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Study of meteoroid stream identification methods

Regina Rudawska[1] **and Tadeusz J. Jopek**[2]

Astronomical Observatory of Adam Mickiewicz University, Poznan, Poland
[1]email: `reginka@amu.edu.pl` [2]email: `jopek@amu.edu.pl`

Abstract. We have tested the reliability of various meteoroid streams identification methods. We used a numerically generated set of meteoroid orbits (a stream component and a sporadic background) that were searched for streams using several methods.

Keywords. meteoroids, data analysis

1. Introduction

The meteoroid stream identification methods are based on three components: dynamical similarity (distance) function, similarity threshold D_c and cluster analysis algorithm – which define the stream itself. Several similarity functions have been proposed: D_{SH} the orbital D-criterion introduced by Southworth and Hawkins (1963), its modifications by Drummond (1981), Jopek (1993), Valsecchi *et al.* (1999), and Jenniskens (2008) and the D_V function defined in the domain of the vectorial heliocentric orbital elements (Jopek *et al.* (2008)). The threshold, D_c is used to test the similarity among two orbits $\mathbf{O}_i, \mathbf{O}_j$ – these two orbits are associated if $D(\mathbf{O}_i, \mathbf{O}_j) < D_c$. Having the distance function and the similarity threshold a meteoroid stream can be detected by a cluster analysis algorithm, one can use e.g.: an iterative methods proposed in (Sekanina (1976), Welch (2001)), a single neighbour linking technique (Southworth and Hawkins (1963), Lindblad (1971)), method of indices (Svoreň *et al.* (2000)) or the wavelet transform technique (Galligan and Baggaley (2002), Brown *et al.* (2008)).

2. Meteoroid data sample preparation

We searched for streams among the numerically generated orbits. For selected NEOs (see table 1), fifteen sets of genetically associated particles were generated; the motion of all stream particles was integrated numerically over 40KA with the Newtonian force model of the Planetary System. At each of six intermediate epochs (see table 2) the stream component was completed by a set of sporadic orbits generated with the distribution of orbital elements that were statistically similar to the distribution of the background meteors taken from the IAU MDC photographic catalogue, Lindblad *et al.* (2003).

3. Searching methods tested in this study

The orbital samples were searched by the following methods:

• $W1DSH$ – a simplified version of Welch's method (Welch (2001)) equipped with the D_{SH} function. In this method, the density at mean orbit of a stream $\mathbf{O}_A$ in orbital

Parent body	q	a	e	i	Ω	ω	Q	P	Associated meteoroid stream
1998 SH_2	0.743	2.686	0.723	2.5	13.1	261.2	4.629	4.40	α Virginids
2004 BZ_{74}	0.330	3.048	0.892	16.6	233.9	121.3	5.767	5.32	α Scorpiids
2004 HW	0.976	2.688	0.637	0.8	220.4	62.3	4.401	4.41	Corvids
2004 TG_{10}	0.315	2.242	0.859	3.7	212.3	310.0	4.169	3.36	N. Taurids, Dayt. β Taurids
2005 NZ_6	0.248	1.834	0.865	8.5	39.7	48.0	3.419	2.48	Dayt. April Piscids
3200 Phaethon	0.140	1.271	0.890	22.2	265.4	322.0	2.403	1.43	Geminids
1P/Halley	0.587	17.942	0.967	162.2	58.9	111.9	35.296	76.00	Orionids, η Aquariids
2P/Encke	0.331	2.209	0.850	11.9	334.7	186.2	4.087	3.28	S. Taurids, Dayt. ζ Perseids
7P/Pons-Winnecke	1.256	3.435	0.634	22.3	93.4	172.3	5.615	6.37	June Bootids
8P/Tuttle	0.998	5.672	0.824	54.7	270.5	206.7	10.346	13.50	Ursids
21P/Giacobinni-Zimmer	1.034	3.522	0.706	31.8	195.4	172.5	6.010	6.61	Draconids
26P/Grigg-Skjellerup	0.997	2.965	0.664	21.1	213.3	359.3	4.933	5.11	π Puppids
55P/Temple-Tuttle	0.977	10.337	0.905	162.5	235.3	172.5	19.698	3.28	Leonids
73P/Schwassmann-Wachmann3	0.941	3.063	0.693	11.4	69.9	198.8	5.186	5.36	τ Herculids
109P/Swift-Tuttle	0.958	26.317	0.963	113.4	139.4	153.0	51.675	135.00	Perseids

Table 1. Orbital elements of 15 NEOs for which the responding, artificial streams have been generated. The orbits were gathered from Marsden and Williams (2003), NeoDys (2007).

element space, operating on a set of orbits $\mathbf{O}_i, i = 1, ..., N$, was given by

$$\rho(\mathbf{O}_A) = \sum_{i=1}^{N} \left(1 - \frac{D^2(\mathbf{O}_i, \mathbf{O}_A)}{D_c^2}\right) \tag{3.1}$$

- $W2DSH$ - a simplified Welch's method with D_{SH} function, however the density at mean orbit of a stream was calculated from

$$\rho(\mathbf{O}_A) = \sum_{i=1}^{N} \left(1 - \frac{D(\mathbf{O}_i, \mathbf{O}_A)}{D_c}\right)^2 \tag{3.2}$$

- $W1DV$ - similarly to $W1DSH$, but with D_V function as described in Jopek *et al.* (2008),
- $W2DV$ - similarly to $W2DSH$, but with D_V function,
- MI - method of indices (Svoreň *et al.* (2000)),
- $SLDSH$ - single neighbour linking technique with D_{SH} function,
- $SLDV$ - as above, but with D_V function.

All methods, except for the last three, were applied with the values of D_c corresponding to their largest reliability. In case of $SLDSH$ and $SLDV$ methods, the constant threshold $D_c = 0.02$ and $D_c = 0.01 \cdot 10^{-2}$ were adopted. MI method was used in the form described by Svoreň *et al.* (2000).

To evaluate the reliability level of the result obtained for a given stream with the applied method, we introduced two parameters, S_1 and S_2, defined as

$$S_1 = \frac{N_p}{N_{max}} \cdot 100\%, \qquad S_2 = \frac{N_i}{N_p + N_i} \cdot 100\%$$

where N_p – a number of correctly identified members of a stream, N_{max} – a total amount of particles in the stream, and N_i – a number of interlopers i.e. sporadic meteoroids and meteoroids belonging to another streams.

In addition, for all streams identified at the same epoch, a general reliability parameter was evaluated with

$$SS_1 = \sum_{k=1}^{N} N_{kp} \cdot \left[\sum_{k=1}^{N} N_{k\ max}\right]^{-1} \cdot 100\%$$

where $k = 1, \ldots, N = 15$, denotes all the identified streams.

4. Results

At each epoch, for each stream, the values of the above parameters have been calculated. The results of the stream identification were accepted as reliable, only if $S_2 < 10\%$. Next, a ranking of all reliable results was accomplished, and the results obtained are given in table 2. We can see that the results with highest reliability were most often obtained using D_V function and the Welch iterative or single linkage cluster analysis algorithm. When the same algorithms were used with D_{SH} function, the results were considerably worse.

The ranking, in the way it was carried out, informs us only which of the methods was better. To illustrate the relative differences between the results obtained with various methods we need another measure. For this purpose we used a general reliability level SS_1. Close to the starting epoch SS_1 was above 90% for all the methods (Fig. 1), while as the stream dispersion proceeded in time the reliability of methods decreased. For $W1DV$, $W2DV$ and $SLDV$ methods decrease was approximately linear, while for $W1DSH$, $W2DSH$, MI and $SLDSH$ methods the decrease of reliability was faster, with distinct fluctuation. In the first group the most reliable results were obtained more often with $W1DV$ method (from 100% to 60%), and the reliability of $W2DV$ and $SLDV$ was equivalent. At the beginning, $SLDV$ was slightly more effective, while the $W2DV$ method gained the advantage in the later epochs. In the case of the second group of methods, their initial high reliability distinctly decreased with time, and finally reached values below 50–40%. The lowest reliability, about 20%, was obtained by $W2DSH$ method.

Table 2. Final score of the ranking of the meteoroid stream identification. In each column we see how many times a given method achieved the best result, e.g. at starting epoch, using $W1DV$ method three streams have been identified with the highest reliability level. Sometimes a few methods achieved exactly the same reliability for a given stream. In such cases each method scored one point.

Epoch\Method	$W1DSH$	$W2DSH$	$W1DV$	$W2DV$	MI	$SLDSH$	$SLDV$
00000	2	2	3	3	10	8	4
01200	2	1	1	2	3	1	8
07200	0	0	7	3	2	0	5
15200	0	0	10	3	0	0	3
22000	0	0	2	5	2	0	4
30000	0	0	10	6	0	0	0
Total	4	3	33	22	17	9	24

5. Conclusion

Our survey was the first step in the assessment of reliability of meteoroid stream identification methods. The obtained results let us state that identification methods based on D_V function clearly distinguish themselves from others. Cluster analysis algorithms: simplified Welch's algorithm and single linking technique with D_V function, most often appeared to be the most effective, whereas methods with D_{SH} criterion, i.e $W1DSH$, $W2DSH$ and $SLDSH$ were less effective.

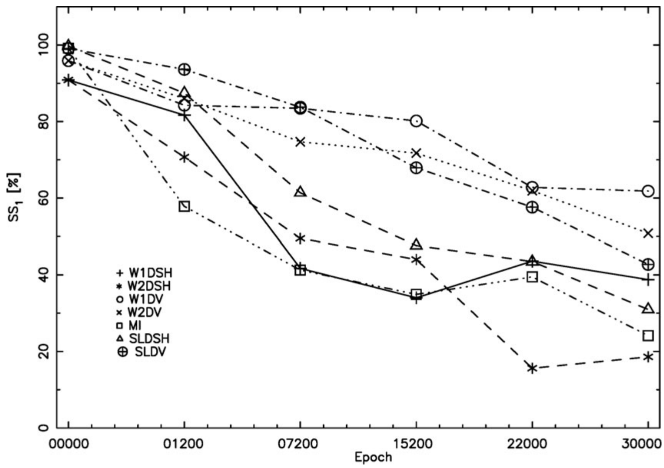

Figure 1. The general reliability parameter SS_1 obtained for all identified streams. The value of SS_1 was calculated by formulae 3 for each epoch.

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