RADIO ECHO OBSERVATIONS OF METEORS IN THE SOUTHERN HEMISPHERE

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Summary

The results of a radio survey of meteor activity at Adelaide are presented. The radiants and activities of six major meteor showers (Geminids, day-time Arietids, ζ-Perseids, δ-Aquarids, Corona Australids, Orionids) have been measured by methods which are described, and the mass distributions in three of these showers are discussed. Seasonal and diurnal variations in the background activity of sporadic meteors are examined in relation to the radiation patterns of the aerial systems. Height distributions for meteors of three showers (Geminids, day-time Arietids, ζ-Perseids) are given. Diurnal variations in the height distribution of sporadic meteors do not conform to those expected from the motion of the apex of the Earth's way.

I. Introduction

The successful application, at the Jodrell Bank Experimental Station of the University of Manchester, of radio echo techniques to the continuous monitoring of meteor activity in the northern hemisphere, prompted the initiation of a complementary survey in the southern hemisphere. Up to the time of commencement of this survey lists of southern hemisphere visual observations had been published by McIntosh and by Hoffmeister, and McIntosh (1935) had compiled " An Index to Southern Meteor Showers " which lists 320 radiants visible at mid-southern latitudes. These visual observations have since been supplemented by radio echo observations on the δ-Aquarid shower by Hawkins and Almond (1952) and by Lindblad (1952).

Although it is certain that all major southern night-time showers have been detected by the visual workers, the cover in the months September to March is not altogether satisfactory (McIntosh 1935). The chief objects of the southern hemisphere survey were therefore to determine radiants and activities of the known night-time showers, to search for day-time showers, and to measure the hourly rate of sporadic meteors.

This paper presents results obtained from June 1952 to December 1953. The survey was not completed during this period, portions of the first half of the year not being covered. The radiants and activities of the major meteor showers visible from Adelaide have been measured using two different radio equipments. No major day-time showers have been discovered. Seasonal and diurnal variations in the rate of sporadic meteors have been determined and an attempt is made to relate these variations to the polar diagrams of the aerial systems of the respective equipments. The heights of occurrence of a large

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number of echoes from sporadic meteors have been examined for seasonal and diurnal variations.

The records also furnish the rate of decay of meteor echoes. As the decay rate is of physical rather than astronomical importance, this topic is reserved for a subsequent paper.

II. The Equipment

Two different types of equipment have been used at Adelaide, lat. $-34° 45'$. Of these, one (the radiant equipment) is designed for the measurement of shower radiants and activity, whilst the other (the wind equipment) is intended primarily for measurement of upper atmosphere winds using meteor trails as drifting test bodies, and the astronomical information is obtained incidentally.

The radiant equipment is essentially similar to the radio echo apparatus described by Aspinall, Clegg, and Hawkins (1951). In the installation at Adelaide two identical beamed aerial arrays are used, directed at low elevation along azimuths $35 \cdot 5°$ S. of E. and $14°$ N. of E. Each array is adapted for common transmission and reception by means of a TR device. The transmitter delivers into each aerial about 3 kW peak power in double pulses 30 μsec wide and 150 μsec apart, at a pulse repetition frequency of 47 c/s and at a frequency of 67 Mc/s. The minimum signal detectable at the receiver input is 10^{-13} W. Amplified echoes from each aerial are fed to an intensity modulated cathode-ray tube and are photographed on film moving in a direction perpendicular to the time-base sweep. Range markers at intervals of 200 km, and time signals at 10-min intervals, are placed on the film at the same time. Film speed is 12 cm/hr.

Each aerial array consists of six Yagi aerials mounted at horizontal distances $1 \cdot 2\ \lambda$ apart and at a height of $1 \cdot 5\ \lambda$ above ground. The beams are directed at elevation 9° and have half-power widths $\pm 3 \cdot 5°$ in azimuth and $\pm 4 \cdot 5°$ in elevation.

The time of occurrence and the range of each echo detected with the radiant equipment are measured.

The wind equipment was constructed by and has been fully described by Robertson, Liddy, and Elford (1953), but the following equipment parameters are relevant here. The transmitter delivers 250 W c.w. at a frequency of $26 \cdot 8$ Mc/s, and the minimum detectable signal at the receiver is 3×10^{-14} W. The overall gain of the aerial system is 25. The direction of maximum gain points to the zenith, the first zero occurs at a zenith angle of about 45°, and there is a further minor lobe of low gain at low elevation.

The time of occurrence of each echo detected by the wind equipment is measured. In addition, the direction of the reflection point and the slant range are measured for selected echoes. The remaining echo characteristics measurable with this equipment, namely, line-of-sight drift velocity and rate of decay of the meteor trail, have no astronomical significance.

For echo counting purposes, the sensitivities of the respective equipments are continually monitored, either by metering or by injection of test signals. Despite the double pulses of the radiant equipment and the insertion in the video stages of the receiver of a discriminator unit of the type used by Davies and

Ellyett (1949), interference by noise impulses remains a problem. This form of interference is eliminated by the narrow bandwidth and high film speed of the wind equipment.

Using the equipment parameters listed above, and the scattering formula of Lovell and Clegg (1948), the line density of electrons in the meteor trail detected at limiting sensitivity on the axis of the aerial beam is readily found. These limiting sensitivities are: radiant equipment, 3×10^{10} electrons/cm; wind equipment, 1×10^{11} electrons/cm. In other directions the limiting line densities are of course higher.

III. The Determination of Meteor Shower Radiants

The methods of radiant determination applicable to either equipment rest on the property of the meteor trail of specular reflection (Hey and Stewart 1947; Lovell, Banwell, and Clegg 1947). When the Earth passes through an active meteor stream, radio echoes observed on high frequencies proceed from a narrow zone of the atmosphere of limited depth, which lies in a plane passing through the observing station and perpendicular to the position of the radiant. The rate of occurrence and ranges of the echoes, and the directions of possible reflection points, depend upon the orientation of this plane relative to the aerial coverage, and vary with time as the radiant moves across the sky. The different radiation patterns of the aerial systems of the two equipments result in quite different responses to the same shower.

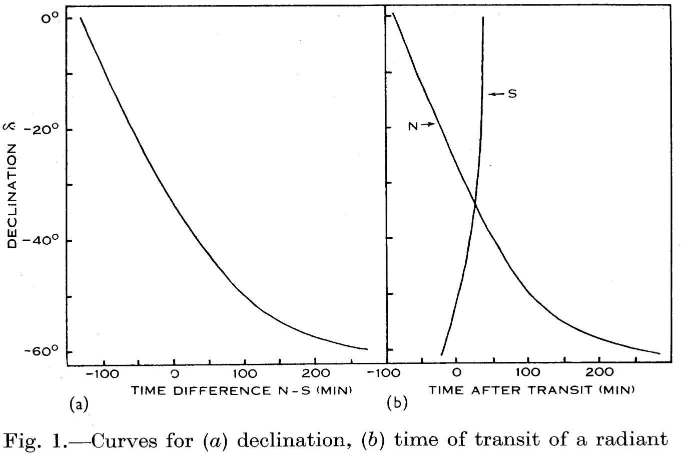

Fig. 1.—Curves for (*a*) declination, (*b*) time of transit of a radiant from the times of appearance of echoes of 700 km range in the two aerials (N and S) of the radiant equipment.

For the radiant equipment, the method of radiant determination has been fully described by Clegg (1948) and by Aspinall, Clegg, and Hawkins (1951), and elaboration is unnecessary. By fitting computed range-time envelopes to observed echoes, the time of occurrence of echoes of 700 km range is determined for each aerial. From these times the coordinates of the radiant may be read off immediately from Figure 1, which has been prepared for a mean height of reflection points of 90 km. The N aerial is directed at azimuth 35·5° S. of E., the S aerial at 14° N. of E. These curves may be readily extended to north declinations. For radiants more southerly than Dec. $-60°$ echoes do not appear at all in the N aerial, but are detected by the S aerial for many hours and continually if the radiant lies sufficiently close to the south pole of the celestial sphere. Comparison of the theoretical with the experimental range-time envelopes for a given radiant also leads to an estimate of the effective diameter of the radiant area.

A method of radiant measurement, applicable to a wide aperture aerial system, which depends on the variation of the most probable range with time, has been described by McKinley and Millman (1949). This method cannot be applied to the wind equipment because of the small number of suitable echoes. An alternative method which makes use of the known directions of reflection points has therefore been developed for the wind equipment.

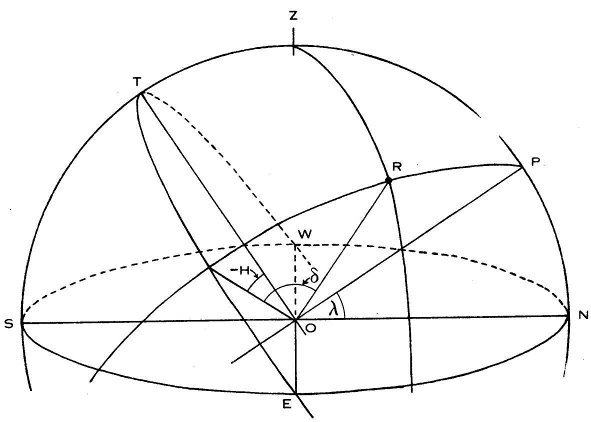

Fig. 2.—Geometry for the determination of radiants by the wind equipment.

In Figure 2, O is the observing station, R the radiant, Z the local zenith, OP the celestial polar axis, and $NESW$ the observer's horizon. Let the direction cosines of the radiant R with respect to the axis system OP, OE, OT be L, M, N; and those of the reflection point (not shown in the diagram) with respect to these same axes be l, m, n. Then from the condition of specular reflection the equation of the plane containing the observer, the reflection point, and the radiant is

$$lL + mM + nN = 0.$$

If H is the hour angle of the radiant, measured westwards from transit, and δ the declination, then

$$L = \sin \delta,$$
$$M = -\cos \delta \sin H,$$
$$N = \cos \delta \cos H,$$

and

$$\tan \delta = \tan \alpha \cos (\varphi + H), \qquad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

where $l = \cos \alpha$, $m/n = \tan \varphi$.

Putting H_0=hour angle of the radiant at midnight, and t=time of observation in minutes after midnight (t=0), then $H=H_0+t/4$ and (**1**) becomes

$$\tan\delta=\tan\alpha\cos\{H_0+(\varphi+t/4)\}.$$

This is the polar equation of a straight line in the variables $\tan\alpha=(1-l^2)^{\frac{1}{2}}/l$ and $(\varphi+t/4)=\arctan(m/n)+t/4$, from which the constants $\tan\delta$ and H_0, which are related to the declination and Right Ascension of the radiant, may be determined.

The direction of the reflection point is actually measured in the axis system NS, EW, OZ. Let these observed direction cosines be l_A, m_A, n_A. The required l, m, n are then found from the observed l_A, m_A, n_A by a simple rotation of axes about EW, thus:

$$\begin{aligned} l&=l_A\cos\lambda+n_A\sin\lambda,\\ m&=m_A,\\ n&=-l_A\sin\lambda+n_A\cos\lambda. \end{aligned}$$

Here λ is the latitude of the observing station.

In the course of radiant determination by this method echoes are grouped into the two categories, shower and sporadic. This grouping is often desirable for such special studies as heights and rates of decay.

Both equipments afford a complete coverage of the visible hemisphere. The accuracy and sensitivity of the radiant equipment are highest for a radiant which transits close to the zenith. On the other hand, an analysis of the echoes indicates that a radiant is most favourably placed for detection by the wind equipment when its elevation is about 30°, so that the sensitivity of this equipment is highest for radiants which transit at this elevation, corresponding to declinations +25° and −85°. The discrimination, as between showers and sporadic echoes, of the wind equipment is inferior to that of the radiant equipment.

With equipments of the wind type, shower activity is readily surveyed by assessing the background (sporadic) rate over periods of shower activity. The shower activity is symmetrical about the time of transit; and, as it has been found that echoes are received from a radiant at very low elevation, the declination δ of the radiant may be found from the relation

$$\cos(T/8)=\tan\lambda\tan\delta,$$

where T is the total time in minutes between onset and cessation of activity and λ the observer's latitude. Radiants determined in this manner do not attain the high accuracy inherent in the two other methods described above but, except in the case of minor showers of short duration, the integration of activity results in a reasonably accurate mean radiant over the duration of the shower.

IV. Radiants and Activities of Showers

(a) *Geminids*

Radio observations (Hawkins and Almond 1952) show that the radiant diameter does not exceed 4°, and the mean radiant and the peak activity remain constant from year to year. This radiant has therefore been used in the calibration of the Adelaide equipments.

Although the Geminid radiant is not favourably situated for observation with the Adelaide radiant equipment, this equipment gave a radiant position for December 14, 1953 of $113 \pm 2°$, $+31 \pm 2°$. The agreement of this radiant with the weighted mean radiant found at the Jodrell Bank Experimental Station for the nights of December 13–15, namely $113 \cdot 6 \pm 1 \cdot 2°$, $+31 \cdot 1 \pm 1 \cdot 5°$, constitutes an assurance that the error in radiant coordinates due to aerial orientation at Adelaide will not exceed 1°. Uncorrected hourly echo rates, based on the echoes falling within the range-time envelopes, are shown in Figure 3 (*a*).

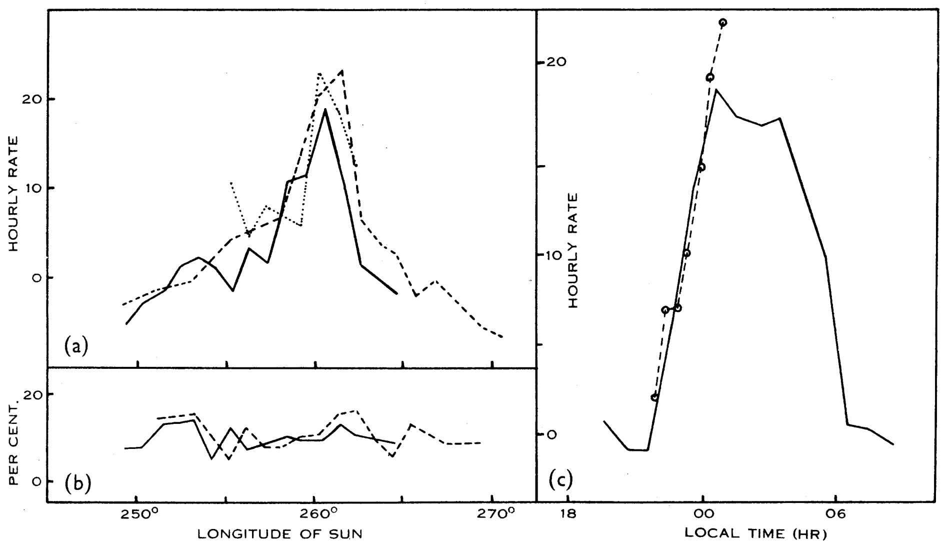

Fig. 3.—Echo rates for the Geminid shower. (*a*) Rate of shower echoes for each day, averaged over the period 22–06 hr, wind equipment, ——— 1952, – – – – 1953. Rate of echoes, for each day, falling within range-time envelopes, radiant equipment, · · · · 1953. (*b*) Percentage of all echoes (background+shower) whose duration exceeds 2 sec. (*c*) —— Hourly rate, for each hour, of shower echoes averaged over December 11–14, 1952 and 1953, wind equipment. ○ - - - - ○ visual half-hourly rates, 1952.

The shower echo rate as a function of the time of day (00 hr=midnight) for December 11–14 inclusive, as recorded by the wind equipment, is illustrated in Figure 3 (*c*), in which data for 1952 and 1953 are combined. These rates lead to a radiant position 110°, +30°. Day-to-day radiant coordinates found in 1952 by the more rigorous method are as follows:

December	11	111°, +27°
,,	12	111°, +26°
,,	13	113°, +29°
,,	14	115°, +29°

The activity observed on each day, which is the shower activity averaged over the 8 hr from 2200 to 0600 inclusive, is shown in Figure 3 (*a*). The peak of the activity falls between $\odot = 260°$ and $\odot = 261 \cdot 5°$, which is to be compared with other determinations by Hawkins, $261 \cdot 1°$, and Hoffmeister, $261 \cdot 5°$ (Hawkins and Almond 1952).

Figure 3 (*b*) indicates the percentage of echoes whose duration exceeds 2 sec. This information is relevant to the study of the structure of the Geminid stream and is considered in this context in Section V.

TABLE 1
RADIANTS OF DAY-TIME SHOWERS 1953

Date		Arietids		ζ-Perseids	
		R.A.	Dec.	R.A.	Dec.
June	5 ..	46°	+21°	65°	+21·5°
	6 ..	Low activity		62°	+23°
	7 ..	Not resolvable		Not resolvable	
	8 ..	42°	+22°	68°	+23°
	9 ..	44°	+23·5°	66°	+22·5°
	10 ..	45°	+24°	69°	+21°
	11 ..	48°	+19°	Low activity	
	12 ..	47°	+22°	66°	+26°

(*b*) *June Day-time Showers*

These showers have been observed during 1952 and 1953 with the wind equipment. The hourly echo rates are given in Figure 4 (*c*); after noon gaps appear in the records for some days and the descending portions of the curves

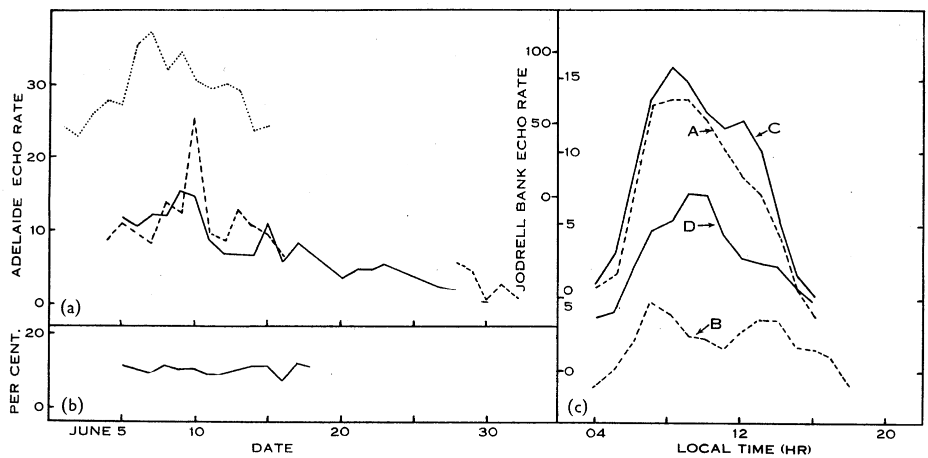

Fig. 4.—Echo rates for the June day-time showers. (*a*) Rate of shower echoes for each day averaged over the period 05–16 hr, wind equipment, - - - - 1952, ——— 1953. Rate of echoes, for each day, falling within range-time envelopes, Jodrell Bank radiant equipment, · · · · 1952. (*b*) Percentage of all echoes whose duration exceeds 2 sec, 1953, wind equipment. (*c*) Hourly rate, for each hour, of shower echoes averaged over the following periods: curve *A*, June 1–16, 1952; curve *B*, June 28–July 3, 1952; curve *C*, June 4–18, 1953; curve D, June 20–28, 1953.

are not considered to be as reliable as the ascending portions. The shape of the rates curves may also be influenced by the diffuse background (Lovell and Clegg 1952, p. 95). The Arietid and ζ-Perseid radiants cannot be resolved by this analysis. The activity from June 28 to July 3, 1952 proceeds from the β-Taurid radiant. Day-to-day radiant positions for the two main showers during 1953 are given in Table 1.

The day-to-day activity on the wind equipment, averaged over a period of 11 hr, is shown in Figure 4 (*a*). For comparison, the sum of the activities of the Arietids and ζ-Perseids for 1952, as measured at Jodrell Bank by Almond, Bullough, and Hawkins (1952) over the same days, using an equipment of the radiant type, is reproduced. Further investigation is necessary before ascribing the very decided differences between these two measures of the activity to real (and large) short-period irregularities in the activities of these streams, rather than to different instrumental techniques.

TABLE 2
RADIANTS OF δ-AQUARID SHOWER 1953

Date	R.A.	Dec.	Hourly Rate	Type of Radiant*	No. of Echoes >600 km
July 21 ..	336°	—17°	18	D { ? Second radiant at	0
22 ..	336°	—17°	19	C { 342°, —18°	3
23 ..	337°	—17°	—		—
24 ..	338°	—17°	33	D Second centre	3
25 ..	338°	—17°	41	C	4
26 ..	339°	—17°	52	D; Sc; Second centre	3
27 ..	340°	—17°	54	C; Sc; <3°	5
28 ..	340°	—18°	41	D; Sc; <3°	0
29 ..	340°	—18°	48	C; Sc; <3°	2
30 ..	342°	—16°	32	D	3
31 ..	343°	—16°	44	D; Sc;	6
Aug. 1 ..	344°	—16°	43	C; Sc; <3°	0
2 ..	345°	—15°	50	VC; 3°	8
3 ..	346°	—15°	26	D	6
4 ..	347°	—14°	21	C	0
5 ..	348°	—14°	33	VD	8
6 ..	348°	—14°	21	D	4
7 ..	348°	—15°	18	D	2
8 ..	347°	—17°	12	C	1

* C=compact, a well-defined radiant with little activity outside the envelope ; D=diffuse, considerable activity on either side of the main radiant ; Sc=strong concentration, a concentration of echoes to the theoretical envelope which implies a rather small radiant area.

(*c*) δ-*Aquarids*

The visual workers have established that the period from the beginning of July to the middle of August is one of high meteor activity in the southern hemisphere. The principal shower is the δ-Aquarids, but McIntosh (1935) lists no less than 43 minor radiants in the range of Right Ascension from 300° to 11°, and of declination from —8° to —33°, during this period. The most active of these minor streams are the ζ-Aquarids, δ-Capricornids, and α-Pisces Australids. In view of the low resolution of the radio equipments, as opposed to visual methods, it is not to be expected that these minor streams will be resolvable by the radiant equipment, and this has in fact been confirmed.

The position, activity, and nature of the δ-Aquarid radiant for 1953, as measured with the radiant equipment, are listed in Table 2. The hourly echo rate is an average over the number of echoes falling within fitted range-time envelopes. The column headed "Type of Radiant" lists the nature of the activity, thus: C—compact, a well-defined radiant with little activity outside the envelope; D—diffuse, considerable activity on either side of the main radiant; Sc—strong concentration, a concentration of echoes to the theoretical envelope which implies a rather small radiant area. This method of dealing with the problem of the size of the radiant is forced by the presence of the diffuse

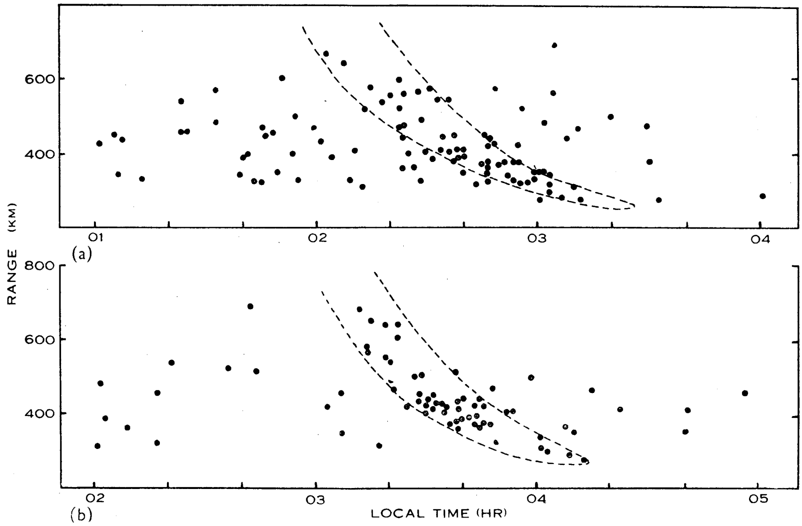

Fig. 5.—Observed echoes (·) and fitted theoretical range-time envelopes (- - - -) for radiant equipment, δ-Aquarids 1953. (*a*) July 26, N aerial; (*b*) July 27, S aerial.

activity, but when the diameter of the radiant area could be determined it appears in Table 2. Finally, the number of echoes whose range exceeds 600 km is an index of the reliability of the radiant, a large number of long-range echoes implying an accurate radiant. Two experimental range-time plots with fitted envelopes are drawn in Figure 5 to illustrate the nature of the classification problem.

These radiant positions agree closely with earlier visual determinations by McIntosh (1935) and Hoffmeister (1948). Radar determinations in the northern hemisphere (Hawkins and Almond 1952; Lindblad 1952), which give too northerly declinations, are apparently influenced by the diffuseness of the radiant and its low elevation.

At the edges of the δ-Aquarid stream, i.e. for several days prior to July 21 and after August 8, the activity was confused. It was spread more or less uniformly over a period of several hours each night and the radiant was diffuse and ill-defined. Whilst the radiant had contracted by July 21, over the next few days subsidiary active centres appeared, with a possible radiant at 342°, −18° active on July 21–22. Over the peak of the activity, from July 27 to August 2, the δ-Aquarid radiant proper was compact, its diameter usually being less than 3°. The diffuse activity attributed to the minor streams appears intermittently throughout the duration of the main shower. Its importance is well brought out in Figure 6, which compares the hourly rate of activity attributed to the δ-Aquarid radiant proper with the total number of echoes detected each day over a period of 3 hr centred on the times of peak activity in the respective aerials.

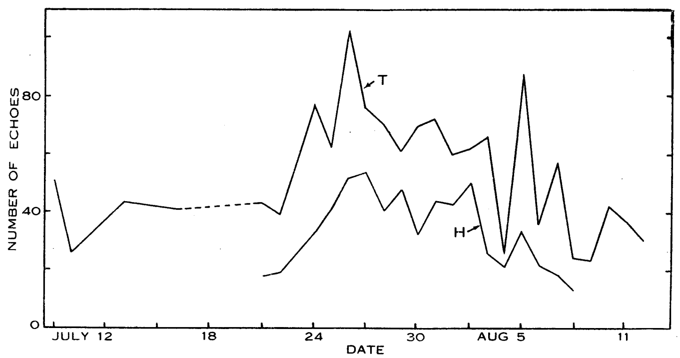

Fig. 6.—Echo rates for δ-Aquarids 1953, radiant equipment. Curve T, total number of echoes detected each day in the 3-hr intervals from 01 to 04 hr N aerial, and from 02 to 05 hr S aerial ; curve H, hourly rate of δ-Aquarid echoes for each day.

(*d*) *Corona Australids*

Figure 7 depicts the echo rates for this shower as recorded by the wind equipment in 1953.

The radiant position, estimated as 250°, −50°, cannot be fixed precisely because of the low activity and also because of the marked deficiency of large meteors in this stream (Section V). As the radiant culminates after sunrise, very few visual observations are available. McIntosh (1935) lists five radiants falling between 272°, −40° and 283°, −38°.

Clearly an accurate radar fix on this radiant is essential.

(*e*) *Orionids*

The Orionids 1952 appeared on the wind equipment with peak activity 20/hr on October 25. No shower was detected during 1953. Similar variability has been reported by Hawkins and Almond (1952).

(*f*) *Other Showers*

Two minor showers have been detected at the limit of resolution of the radiant equipment. The first, giving an echo rate of 7/hr, was active over August 26–29, 1953, at a radiant position 03°, −14° ; the second over September 6–7, 1953, at 02°, −53° with an activity of 11/hr.

At the end of May and the beginning of July 1953 the radiant equipment operated intermittently on one aerial only. Two radiants were active over the period May 26–31, giving echoes in the S aerial at 04 and 12 hr respectively, but unfortunately the range-time plots were too confused for even approximate radiant positions to be deduced with the single aerial. No visual activity during this period has been listed.

Day-time activity was observed on the S aerial on July 9, 10, and 13 between 07 and 10 hr, and again on the N aerial on July 16 from 08 to 11 hr, the rate being about 10/hr. However, the gaps in the records are too wide to justify the assumption that this activity proceeds from only one radiant.

As already mentioned, no major day-time showers active in the southern hemisphere have yet been detected.

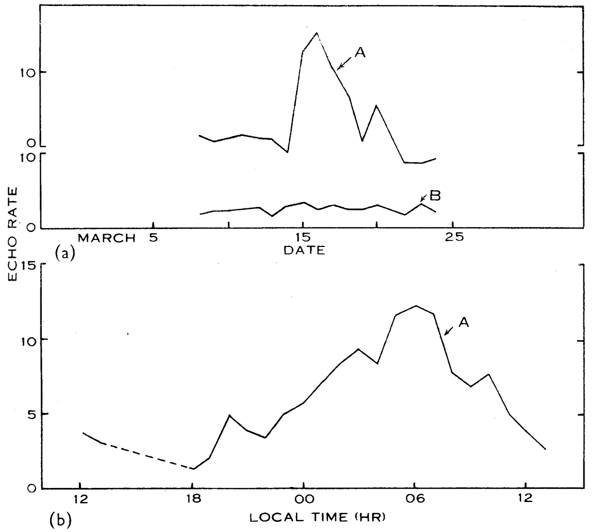

Fig. 7.—Echo rates for Corona Australids 1953, wind equipment. The rate of shower echoes for each day is an average over the period from 00 to 11 hr. Curve A, all shower echoes ; curve B, echoes used in wind measurement. The hourly rate, for each hour, of shower echoes is an average over March 15–20, 1953.

V. The Mass Distributions of Meteor Streams

(a) *Rate of Detection of Meteors*

After making due allowance for the striking variability in the activity of a given shower from day to day and from year to year, the activities observed at different latitudes, or using different techniques, are not the same. Some interesting information regarding the structure of meteor streams emerges from an attempt to reconcile these various rates.

The visual activity of a shower depends of course upon the incident flux of the meteors and their mass distribution. In addition, the observed visual rate is a function of the zenith angle z of the radiant, the relation being

$$N_v = 1\cdot 007\ N_0 \cos(z - 6\cdot 5°), \qquad \ldots\ldots\ldots\ldots \quad (2)$$

where N_0 is the zenithal rate (Olivier 1925, p. 195).

The radio echo rates are influenced by factors other than the mass distribution and the ionizing efficiency. These are (i) the collecting area of the aerial system, which may vary widely with radiant position ; and (ii) the limiting sensitivity of the equipment, which usually corresponds to meteors lying below the visual limit.

Starting with the mass distribution

$$\nu_m \mathrm{d}m = \text{const.}\, m^{-p}\mathrm{d}m, \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

Kaiser (1953) has calculated the observed echo rate in terms of the properties of the incident meteor flux and the radio equipment parameters. Applying his formula to the radiant equipments at Adelaide and at Jodrell Bank, whose main aerial lobes are almost axially symmetrical, the dependence of the echo rate upon the zenith angle is found to be approximately

$$N_R = F(p)\cos^{p-1}z \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

for radiants for which $z < 70°$. The function $F(p)$ depends upon the equipment parameters, which are constant for a given equipment.

The expression (4) is not applicable to the wide aperture aerial system of the wind equipment. For low radiant elevations shower meteors are collected near the zenith, where aerial gain and collecting area are relatively insensitive to zenith angle, and the shower rate for the wind equipment will follow a law of the form

$$N_W = \text{const.}\cos^n z, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

where the exponent n is close to unity. Actual values found for n range from $0 \cdot 8$ to $1 \cdot 1$. The close correspondence between the relations (2) and (5) is well brought out by some visual observations at Adelaide on the Geminid shower 1952. These observations, made on December 13 and 15, are shown in Figure 3 (*c*). Individual points represent half-hourly rates for the whole of the visible hemisphere, watched by four observers.

Activities of the major showers observed visually in the northern hemisphere, by the radiant equipment at Jodrell Bank, and by the two Adelaide equipments, have been freed from the influence of zenith angle by use of (2), (4), and (5). The values of p found by Kaiser (1953) were adopted. Any differences remaining between the four sets of activities for individual showers must then be the result of different incident fluxes, which in turn are determined by the mass distribution (3) as well as by the limiting sensitivities of the equipments.

Consistent zenithal rates were found for the Geminids ($p = 1 \cdot 7$) and the Perseids ($p = 1 \cdot 6$). The Adelaide wind rates were much less than the Jodrell Bank radiant rates for the June day-time showers, which appears to confirm the deficiency of meteor particles of larger masses implied by the value of $p = 2 \cdot 25$ for the Arietid stream. The radiant equipment rates for the δ-Aquarid shower exceed the visual rate by a factor of 3, which again may imply a large value of p. This is suggestive in view of the proposal by Almond (1952) that the δ-Aquarid and the day-time Arietid showers are produced by one extended meteor stream.

(b) *Durations of Echoes*

According to Kaiser (1953), the distribution of durations of echoes of the long-enduring type, observed with a sufficiently sensitive equipment, is

$$\nu_t \propto t^{-(3p+1)/4}, \qquad \text{(6)}$$

where t is the duration of an individual echo, and ν_t is the number of echoes per duration increment δt. The mass distribution may thus be found from an analysis of the durations of individual echoes, and the wind equipment records have been examined to this end. Distributions have been determined for the Geminids 1952 and 1953, and the June day-time showers 1953. Assuming that the observed distributions may be represented by the power law

$$\nu_t \propto t^{-s},$$

the values of s are:

Geminids	..	Shower 1952	2·14
		Shower 1953	1·44
		Background	2·09
June showers	..	Shower 1953	2·54
		Background	1·73

For sporadic meteors $p=2 \cdot 0$ and $(3p+1)/4=1 \cdot 75$. The agreement between this value and the values of s given above for background echoes is satisfactory, in view of the undoubted admixture, into the echoes used in deriving these values of s, of a number of short, decay type, echoes.

The high value of s for the June day-time showers is consistent with the deficiency of large meteors already inferred. Figure 4 (*b*), in which the percentage of all echoes whose duration exceeds 2 sec is plotted over the duration of the two principal showers, indicates that the structure of these streams is uniform in cross section.

The value of $s=1 \cdot 44$ for the Geminids 1953, and Figure 3 (*b*), indicate the existence of an asymmetrical core of heavy meteors within this stream, a conclusion already reached by Hawkins and Almond (1952). However, there is no evidence for such a core in 1952.

Finally, Figure 7 (*a*) shows the day-to-day activity over the duration of the Corona Australids, as assessed by the numbers of echoes actually used in wind measurement. Although selection of echoes is involved, this sample is thought to afford a reliable indication of the incidence of echoes whose duration exceeds $\frac{1}{2}$ sec. Although at the peak of the activity the total number of shower echoes detected exceeds the background rate, there are evidently very few shower echoes of the long-enduring type. This is confirmed by calculation of the hourly rates for the same group of echoes used in wind measurement; the total hourly rate averaged over shower days differs from that for the non-shower days by $0 \cdot 1 \pm 0 \cdot 8$. The Corona Australid stream is apparently quite deficient in large meteors.

VI. The Background Echoes

The background echoes represent the sum of true sporadic meteors and the minor showers which are not resolvable by the radio equipments. The following discussion is based on over 36,000 echoes.

Typical diurnal rates of background echoes are illustrated in Figure 8, for the month of December 1953. Figure 10 shows the seasonal variation of the mean monthly hourly rates, normalized to December. The higher background rate of the wind equipment, despite its lower sensitivity, is due to the much larger collecting area of its aerial system.

Detailed examination of the available material suggests that the seasonal change in the background rate for the wind equipment is simply an alteration in the scale of the diurnal rate. Neither the ratio of maximum to minimum diurnal rate, nor the times of these maxima and minima, depend significantly upon the season. For the radiant equipment, the extent of the diurnal variation and the mean monthly hourly rate appear to be almost independent of season. The diurnal variation in the background rate for the radiant equipment is

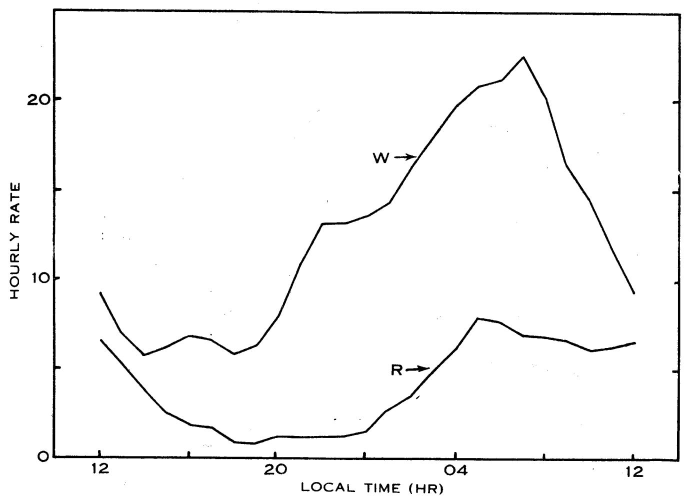

Fig. 8.—Diurnal variation in background rates, December 1953. Curve *R*, radiant equipment ; curve *W*, wind equipment.

almost twice that for the wind equipment, the respective ratios of maximum to minimum being 8·3 and 4·4. It should be remembered that the radiant equipment observations are confined to the latter half of the year. The shapes of the diurnal curves for the two equipments are dissimilar ; for the wind equipment there is a tendency to sharp maxima near 06 hr and flat minima near 18 hr, whilst for the radiant equipment the maxima are flat and the minima much sharper. The explanation of these facts lies in the different radiation patterns of the two aerial systems.

The geocentric velocity and the apparent radiant of any meteor are the result of compounding the true (heliocentric) velocity of the meteor with the velocity of the Earth, which is directed towards the apex of the Earth's way. If a uniform distribution of radiants and activity of background meteors is assumed and the dependence of luminous and ionizing efficiency on zenith angle is ignored, the seasonal and diurnal variations in the background rate may be evaluated without difficulty. The method of calculation of these rates for the visible hemisphere has been given in detail by Davidson (1914). These calculations are readily extended to meet the case of the more limited collecting areas of the radio equipments.

An analysis of the directions of the reflection points for echoes detected by the wind equipment shows that the very great majority of the echoes proceeds from zenith angles between 20 and 40° and that there is no seasonal variation. For this equipment, therefore, the apparent radiants may be taken to lie in a

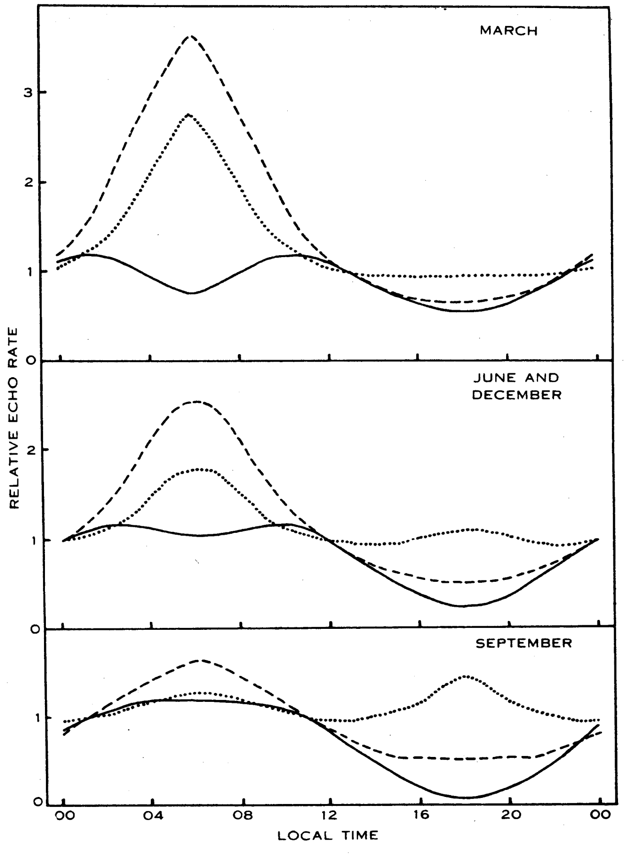

Fig. 9.—Diurnal variation in the rate of background echoes at the equinoxes and the solstices, for various collecting areas. ——— 30° spherical cap ; – – – – strip comprising elevations 20–40° ; · · · · · · strip comprising elevations 0–20°.

narrow strip of the visible hemisphere lying between elevations 20 and 40°. For the radiant equipment the majority of apparent radiants are located near the zenith, and a spherical cap of radius 30° is a reasonable first approximation to the zone of apparent radiants. The diurnal variations in activity associated with these two areas of the sky are shown in Figure 9 for the latitude of Adelaide, at the equinoxes and the solstices, on the assumption of parabolic velocities for meteors.

It will be seen that the characteristic shapes of the observed diurnal variations for the two equipments are reproduced by these two geometries, as is also the greater diurnal range for the radiant equipment over the latter half of the year. The small seasonal variation in the ratio of maximum to minimum diurnal rate is also predicted by the model for the wind equipment, but in view of the assumptions made in the derivation of the theoretical curves it would not be wise to press such comparisons.

Seasonal variations in the mean monthly hourly rate expected on the two geometries, along with the observed values, are shown in Figure 10. Incidental calculations suggest that a strong seasonal variation is not to be expected with a collecting area of any shape. The increase in activity observed from June

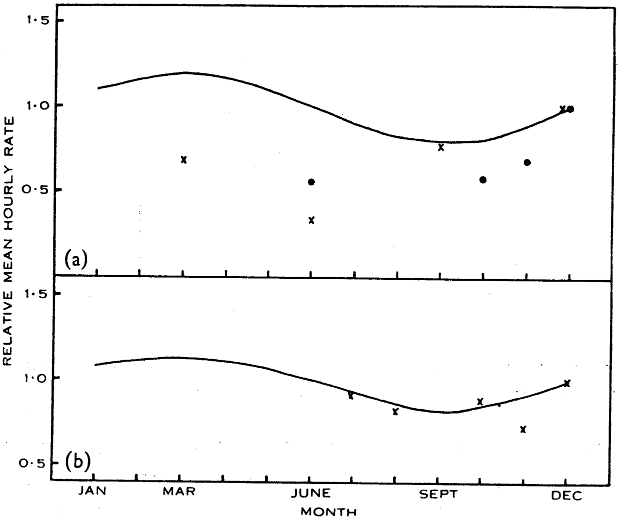

Fig. 10.—Seasonal variation in the relative mean monthly hourly rate of background echoes. (*a*) Wind equipment 1952 (·) and 1953 (×); (*b*) Radiant equipment 1953 (×). Expected variations are shown by full lines.

to December, for the wind equipment, occurred in both 1952 and 1953, and appears to be due to a real increase in background activity towards the end of the year. However, this is not confirmed by the limited observations with the radiant equipment, nor by visual observations of McIntosh (Hoffmeister 1937, p. 60) in the southern hemisphere, although according to Olivier (1925) the real visual background activity in the northern hemisphere increases towards the end of the year. The visual observations contain ample evidence of discrepancies from observer to observer, and further sampling by radio techniques is necessary.

The diurnal variation of activity expected from apparent radiants lying between elevations of 0 and 20° is shown in Figure 9. Although no allowance has been made here for the rapid falling off of ionizing efficiency at very low elevations, it appears that a valuable contribution to this problem may be made by special radio equipments designed for the purpose of counting sporadic, rather than shower, meteors.

VII. Heights of Reflection Points

The heights of reflection points of over 3000 echoes detected with the wind equipment have been computed from measured directions and slant ranges. Individual heights are accurate to ± 2 km.

(a) *Showers*

The height distribution of approximately 100 Geminid echoes is shown in Figure 11 (*c*). This distribution was determined by a statistical method; but a smaller sample of echoes, known by the sorting method described in Section III to belong to Geminid meteors, gave an identical distribution.

The height distributions of Figures 11 (*a*) and (*b*) refer to the ζ-Perseids and the day-time Arietids. The most probable height of 89 km for the Arietids is much higher than the height of 80 km found by Clegg and Davidson (1950), but less than the more recent value of 92·5 km derived from decay times (Kaiser

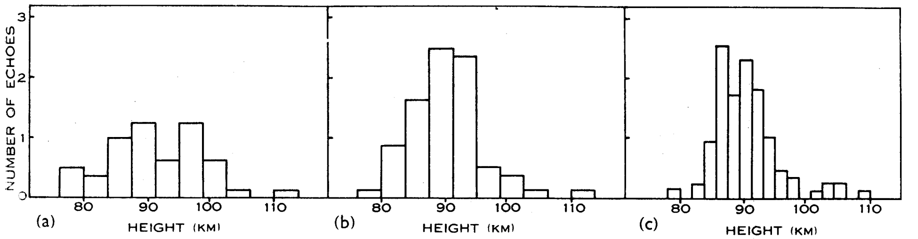

Fig. 11.—Height distributions of shower echoes. (*a*) ζ-Perseids 1953 (47 echoes); (*b*) day-time Arietids 1953 (69 echoes); (*c*) Geminids 1952 (100 echoes).

1953). The height of maximum ionization of a meteor trail depends on the zenith angle χ of the meteor path, the relation being approximately $h-h_0=6 \ln \cos^{2/3}\chi$. The height change corresponding to a change of zenith angle from e.g. 60 to 30° is 2 km. This will be reflected in a dependence of the height of the reflection point upon χ, but as the zenith angles for the Jodrell Bank echoes are not known the correction cannot be assessed.

(b) *Sporadic Meteors*

Background echoes observed during March, June, September, and December 1953 have been analysed in 6-hourly groups centred on 00, 06, 12, and 18 hr.

The diurnal variations in most probable heights are shown in Figure 12. Furthermore, the height distribution is much sharper at 12 hr than at 00 hr, whilst at 06 and 18 hr the distribution is intermediate. No seasonal effects were found, either in most probable heights or in the shapes of the distributions. The general nature of the height distributions is sufficiently illustrated by those for some other months already given by Elford and Robertson (1953).

Meteor heights are strongly influenced by the geocentric velocity, which depends on the elongation of the apparent radiant, i.e. the angular distance of the apparent radiant from the apex of the Earth's way. In March at Adelaide the apex reaches an elevation of 79°, whilst in September the maximum elevation is only 33°. Height distributions taken near 06 hr in March and 18 hr in

September would be expected to be sharper than those taken at 18 hr in March and 06 hr in September. On this simple picture, also, maximum heights are expected at 06 hr and minimum heights at 18 hr, whilst the distributions at 00 and 12 hr should be identical. These expectations are not confirmed by the observed distributions.

The selection of echoes used in this analysis is partly conditioned by the wind pattern in the meteor zone, but no relation between wind velocity and measured heights (other than the wind gradient) could be found. There are no marked diurnal or seasonal changes in the zenith angles of reflection points.

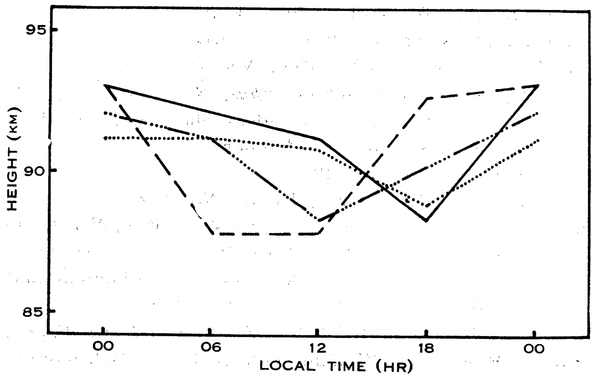

Fig. 12.—Diurnal variation of the most probable height of background echoes. ——— March ; – – – – June ; –·–··–·· September ; ······ December.

In any case the occurrence of the maximum diurnal echo rate at 06 hr and of the minimum at 18 hr renders any explanation in terms of zenith angles improbable. Nevertheless the distinctive features of the height distribution are thought to be real and probably astronomical in origin, although the possibility of atmospheric influence cannot be ruled out.

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