RADAR METEOR ECHO DURATION – AMPLITUDE RELATION

A. HAJDUK

Astronomical Institute of the Slovak Academy of Sciences, Bratislava, Czechoslovakia

Abstract: Relation between the radar meteor echo duration and amplitude is studied on the basis of Ondřejov radar observations during the Orionid shower periods 1961–1965. Dependences of mean echo duration and mean echo amplitude on the shower activity and zenith angle of the radiant is demonstrated.

Introduction

In general, there are two independent ways how to deduce statistically meteor magnitudes from radar echo observations: the first one, more often used, is based on the number distribution of echo durations, the second one on the number distribution of echo amplitudes. Both methods indicate the corresponding values of electron line density in a meteor train, and allow to determine the mass distribution factor *s* of meteors. Many objections can be made against both methods. The combined visual-radar observations (Lindblad, 1956; Millman and McKinley, 1956), show a very wide scatter of the relation between the echo duration classes and visual magnitudes. Meteor echo duration depends not only on the atmospheric height of the meteor ionization as the principal factor (Brown, Bullough, Evans and Kaiser, 1956; Kaiser, 1956; McKinley, 1956, 1961) but also on such factors as the radiant position or the method of observation (Hajduk, 1968). On the other hand, the echo amplitude varies with the distance of the train and with the train position with respect to the beam axis of the antenna. A precise determination of the magnitude distribution of echoes of a given sample of amplitudes of radar echoes requires the application of corrections due to the statistical distribution of magnitudes in the horizontal plane, the corresponding arcs of the radius used, and the height distributions of meteors observed (Hajduk, 1970). The orientation of a meteor trail can affect both amplitude and duration of the echo when directional antenna is used.

It appears most reasonable to combine both echo characteristics mentioned – amplitudes and durations for the meteor magnitude determination.

The present paper deals with the relations between the echo amplitudes and echo durations as observed during the Orionid shower period in 1961–1965. The data on the observed hourly rates and other characteristics can be found elsewhere (Hajduk, 1974).

Variation of the Mean Echo Duration with Echo Amplitude

Meteor echoes observed with the 20 kW radar equipment of the Ondřejov Observatory during the Orionid shower periods in 1961–1965 were used for the construction of statistical relations which follow below. The mean values of echo durations obtained from about 10 000 radar echoes observed during the period of Oct. 19–24, 1961, have been used in the relation plotted in Figure 1 (crosses). Each value is the logarithmic mean from a sample of echo durations of particular amplitude class. Amplitudes as used here, are expressed in terms of the width (vertical size) of the echo image on the range-time record. Relative values of the amplitude are compared with a noise level, for which $y = y_0 = 1$. The linearity of the relation between the log echo amplitude and echo image width has been checked earlier (Hajduk, 1965). The accuracy in the determination of y values is ±0.5. The dots in Figure 1 represent arithmetic means of the sample of amplitudes of a particular duration class. The accuracy in the determination of the echo duration is ±0.05 s.

The true dependence between the echo amplitude and echo duration lays between the two lines corresponding to dots and crosses of Fig. 1.

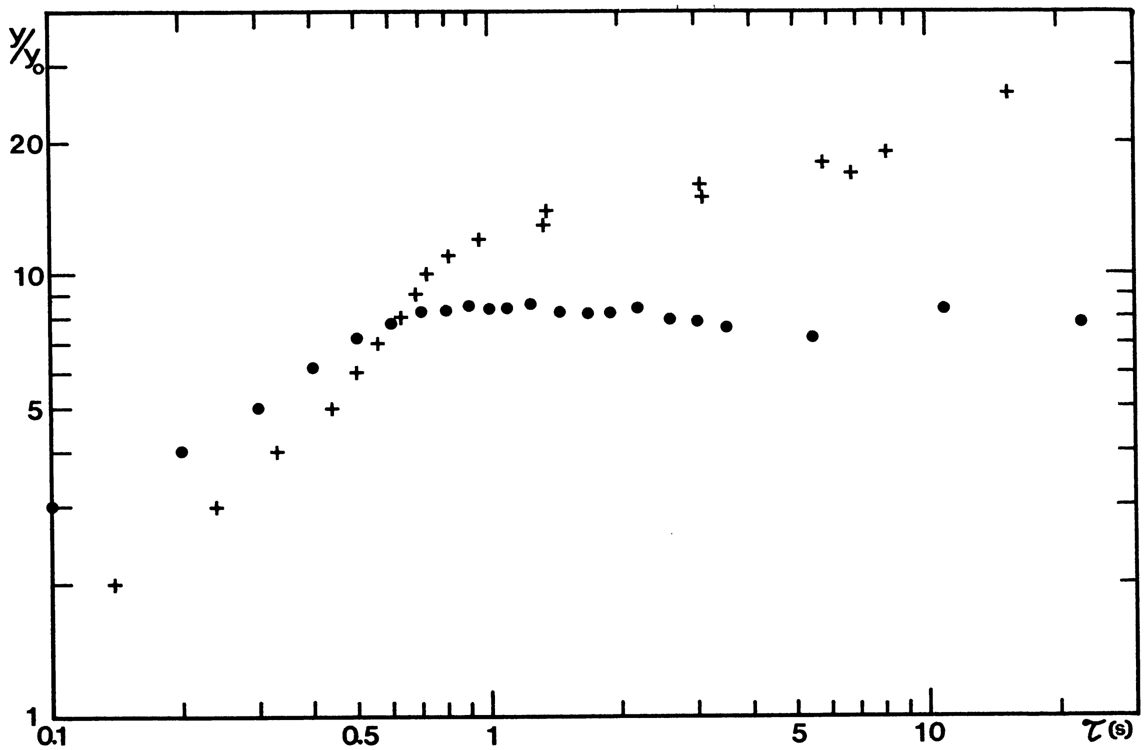


Fig. 1. Echo duration – echo amplitude correlation: dots – values of the mean relative amplitude (y/y_0) for different duration classes; crosses – values of the mean echo duration for classes of amplitudes (10 000 meteors, Orionids 1961).

The break near the values $y = 8$ and $\tau = 0.9$ s corresponds to the limit between overdense and underdense trains. It should be mentioned here that echo amplitude, e.g. echo image width, affects a little the real echo duration in consequence of the circular form of the echo of particular amplitude. Therefore the critical value of the overdense/underdense limit should be shifted a little towards shorter duration.

Separate data of the mean amplitude for each particular day can be found in Table 2, where logarithmic means have been calculated to eliminate the influence of individual large values. Similarly, Table 3 contains logarithmic means of echo durations for each particular day for a given amplitude class.

In general we can say that higher amplitudes correspond to the longer durations and therefore we can use either amplitudes or durations for the determination of the meteor magnitudes. However, the spread defined by the two regression lines is relatively large.

Table 1 represents the number of echoes of particular duration and amplitude, from the period Oct. 19–24, 1961.

The Relation Between the Mean Echo Duration and Mean Echo Amplitude in Dependence on the Shower Activity

The linear dependence of the log duration on the visual magnitude, as shown in Figures 3 and 4 of Millman's and McKinley's (1956) paper may be distorted when comparing the duration distribution of echoes for different time intervals of the shower activity. As it was shown in Figures 2 and 3 of the paper of the present author (Hajduk 1968), the proportion of echoes with longer durations varies with the shower radiant elevation. (As a secondary effect also an increase of the proportion of echoes of longer durations may appear in hours after sunrise).

Range distribution of the echoes is often used to detect minor effects, which do not appear in the hourly rates of echoes.

The mean echo duration does not show any remarkable change in the range distributions constructed separately for different periods of the shower activity (see Fig. 2). A very little decrease of the mean duration at the range between 120–170 km corresponds to the combined

Table 1. Echo amplitude – echo duration diagram

y \ τ	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
1	–	–	–	–	–	1	–	–	–	–
2	47	7	–	3	1	1	2	2	–	–
3	181	205	37	12	15	16	5	2	4	2
4	57	1125	509	131	66	67	51	21	11	13
5	2	233	772	242	117	58	27	26	9	8
6	–	23	448	528	174	105	46	31	14	21
7	–	2	95	321	177	85	34	30	10	4
8	–	–	9	196	240	110	51	22	17	12
9	–	–	–	46	130	75	20	14	8	11
10	–	–	–	12	145	121	47	26	8	15
11	–	–	–	1	47	106	53	24	16	7
12	–	–	–	–	18	76	39	28	14	12
13	–	–	–	–	1	13	19	15	4	4
14	–	–	–	–	–	7	7	15	1	4
15	–	–	–	–	1	–	–	–	1	4
16	–	–	–	–	–	–	–	–	2	1
17	–	–	–	–	–	–	–	1	–	–
18	–	–	–	–	–	–	–	–	–	–
19	–	–	–	–	–	–	–	–	–	–
≥ 20	–	–	–	–	–	–	–	–	–	–
$\bar{y}$	3.0	4.0	5.0	6.1	7.2	7.8	7.7	8.0	7.8	7.9
ΣN	287	1595	1870	1492	1132	844	401	257	119	118

Table 1 – continued

y \ τ	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
1	–	–	–	–	–	–	–	–	–	–
2	–	–	–	–	–	–	–	–	–	–
3	2	2	2	2	1	5	3	2	–	1
4	5	15	11	10	4	11	3	10	1	3
5	9	16	7	10	5	12	3	7	3	3
6	13	11	7	10	4	6	7	3	2	2
7	4	10	6	7	3	1	2	4	2	1
8	7	11	4	3	7	4	–	3	1	–
9	5	6	4	3	1	4	4	2	–	1
10	9	8	4	4	3	2	–	2	2	1
11	6	5	3	6	–	2	2	2	2	–
12	11	11	9	6	2	3	5	2	2	–
13	1	2	4	3	1	3	2	4	–	1
14	2	4	2	5	1	4	2	–	1	–
15	4	1	1	3	1	–	–	1	–	–
16	–	2	3	3	1	2	4	–	–	–
17	–	–	1	–	–	1	–	–	–	–
18	–	–	–	–	–	1	–	–	–	–
19	–	–	–	–	–	–	–	–	–	–
≥ 20	–	–	–	–	1	–	–	1	–	–
$\bar{y}$	7.9	7.2	7.6	7.6	7.4	6.7	7.9	6.6	7.8	6.6
ΣN	78	104	68	75	35	61	37	43	16	15

Table 1 – continued

y \ τ	2 – 3	3 – 4	4 – 8	8 – 16	16 – 32	> 32
1	–	–	–	–	–	–
2	–	–	–	–	–	–
3	7	5	9	6	3	1
4	40	22	36	23	12	9
5	26	17	35	13	8	12
6	22	12	19	17	6	8
7	11	7	15	5	8	4
8	14	7	14	6	8	1
9	7	5	7	2	2	–
10	9	3	3	4	1	4
11	9	3	8	1	2	2
12	6	5	4	4	4	1
13	4	5	2	1	3	3
14	9	–	3	1	–	2
15	4	–	2	1	1	6
16	5	3	4	4	1	2
17	1	2	5	6	3	1
18	4	2	–	5	1	1
19	–	–	–	–	–	–
≥ 20	2	2	2	3	–	6
$\bar{y}$	6.9	6.7	6.3	7.0	6.9	8.4
Σ N	180	100	168	102	63	63

Table 1 – continued

y	Σ N	$\bar{\tau}$
1	1	0.60
2	63	0.14
3	530	0.24
4	2266	0.33
5	1680	0.44
6	1539	0.50
7	848	0.56
8	747	0.63
9	357	0.68
10	433	0.72
11	307	0.81
12	262	0.95
13	95	1.3
14	70	1.4
15	34	3.1
16	39	3.1
17	21	6.8
18	14	5.8
19	–	–
20	4	8.1
21	1	2.6
22	3	6.2
23	1	3.3
24	2	14.5
> 25	6	95.1

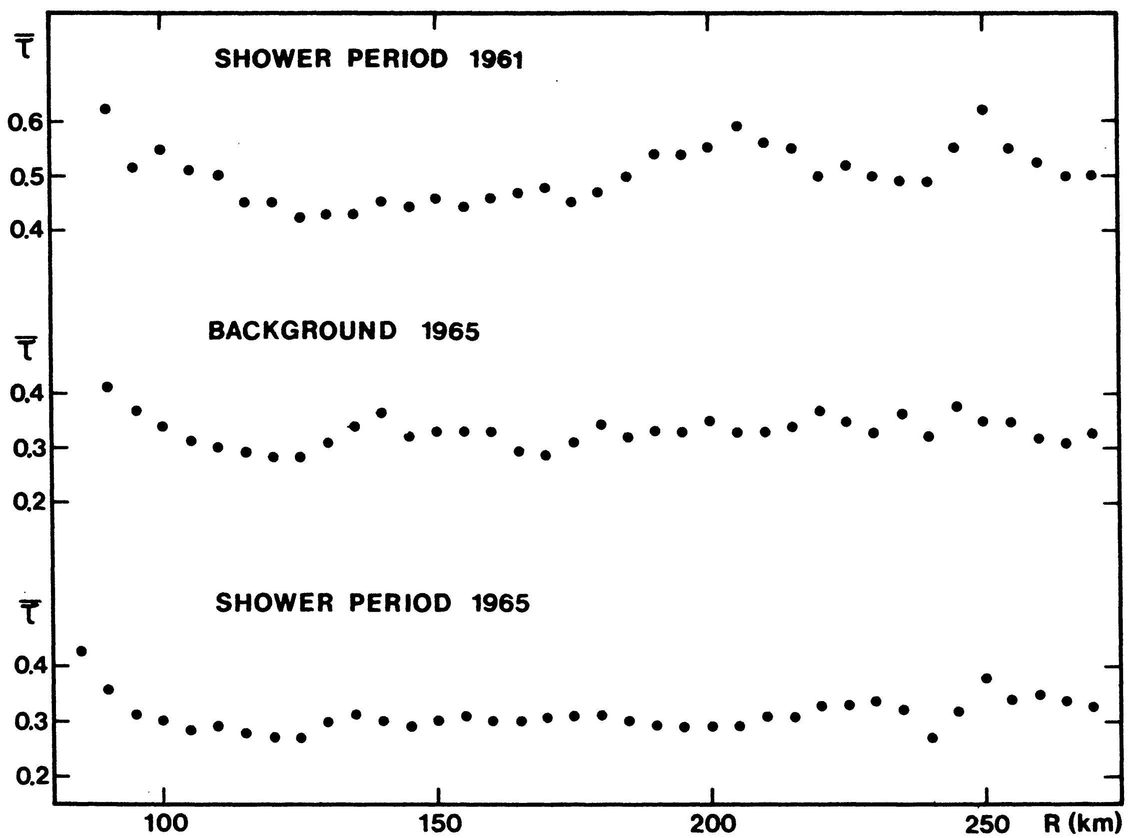


Fig. 2. Variation of the mean echo duration with range (see text).

Table 2. Variation of the mean echo amplitude in the dependence on the echo duration

$\bar{\tau}$ (s)	Oct. 20		21		22		23		24	
	N	$\bar{y}$	N	$\bar{y}$	N	$\bar{y}$	N	$\bar{y}$	N	$\bar{y}$
0.1	98	2.7	84	3.1	58	3.4	17	3.1	30	3.2
0.2	468	3.8	334	4.2	357	4.2	133	4.0	303	4.1
0.3	587	5.0	414	5.2	451	4.9	155	4.7	263	4.9
0.4	455	6.0	303	6.3	373	6.1	112	5.8	249	6.4
0.5	341	7.3	231	7.5	311	7.3	83	7.1	166	7.0
0.6	319	8.4	181	8.1	195	8.2	42	6.2	107	6.9
0.7	162	8.7	81	8.3	89	7.8	25	6.1	44	6.0
0.8	84	9.3	48	8.5	68	8.2	18	6.5	39	6.6
0.9	38	7.8	26	9.5	28	7.6	10	6.0	17	8.5
1	48	8.2	27	7.9	12	9.4	8	6.7	23	8.3
1.1	26	8.3	19	8.7	18	7.2	5	9.8	10	7.6
1.2	29	8.2	25	7.4	22	7.7	11	5.5	17	7.0
1.3	27	8.1	14	9.3	13	9.0	3	4.9	11	6.2
1.4	29	9.1	22	7.8	13	8.7	6	3.9	5	6.9
1.5	19	8.3	3	7.8	5	9.9	3	5.0	5	6.6
1.6	16	7.3	13	6.8	20	8.1	4	5.7	8	5.2
1.7	14	9.5	6	8.5	7	9.7	6	6.4	4	4.6
1.8	14	9.6	7	6.9	9	6.8	4	5.9	9	4.5
1.9	3	10.0	5	7.5	3	6.3	1	11.0	4	7.5
2	5	7.4	–	–	4	8.5	1	4.0	5	6.3
2.1	2	11.0	1	4.0	1	5.0	6	10.3	6	7.1
2.2	11	8.4	10	7.0	9	6.9	1	4.0	4	8.0
2.3	4	8.8	3	6.5	4	6.7	2	9.2	1	7.0
2.4	5	8.8	2	9.2	5	8.0	1	8.0	2	3.9
2.5	10	7.8	4	6.1	4	7.8	2	5.5	5	4.4
2.6	4	7.0	5	6.9	3	11.4	–	–	4	7.3
2.7	4	12.5	4	5.4	3	6.4	–	–	3	5.4
2.8	8	7.4	6	6.5	3	5.2	2	4.0	5	7.7
2.9	2	11.0	3	5.2	2	6.3	–	–	1	5.0
3	5	10.2	2	6.3	3	3.6	–	–	3	4.2
3.1	3	14.0	–	–	1	7.0	–	–	1	10.0
3.2	9	6.2	5	6.9	8	5.8	2	6.6	1	9.0
3.3	4	9.3	–	–	5	7.7	1	4.0	2	7.1
3.4	4	10.0	–	–	1	5.0	1	5.0	2	7.8
3.5	6	6.7	7	6.3	6	5.2	3	4.8	5	6.5
3.6	–	–	–	–	3	5.6	2	5.3	1	16.0
3.7	1	13.0	–	–	1	5.0	1	6.0	2	4.5
3.8	1	9.0	5	7.4	2	6.0	1	8.0	3	8.9
3.9	–	–	–	–	–	–	–	–	–	–
4–8	34	7.6	28	7.4	59	6.2	19	5.3	28	5.7
8–16	26	9.4	21	6.9	26	7.6	8	7.9	21	5.1
16–32	19	7.8	13	6.1	19	7.6	5	6.2	7	7.7
> 32	25	7.7	11	11.6	18	10.7	3	8.1	6	6.5

maxima of the sporadic meteors (120 km) and shower meteors (170 km). The values (Fig. 2 above) have been constructed for ca 3000 echoes recorded on Oct. 20, 1961. Other 2300 echoes recorded during the period of Oct. 14–22, 1965 does not show any variation of the mean duration with range. (The shift in a scale between the data from both years are due to the different records. The dots in Figure 2 represent running means for each 15 km range interval.) The echo numbers for the background 1965 and the shower data can be found in the preceding volume of these Contributions (Hajduk, 1974).

More information can be obtained from Figure 3, constructed for the periods with about 50 deg. of a shower radiant elevation, cumulated during the Orionid shower days in 1962 (Oct. 19–24). Radar echoes from three hours (4:00–7:00) each day have been included in this range distribution. In the distribution of a relative number dN of all echoes (about 2200 echoes; Fig. 3 above) both sporadic and shower maxima are clearly visible. A third maximum at about 240 km belong very probably to the Taurid meteors which are already numerous in the observing period. It is very interesting that remarkable minima in the range

Table 3. Variation of the mean echo duration in the dependence on the echo amplitude

y (relat. units)	Oct. 20 N	$\bar{\tau}$ (s)	21 N	$\bar{\tau}$ (s)	22 N	$\bar{\tau}$ (s)	23 N	$\bar{\tau}$ (s)	24 N	$\bar{\tau}$ (s)
1	1	0.60	–	–	–	–	–	–	–	–
2	56	0.14	7	0.11	–	–	–	–	–	–
3	291	0.24	85	0.15	41	0.14	44	0.36	69	0.43
4	574	0.35	407	0.31	573	0.32	244	0.34	468	0.34
5	437	0.47	386	0.39	474	0.44	137	0.46	246	0.40
6	520	0.47	361	0.49	376	0.51	99	0.60	183	0.51
7	294	0.57	199	0.53	168	0.63	52	0.55	135	0.52
8	231	0.63	155	0.59	177	0.67	51	0.70	135	0.62
9	106	0.67	75	0.63	87	0.65	25	0.61	64	0.88
10	121	0.72	102	0.75	121	0.66	21	0.71	68	0.82
11	121	0.81	62	0.77	81	0.76	12	0.93	31	0.98
12	98	0.90	59	0.89	73	0.93	12	1.2	20	1.3
13	46	1.2	22	1.5	17	1.4	3	1.1	7	2.0
14	29	1.3	26	1.4	14	1.4	–	–	1	1.6
15	15	4.0	7	0.98	10	2.0	2	2.1	–	–
16	15	4.3	9	1.4	8	2.3	2	17.4	5	3.5
17	5	9.5	4	4.7	9	7.2	2	6.8	1	3.3
18	5	4.6	2	5.9	5	6.1	1	41.0	1	2.1
19	–	–	–	–	–	–	–	–	–	–
20	2	1.6	1	120	1	13.0	–	–	–	–
21	–	–	–	–	1	2.6	–	–	–	–
22	1	2.7	1	16	1	5.5	–	–	–	–
23	–	–	–	–	1	3.3	–	–	–	–
24	–	–	2	14.5	–	–	–	–	–	–
> 25	1	8.5	1	56	4	131.4	–	–	–	–

distribution of echoes with duration τ>0.5 s correspond to the all three maxima mentioned. The relative proportion of echoes with duration τ>1 s is also less at ranges corresponding to the condition of the specular reflection. This could indicate a dependence of the echo duration on the angle of incidence of the meteoroid body into the atmosphere.

The most remarkable in the distribution of the relative number of echoes with duration τ>1 s is the Taurid minimum. The sample of these echoes shows a continuous increase of the number of long duration echoes with range. For the comparison in Figure 4 is the same distribution for the near background period (Oct. 17, 1962). The scale of relative echo numbers corresponds to that in Figure 3. The large scatter is due to the small number of echoes recorded in larger distances.

To illustrate the relation between the echo amplitude and echo duration, Figures 5–12 show the echo numbers, in scales of y and τ, observed during the period of Oct. 19–24, 1961 at different zenith angles of the shower radiant. In addition the range intervals have been selected, for which the sporadic and shower meteors can be compared. The values of τ>10 s lie outside the duration scale. The distributions demonstrate that more similar to the general relation between τ and y they are the periods with large zenith angle. The larger is the zenith angle of the radiant, the more frequent is also the appearance of long duration echoes. A further study of the $y-\tau$ relation requires more observational data which may lead to better approximations in the statistical determination of radar meteor magnitudes.

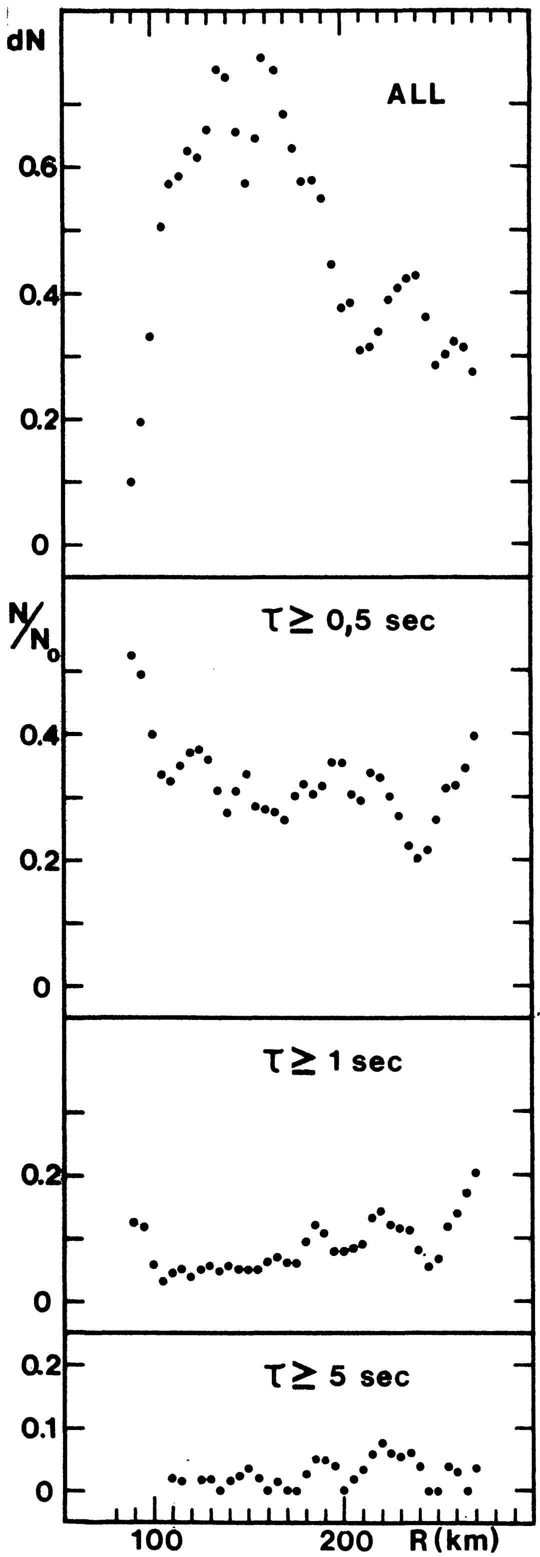


Fig. 3. Range distribution of the relative number of echoes of four duration classes for the Orionid shower period meteors 1962 (2200 meteors).

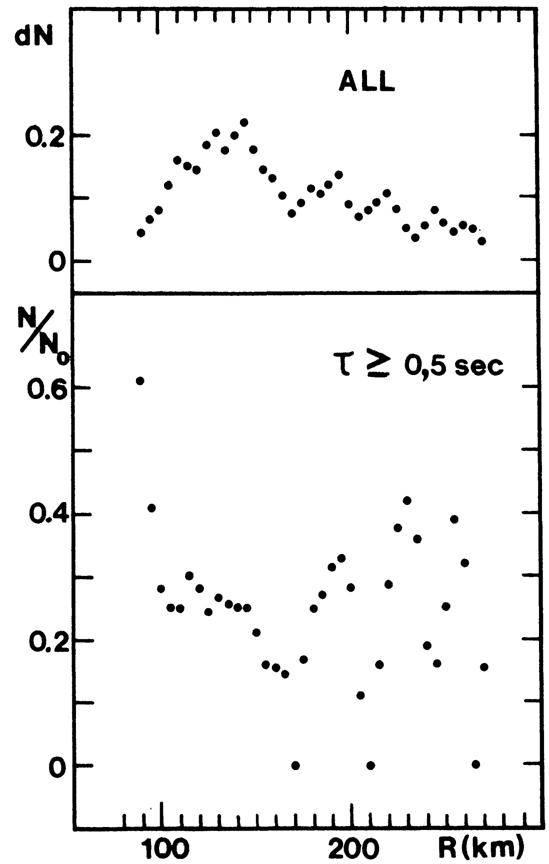


Fig. 4. Range distribution of the relative number of all echoes and echoes of duration $\tau \gtrsim 0.5$ s for the Orionid background meteors 1962 (1000 meteors).

REFERENCES

BROWN, I.C., BULLOUGH, K., EVANS, S., and KAISER, T.R. (1956): Proc. Phys. Soc., *B69*, 83.

HAJDUK, A. (1965): Bull. Astron. Inst. Czechoslov., *16*, 135.

HAJDUK, A. (1968): In: Ľ. Kresák and P.M. Millman (Eds), Physics and Dynamics of Meteors, p. 45. I.A.U. Symp. No. 33. Dordrecht.

HAJDUK, A. (1970): Bull. Astron. Inst. Czechoslov., *21*, 297.

HAJDUK, A. (1974): Contr. Astron. Observ. Skalnaté Pleso, Vol. 5, p. 156.

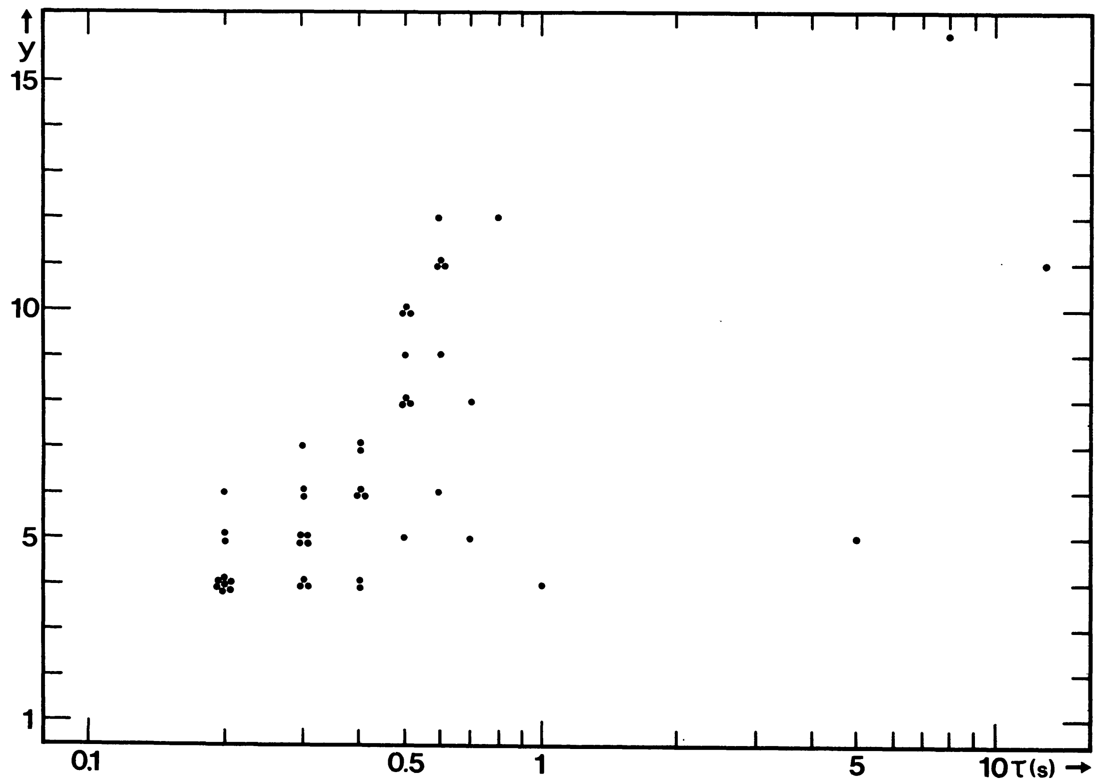
KAISER, T.R. (1954): Mon. Not. Roy. Astron. Soc., *114*, 39.

LINDBLAD, B.A. (1956): Medd. franc. Lunds Astron. Observ. *1*, No. 189.

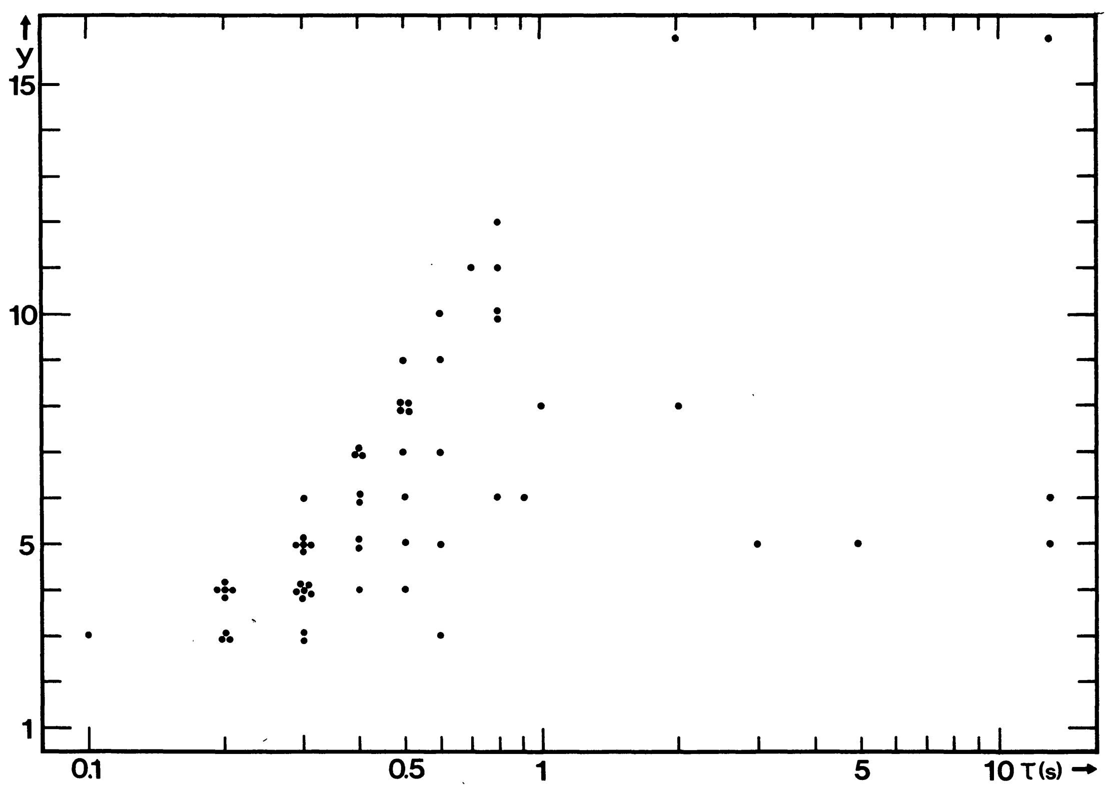
McKINLEY, D.W.R. (1956): J. Atm. Terr. Phys., *8*, 76.

McKINLEY, D.W.R. (1961): Meteor Science and Engineering, p. 133, 225. New York, McGraw-Hill Co.

MILLMAN, P.M. and McKINLEY, D.W.R. (1956): Canad. J. Phys., *34*, 50.



F i g. 5. y vs. τ diagram of echo numbers: for $R \lesssim 120$ km, $z = 55^{\circ}$.



F i g. 6. y vs. τ diagram of echo numbers: for 175 km $\lesssim R \lesssim$ 185 km, $z = 55^{\circ}$.

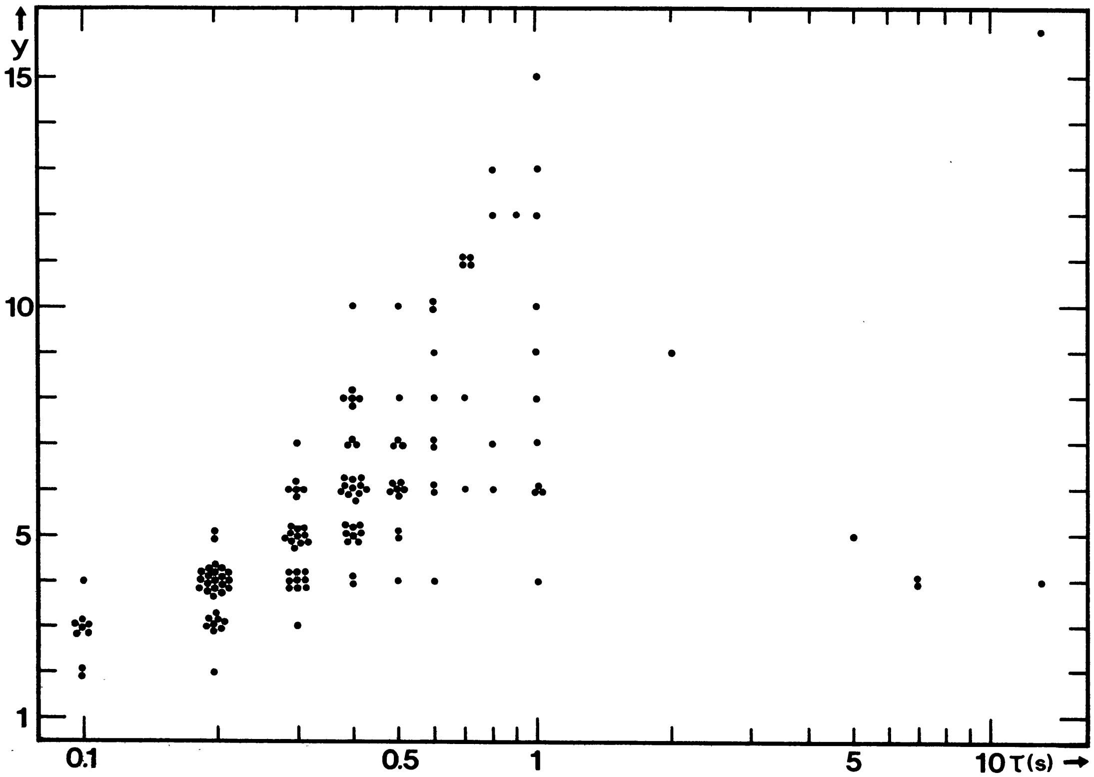


Fig. 7. y vs. τ diagram of echo numbers: for $R \leq 120$ km, $z = 50^{\circ}$.

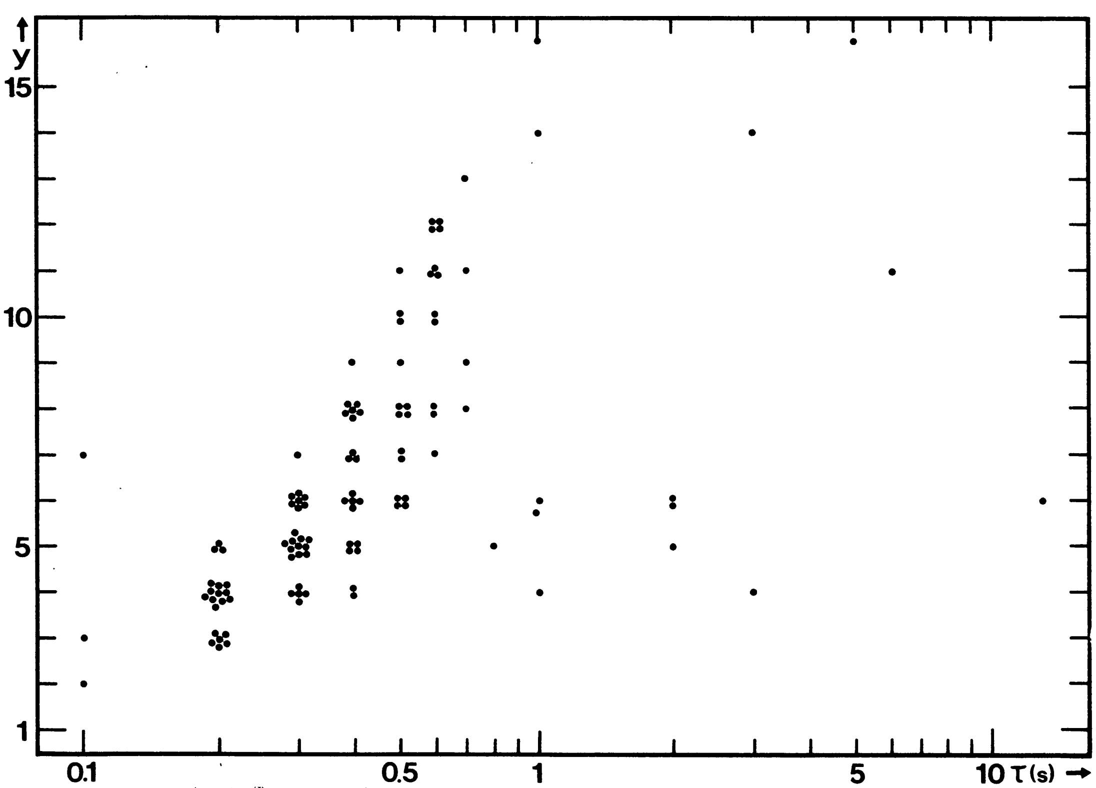


Fig. 8. y vs. τ diagram of echo numbers : for 160 km $\leq R \leq$ 170 km, $z = 50^{\circ}$.

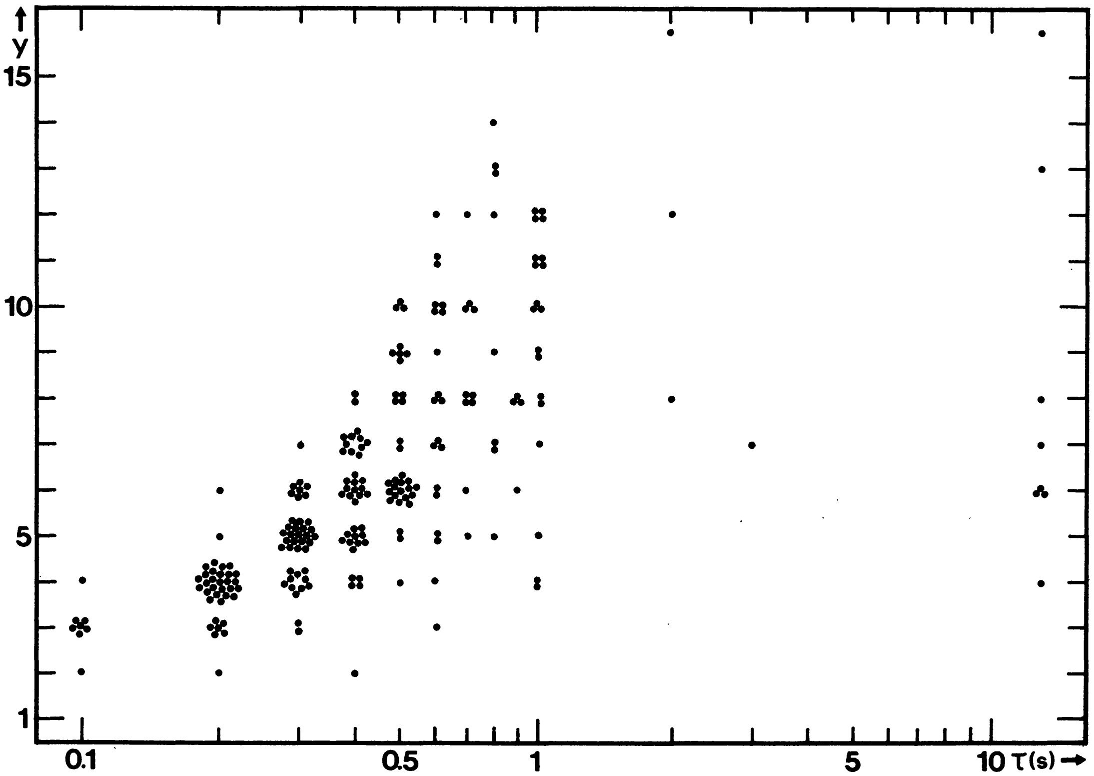


Fig. 9. y vs. τ diagram of echo numbers: for $R \leq 120$ km, $z = 40^{\circ}$.

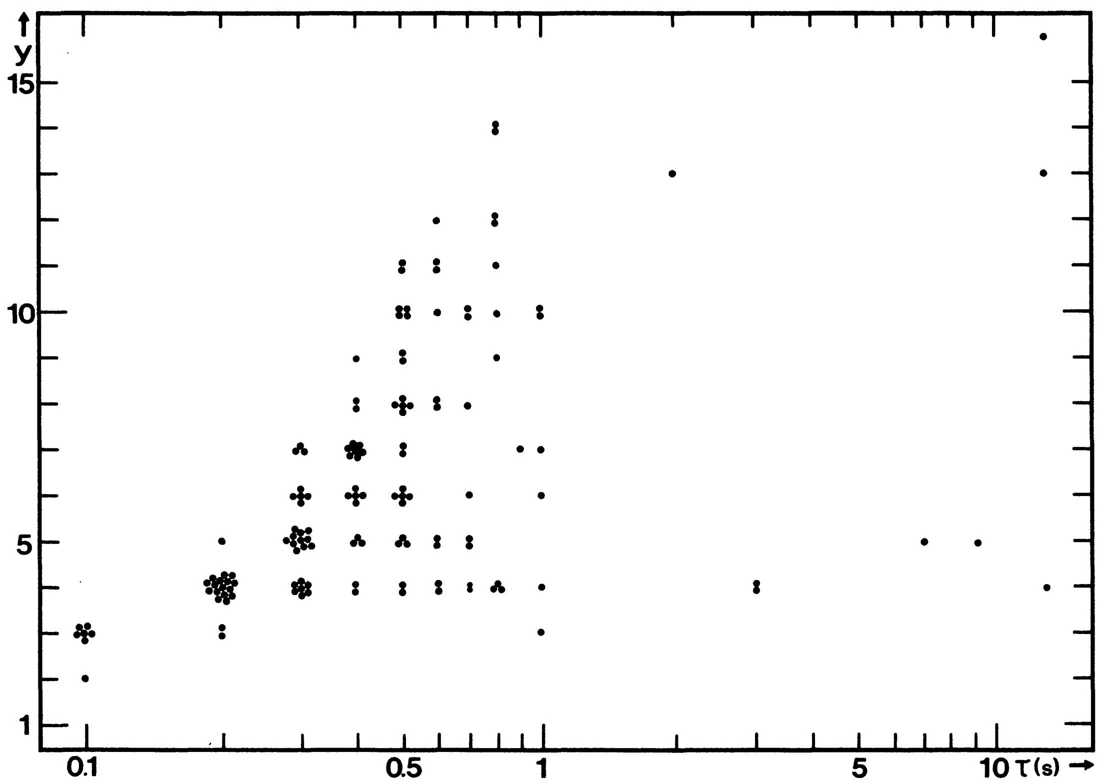
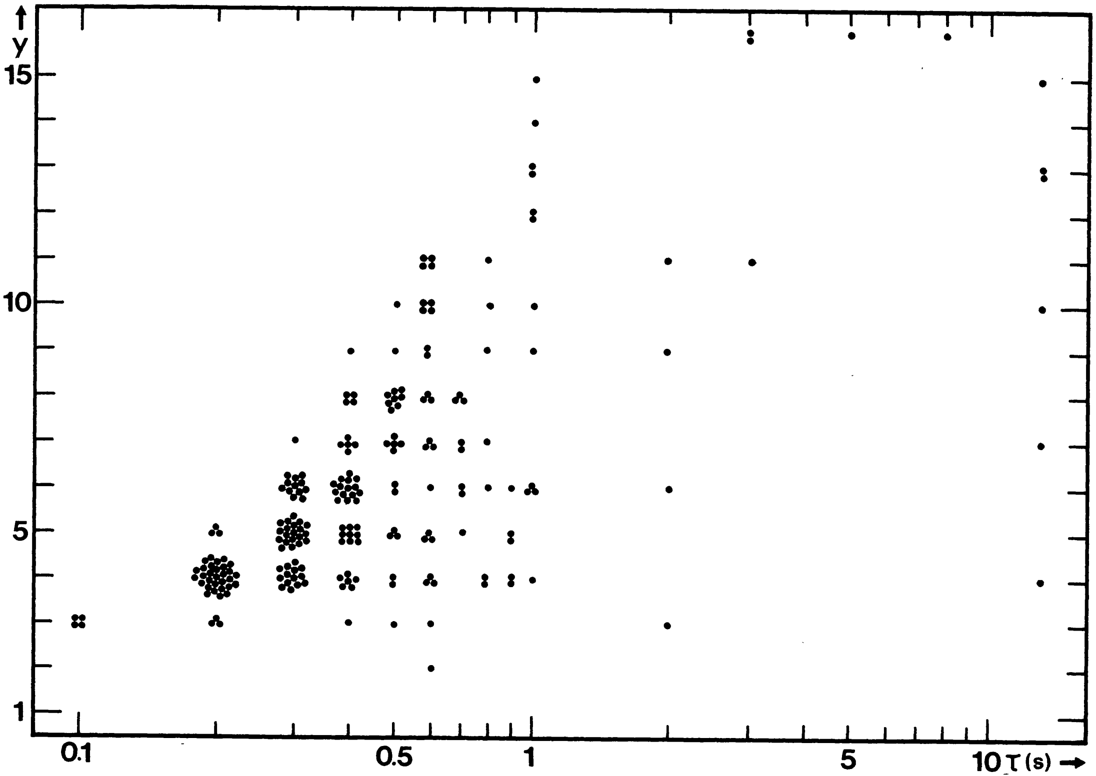
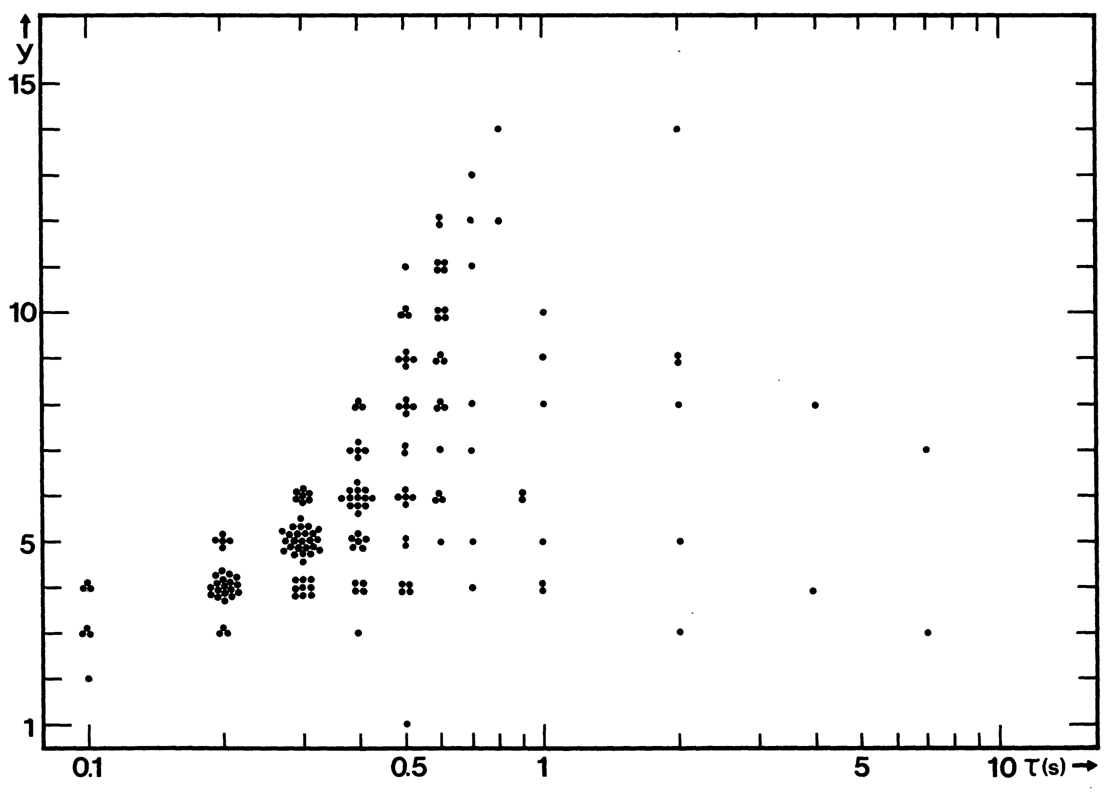


Fig. 10. y vs. τ diagram of echo numbers: for 145 km $\leq R \leq$ 155 km, $z = 40^{\circ}$.



F i g. 11. y vs. τ diagram of echo numbers: for $R \leq 120$ km, $z = 30°$.



F i g. 12. y vs. τ diagram of echo numbers: for 130 km $\leq R \leq$ 140 km, $z = 30°$.

VZŤAH MEDZI TRVANÍM A AMPLITÚDOU RADAROVÝCH OZVIEN METEOROV

A. HAJDUK

Astronomický ústav Slovenskej akadémie vied,
Bratislava, Československo

Súhrn

Na základe údajov viac ako 15 000 radarových ozvien pozorovaných aparatúrou 20 kW meteorického radaru v Ondřejove v rokoch 1961–1965, v obdobiach činnosti meteorického roja Orioníd sa v práci študuje vzťah medzi trvaním τ a amplitúdou y meteorickej ozveny. Vzhľadom na veľký rozptyl hodnot amplitúd pre dané triedy trvaní i naopak, nadobúda vzťah $\tau \sim y$ veľký význam pri určovaní lineárnej elektrónovej hustoty v stope meteoru a tým aj pri určovaní magnitúd meteorov. Výsledky pozorovaní sú zobrazené graficky a niektoré závislosti sú v tabuľkách.

ОТНОШЕНИЕ ДЛИТЕЛЬНОСТЬ – АМПЛИТУДА МЕТЕОРНЫХ ЭХО

А. ХАЙДУК

Резюме

Астрономический институт Словацкой академии наук,
Братислава, Чехословакия

По данным радиолокационных наблюдений более чем 15 000 метеорных эхо установкой Астрономической обсерватории в Онджееве в периодах активности метеорного потока Орионид в 1961–1965 гг. анализируется отношение длительности радиоэхо к его амплитуде. Исследуется влияние отношения длительность – амплитуда на определение линейной плотности электронов в метеорных следах и, вследствие того, на определение звездных величин метеоров. Результаты наблюдений приводятся на графиках и в таблицах.