THE RADAR DETERMINATION OF METEOR SHOWERS IN THE SOUTHERN HEMISPHERE

By C. D. Ellyett* and K. W. Roth*

[*Manuscript received May* 20, 1955]

Summary

During the greater part of 1953 a radar survey was made of meteor activity in the southern hemisphere. The results are presented, together with a brief description of the apparatus used. Radiants are calculated from daily range-time plots of meteor echoes, and the resulting showers are in accord with data reduced from earlier visual observations.

Both radar and visual data for the southern hemisphere show many night radiants between mid June and mid August. Showers in this period are clearly defined but overlap in date, and there is a marked drift in the direction of the meteor activity as the date progresses. Two new southern hemisphere daylight showers of moderate strength have been found by radar in June and October respectively, and considerable confused night activity is present in early December. The greater proportion of both the northern and the southern hemisphere meteor shower radiants appear to lie close to the plane of the ecliptic.

I. Introduction

Meteor showers have been studied extensively in the northern hemisphere (Almond, Bullough, and Hawkins 1952 ; Hawkins and Almond 1952*a*, 1952*b* ; Bullough 1954 ; Prentice 1955). Most showers contain many individual meteors of sufficient size to leave visual trails in the upper atmosphere, and recur annually at fixed dates. The meteors in any given shower travel in a definite orbit about the Sun, and this orbit generally intersects the Earth's orbit over a number of days, determined by the width of the stream at the chord of the Earth's crossing. Knowledge of individual meteor shower directions in space, or radiants, seen from the northern hemisphere is fairly complete, but the southern hemisphere radiants, which have been based on comparatively few visual observations, are much less well known.

The aim of the present paper is to indicate the technique and present the results of a radar survey of meteor activity in the southern hemisphere carried out in 1953. These results are compared with earlier visual observations which are outlined in Section II. Finally, when the principal northern and southern hemisphere meteor radiants are plotted together it is shown that many of the major meteor showers lie closely in the plane of the ecliptic.

II. Most Probable Southern Hemisphere Meteor Showers

Lists of southern hemisphere visual meteor observations have been published by Hoffmeister (1948) and by McIntosh (1934, 1935, 1936, 1940). Radiants found from these visual observations were based on very small numbers of

* Canterbury University College, Christchurch, N.Z.

meteors, and in consequence many sporadic groupings have undoubtedly been regarded as radiants. Sporadic meteors from random directions are always present, and no criterion has been established which specifies the number or the rate of arrival of meteors from a particular direction which can be regarded as constituting a stream. A radiant due to McIntosh requires a minimum of four similarly directed meteor paths on a single night. Separate radiants are recorded on separate nights and on separate years. These results have been reduced to Table 1, in which showers seen by McIntosh are only included if nine or more separate but coincident radiants have been listed. Hoffmeister gives a probability rating from 1 to 10 for observed radiants, and of these only probability 10 has been included in Table 1. Visual showers recorded on a single night only have been excluded independent of rating.

A complete radar study of the meteor streams incident in the northern hemisphere has been made by the Jodrell Bank research team of the University of Manchester (Almond, Bullough, and Hawkins 1952 ; Hawkins and Almond 1952*a*, 1952*b* ; Bullough 1954), and their results have been shown to be in accord with the less complete early visual work. Northern hemisphere radar experience indicates that showers of lower altitude than about 20° above the horizon at transit are only weakly recorded. In considering northern hemisphere radar results for possible inclusion in Table 1 all showers for which the mean radiant exceeds 26·5° N. have therefore been excluded, as the altitude of such showers at transit is less than 20° above the horizon at Christchurch, New Zealand (43·5° S.). Mid northern and mid southern hemisphere observations overlap in an equatorial belt.

The primary purpose of the present paper has been to identify showers. The accuracy of the Christchurch radar observations does not yet justify a determination of the slight day-to-day changes in radiant as the Earth moves through a particular shower. Consequently where such variations have been reported elsewhere, they have been grouped as mean radiants in Table 1.

III. Equipment and Method

Surplus defence radar equipment provided the basic transmitting and receiving units. Pulses of 75 kW peak power and 3·5 μsec width were generated by the transmitter at a frequency of 69 Mc/s and a recurrence rate of 145/sec. Automatic control was provided, so that reswitching was effected after transient overloads or failures in the mains power supply. The equipment was kept inoperative between 14 and 21 hr L.T. each day in order to conserve power and film when the rate was at its minimum.

The aerial array consisted of 12 horizontal half-wavelength dipoles, all lying in the one vertical plane and end-fed in pairs, with each vertical stack containing three elements. Fine gauge wire netting, located one-eighth wavelength behind the plane of the dipoles, served as a reflecting screen, and the centre of the array was located one wavelength above the ground. The measured and calculated horizontal radiation patterns agreed very closely. The vertical pattern, which could not readily be measured, was calculated on the assumption of perfect ground reflection. The resulting cone of radiation has maximum power at 15° elevation, with beam widths between half-power points of 14° and 20° respectively in the vertical and horizontal directions. An aerial power gain of 75 is obtained compared with a half-wave dipole. Small side lobes are situated on either side of, and at the same elevation as the main lobe, but the power gain is only 4·4 per cent. of the maximum. Smaller lobes present at greater elevations

TABLE 1

OCCURRENCE OF SOUTHERN HEMISPHERE METEOR SHOWERS ESTIMATED FROM SOUTHERN HEMISPHERE VISUAL DATA AND NORTHERN HEMISPHERE RADAR DATA

Shower Number	Date*	Apparent Radiant R.A.,	Apparent Radiant Dec.	Constellation	Observer†	Number of Radiants, or Rating
	Jan. Feb. Mar.	Nil				
I	Apr. 1–21	228/239°,	—19/—22°	ϰ Libra	M (V)	18
II	Apr. 4–30	208½°,	—10°	α Virgo	M (V)	24
III	Apr. 28–May 16	330½/346½°,	+3½/—3°	η Aquarius	M (V)	24
	May 1–6	313/338°,	+3/—4°		J (R)	A
IV	Apr. 29–May 7	323½°,	—17°	γ Capricornus	M (V)	9
V	May 29–June 19	38/50°,	+16/+30°	Aries	J (R)	A
VI	June 1–16	57/72°,	+14/+30°	ζ Perseus	J (R)	A
VII	June 1–10	250/259°,	—22/—23°	ξ Ophiuchus	M (V)	9
VIII	June 25–28	196/199°,	—17/—23°	γ Hydra	H (V)	Py. 10
IX	June 26–July 4	81/92°,	+13/+26°	β Taurus	J (R)	A
X	June 30–July 10	262/275°,	—20°	μ Sagittarius	M (V)	10
XI	July 2–19	283°,	—15°	Sagittarius	M (V)	9
XII	July 5–9	257/261°,	—8/—12°	μ Ophiuchus	M (V)	9
XIII	July 5–8	238°,	—19°	β Scorpius	M (V)	9
XIV	July 10–Aug. 5	300/325°,	—10/—19°	Capricornus	M (V)	63
XV	July 22–Aug. 15	331/351°,	0/—17°	δ Aquarius	M (V)	78
	July 29–31	345°,	—20°		H (V)	Py. 10
	July 25–Aug. 6	339°,	—12°		L (R)	
		340±5°,	—17±2°		K (R)	
XVI	July 19–Aug. 1	352/11°,	—18°	β Cetus	M (V)	13
XVII	July 14–Aug. 22	330/339°,	—30°	β Pisces Australis	M (V)	11
XVIII	July 26–Aug. 8	337/350°,	—30/—33°	α Pisces Australis	M (V)	24
XIX	Oct. 15–25	97°,	+11°	Orion	J (R)	
XX	Oct. 26–Nov. 16	58°,	+23°	Taurus	J (R)	
XXI	Nov. 17–18	150/151°,	+21/+22°	η Leo	H (V)	Py. 10
	Nov. 15–20	152°,	+22°		B (R)	
	Dec.	Nil				

* Dates in this table are based on N.Z.S.T. = U.T. + 12 hr.

† (V) = Southern hemisphere visual observations, (R) = northern hemisphere radar observations. M = McIntosh (1934, 1935, 1936, 1940); J = Jodrell Bank group, University of Manchester (Almond, Bullough, and Hawkins 1952; Hawkins and Almond 1952*a*, 1952*b*; Bullough 1954); H = Hoffmeister (1948); L = Lindblad (1952); K = McKinley (1954); B = British Astr. Ass. Handbook, 1955.

can only give rise to short range echoes. The effect of the side lobes is thus slight, and has not been further considered. In order to determine radiants the array, which was rotatable in azimuth, was held at 22·5° N. of W. and 22·5° S. of W. respectively on alternate days.

Before observations were commenced a new input stage was built for the receiver which had been supplied, giving an overall receiver noise figure of 6·8 db. The bandwidth was 300 kc/s. The system sensitivity was adjusted so that the non-shower rate lay roughly between 5 and 10/hr throughout the year. The figure of 8/hr given by McIntosh (personal communication) for visual viewing in New Zealand with a 50° viewing cone is therefore somewhat less than the radar rate, when the smaller radar viewing angle is taken into account.

Intensity modulation was used to present the receiver output signal on the oscillograph, which was viewed by 35 mm film moving at $1{\cdot}23\times10^{-2}$ cm/sec. A continuous record was thus obtained showing echo range transversely and time longitudinally. (A small step voltage was added on alternate sweeps across the screen, causing genuine echoes to appear as close dense twin spots or lines, against the random spots resulting from background noise.)

A radiant passing through the aerial beam is characterized by a rise in echo rate and a progressive increase in echo range to a maximum, followed by a fairly rapid collapse (Clegg 1948). Some 50,000 echoes, recorded during the survey, were plotted on daily range-time graphs. Transparencies of all possible radiant envelopes were drawn independently by both authors, following the Clegg technique (Clegg 1948 ; Aspinall, Clegg, and Hawkins 1951). The reality of the various envelopes was considered, and similarly shaped envelopes were then looked for on adjacent days, since two days with different aerial azimuth setting are necessary before a radiant can be calculated. The remaining radiant results calculated from these envelopes, after all dubious envelopes or results had been discarded, were then grouped where possible into adjacent pairs of days with similar radiants. Interlocking radiants and subgroups made the whole procedure formidable but not impossible. (Envelopes of meteors referring to possible showers from the direction of the South pole could not be delineated.)

IV. Southern Hemisphere Radar Shower Results

The reproducibility of results is indicated in Figure 1. The top two plots are for adjacent nights with the same aerial setting, and the third plot is for the same night and aerial setting as the second plot, but in the following year when the sensitivity had been adjusted slightly below that of the 1953 records. Echoes in general are only observed when the aerial beam is at right angles to the incoming meteor trails (Clegg 1948). In all three cases a major group passes through the aerial beam with maximum range at approximately 15 hr. Another group is indicated at 13 hr. Mid-morning activity is also pronounced, with a group present at 21 hr and another probably present at 22 hr 20 min. During the first half of June, for other reasons, the aerial was not turned, so radiants could not be calculated during this period, but the activity—both day and night—outweighed that of any other month.

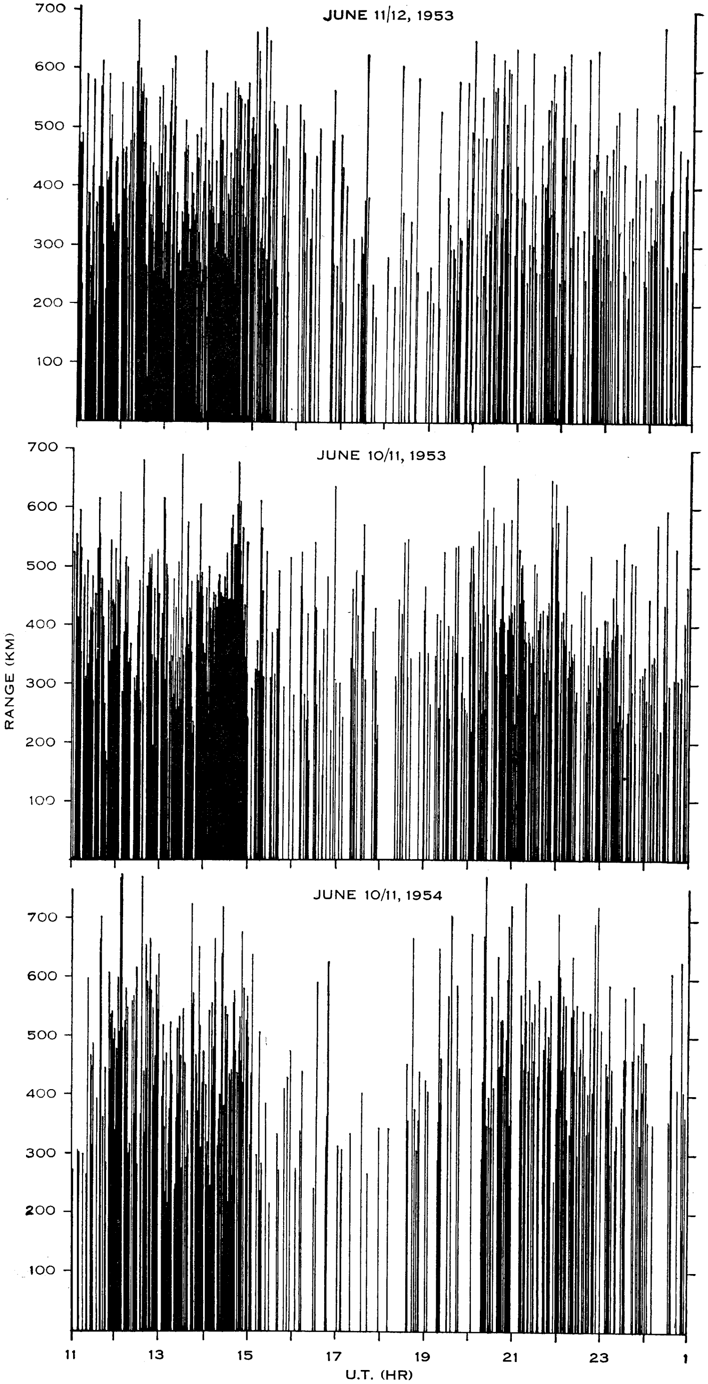

Fig. 1.—Meteor echoes, received with directional aerial array, showing strong day and night activity.

For comparison a September plot with unchanged sensitivity is shown in Figure 2. During this month echoes were scattered, and no radiant could be identified which lasted for more than two adjacent nights.

Each radiant group, found as described in Section III, was given an arbitrary grading. This was based on the consistency of the shape, range, and strength of the group, combined with factors incorporating the number of envelopes seen, the number of pairs calculated, and the compactness of the radiant limits. Four grades were made. Grade A is considered to be certain, and grade B is highly probable. The final results obtained are set out in Table 2.

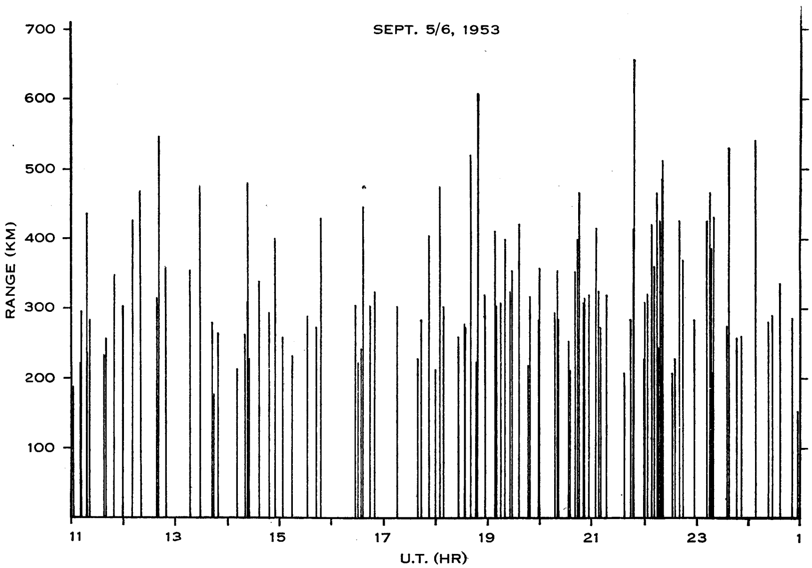

Fig. 2.—Meteor echoes received during an inactive period. (Mean rate = 8·6/hr.)

A comparison between the most probable southern hemisphere meteor showers evaluated from visual data (Table 1) and from the radar results (Table 2) is given in Figure 3. Showers shown in contact are considered to be subgroups of a single major radiant. In general the radar activity associated with any given shower covers fewer nights than the visual estimate, although this is only to be expected since the radar technique is more stringent in its selection. Showers of similar radiant determined by the two methods are connected by cross lines. The overlap of dates is often incomplete. However, there is a sufficiently high degree of correspondence to identify the radar observations clearly with the earlier visual results.

Of the 21 visual showers listed in Table 1, only numbers IV, V, VI, VII, VIII, XIII, XIX, XX, and XXI are not immediately evident by radar. Of these, numbers V, VI, XIX, XX, and XXI are essentially northern hemisphere radiants. Some radar trace of the Leonids (XXI) was found, but was considered insufficient to include in Table 2. The Leonids (XXI), Taurids (XX), and Orionids (XIX) are known to be weak, and their absence at an observatory situated at 43·5° S. is not surprising. Numbers V and VI are very strong

TABLE 2

SOUTHERN HEMISPHERE METEOR SHOWERS CALCULATED FROM RADAR METEOR ECHOES

Shower Number	Date*	No. of Envelopes Included	Mean Apparent Radiant R.A. Dec.	Limits of Radiant R.A.	Limits of Radiant Dec.	Constellation	Arbitrary Grading of Shower Probability
1	Feb. 17–22	6	297°, —6°	296/298°,	—1/—10°	Aquila	D
2	Apr. (10)–(15)	5	212°, —9°	208/214°,	0/—14°	Virgo	C
3	Apr. 29–May 8	9	228°, —23°	226/229°,	—19/—24°	Libra	C
4	Apr. 29–May 4	5	343°, +1°	342/344°,	+2/—2°	Pisces/ Aquarius	D
5	June (17)–29	12	303°, —21°	302/305°,	—19/—23°	σ Capri-cornus	B
6	June 19–25	6	268°, —23°	268/269°,	—23°	μ Sagittarius	C
7	June (17)–28	11	270°, —13°	267/274°,	—10/—15°	Ophiuchus/ Aquila	A
8	June (17)–28	10	263°, —21°	260/266°,	—19/—23°	ξ Ophiuchus	A
9	June (17)–21	5	252°, —20°	249/254°,	—19/—21°	η Ophiuchus	D
10	June (17)–26	9	84°, +23°	82/85°,	+20/+25°	β/ζ Taurus	B
11	June 19–27	8	69°, —27°	65/71°,	—23/—30°	Eridanus	B
12	June 18–21	4	48°, —25°	46/50°,	—21/—26°	Eridanus	D
13	July 3–13	9	302°, —33°	301/303°,	—32/—34°	θ Sagittarius	B
14	June 29–July 13	13	300°, —19°	299/301°,	—18/—20°	Sagittarius	B
15	July 5–15	11	310°, —33°	309/311°,	—26/—38°	Capri-cornus/ Micro-scopium	A
16	July 3–9	5	317°, —17°	316/318°,	—15/—18°	θ Capri-cornus	D
17	July 17–25	8	275°, —8°	271/279°,	—5/—11°	α Aquila	C
18	July 16–25	10	321°, +2°	319/322°,	+1/+2°	β Aquarius	A
19	July 20–Aug. 2	12	299°, —3°	297/302°,	+1/—7°	θ Aquila	A
20	July 21–30	8	322°, —17°	320/322°,	—14/—19°	δ Capri-cornus	C
21	July 21–26	5	328°, —27°	326/329°,	—26/—27°	Pisces Australis	B
22	July 30–Aug. 5	7	338°, —18°	334/338°,	—14/—22°	δ Aquarius	A
23	July 29–Aug. 12	14	301°, —10°	297/304°,	—7/—14°	α Capri-cornus	A
24	Aug. 1–12	13	321°, —8°	319/323°,	—2/—11°	ξ Aquarius	B
25	Aug. 2–9	8	329°, —11°	328/331°,	—9/—14°	θ Aquarius	C
26	Oct. 7–14	6	63°, —8°	62/65°,	—8/—9°	ξ Eridanus	D
27	Oct. 9–16	8	49°, +3°	48/50°,	0/+6°	Cetus	D
28	Oct. 23–31	8	46°, 0°	44/48°,	+1/—3°	α Cetus	C
29	Oct. 22–28	7	200°, —19°	199/201°,	—10/—24°	Virgo/ Hydra	B
30	Oct. 31–Nov. 7	7	204°, —6°	202/205°,	—1/—8°	α Virgo	C

* Dates in this table are based on N.Z.S.T. Dates shown in brackets represent activity present immediately before or after a non-operative period. Such showers may have started or terminated earlier or later respectively than the date shown.

TABLE 2 (*Continued*)

Shower Number	Date*	No. of Envelopes Included	Mean Apparent Radiant		Limits of Radiant		Constellation	Arbitrary Grading of Shower Probability
			R.A.	Dec.	R.A.	Dec.		
31	Nov. 12–(16)	5	78°,	—15°	76/79°,	—11/—19°	μ Lepus	D
32	Dec. (1)–8	5	224°,	—27°	222/228°,	—25/—29°	σ Libra	C
33	Dec. (1)–10	7	147°,	—5°	147°,	—1/—9°	γ Sextans	D
34	Dec. 2–11	6	253°,	—20°	252/256°,	—18/—23°	Ophiuchus	D
35	Dec. (1)–11	6	235°,	—19°	234/235°,	—15/—22°	θ Libra	D
36	Dec. 2–10	6	114°,	—25°	112/116°,	—24/—26°	Puppis	C
37	Dec. (1)–6	5	88°,	—3°	86/91°,	—2/—4°	Orion	D
38	Dec. 12–19	5	112°,	—16°	109/114°,	—14/—18°	Puppis	D
39	Dec. 12–20	8	193°,	—31°	190/195°,	—26/—35°	Hydra/ Centaurus	D
40	Dec. 12–20	7	230°,	—3°	228/231°,	—2/—3°	Libra/ Serpens	B

* Dates in this table are based on N.Z.S.T. Dates shown in brackets represent activity present immediately before or after a non-operative period. Such showers may have started or terminated earlier or later respectively than the date shown.

northern hemisphere daylight showers. They occur in the June period when the aerial was not being turned daily, and hence it can only be shown that the known radiants do in fact give rise to envelopes at the time expected. By this means, however, these two showers have definitely been confirmed, and part of the morning activity seen in Figure 1 is due to their presence. Shower VII was not clearly found as it also occurred in the June period of aerial non-rotation. It will be shown in Section V that it is possible to include numbers VIII and XIII in a more general radiant scheme. Consequently number IV, referring to an April-May γ-Capricornid group is the only visual shower for which no evidence at all has been found.

(*a*) *Night Radar Showers*

It is remarkable that at the time of the very strong northern hemisphere June daytime activity there is also very strong southern hemisphere night activity (Fig. 1). In July all the strong southern hemisphere visual showers reported by McIntosh (1934, 1935, 1936, 1940) have been found, and no new activity is apparent in this month. No other particularly strong night activity has been found, but there is considerable confused activity during the earlier part of December. No visual night activity at all has been reported during December, January, February, or March. Long hours of daylight would tend to engender this result for visual observations in these months, so it is of interest to find from the radar observations that the latter half of December, February, and March do in fact appear to be largely inactive. (January has not yet been sufficiently investigated by radar to allow an estimate of activity to be given.)

(b) *Daylight Radar Showers*

No previous observations exist for southern hemisphere daylight meteor activity.* A weak grade D shower is possible in February. A new shower

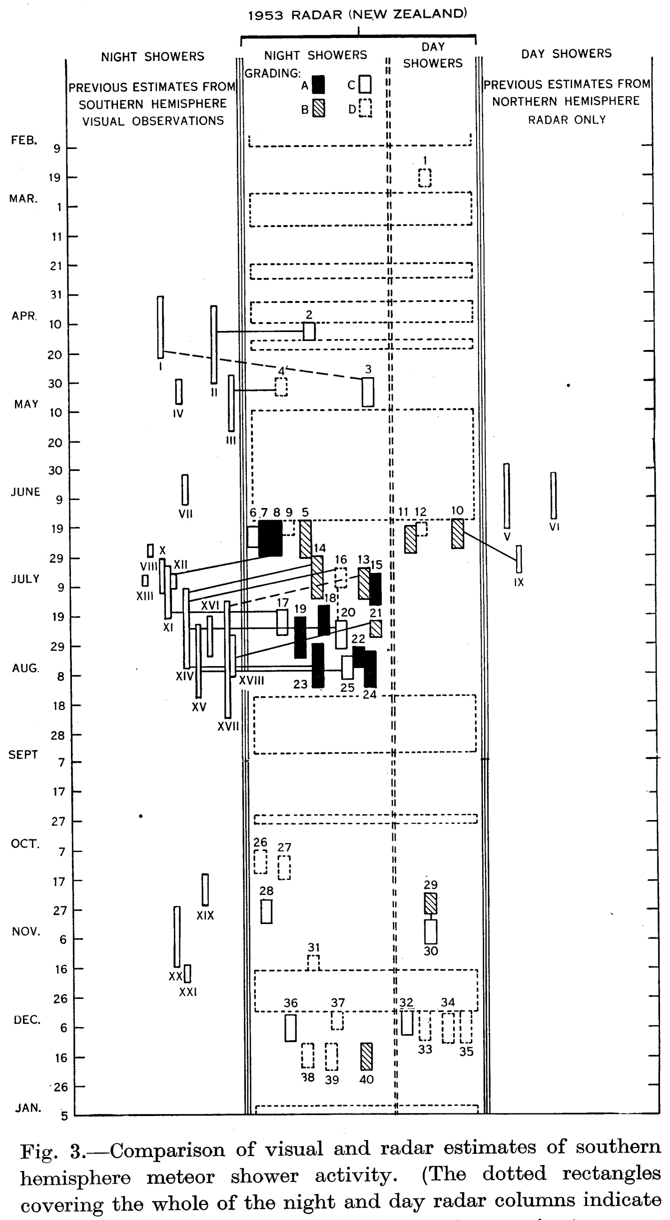

Fig. 3.—Comparison of visual and radar estimates of southern hemisphere meteor shower activity. (The dotted rectangles covering the whole of the night and day radar columns indicate periods when the equipment was inoperative.)

* *Note added in Proof.*—Subsequent to the submission of this paper for publication a paper has been published by Weiss (1955) in which six showers have been investigated in some detail at Adelaide by radar methods. The results are in general agreement with those in the present paper. Weiss mentions daytime activity on five scattered days in July but finds no daytime showers.

from the direction of Eridanus is present in late June, and there appears to be a strong and quite enduring shower from the direction Virgo over the period October 22–November 7. Early December activity is again confused, but some weaker radiants appear to be present. No significant daylight activity has been found over the other months.

V. The Spatial Distribution of Meteor Radiants

Southern hemisphere night meteor activity is very strong between mid June and mid August, with a number of radiants clearly defined but overlapping in date. When the activity is grouped as in Figure 4 a marked drift in the origin of the meteor activity over the two-month period becomes apparent.

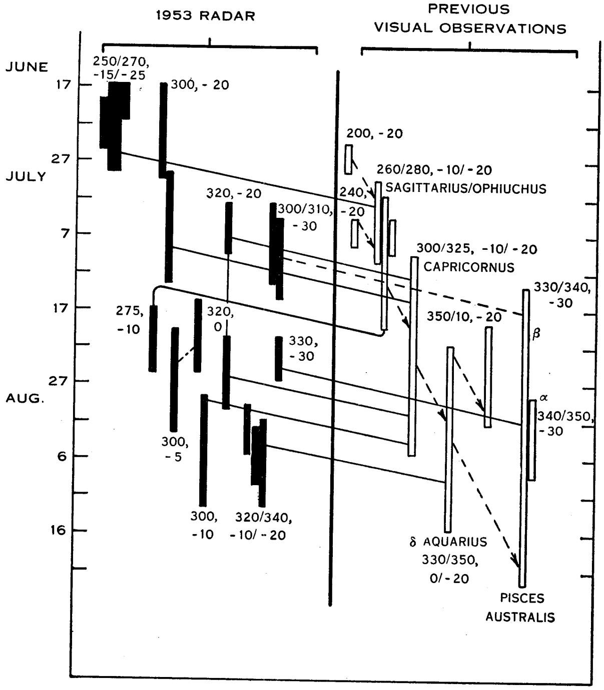

Fig. 4.—Interrelation of major night meteor showers in the period June-August.

The visual observations (based on Table 1) commence with possible activity from the region (200°, −20°) of the sky. The Right Ascension drifts with date through the region 240°, and then 260/280°. At the same time there is a progressive downward drift in declination, as shown by the connexion of showers with dotted arrows. The Capricornids, δ-Aquarids, and Pisces Australids are all very strong showers which fit into this progression, concluding about mid August with coordinates (340/350°, −30°).*

* *Note added in Proof.*—The drift *within* the δ-Aquarid shower radiant found by Weiss (1955) conforms with the general drift of all showers in the July-August period as found in the present paper.

The same tendency is evident from an examination of the radar results. Every group except one can be paired with a visual report, and the coordinates and date of the one isolated group are not greatly divergent from the general trend.

This passage of activity across the sky with date is similar to the northern hemisphere daylight activity (Almond, Bullough, and Hawkins 1952; Hawkins and Almond 1952*a*, 1952*b*; Bullough 1954) and led to the construction of Figure 5, which is a plot of the divergence of mean shower radiants from the ecliptic. The two dotted lines represent a divergence of 10° from the plane of the ecliptic, and both northern and southern meteor radiants have been included,

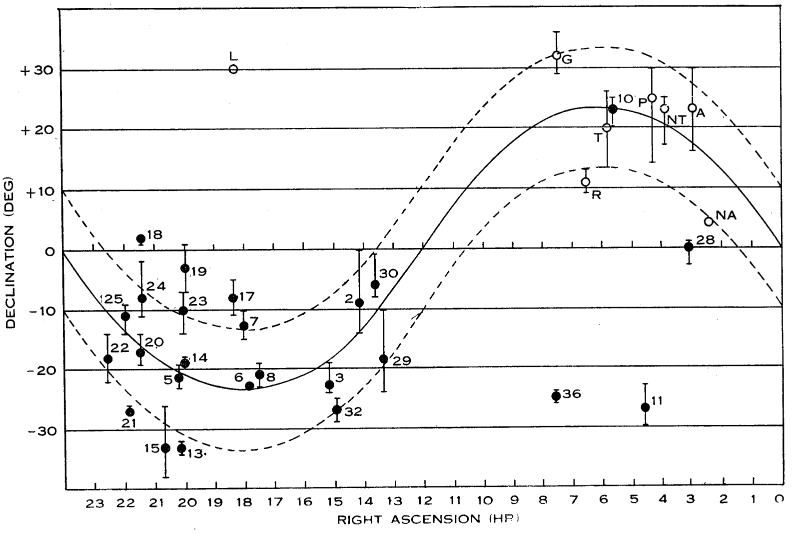

Fig. 5.—Meteor radiants plotted in relation to the plane of the ecliptic. *A*, Arietid; *G*, Geminid; *L*, Lyrid; *NA*, night Arietid; *NT*, night Taurid; *P*, ζ-Perseid; *R*, Orionid; *T*, β-Taurid.

excepting grade D showers of Table 2. Three northern hemisphere showers, namely the Ursids, Quadrantids, and Perseids, have not been shown on Figure 5 as they are of very high northern declination. The present radar apparatus as mentioned earlier, is not suitable for the detection of high southern radiants so similar high declination southern showers may yet be found to exist. It is clearly apparent, however, from Figure 5, that a high proportion of the major meteor shower radiants lie close to the plane of the ecliptic.

VI. Acknowledgments

This paper, covering the results of an initial survey of southern hemisphere meteor activity, is part of a programme of radar-meteor observations which has been made possible by grants received from the Nuffield Foundation, the University of New Zealand, and the New Zealand Department of Scientific and Industrial Research.

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