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ANALYSIS OF AURORAL OBSERVATIONS, HALLEY BAY, 1960

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ABSTRACT

THE programme of visual and photographic observations carried out is described, and an analysis of the visual observations in terms of all aurorae and of the individual forms is presented. Particular emphasis is placed on the frequency of occurrence and the positions of quiet arcs. The significance of the various colours and movements observed in the displays is discussed. The pattern of events in displays of varying magnitude and duration is considered and illustrated by detailed descriptions of some typical displays. These are accompanied by reproductions of the relevant magnetograms and series of prints from the all-sky camera films. Descriptions are also given of a number of displays which differed radically from the normal pattern.

A comparison with the data from the years 1956–59 shows that the decrease in auroral activity from the 1957–58 peak, and the accompanying northward movement of the quiet-arc zone, continued during 1960.

CONTENTS

I. INTRODUCTION

1. The Aurora Australis

Auroral observations were made by most of the explorers who ventured into Antarctic waters in the late eighteenth and nineteenth centuries, and by all of the scientific expeditions which wintered on the continent during the early part of the present century. This small volume of data, although obtained in comparatively few localities and widely scattered in time, provided the basis for an estimate of the position of the southern auroral zone by White and Geddes in 1939, and also for the isochasms proposed by Vestine and Snyder in 1945. However, it was not until the International Geophysical Year (I.G.Y.), 1957–58, which coincided with the period of maximum solar activity, that a detailed investigation of the exact position and movements of the zone was made.

A comparison of the descriptions of Antarctic displays, such as those of Wright (1921), with those seen close to the northern auroral zone, established that the forms occurring in the two hemispheres were similar. More recently, comparisons of displays in the two hemispheres, such as that of Little and Shrum (1950), indicated that a definite correlation exists between them, but lack of comprehensive observations from the Antarctic severely limited the development of detailed theory. During the International Geophysical Year, therefore, a large number of the bases established in the Antarctic undertook to carry out programmes of auroral observations. The observation times were standardized at each quarter-hour of Universal Time (U.T.), and at many bases the visual observations were supplemented by all-sky camera photography. The numerous papers now being published on this work suggest that the aurora australis is an even more complex phenomenon than had hitherto been suspected. It is hoped, however, that the collation of these data will eventually produce a clearer picture of the position and movements of the southern auroral zone during the period of maximum solar activity.

2. The Halley Bay Observatory

The Halley Bay Geophysical Observatory was established by the Royal Society in Coats Land for the duration of the I.G.Y. Descriptions of the observatory and of the scientific programme carried out there are given in the introductions to the report on the expedition, edited by Sir David Brunt and published by the Royal Society in 1960. At the close of the I.G.Y., the Falkland Islands Dependencies Survey* agreed to maintain the observatory and to continue the scientific programme. It was considered desirable to continue the auroral observations at as many Antarctic stations as possible, at least until the minimum of solar activity in the present cycle, so that information on the changes occurring in the position of the auroral zone and in the nature of the displays could be obtained. In this report the observations made at Halley Bay during 1960 are analysed and the results compared with those from the previous four years.

As an auroral observatory, Halley Bay lies in a very interesting position (Fig. 1). It is at lat. 75°31′S., long. 26°39′W. in geographical co-ordinates and 65·9°S., 25·4°E. in geomagnetic co-ordinates, in one of the few accessible locations lying just to the north of the auroral zone. Since it is so far south geographically in relation to its geomagnetic position, displays can be observed for much longer periods in each day during the winter months than would otherwise be possible, and as it is close to the auroral zone the forms occurring there can be observed under quiet conditions. The most frequent of these forms, the homogeneous arc (HA), normally appears between 5° and 20° elevation above the southern horizon so that its frequency of occurrence, position and brightness can be studied in detail.

When large geomagnetic disturbances and the associated bright active displays occur the auroral zone expands equatorwards, but it is only during exceptional storms that the display observed from Halley Bay extends beyond the northern horizon. This is because the lower limit of the forms occurring even in the most active displays is rarely below 100 km., and the field of view of this level of the atmosphere from Halley Bay extends from 76° to 56°S. in geomagnetic latitude. Another advantage of the situation of Halley Bay is that it lies on a flat ice shelf which allows an uninterrupted view in all directions.

Magnetically its position is unusual. The influence of the South African and South American anomalies causes the local magnetic field to differ considerably from that of the dipole field. The inclination of the field is 65°, which is the dipole field value of the inclination at a geomagnetic latitude of 47° rather than

* Since re-named the British Antarctic Survey.

65·9°. The direction of the horizontal component of the local field is 178·5° east of true north, while that of the dipole field, i.e. geomagnetic south, is 160·8°, a difference of about 18°.

The position of the station also has a number of disadvantages. Among these is the scarcity of homogeneous arcs occurring overhead, where they are most interesting magnetically, and the fact that poleward movements of the arcs cannot be measured very accurately. Also, observations of the aurora

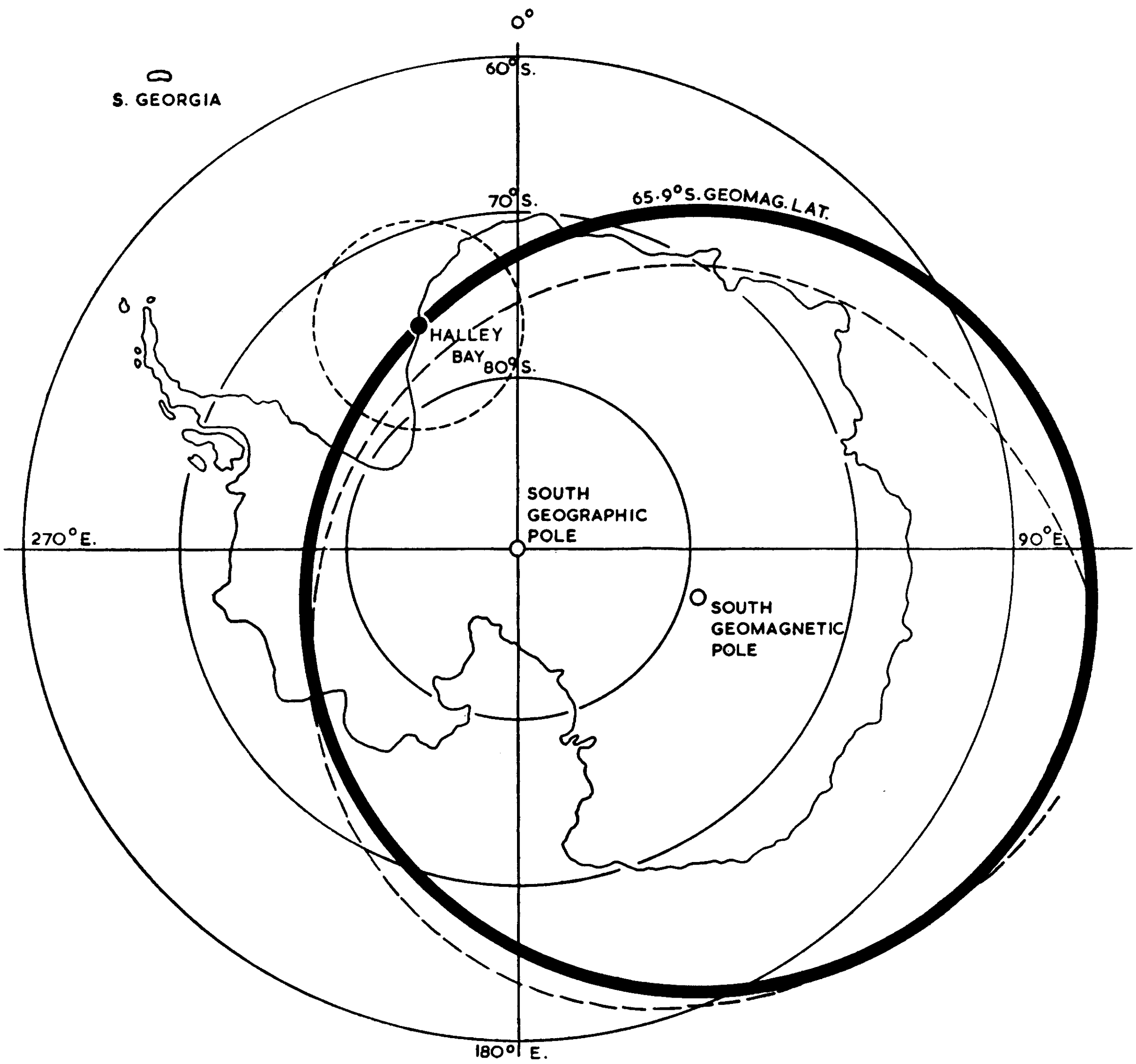

FIGURE 1

— — — — Proposed zone of maximum auroral frequency (Vestine and Snyder, 1945).
- - - - - - Approximate field of view of 100 km. level at 5° elevation from Halley Bay.

are limited to periods of darkness, which at Halley Bay extend over little more than six months of the year.

The greatest disadvantage, however, is the adverse weather, especially the presence of cloud, which invariably interrupts observations so that the visual records are never complete. In addition, the station is situated on snow, and high thick drift occurs whenever the wind speed exceeds the critical value determined by the condition of the surface snow; this is generally about 30 kt. (15·4 m./sec.). Of the 200 nights, from 15 March to 1 October, when observations were made during 1960, the sky was completely obscured by cloud or drift or both on no fewer than 78. On a further 81 nights it was partially or completely obscured for part of the night.

3. Methods of Observation and Equipment Used

The programme of observations carried out at Halley Bay in 1960 was essentially the same as that in 1956, 1957, 1958 (Evans and Thomas, 1960) and 1959 (Sheret, 1960). It consisted of visual observations supplemented by all-sky camera photography.

a. *Visual observations*

Visual observations were made exactly on each quarter-hour of Universal Time during each night, irrespective of meteorological conditions, but were more frequent during active displays.

During the I.G.Y., observations were made from the loft of the hut through a hatch in the roof, but the hut eventually became buried under snow and a shaft composed of staggered 2-ft. box sections was erected from the hatch so that the upper end remained just above the snow surface. By the end of the 1960 season this shaft extended 14 ft. upwards from the original hatch. It acted as a vent for the warm air from the hut and provided a certain amount of warmth for the observer, but the accumulation of drift-snow in the top section, or the rapid build-up of frost deposits during cold spells, made it almost impossible to take notes in this position. Frequent descents to the loft were therefore necessary, and resulted in a certain amount of discontinuity in observation during active displays.

The equipment used consisted of an elevation-azimuth indicator, a hand alidade and a pair of interference filters. The elevation-azimuth indicator was made up from a Meteorological Office alidade,* fitted with a small heater to prevent frost deposition, and an azimuth plate. It was attached to the top section of the shaft at the beginning of each observation period and levelled by means of a sensitive spirit bubble; the azimuth plate was orientated against a number of land-marks, the bearings of which were accurately determined with a prismatic compass. In this way, elevation and azimuth of auroral features could be determined to an accuracy of less than 1°. This indicator was used mainly for forms in the southern sky; a hand alidade was used for those in the north.

Interference filters, composed of Fabry-Perot type plates set to detect the 5577Å "auroral" green line of the monatomic oxygen spectrum, were used to identify weak aurorae. For convenience these were mounted in a pair of goggles.

All outside lights were switched off at each observation and a small "wanderlight", which could be rheostatically adjusted so that it did not disturb the observer's dark-adaptation, was used to read the elevation-azimuth indicator.

At each observation notes were made on the cloud conditions, the presence of moonlight and the presence or absence of the aurora. If the sky was obscured, the interference filters were used and the presence or absence of an interference ring ("i-ring") was noted. If the sky was clear and a display was observed, the forms and brightness were recorded in accordance with the codes in the *Photographic Atlas of Auroral Forms* (1951). In addition, the colour of the display, its upper and lower elevations, azimuth bearings and directions of motion (where relevant) were noted together with a description of any unusual features. If the sky was clear and no display was visible, the interference filters were again used to detect the possible presence of a very weak display.

b. *Photographic observations*

The all-sky camera used at Halley Bay was of the Alaskan type. A detailed description of its construction has been given elsewhere (Evans and Thomas, 1960; Sheret, 1962) and the main features are illustrated in Fig. 2.

The camera, a Paillard Bolex H16 16-mm. cine camera with Switor f/1·4 50-mm. lens, is housed in the upper box. It is focussed vertically downwards on the image of the sky formed by the convex hemispherical mirror. This mirror rests on the lid of the control box in which is housed the control system. The box also contains a date-wheel and a watch which are visible to the camera through perspex windows in the lid. Thermostatically controlled heaters are installed in both the camera box and the control box.

The camera is set to operate as a single shot time-lapse device. The shutter is operated by a solenoid attached to the camera. A synchronous motor in the control box activates a micro-switch which controls the current to the solenoid and also a second micro-switch which causes small neon lights to illuminate the watch and date-wheel on every fourth frame (Plate I).

* As used for cloud-searchlight work.

An alternate short- and long-exposure sequence was used throughout 1960. This provided details of bright active forms on the short exposures while still recording very weak displays on the long exposures. The sequence was as follows:

FRAME 1 — 27-sec. exposure; date and time recorded
3-sec. delay
FRAME 2 — 3-sec. exposure
3-sec. delay
FRAME 3 — 27-sec. exposure
3-sec. delay
FRAME 4 — 3-sec. exposure
3-sec. delay
FRAME 5 — 27-sec. exposure; date and time recorded

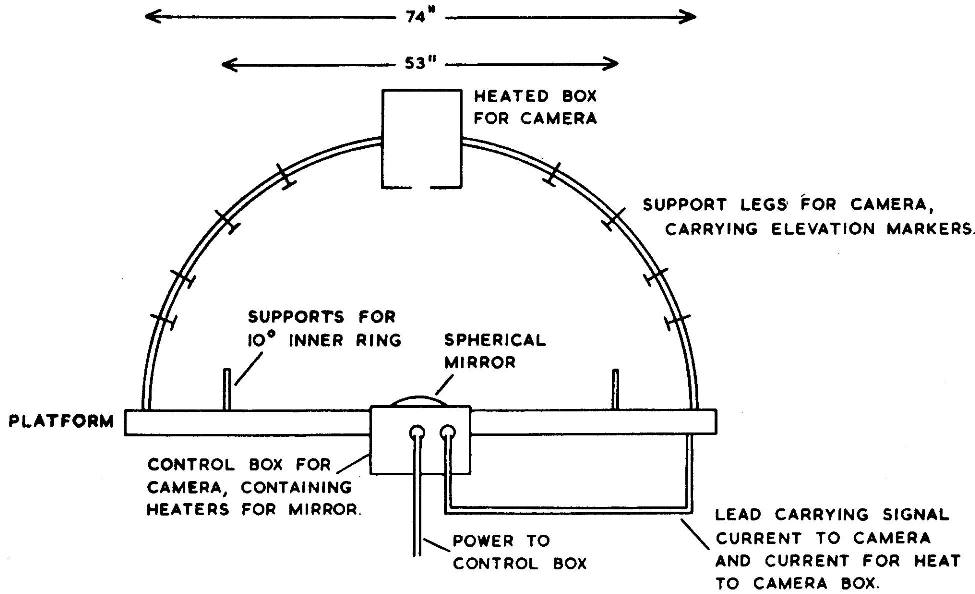

FIGURE 2

Diagram of the all-sky camera system which is mounted at the top of a tower.

The two pairs of support legs for the camera box act as azimuth markers and are orientated along and at right angles to the local magnetic meridian within 1° (2°±0·5° west of true north). A 10° elevation marker ring extends from west through south to north. The supports for this provide further azimuth markers at 30° intervals. Elevation marker bars are attached to the north and south support legs at 20°, 30°, 45° and 60°.

The whole unit is mounted on a Dexion tower about 8 ft. (2·4 m.) above the snow surface, 250 yd. (229 m.) north-east of the observation point from which it can be switched on and off as required.

The optics of the system result in the part of the sky below 10° elevation being greatly compressed in the image. Consequently, the camera was operated only when a display was present above 10° elevation on clear nights.

Only minor faults appeared in the control system during the season, but a considerable amount of running time was lost because of a persistent tendency of the film transport system in the camera to drift out of synchronization with the shutter, which resulted in a blurred image. Details of the amount of useful film obtained and of the developing procedure are given in the Appendix, together with a brief survey of the relative merits of the short- and long-exposure times.

II. ANALYSIS OF THE VISUAL OBSERVATIONS

In attempting a statistical analysis of the visual observations made at Halley Bay, a number of difficulties are encountered. The most important of these has already been mentioned, namely the frequent occurrence of cloud and other obscuring factors which severely limit the number of observations. The data available are thus effectively a random sample rather than a complete set, and a correspondingly greater degree of uncertainty is attached to the results. Another difficulty is the variation of the period of darkness and hence of the daily number of observations throughout the season. Taking the end of nautical twilight as a criterion of darkness, the variation was from half an hour on 15/16 March to nineteen hours at mid-winter to half an hour on 29/30 September. Thus, in deriving diurnal frequency curves, the results obtained for the period around local midnight (0146 U.T.) will be much more significant statistically than those for the evening and morning periods.

1. Distribution of Observations

The programme of routine quarter-hourly observations commenced on the 15/16 March and was continued until 1 October. An irregular watch had been kept from 1 March during twilight hours but nothing was seen until the night of 15 March. Ideally, the quarter-hourly observations should have been maintained throughout the daily period of darkness, but as there was only one observer this was not possible during the darkest period. The results from previous years had shown that displays rarely commenced before 1900–2000 U.T. but tended to linger on until 1000 U.T. or later in the morning. It was therefore decided that during the darkest period a watch would be kept from 2000 U.T. to 1000 U.T. When a display extended beyond this period the watch was extended accordingly.

The following analysis is based on the period from 15 March to 30 September, during which the sun was 12° below the horizon for some part of each day. In this total of 199 nights, the sky was completely clear and dark all night on 27 occasions, completely clear but moonlit on 14 occasions and either partially or completely obscured for part of the night on 80 occasions. On the remaining 78 occasions it was completely obscured.

The unit of time used in the analysis was the quarter-hour of U.T., i.e. from the exact hour U.T. to the end of the fifteenth minute, thence to the end of the thirtieth minute and so on.

The numbers of quarter-hours which were used for deriving diurnal frequencies of occurrence are given in Table I. In this table the period 2000–2100 U.T., for example, refers to observations at 2015, 2030, 2045 and 2100 U.T. Thus, in any one hour on any night, the maximum number of observations is four.

Dark periods are defined as those in which the sun is more than 12° below the horizon. Moonlit periods are those in which the moon is above the horizon and between the first and last quarters.

Table I

DISTRIBUTION OF OBSERVATIONS

Period (hr. U.T.)		16	17	18	19	20	21	22	23	24	01	02	03	04	05	06	07	08	09	10	11	1200
a						36	103	113	124	136	125	126	112	103	96	94	86	64	32			
b				1	4	55	154	172	178	191	189	192	169	166	165	160	140	116	56	1		
c		48	230	351	458	540	621	688	742	776	788	782	764	720	656	582	495	400	295	147	6	

a. Number of clear dark periods (quarter-hours) when there was no moonlight.

b. Number of clear dark periods plus the number of clear, moonlit periods when the moonlight did not obscure the aurora.

c. Total number of dark periods, clear or obscured, with or without moonlight.

2. Seasonal Variations of the Aurora

In view of the difficulties already discussed, it was not possible to obtain a clear-cut picture of the seasonal frequency of occurrence of displays.

Of the 199 nights when it was dark for at least part of the night, aurorae were seen on 93 nights and their presence detected with the interference filters on a further 64. Displays were detected overhead, i.e. above 60° elevation on the geomagnetic meridian, on 38 nights. Thus, from mid-March until the end of September 1960 aurorae were present on 79 per cent of the nights and were in the overhead position at some time on 19 per cent. It must be emphasized that these figures represent minimum values of the seasonal frequencies.

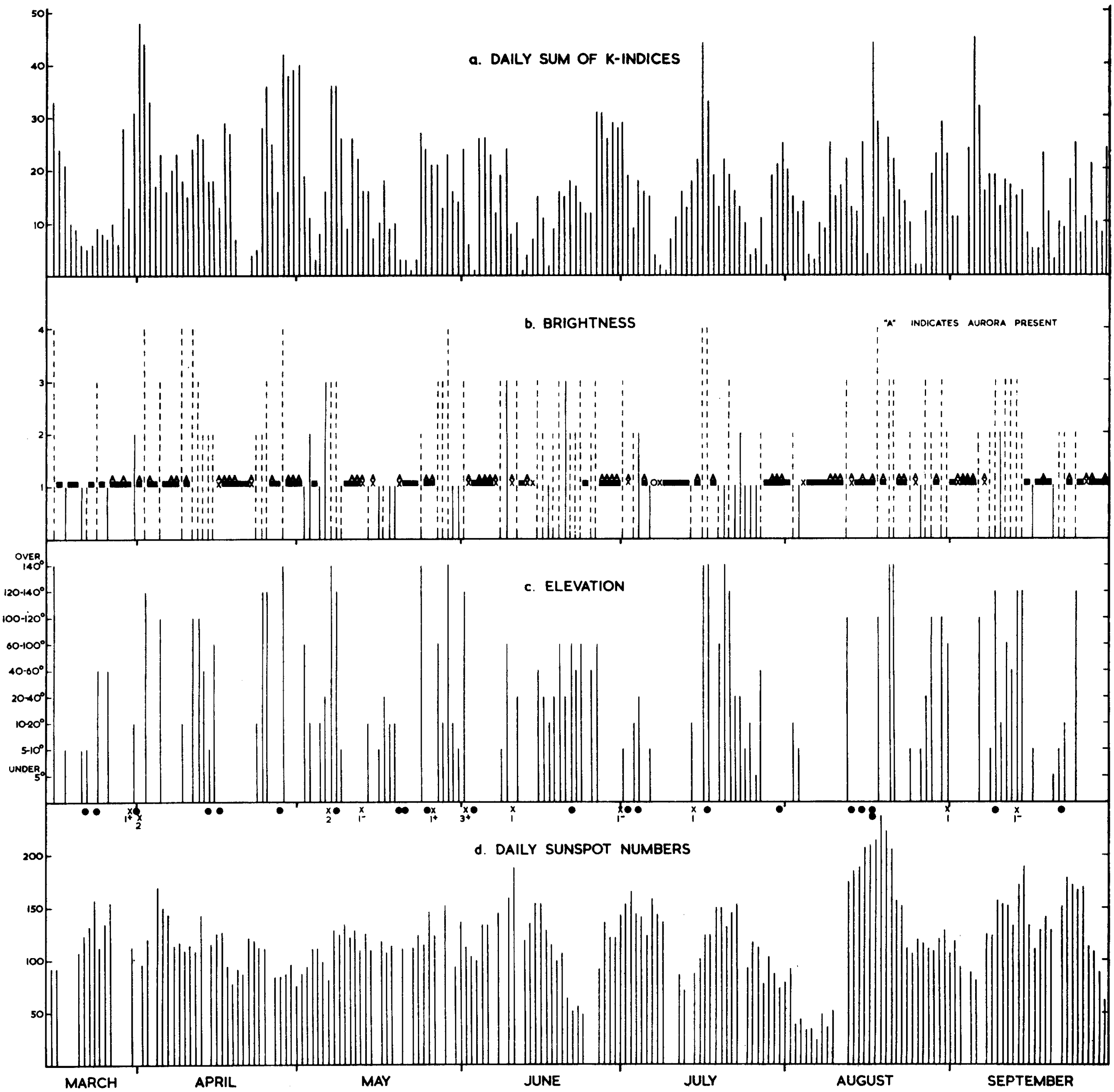

FIGURE 3

Summary of the distribution of aurorae and of geomagnetic and solar activity over the period 15 March to 30 September 1960.

A summary of the seasonal variations is given in Figs. 3b and c. Each division of the abscissae in Fig. 3 denotes 24 hours measured from 1200 U.T. on one day to 1200 U.T. on the following day.

In Fig. 3b the ordinates represent the maximum brightness attained on each night when forms were visible, using the internationally accepted scale of 1–4 defined in the *Photographic Atlas of Auroral Forms*. Broken ordinates indicate the presence of active forms such as rayed arcs (RA), rayed bands (RB), drapery (D), homogeneous bands (HB), and solid ones indicate the presence of quiet forms only. On the nights when no forms were visible the symbols o, x, ■, are used to denote sky clear, sky partially obscured, and sky obscured. The presence of aurorae detected with the interference filters is noted.

In Fig. 3c the ordinates denote the maximum northerly extent in elevation above the southern geomagnetic horizon attained by the forms present. Figs. 3b and c together give an approximate idea of the type and extent of the display occurring on each night. Fig. 3a summarizes the geomagnetic activity on each day as recorded at Halley Bay. The ordinates represent the sum of the 3-hourly *K*-indices from 1200 U.T. to 1200 U.T. on the following day.

In Fig. 3d the ordinates represent the daily sunspot numbers as recorded at Greenwich. Solar flares are denoted by the symbol X above the ordinates, and the numbers indicate their relative importance. The central meridian passage of sunspots larger than 500 millionths of the visible hemisphere are denoted thus, ●. These data were obtained from Royal Greenwich Observatory Circulars Nos. 55, 58, 60, 62, 65, 67 and 69.

From Fig. 3 it appears that no marked seasonal variation occurs over that part of the year covered by the observations. The largest displays, i.e. those reaching brightness 4 and extending beyond 140° elevation, occurred in March, April, May, July and August, and were generally associated with considerable solar activity and magnetic disturbance. No large displays were seen during the darkest period from early June to mid-July and the magnetic and solar data suggest that none occurred during this period.

3. Diurnal Frequency of Occurrence of the Aurora

Observations covered the period 15 March to 29 September 1960, and are therefore of greater value in analysing diurnal variations than seasonal ones. Table II, which gives the diurnal analysis, uses Table I and assumes a random distribution of cloud, drift and other obscuring factors. It is subject to the limitations listed on p. 4 and there is a considerable degree of uncertainty in the results.

TABLE II

DIURNAL FREQUENCY OF AURORAE

Period (hr. U.T.)	18–19	19–20	20–21	21–22	22–23	23–24	24–01	01–02	02–03	03–04	04–05	05–06	06–07	07–08	08–09	09–10	10–1100
a	1	4	47	132	187	266	355	409	433	436	406	339	244	183	124	56	4
b	0·3	0·9	8·7	21·2	27·2	35·8	45·6	52·0	55·4	57·1	56·4	51·6	41·9	37·0	31·0	19·0	2·7
c			15	37	51	85	102	102	108	101	93	79	66	53	28	10	
d			41·6	36·0	45·1	68·5	75·0	81·5	85·7	90·3	90·4	82·2	70·2	61·6	43·7	31·3	
e			2	4	5	11	13	24	26	20	22	10	10	8	1	0	
f			5·5	3·9	4·4	8·9	9·5	19·2	20·6	17·8	21·4	10·4	10·6	9·3	1·6	0	

a. Total number of quarter-hour periods in which aurorae were detected visually or with interference filters.
b. Percentage frequency of aurorae (using Table I, line *c*).
c. Number of clear dark periods in which aurorae were present.
d. Percentage frequency of aurorae in clear dark periods (using Table I, line *a*).
e. Number of clear dark periods in which aurorae occurred between 60° and 120° above the southern geomagnetic horizon.
f. Percentage frequency in clear dark periods of aurorae between 60° and 120° above the southern geomagnetic horizon (using Table I, line *a*).

Table II, line *b* is illustrated graphically in Fig. 4a, and Table II, lines *d* and *f* in Figs. 5a and b. In these figures, and in all such subsequent figures, the letters "L" and "G" on the horizontal axis indicate the mean times of local and geomagnetic midnights.

Figs. 4a and 5a show a fairly close similarity. Both indicate a maximum frequency of occurrence of aurorae between 0300 U.T. and 0500 U.T. Fig. 5a also indicates a minimum frequency of occurrence between 2100 U.T. and 2200 U.T., but as the data for this period are so meagre it is difficult to say whether this is a true minimum. The maximum frequency of occurrence of overhead aurorae is much less sharply defined. Fig. 5b shows a broad maximum extending from 0100 to 0500 U.T. and there is a suggestion that this maximum is a post-midnight feature.

Figs. 4b, c, d and e show the frequency distributions of various auroral forms, which are discussed in later sections. It should be pointed out, however, that Fig. 4a includes not only these forms but also the aurorae detected when the sky was obscured.

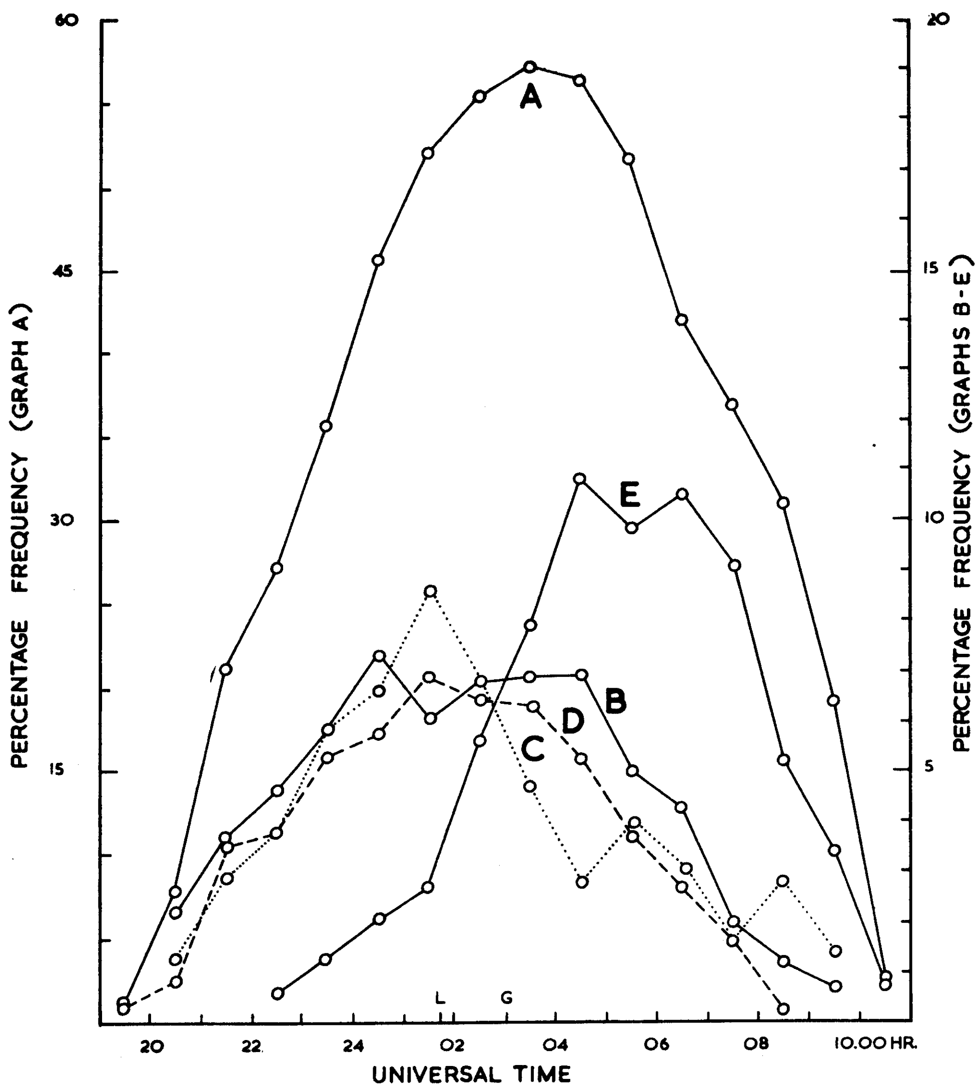

FIGURE 4

Percentage frequency of occurrence of aurorae when the sun was below —12° elevation.

A. All aurorae
B. Arcs
C. Glows
D. Active forms
G. Geomagnetic midnight
L. Local midnight

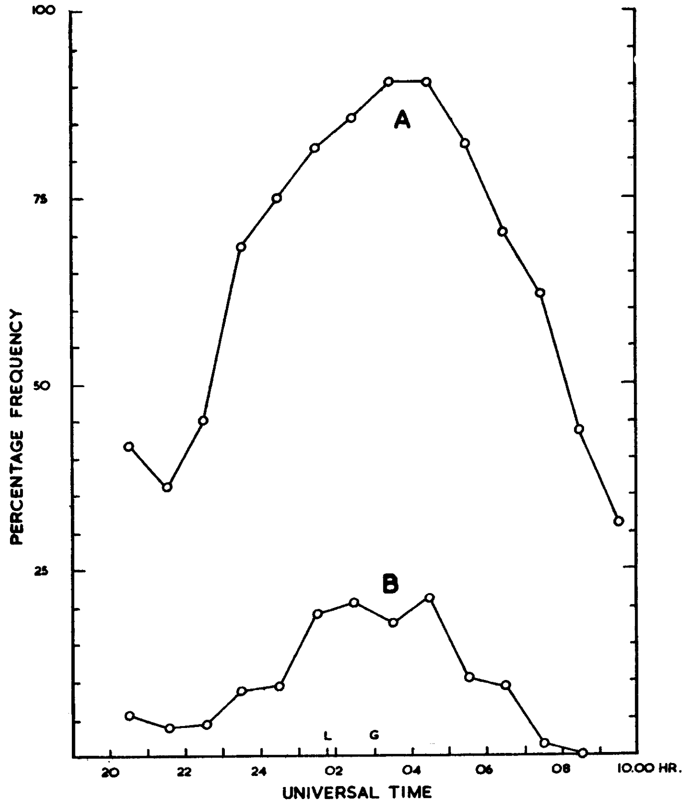

FIGURE 5

A. Percentage frequency of aurorae under clear dark conditions.
B. Percentage frequency of aurorae under clear dark conditions, between 60° and 120° above the southern geomagnetic horizon.
G. Geomagnetic midnight
L. Local midnight

4. Auroral Forms used in the Analysis

In the *Photographic Atlas of Auroral Forms* eleven distinct forms are described. They are grouped under two headings, namely, those with ray structure and those without. Under the former are the rayed arc (RA), the rayed band (RB), drapery (D), rays (R) and coronae (C). The latter comprise the homogeneous arc (HA), the pulsating arc (PA), diffuse surfaces (DS), pulsating surfaces (PS) and glows (G). Of these forms, the pulsating arc and pulsating surfaces were not detected at Halley Bay during 1960. All the other forms were seen and recorded on the report sheets.

For the purposes of analysis, however, it was felt that the above distinctions and groupings of the forms were unsuitable. Instead, the forms are considered under three groups, namely, quiet forms, active forms and diffuse surfaces. Those considered as quiet forms are the homogeneous arc and the glow. In the second group are the rayed arc, the rayed band, drapery, isolated sharp rays and the homogeneous band. The term "diffuse surfaces", covering the third group, is here taken to include the form so described in the *Photographic Atlas of Auroral Forms* and also that form in which numerous short-lived very diffuse rays intermingle with an indeterminate patchwork of auroral light. This latter variation of the form was frequently observed in displays at Halley Bay. Since a coronal effect is seen when any of the rayed forms in the second group or the variation in the third group pass through the magnetic zenith, the corona is not considered to be a separate form.

5. Quiet Forms

a. *The homogeneous arc*

The homogeneous arc or quiet arc is the easiest auroral form to study in detail because of its simple shape and its comparative stability. Many thousands of observations, made mostly in the Northern

Hemisphere by the method of parallactic photography developed by Störmer (1955), have shown that the lower border of this form tends to be of a uniform height, very close to 100 km., throughout its length. This fact is now so well established that it is generally assumed in observations on the arcs. Thus, by determining the elevation of an arc above the horizon and the azimuth-bearing of the highest point of its lower border, its position in space can be calculated.

b. *Latitude distribution*

The positions of arcs observed from Halley Bay in 1956, 1957 and 1958 were found to be concentrated in a narrow belt of geomagnetic latitude. The interquartile range of this distribution was about 2°. This prompted Evans and Thomas (1960) to suggest that the position of the auroral zone under quiet conditions could be more accurately described by defining a "quiet-arc zone", the width of the zone being determined by the interquartile range of the position distribution of the quiet arcs.

Table III gives the numbers of quarter-hourly observations of quiet arcs on clear dark periods in each hour of U.T. in each degree of geomagnetic latitude, Φ, made during 1960. The simultaneous occurrence of two arcs is listed as two separate occurrences. The numbers occurring in each degree of latitude are shown in histogram form in Fig. 6. Of all the arcs observed under clear dark conditions, 28 per cent occurred between geomagnetic latitudes 70° and 71° and 63 per cent between 69° and 71°. The median latitude and interquartile range of the distribution was

$$\Phi = 70{\cdot}3° \pm 1{\cdot}2°.$$

The median latitudes of arcs occurring in each hour of U.T. are illustrated in Fig. 7. Though the spread in those latitudes is small, little more than 2°, it does show a tendency for the arcs to move equatorwards

TABLE III

NUMBERS OF QUIET ARCS* AND THEIR HOURLY VARIATION IN ELEVATION

Elevation (degrees)	*Period* (hr. U.T.) 19	20	21	22	23	24	01	02	03	04	05	06	07	08	09	10 11	*Totals*	Φ (degrees)
1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	75
2	—	—	1	—	—	—	—	—	—	—	—	—	1	—	—	—	2	74
3	—	—	—	1	6	2	2	—	1	1	—	—	—	—	—	—	13	73
4–5	—	2	4	2	8	5	5	7	5	3	4	3	3	1	—	—	52	72
6–7	—	—	1	5	8	5	6	7	1	6	5	7	3	—	—	—	54	71
8–10	—	3	4	6	8	12	7	9	15	6	6	7	2	—	—	—	85	70
11–15	—	2	1	2	2	8	7	4	11	11	1	1	—	2	2	—	54	69
16–23	—	—	—	2	—	6	7	4	3	9	2	2	—	—	—	—	35	68
24–40	—	—	—	—	—	—	1	—	1	2	2	—	—	—	—	—	6	67
41–90	—	—	—	—	—	—	1	2	—	—	—	—	—	—	—	—	3	66
91–140	—	—	—	—	—	3	—	—	—	—	—	—	—	—	—	—	3	65
141–157	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	64
Totals†	—	7	11	18	32	41	36	33	37	37	21	20	9	3	2	—	307	
Median latitudes (degrees south)	—	70·0	71·3	70·6	71·3	70·0	69·9	70·5	69·9	69·4	70·3	70·8	71·6	69·2	69·4			

* Those occurring in clear dark quarter-hour periods only.
† Used in Table V, line *a*.

during the hours from 2400 U.T. to 0500 U.T. with a minimum latitude between 0400 and 0500 U.T. The low latitudes indicated from 0800 to 1000 U.T. are almost entirely due to the transformation of DS to arcs as they recede polewards after large displays.

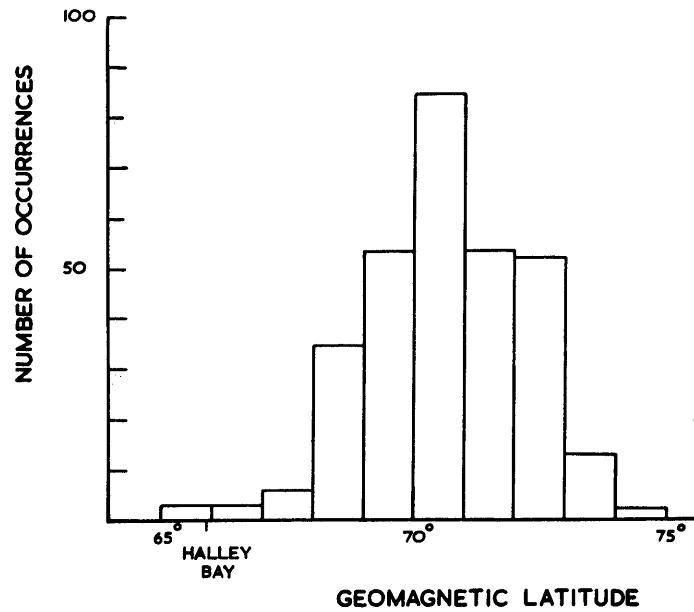

FIGURE 6

Number of occurrences of quiet arcs in each degree of latitude.

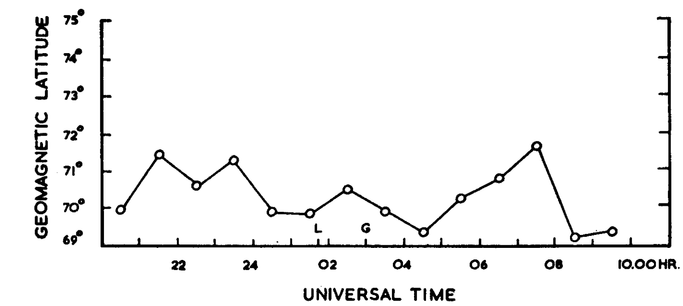

FIGURE 7

Hourly median latitudes of quiet arcs.
G. Geomagnetic midnight
L. Local midnight

c. *Distribution of centre bearings*

The centre bearings of quiet arcs were measured to the nearest degree east of magnetic north. Bearings of arcs occurring in clear dark periods have been converted to degrees east of true north (declination 1·5°W.) and are given in Table IV. The number in each 5° sector and the mean bearing and standard deviation in each hour of U.T. were calculated as shown, and they are illustrated in Figs. 8 and 9 respectively.

In Fig. 8, "g" and "l" indicate geomagnetic and local magnetic south, and show that the centre bearings were grouped closely around geomagnetic south. The centre bearing invariably coincided with the bearing of the highest point, which suggests that the centre of the quiet-arc zone lies close to the geomagnetic axis point. Consequently, it is probable that under quiet conditions the dipole field exerts a stronger influence on the aurora than the theoretically calculated local field at auroral heights which bears a closer resemblance to the surface local field than the dipole approximation.

TABLE IV

BEARINGS OF THE CENTRES OF QUIET ARCS

Bearing (degrees E. of true N.)	Period (hr. U.T.)																	*Totals*
		19	20	21	22	23	24	01	02	03	04	05	06	07	08	09	10 11	
180–185													1					1
175–180												1	1 1					3
170–175								1 1 1	1		2	2 2 1 1	2 1 2 4 1	1				23
165–170				1		1 1 1	1 5	2 2 1 1	2 2 2	3 2 1 3	2 2 3 5 4	1 1 1 2	1 2 2	1 2 2	1			63
160–165			1 1	1 2	3 2	1 2 1 3	1 4 3	2 2 3 5	2 3 4 4 3	1 10 3 4	1 7 4 1	2 3	2	1 2	2	2		98
155–160			4 1	2 4	3 2 2	2 6 3 2	2 16 2 2	4 4 2	2 7 1	3 7	6	1 2						92
150–155					1 3 1 1	5 1	2 1	1 2				1						19
145–150						1 1	2	1										5
Totals			7	10	18	31	41	35	33	37	37	21	20	9	3	2		304
Mean bearing			159·2	160·4	157·7	158·5	159·3	161·9	162·2	162·7	164·6	166·0	171·4	166·6	165·2	163·5		
Standard deviation			±1·7	±2·7	±3·8	±5·0	±4·3	±5·5	±3·6	±3·2	±3·9	±6·3	±4·9	±3·1	±2·3			

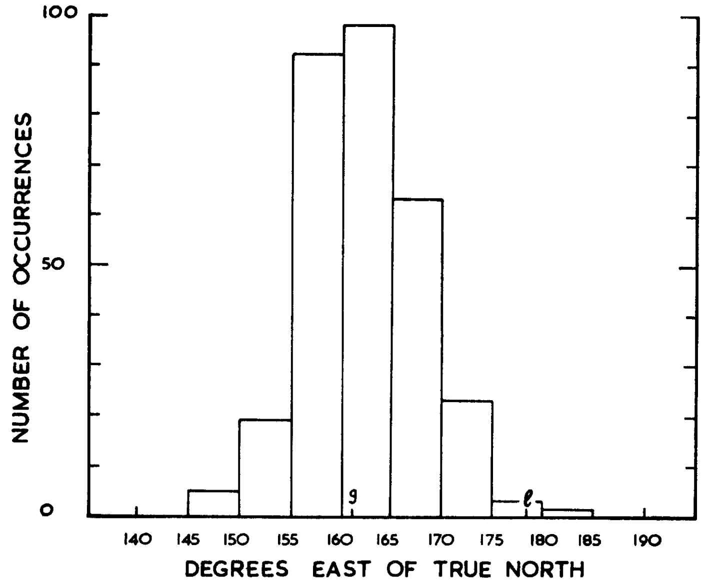

FIGURE 8

Distribution of centre bearings of quiet arcs.
g. Geomagnetic south
l. Local magnetic south

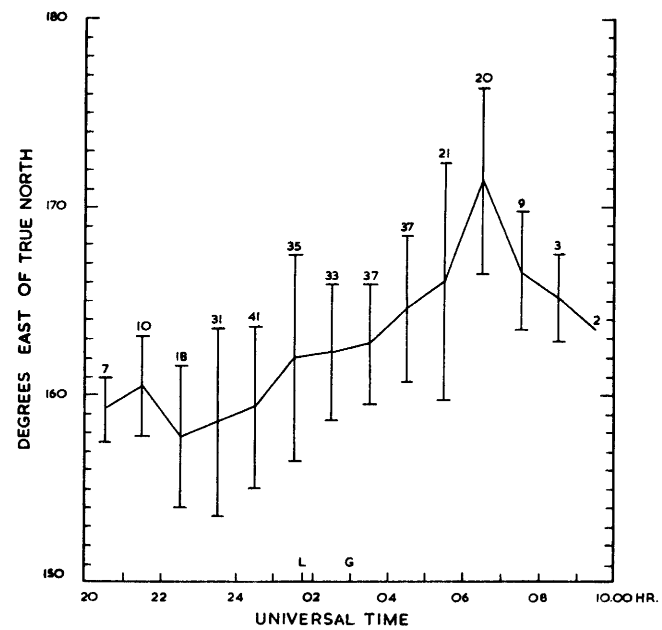

FIGURE 9

Hourly mean centre bearings and standard deviations of quiet arcs. The number of observations used in deriving each mean are given above the relevant point on the graph.
G. Geomagnetic midnight
L. Local midnight

Fig. 9 illustrates the gradual westward drift of the arcs during the course of the night. The most westerly extent was reached between 0600 and 0700 U.T. This westerly drift has been seen from Halley Bay in each year since 1956. Evans and Thomas (1959) proposed an explanation of this movement in terms of a circular quiet-arc zone, eccentric in local time co-ordinates with centre shifted 2° along the local time meridian 0200 hr. On this model the centre bearings of arcs would be 5° east of geomagnetic south at 2200 U.T., due south at 0400 U.T. and 5° west of geomagnetic south at 1000 U.T. Furthermore, the zone would be 2° of latitude closer to Halley Bay at 0400 U.T. than at 2200 U.T. and 1000 U.T. The general trend of the bearings in Fig. 9 is in accord with this prediction though the maximum westerly displacement between 0600 and 0700 U.T. is inconsistent. The median latitudes of the arcs shown in Fig. 7 conform with the model at the 2200 and 0400 U.T. positions, but again the morning positions are not in agreement.

d. *Diurnal frequency*

The diurnal frequency of quiet arcs is given in Table V. Line *b* is illustrated graphically as Fig. 10 and line *d* as Fig. 4b.

Arcs occurred most frequently between 2400 and 0500 U.T., and in Fig. 10 there is a definite peak between 0400 and 0500 U.T. Comparison of Figs. 7 and 10 shows that there is a close correspondence between the frequency of arcs and their displacement equatorwards.

TABLE V

FREQUENCY OF QUIET ARCS

Period (hr. U.T.)	19	20	21	22	23	24	01	02	03	04	05	06	07	08	09	10	1100
a	0	7	11	18	32	41	36	33	37	37	21	20	9	3	2		
b		19·5	10·7	16·0	25·8	30·2	28·8	26·2	33·0	36·9	21·9	21·3	10·5	4·7	6·2		
c	0	12	23	32	43	57	47	53	53	50	33	25	10	5	2		
d		2·2	3·7	1·6	5·8	7·3	6·0	6·8	6·9	6·9	5·0	4·3	2·0	1·2	0·7		

a. Number of clear dark quarter-hour periods in which quiet arcs occurred.
b. Percentage frequency in clear dark periods (using Table I, line *a*).
c. Number of quarter-hour periods in which arcs were detected irrespective of of visibility.
d. Percentage frequency of arcs in all periods (using Table I, line *c*).

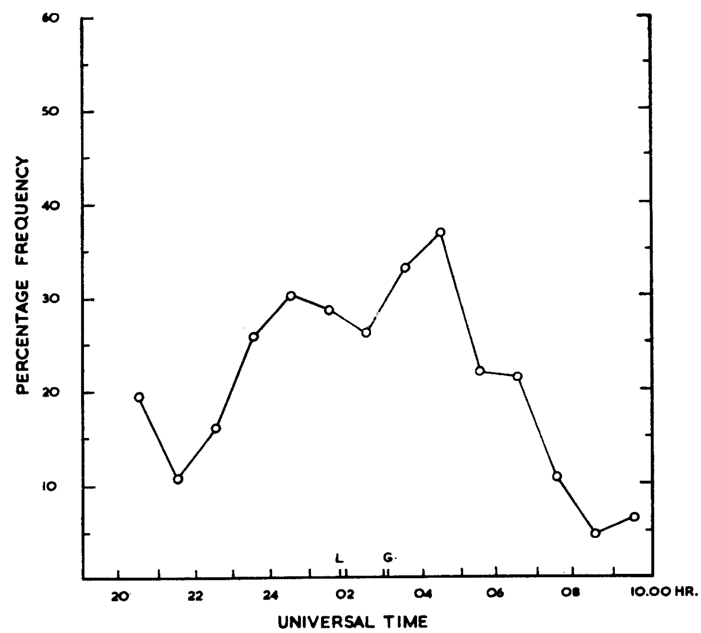

FIGURE 10

Diurnal frequency of occurrence of quiet arcs in clear dark periods.
G. Geomagnetic midnight
L. Local midnight

e. *Glows*

The glow is an auroral form that, until recent years, has received comparatively little attention in descriptive literature and analyses of visual observations. In the *Photographic Atlas of Auroral Forms* (1951) and in Störmer's *The Polar Aurora* (1955) they are described as being the upper parts of arcs whose borders lie below the horizon, and in statistical work they are generally either ignored or included with the arcs.

Detailed observation has convinced the present writer that in the majority of cases it would be wrong to classify the glow as the upper limits of an arc below the horizon. It appeared to have a convex upper limit of its own, although this was ill-defined and varied from 5° to over 50° above the southern horizon. The latter figure alone would appear to confirm that the glow was not the upper limits of an arc but a phenomenon spread over a much wider area. Further evidence is provided by the fact that, although glows and arcs frequently alternated on quiet nights, on no occasion was the lower border of an arc actually seen to rise over the horizon. The strongest evidence, however, was obtained by close observation of the transformation from glow to quiet arc on such nights. It was seen that the arc appeared as an intensification of the glow at various levels of elevation. Thus, the glow may be defined as a lower intensity form covering a much larger area than the strongly localized arc.

The glow seen under quiet conditions was normally just within the range of brightness detectable visually. A similar glow was also frequently present as a background to active forms on disturbed nights. This glow tended to be brighter than the quiet night glow (1+ to 2 as opposed to 1− to 1) and frequently extended far into the northern sky. It is not known whether both of these glows are due to the same mechanism or whether the "active" glow is a secondary effect of the mechanism producing active forms.

Studies by Hatherton and Midwinter (1960) and all-sky camera work with colour film by Sandford (1961) at Scott Base inside the auroral zone (geomagnetic latitude 79·0°S.), have shown that an extensive glow is a fairly common feature of displays observed there. These glows are, however, red in colour and appear to be closely associated with magnetic storms. Though the glows seen at Halley Bay were invariably below the level of visual colour determination, the intensity of the 5577Å line (seen through the interference filters) in relation to their visual brightness suggests that these glows were predominantly green in colour, and they appeared most frequently during magnetically quiet periods. It seems, therefore, that the glows seen from Halley Bay are different in character from those seen inside the auroral zone.

f. *Diurnal frequency of glows*

During the period of observation at Halley Bay in 1960, glows were recorded on a total of 192 occasions during clear dark periods in comparison with 307 arcs under the same conditions. The diurnal distribution and percentage frequencies are given in Table VI, lines *a* and *b*, and illustrated in Fig. 11. Similarly, the distribution and frequencies under all observing conditions are given in Table VI, lines *c* and *d*, and illustrated in Fig. 4. From Fig. 11 it is seen that the glow is essentially a pre-midnight feature of the aurora.

TABLE VI

FREQUENCY OF GLOWS

Period (hr. U.T.)	19	20	21	22	23	24	01	02	03	04	05	06	07	08	09	10	1100
a	0	6	15	21	31	21	28	22	9	10	11	8	3	3	1		
b		16·7	11·6	18·6	25·0	17·7	22·4	17·5	8·0	9·7	11·5	8·5	3·5	4·7	3·1		
c		7	18	20	43	51	68	54	36	20	26	18	8	11	4		
d		1·3	2·9	3·8	5·8	6·6	8·6	6·9	4·7	2·8	4·0	3·1	1·6	2·8	1·4		

a. Number of clear dark quarter-hour periods in which glows occurred.
b. Percentage frequency in clear dark periods (using Table I, line *a*).
c. Number of quarter-hour periods in which glows were detected irrespective of visibility.
d. Percentage frequency of glows in all periods (using Table I, line *c*).

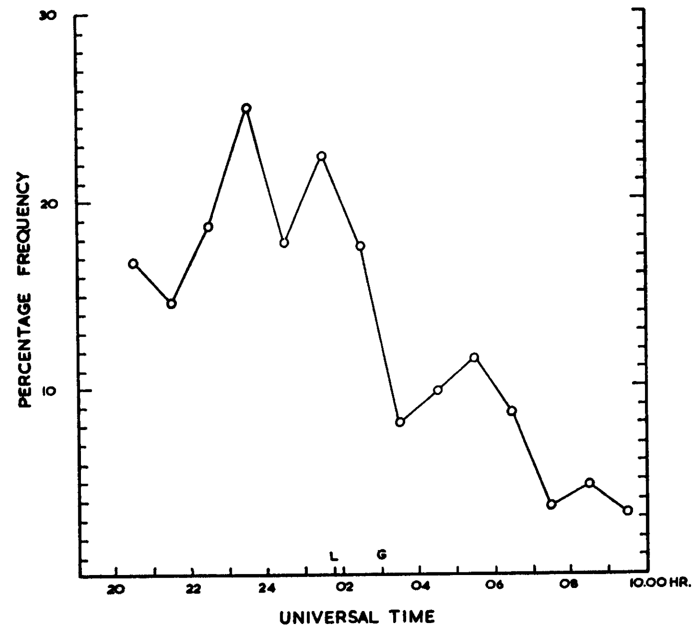

FIGURE 11

Diurnal frequency of occurrence of glows in clear dark periods.
G. Geomagnetic midnight
L. Local midnight

6. ACTIVE FORMS

a. *Description*

Though they are the brightest and most sharply defined, the forms in the second group listed on p. 11 (rayed arc, rayed band, drapery, isolated sharp rays and the homogeneous band) are the most difficult to observe accurately in terms of position. Active forms may be present for periods of several hours during large displays, but the individual forms tend to be short-lived and to undergo rapid changes in position, shape and brightness. Parallactic photography by Störmer (1955) and others has shown that the lower borders of these forms occur over a wide range of heights from 80 to 300 km. Thus, no assumptions about their heights can be made and consequently their positions in space cannot be determined from single station observations.

TABLE VII

FREQUENCY OF ACTIVE FORMS

Period (hr. U.T.)		19	20	21	22	23	24	01	02	03	04	05	06	07	08	09	10	1100
a		2	11	14	16	25	31	41	35	37	21	7	9	8	1			
b			7·3	9·1	9·3	14·1	16·2	21·8	18·2	21·9	12·7	4·2	5·6	5·7	0·9			
c		2	5	22	26	39	44	54	50	48	38	24	16	8	4			
d		0·4	0·9	3·5	3·8	5·3	5·7	6·9	6·4	6·3	5·3	3·7	2·7	1·6	0·25			

a. Number of clear dark and clear moonlit periods (quarter-hours) in which active forms were present.
b. Percentage frequency of active forms in clear dark and clear moonlit periods (using Table I, line *b*).
c. Number of periods, irrespective of visibility or presence or absence of moonlight, in which active forms were present.
d. Percentage frequency of active forms (using Table I, line *c*).

b. *Diurnal frequency*

The number of quarter-hours during clear dark and clear moonlit periods and the number of quarter-hours under all weather conditions during which active forms were present, are given in Table VII, lines *a* and *c*, respectively. The corresponding percentage frequencies are given in lines *b* and *d*. Line *b* is presented graphically in Fig. 12, and line *d* in Fig. 4d. These figures show that the probability of

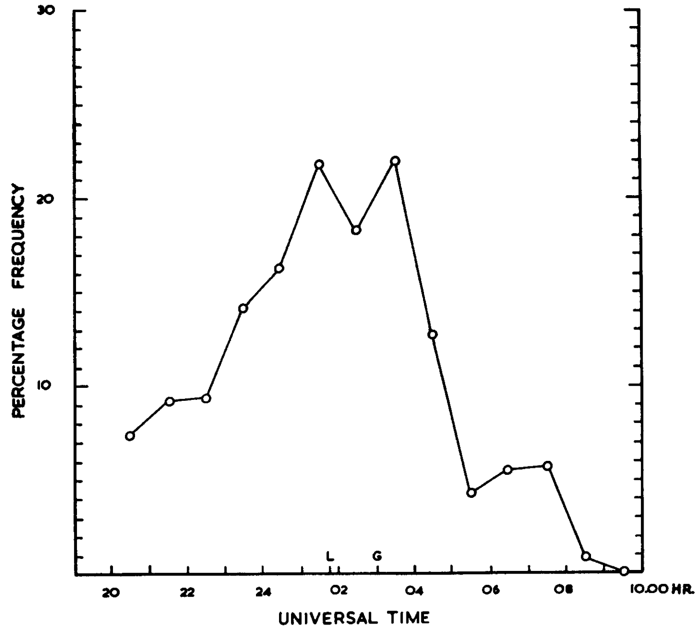

FIGURE 12

Frequency of occurrence of active forms during clear dark and clear moonlit periods.
G. Geomagnetic midnight
L. Local midnight

occurrence was greatest between 0100 and 0400 U.T., i.e. in the period including both local and geomagnetic midnights.

Clear moonlit nights are included in this part of the analysis as active forms are much brighter than quiet forms and can be distinguished easily even in bright moonlight.

c. *Elevation and brightness*

The mean elevations above the southern geomagnetic horizon of the upper and lower limits of active forms occurring in each hour U.T. during clear dark and clear moonlit periods are shown graphically in Fig. 13. The numbers of observations used in deriving the means are given above each point. Fig. 14 gives the mean brightness of active forms in each hour of U.T. under the same conditions.

Figs. 13 and 14 show that maximum brightness and northerly extent are reached between 2100 and 2300 U.T. Bright extensive displays therefore occurred most frequently in the early evening when the transition to active forms took place. The upward trend of Fig. 14 and the upper curve in Fig. 13 in the morning hours illustrates the tendency of active displays to increase in brightness and extent before the final transition to diffuse surfaces.

d. *Colour*

Two shades of red and two shades of violet were seen in addition to the normal white-green, but only during active displays.

A pale pink-red appeared briefly along the lower borders of active forms during moments of intense activity. It occurred most frequently during the transition from the homogeneous arc to the rayed arc generally known as "break-up". A much deeper red appeared in the middle regions of bright sharp draperies and rayed bands composed of long rays. The pink colour was a transient feature of the displays,

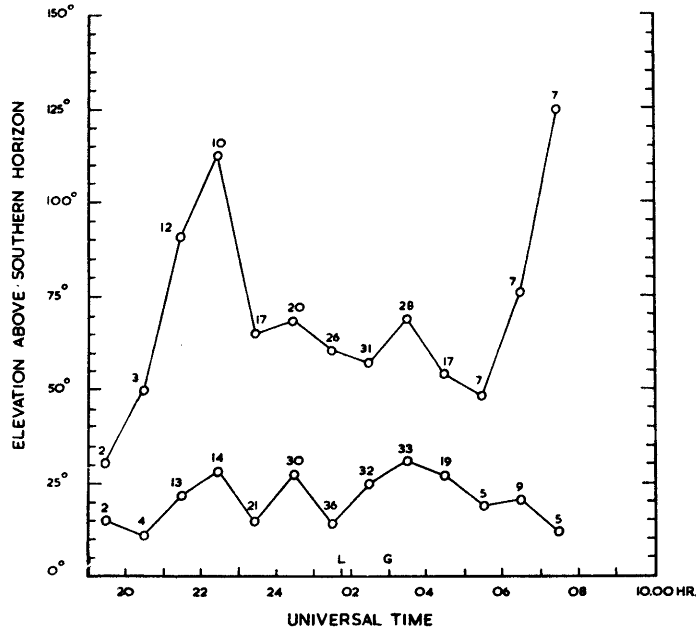

FIGURE 13

Hourly mean upper and lower limits of active forms during clear dark and clear moonlit periods. The number of observations from which each mean is derived is given above the relevant point on the graph.
G. Geomagnetic midnight
L. Local midnight

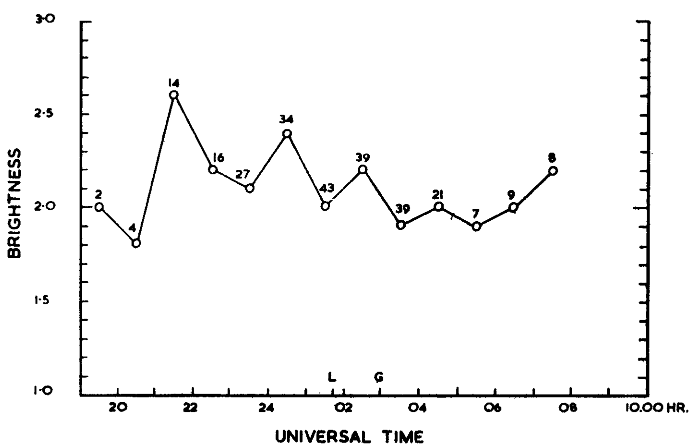

FIGURE 14

Hourly mean brightness of active forms during clear dark and clear moonlit periods. The number of observations used from which each mean is derived is given above the relevant point on the graph.
G. Geomagnetic midnight
L. Local midnight

and the period during which it appeared and disappeared spasmodically rarely lasted for more than two minutes. The deep red colour, however, was remarkable for its stability and slow rate of spread over the middle and upper regions of the rays in which it appeared, as long as these retained their brightness and sharpness; it persisted for periods ranging up to three-quarters of an hour. An interesting feature of this colour was that on the comparatively few occasions on which it was seen it invariably appeared first in the western or south-western sectors of the form. This applied throughout the season and to both morning and evening displays.

Because of their similarity to the descriptions given by Störmer (1955) it was assumed that these two reds were those classified by Vegard as "type B" and "type A", respectively.

The excitation processes giving rise to the two emissions obviously occurred at different levels of the atmosphere. Observations of the first during break-up suggested that it occurred slightly below the lower level of the quiet arc, i.e. below 100 km., whereas the appearance of the second colour in the upper limits of long rays placed it at a much higher level. Both processes appear to require higher energy or density in the incoming streams of charged particles than the process giving rise to the 5577Å oxygen emission.

The seasonal and diurnal distributions of occurrences of the two are shown in Figs. 15 and 16, respectively. In Fig. 16 each occurrence is shown in the hour in which it first appeared. Fig. 15 shows that

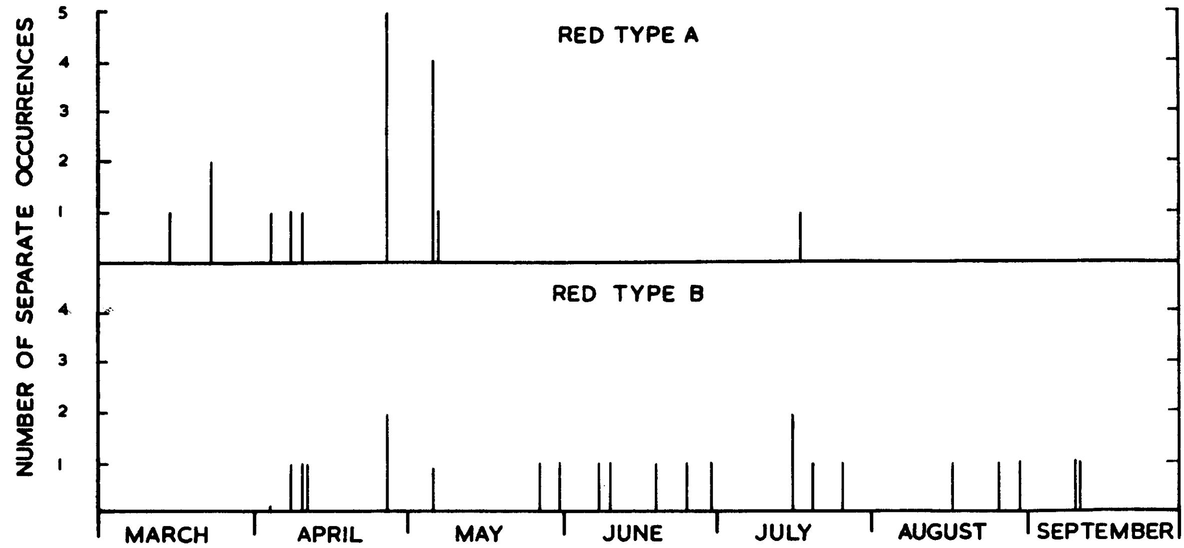

FIGURE 15

Seasonal distribution of occurrences of red coloration.

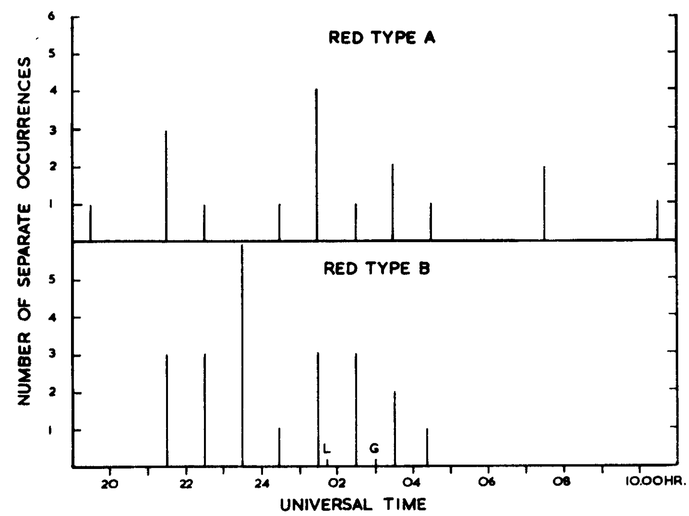

FIGURE 16

Diurnal distribution of occurrence of red coloration.
G. Geomagnetic midnight
L. Local midnight

of the seventeen occurrences of type A observed, sixteen were in the period from mid-March to mid-May, whereas the twenty-two observed occurrences of type B were fairly evenly distributed throughout the season. In Fig. 16 the type A occurrences are seen to be randomly distributed throughout the night, whereas the type B are mainly confined to the evening and midnight periods.*

* The term "midnight" refers to the period around local midnight, 0146 U.T., of about two hours duration or longer.

The two shades of violet were each seen on only one occasion. The first occurred in conjunction with green and the two types of red in a violently active display (brightness 4, RB, C) which burst over the zenith at 2239 U.T. on 10 April. The strong violet colour was seen for only about two minutes while this activity was greatest, and may have been a purely optical effect due to the mixing of the other colours present. The second occurred during a morning display of active forms on 27/28 April. A pale violet colour gradually appeared in the upper regions of the rays of a drapery between 0725 and 0730 U.T. As these rays extended to form a corona in the zenith the colour spread, though the lower limits remained green. This colour was the same as that mentioned by Störmer (1955) in his description of sunlit rays. It persisted until the forms could no longer be distinguished in the twilight.

e. *Movement*

A number of different motions occur in the forms during an auroral display. The most obvious of these is the periodic motion to zenith known as "flaming" which is discussed on p. 26–27. Evans and Thomas (1960) made a study of the slow drifts of the forms during a display, using the I.G.Y. all-sky camera film from Halley Bay. The extremely rapid and apparently random changes of position and shape of the forms during periods of intense activity, are not amenable to detailed study either by photography or visual observation. One other motion, which has been observed at Halley Bay in each year since observations started, is a horizontal motion of waves of brightness along a rayed arc, rayed band or homogeneous band.

In 1960, this horizontal flaming motion occurred most frequently during break-up, and occasionally during a sudden increase in brightness of one of the active forms or during a transition from one to another. On those occasions when it was most pronounced, red type B colour also occurred along the lower border of the forms. The period of the motion was greater than that of normal flaming, being generally of the order of one second. The duration of the phenomenon never exceeded five minutes and was normally less than one minute. The direction of the motion was not always immediately obvious. On a number of occasions there appeared to be motions in both directions simultaneously.

The 32 occurrences observed during 1960 are listed in Table VIII according to their time of occurrence and direction. The forms affected and the presence of red type B are also given. The occasions when the motion occurred during break-up are given in bold type.

From this table it is seen that the times of occurrence of the motion were widely spread throughout the night, although the probability of occurrence was greatest between 2300 and 0400 U.T. In the case of occurrences during break-up in particular, there was a fairly clearly defined reversal in the direction of the motion during the period from 2400 to 0200 U.T. Before this the motion was from east to west and afterwards from west to east. The fact that it also occurred in transitions from one active form to another and during moments of enhanced brightness in any one active form, suggests that this motion is not solely a feature of the break-up phenomenon but rather a more general manifestation of any increase in density or energy of the incoming streams of charged particles. A similar explanation was suggested for the occurrence of red type B. Table VIII shows that the motion occurred on a number of occasions when the forms involved were of brightness 2, but that it was never accompanied by red type B unless the form was of brightness 3 or more.

7. Diffuse Surfaces

a. *Diurnal frequency*

The numbers of clear dark quarter-hour periods during which diffuse surfaces, as defined on p. 11, were present are given in Table IX, line *a*, and the percentage frequencies of occurrence are given in Table IX, line *b*. The numbers under all conditions and the corresponding percentage frequencies are given in lines *c* and *d*, respectively. Line *b* is presented graphically in Fig. 17 and line *d* in Fig. 4e. From both these figures it is seen that diffuse surfaces are clearly a morning feature of displays, the maximum probability of occurrence being between 0400 and 0800 U.T.

b. *Elevation and brightness*

The mean elevations of the upper and lower limits of diffuse surfaces above the southern horizon are given in Fig. 18. These means were derived by using all observations when the limits were visible and

TABLE VIII

OCCURRENCES OF HORIZONTAL FLAMING MOTION

Period (hr. U.T.)	*E. → W.*	*Confused*	*W. → E.*
21/22	HA3 **RB4 Type B*** RB3 Type B	RB4 Type B RB2 HB2 RB3 RB4 Type B	
22/23	HB2 RB3 Type B		
23/24	**HA2 RA2** RA2 RA3 Type B HA2 RA3 **RB3 Type B**	D3 Type B RB3 Type B	RB2 RB3 Type B HA2 HB2 HA1
00/01	HA1 **HB2** **HA2 RB2** HA3 **RB3**		**HA2 HB2** HB2 HB3
01/02	RA2 RA2 HA1 **RB3 Type B**	D3 Type B RB3 RB4 Type B	
02/03	**HA2 RB3**		**HA2 RA2** RB1 RB2 **HA1 HB3 Type B**
03/04			**HA2 RA4 Type B** **HA1 RA2** **HA1 RB2**
04/05			**HA2 RA2** HB3 RB3 Type B

* Bold type indicates the occasions on which the motion occurred during break-up.
Forms occurring simultaneously are given on the same line.

TABLE IX

FREQUENCY OF DIFFUSE SURFACES

Period (hr. U.T.)	19	20	21	22	23	24	01	02	03	04	05	06	07	08	09	10	11	00
a					1	6	9	17	29	30	39	37	31	36	15	6		
b					0·9	4·7	6·6	13·6	23·0	26·8	37·9	38·6	33·0	41·9	23·4	18·8		
c					4	10	16	21	44	60	78	64	61	45	21	10	1	
d					0·6	1·3	2·1	2·7	5·6	7·9	10·8	9·8	10·5	9·1	5·2	3·4	0·7	

a. Number of clear dark quarter-hour periods in which diffuse surfaces occurred.
b. Percentage frequency of occurrence in clear dark periods (using Table I, line *a*).
c. Number of occurrences under all conditions.
d. Percentage frequency of occurrence under all conditions (using Table I, line *c*).

measurable, the actual number of observations used being given above each point. The tendency to move northwards when first formed and then gradually recede southwards as they decay is well illustrated.

Fig. 19 gives the mean brightness in each hour of DS observed during clear dark periods. Comparison with Fig. 18 shows a similar trend of maximum brightness during the period of formation and northward extension, followed by a gradual weakening as the forms decay and recede southwards.

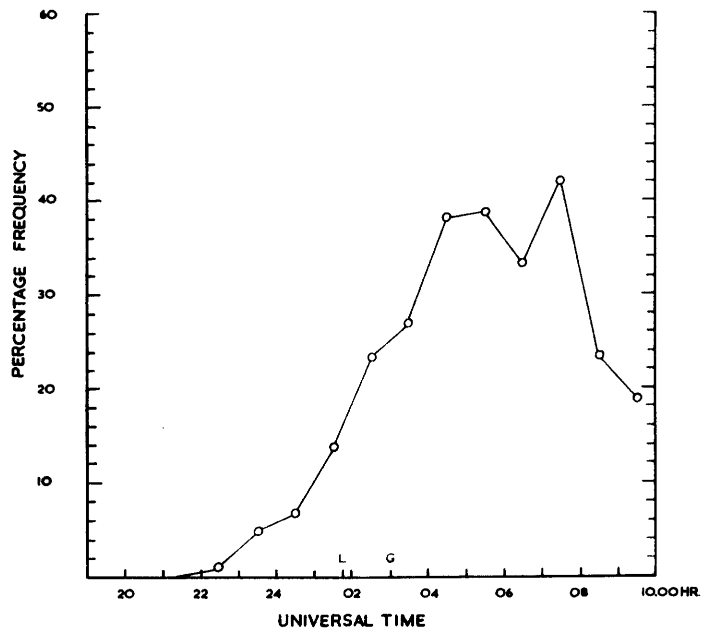

FIGURE 17

Frequency of occurrence of diffuse surfaces during clear dark periods.
G. Geomagnetic midnight
L. Local midnight

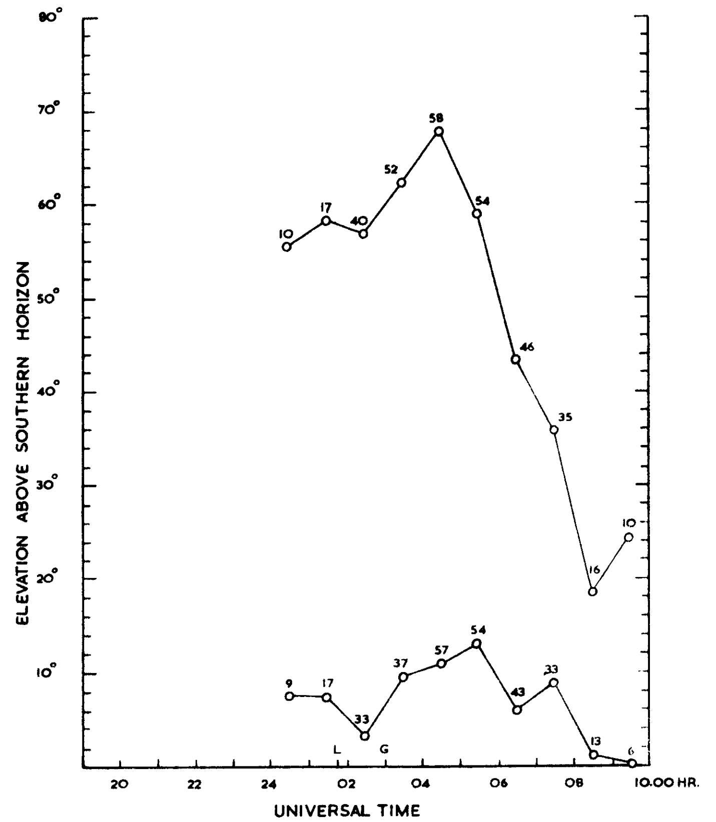

FIGURE 18

Hourly mean upper and lower limits of diffuse surfaces on all nights when limits were visible. The number of observations from which each mean is derived is given above the relevant point on the graph.
G. Geomagnetic midnight
L. Local midnight

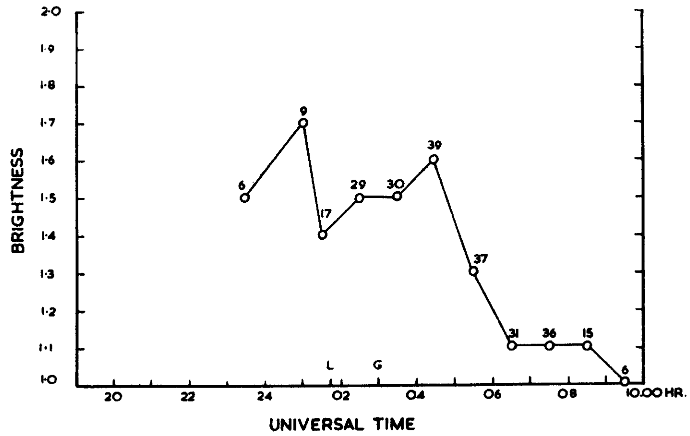

FIGURE 19

Hourly mean brightness of diffuse surfaces during clear dark periods. The number of observations from which each mean is derived is given above the relevant point on the graph.
G. Geomagnetic midnight
L. Local midnight

8. FLAMING

a. *Diurnal frequency*

The percentage of clear dark quarter-hours during which flaming was observed over the forms present is shown graphically in Fig. 20; the percentage frequency of occurrence over all periods is shown similarly in Fig. 21. Comparison of Figs. 17 and 20 and of Figs. 4e and 21 shows a close similarity in distribution between flaming and diffuse surfaces.

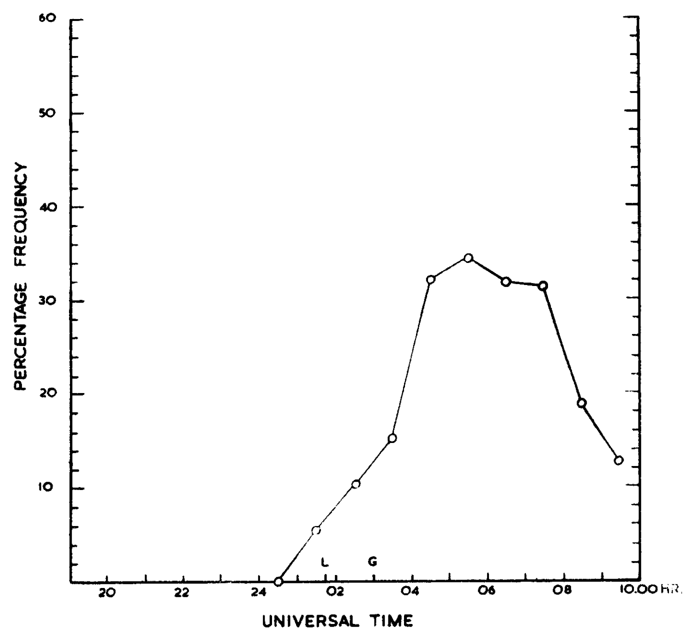

FIGURE 20

Frequency of occurrence of flaming during clear dark periods.
G. Geomagnetic midnight
L. Local midnight

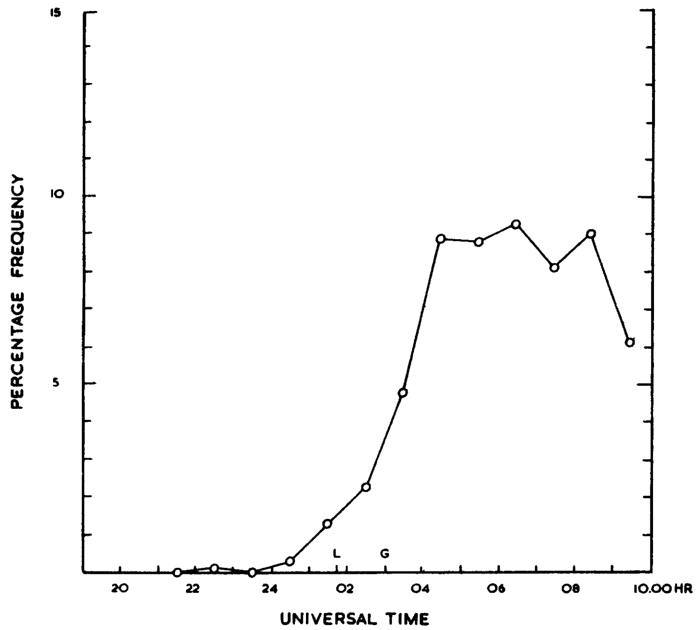

FIGURE 21

Frequency of occurrence of flaming when the sun was more than 12° below the horizon.

b. *Discussion*

In their discussion of flaming seen at Halley Bay during the I.G.Y., Evans and Thomas (1960) conclude that the effect must be due to horizontal surfaces moving vertically upwards, the apparent motion to magnetic zenith being an optical effect arising as these sheets intersect rayed forms which are aligned towards this point. Sheret (1960) suggests that the effect is due to two motions, one towards the local zenith, as suggested by Evans and Thomas (1960), and also a periodic south to north spread of this vertical motion along the geomagnetic meridian. Sheret also remarks that flaming appeared to commence from the main arc system and that only occasionally does the appearance of diffuse surfaces precede the appearance of flaming.

Neither of these latter remarks could be applied to this phenomenon during 1960, when the normal sequence of events was as follows: active forms would diminish slightly in brightness and become progressively less sharply defined until the display could only be described as diffuse surfaces; flaming would then commence. Slight variations in this sequence did occur. For example, during a large display it was not unusual for forms in the north to decay to DS, and flaming to begin over them while active forms remained in the southern sky. On such occasions the flaming motion could not be observed over the active forms, but it was not possible to determine whether it was in fact present but could not be detected because of the greater brightness and "denseness" of these forms. Also, in a number of small displays the quiet arc or glow "dissolved" into DS with only a weak momentary appearance of rays, and flaming would commence as the DS spread northwards.

In all cases, the flaming action appeared initially to be a regular high-frequency motion of waves of brightness with a period in the range from one-half to one-tenth of a second. At this stage the amplitude of the waves of brightness appeared to be small. The DS would then fade, generally from 2 to 1, and in the course of a period ranging from 15 to 30 min. become more thinly scattered. At the same time the frequency would decrease and become less regular, while the amplitude of the brightness waves apparently increased. However, this apparent increase in amplitude may have been an illusion due to the background becoming darker as the surfaces thinned out.

If the display extended into the northern sky, these DS near the zenith would frequently form very diffuse twisted bands which appeared to undergo violent contortions as each wave passed over them. From then on, the changes in the display took place very slowly over a period of from one hour to several hours. The flaming action would become more sporadic and weaker. The DS would become sparser as they slowly faded, the intermingled short diffuse rays described on p. 11 having completely disappeared.

Then the whole display would gradually recede southwards. This appeared to take place partly as a southward movement of the forms and partly as a progressive fading from the northern limit. Sometimes a broad diffuse arc was formed as the display receded. As this became narrower and more sharply defined, the flaming action would disappear. Otherwise the DS gradually weakened and the flaming motion would remain detectable after no surfaces were permanently visible.

The direction of the flaming motion was extremely difficult to ascertain. When the DS were present only in the southern sky the direction appeared to be from the south along the geomagnetic meridian. When they spread northwards through zenith the intermingled diffuse rays gave rise to a weak corona. Though the position of the radiation point of this corona could not be determined with any great accuracy, a series of readings were taken each time it appeared. The means of these readings, as with similar readings on coronae due to active forms, always lay in the ranges 112°–118° elevation above the southern horizon and 340°–350° azimuth bearing east of true north. Thus, the radiation points were at approximately the same elevation but on a bearing 10°–20° west of magnetic zenith. The presence of the diffuse bands, mentioned above, close to zenith made it even more difficult to determine the direction of the motion in this region, but at lower levels the motion appeared to be upwards towards this radiation point.

III. DESCRIPTIONS OF DISPLAYS

1. Introduction

"It is in fact surprising how varied may be the great aurorae. In almost every individual case something remarkable occurs." These words from Störmer's *The Polar Aurora* (1955, p. 4) sum up well the displays seen from Halley Bay during 1960. Despite this, however, there did appear to be a definite sequence of events, a basic theme from which the many variations were built up.

This sequence was indicated on p. 11 where the forms were classified under three headings, namely, quiet forms, active forms and diffuse surfaces. Invariably, one of the quiet forms was the first to appear. The next step was the transition from quiet forms to active forms, and this took place in a number of ways ranging from the appearance of rays in a glow to the classical "break-up". In break-up, a quiet arc was transformed into a rayed arc with the appearance of horizontal waves of brightness and of red type B along the lower border. The duration of the active stage varied greatly from a few minutes to several hours. It was followed by the transition to diffuse surfaces already described above in the discussion of flaming. As the diffuse surfaces finally receded southwards a third transition, to a diffuse quiet arc over which no flaming was visible, was sometimes seen.

In very weak displays only quiet forms appeared, and these remained low in the southern sky. In those of slightly greater intensity a direct transition from quiet forms to diffuse surfaces was frequently observed. Other displays were somewhat arbitrarily considered as medium or large according to the duration and intensity of the active forms.

Apart from variations within the sequence outlined above it was not unusual for the sequence to be repeated several times in the course of a night. A feature of the very large displays was the appearance of diffuse surfaces and flaming between maxima of brightness and activity in the active forms.

2. Typical Displays

In this section are given descriptions of displays of different intensities which followed the general pattern outlined above. Prints from the all-sky camera film and reproductions of the Halley Bay magnetograms are included where relevant.

In these descriptions, the term "i-ring" is used to describe the presence of the 5577Å "auroral" green line detected by using the interference filters. All times quoted are in Universal Time. Bearings were measured in degrees east of local magnetic north but have been converted to degrees east of geographic north (declination 1·5° W.). Unless specifically defined, the term "south" is used to denote geomagnetic south, and where no other indication is given elevations are measured from this horizon.

On the original magnetograms the scale values of the three elements were:

$$H : 7 \cdot 09 \ \gamma/\text{mm.}$$
$$D : 0 \cdot 93 \ \gamma/\text{mm.}$$
$$V(=|Z|) : 6 \cdot 94 \ \gamma/\text{mm.}$$

In the reproductions at the end of this report they have been reduced to approximately one-third of their original size. The sign convention is such that H increases upwards, D increases westerly downwards and V increases downwards.

A standard development time was used in processing the all-sky camera film, but because of variations in the brightness of the sky due to moonlight and twilight, this did not result in a standard degree of contrast in the film. Thus, it was impracticable to use a standard exposure in making prints from film taken on different nights. The same aperture of the enlarger lens was used throughout, however, and a constant exposure time was used in each series of prints. In general, the 27-sec. exposure frames were used when printing quiet forms to obtain maximum contrast, and the 3-sec. exposures were used for active forms to give as much detail of the fine structure as possible.

Since the watch appeared only on every fourth frame it was not included in the prints. The figure number, film and print exposure times, and the universal time are given below each figure.

Further details concerning the film, paper and developers used are given in the Appendix.

a. *Weak displays*

*20/21 March: Magnetogram No. 1**

Observations were made from 2300 to 0500 U.T. The sky was completely obscured by cloud until 0130 U.T. No i-ring was detectable. Cloud then cleared rapidly from south to north and the sky remained clear for the rest of the night. An i-ring was first detected in the south at 0215 U.T. By 0218 a HA1 had appeared at h = 5°, centre 162·5°. This had faded by 0230 U.T. when only a very weak i-ring could be detected. This too had faded by 0300 U.T. No further aurorae appeared.

30/31 May: Magnetogram No. 2

Observations were made from 2015 to 0930 U.T. The sky was effectively clear until 0230 U.T. Some thin broken cloud then spread over the southern sky below 30° elevation. This did not greatly affect observation of the display. It had dispersed by 0800 U.T.

An i-ring was detected low in the south at 2015 U.T. and remained till 2100 but could not be detected at 2115. No aurora was present from then until 2300 U.T. By 2315 U.T. a weak glow had appeared in the south-east below 5° elevation. At 0030 U.T. the lower border of a HA1 was discernible at h = 3°, centre 160·5°. This rose slowly, reaching h = 8°, centre 156·5°, at 0100 U.T. The lower border then weakened and by 0115 U.T. only a very weak glow along the horizon remained. A second arc had emerged from the glow by 0145 U.T. at h = 4°, centre 171·5°. This had risen to h = 7° at 0200 U.T. when its centre bearing was 172·5°. It remained at this elevation until 0215 U.T. when its centre bearing was 168·5° and then it receded to h = 5°, centre 173·5°, at 0300. The lower border then became diffuse and faded, leaving a weak glow which persisted until 0615 U.T. An i-ring was still detectable at 0700 U.T., but this too had faded by 0715. Nothing further was seen.

In the above displays only quiet forms appeared. In the two described below, quiet forms and DS appeared with transitions from one form to the other without any intermediate active forms.

18/19 May: Magnetogram No. 3

Observations were made from 2045 to 0930 U.T. The sky was partially obscured to 15° elevation in the south-east till 2115 U.T. Cloud then spread rapidly westwards and the sky was almost completely obscured until 2230 U.T. It then began to clear, and by 2315 U.T. only a bank of cloud below 5° in the south remained. This persisted throughout the period. A thin layer in conjunction with weak moonlight slightly hampered observation from 0215 to 0315 U.T.

No forms or i-ring were detected until 2315 U.T. when a weak glow became visible low in the south.

* Plates and magnetograms appear at the end of the report.

At 2330 U.T. a HA1 had appeared at h = 5°, centre 161·5°. This had risen to h = 7°, centre 164·5°, at 2400 U.T. It then began to broaden and become diffuse. An ill-defined lower border was still present at h = 4° at 0015 U.T., but by 0030 only a G1 extending to 15° elevation remained. This disappeared between 0200 and 0215 U.T. An i-ring remained detectable until 0315 U.T. Nothing further was seen until 0515 U.T. when a weak i-ring was again detected. At 0530 a HA1 had appeared at h = 8°, centre 164·5°. This was at h = 9°, centre 166·5°, at 0545 U.T. and at h = 7°, centre 162·5°, at 0600. It then gradually broke up into DS1 over which a weak flaming had become visible by 0615 U.T. These had faded by 0630 U.T. An i-ring remained detectable until 0830 U.T. Nothing further was seen. From this it is seen that small disturbances in all three traces coincide with the decay of the first arc between 2400 and 0030 U.T. and with the HA to DS transition and their subsequent decay between 0600 and 0630 U.T.

9/10 September: Magnetogram No. 4; Plate II, figs. 1–6

Observations were made from 2200 to 0600 U.T. Apart from some thin scattered streaks of cirrus the sky was clear all night. The 19-day moon rose at approximately 0400 U.T. but remained below 3° in the north.

A strong twilight glow was still present in the south-west at 2200 U.T. Despite this, an i-ring was detectable in the south. By 2245 U.T. a HA1 could be distinguished at h = 6°, centre 159·5°. This had receded to h = 3° at 2300 U.T., and by 2330 it had faded, leaving a weak glow from the horizon to 20° elevation. At 0015 U.T. a very diffuse arc had reappeared at h = 4°, centre 158·5°. It had faded again by 0030 U.T. A very weak glow remained below 10° elevation until 0430 U.T. It was then brightening a little and by 0445 U.T. a HA2 had reappeared and risen to h = 20°, centre 161·5°. This was becoming very diffuse by 0455 U.T. and by 0500 the lower border had receded to h = 14°, centre 158·5°. This then began to break up into DS2. At 0505 U.T. these lay in a band between 10° and 35° elevation. Weak flaming could then be detected in their upper limits. By 0530 U.T. twilight was strengthening, but DS1 were still visible low in the south-west. An i-ring was detectable at 0545 U.T., but by 0600 this too had faded into the twilight.

The series of prints from the all-sky film, given in Plate II, shows the dissolution of the diffuse arc into diffuse surfaces. The twilight glow is seen strengthening below it in the south-east and the moon below 5° in the north.

In the displays described below, weak active forms appeared briefly.

17/18 May: Magnetogram No. 5

Observations were made from 2045 to 0930 U.T. A bank of cloud had appeared below 10° in the south-east by 2315 U.T. and it persisted all night. Neither this nor the 23-day moon which rose after 0100 U.T. greatly hampered observation.

No aurorae were present before 0130 U.T. An i-ring was first detected at 0145 and by 0155 U.T. a HA1 had appeared at h = 6°, centre 163·5°. This rose slowly until at 0230 U.T. it was at h = 9°, centre 161·5°. At 0238 U.T. it was becoming diffuse and had receded to h = 8°. Weak ray structure in which some slight, confused horizontal motion was discernible, then appeared in it. The resultant RA1 then broke up into a series of intermingling RB1 and RB2. At 0245 U.T. these lay between 134° and 240° in azimuth, and nowhere exceeded 15° elevation. They were weakening and becoming diffuse by 0250 U.T. and by 0300 had transformed into patches of DS1 which persisted until after 0315. By 0330 U.T. they had become compressed into a diffuse HA1 at h = 8°, centre 162·5°. This remained until 0400 U.T. and then faded. An i-ring could be detected until 0545 U.T. At 0600 U.T. a HA1 had appeared at h = 7°, centre 166·5°. This persisted until 0700 U.T. when it was at h = 6°. At 0715 U.T. only a faint glow remained below 10°. This too had faded by 0730 U.T., but an i-ring was still detectable until 0815. Nothing further was seen.

15/16 June: Magnetogram No. 6

Observations were made from 2045 to 0930 U.T. Apart from a few streaks of cloud in the east the sky was clear all night. There was a 21-day moon from 0100 U.T. onwards.

An i-ring was first detected at 2245 U.T. A faint glow was present below 5° at 2300 U.T. and a HA1 at h = 3°, centre 162·5°, at 2315. This had faded by 2330 U.T., leaving a glow to 10°. At 2400 U.T. the upper limit was at 15° and a few short scattered R1 were seen to be appearing, becoming diffuse and disappearing in its upper limits. These were no longer visible at 0015 U.T. The glow then faded slowly and by 0100 U.T. only an i-ring could be detected.

This persisted until 0200 U.T. when a glow could be distinguished again below 5° elevation. This had risen to 15° by 0245 U.T. and then a HA1 emerged from it. At 0300 U.T. the arc was at h = 12°, centre 163°. It had faded by 0305 U.T. At 0315 U.T. the upper limit of the glow was at 20° elevation. Against this background a very narrow fragmentary RA2 appeared at h = 6°, centre 162·5°, and then faded. Long sharp R2 were appearing in the glow and extending from 3° to over 25° elevation at 0345 U.T. These quickly became diffuse and weakened, and by 0350 U.T. the display consisted of a patchwork of DS1 and DS2 with intermingling diffuse R1 extending from the horizon to 40° elevation and a flaming action detectable over it. The display then gradually faded and receded until at 0530 U.T. it was below 5° elevation. It then began to rise and brighten again, reaching 10° by 0545 U.T. and brightness 2 by 0615. It remained thus until 0630 U.T. and then faded slowly. Flaming could no longer be detected at 0645 U.T., and at 0730 only an i-ring could be detected. This too had faded by 0815 U.T. Nothing further was seen.

b. *Medium displays*

In each of the following displays the transition from quiet forms to active forms occurred in a different way.

8/9 April: Magnetogram No. 7

Observations were made from 2130 to 0700 U.T. The sky was clear at first but by 2215 U.T. cloud cover was virtually complete. It remained so until 0200 U.T. when a few breaks began to appear. By 0300 U.T. the southern sky was sufficiently clear for the display to be observed. Cloud had spread again by 0345 U.T. when it was 8/8 and it varied between 6/8 and 8/8 during the rest of the period.

An i-ring was first detected through cloud at 0200 U.T. At 0210 U.T. a HA1 had become visible through a break in the cloud at h = 8°, centre 160·5°. This had brightened to 2 at 0215 U.T., and at 0217 some scattered diffuse rays appeared momentarily in the centre section of the arc, accompanied by a rapid eastward motion of waves of brightness. So far as could be ascertained, the arc remained of brightness 2 and in the same position until 0300 U.T. At 0304 U.T. it was seen to brighten suddenly to 3 and sharp ray structure appeared. At 0306 U.T. it brightened further to 4, and red type B coloration appeared along the lower border followed immediately by a violent west to east motion of waves of brightness. The sudden intense brightening, the appearance of red type B and the violent movement all occurred within a period of not more than 20 sec. The lower border then weakened to 3 as the red faded, became diffuse and appeared to merge with the horizon. At 0307 U.T. a faint red type A colour had become visible in the upper limits of the rays. They then lost their sharpness and faded. The red was no longer visible at 0309 U.T., and by 0315 only DS1 and 2 remained. Flaming commenced over these at 0319 U.T. The period of this motion was considerably less than 1 sec. At 0330 U.T. the DS were all of brightness 1 and the flaming was much more sporadic. The display had become obscured by cloud at 0335 U.T. The i-ring became progressively weaker and could no longer be detected at 0615 U.T. Nothing further was seen.

20/21 June: Magnetogram No. 8

Observations were made from 2100 to 0930 U.T. The sky remained clear all night.

An i-ring was first detected at 2145 U.T. but had faded by 2200. It was detected again at 2230 U.T., and at 2300 a weak glow could be distinguished along the southern horizon. This remained until 0015 U.T. At 0030 U.T. a HA2 had appeared at h = 9°, centre 161·5°. This had receded to h = 5° by 0100 U.T. when its lower border was becoming very diffuse. It then faded, leaving a glow from horizon to 10° elevation. At 0130 U.T. an arc had again emerged at h = 6°, centre 164·5°. This had receded to h = 4° at 0200 U.T., and at 0215 only a glow remained. The upper limit of this had risen to approximately 15° at 0245 U.T. and a weak arc then emerged from the upper limit. It had risen to h = 20°, centre 162·5°, at 0300 U.T. It then brightened to 2, and by 0315 U.T. the lower border was losing all definition as a narrow twisting RB2 appeared below it. This brightened to 3, and scattered long rays began to appear in the remains of the arc above it. These extended to 30° elevation at 0330 U.T., by which time the RB had faded to 2 and was becoming diffuse. At 0340 U.T. all ray structure had faded leaving a broad HB1 between

15° and 40° elevation. At 0345 U.T. this was beginning to break up into DS1 and 2 interspersed with short-lived R1 and R2. The display remained thus until 0400 U.T., but by 0415 DS2 were extending northwards to 70° elevation and rapid flaming to zenith had begun. These then weakened and gradually receded southwards until by 0930 U.T. they were below 5° elevation.

20/21 July: Magnetogram No. 9; Plate II, figs. 7–20

Observations were made from 2030 to 0930 U.T. The sky was at first completely obscured by 8/8 altostratus cloud. This had begun to break up by 2215 U.T. and by 0115 it had cleared completely.

An i-ring was first detected through cloud at 2215 U.T. At 0130 U.T. a weak glow was distinguishable in the south below 20° elevation. At 0112 U.T. a narrow HA2 appeared at h = 6°, centre 162·5°. The eastern half of this was fading by 0145 U.T., but by 0150 it was at h = 10° and of brightness 1. It remained thus until after 0200 U.T., gradually becoming broader. It had receded to 7° at 0215 U.T. and remained at this elevation until 0245. Then it began to rise again and move westwards. At 0300 it was at h = 13°, centre 165·5°. It had become so diffuse by 0315 U.T. that no accurate measurement of its position could be made, but by 0330 it was at approximately h = 8°, centre 163·5°, and remained there until 0400. It then began to brighten and became more clearly defined. At 0415 U.T. it was at h = 10° and at 0430 it had reached h = 17°, centre 167·5°, and was of brightness 3. The lower border then became uneven until at 0433 U.T. it had become a twisted HB3 lying across the southern sky at approximately 20° elevation on the meridian. At 0435 U.T. short ray structure began to appear, accompanied by a west to east motion with brief tinges of red type B along the lower border. Ray structure then faded from west to east, leaving patches of DS2 extending to approximately 25° elevation. At 0437 U.T. the eastern end of the band still retained the ray structure while flaming had commenced over the DS in the western sector. This flaming appeared to be a regular motion of frequency greater than one cycle per sec. All ray structure had faded by 0440 U.T. and at 0445 the DS2 extended from the horizon to 50° elevation. They had spread through zenith by 0500 U.T. and their brightness had faded to 1. The fading of the forms continued and by 0530 U.T. only those below 60° elevation remained visible. By 0615 U.T. the remaining visible DS1 were below 20° elevation. Flaming was still detectable but appeared to be of lower frequency and less regular than it was originally. At 0630 U.T. a weak glow was present below 10° elevation, but no flaming could be detected over it. This had faded by 0645 U.T. and the i-ring was no longer detectable at 0715. Nothing further was seen.

The series of prints from the all-sky camera film, reproduced in Plate II, show the transitions from HA to HB to RB to DS.

In the quiet stages of the displays described above, only very small displacements of the magnetic elements occurred. On 8/9 April and 20/21 July, decreasing bays in each of the elements commenced at approximately the same time as the transitions to active forms. The transitions to DS and the appearance of flaming occurred during the period of maximum displacement of the elements on both these occasions. On 20/21 June the decrease in H and the easterly (decreasing) movement of D commenced as the first active forms appeared. The decrease in V, however, did not begin until 15 min. later. All three elements were still decreasing when the transition to DS took place. On 8/9 April and 20/21 July, the return to normal of the elements commenced as the DS faded. This applied to H on 20/21 June, but not to V and D. V did not start to increase again until half an hour after the DS reached their maximum. Also, there appeared to be a positive (westerly) bay superimposed on the decreasing one in the D element and this commenced as the DS transition was taking place.

In these three displays the sequence of events was basically the same, i.e. transitions from quiet forms to active forms to DS, and their subsequent decay. All occurred at approximately the same latitude in the immediate post-midnight period of 0300 to 0500 U.T., and were of approximately the same duration. The accompanying magnetic disturbance pattern was similar on two occasions, while on the third the correlation in time and in the sense of the displacement was similar only in the H element.

c. *Large displays*

Such displays invariably accompanied large magnetic storms. They were characterized by the long duration of the active forms and their equatorward expansion. In such displays, forms were frequently seen to extend to an elevation of 10° or less above the northern horizon. As the heights of the lower borders of active forms are rarely below 100 km., although they vary considerably, the above elevation corresponds to a geomagnetic latitude of at least 10° less than the median quiet-arc position.

6/7 May: Magnetogram No. 10; Plate III, figs. 21–49

Observations were made from 1900 to 0845 U.T. The sky remained clear all night. Because of the relative brightness of the display the presence of an 8-day moon until 0315 U.T. did not hamper observation.

Active forms were already present at 1900 U.T. in the shape of a RA3 at 20° elevation. The upper limits of the rays in the western end of this were red in colour (type A). At 1930 U.T. an east to west flaming motion of brightness occurred in the arc. It then faded slowly, until by 2030 U.T. only an i-ring could be detected. Scattered R2 were reappearing in the southern sky at 2120 U.T. These became more numerous and, by 2130, lengthened towards zenith forming a C2 whose radiation point was at 115° elevation above the southern horizon on a bearing of approximately 340°. This had brightened to 3 by 2134 U.T., and at 2136 a patch of red type A appeared in the western sector. This had disappeared at 2140 U.T., when the corona had faded to 2, but reappeared at 2156 as it brightened again and by 2158 the corona was almost entirely red. The zenith display was weakening by 2215 U.T. when several twisted RB3 were appearing in the southern sky. These fluctuated in brightness, shape and position until after 2300 U.T., and then faded completely. Only an i-ring was detectable from then until 2345 U.T. when a RB1 in the south-west and a HB1 across zenith began to appear. A series of HB1 then appeared across zenith. These had coalesced and developed ray structure to form a RB2 by 0030 U.T. This had faded at 0100 when scattered rays in the south were consolidating into an active D3. Random fluctuations occurred along the lower border of this, accompanied by brief appearances of red type B, while above 30° elevation the rays became predominantly red type A in colour. By 0115 U.T. this was becoming diffuse and fading, leaving a C2 in the zenith which underwent considerable fluctuations in brightness and "density" until 0230. At 0230 it decayed into DS2 intermingled with diffuse rays over which flaming became detectable. By 0315 U.T. these were moving into the northern sky and a RB2 was appearing in the south. As it faded, a series of roughly parallel fluctuating HB2 appeared between the zenith and the weak remaining DS in the north. In the course of the next hour these bands performed a series of convolutions before decaying into DS2. At 0445 U.T. these DS2 and those in the north lay in a band, between 110° and 170° elevation above the southern horizon, over which there was a strong rapid flaming action. The display remained essentially thus until 0545 U.T., when a few sharp rays began to appear in the south and west. By 0550 U.T. a C2 had formed with radiation point at 115° elevation on bearing 345°. Flaming continued over the DS in the north but was not detectable over the rays. The lower borders of the rays became slightly more even until, by 0610 U.T., there was an irregular RB3 across the zenith. The southern limit gradually receded until, at 0630 U.T., it formed a RA2 at h = 20°, centre 163°. The DS and diffuse rays in the north were also receding. At 0645 U.T. the RA was becoming diffuse and weakening, and by 0700 it too had decayed into DS. DS with flaming over them then extended from 8° to 110° elevation. By 0730 U.T. these had weakened to brightness 1 and lay between 5° and 20°. They could just be detected along the southern horizon at 0800, and by 0830 only a weak i-ring was detectable in the strengthening twilight.

Part of the magnetogram for this night is reproduced as Magnetogram No. 10. From this it is seen that changes in sign of the displacements in *H* and *D*, from *H* increasing to *H* decreasing and from *D* increasing (westerly) to *D* decreasing, occurred at 0100 U.T. as the RB across zenith faded and the active D3 in the south developed. All three elements returned abruptly to normal at 0600 U.T. as the forms receded into the southern sky.

Three series of prints from the all-sky camera film are reproduced in Plate III. Those in Plate III, figs. 21–32, show the development and decay of the D3. Those in Plate III, figs. 33–41, show the movements of the HB2 in the zenith between 0346·5 and 0434·5, while Plate III, figs. 42–49, show the development of the C2 and RB3 in the final active phase and its southerly retreat.

3. Unusual Displays

In this section a number of displays are described in which events considerably removed from the normal pattern occurred.

The first of these, that of 10/11 April, has already been referred to on p. 22 in the description of colours seen in the displays.

10/11 April: Magnetogram No. 11; Plate IV, figs. 50–57

Observations were made from 2100 to 0715 U.T. A veil of cirrus, which varied greatly in density throughout the night, and a full moon considerably hampered observation of the weaker forms.

An i-ring was present at 2100 U.T., but no forms could be distinguished through cloud. At 2115 U.T., however, parts of a RA1 could just be distinguished at h = 39°, centre 163·5°. Though varying in brightness from 1 to 3, this RA retained its shape for an hour and a quarter, during which time it moved steadily northwards. At 2130 U.T. it was at h = 50°, at 2202 it was at h = 70° and at 2219 it had reached h = 110°. It remained in this position until 2230 U.T. and had receded to h = 100° at 2235. Then the two ends of a RB2 were appearing in the north-east and north-west. At 2239 U.T. violent, intense activity burst forth in the zenith. The forms appeared to consist of numerous rapidly moving RB4. Colours observed were the two types of red, green and violet. At 2245 U.T. activity was diminishing slightly, but red type A was still present. The display had weakened to 2 at 2250 U.T., when the main forms present were a C2 and a fluctuating RB2 in the southern sky. The rays of the latter had lengthened to form a D2 at h = 15° by 2300 U.T., and at 2315 the only form distinguishable through cloud in the moonlight was a C1. This had faded by 2330 U.T., and though an i-ring remained detectable until 0330 no further forms were observed. Because of the poor visibility no definite statement about the presence or absence of forms could be made.

Magnetogram No. 11 shows that the signs of the displacements in *H* and *D* changed to decreasing (easterly in *D*) as the RA passed through the zenith. The sudden outburst at 2239 U.T. coincided with a large decrease in *D* but no large displacements in *H* or *V* occurred at this time.

In Plate IV, figs. 50–57, a series of prints from the all-sky film show the development of activity at 2239 U.T. These prints are taken from 3-sec. exposure frames, but even this was not short enough to "stop" the movements in the display.

The second display described was unusual because of the brightness and shape of a RB4 which appeared across the zenith.

16/17 July: Magnetogram No. 12; Plate IV, figs. 58–67

Observations were made from 2015 to 1000 U.T. The sky remained clear until 0415 U.T., but by 0430 was obscured by 8/8 altostratus which remained for the rest of the period.

An arc was first seen at 2020 U.T. It was at h = 10°, centre 158·5°. At 2145 U.T. this was breaking into a series of short narrow HB2 at the same elevation. These merged again into an arc which then rose to h = 15°. At 2222 U.T. an HB2 appeared above the arc, and at 2223 ray structure, red type B coloration and east-to-west flaming appeared in the arc. The ray structure then developed, but disappeared by 2237 U.T., and from then until after 2300 a series of HB were present below 25° elevation in the south. At 2307 U.T. a weak glow was spreading over the whole sky. Diffuse rays were appearing momentarily in this. At 2345 U.T., the northern limit of the glow could be distinguished at an elevation of 30° above the northern horizon. It remained thus until 0015 U.T. At 0030, however, it had faded and an RB2 was appearing at 115° elevation in an approximately east–west orientation. A slight coronal effect was observed in this on bearing 340·5°. At 0037 U.T. this was brightening to 3 and tinges of red type B were appearing on it briefly. By 0045 U.T. it had brightened and consolidated into a massive RB4 composed of equally spaced horseshoe-shaped cells, concave towards the south. The mean southern limit was at 90° elevation. The colours present were green, white and red type B, intermingled in equal proportions. The band then moved rapidly southwards until at 0049 U.T. its lower border was at 30° elevation. As it moved southwards it left in its wake a dense diffuse "blanket" of auroral light of brightness 2–3 which quickly became patchy and faded to 2. At 0052 U.T. the southern limit was at 12° and the colours and activity were fading. By 0100 U.T. only a narrow diffuse RB2 remained with scattered DS1 extending to within 40° elevation of the northern horizon. The display was composed of DS1, as above, and a few short scattered RB2 in the south at 0115 U.T. By 0145 U.T. the latter had faded, leaving DS1 and diffuse R1 from 5° to 150° elevation. Flaming was first detected at 0215 U.T. The limits of the DS had contracted at 0400 U.T. when they lay between 30° and 120° elevation. By 0430 cloud had obscured the display, but an i-ring remained detectable through it until 0915 U.T.

The most notable features of the magnetogram are the changes from *H* increasing to *H* decreasing and from *V* increasing to *V* decreasing at the time of formation and southward movement of the RB4.

In Plate IV, figs. 58–67, a series of prints from the all-sky camera film show the appearance and southward movement of the RB4.

18/19 July: Magnetogram No. 13

This display was remarkable for the appearance of active forms after a quiet display had decayed to DS late in the morning, and for the spread of red type A over these forms.

Observations were made from 2030 to 1100 U.T. Thin broken cirrus partially obscured the southern sky until 2245 U.T. It then cleared and remained clear for the rest of the period.

At 2130 U.T. a very weak (1—) glow had appeared in the south-west. The position and shape of this was unusual. It extended some 15° in azimuth, centred on approximately 260° bearing. On this bearing it extended to 18° elevation in a roughly conical shape. A weak i-ring was detected from it. This form faded abruptly at 2135 U.T.

An i-ring was again detected at 2345 U.T. and at 2400 a glow extended to 10° in the south. An HB1 had emerged from this by 0115 U.T., and this remained until 0500 at approximately 10° elevation. It had disappeared by 0515 U.T., leaving a glow to 10°. At 0600 U.T. this was brightening slightly and by 0630 the upper limit had risen to 35°. It then broke up into DS which continued to move northwards, extending through zenith by 0700 U.T. Flaming was first detected at 0645 U.T. The DS gradually faded from the north from 0730 U.T. onwards, and those still visible at 0930 U.T. were entirely below 25° elevation. The DS were moving northwards again at 0945 U.T. and by 1000 they extended through the zenith. At 1005 U.T., a D2 composed of short rays was extending upwards from 10° elevation between due south and bearing 240°. The upper limits of the rays extended to 40° at 1008 U.T. and to 70° one minute later. The dominant colour was then grey, merging into red type A in the upper limits. The red became suffused throughout the rays but faded as the rays became diffuse and began to break up into DS. The DS appeared to be fading at 1020 U.T. but twilight was strengthening by then, making it difficult to judge brightness. At 1045 U.T. forms could no longer be distinguished in the twilight, but an i-ring was still detectable at 1100.

Magnetogram No. 13 shows that no disturbances accompanied the quiet display. The first displacements in all three elements are seen to coincide with the northward extension of the glow which preceded the transition to DS.

The two descriptions which follow, both contain cases of a form appearing in the northern sky when the display had not been first observed to pass from the south through the zenith.

19/20 July: Magnetogram No. 14

Observations were made from 2100 to 0930 U.T. Broken cloud of varying thickness and extent in the southern sky made it difficult to follow in detail the development of this display.

A G1 was present below 10° elevation in the south at 2100 U.T. and it appeared to persist until 2230. At 2245 U.T. an arc had formed at h = 5°, centre 158·5°. This was still present at 2300 U.T. but was then obscured by cloud. The cloud was breaking again at 2345 U.T. and a glow was present below 10°. Also a very weak (1—) form was present in the north. It was not sharply defined but appeared to extend through some 15° in azimuth, centred on bearing 345°, and to lie between 20° and 25° elevation on this bearing. It gave a very weak i-ring. The all-sky camera was switched on at 2346·5 U.T., but it was fading by then and nothing was recorded on the film. No trace of it could be found with the interference filters at 2348 U.T.

The glow in the south extended northwards slowly. At 0130 U.T. the upper limit was at 45° elevation. It had moved through zenith by 0145 U.T. but at 0200 it was fading and receding. By 0230 U.T. only an i-ring could be detected and this too had faded by 0345. Nothing further was seen.

The magnetogram shows displacements in the *D* and the *V* traces at the time of appearance of the form in the north.

7/8 September: Magnetogram No. 15; Plate V, figs. 68–78

Observations were made from 2145 to 0630 U.T. A thin low haze was present for most of the period. After 2330 U.T. this, in conjunction with a sixteen-day moon, made it difficult to observe the weaker forms close to the horizon.

No forms or i-rings were detected before 2300 U.T. At 2306 U.T. a form was seen in the northern sky. It extended through some 60° in azimuth centred on bearing 330°. Its lower border was at an elevation of 20° above the horizon throughout its extent. It tapered off symmetrically from a maximum width of 3° on its centre bearing. Throughout its duration it was undergoing irregular fluctuations in brightness, with periods varying from 2 to 5 sec. Until 2320 U.T. these fluctuations were from brightness 1— to 2. Thereafter the form gradually weakened, disappearing at 2325 U.T. The more northerly sector was seen to fade before the western one. At no time could an interference ring be detected from this form. In view of the brightness of the form this suggests that no 5577Å emission was present. Had the form been due to 6300Å oxygen emission (red type A) then at the maximum brightness attained it would have appeared red in the absence of the 5577Å emission, but it remained greenish-white.

An i-ring was first detected in the south at 2330 U.T. A HA2 had appeared by 2345 U.T. at h = 5°, centre 153·5°. This then rose to h = 9°, centre 157·5°. It then weakened to HA1, and though it appeared to remain at approximately the same position no further measurements could be made in the combination of haze and moonlight. At 0200 U.T. a narrow fragmentary RB2 was present at h = 7°. Ray structure had faded from this by 0215 U.T. leaving a HB2 at 5° elevation between 150° and 180°. This was no longer visible at 0230 U.T. An i-ring remained detectable until 0600 U.T., but no forms were seen.

A number of displacements occurred during the night, but the magnetogram shows that all three traces were undisturbed while the form was present in the north.

In Plate V, figs. 68–78, a series of prints from the all-sky camera film shows the gradual fading of the form. These cover the period 2318 to 2324 U.T. at 36-sec. intervals.

From the facts given in the above descriptions, it is seen that the only similarities in the two forms occurring in the north were in their position and approximate time of occurrence. The form observed on 7/8 September may not have been an auroral form. On no other occasion was a form observed in the northern sky prior to the appearance of forms in the south, nor was any other form observed which did not give an interference ring. On the other hand, no obvious explanation in non-auroral terms can be found. The position, symmetrical shape, sharp definition and periodic fluctuations in brightness of the phenomenon, together with the absence of cloud, appear to rule out atmospheric reflection or refraction of sunlight or moonlight.

The last display to be described in this section was remarkable for the number of changes of form that occurred during its active phase.

10/11 September: Magnetogram No. 16; Plate V, figs. 79–85

Observations were made from 2200 to 0545 U.T. Apart from some scattered streaks of cirrus and, later, some narrow bands of altocumulus, the sky remained clear all night.

Strong twilight was persisting at 2200 U.T., but by 2230 an i-ring could be distinguished in it in the south. At 2245 U.T. a glow extending to 10° elevation was visible. A HA2 was present at h = 9°, centre 156·5°, at 2300 U.T., but this slowly receded until at 2330 it was at h = 4°, centre 154·5°. At 2345 U.T. a weak glow to 20° elevation was present.

From 2345 to 0200 U.T. the display was most unstable. The period was characterized by continual changes in form and in the position and brightness of the forms. Throughout, these changes and movements took place without any violent activity. The mean elevations of the lower borders of the forms remained in the range of 9°–17° and the upper limits rarely exceeded 30°. A weak "active" glow (see p. 17) extended from horizon to zenith as a background to the forms. A homogeneous arc was one of the most frequently occurring forms in this period, yet the changes from it to other forms did not show any of the normal features of break-up—such as horizontal motion or the appearance of red type B. Frequently several different forms were present at once, but the main forms occurring in chronological order were as follows: RA2, RA3, R3, HA3, HB3, RB3, HA2, RA3, RB3, HA2, HA3, RB3, HA3, HB2, RB2, RA2, RB3, RA2, RB2, R3.

The rays were becoming diffuse and extending towards zenith by 0210 U.T., fading to 2 as they did so. By 0215 U.T. they had decayed into DS1 and DS2 which extended to zenith. These slowly faded and receded and at 0245 U.T. the upper limit was approximately 40°. Flaming was first detected at 0255 U.T. The DS continued to recede and at 0330 U.T. they were merging into a very diffuse HA1 at h = 15°, centre 163·5°. Flaming was not detectable over this. The arc was at h = 12°, centre 163·5°, at 0345 U.T., and at 0400 only a weak glow extending to 20° elevation remained. Twilight was strengthening by 0430 U.T. and the glow could not be distinguished in it. An i-ring remained detectable until 0515 U.T.

The only significant displacements in the magnetic elements, as shown in Magnetogram No. 16, occurred during the final stages of the active phase and the transition to diffuse surfaces. Comparison of this magnetogram with that of 6/7 May (Magnetogram No. 10) is interesting. On both nights active displays of fairly long duration occurred, but whereas that of 6/7 May was largely an overhead display, that of 10/11 September was confined to the region at 9°–17° elevation above the southern horizon, i.e. some 2°–4° of geomagnetic latitude south of Halley Bay. The difference in magnitude of the magnetic disturbances suggests that those associated with an active display are severely localized.

In Plate V, figs. 79–85, a series of prints from the all-sky camera film shows the final stages of the active display and the decay to diffuse surfaces.

IV. COMPARISON WITH PREVIOUS YEARS' OBSERVATIONS

1. Introduction

In this section a brief study is made of the changes that have taken place in the aurorae seen from Halley Bay in the years 1956–1960. The data used have been obtained from the auroral section by Evans and Thomas in *The Royal Society International Geophysical Year Expedition, Halley Bay, 1955–1959*, Volume I (Brunt, ed., 1960), from the M.Sc. Thesis of Sheret and from the observations made during 1960 by the present writer. Included in this five-year period was the 1957–58 maximum in the eleven-year cycle of solar activity.

This data is inadequate for a complete statistical survey of the displays occurring in the five years, chiefly because observations were made for only some six months in each year and even these were incomplete because of the prevalence of cloud. A second reason is that the observations were made by four different observers. A certain degree of subjectiveness is unavoidable in classification of observing conditions, of forms during transition periods and of brightness of forms. This inevitably varies from observer to observer giving rise to inconsistencies in the data.

In order to minimize these objections only data obtained in clear dark periods have been used. Apart from a slight tendency for large, active displays to occur more frequently close to the equinoxes, no significant seasonal variations in the displays were reported. Thus, if it is accepted that the seasonal and diurnal distribution of clear dark periods in each year came fairly close to being random, this data can be considered as representative of the displays occurring in the period mid-March to the end of September in each year.

2. Probability of Occurrence of the Aurora

The first comparisons made are of the probabilities of occurrence of aurorae anywhere in the sky and of aurorae in the zenith (i.e. above 60° elevation). These probabilities have been obtained by dividing the numbers of clear dark periods when aurorae were present by the number of such periods as is shown in Table X. They are given graphically in Fig. 22b. Half-hourly periods have been used in 1956 and quarter-hourly ones in subsequent years.

The mean daily sunspot numbers for the total period of observation in each year, as derived from the data in the relevant Royal Greenwich Observatory Circulars, are given for comparison in Fig. 22a. The median latitudes of the quiet arcs with their interquartile ranges are given in Fig. 22c.

These three figures show that the probability of occurrence of aurorae approached unity, and the zenith probability reached a maximum during the 1958 season when the greatest solar activity occurred. As solar activity has decreased the probability of aurorae has also decreased and the quiet-arc zone has expanded equatorwards, continuing in 1960 the trend noted by Thomas and Sheret in 1959. The proportionately greater occurrence of overhead aurorae in 1960 suggests that the equatorward movement of the quiet-arc zone is indicative of the movement of the entire auroral zone.

TABLE X

PROBABILITY OF OCCURRENCE OF AURORAE

Year	*Number of Periods**	*Number with Aurorae*	*Percentage Probability of Aurorae*	*Number with Zenith Aurorae*	*Percentage Probability of Zenith Aurorae*
1956	934	522	56·0	126	13·5
1957	1,055	946	89·7	255	24·2
1958	1,184	1,170	98·8	337	28·4
1959	945	888	94·0	108	11·4
1960	1,350	930	68·9	156	11·5

* Clear dark periods.

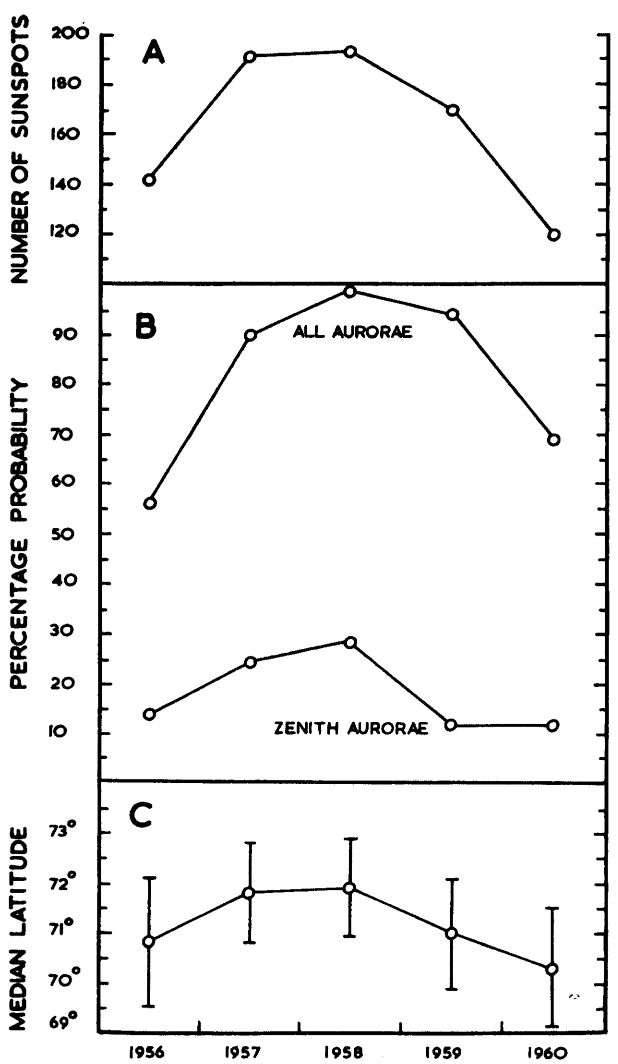

FIGURE 22

A. Mean daily sunspot numbers during period of observation.
B. Percentage probability of occurrence of aurorae.
C. Median latitudes of quiet arcs.

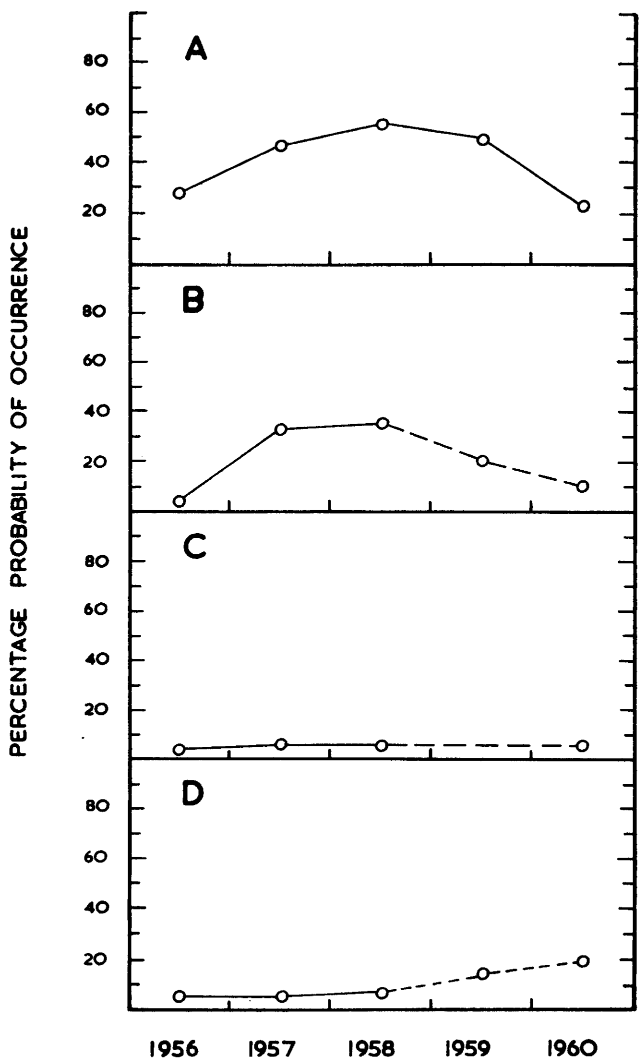

FIGURE 23

Probability of occurrence of various auroral forms.

This equatorward expansion of the quiet-arc zone in phase with the decreasing solar activity is not easily explained in terms of direct penetration of streams of charged particles from the sun. The discovery of the Van Allen radiation belts has, however, led to new theories of auroral morphology. Though these are still incomplete, they offer the prospect of a more satisfactory explanation of this movement. The data obtained from satellite observations suggest that the outermost of these belts, lying at a distance of from 3–4 earth radii, consists mainly of solar emission trapped in the earth's field (Gold, 1959), and has shown it to be highly sensitive to solar and geomagnetic disturbances (Arnoldy, Hoffmann and Winckler, 1960). In an early paper Van Allen and Frank (1959) pointed out that projections along the dipole field lines from the "horns" of the outer belt reached the earth's surface in auroral zone latitudes. Thus, in current theories of the aurorae (for example, Kern and Vestine, 1961), it is assumed that the activating charged particles escape from this belt. Should the relationship between the "horns" of the belt and the quiet-arc zone prove to be geometrical, then the equatorward movement of the latter would imply a contraction or lowering of the belt as solar activity decreases.

The probabilities of occurrence of quiet arcs, rayed forms, homogeneous bands and diffuse surfaces in clear dark periods are shown in Table XI and in Fig. 23. Owing to the different treatment of the 1959 data no directly comparable figures for the latter three forms are available. The figures quoted in the rayed forms and DS columns of the 1959 line of Table XI are the probabilities of occurrence of all active forms and of diffuse surfaces in clear dark and clear moonlit periods.

A proportionate increase in the probability of DS and to a lesser extent of homogeneous bands is seen to have occurred as the over-all probability has decreased since sunspot maximum.

TABLE XI

PROBABILITY OF OCCURRENCE OF QUIET ARCS, RAYED FORMS, HOMOGENEOUS BANDS AND DIFFUSE SURFACES

	*Number of Periods**	*Number of HA*	*Percentage Probability of HA*	*Number of Active Forms*		*Percentage Probability of Active Forms*		*Number of DS*	*Percentage Probability of DS*
				R	*B*	*R*	*B*		
1956	934	261	28	40	35	4·3	3·7	46	4·9
1957	1,055	497	47	346	62	33	5·9	48	4·5
1958	1,184	665	56	428	69	36	5·8	75	6·3
1959	945	473	50			20·2†			14†
1960	1,350	307	23	137	74	10·1	5·5	256	19

* Clear dark periods.
† Probability of occurrence in clear dark and clear moonlit periods.

3. Comparison of Diurnal Frequencies

In this section the diurnal variations in frequency of occurrence of all aurorae and of selected forms in each of the five years are compared.

a. *All aurorae*

The hourly frequencies of occurrence of aurorae and of zenith aurorae are listed in Tables XII and XIII, respectively, and presented graphically in Fig. 24. Since sunspot maximum, the over-all probability of occurrence of aurorae has decreased and the time of maximum frequency of occurrence has shifted towards the morning hours. This trend is particularly noticeable in the frequencies of zenith aurorae. It can be accounted for, at least partly, by the increase in the frequency of occurrence of diffuse surfaces (see Figs. 23 and 27) which are essentially a morning feature of the displays.

b. *Individual forms*

The diurnal frequencies of quiet arcs, rayed forms and diffuse surfaces in each of the five years are listed in Tables XIV, XV and XVI, and shown graphically in Figs. 25, 26 and 27, respectively. No

TABLE XII

DIURNAL FREQUENCIES OF AURORAE

Period (hr. U.T.)	18	19	20	21	22	23	24	01	02	03	04	05	06	07	08	09	10	1100
1956		16	19	17	36	75	72	76	94	95	72	60	40	34				
1957	58	38	37	69	86	92	97	100	98	95	99	100	100	92	100	100		
1958	100	94	86	98	96	96	100	100	100	100	100	100	100	100	100	100		
1959	76	80	89	94	93	88	92	97	100	100	100	99	99	97	93	90	92	
1960			41·6	36·0	45·1	68·5	75·0	81·5	85·7	90·3	90·1	82·2	70·2	61·6	43·7	31·3		

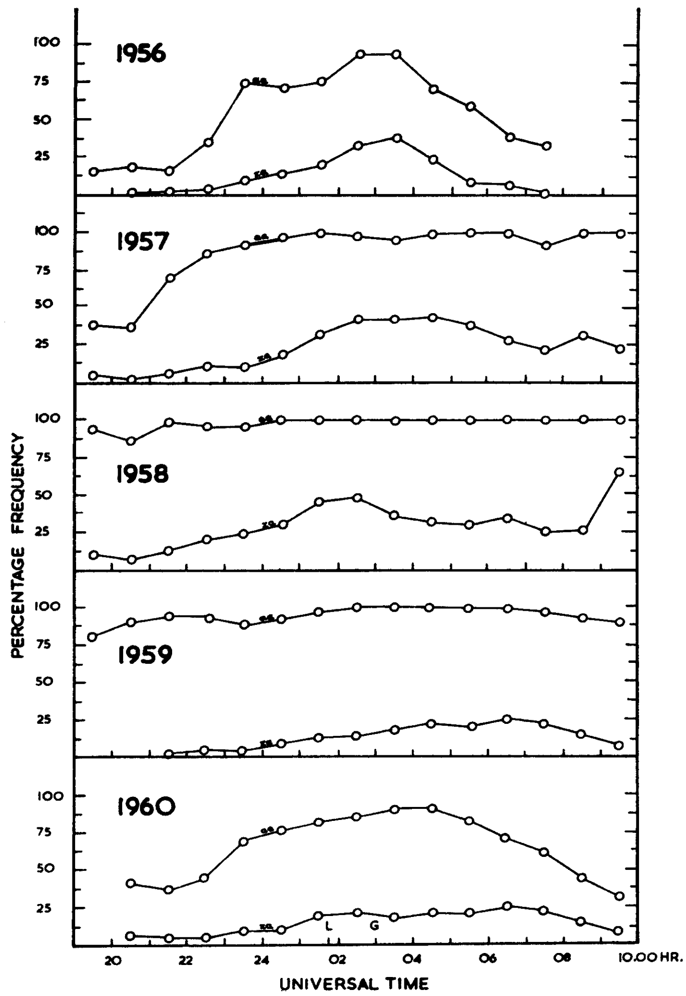

FIGURE 24

Diurnal frequencies of occurrence of all aurorae and of zenith aurorae.
aa. All Aurorae
za. Zenith aurorae
G. Geomagnetic midnight
L. Local midnight

TABLE XIII

DIURNAL FREQUENCIES OF ZENITH AURORAE

Period (hr. U.T.)	18–19	19–20	20–21	21–22	22–23	23–24	24–01	01–02	02–03	03–04	04–05	05–06	06–07	07–08	08–09	09–10	10–11
1956			1	3	4	10	15	20	33	39	24	8	7	1			
1957		4	1	6	11	10	18	32	42	42	44	38	28	22	32	23	
1958		10	6	12	20	21	30	44	48	36	31	29	35	25	26	66	
1959				2	4	4	8	13	13	18	22	20	25	22	15	8	
1960			5·5	3·9	4·4	8·9	9·5	19·2	20·6	17·8	21·4	10·4	10·6	9·3	1·6		

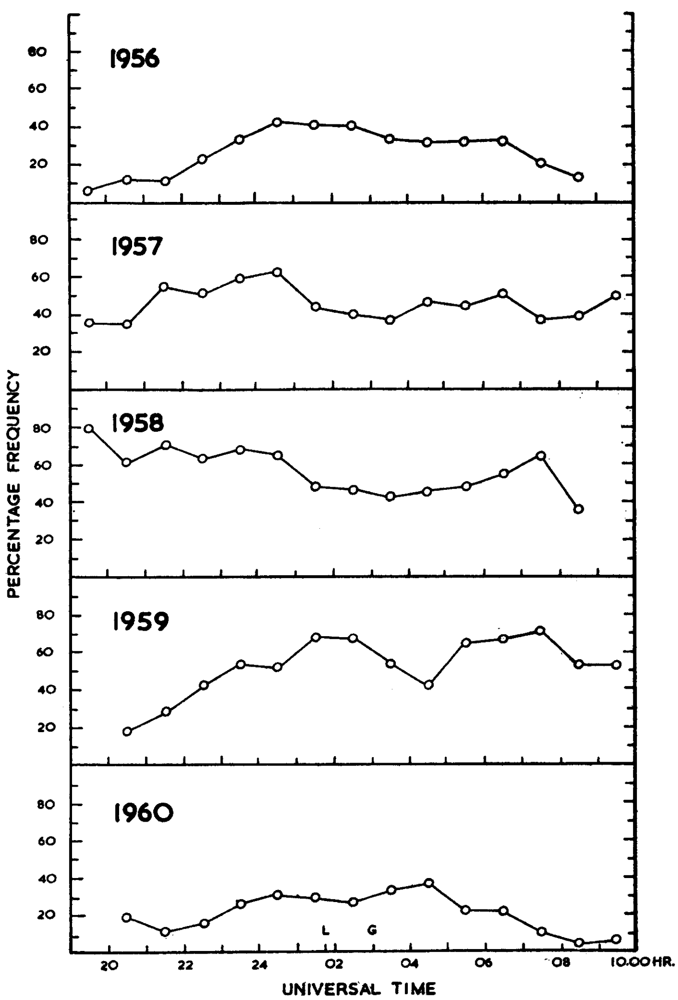

FIGURE 25

Diurnal frequency of occurrence of quiet arcs.
G. Geomagnetic midnight
L. Local midnight

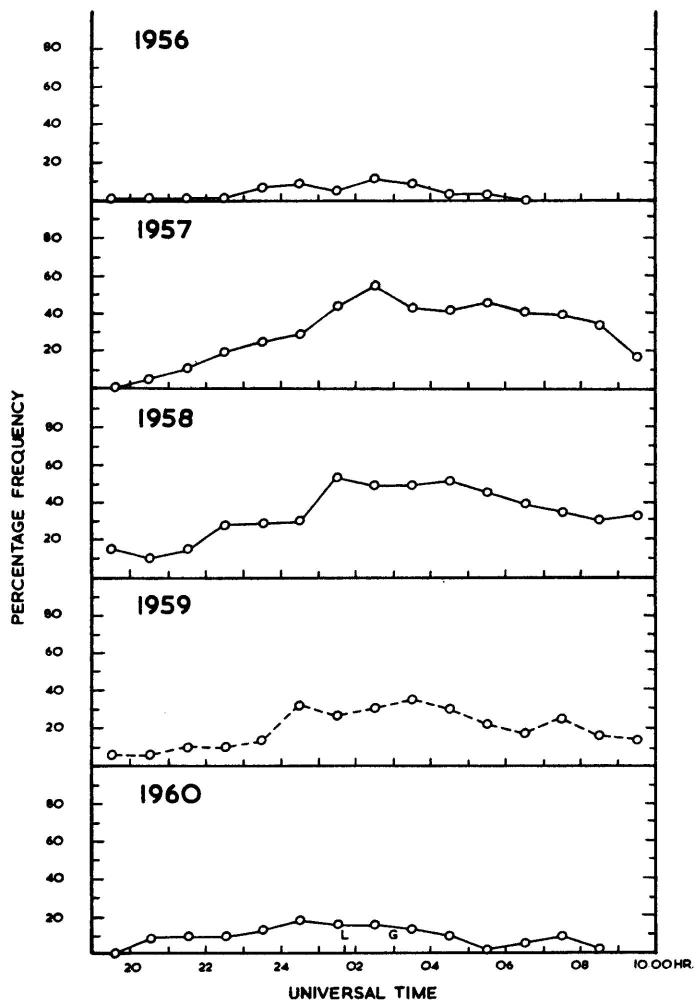

FIGURE 26

Diurnal frequency of occurrence of rayed forms.
G. Geomagnetic midnight
L. Local midnight

directly comparable data are available for 1959 concerning rayed forms and diffuse surfaces, and diurnal frequencies of all active forms and of diffuse surfaces in clear dark and clear moonlit periods have therefore been quoted. The proportionate frequency of occurrence of homogeneous active forms is small (see Fig. 23), but as active forms and diffuse surfaces can be distinguished easily even in bright moonlight the degree of uncertainty in the observations is also small. Thus, for the purpose of detecting any significant

TABLE XIV

DIURNAL FREQUENCIES OF QUIET ARCS

Period (hr. U.T.)	18	19	20	21	22	23	24	01	02	03	04	05	06	07	08	09	10	1100
1956		5·8	11·3	10·3	22·2	33·8	42·4	41·0	41·0	33·4	31·6	32·4	32·8	21·4	13·6			
1957	17·7	35·8	35·2	55·8	51·8	60·0	63·2	44·0	40·0	37·0	47·6	44·7	51·5	37·7	39·5	50·0		
1958	64·3	80·0	60·5	70·6	63·4	68·4	65·5	48·5	47·0	42·7	46·0	48·5	55·0	65·4	36·4			
1959			18	28	42	54	52	68	67	54	42	64	67	72	53	53	62	
1960			19·5	10·7	16·0	25·8	30·2	28·8	26·2	33·0	36·9	21·9	21·3	10·5	4·7	6·2		

TABLE XV

DIURNAL FREQUENCIES OF RAYED FORMS

Period (hr. U.T.)	18	19	20	21	22	23	24	01	02	03	04	05	06	07	08	09	10	1100
1956	0	0·9	0·6	0·5	0·4	6·8	9·0	5·1	11·5	9·0	2·6	2·7	0	0	0			
1957	29·4	0	5·6	11·7	19·8	25·2	28·6	44·0	55·5	43·0	41·7	46·0	40·5	39·6	34·2	16·7		
1958	7·1	15·0	10·3	14·6	27·8	28·7	29·9	53·6	49·0	49·0	51·8	45·5	39·4	34·7	30·3	33·3		
1959*	16	6	6	10	10	13	32	26	30	35	30	22	17	25	16	14		
1960		0	8·3	8·7	8·9	12·0	17·5	15·2	15·1	12·5	8·7	1·4	5·3	9·3	1·6	0		

* Frequencies given are those for clear dark and clear moonlit periods.

TABLE XVI

DIURNAL FREQUENCIES OF DIFFUSE SURFACES

Period (hr. U.T.)	18	19	20	21	22	23	24	01	02	03	04	05	06	07	08	09	10	1100
1956	0	0	0	0	1·4	1·4	2·6	8·9	8·9	15·4	10·5	4·1	6·2	3·6	0			
1957	0	0	0	0	0	0·9	2·1	5·4	4·4	9·5	4·8	2·6	9·4	5·7	21·0	27·8		
1958	0	0	0	2·3	1·1	0	0	1·0	11·0	11·5	6·4	9·0	12·5	13·5	30·2	55·6		
1959*	0	0	0	0	1	2	2	11	15	25	28	21	29	31	31	25	13	
1960		0	0	0	0·9	4·7	6·6	13·6	23·0	26·8	37·9	38·6	33·0	41·9	23·4	18·8		

* Frequencies given are those for clear dark and clear moonlit periods.

trends in diurnal frequency, these 1959 data were considered to be comparable in weight to those of the other years.

In Fig. 25 the quiet-arc diurnal frequency curves for 1957, 1958 and 1959 are characterized by pre-midnight and post-midnight maxima, with minima in the early post-midnight period. Although this configuration is also present in the 1960 curve, it is less pronounced and the morning maximum frequency occurs considerably earlier.

Comparison of Figs. 26 and 27 shows that as the drop in frequency of the active forms has commenced progressively earlier in the night in 1959 and 1960, so has the increase in frequency of the diffuse surfaces. This suggests that the average duration of the active stage in the displays is decreasing as the over-all frequency and the solar activity decrease.

4. Positions of Quiet Arcs

a. *Latitude distribution*

The median positions of quiet arcs and their interquartile range, defining the quiet-arc zone, in each year were discussed on p. 12–13. It was shown that in 1960 the quiet-arc zone continued moving equatorwards from its position of closest approach to the geomagnetic pole at sunspot maximum. In Fig. 28 the diurnal variations in position of the quiet arcs in each year are shown in terms of their hourly median

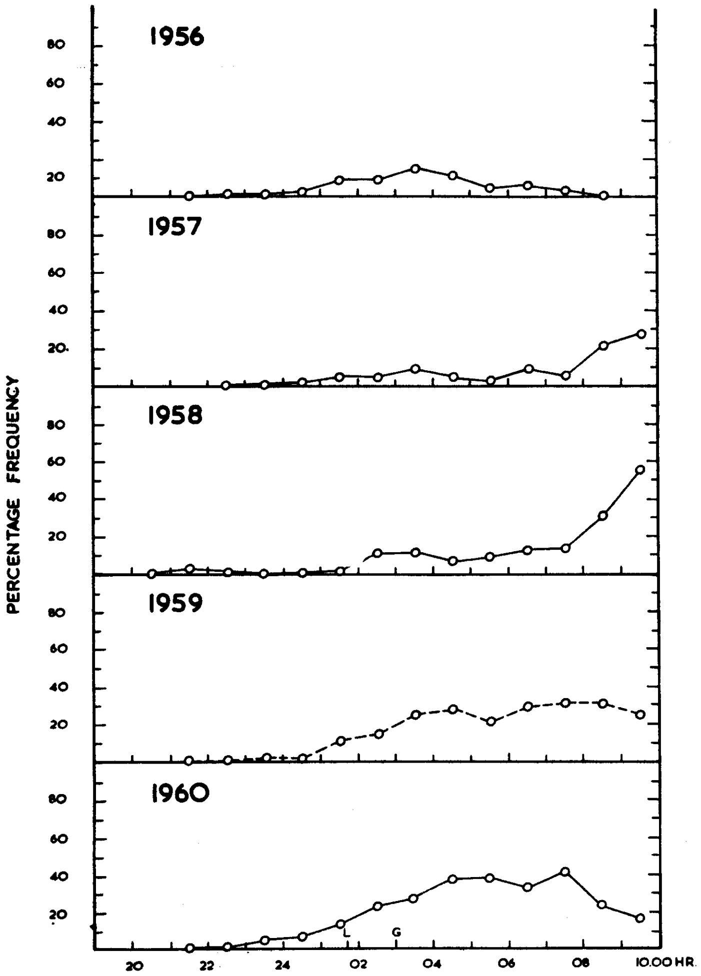

FIGURE 27

Diurnal frequency of occurrence of diffuse surfaces.
G. Geomagnetic midnight
L. Local midnight

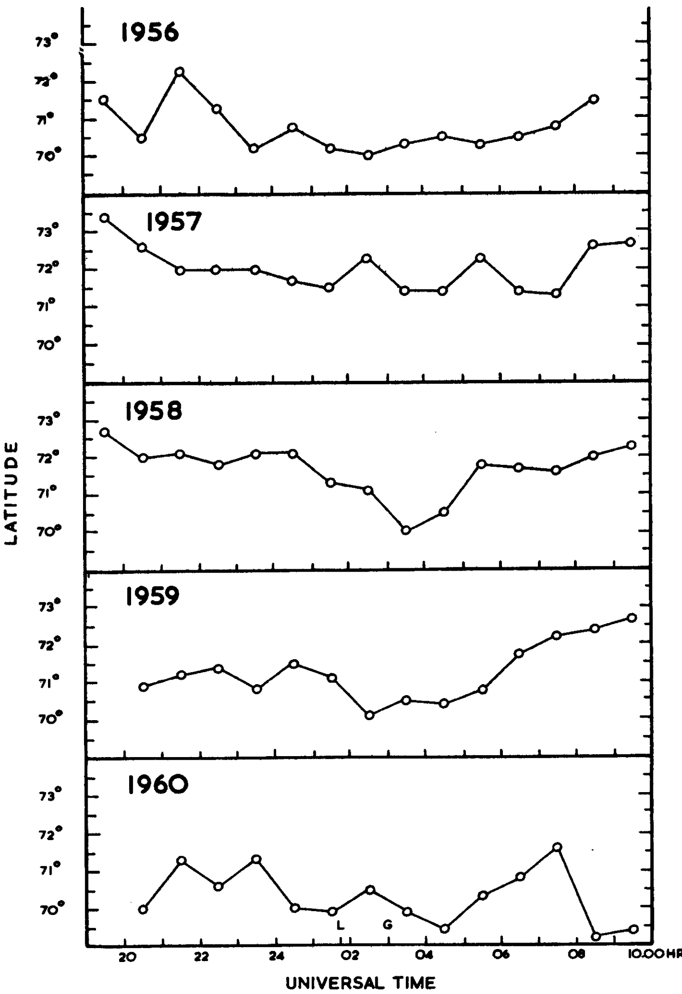

FIGURE 28

Hourly median latitudes of homogeneous arcs.
G. Geomagnetic midnight
L. Local midnight

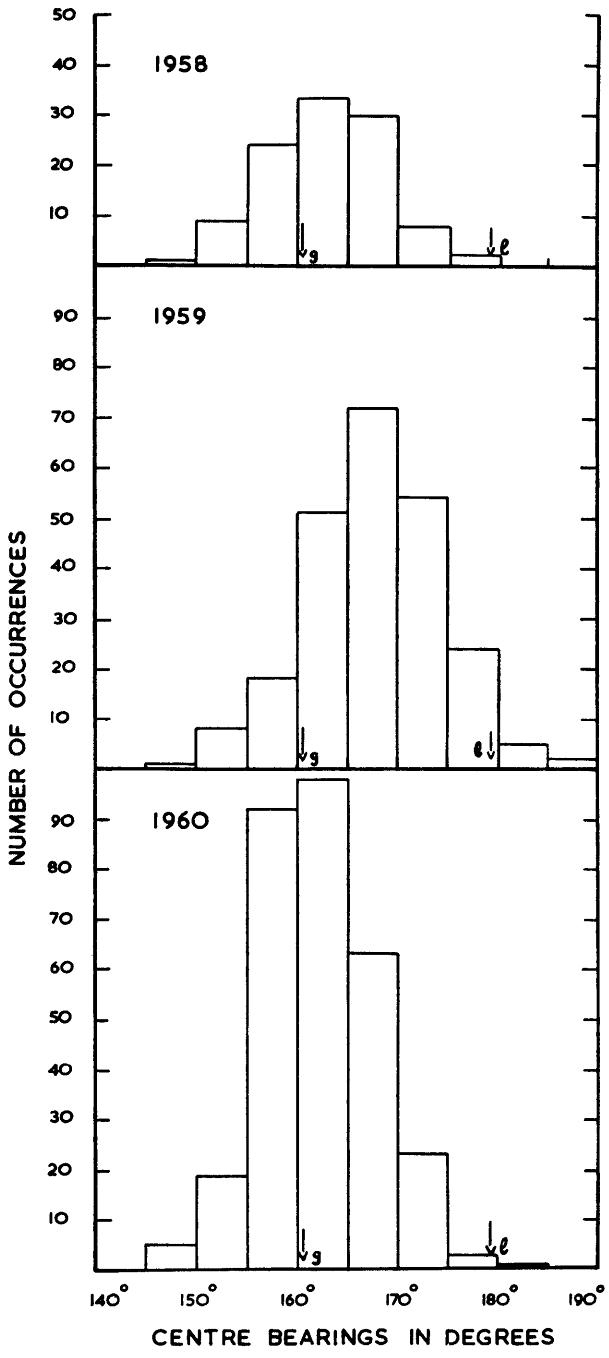

FIGURE 29

Distribution of centre bearings of quiet arcs.
g. Geomagnetic south
l. Local magnetic south

latitudes. In each year the arcs advance equatorwards in the pre-midnight period, reaching a maximum northerly displacement between 0200 and 0500 U.T., and then recede southwards again. The low median latitudes in 1960 between 0800 and 1000 U.T. were discussed on p. 13.

b. *Distribution of centre bearings*

The distribution of centre bearings of quiet arcs in 1958, 1959 and 1960 are shown in histogram form in Fig. 29. Although a considerably greater number of measurements were made in 1959 and 1960 the distribution is essentially the same, showing the greater influence of the dipole field.

Hourly mean centre bearings for the years 1957–60 are given in Fig. 30 and show the slow westward drift of the arcs throughout the night, already discussed on p. 15–16. Both Figs. 29 and 30 show an additional westward shift of the 1959 bearings, which suggests that the shift may have been a real one and not merely due to the maximum frequencies of occurrence being reached later in the night in 1959.

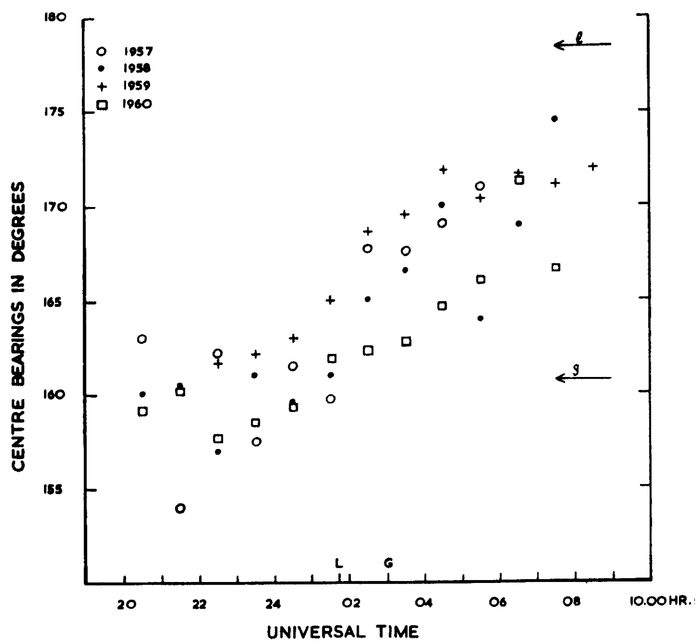

FIGURE 30

Hourly mean centre bearings of homogeneous arcs.
G. Geomagnetic midnight
L. Local midnight

During the I.G.Y. there was a diurnal rotation of the orientation of homogeneous arcs and bands seen from Wilkes, Dumont D'Urville, Hallett and Scott bases, in such a sense that the forms remained aligned on the azimuth of the sun (Denholm and Bond, 1961). These bases are all situated well inside the auroral zone. The data from Halley Bay show no such movement. On the contrary, the small diurnal change in orientation is in the opposite sense to the movement of the azimuth of the sun, and when considered in conjunction with the diurnal change in median latitudes it approximates fairly closely to the movement of a zone eccentric in local time co-ordinates as proposed by Evans and Thomas (1959).

V. CONCLUSIONS

THE following paragraphs summarize the main points arising out of the analysis of the 1960 data and the comparison of the results with those of previous years.

1. A close study of glows showed that they were distinctive quiet auroral forms and not merely the upper limits of other forms below the horizon. Those seen from Halley Bay appeared to be different in character from the extensive sub-visual red glows reported from stations inside the southern auroral zone.

2. Flaming in 1960 was observed to occur only over diffuse surfaces or the combination of diffuse surfaces and very diffuse rays which was a common feature of the latter stages of a display. It appeared to commence as a regular wave motion, with a period of about 0·5 sec. or less, and then gradually to become irregular and sporadic. Its direction was extremely difficult to determine. When the combination of diffuse surfaces and diffuse rays was present in the zenith, a weak coronal effect was visible with the radiation point at the same elevation as the magnetic zenith but lying close to the direction of the geomagnetic meridian in azimuth. The direction of the motion then appeared to be towards this point from all directions.

3. Vegard type B red coloration and the horizontal undulating motion of brightness, with which it appeared to be closely correlated, were observed to occur not only during break-up but also during later enhancements in the brightness of active forms. The distribution of occurrences of this colour showed no seasonal variation but had a marked diurnal peak in the pre-midnight period. Vegard type A red, on the other hand, was observed to occur 16 times between mid-March and mid-May and only once from mid-May until the beginning of October. These 17 occurrences showed a random diurnal distribution, but it was remarkable that the colour always appeared first in the western or south-western sectors of the display irrespective of the time of occurrence.

4. Although variations in the sequence of forms occurring in displays were observed, one sequence was found to occur most frequently. This consisted of the appearance of quiet forms (quiet arc or glow), a transition to active forms (rayed forms or homogeneous bands), the decay of these into diffuse surfaces and finally the re-formation of a quiet arc as the diffuse surfaces receded southwards.

5. Comparison of the descriptions of displays with the Halley Bay magnetograms showed that there was no simple correlation between the type and position of a display and the simultaneous pattern of magnetic disturbance. Quiet displays were normally accompanied by very small disturbances. The transition to active forms was normally associated with decreasing bays in H and V, but the sign of the displacement in D varied on such occasions. During prolonged active displays the displacements in all three elements were extremely complex, but they were always considerably greater in magnitude for overhead displays than for those occurring south of the station.

6. The over-all frequency of occurrence of aurorae, in that part of the sky visible from Halley Bay, was found to have decreased in 1960, and thus continued the downward trend from the peak frequency which coincided with the sunspot maximum in 1957–58. A well-defined maximum diurnal frequency of occurrence between 0300 and 0500 U.T. was found in 1960.

7. The frequencies of occurrence of quiet arcs and of active forms had also decreased since 1957–58, while there was some evidence of a relative increase in the frequency of diffuse surfaces.

8. The median position of homogeneous quiet arcs was found to have shifted equatorwards by 0·7° of geomagnetic latitude since 1959. This small movement was similar to that recorded in 1959 and provided further evidence of an equatorward expansion of the quiet-arc zone as solar activity decreases. It was also consistent with the hypotheses of a close geometrical relationship of the zone with the "horns" of the outer Van Allen radiation belt, and of the contraction of this belt with the decrease in solar activity.

9. The diurnal variation of the median latitudes of quiet arcs showed a maximum equatorward displacement close to 0200 hr. local time, and the mean centre bearings of quiet arcs showed a gradual westward movement throughout the night in the range 157° to 172° east of true north. These two movements were similar to those recorded in each of the previous years and were consistent with the proposed model of a circular quiet-arc zone, with centre displaced along the 0200 hr. local time meridian from the geomagnetic axis point.

VI. RECOMMENDATIONS FOR FUTURE WORK

CONTINUATION of the programme of observations throughout the present solar cycle should yield further important information on the movement of the quiet-arc zone. It should be interesting to compare the data obtained, with the ionospheric soundings and auroral radar observations which are now being carried out at Halley Bay.

If the northward movement of the zone continues, a number of the unusual forms reported from inside the auroral zone should become visible from Halley Bay.

VII. ACKNOWLEDGEMENTS

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The maintenance of the auroral observations throughout the period of darkness was made possible only by the generous co-operation of all members of the party at Halley Bay during 1960.

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APPENDIX

THE ALL-SKY CAMERA FILM

The film used in the all-sky camera during 1960 was Ilford H.P.3 negative 16 mm. perforated cine film. This was supplied in 100-ft. reels. The frame size was such that 40 frames occupied one foot length of film. Using the exposure sequence given on p. 6, 5 ft. of film was exposed in one hour of operation. When approximately 50 ft. of film had been exposed, it was removed from the camera and developed. This provided a frequent check on the operation of the camera.

The film was developed in total darkness in a Todd tank using Ilford I.D.33 contrast developer. A standard developing time of 15 min. at 20° C. was adopted. By developing to finality in this way maximum contrast was obtained at the expense of some increase in grain size. Development was followed by 10 min. fixing in Ilford I.F.2 fixer and one hour's washing with five changes of water.

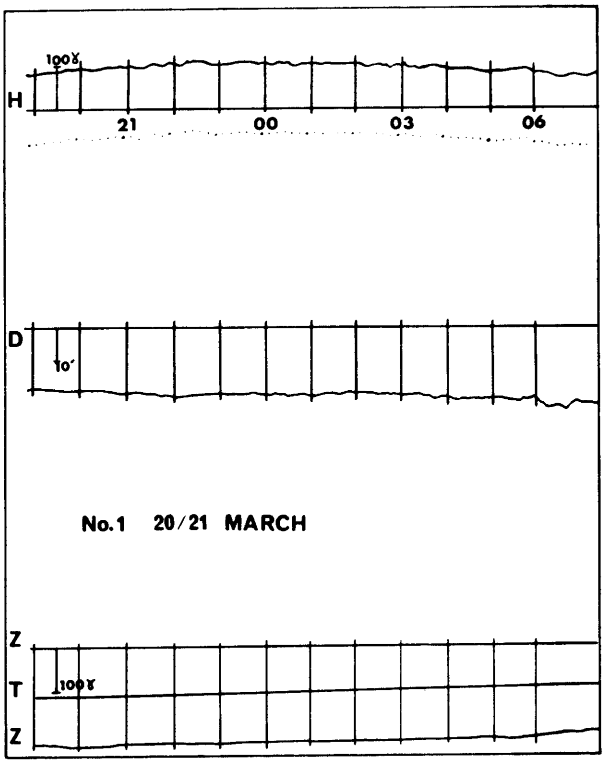
During the season 397 ft. of film were exposed when aurorae were present above 10° elevation from the horizon. Of this, 128 ft. was blurred due to trouble with the camera. Thus 269 ft. of usable film was obtained (i.e. 10,770 frames).

Opinions vary as to whether it is better to use a uniform exposure time or alternate short and long exposures in all-sky camera auroral photography. With a single exposure time a greater number of directly comparable frames can be obtained in a given period, making possible a more detailed study of rapid movements of the forms. If such film is run through a cine projector, an immediate picture of the movements of the forms is obtained. Difficulty is encountered, however, in choosing an exposure time which will "stop" the faster moving bright forms and still record as many as possible of the weaker ones. The alternate short- and long-exposure sequence is much more flexible in this respect as it is possible to select, within the limitations of the film and the camera lens, the optimum times for each of these requirements.

With regard to the times used at Halley Bay in 1960, it was found that under clear dark conditions the 27-sec. exposure recorded all visual forms. In the presence of moonlight or twilight, however, weak forms tended to be blotted out on this exposure. The fact that any form of brightness 2 or greater was recorded on the 3-sec. exposure under normal conditions, suggested that less than 27-sec. would have sufficed for the long exposure. On all but the fastest moving bright active forms the 3-sec. exposure gave a reasonable picture of the fine structure. On the 269 ft. of usable film obtained, the forms present were most sharply recorded on the 3-sec. exposure on 127 ft.

It is felt that at stations, such as Halley Bay, where an observer is always on watch, optimum results would be obtained by using an exposure sequence which could be varied quickly to suit the sky conditions and the type of display.

The photographic paper used in the series of prints from the all-sky camera film was Agfa Brovira BHI W single-weight hard white glossy. This was found to be approximately equivalent to Kodak WSG Grade 4. It was developed for 50 sec. in a 1 : 4 solution of Johnson Contrast Developer. The exposure times were kept constant for each series.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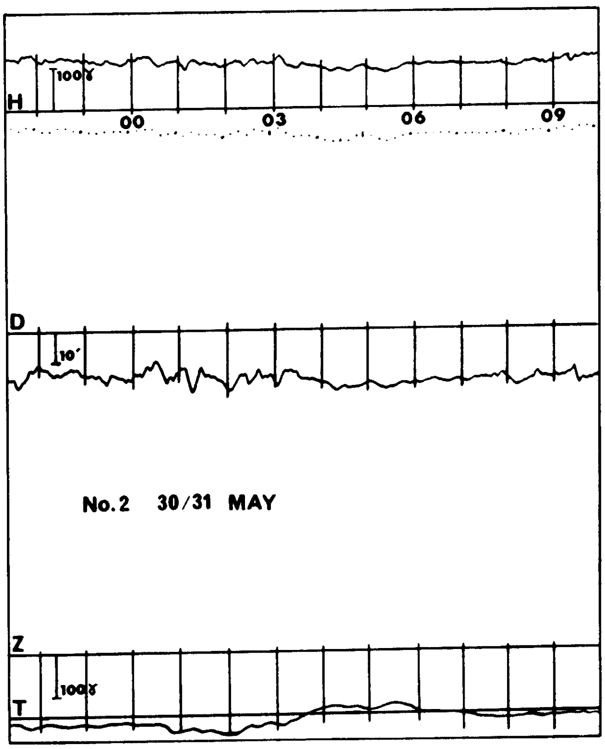
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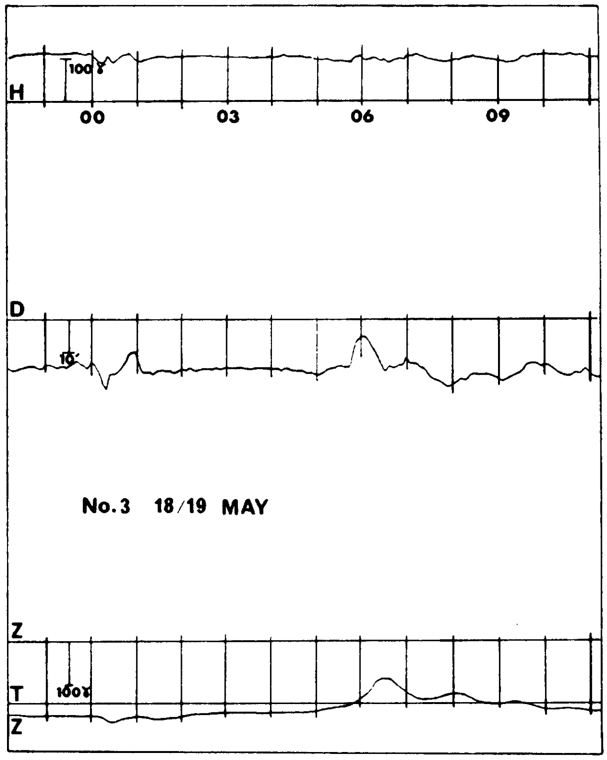
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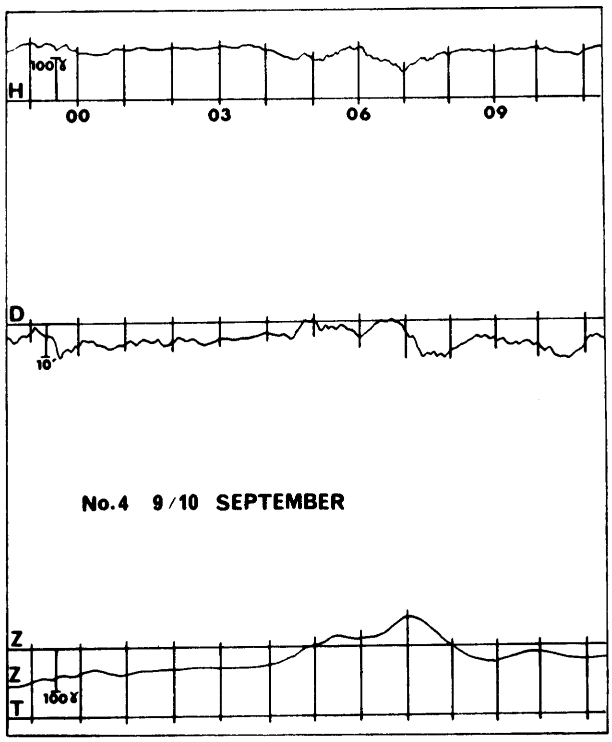
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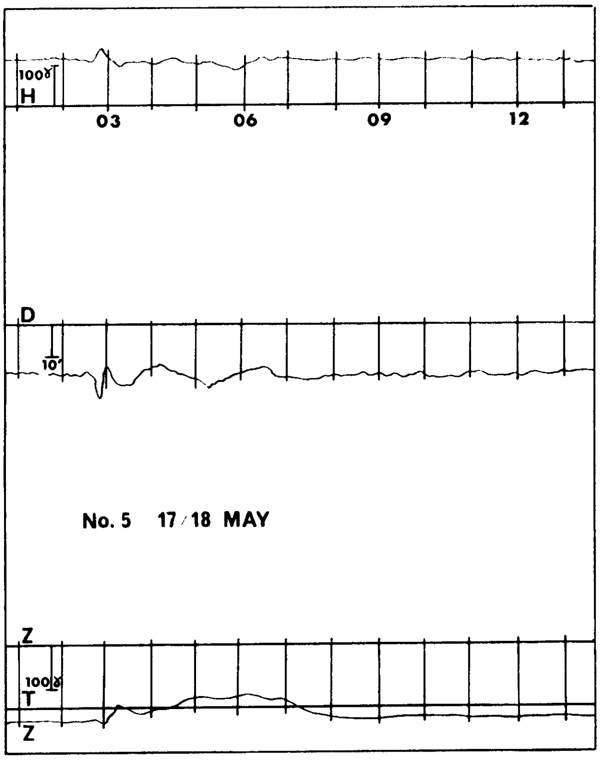
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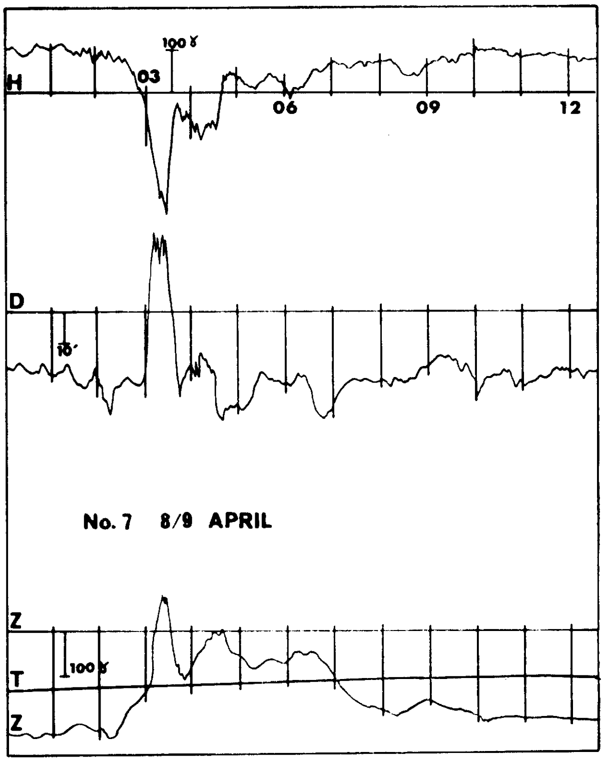
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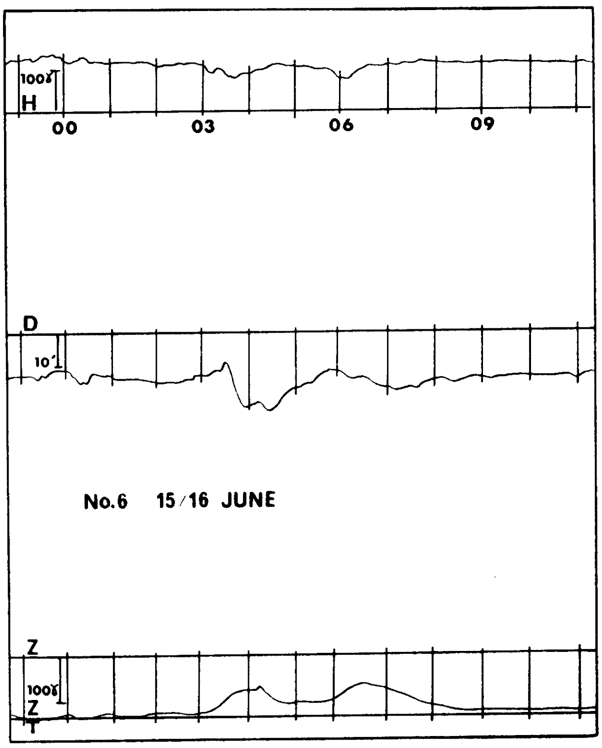
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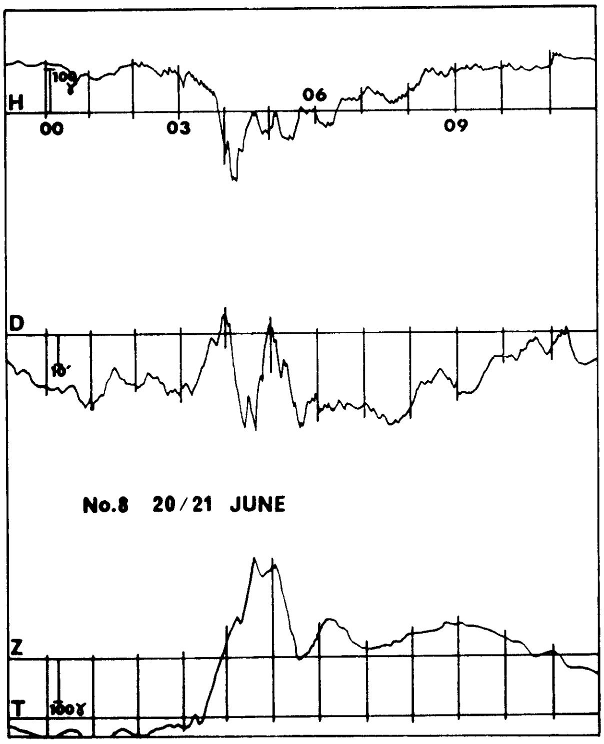
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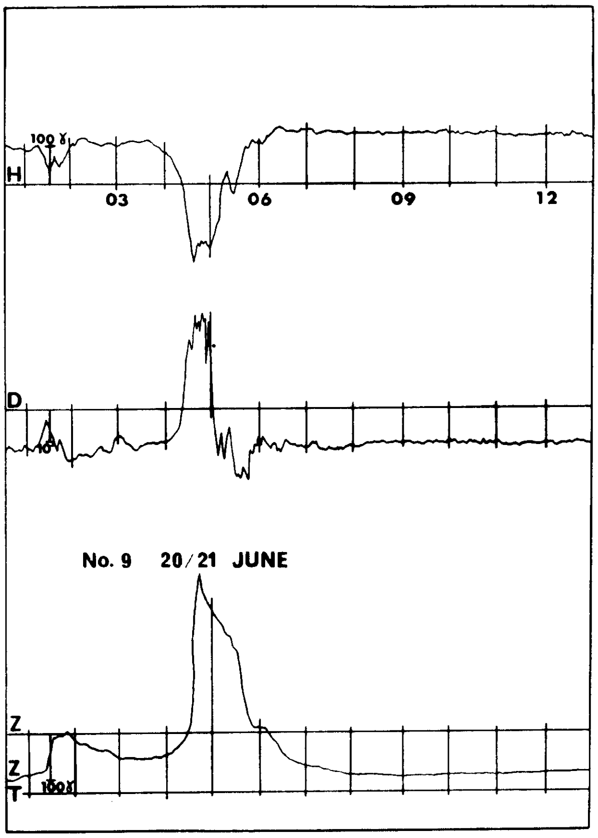

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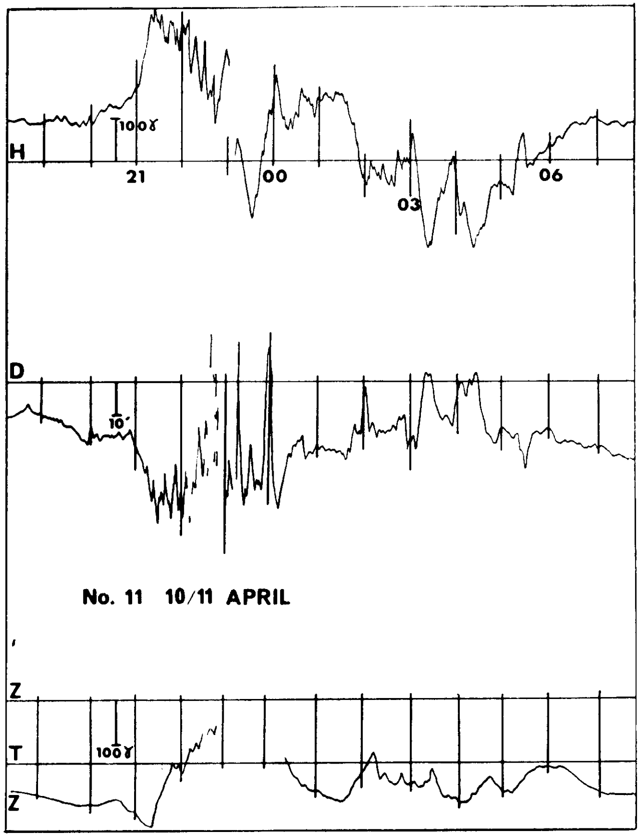

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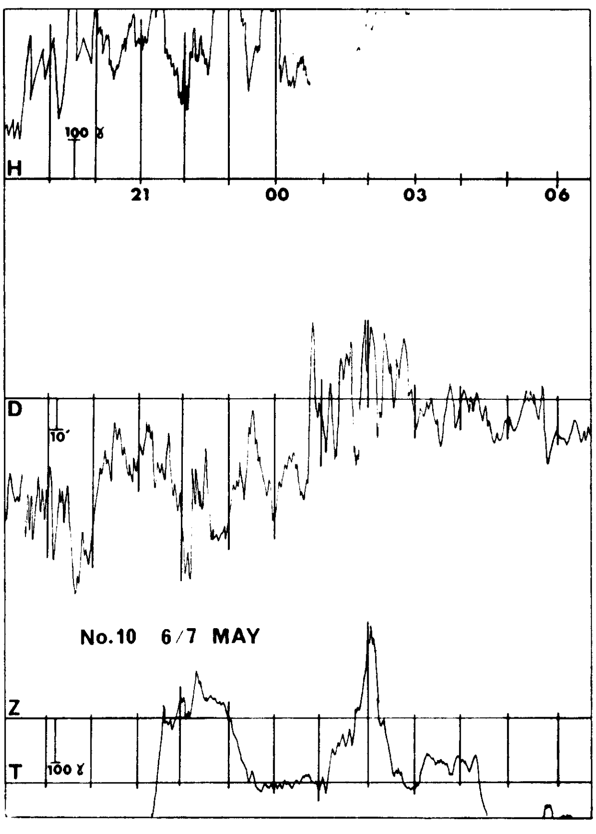

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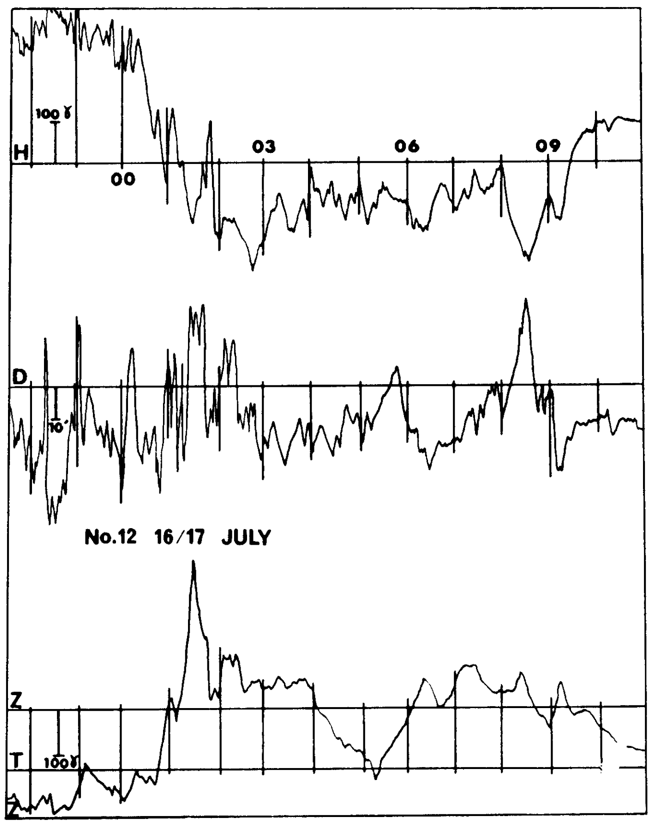

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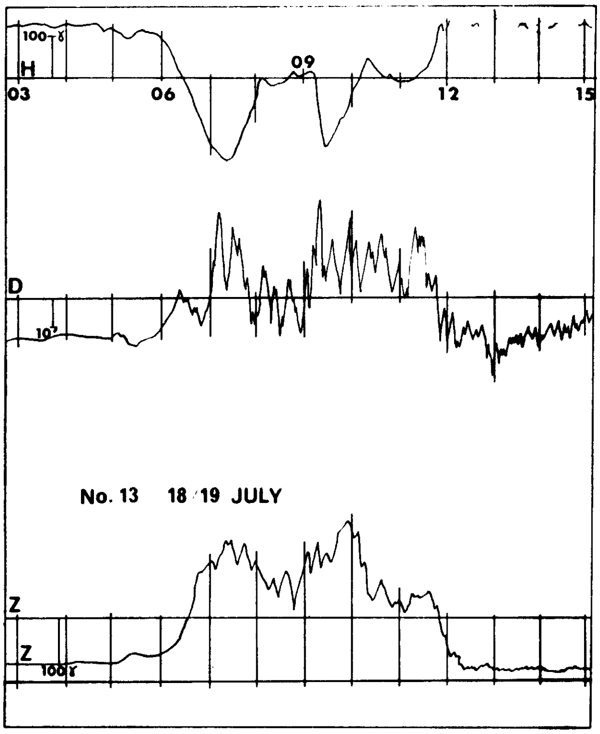

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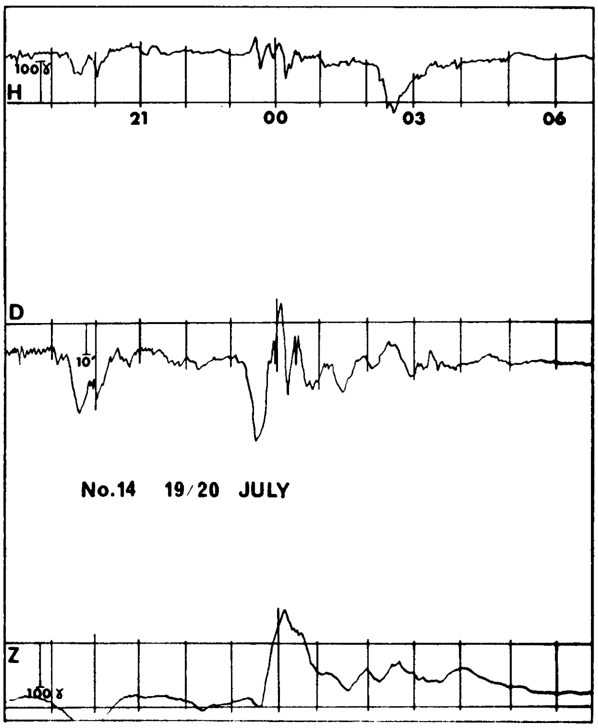

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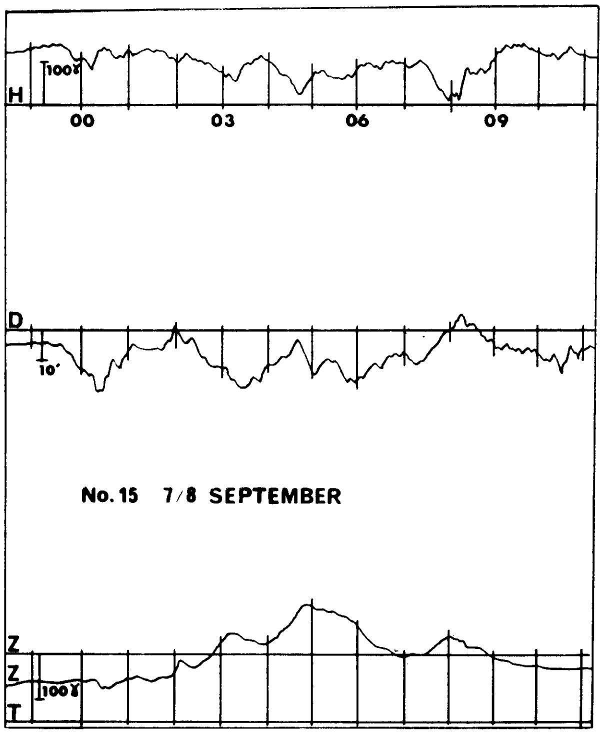

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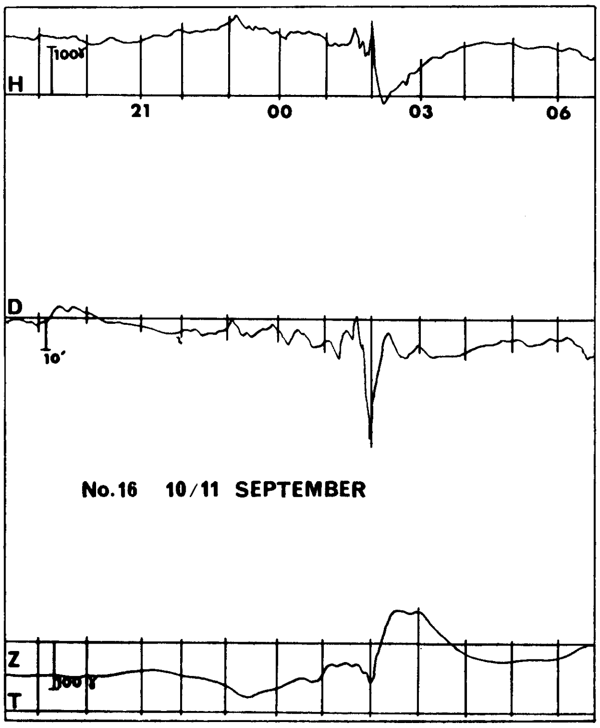

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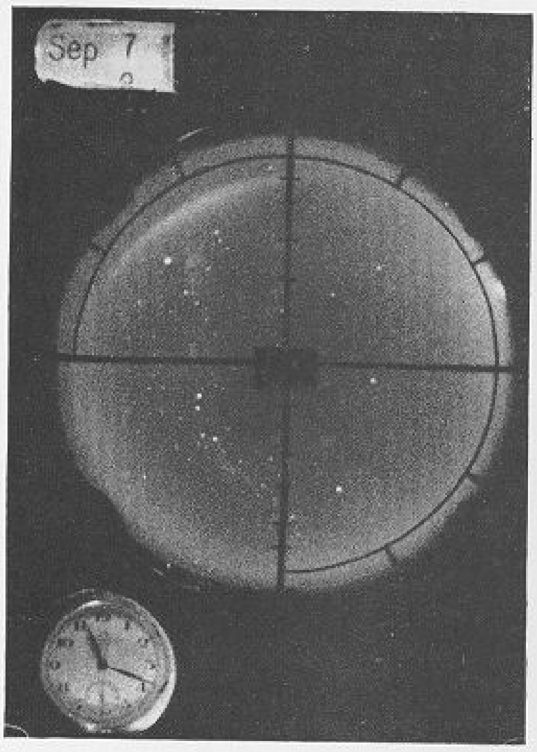
PLATE I

One print from a 27-sec. exposure frame of the all-sky camera film. North is towards the top of the page and east towards the right. The 10° marker ring and the elevation marker bars on the north and south support legs are shown. The Milky Way is recorded in the western sector and the constellations Crux and Centaurus are prominent in the south-western sector. The moon is on the horizon at 70° azimuth. The form is described on p. 35.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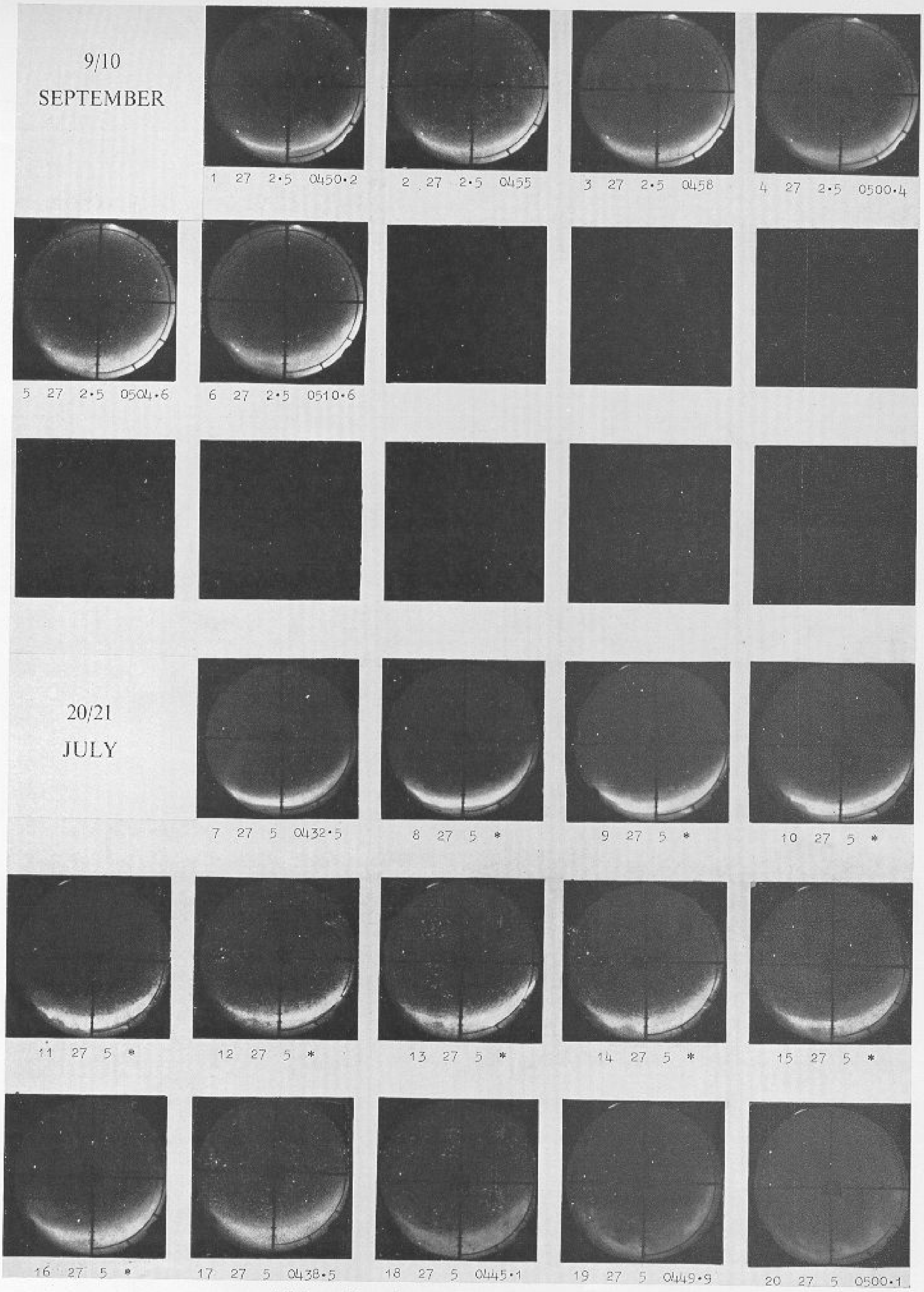
PLATES II–V

Positive prints taken from single frames of the all-sky camera film, processed and printed to produce the maximum contrast.

The date and time which normally appear on each frame (see Plate I) have been omitted so that a larger print of the mirror could be made. The following information is therefore given below each figure: figure number, film exposure in seconds, print exposure in seconds and universal time—in that order.

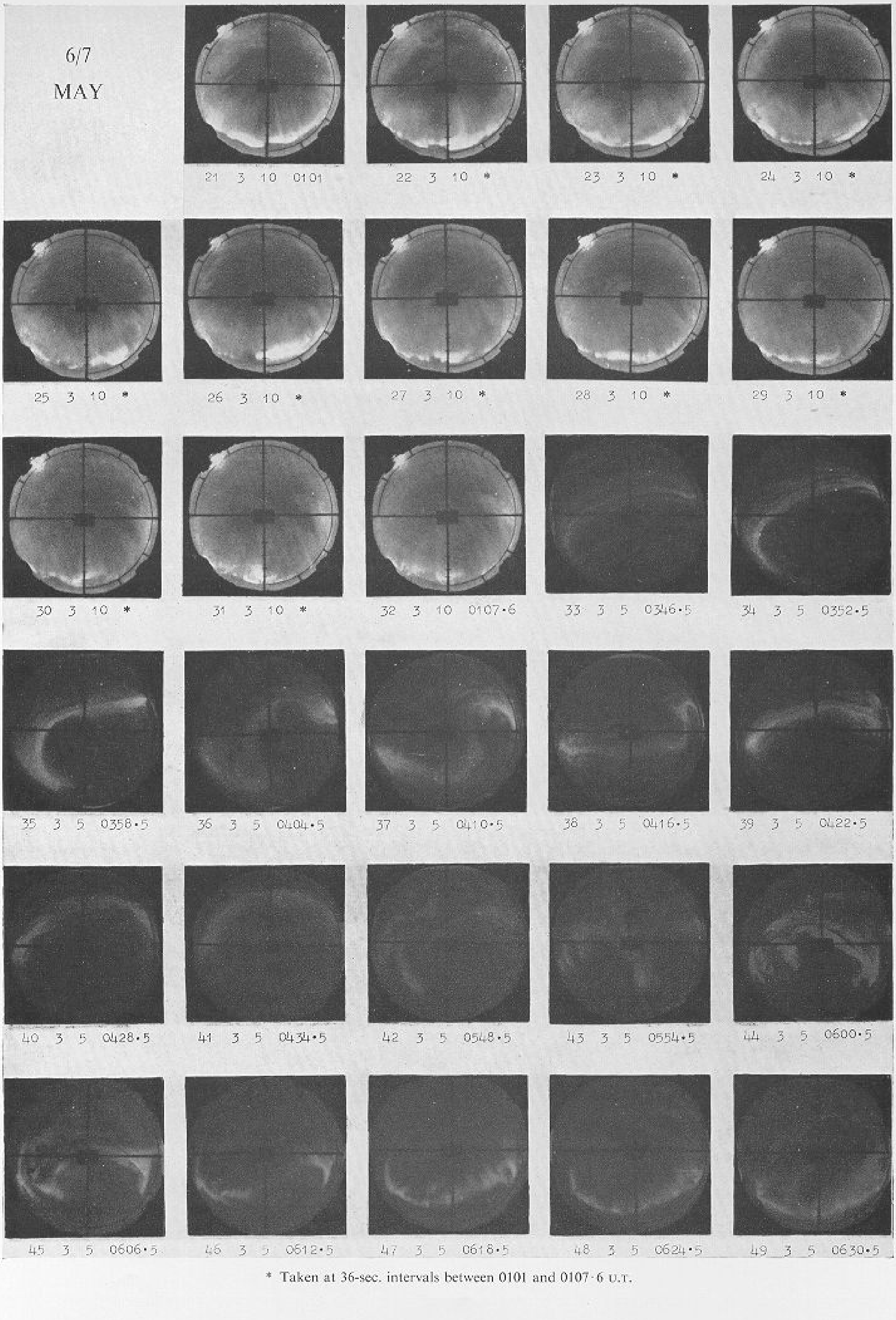
Photographs 1–20



* Taken at 36-sec. intervals between 0432·5 and 0438·5 U.T.

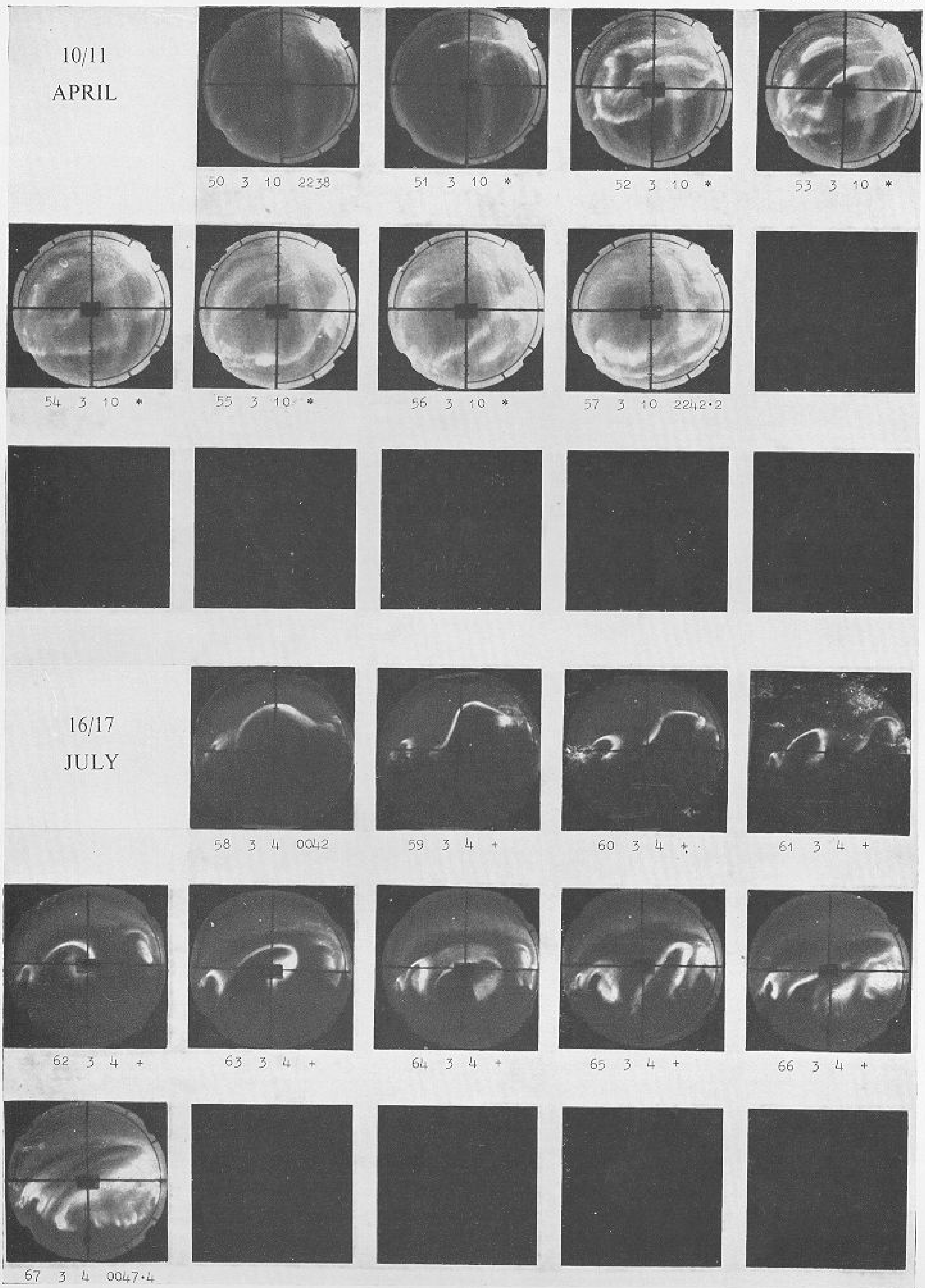
PLATE III

Photographs 21–49



* Taken at 36-sec. intervals between 0101 and 0107·6 U.T.

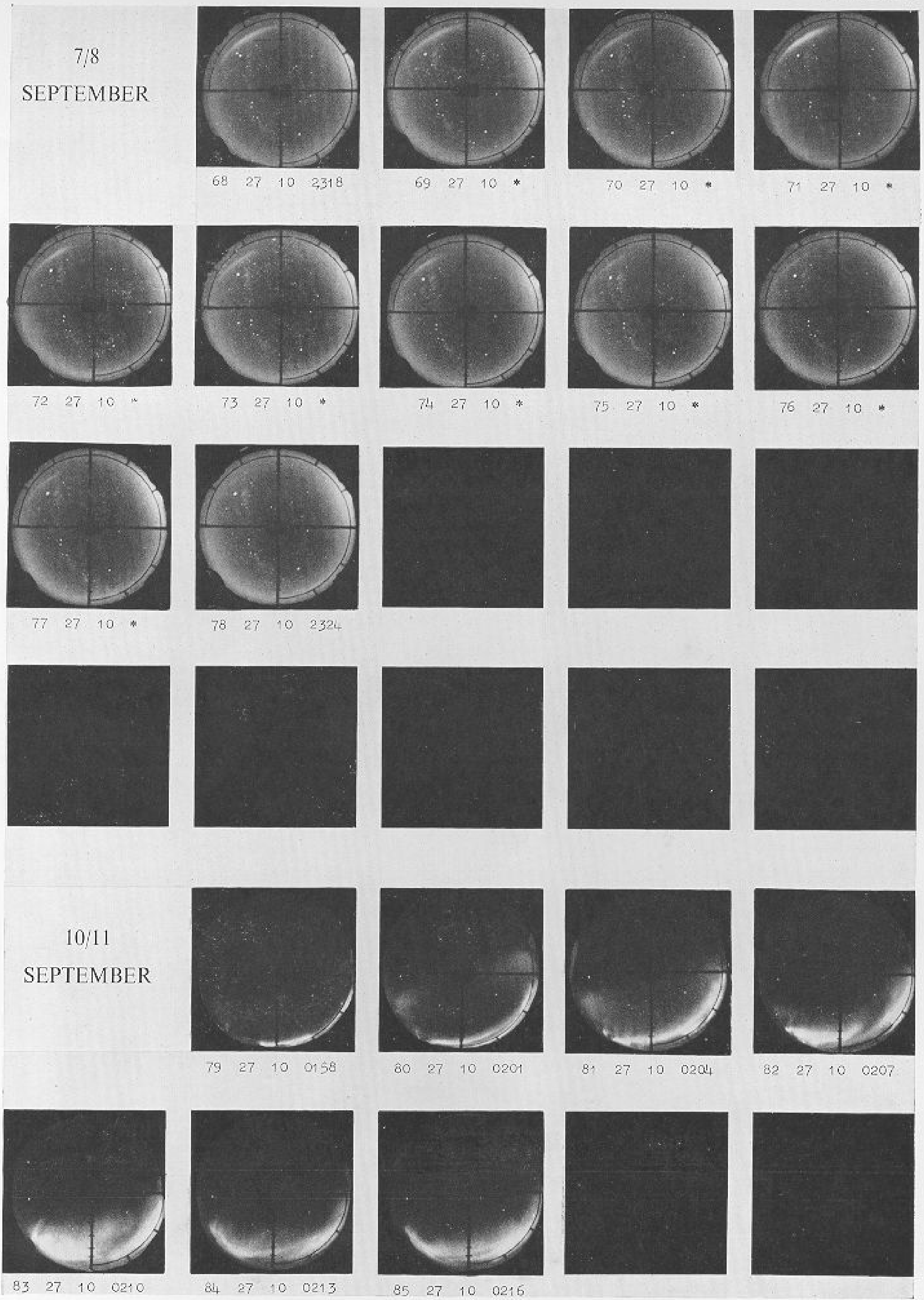
Photographs 50–67



* Taken at 36-sec. intervals between 2238 and 2242·2 U.T.
Display partially obscured by moonlit cirrus.
† Taken at 36-sec. intervals between 0042 and 0047·4 U.T.

PLATE V

Photographs 68–85



* Taken at 36-sec. intervals between 2318 and 2324 U.T.