Ongoing Meteor Work

A meteor shower catalog based on video observations in 2007–2008

SonotaCo [1]

A new meteor shower catalog was established from two years of continuous video observations based on almost 240,000 single-station observations by more than 100 video cameras operated at 25 stations in Japan. 39 208 meteor orbits were computed from them as qualified multi-station observations. From this sample, 38 meteor showers were obtained as the result of applying a uniformized method of clustering in the four-dimensional space of appearance in Solar longitude, radiant position, and geocentric velocity. The full set of showers in the new catalog covered 37% of all meteors. No other concentration was confirmed from the remaining 63%. The catalog is the first one based on long term, wide area, multi-station video observations, and shows the recent real activity for all major meteor showers that are optically observable from northern hemisphere. Eleven showers have been added to the list of meteor showers of the IAU Meteor Data Center (MDC).

Received 2009 January 29

1 Introduction

Automated multi-station video meteor observations present a very good detection ability, fair accuracy of orbit computation, and the capability for long term continuous observations necessary to creating a shower catalog.

UFOCapture (SonotaCo, 2005) is a motion detection software which allows video recording from a few seconds before the trigger. Written by SonotaCo in 2003, it has been used by scientific observers chronicling rare events such as meteors or TLEs (transient luminous events caused by lightning discharge). By the end of 2006, the meteor measurement software UFOAnalyzerV2 (SonotaCo, 2007), and the orbit computation software UFOOrbitV2 (SonotaCo, 2007) had been published, and the environment for multi-station meteor observation had been established. Results of the system have already been used for the detection of the τ-Ursae Majorids (Uehara, et al., 2006; now October Ursae Majorids) and the analysis of meteor altitudes (Molau & SonotaCo, 2008).

Having started as an online user forum for UFOCapture, SonotaCo Network has been working since 2004. The members of the network are amateur astronomers, staffs of public observatories, and a few professional researchers. The network itself had grown to more than 30 stations by 2007. These stations are observing the night sky above Japan every night, even when it is raining.

In this paper, we describe a set of meteor showers which are a result of two years of observations by the SonotaCo Network.

2 Outline of observation

For this study we used the SonotaCo Network's published observational results for the period 2007 January 1 to 2009 January 1 (731 nights). This data was compiled by 25 stations using more than 100 cameras. The totals are listed in Table 1, and the contributing stations are listed in Table 2. Figure 1 shows the distribution of the observed trajectories. Many stations use multiple cameras with standard lenses to inprove the accuracy and to cover larger area. The typical equipment is as follows:

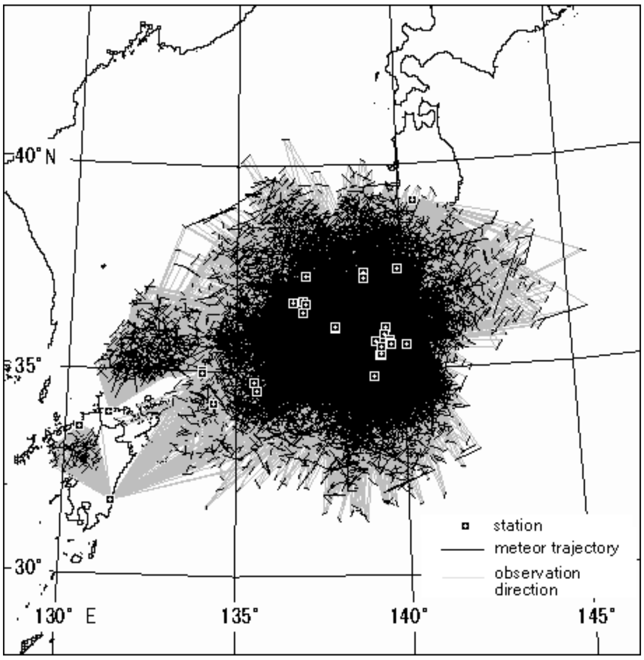

Figure 1 – Observation area and the stations.

- **Camera:** Hi-sensitivity monochrome CCD video camera, WATEC-100N or WATEC-902H2U.
- **Lens:** CS-mount lens, $f/0.8, f = 3.8 - 12$ mm (FOV: 90 – 30°).
- **Video format:** 720 × 480 or 640 × 480 AVI digitized from analog NTSC signal (29.97fps, interlaced).
- **Software:** UFOCaptureV2, UFOAnalyzerV2, UFOOrbitV2.

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IMO bibcode WGN-372-sonotaco-catalog
NASA-ADS bibcode 2009JIMO...37...55S

Table 1 – Totals of the observations in 2007–2008.

Number of single-station meteors:	293 702
Number of qualified single-station meteors:	244 247
Number of single-station observations composing simultaneous observations:	114 026
Number of meteors qualified for multi-station observation:	39 208 (see Figure 2)
Average number of simultaneous observations per meteor:	2.93 camera/meteor
Average number of qualified meteors per night:	53.6 meteors/night
Number of nights with > 100 qualified meteors:	120 nights / 2 years
Number of nights with no meteor observed:	133 nights / 2 years
Top 6 nights which had most meteors (UT)	2007/12/14 (1051 meteors) 2007/08/12 (845 meteors) 2007/12/13 (796 meteors) 2007/08/13 (700 meteors) 2007/10/20 (655 meteors) 2008/12/14 (603 meteors)

Table 2 – Number of single-station observations and the observers. (The location ID includes the prefecture name in Japan.)

Location ID	Observations	Observer
Akita1	3304	Izumi
Chiba2	18843	Ada
Fukuoka1	720	Shigetaka Shiraishi
Fukushima1	687	Hiromichi Horigane
Ishikawa1	4169	Hideaki Muroishi
Ishikawa2	13078	Hiroshi Yamakawa
Kanagawa1	19744	Hiroyuki Inoue
Miyazaki1	11457	Kouji Maeda
Okayama1	4749	Junichi Yokomichi
Okayama4	297	Junichi Yokomichi
Nagano1	56576	T. Masuzawa
Niigata1	138	PURU
Niigata2	19113	Toshio Kamimura
Osaka01	17063	Satoshi Uehara
Osaka03	12011	Masayoshi Ueda
Saitama1	37531	Takashi Sekiguchi
Saitama2	604	NOMOTO Satoko
Sizuoka3	99	SonotaCo
Tokyo1	34232	SonotaCo
Tokyo2	536	Koji Ito
Tokyo4	6338	Hiroshi Yamakawa
Tokyo5	20914	Junichi Nakai
Tokyo6	7281	Naoya Saito
Toyama1	4460	Toyama Astronomical Observatory
Toyama2	204	T. Komai
Others	52	–

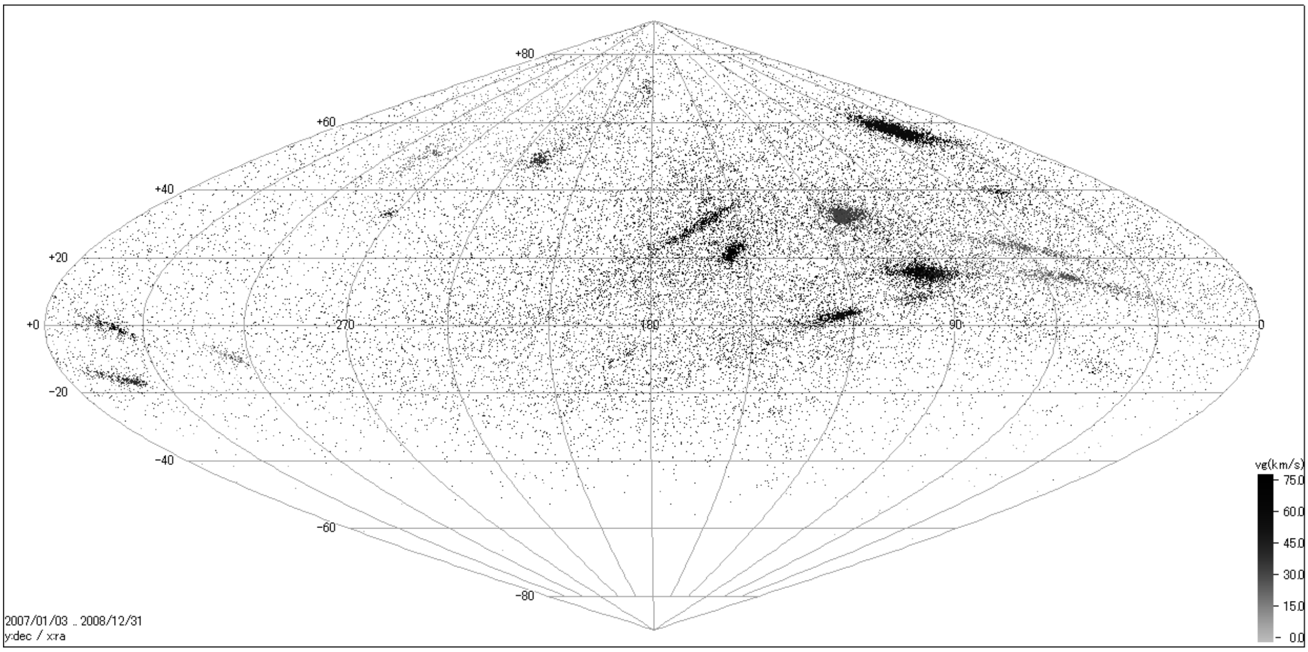

Figure 2 – Radiant of 39 208 meteors observed over two years, in a sinusoidal projection with x the right ascension α and y the declination δ (J2000.0). The original graph with the colour coded geocentric velocity is printed on the outer back cover.

3 Observation accuracy

The typical accuracy of single-station observation measurement is 0°.03 for the direction and 0.5 s for the absolute timing. This level of accuracy is achieved from UFOAnalyzerV2 plate adjustment using fixed stars and time synchronization obtained from Network Time Protocol on the Internet. The time resolution is 0.017 s, and it is very accurate for timing of NTSC video. This accuracy can be used as basic measurement accuracy for most of the meteors which show a narrow trajectory and no burst or explosion.

The accuracy of the radiant position and the velocity depend on the geometric conditions of simultaneous observations, such as distance from station to the meteor or the cross angle of the observed planes. Although UFOOrbitV2 improves the accuracy by calculating all (more than two) simultaneous observations by the least square method (unified radiant mode), the effectiveness of this method also depends on the number of simultaneous observations and their geometric situations. Therefore, the accuracy is different for each meteor. In this study, the lowest quality check of UFOOrbitV2 (mode Q1) was used for all data. It checks the intersection angle, duration time, height, velocity, and matching of the trajectory. It rejects results which have obvious large errors. As a statistical result, the radiant of compact showers, such as the Quadrantids, show a concentration within a radius of a 3° circle, and 20% deviation of the velocity if data from one night are used.

The commixture of non-meteoric objects such as air planes, satellites, or cosmic ray noise was negligible, because all single-station observations have been checked manually by the observer and UFOOrbitV2 checked it again. But because the post-process was fully automated, the data set possibly includes a small number of the following cases:

- Records that have big errors caused by an explosion, asymmetrical brightness, or background noise.
- Mis-combined data from multiple meteors which happened almost simultaneously, close to each other, and along a very similar vector.
- Mis-combined data caused by time adjustment failure.

4 Statistical bias of the data set

The analysis involves a number of different biases which are discussed here.

Magnitude: Figure 3 shows the distribution of magnitudes. The average visual magnitude was 0.84 for single-station observations, and 0.20 for simultaneous observations. The average absolute magnitude was

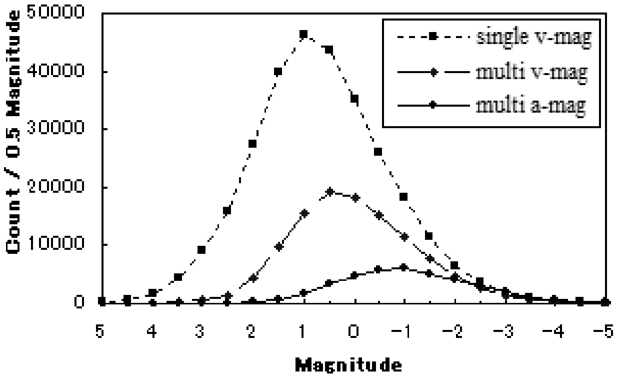

Figure 3 – Distribution of meteor magnitudes. Single v-mag is the visual magnitude of single-station observations, multi v-mag the visual magnitude of simultaneous observations, and multi a-mag absolute magnitude of qualified meteors.

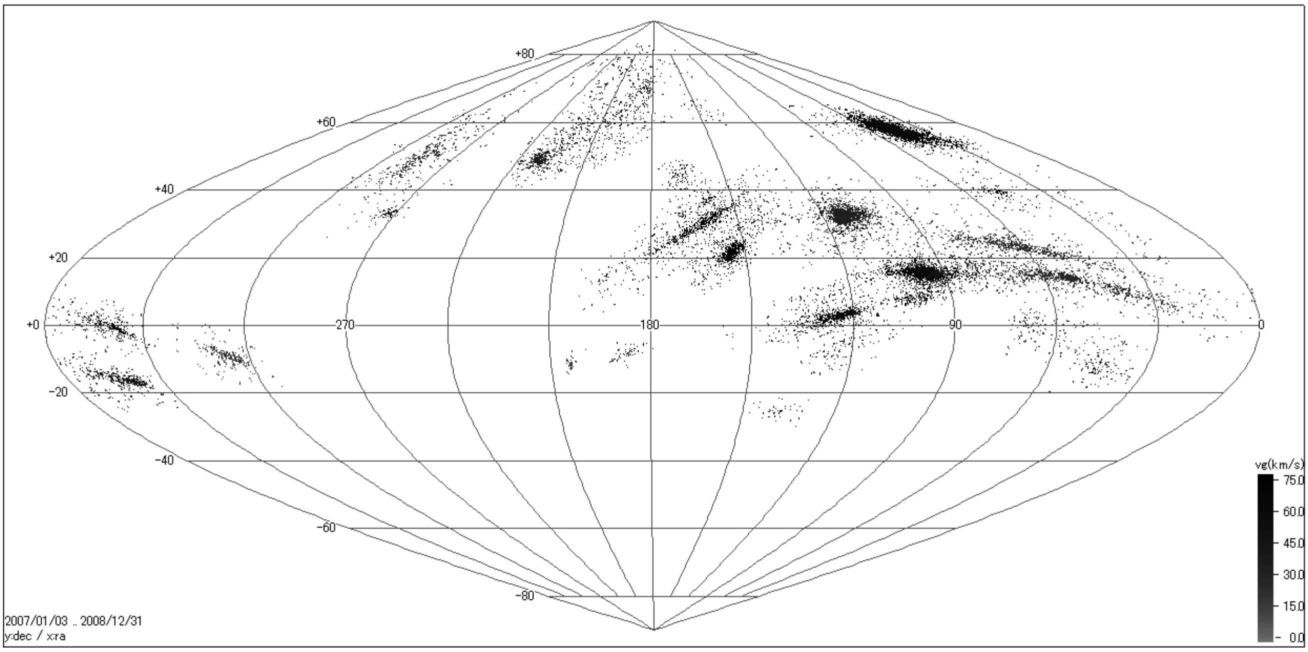

Figure 4 – Radiant areas of 38 meteor showers obtained from the clustering.

−0.87. Meteors fainter than absolute magnitude 2.0 are very rare in the set.

Length: meteors which had less than 1° trajectory length were rejected.

Geographical condition: all observations were made in the latitude range between 32° and 40° N. Therefore, many of the southern hemisphere radiants are out of range.

Weather: the dependency on the weather over Japan in 2007 and 2008 was not small. The effect of clouds, reduced transparency, or Moon light could not be omitted even by combining data collected over two years.

5 Clustering method

The purpose of clustering is to determine the set of the minimum number of meteor showers which covers all obvious concentrations and does not include too many sporadic meteors. Correcting for clustering also means that we obtain a smooth distribution of sporadic meteors.

This clustering was done in a four-dimensional space. The axes are the time of the meteor appearance in Solar ecliptic longitude ($\lambda_\odot$), the radiant's right ascension (α_p) and declination (δ_p), and the geocentric velocity (V_g). The radiant positions α_p, δ_p and the velocity V_g are corrected for the effect of zenith attraction due to the Earth's gravity. As is well known, the observed radiant position and observed velocity varies with the radiant elevation angle in the sky, while α_p, δ_p and V_g do not depend on the time of night.

In this study, one shower is expressed by 10 parameters as summarized in Table 3. The clustering involved the following steps.

1. Initialization: combine a meteor data set from all observations.
2. Reference making: select one meteor which is near the center of the largest concentration in the set and select it as the reference. (A dominant orbit of a known shower can be used as the reference for the confirmation of shower's existence.)
3. Clustering: select meteors which are close to the reference in the four-dimensional space from the set. Consider the radiant drift if it has already been computed. Then, the ranges of $\lambda_\odot$, R and ΔV are tuned, depending on the characteristics of the shower, to cover the whole concentration and not to include too many surrounding sporadic meteors.
4. Reference update: compute the shower parameters from the selected meteors, and update the reference as the center of selected meteors.
5. Iteration: repeat steps 3 and 4 until the association of the selected meteors does not change, or an association to another shower occurs.
6. Set update: once a cluster is found, its parameters are recorded and the clustered meteors are deleted from the set. Then the procedure is repeated from step 2 until all concentration disappears.

After this process, parameters of other known showers were checked to find out whether there was any concentration among the remaining meteors. If the concentration was confirmed and compared with the sporadic meteors surrounding it, then it was added to the catalog even if the number of observations was small The checked known radiants were those in the established IAU list (IAU, 2008) which contains 56 showers, and the UFOAnalyzerV2 current stream list (145 showers).

Table 3 – Observed parameters of 38 meteor showers. IAU code: number and code of the IAU Meteor Data Center list. $\lambda_{\odot 1}$, $\lambda_{\odot 2}$: Solar longitude of the shower activity start and end. $\lambda_{\odot p}$: Solar longitude of the shower peak date in 2008. α_p, δ_p: Right ascension and declination of the radiant at its peak. $\Delta\alpha, \Delta\delta$: radiant drift in right ascension and declination measured at its peak. The motion of the shower radiant is assumed as a motion along a great circle of the celestial sphere. The $\Delta\alpha, \Delta\delta$ compose one vector which shows the direction and velocity of the motion at its peak. Therefore the computation of a radiant position on a specified day becomes rather complex, but it can express the motion in the higher declination region by only one vector. V_g: geocentric velocity. R: radius of the radiant distribution circle that was allowed for the shower association. ΔV: difference of V_g that was allowed for the shower. SN2006 is the code which is used by the current UFOOrbitV2.

IAU Code	Name	$\lambda_{\odot 1}$ [°]	$\lambda_{\odot 2}$ [°]	$\lambda_{\odot p}$ [°]	Date (2008)	α_p [°]	δ_p. [°].	$\Delta\alpha$ [°]	$\Delta\delta$ [°]	V_g [km/s]	R [°]	ΔV [km/s]	Number of meteors	SN2006
334 DAD	December α-Draconids	236.4	278.3	256.5	12/08	207.9	60.6	0.40	−0.14	41.0	9.0	4.0	145	–
331 AHY	α-Hydrids	266.3	290.8	279.0	12/30	124.9	−7.7	0.45	−0.10	44.2	5.0	3.0	38	J1_aHy
018 AND	Andromedids	212.6	241.9	228.6	11/10	22.5	29.7	0.12	0.30	17.0	5.0	5.0	18	J1_tPs
343 HVI	h-Virginids	27.8	43.6	39.0	04/29	204.2	−11.6	0.11	−0.27	18.7	3.0	3.0	16	–
342 BPI	August β-Piscids	128.8	151.2	140.0	08/12	346.4	1.4	0.74	0.22	38.3	6.0	4.0	71	J1_bPs
001 CAP	α-Capricornids	114.3	138.4	126.1	07/28	305.7	−9.4	0.50	0.26	22.4	6.0	3.0	122	J1_Cap
020 COM	December Comae Berenicids	244.0	311.2	265.7	12/17	159.7	31.6	0.79	−0.32	63.0	6.0	4.0	652	J1_Com
335 XVI	December χ-Virginids	246.1	266.4	256.7	12/08	186.8	−7.9	0.20	−0.14	67.8	3.0	7.0	31	–
221 DSX	Daytime Sexantids	187.8	190.9	189.2	10/02	156.3	−2.9	−0.76	−0.86	31.2	3.0	3.0	4	J3_Sex
191 ERI	η-Eridanids	124.1	147.4	137.6	08/09	44.5	−11.7	0.49	0.03	64.0	6.0	6.0	86	–
145 ELY	η-Lyrids	42.5	54.2	49.8	05/10	291.7	43.8	0.20	0.02	44.3	4.0	3.0	14	J1_eLy
031 ETA	η-Aquariids	34.7	68.7	46.3	05/05	338.3	−0.8	0.62	0.29	65.4	5.0	5.0	220	J1_etA
344 JUG	July γ-Draconids	121.8	128.8	125.3	07/28	280.1	51.1	1.17	1.45	27.4	4.0	3.0	22	–
004 GEM	Geminids	245.6	279.4	261.4	12/13	112.8	32.3	0.90	−0.19	33.5	7.0	12.0	2510	J1_Gem
016 HYD	σ-Hydrids	227.9	280.6	252.9	12/04	123.2	3.0	0.49	−0.12	59.0	7.0	5.0	699	J1_Hyd
012 KCG	κ-Cygnids	123.7	155.5	140.7	08/13	285.0	50.1	0.45	0.45	21.9	10	5.0	213	J1_kCg,gDr
336 KDR	December κ-Draconids	239.7	259.7	250.2	12/02	186.0	70.1	0.05	−0.09	43.4	4.0	3.0	61	J1_aDr
013 LEO	Leonids	220.9	247.1	235.4	11/17	153.9	21.9	0.56	−0.39	70.0	4.0	7.0	713	J1_Leo
022 LMI	Leonis Minorids	203.7	220.9	208.9	10/22	158.8	37.1	0.44	−0.08	61.9	4.0	6.0	39	J1_Lmi
006 LYR	April Lyrids	24.3	41.6	32.5	04/22	272.6	33.2	0.82	−0.29	46.7	5.0	5.0	73	J1_Lyr
019 MON	December Monocerotids	245.6	269.9	257.6	12/09	100.1	8.2	0.52	−0.11	41.2	3.0	3.0	161	J1_Mon
337 NUE	ν-Eridanids	156.8	174.5	167.9	09/10	68.7	1.1	0.14	−0.13	65.9	3.0	3.0	29	–
250 NOO	Nov. Orionids	228.7	260.2	249.2	12/01	92.6	15.4	0.53	−0.04	42.0	4.0	5.0	210	J1_nOr
017 NTA	Northern Taurids	202.9	258.0	234.4	11/16	62.0	24.0	0.65	0.12	26.7	5.5	4.0	475	J1_nTa
281 OCT	October Camelopardalids	188.8	199.9	197.1	10/10	163.3	76.7	−0.93	−0.13	45.3	5.0	5.0	10	–
338 OER	o-Eridanids	227.9	245.0	234.7	11/16	60.7	−1.5	0.65	−0.03	26.9	5.0	4.0	26	J1_bEr
008 ORI	Orionids	178.9	234.0	207.9	10/21	95.5	15.5	0.61	0.01	66.2	4.0	8.0	2733	J1_Ori
183 PAU	Piscis Austrinids	124.0	140.6	133.2	08/05	352.8	−20.4	0.27	−0.03	42.8	4.0	3.0	10	J1_oAq
007 PER	Perseids	119.0	160.5	139.2	08/11	47.2	57.7	1.17	0.19	58.7	5.0	20.0	3524	J1_Per
339 PSU	ψ-Ursae Majorids	240.0	265.1	252.9	12/04	167.8	44.5	0.20	−0.01	60.7	3.0	3.0	33	–
010 QUA	Quadrantids	276.4	291.1	283.1	01/04	230.0	49.0	0.15	0.17	40.0	5.0	6.0	243	J1_Qua
208 SPE	September-Perseids	154.8	181.2	167.1	09/09	47.3	39.3	0.77	0.06	63.9	5.0	4.0	109	J1_gAn
005 SDA	Southern δ-Aquariids	118.0	145.4	129.7	08/01	341.9	−16.2	0.62	0.26	39.4	4.0	4.0	324	J1_sdA
002 STA	Southern Taurids	178.0	275.3	219.7	11/01	50.1	13.4	0.73	0.16	27.2	6.0	5.0	707	J1_sTa,gTa
340 TPY	θ-Pyxids	239.9	256.2	249.4	12/01	139.0	−25.5	0.43	0.04	60.1	3.0	3.0	23	–
333 OCU	October Ursae Majorids	194.6	214.6	204.7	10/17	147.6	64.0	0.13	0.09	54.4	4.0	3.0	15	J1_tUm
015 URS	Ursids	257.0	282.7	265.5	12/17	215.1	76.2	0.94	0.04	33.2	5.0	5.0	28	J1_Urs
341 XUM	ξ-Ursae Majorids	296.8	306.3	300.6	01/21	169.0	33.0	−0.13	0.01	40.2	5.0	3.0	12	J1_xUm

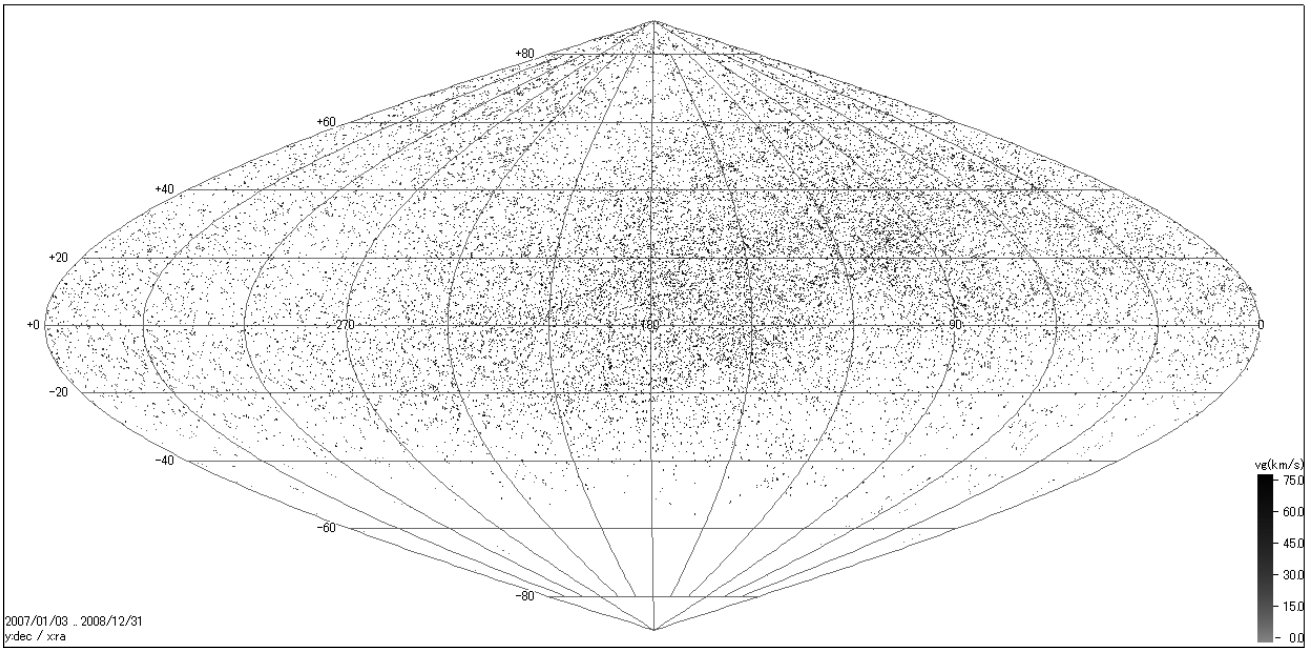

Figure 5 – Radiants of 24 837 non shower meteors in right ascension and declination.

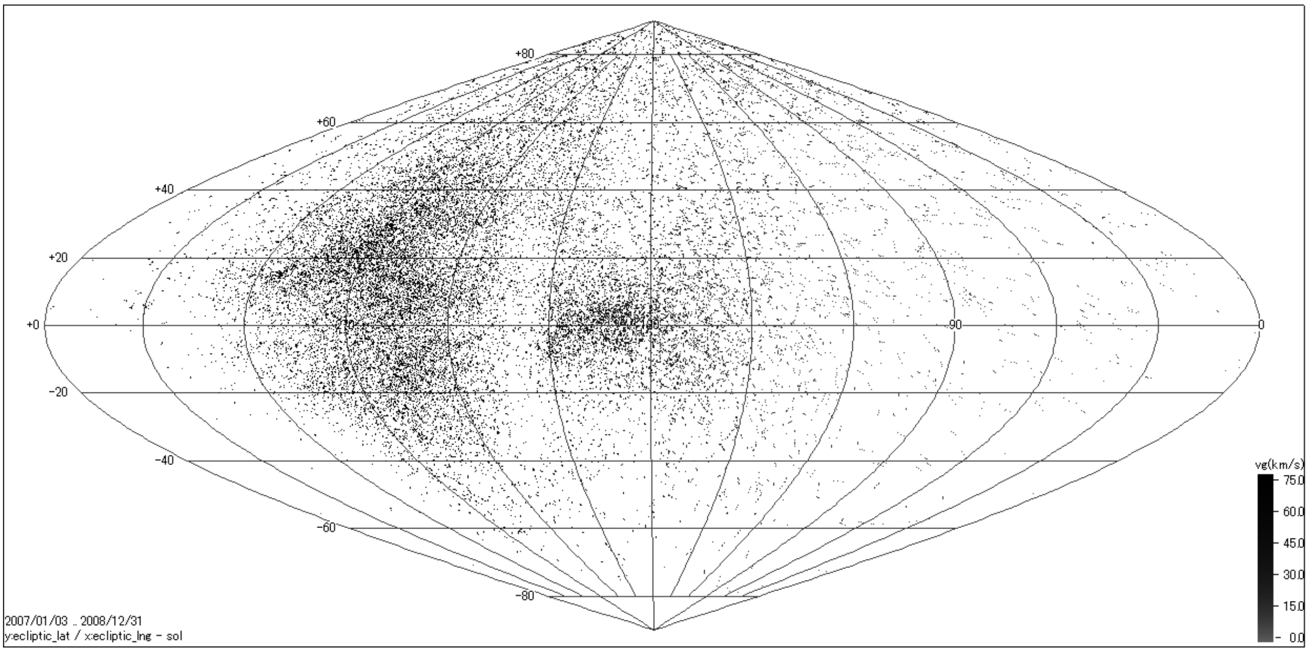

Figure 6 – Radiants of 24 837 non-shower meteors in coordinates of x-axis: ecliptic longitude λ – solar ecliptic longitude $\lambda_\odot (\lambda - \lambda_\odot)$, y-axis: ecliptic latitude. This projection shows the (season independent) solar direction from the Earth (0, 0), the apex direction (270, 0), and the antihelion direction (180, 0). Most of the radiants occur in the range of $\lambda - \lambda_\odot = 90$ to 270°. This almost corresponds to the zenith direction at 18^h and 06^h local time. The high density area around the apex is the maximum of geocentric velocity and it gradually decreases towards (90, 0). It means that the velocity of the Earth's orbital motion dominates the meteor velocity. We find a low-density area around (220, 0). This is the region of Sun-grazing meteors, which are not on stable orbits. The colour version of this Figure can be found on the back cover.

Table 4 – IAU showers unified to one shower because they appear as one source in the four-dimensional space.

020 COM, 032 DLM, 090 JCO	J4_Com (020 COM)
016 HYD, 246 AMO	J4_Hyd (016 HYD)
017 NTA, 256 ORN	J4_nTa (017 NTA)
002 STA, 257 ORS	J4_sTa (002 STA)
005 SDA, 003 SIA	J4_sdA (005 SDA)

6 Clustering result

Table 3 and Figure 4 show the result of the clustering. 38 showers were confirmed and their parameters were obtained. They covered 14 381 meteors and were 37% of all meteors. It was also confirmed that no concentration existed on the remaining 63% of meteors on the condition of more than 10 meteors in the range of $\lambda_\odot \pm 5°$, $R < 3.0$ degree, and $\Delta V \pm 30\%$, except the image of the major showers (Per, Gem, Qua, Ori, Tau) caused by the observation errors. Figures 5 and 6 show the remaining 24 827 meteors.

The comparison with the 56 showers in the IAU list of established showers, shows 24 showers obtained from this study correspond to 30 showers in the IAU list. Another 14 showers found from our analysis are not in the IAU list, while 26 showers listed in the IAU compilation have not been recognized as concentration in our data. A consultation with the IAU MDC yielded eleven new entries in the working list (numbers 334–344; see Table 3).

In our catalog, the IAU showers listed in Table 4 were unified to one source because the parameters in the four-dimensional space gave no reason to divide them.

The Antihelion source as well as the North and South Apex, and the Southern Toroidal source were not confirmed as concentrations. Their borders were too diffuse to distinguish them from the sporadic background.

It should be noted that there were fuzzy concentrations around the Quadrantids, during November to January. This area overlaps the so called Northern Toroidal source. In the new catalog, they are divided into three showers shown in Figure 7. One is the Quadrantids (010 QUA) which is compact and shows a short activity period. The second cluster which has a slightly higher velocity and obviously a short activity period was now included in the working list as number 336 KDR. The other activity center occurring over a long term was listed as 334 DAD.

Close to the κ-Cygnids, one early sharp cluster was extracted and listed as 344 JUG, while others were clustered to one fuzzy shower 012 KCG shown in Figure 8. The cluster 344 JUG, however, shows an unusual radiant drift and requires further investigation.

7 Conclusions

The determination of a meteor shower is difficult because it requires large numbers of accurate observations.

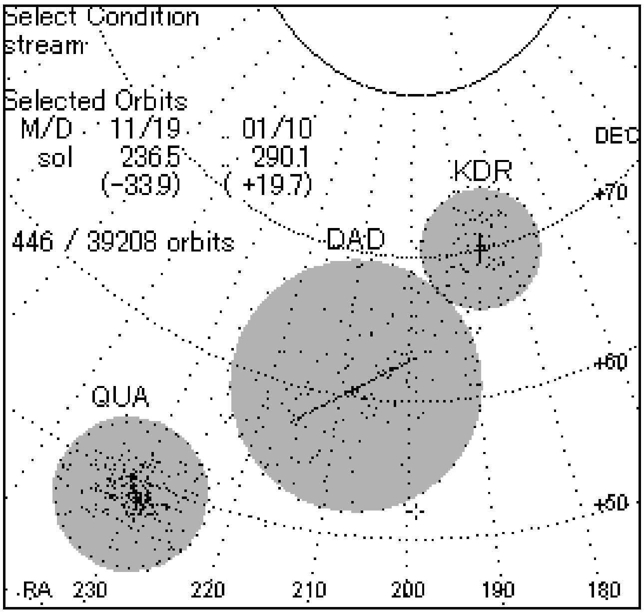

Figure 7 – Three showers in the region of the Northern Toroidal source.

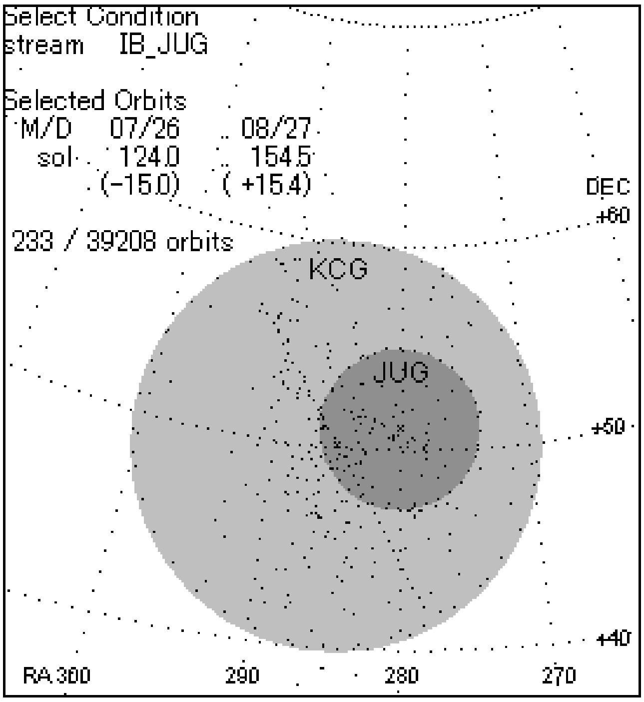

Figure 8 – Clusters of κ-Cygnids.

Sporadic meteors can easily be identified as parts of showers if the number of observations is not sufficient and a calibration with the surrounding sporadic meteors has not been done. Showers which have a long activity period like the Comae Berenicids can easily be (artificially) divided into multiple showers. Applying an automated clustering on a large data set with too sensitive clustering conditions may yield hundreds of meaningless showers. Therefore, a clustering criterion is needed to produce a reliable shower list.

In this study, only clear concentrations in the four-dimensional space that can be thought to maintain a relation to their parent objects were considered to be showers.

The 38 showers in the new catalog were obtained from a uniform procedure based on a larger sample of recent observations than ever previously recorded. Therefore, these data can be assumed to show the recent real activity of major meteor showers that are optically observable from the northern hemisphere.

The difference between this result and the established IAU list is not small. Further research needs to be done for 14 new showers which are not in the IAU list. Ten showers have been included as new entries in the working list of the IAU MDC. For those 26 showers in the IAU list which were not confirmed by this study, a careful study of the activity in recent and future years should be done.

One of the results of this study, the almost smooth distribution of sporadic meteors, suggests the possibility of finding further minor showers or discovering a mechanism responsible for changing sporadic meteor orbits. Since sporadic meteors can only be obtained by subtraction of the meteors of known showers, however, we need to know more details about the distribution of shower meteors.

The current study's results are limited by the detection ability, resolution and accuracy of current video observation. Wider-ranging and longer observations will reduce the effects of weather and moonlight and enable more precise clustering. Continued observation and additional research from many regions on the Earth can be expected to clarify which meteors are associated with showers, and to more sharply distinguish shower-associated meteors from sporadic meteors.

Acknowledgements

This study was made possible by the continuous efforts and contributions of the observers in the SonotaCo Network. I sincerely express my great thanks to the people listed in Table 2, who observe every night and make their results available. Much respect and thanks is also due to Sirko Molau, the pioneer of video meteor observation who brought me into contact with the IMO.

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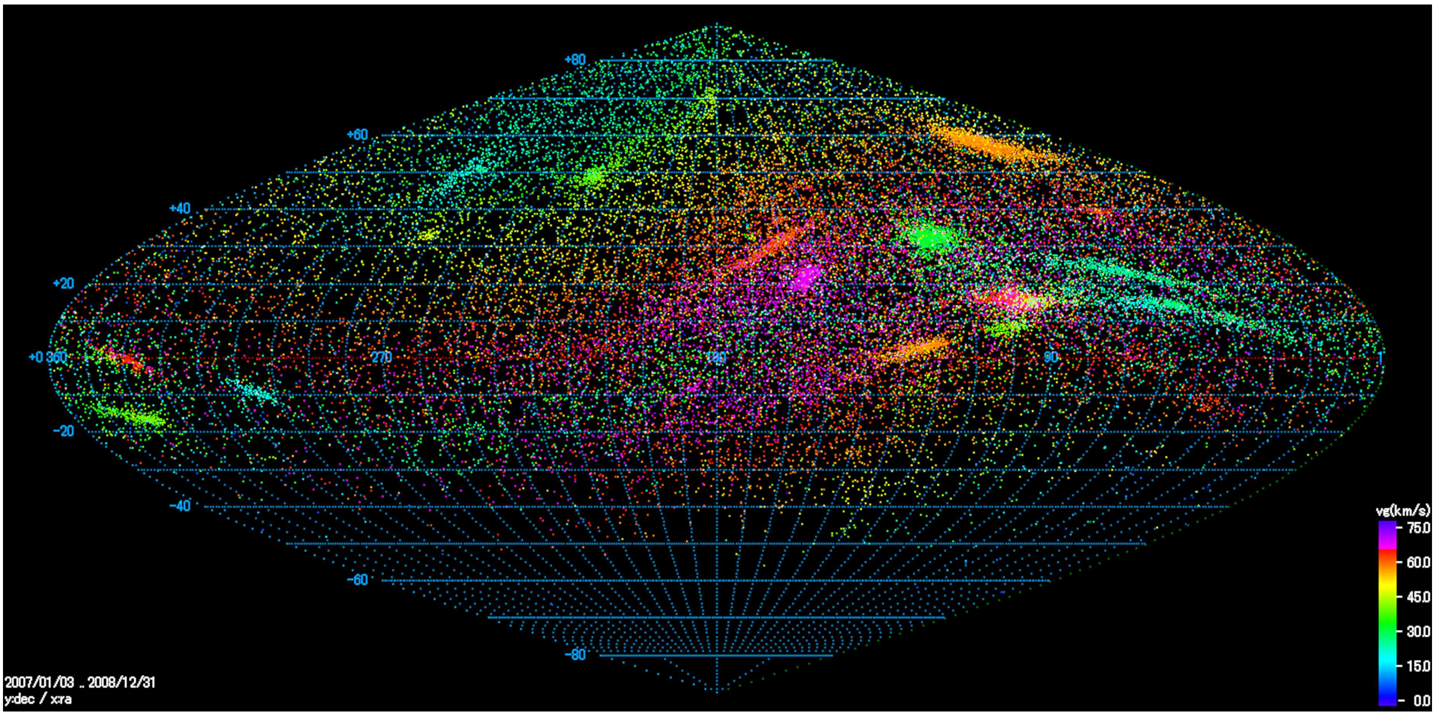
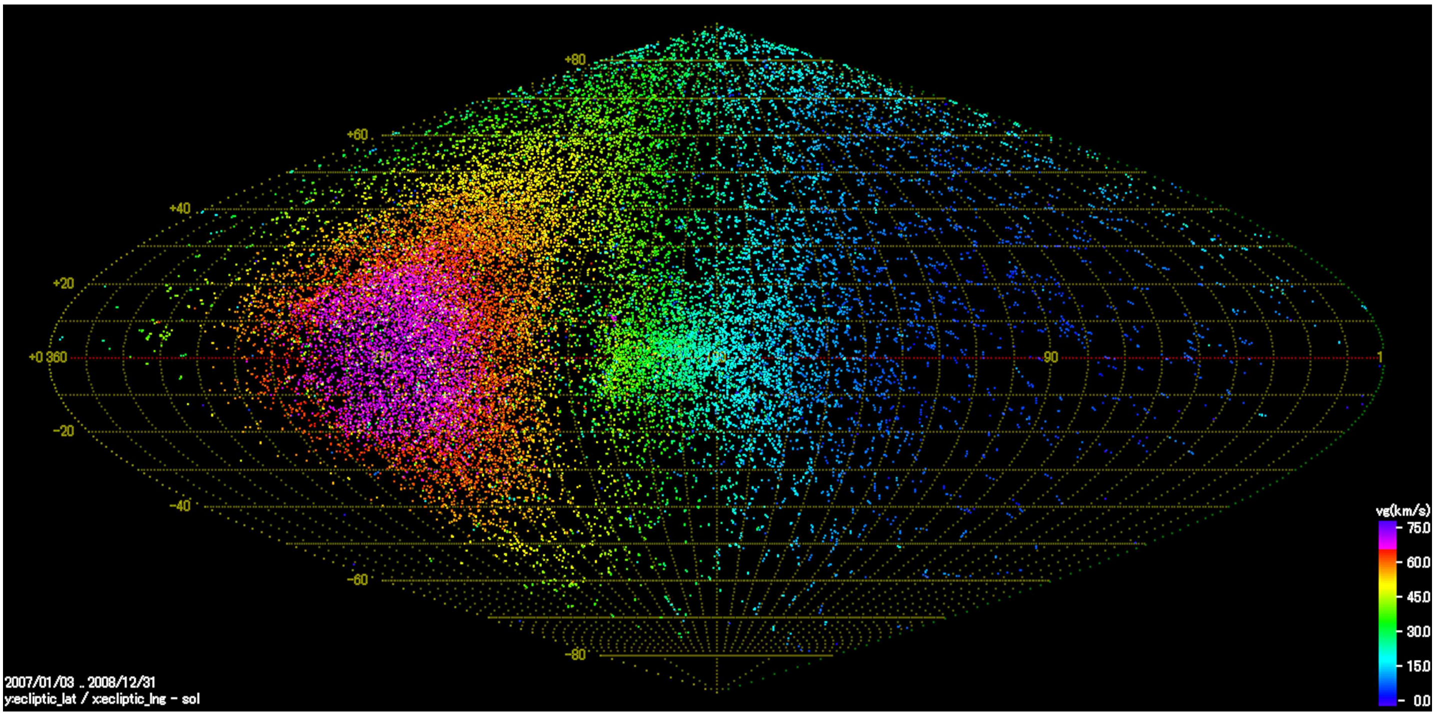
Handling Editor: Jürgen Rendtel

Radiant plots of the SonotaCo Network



Radiant of 39 208 meteors observed over two years, in a sinusoidal projection with the right ascension α on x-axis and the declination δ on y-axis (J2000.0). The geocentric velocity is colour coded.



Radiants of 24 837 non-shower meteors in coordinates of x-axis: ecliptic longitude minus solar ecliptic longitude ($\lambda - \lambda_{\odot}$), y-axis: ecliptic latitude. This projection shows the (season independent) solar direction from the Earth (0, 0), the apex direction (270, 0), and the antihelion direction (180, 0). Most of the radiants occur in the range of $\lambda - \lambda_{\odot} = 90$ to 270°. This almost corresponds to the zenith direction at 18^{h} and 06^{h} local time. The high density area around the apex is the maximum of geocentric velocity and it gradually decreases towards (90, 0). It means that the velocity of the Earth's orbital motion dominates the meteor velocity. We find a low-density area around (220, 0). This is the region of Sun-grazing meteors, which are not on stable orbits.

For more information and full analysis of their video data, see SonotaCo's paper on page 55.