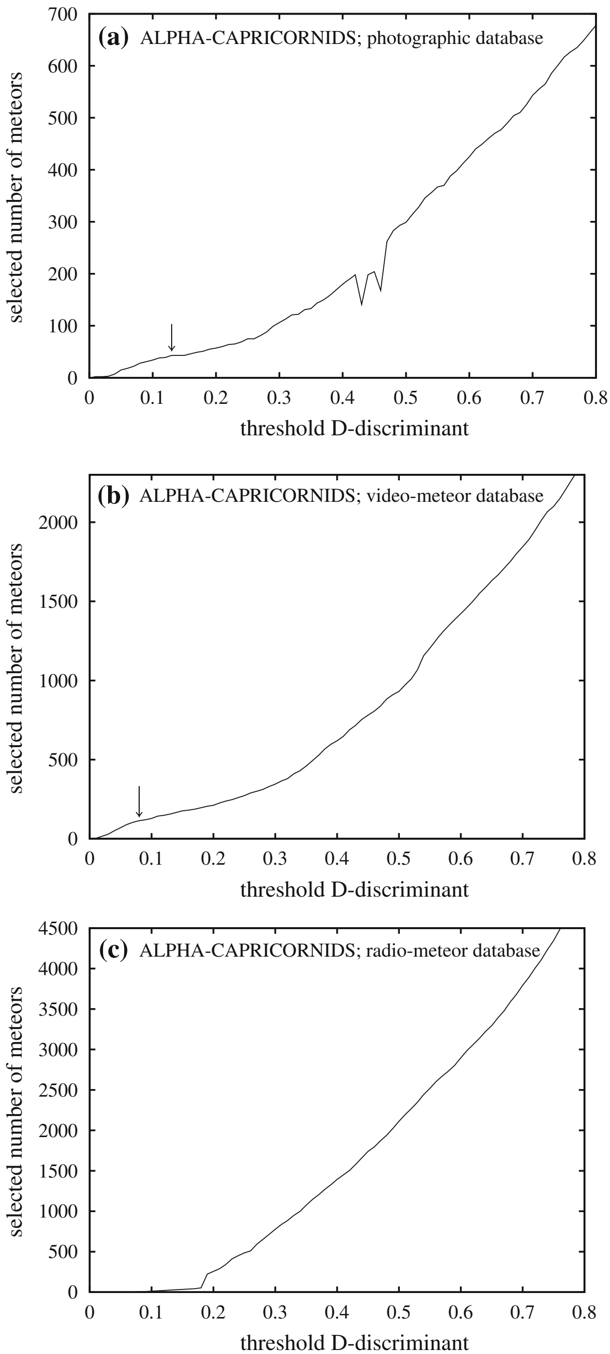
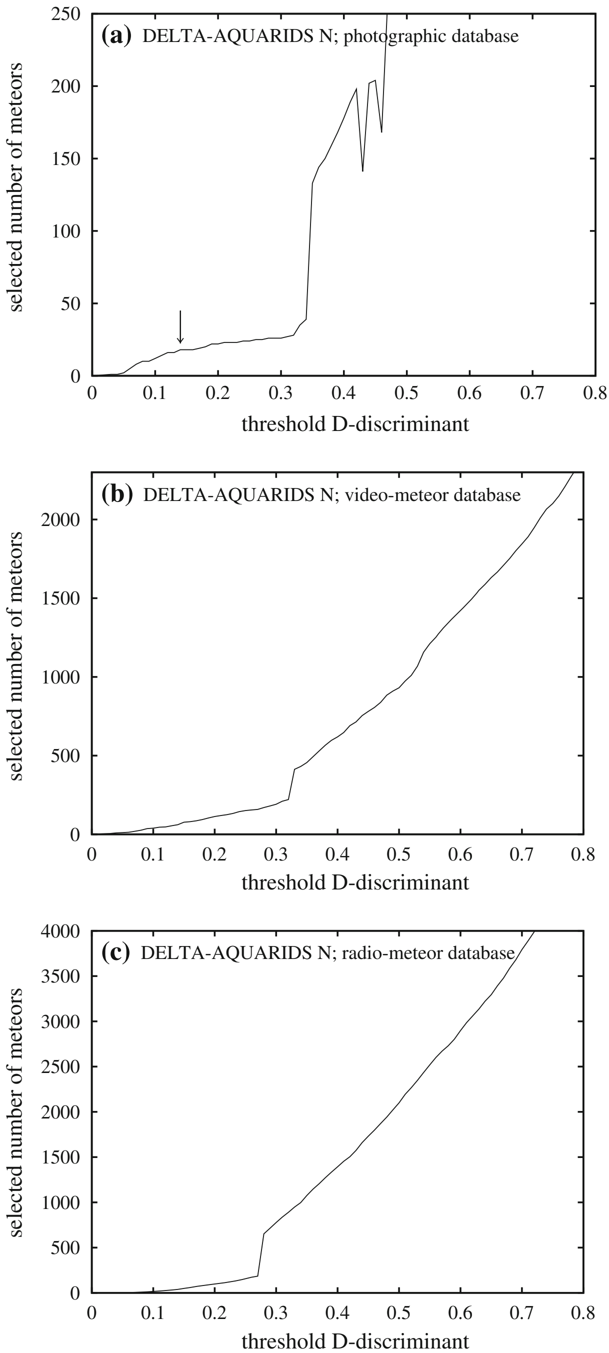


Fig. 6 The same as Fig. 3 but for the α-Capricornids

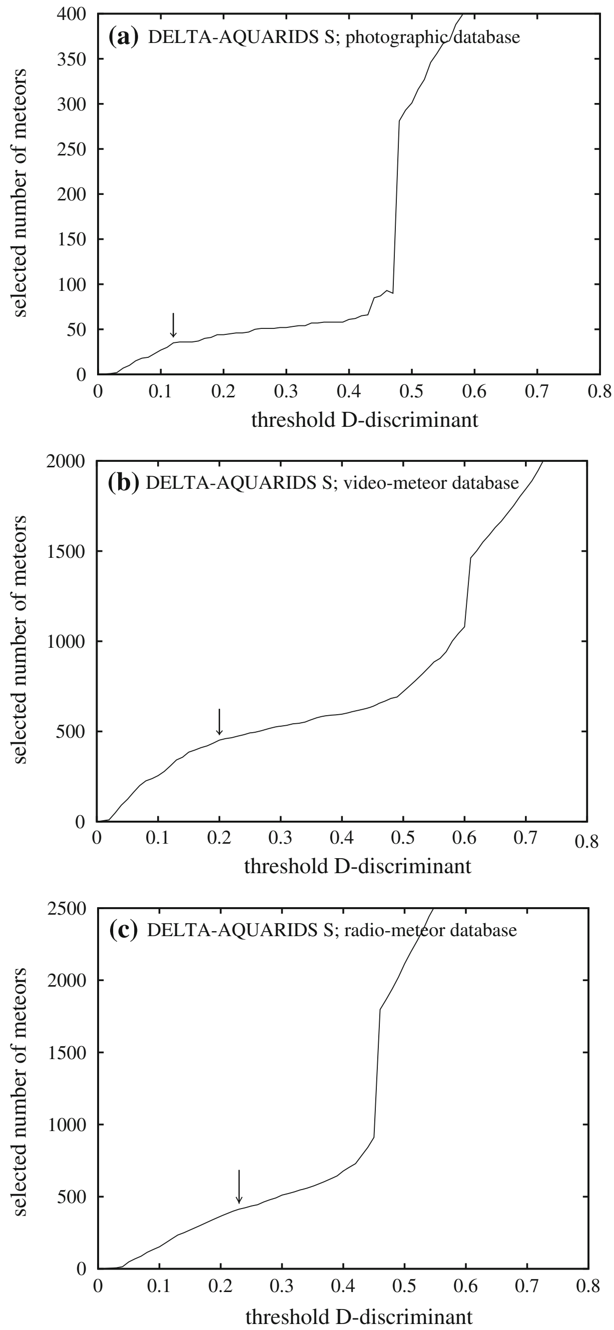
δ-Acquarids N in Figs. 6a and 7a. In the much more numerous video and radar data, the diffuse showers are obviously less abundant relatively to the neighbouring phase space, therefore no "jumps" in the dependence are seen.

Fig. 7 The same as Fig. 3 but for the δ-Aquarids N



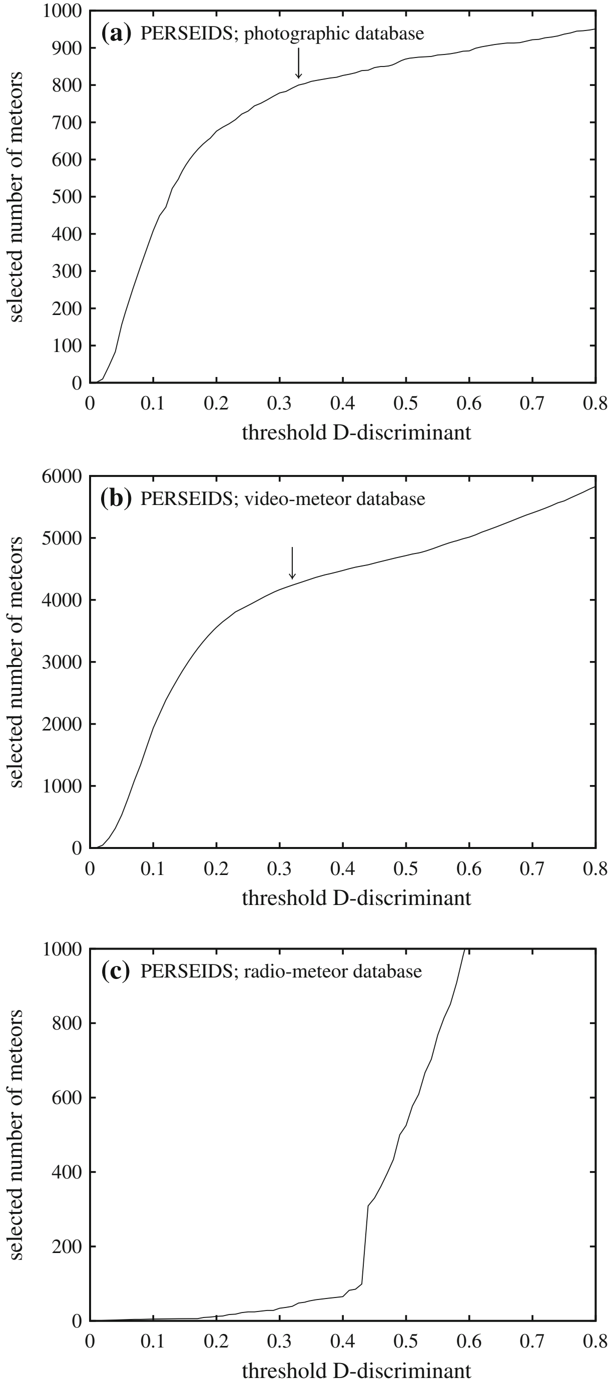
The mean geophysical characteristics of the investigated showers are summarized in Table 1 and the mean orbits in Table 2. The latter lists also the critical values D_B at which the shower meteors were selected and numbers N_B of selected shower meteors. In both

Fig. 8 The same as Fig. 3 but for the δ-Aquarids S



tables, the determined parameters are listed with their standard deviation (σ), which, however, reflects more the dispersion of the parameter during the period of shower activity than a determination uncertainty. For three selected radio showers, the values of σ are

Fig. 9 The same as Fig. 3 but for the Perseids



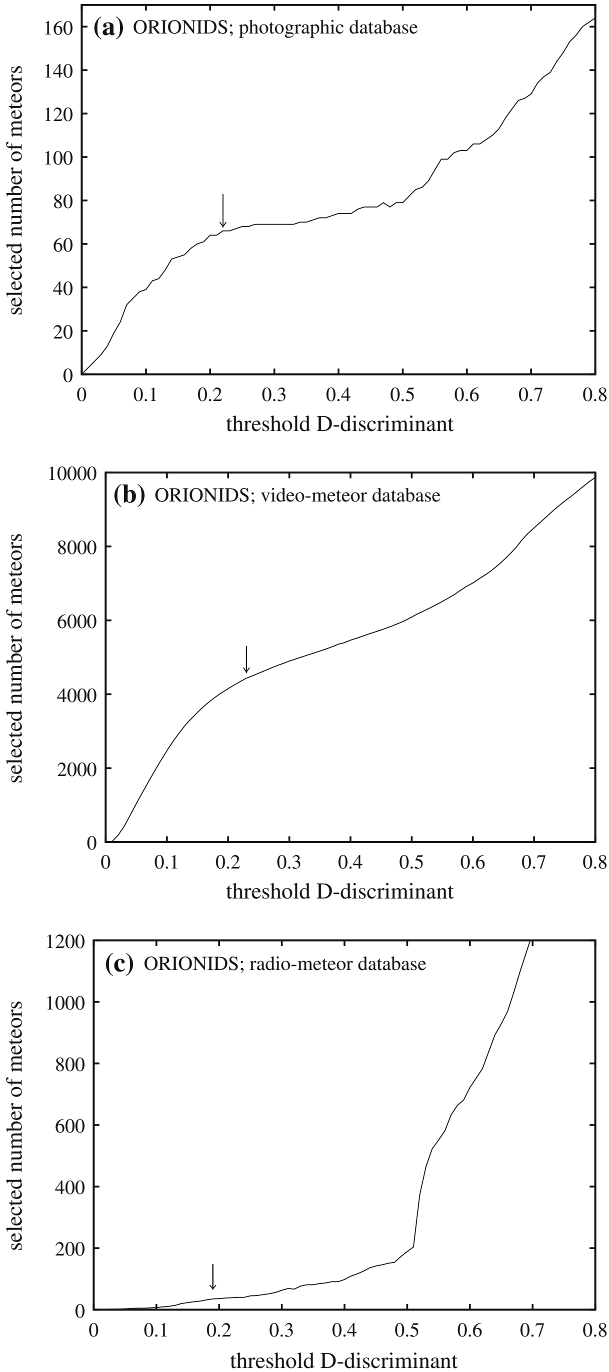


Fig. 10 The same as Fig. 3 but for the Orionids

typically larger than the corresponding values of photographic and video showers. This is, likely, a consequence of combination of two dispersions: the larger real dispersion of orbits of **smaller** radio-meteor particles in comparison to those detected by the photographic or

Fig. 11 The same as Fig. 3 but for the Leonids

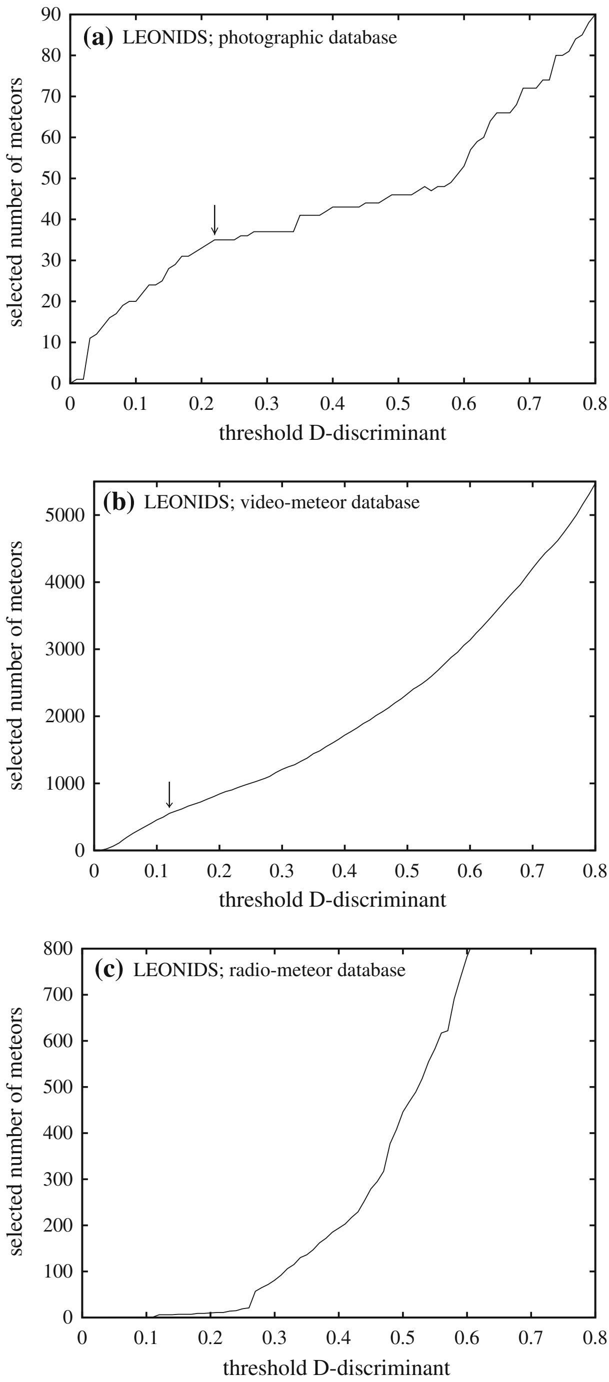


Fig. 12 The same as Fig. 3 but for the Geminids

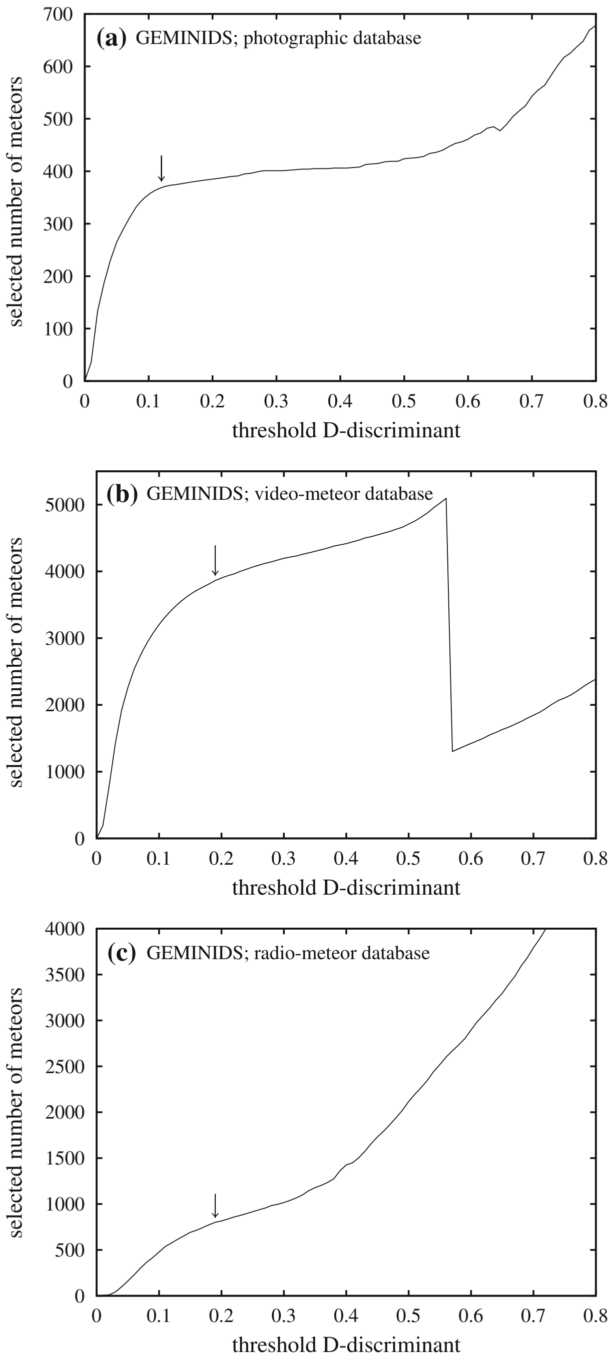


Table 1 Geophysical characteristics of investigated major meteor showers

Shower	DB	$<\lambda_\odot>$	α_g	δ_g	V_g	V_h
Quadrantids	F	283.332 ± 0.767	230.4 ± 2.2	49.2 ± 1.0	41.0 ± 1.0	38.8 ± 0.6
	V	283.148 ± 1.437	229.8 ± 3.1	49.6 ± 1.7	40.1 ± 1.3	38.1 ± 0.8
Lyrids	F	32.588 ± 0.947	272.4 ± 1.2	33.4 ± 0.6	46.9 ± 0.7	41.6 ± 0.7
	V	32.355 ± 0.584	272.1 ± 1.3	33.3 ± 0.7	46.6 ± 0.7	41.4 ± 0.4
η-Aquarids	F	44.550 ± 0.662	337.0 ± 0.6	−1.4 ± 0.3	65.3 ± 0.6	40.7 ± 0.6
	V	46.491 ± 5.406	338.6 ± 3.8	−0.6 ± 2.0	65.7 ± 1.1	41.1 ± 1.1
α-Capricornids	F	128.053 ± 6.102	306.3 ± 3.5	−8.9 ± 2.7	22.2 ± 1.5	37.4 ± 0.7
	V	126.681 ± 4.325	305.6 ± 2.7	−9.4 ± 1.5	22.1 ± 0.9	37.1 ± 0.4
δ-Aquarids N	F	136.222 ± 4.770	342.9 ± 3.5	−0.4 ± 2.8	39.6 ± 2.5	37.0 ± 2.0
δ-Aquarids S	F	132.157 ± 5.193	343.6 ± 4.1	−15.0 ± 1.0	40.1 ± 1.5	37.8 ± 1.1
	V	129.576 ± 5.435	342.4 ± 4.7	−16.0 ± 1.6	39.5 ± 2.1	36.8 ± 1.7
Perseids	F	138.963 ± 3.291	46.3 ± 5.2	57.6 ± 1.6	59.2 ± 1.3	41.3 ± 1.1
	V	139.049 ± 3.801	47.1 ± 6.1	57.7 ± 1.9	58.8 ± 1.3	40.9 ± 1.0
Orionids	F	208.203 ± 4.529	95.0 ± 3.4	15.6 ± 0.8	66.6 ± 1.2	41.6 ± 1.2
	V	208.773 ± 4.141	96.0 ± 3.4	15.6 ± 1.0	66.1 ± 1.2	41.0 ± 1.2
Leonids	F	235.980 ± 5.851	153.8 ± 3.7	21.5 ± 2.2	70.7 ± 1.0	41.4 ± 1.0
	V	236.133 ± 4.036	154.4 ± 2.7	21.6 ± 1.7	70.2 ± 0.6	41.0 ± 0.6
Geminids	F	261.875 ± 1.147	113.5 ± 1.5	32.3 ± 0.7	34.4 ± 1.2	33.8 ± 0.9
	V	261.236 ± 2.566	112.6 ± 2.9	32.4 ± 1.3	33.5 ± 1.5	33.3 ± 1.2

Denotation used: DB—meteor-orbit database (F—photographic, V—video), $<\lambda_\odot>$ - mean ecliptical longitude of the Sun of shower activity, α_g and δ_g - equatorial coordinates of geocentric radiant, and V_g and V_h - geocentric and heliocentric velocity. The angular quantities are given in degrees and velocities in km s^{-1}

video observations and the dispersion due to smaller precision of radio orbits in comparison to photographic and video orbits.

In Table 2, we can see that the values of D_B significantly differ from shower to shower even within a single database. The difference reflects several factors. The error Gaussian of the determination of an element is influenced by geometry of shower observation, which is different for various showers from various observational stations. Worse observational conditions imply a more dispersed Gaussian. The Gaussian is also influenced by numerosity of shower. If the quality of observation of more and less numerous showers is the same, i.e. the ratio of maximum and half-width of Gaussians is identical, the absolute value of the half-width and, therefore, dispersion of more numerous shower is larger.

Of course, the orbital dispersion of a shower depends not only on the observational precision, but largely also on the length of the period of shower activity and internal structure of shower. The value of D_B can obviously be expected larger for a less compact shower. The advance of the break-point method is the ability to quantify, at least in a certain degree, all the factors influencing the shower dispersion and provide the value of D_B closely to an optimal one. The unique value of D_B for all showers, often considered in the past, leads to a large infiltration of a shower by the meteors of sporadic background in the case of low numerous and compact showers and eventual omission of significant number of reliable shower members in the case of large showers.

As evident from Table 2, there is no clear correlation between the numerousity of the database and mutually corresponding values of D_B. Of course, the number of selected

Table 2 Mean orbital elements of investigated major meteor showers on the basis of photographic (F), video (V), and radio (R) databases (DB)

shower	DB	D_B	N_B	q	e	ω	Ω	i
Quadrantids	F	0.15	59	0.978 ± 0.004	0.667 ± 0.050	170.8 ± 3.5	283.3 ± 0.8	71.7 ± 1.6
	V	0.19	792	0.978 ± 0.005	0.614 ± 0.064	171.7 ± 5.4	283.1 ± 1.4	70.6 ± 2.3
Lyrids	F	0.12	16	0.922 ± 0.007	0.969 ± 0.059	213.9 ± 1.6	32.6 ± 0.9	79.6 ± 1.0
	V	0.10	110	0.919 ± 0.009	0.949 ± 0.038	214.6 ± 1.8	32.4 ± 0.6	79.5 ± 1.3
η-Aquarids	F	0.09	14	0.569 ± 0.013	0.935 ± 0.028	95.6 ± 2.2	44.6 ± 0.7	163.7 ± 0.7
	V	0.22	368	0.582 ± 0.046	0.957 ± 0.056	97.6 ± 6.0	46.5 ± 5.4	163.6 ± 1.8
α-Capricornids	F	0.13	43	0.599 ± 0.045	0.764 ± 0.040	266.9 ± 5.5	128.0 ± 6.1	7.3 ± 1.5
	V	0.08	114	0.595 ± 0.029	0.753 ± 0.019	267.9 ± 3.6	126.7 ± 4.3	7.2 ± 0.8
δ-Aquarids N	F	0.14	18	0.084 ± 0.024	0.963 ± 0.023	330.6 ± 4.2	136.2 ± 4.8	21.3 ± 3.2
δ-Aquarids S	F	0.12	35	0.093 ± 0.023	0.967 ± 0.012	148.3 ± 4.1	312.2 ± 5.2	24.7 ± 3.2
	V	0.20	452	0.090 ± 0.026	0.960 ± 0.020	149.7 ± 4.4	309.6 ± 5.4	26.3 ± 4.0
	R	0.23	413	0.080 ± 0.031	0.949 ± 0.032	153.5 ± 5.8	306.2 ± 5.8	28.0 ± 5.3
Perseids	F	0.33	800	0.951 ± 0.017	0.954 ± 0.097	151.0 ± 4.3	139.0 ± 3.3	113.2 ± 2.4
	V	0.32	4238	0.945 ± 0.020	0.922 ± 0.087	149.5 ± 4.7	139.0 ± 3.8	112.9 ± 2.9
Orionids	F	0.22	66	0.579 ± 0.047	0.970 ± 0.062	81.5 ± 6.0	28.2 ± 4.5	163.6 ± 1.7
	V	0.23	4436	0.580 ± 0.044	0.936 ± 0.061	82.3 ± 5.9	28.8 ± 4.1	163.7 ± 2.2
	R	0.19	35	0.577 ± 0.049	0.875 ± 0.064	84.4 ± 6.7	27.8 ± 4.3	164.0 ± 3.7
Leonids	F	0.22	35	0.983 ± 0.010	0.908 ± 0.089	174.0 ± 7.0	236.0 ± 5.9	162.7 ± 1.8
	V	0.12	552	0.983 ± 0.004	0.871 ± 0.056	172.8 ± 4.6	236.1 ± 4.0	162.2 ± 1.7
Geminids	F	0.12	369	0.141 ± 0.010	0.895 ± 0.015	324.5 ± 1.4	261.9 ± 1.1	23.6 ± 2.0
	V	0.19	3863	0.149 ± 0.017	0.885 ± 0.020	324.1 ± 2.6	261.2 ± 2.6	22.3 ± 2.6
	R	0.19	800	0.141 ± 0.024	0.896 ± 0.027	324.7 ± 3.9	259.8 ± 3.3	23.6 ± 3.7

Symbol D_B stands for the critical value of D-discriminant used for the selection and N_B is the number of selected shower members. Perihelion distance, q, is given in astronomical units and eccentricity, e, as dimensionless quantity. The angular elements, i.e. argument of perihelion, ω, longitude of ascending node, Ω, and inclination to the ecliptic, i, are given in degrees shower meteors is typically much larger in the case of much more numerous video or radio data than in the case of less numerous photographic data.

5 An Indication of the Shower Presence in Radio Data

Larger real dispersion of orbits of small radio-meteor particles in combination with their dispersion due to relatively smaller precision of radio orbits can smoothen the cumulative $N = N(D)$ dependence constructed on the basis of radio data. Therefore no break point can be recognized. Nevertheless, replenishment of shower orbits in the appropriate phase space can still be sufficient to enable recovering of the presence of the shower. In the following, we suggest a test based on the iteration procedure used within the break-point method, which brings a serious argument for the presence of the shower in the used database.

Since the radio database is the only source of information about the day-time showers and the break-point method gives selections of only some major showers just from these data, we present our suggestion for the radio database, in this section.

Starting the break-point-method iteration procedure from an initial orbit, the iteration converges to the actual mean orbit of the shower if the used data contain the shower meteors. Usually, there is no large diversity between the chosen initial and determined final mean orbits. However, if the shower is present, then the convergence can also be expected when one starts from an initial orbit more different from the final mean orbit. We suggest making the following steps to find whether the convergence clearly appears and shower is present.

At first, we determine via iteration the mean orbit of shower under study for the threshold value of D equal to $D = 0.20$, which was chosen by Sekanina (1970a, 1970b) as a good, more strict and unique critical D-value. In this step, we use the obvious initial orbit in given study (nominal initial orbit). If there are at least 5 meteors selected, we calculate the standard deviations (σ) for each of five standard orbital elements (q, e, ω, Ω, and i) and establish two modified initial orbits for the iteration, the first with elements $q - 2\sigma_q$, $e - 2\sigma_e, \omega - 2\sigma_\omega, \Omega - 2\sigma_\Omega$, and $i - 2\sigma_i$, and the second with elements $q + 2\sigma_q, e + 2\sigma_e, \omega + 2\sigma_\omega, \Omega + 2\sigma_\Omega$, and $i + 2\sigma_i$. If the number of selected meteors, for $D = 0.20$, is smaller than 5, then the shower is probably not present in the database.

We also experimented with the initial orbits with the elements incremented (reduced) about 1σ (-1σ) and 3σ (-3σ). While for the former initial orbits the clarity of the convergence was still hard to be evaluated, a smaller success occurred for the latter initial orbits. The $3-\sigma$ modification seems to be too large.

We repeat the selection, for threshold $D = 0.20$ again with these two additional initial orbits. If the iterations for all three initial orbits converge to the same final mean orbit then the identification of the shower in the database can be regarded as positive. However, the resultant mean orbit is only indicative since a contamination with meteors not belonging to the given shower is unknown and can be high.

The suggested test is applied to the radio database for the 10 major showers. The mean orbits of these showers found in our previous work (Paper I) are considered as the nominal initial orbits entering the iteration. The result is summarized in Table 3. Besides already selected δ-Aquarids S and Orionids, the test clearly reveals existence of radio-Quadrantids. Starting from three different initial orbits for this shower, almost the same number of shower members is selected (113 or 112) and all three final mean orbits are practically identical (ω of the first mean orbit differs only about 0.2^o from that of the second and third

Table 3 Mean orbital elements used to test occurrence of a given shower in the radio database

shower	orbit type	N_2	q	e	ω	Ω	i
Quadrantids	F	59	0.978 ± 0.004	0.667 ± 0.050	170.8 ± 3.5	283.3 ± 0.8	71.7 ± 1.6
	R-INI−	–	0.958	0.506	155.3	280.3	65.9
	R-SEL−	113	0.971 ± 0.011	0.666 ± 0.076	168.0 ± 7.4	282.7 ± 1.6	71.0 ± 2.9
	R-INI0	–	0.980	0.659	169.9	283.4	71.6
	R-SEL0	112	0.971 ± 0.011	0.666 ± 0.076	168.2 ± 7.3	282.7 ± 1.6	71.0 ± 2.8
	R-INI+	–	1.002	0.812	184.5	286.5	77.3
	R-SEL+	112	0.971 ± 0.011	0.666 ± 0.076	168.2 ± 7.3	282.7 ± 1.6	71.0 ± 2.8
Lyrids	F	16	0.922 ± 0.007	0.969 ± 0.059	213.9 ± 1.6	32.6 ± 0.9	79.6 ± 1.0
	R-INI0	–	0.920	0.966	214.1	32.5	79.6
	R-SEL0	4	–	–	–	–	–
η-Aquarids	F	14	0.569 ± 0.013	0.935 ± 0.028	95.6 ± 2.2	44.6 ± 0.7	163.7 ± 0.7
	R-INI−	–	0.470	0.813	75.3	22.3	156.0
	R-SEL−	5	0.364 ± 0.048	0.620 ± 0.086	46.9 ± 11.0	7.9 ± 6.6	157.0 ± 4.6
	R-INI0	–	0.568	0.938	95.6	44.6	163.8
	R-SEL0	24	0.582 ± 0.060	0.883 ± 0.072	95.6 ± 8.1	48.4 ± 5.1	165.8 ± 4.1
	R-INI+	–	0.666	1.063	115.9	66.9	171.6
	R-SEL+	24	0.582 ± 0.060	0.883 ± 0.072	95.6 ± 8.1	48.4 ± 5.1	165.8 ± 4.1
α-Capricornids	F	43	0.599 ± 0.045	0.764 ± 0.040	266.9 ± 5.5	128.0 ± 6.1	7.3 ± 1.5
	R-INI−	–	0.439	0.624	157.1	17.6	0.0
	R-SEL−	249	0.205 ± 0.062	0.857 ± 0.057	169.3 ± 75.5	194.7 ± 75.1	5.2 ± 3.6
	R-INI0	–	0.598	0.756	267.4	127.6	6.8
	R-SEL0	256	0.236 ± 0.069	0.843 ± 0.059	194.0 ± 87.1	192.1 ± 87.2	4.5 ± 3.0
	R-INI+	–	0.757	0.888	17.7	237.6	15.6
	R-SEL+	0	–	–	–	–	–

Table 3 continued

shower	orbit type	N_2	q	e	ω	Ω	i
δ-Aquarids N	F	18	0.084 ± 0.024	0.963 ± 0.023	330.6 ± 4.2	136.2 ± 4.8	21.3 ± 3.2
	R-INI−	–	0.009	0.865	312.6	122.8	10.7
	R-SEL−	269	0.205 ± 0.077	0.870 ± 0.054	195.7 ± 90.4	183.9 ± 90.4	4.2 ± 2.8
	R-INI0	–	0.097	0.957	328.4	139.7	19.6
	R-SEL0	99	0.120 ± 0.045	0.916 ± 0.049	328.7 ± 8.3	136.4 ± 9.3	18.2 ± 4.9
	R-INI+	–	0.185	1.049	344.2	156.6	28.5
	R-SEL+	68	0.151 ± 0.055	0.889 ± 0.065	325.1 ± 9.7	181.1 ± 9.4	19.9 ± 4.5
δ-Aquarids S	F	35	0.093 ± 0.023	0.967 ± 0.012	148.3 ± 4.1	312.2 ± 5.2	24.7 ± 3.2
	R-INI−	–	0.028	0.903	137.2	299.6	14.6
	R-SEL−	262	0.203 ± 0.076	0.868 ± 0.056	187.9 ± 88.2	193.9 ± 87.7	4.4 ± 2.9
	R-INI0	–	0.090	0.967	148.8	311.2	25.2
	R-SEL0	413	0.080 ± 0.031	0.949 ± 0.032	153.5 ± 5.8	306.9 ± 5.8	28.0 ± 5.3
	R-INI+	–	0.152	1.031	160.4	322.8	35.8
	R-SEL+	364	0.078 ± 0.028	0.952 ± 0.029	153.7 ± 5.4	306.5 ± 4.8	28.4 ± 4.9
Perseids	F	800	0.951 ± 0.017	0.954 ± 0.097	151.0 ± 4.3	139.0 ± 3.3	113.2 ± 2.4
	R-INI−	–	0.908	0.771	140.6	135.1	104.1
	R-SEL−	15	0.929 ± 0.024	0.785 ± 0.082	144.4 ± 6.0	140.6 ± 1.1	110.4 ± 4.4
	R-INI0	–	0.948	0.953	150.3	139.0	113.1
	R-SEL0	12	0.943 ± 0.021	0.895 ± 0.088	148.3 ± 4.9	140.5 ± 2.0	112.9 ± 5.0
	R-INI+	–	0.988	1.135	160.0	142.9	122.1
	R-SEL+	7	0.951 ± 0.013	1.062 ± 0.116	151.3 ± 3.9	141.1 ± 2.3	111.6 ± 4.4

Table 3 continued

shower	orbit type	N_2	q	e	ω	Ω	i
Orionids	F	66	0.579 ± 0.047	0.970 ± 0.062	81.5 ± 6.0	28.2 ± 4.5	163.6 ± 1.7
	R-INI−	–	0.480	0.840	62.9	7.0	156.2
	R-SEL−	35	0.567 ± 0.046	0.872 ± 0.065	85.7 ± 6.5	28.5 ± 3.6	163.3 ± 3.6
	R-INI0	–	0.578	0.967	81.4	28.3	164.0
	R-SEL0	35	0.577 ± 0.049	0.875 ± 0.064	84.4 ± 6.7	27.8 ± 4.3	164.0 ± 3.7
	R-INI+	–	0.676	1.094	99.9	49.6	171.8
	R-SEL+	36	0.576 ± 0.049	0.875 ± 0.064	84.6 ± 6.7	27.9 ± 4.3	163.7 ± 4.0
Leonids	F	35	0.983 ± 0.010	0.908 ± 0.089	174.0 ± 7.0	236.0 ± 5.9	162.7 ± 1.8
	R-INI−	–	0.976	0.753	164.1	231.0	152.2
	R-SEL−	25	0.971 ± 0.012	0.601 ± 0.085	177.1 ± 15.6	248.7 ± 12.3	156.9 ± 4.4
	R-INI0	–	0.984	0.928	172.3	235.5	162.5
	R-SEL0	10	0.989 ± 0.003	0.937 ± 0.068	178.6 ± 3.1	235.2 ± 2.2	163.3 ± 6.0
	R-INI+	–	0.992	1.103	180.5	240.0	172.8
	R-SEL+	9	0.979 ± 0.030	0.988 ± 0.063	179.1 ± 5.6	236.3 ± 8.1	169.4 ± 5.7
Geminids	F	369	0.141 ± 0.010	0.895 ± 0.015	324.5 ± 1.4	261.9 ± 1.1	23.6 ± 2.0
	R-INI−	–	0.093	0.840	316.9	255.2	16.3
	R-SEL−	815	0.141 ± 0.024	0.896 ± 0.028	324.7 ± 4.1	260.5 ± 3.3	23.6 ± 3.7
	R-INI0	–	0.141	0.894	324.7	261.7	23.7
	R-SEL0	801	0.141 ± 0.024	0.896 ± 0.027	324.7 ± 3.9	260.5 ± 3.3	23.6 ± 3.7
	R-INI+	–	0.189	0.948	332.5	268.2	31.1
	R-SEL+	815	0.141 ± 0.024	0.896 ± 0.028	324.7 ± 4.1	260.5 ± 3.3	23.6 ± 3.7
MODEL 1	R-INI0	–	0.677	0.198	17.5	311.0	117.5
	R-SEL0	2	–	–	–	–	–

Table 3 continued

shower	orbit type	N_2	q	e	ω	Ω	i
MODEL 2	R-INI−	–	0.256	0.260	130.0	321.5	147.3
	R-SEL−	0	–	–	–	–	–
	R-INI0	–	0.426	0.421	159.6	343.1	154.3
	R-SEL0	9	0.429 ± 0.085	0.473 ± 0.080	144.1 ± 14.8	43.5 ± 10.8	160.5 ± 3.5
	R-INI+	–	0.596	0.582	189.1	4.7	161.4
	R-SEL+	0	–	–	–	–	–
MODEL 3	R-INI−	–	0.080	0.848	127.9	61.7	136.1
	R-SEL−	0	–	–	–	–	–
	R-INI0	–	0.129	0.939	143.0	77.6	141.6
	R-SEL0	7	0.107 ± 0.024	0.927 ± 0.045	149.9 ± 7.5	82.4 ± 7.9	144.8 ± 2.8
	R-INI+	–	0.178	1.029	158.0	93.4	147.1
	R-SEL+	6	0.105 ± 0.026	0.930 ± 0.048	150.2 ± 8.2	84.1 ± 7.0	145.6 ± 2.1
MODEL 4	R-INI0	–	0.670	0.437	94.8	157.3	104.3
	R-SEL0	0	–	–	–	–	–
MODEL 5	R-INI0	–	0.684	0.869	71.3	271.3	100.6
	R-SEL0	0	–	–	–	–	–

For each shower listed, the mean elements calculated from the shower members selected from photographic (F) and radio (R-SEL) databases are given. We also give the initial orbits of iteration procedure for the radio-meteor data (R-INI). In more detail, the nominal initial orbit (R-INI0), the initial orbit with elements reduced about 2σ (R-INI −), and that with elements enlarged about 2σ (R-INI +) with the mean orbits (R-SEL− , R-SEL0, and R-SEL + , respectively) of correspondingly selected meteors are presented (see Sect. 5) N_2 is the number of shower members selected at the critical D-discriminant equal to 0.20 (the selection of δ-Aquarids S, Orionids, and Geminids from the nominal initial orbit was possible by the break-point method, therefore the critical D is that given in Table 2, here)

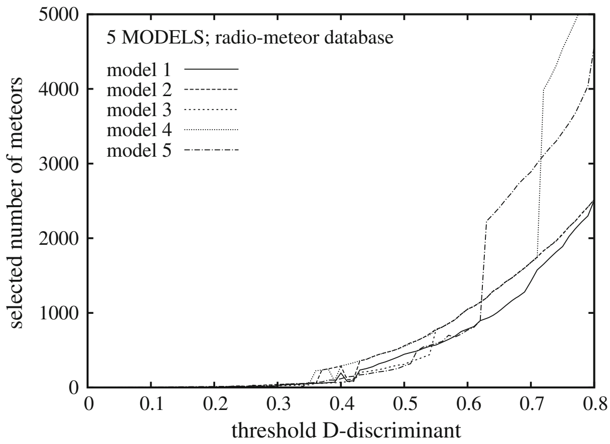


Fig. 13 The same as plots (**c**) in Figs. 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 (radio database), but for 5 randomly modelled mean orbits situated in the orbital phase spaces, where no apparent shower is expected

orbit). One can notice that the convergence appears despite the fact that initial values of elements are outside the corresponding dispersion intervals. A strong convergence trend can occur only due to the presence of the shower.

In the case of Perseids, three final mean orbits are consistent within the given dispersion of orbital elements. However, the values of elements of the final mean orbit are roughly in the middle between the corresponding initial values and values obtained starting from the nominal initial orbit. The convergence is not so clear than in the case of Quadrantids. It is worthy to notice that the number of separated members of radio-Perseid shower is low (7–15). We suggest to regard the existence of the Perseids in the radio data used as questionable.

While the test well confirms existence of radio-Orionids, the existence of η-Aquarids, belonging to the same spatial stream, is questionable because the iteration converges to the same final mean orbit only for two of three initial orbits (Table 3). Interestingly, such partial convergence also occurs for δ-Aquarids S, clearly selected with the help of break point (see Sect. 4). Likely, a presence of other shower near the phase space of the modified initial orbit caused a deflection of the convergence in iteration away from the analysed-shower orbit, in both cases.

Besides of the questionable identification of η-Aquarids, our recognition of four showers in the radio database is consistent with their detection by the Canadian Meteor Orbit Radar, CMOR (Brown et al. 2008, Fig. 2). There were five large peaks in the number of detected meteors during year corresponding to the activity of Quadrantids, η-Aquarids, day-time Arietids, δ-Aquarids S, and Geminids. The peak in the CMOR's detections corresponding to Orionids, though not comparably high, was also relatively wide.

The test cannot be applied to the Lyrids, which are obviously not present in the radio data because only 4 meteors are selected for $D = 0.20$ starting from the nominal initial orbit. The application of the test is possible, but no convergence is found for α-Capricornids, δ-Aquarids N, and Leonids. At α-Capricornids, no meteor was separated starting with the initial orbits having the elements increased about 2σ for $D = 0.20$.

To demonstrate the $N = N(D)$ trend in the interval of orbital-element phase space, where no apparent shower is expected, we model 5 random initial orbits and construct the corresponding cumulative $N = N(D)$ dependences using the radio database (Fig. 13). The test does not result in any convergence (see the second part of Table 3) as expected. The number of selected meteors starts to rise typically at the threshold value $D \approx 0.3$ in contrast to actual showers where this increase occurs at significantly lower threshold D values.

6 Concluding Remarks

The break-point method is found to be applicable to photographic and video databases. The mean characteristics of 10 major meteor showers obtained using both databases are similar.

Applicating the method to the radio database, only three of ten investigated showers were selected successfully. It seems that only a shower in the orbital phase space with a relatively lower number of sporadic-background meteors and/or meteors of other showers can be well separated. Consequently, the relatively larger dispersion, real or due to the observational uncertainty, of shower orbits in the radio data does not enable so good working of the break-point method than in the case of photographic or video data.

Since the radio database is a unique source of information about the day-time showers, it is desirable to gain any evidence of a shower. In course to at least confirm the existence of a suspected shower in the radio data, we suggested the test giving an argumentation for such confirmation, if the shower is present. This test revelaed another one of 10 major showers in the radio data. The test should, however, be regarded as applicable in a positive sense: presence of a shower in the data can be confirmed, but cannot be excluded.

Acknowledgements This work has been supported, in part, by the VEGA - the Slovak Grant Agency for Science (grants Nos. 0011, 0022, 0636). The work was also supported by the Slovak Research and Development Agency (grant APVV No. 0516).

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