THE TEMPORAL VARIATION OF THE HEIGHTS OF REFLECTION POINTS OF METEOR TRAILS

By A. A. Weiss*

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Summary

Heights of reflection points of over 6000 sporadic meteors measured with a 27 Mc/s combined C.W.-radar equipment are analysed. There is no significant seasonal variation in either the mean height or the width of the height distribution. The mean height alone shows a diurnal variation, with maximum height near midnight. A regrouping of the data reveals a dependence of both height parameters on the zenith angle of the apex of the Earth's way, with a large scatter. The observations are compared with height distributions computed for a uniform heliocentric distribution of sporadic meteors with uniform heliocentric velocities. Observed and predicted r.m.s. deviations are in agreement. The model reproduces correctly the form of the observed dependence of mean height on the zenith angle of the apex, for zenith angles less than 100°, but the extent of the predicted variation of mean height (12–20 km, depending on the assumptions) far exceeds the observed 3 km. This discrepancy may be reduced considerably by adding to the uniform model distribution a large component of sporadic meteors moving with low speeds in direct orbits whose inclination to the plane of the ecliptic is small.

I. Introduction

Three of the factors which determine the radio-echo height distribution of sporadic meteors are the properties of the atmosphere, the mass distribution of the incident meteors, and the characteristics of the equipment. These are either well established or can be measured. As a consequence, their virtual elimination from the height problem opens the way to a discussion of the two remaining factors, namely, the apparent distribution of sporadic meteor radiants over the celestial sphere and their velocity spread. The contributions of these two astronomical quantities to the observed height distributions are interrelated through the dependence of the apparent radiant upon velocity, which is imposed by the motion of the Earth. Inability to consider them separately is not, however, confined to the height data. It is common to every approach to the problem of the sporadic meteor distribution through temporal variations in quantities measured over an extended collecting area, and applies, for instance, to the interpretation of the measured velocity distributions themselves and to meteor rates.

The present paper deals with the heights of some 6400 sporadic meteors recorded from December 1952 to February 1955. The brightnesses of these meteors at their echoing points lie between the 3rd and 6th magnitudes. Meteors belonging to all showers resolvable with the equipment have been excluded.

* Division of Radiophysics, C.S.I.R.O., at Department of Physics, University of Adelaide.

II. Equipment

Heights of the reflection points have been measured with the 27 Mc/s equipment described by Robertson, Liddy, and Elford (1953). This is a combined C.W.-radar equipment. The direction cosines of each reflection point are determined by using spaced aerials associated with the C.W. portion of the equipment, and a superimposed radar pulse gives the slant range. Operation is semicontinuous, records being obtained on a 24-hr basis for periods of about a month at a time.

Measurements are accurate to within about 2 per cent., but there is reason to suspect that small changes of the same order have occurred in the absolute calibration of the system after 1953.

III. Analysis of Data

Table 1 indicates the periods selected for analysis, with some properties of the height distributions for these months.

Table 1

SUMMARY OF HEIGHT DATA ANALYSED

Month		Number of Meteors	Mean Height (km)	R.M.S. Deviation (km)
1952	December ..	683	91·2	6·98
1953	March	724	91·0	6·55
	June	596	89·9	7·06
	September ..	870	91·2	6·68
1954	May	1251	89·8	7·47
	July	740	88·9	7·16
	October	760	89·7	7·12
1955	February ..	743	90·3	6·62

A first appreciation of the diurnal and seasonal variations in the heights of echoing points is obtained from a more detailed examination of the data for the first four periods. Histograms showing the distribution of heights for each month separately are drawn in Figure 1. There is no evidence here of any stratification of the atmosphere into narrow "preferred" regions of high probability of detection of meteor trails, and no such tendency was found in the data for any of the other periods. Table 2 gives mean heights and r.m.s. deviations from the means, for 6-hr periods. There is no significant seasonal variation in either parameter. The diurnal variation in the r.m.s. deviation, if real, is scarcely significant. The only definite variation is the diurnal variation in the mean height, with minimum height near midday and maximum height near midnight.

The phase of the diurnal variation found from this crude division of the data is not obviously related to any property of the apparent sporadic radiant distribution. The most convenient and useful astronomical variable for relating height to apparent radiant distribution and velocity at any time is the zenith angle of the apex of the Earth's way. The azimuths of the reflection points, which reveal a marked concentration of sporadic radiants to the apex (Weiss 1957), suggest that this is a reasonable choice.

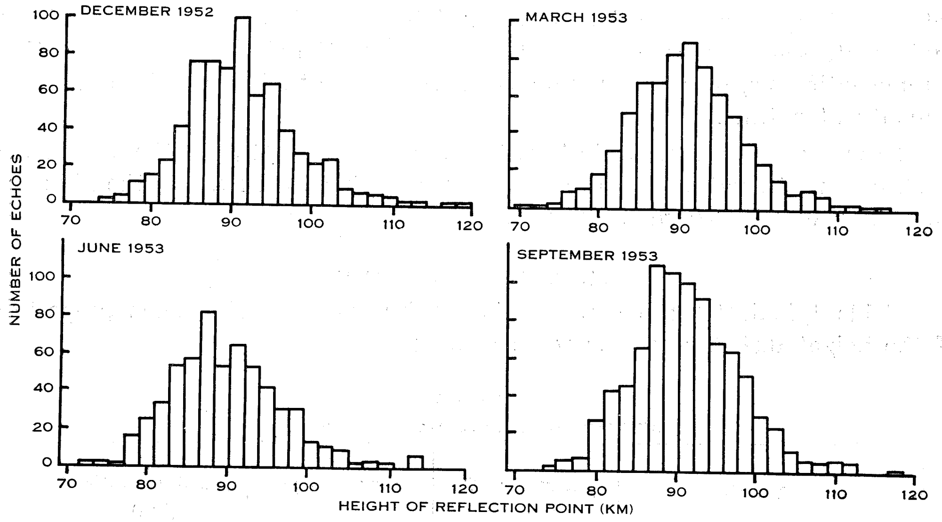

Fig. 1.—Height distributions for four observing periods.

Data for six periods have therefore been grouped by narrow (10°) intervals of the zenith angle Z of the apex. Uncorrected mean heights, and r.m.s. deviations from the means, are listed in Tables 3 and 4. Mean heights for the earlier

TABLE 2

MEANS AND R.M.S. DEVIATIONS FOR 6-HR PERIODS

Month	Period (Local Time)			
	03–09	09–15	15–21	21–03
	(a) Mean Height (km)			
March	90·6	90·2	89·2	93·6
June	91·0	86·5	90·8	91·3
September	91·7	89·0	90·1	93·3
December	91·9	90·1	89·1	92·8
	(b) R.M.S. Deviation (km)			
March	6·8	6·7	6·2	7·3
June	7·9	5·5	6·4	6·8
September	6·9	6·5	5·3	6·7
December	6·6	5·8	6·7	7·6

periods differ consistently from those for the later periods, by up to 3 km. On the assumption that these differences are caused by calibration errors, the mean heights for all six periods have been reduced to a common basis by adjustment

TABLE 3

MEAN HEIGHTS (KM) AT 10° INTERVALS OF ZENITH ANGLE OF APEX

Zenith Angle of Apex (degrees)	Month					
	February 1955	March 1953	May 1954	July 1954	September 1953	October 1954
15		90·6				
25	89·3	90·1	89·2			
35	89·2	93·3	92·7			
45	90·6	91·4	90·2	89·2		
55	91·9	92·7	91·2	89·5		
65	90·6	91·6	89·0	90·1	92·1	90·2
75	91·6	92·9	88·9	89·4	93·0	90·2
85	89·2	92·8	90·2	87·4	92·7	91·3
95	89·5	92·3	88·1	89·1	90·1	89·1
105	89·5	92·1	88·8	87·9	90·6	89·1
115	89·9	89·6	89·3	87·9	91·1	90·1
125	92·8		90·5	89·6	91·1	88·4
135				87·4	93·9	89·6
145				89·8	90·2	88·7
155				88·4	90·8	86·1
165					90·5	89·6

TABLE 4

R.M.S. DEVIATIONS (KM) AT 10° INTERVALS OF ZENITH ANGLE OF APEX

Zenith Angle of Apex (degrees)	February 1955	March 1953	May 1954	July 1954	September 1953	October 1954
15		5·9				
25	6·5	7·1	6·9			
35	6·3	8·0	8·3			
45	6·7	6·8	8·5	6·6		
55	6·4	6·1	7·8	6·2		
65	6·2	6·8	7·7	9·1	6·6	7·2
75	7·2	5·5	7·9	6·9	8·3	8·3
85	6·7	7·9	8·4	7·3	7·9	7·4
95	8·0	6·8	6·4	8·2	5·7	6·2
105	6·8	7·8	7·7	7·6	6·1	8·1
115	6·9	6·3	7·0	5·5	6·1	7·7
125	6·3		6·9	7·1	6·5	7·1
135				6·8	6·9	6·7
145				8·4	5·5	5·8
155				6·3	5·1	6·6
165					5·3	6·4

for best fit over the interval of zenith angle 60–120°, where they all overlap. This correction does not affect the r.m.s. deviations.

Average mean heights $\bar{h}(Z)$, and average r.m.s. deviations $\delta h(Z)$, are plotted in Figure 2. There is a significant dependence of $\bar{h}$ on Z for $Z<100°$, i.e. only whilst the apex is close to or above the horizon. The width of the height distribution shows the reverse behaviour: δh is almost independent of Z whilst the apex lies above the horizon (there is perhaps a tendency for δh to decrease as Z becomes small) but decreases as the apex recedes towards the nadir. The plots of Figure 2 are obviously consistent with the failure to detect a seasonal variation, already noted.

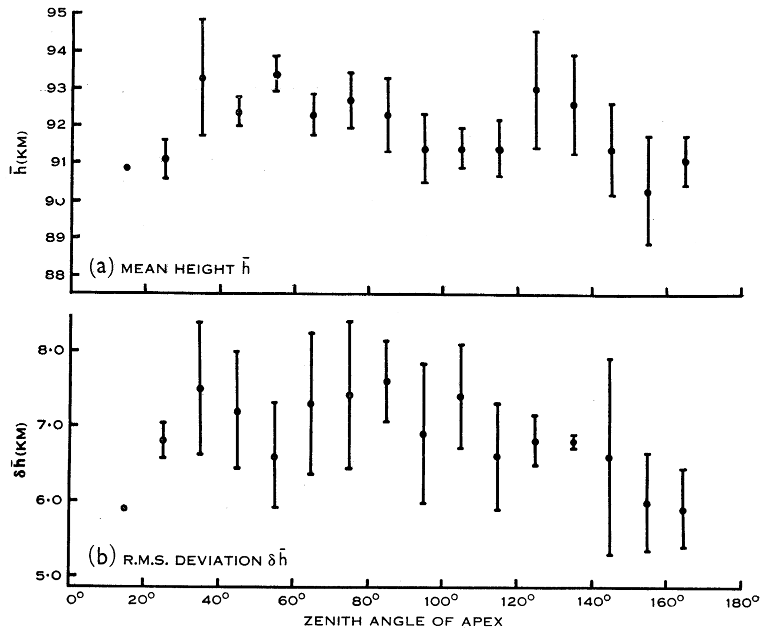

Fig. 2.—Mean heights and r.m.s. deviations from the means for the six periods summarized in Tables 3 and 4. Dots are values averaged over all periods; barred lines show the r.m.s. deviations of the average values.

One noteworthy feature of the data summarized in Figure 2 and Tables 3 and 4 is their large scatter. It is perhaps not unexpected that for a given zenith angle of the apex considerable fluctuation should be encountered when data for periods widely separated in time are brought together in this way. This is especially so since a non-uniform apparent radiant distribution cannot be represented satisfactorily by only one independent variable. The phase of the diurnal variation for the 1953 data also raises the possibility of a small variation in local time, unrelated to the apex of the Earth's way. What is more surprising are the irregular and large differences between the mean heights and also the r.m.s. deviations, for successive narrow intervals of zenith angle for the same run. Each individual entry in Tables 3 and 4 is based on at least 40 echoes and usually considerably more. This leaves us with little alternative but to ascribe the scatter to short-lived irregular changes in the mass, radiant distribution, and velocity of the incident meteors.

The overall height distribution for the six periods of Table 3 appears in Figure 3, where it is compared with the heights of 367 sporadic meteors detected at Jodrell Bank, as tabulated by Evans (1954). The ranges of heights detected by the two equipments are similar, but the mean heights differ by about 4 km. This is probably connected with the different areas of the sky sampled by the two equipments. The resulting difference in the average radiant zenith angle will act in the correct sense to depress the Adelaide mean height. Another, but more unlikely, possibility is a larger deficiency of high reflection points at Adelaide, occasioned by failure to record or to measure echoes whose duration is limited by rapid diffusion of the trail after formation.

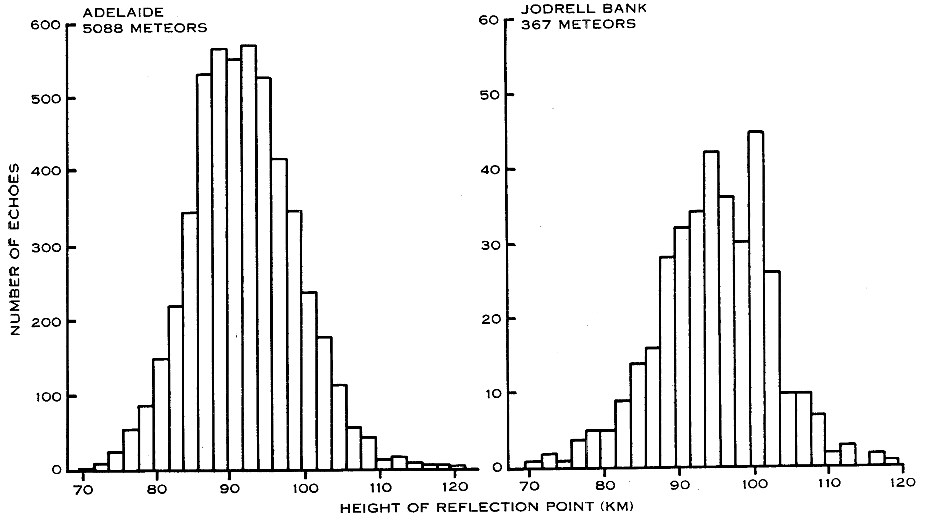

Fig. 3.—Total height distributions observed at Adelaide (six periods of Tables 3 and 4) and at Jodrell Bank (January-July 1952).

Mean hourly echo rates are plotted in Figure 4. Rates for September 1953 and October 1954 exhibit very similar behaviour, and data for these two months have been combined. The same applies to March 1953 and February 1955. In deriving these mean rates no attempt has been made to correct for short losses of operating time or interference to records. The close correspondence between the behaviour of the hourly rates for adjacent months in different years indicates that these omissions are not serious.

IV. Model Height Distributions

In an endeavour to account for the observational data, height distributions corresponding to some assumed distributions of sporadic meteor radiants and velocities have been determined. As the work proceeded it became evident that the experimental results could not be reproduced by any of the usual models, which are greatly oversimplified. The best representation has been obtained with a uniform heliocentric distribution of meteors moving with identical heliocentric velocities. These are the models U (Weiss 1957), which are not inconsistent with the total rate of all meteors detected by the equipment (not merely those whose heights are measured), and which are suggested by the azimuth data.

The sporadic radiant distribution may be regarded as built up from a large number of small radiant areas distributed over the whole of the celestial sphere. The first step in determining the theoretical height distribution is therefore to evaluate the relative sensitivity of the equipment as a function of the zenith angle χ of the radiant. This function has already been determined (Weiss 1957,

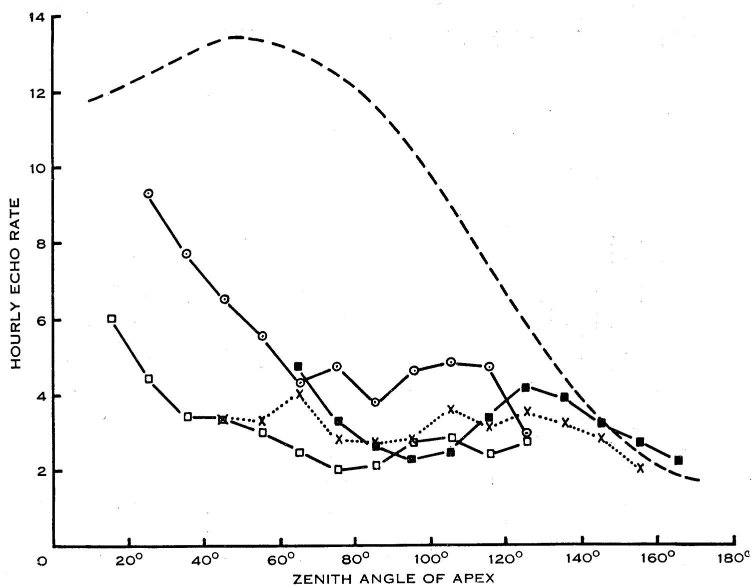

Fig. 4.—Observed and predicted echo rates. Observed rates: □———□ February-March; ⊙———⊙ May; × · · · · · · × July; ■——— ■ September-October. Rates predicted for model U_{42} (arbitrary scale) – – – – –.

Fig. 8 (*a*); only the major lobe is retained) but requires minor modification to take account of selection of echoes for height measurement, particularly of selection against radiants near the horizon which arises in an almost complete lack of measurable echoes near the zenith. The height distribution is not sensitive to small changes in the aerial polar diagram, and a quantitative estimate of the effects of echo selection on the response of the equipment is difficult. For these reasons correction of the theoretical response function of the equipment has not been attempted.

In any model for which the heliocentric velocity of meteors is uniform, the geocentric velocity is a unique function of the apparent elongation of the radiant. Hence the observed velocity distribution is completely determined by the radiant distribution and the equipment response function (McKinley 1951). Typical echo rates as a function of *apparent* elongation ε for model U_{42} (heliocentric velocity 42 km/sec) are drawn in Figure 5. These illustrate the spread in apparent elongation of the radiants contributing to the height distribution at any time, and also the negligible contribution from radiants for which $\varepsilon > 120°$. The total echo rate as a function of Z is shown in Figure 4.

A relation between velocity and height is now all that is required to convert these echo rates into height distributions. Here the theory of the radio-echo height distribution in an isothermal atmosphere (Kaiser 1954) is applicable. The mean height of a homogeneous velocity group of meteors with a well-defined radiant is close to the characteristic height

$$x_c = \text{constant} + H \ln\left[\alpha_m^{-\frac{1}{3}} \cos^{-\frac{2}{3}} \chi \, v^2 \beta^{\frac{1}{3}}\right],$$

where H is the atmospheric scale height, v the meteor velocity, and α_m the minimum detectable line density at height x_c in the direction of maximum aerial gain in the echo plane. The new height variable x has been introduced to

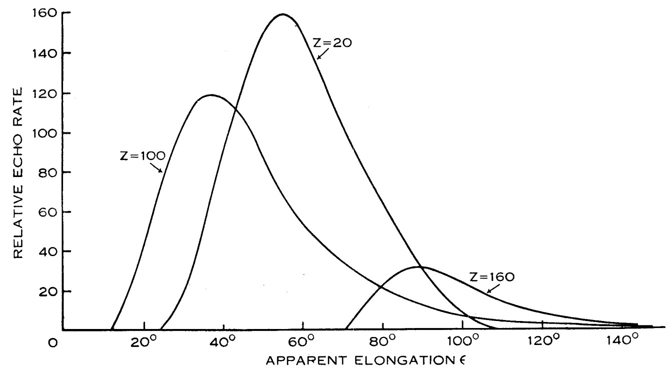

Fig. 5.—Relative echo rate as a function of apparent elongation of radiants from the apex of the Earth's way, for three values of Z=zenith angle of apex. Model U_{42}.

distinguish theory from observation. β, the probability that an evaporated meteor atom will produce a free electron, may be a function of velocity. The mean height x_m differs from the characteristic height by a small quantity, which depends on but is insensitive to the aerial polar diagram and the height, and it is sufficient to put $x_m = x_c + \text{constant}$. Since there is only a narrow spread in the elevation of echoing points (Weiss 1957), $\alpha_m^{-\frac{1}{3}}$ is substantially constant; the factor $\ln \cos^{-\frac{2}{3}} \chi$ also does not vary strongly except for radiants very close to the horizon, which are detected infrequently because of low maximum line density in the corresponding trails. Omitting these factors, the mean height $x_m(\varepsilon)$ becomes a function of apparent elongation only.

The form of the ionizing probability function β is not well established. Two forms, β=constant and $\beta \propto v^3$ respectively, have been used in the numerical computations. Simultaneous velocity-height measurements by Evans (1954, 1955) suggest that β is insensitive to velocity, but there is other evidence in favour of a strong velocity dependence, in which case $\beta \propto v^3$ is more appropriate. Figure 6 shows the relation between x_m and ε for these two forms for β, with

$H=7$ km. The absolute values are arbitrary. Heights of beginning and end of trails of 480 sporadic meteors observed visually (Porter 1944) and analysed by elongation groups, also appear in this diagram.

The distribution of the mean heights for all elementary sporadic radiant areas accessible to the equipment at a given time (given Z) is found by combining the appropriate echo rate-ε relation (Fig. 5) with the x_m-ε relation (Fig. 6). Incorporation of the spread in heights associated with each elementary area finally leads to the complete height distribution, which is directly comparable with the

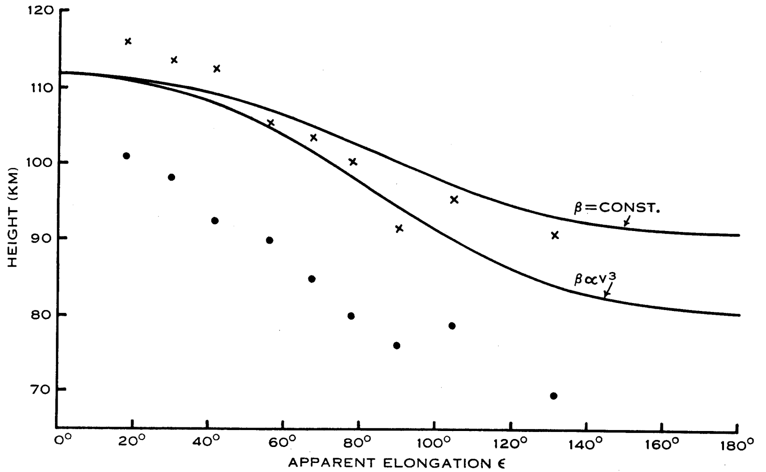

Fig. 6.—Mean height as a function of apparent elongation of radiant, model U_{42}. The position of the theoretical curves is arbitrary. β=ionizing probability of an evaporated meteor atom. Heights of visual trails (after Porter) : $\times$ beginning ; ● end.

distribution observed at the appropriate time. This additional spread is due to the spread in mass of the incident meteors and to the fact that a given trail may be detected at any point on its length, subject only to the limitations set by electron line density and specular reflection. It is approximately Gaussian in form (Kaiser 1954). Hence

$$\bar{x} \sim \bar{x}_m,$$
$$(\delta x)^2 \sim (\delta x_m)^2 + (\delta x_s)^2,$$

where $\bar{x}$, δx are respectively the mean and r.m.s. deviation from the mean of the complete theoretical height distribution, and δx_s is the r.m.s. deviation of heights for an elementary radiant area.

$\bar{x}$, δx_m, and δx for the model U_{42} are illustrated in Figure 7, in units of scale height. A uniform model with heliocentric velocity less than 42 km/sec will give substantially similar results, as the total geocentric velocity spread is insensitive to heliocentric velocity. The decrease of mean height $\bar{x}$ as Z decreases below 70° is caused by the movement of the region near the apex upwards away from the zenith angle (70°) of maximum equipment response, and eventually altogether outside the collecting area of the equipment. This behaviour will be typical of any equipment whose collecting area does not extend to the zenith.

The variation of δx_m with Z is a reflection of the orientation of the loci of constant apparent elongation relative to the loci of constant equipment response. According to Kaiser, $\delta x_s \sim 1$ scale height for the mass distribution appropriate to sporadic meteors. The resulting δx is shown in Figure 7. For heliocentric velocities lower than 42 km/sec, the range of δx will be slightly smaller. The width of the height distribution found in this way is always a minimum value, by virtue of the neglect of the factors α_m and χ in the derivation of the x_m.

A concentration of sporadic radiants to the plane of the ecliptic (model E of Weiss 1957), in combination with the x_m-ε relation of Figure 6, gives a mean height $\bar{x}$ which covers much the same range of heights as model U_{42}, but the r.m.s. deviation δx varies much more widely. Because of the greater population of apparent radiants near the antapex, δx is almost twice as large when the apex is near the horizon as it is when the apex is in either of its two extreme positions.

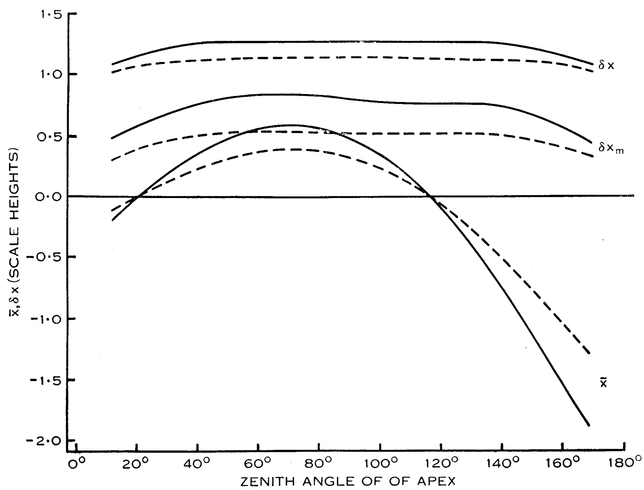

Fig. 7.—Mean height $\bar{x}$ and r.m.s. deviations δx_m, δx for model U_{42}. Position of $\bar{x}$ curves is arbitrary. ——— $\beta \propto v^3$; - - - - β = constant.

V. Interpretation of the Observations

Model U_{42} reproduces correctly the form of the dependence of mean height $\bar{h}$ on the zenith angle of the apex, for zenith angles less than 100°. In particular, it predicts the observed decrease in mean height at small zenith angles. The predicted height variation, however, far exceeds that observed and cannot be reconciled with it by any reasonable choice for the ionizing probability function β, or for the atmospheric scale height H. The small change observed in the r.m.s. deviation δh is also a feature of the model U_{42}; the observed values of this parameter, although a little low, do not lie outside the limits set by the uncertainties in β and in H. Observed and expected echo rates (Fig. 4) are quite incompatible.

It is well known that a uniform heliocentric distribution is far from representing the true distribution of sporadic meteors. The orbits of brighter meteors show a preference for the plane of the ecliptic, with a preponderance of direct orbits (e.g. Hawkins and Prentice 1957). The discrepancy between observed and predicted rates may be eliminated easily by postulating a greater concentration of apparent radiants to the antapex, which is what the facts demand ; but this solution only enhances the failure of the models in other directions. The excessive range of mean height is not reduced and the r.m.s. deviation becomes very large. This is true whether or not the additional radiants lie in the plane of the ecliptic. Evidently a further modification is required.

The pronounced helion and anthelion concentrations of sporadic radiants (Weiss 1957) in fact require that the meteors moving in direct orbits of low inclination have velocities not much in excess of the Earth's. These meteors have low geocentric velocities, and as they are non-uniformly distributed the x_m-ε relation drawn in Figure 6 will not apply to them. The incorporation of such a component into the model distributions already considered will exert a moderating influence on the variation of the mean height with zenith angle of the apex. However, a second (unpublished) survey of meteor activity at Adelaide in 1957–1958, using narrow-beam equipment, raises serious doubts as to whether the helion-anthelion component of meteors is sufficiently strong to reduce the variation of the mean height to the extent observed. It should also be pointed out that the visual observations summarized in Figure 6, although lacking in precision, are scarcely compatible with this hypothesis and that published distributions of velocities (McKinley 1951 ; Evans 1954) are not dominated by a large component of slow meteors.

The large number of variables involved and the necessity for considering the interaction between the meteor particle and the atmosphere make the prediction of temporal variations in the radio height distribution a problem of considerable complexity. It should, however, be profitable to re-examine the problem when firm data on the distribution of radiants, and more particularly of velocities, become available.

VI. Acknowledgments

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