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ANALYSIS OF
AURORAL OBSERVATIONS, HALLEY BAY, 1959

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ABSTRACT

A STATISTICAL analysis of the visual records is made, the results having been weighted according to the number of occasions on which observing conditions were favourable. In this way the characteristic pattern for a typical auroral display becomes evident, although it is not completely elucidated in the case of large-scale displays. Comparisons are made with the results from previous years, paiticularly regarding the position of the quiet-arc zone. The auroral forms used in the analysis are fully described.

A special study is made of the relationship between auroral activity and the simultaneously recorded pattern of geomagnetic disturbance. Individual auroral displays are considered together with their corresponding magnetograms. A very close resemblance between these auroral–magnetic patterns and those obtained from similar northern latitudes is demonstrated. Examples of the magnetic effect of quiet arcs are given and particular attention is paid to the variability of this effect throughout the night. A few special occurrences, such as a distinctive east–west undulating motion and the phenomenon of repetition, are also considered at some length.

Several of the individual displays are extensively illustrated by means of prints made from single frames of the all-sky camera film.

CONTENTS

I. INTRODUCTION

1. Site of Station

The Halley Bay station is one of a network of permanent scientific stations maintained by the British Antarctic Survey.* It is situated on the ice shelf which forms the coastline of Coats Land in the southern part of the Weddell Sea, and is approximately two miles from the ice front. Its position in geographical co-ordinates is lat. 75° 31′S., long. 26° 39′W., and in geomagnetic co-ordinates lat. 65·8°S., long. 25·4°E. This report is concerned with the observations of the aurora australis made there during 1959; a short

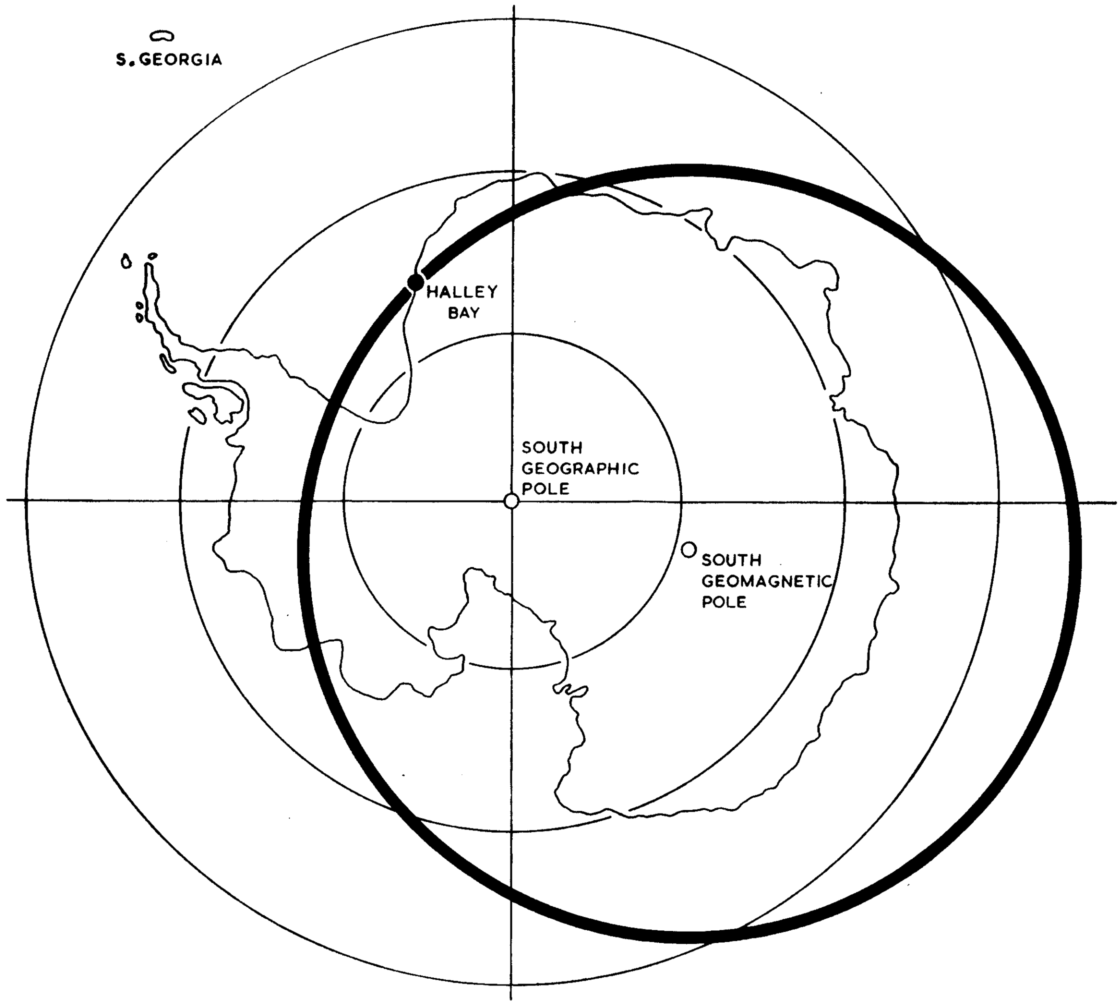

FIGURE 1
Map of Antarctica showing the geomagnetic latitude line (65·8°S.) which runs through Halley Bay. Geographical latitudes 60°, 70° and 80°S., are shown.

review of the value of Halley Bay as an auroral observatory is given below and indicates the part of the total auroral morphology which these single station observations represent.

Vestine and Snyder (1945, p. 122) have produced a map of the Southern Hemisphere which gives the lines of equal frequency of occurrence of aurorae. It shows that Halley Bay is situated very close to the zone of maximum auroral frequency. Only a relatively small part of the continent lies on or near this geomagnetic latitude (Fig. 1) and very little of it is as easily accessible as Halley Bay. The station is, therefore, in an especially favourable position, and as auroral patterns vary according to geomagnetic latitude observations from this station are of great importance.

* Formerly the Falkland Islands Dependencies Survey.

The geomagnetic latitude of Halley Bay is such that the observer sees the auroral quiet arcs low on the southern horizon. These arcs normally form the southern limit of an auroral display and are the most stable and characteristic feature of quiet to moderate displays. By the time one of these arcs has reached an overhead position it has become active and other auroral forms have appeared. Thus, within the range of one observer are all the main features of a polar display. For a display to pass over the northern horizon activity must be great, i.e. a magnetic storm on a world-wide scale.

The main disadvantage of the position of Halley Bay is that quiet arcs passing overhead, which are interesting because of their geomagnetic effect, seldom occur. Also, the rare movements of quiet arcs to the south of their mean position (5°–10° above the southern horizon) are not easily observed. Although the flatness of the ice shelf allows a completely unobstructed view round the entire horizon, exceptionally clear conditions are necessary before good observations can be made of aurorae near the horizon.

An unusual feature of Halley Bay, which further increases the value of the auroral observations, concerns the magnetic field: there are large differences between the actual magnetic field and the idealized dipole field, e.g. the magnetic declination is 1·5° west of true north but the direction of the geomagnetic meridian is 18° west of true north. As continuous magnetic recordings were made at the same station it was possible to study the auroral–magnetic patterns only a short time after the actual auroral display had taken place.

General observing conditions were not often good, mainly because of cloud and drifting snow. The average cloud coverage for the whole year was 5·5 oktas, and the most common form was thick uniform stratus or stratocumulus, which completely obscured the sky. Even on clearer nights the sky was often partly obscured by a haze which might have been thin cloud although this was doubtful. Drifting snow was the most frequent cause of poor visibility, and between 24 March and 20 September it prevented observations on a total of 37 nights. The number of days in each month on which visibility was less than 1 km. (due to all causes) is given below:

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
5	9	9	21	22	9	19	13	19	20	13	16

In the analysis given in section II, the following numbers of nights were used:

i.	Entire nights, clear and dark:	13
ii.	Part nights, clear and dark:	21
iii.	Entire nights, clear with some moonlight:	4
iv.	Part nights, clear with some moonlight:	7

Data from (iii) and (iv) were not used in the analysis of quiet arcs.

2. Visual Observations

Visual observations of the aurora were made every quarter of an hour, exactly on the quarter, and events were recorded to the nearest minute in terms of Universal Time. Systematic observations in this manner are convenient for later statistical analysis. During periods of interesting activity a continuous watch was kept.

The observations were made through a hatch in the roof of the main hut, and recorded within the hut. For the quieter forms in the south, both altitude and azimuth were measured by means of a combined indicator fixed at the head of the hatch. For active forms with higher elevations a hand alidade was used, most elevations being measured along the geomagnetic meridian. At times, measurements of the azimuth of the centre of a quiet arc could be made only to the nearest 5 degrees (see Table VI), but all other measurements were made to the nearest degree. As a necessary aid to making these observations the auroral observer controlled a master switch for all exterior lighting.

The classification of auroral forms used was that given in the *Photographic Atlas of Auroral Forms*, although distinction between forms was not as clear as is given there (see p. 6-8). Brightness indices of 0–4 were used as recommended in the International Geophysical Year manuals and the observer was able to use half steps. In this report the auroral features will be described by the standard abbreviations for the form, brightness and elevation above the southern horizon, in that order, e.g. HA2 8°.

An interference filter for the auroral green line, 5577 Å, was useful for identifying weak aurorae. When cloud, drift, etc., prevented observation of the auroral form the presence or absence of the interference ring was noted.

The complete records of the visual observations have been deposited at I.G.Y. World Data Centre C for auroral observations, in the Department of Natural Philosophy, University of Edinburgh. They may be consulted there after prior application.

3. Photographic Observations

The photographic observations of the aurora were made with an all-sky camera which was originally installed in 1956 by Dr. S. Evans of the advance party of the Royal Society I.G.Y. Antarctic Expedition to Halley Bay, 1955–59. Exposures were at a rate of 4 per 72 sec. The camera was mounted on a steel tower some 12 ft. above the snow surface, about 200 yd. from the main buildings of the station (Plate Ia).

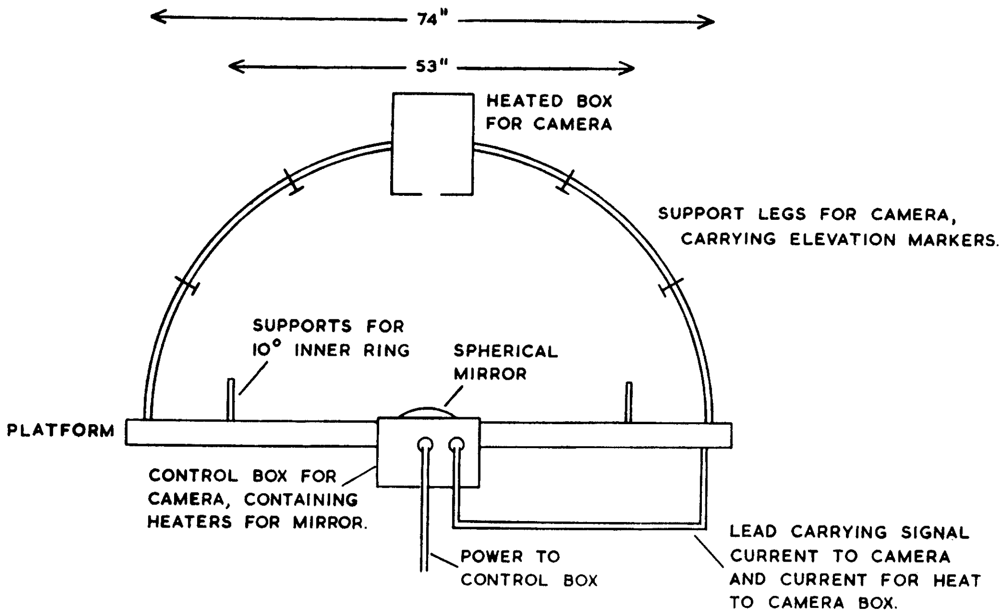

Figure 2

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

Fig. 2 shows diagrammatically the system on top of the tower. A 16-mm. ciné camera (Bolex H16) is supported so that the lens points downwards at a spherical glass mirror. The lens is of focal length 50 mm. and is focussed at 3·25 ft.; the dimensions of the mirror are—diameter 4·47 in., centre thickness 1·03 in., radius of curvature 2·93 in. With such an optical system the camera "sees" the whole sky reflected in the mirror (in fact the field of view dips slightly below the horizon), but the image is very distorted below 10° elevation and the camera was therefore generally used only for an aurora above 10° elevation. Plate Ib and the accompanying explanation show how the sky is recorded by the camera.

Before 6 June there were elevation markers at 30° and 59·3° on the north camera leg and 29·6° and 58·5° on the south, in addition to the 10° ring. After 6 June the markers were mounted at 20°, 30°, 45° and 60° on each leg.

The four camera support legs also acted as azimuth indicators; two were aligned in the direction of magnetic north, i.e. 1·5° west of true north, and the other two were at right angles to them.

The lens was used at maximum aperture, f/1·4. The film used throughout was negative Ilford HP3, manufacturer's speed rating 200 A.S.A.; it was developed to completion in contrast developer.

The following exposure sequences in seconds were used:

Beginning of season to 29 April

12 open, 6 closed; 12 open, 6 closed; 12 open, 6 closed; 12 open, 6 closed.

29 April to 6 June
18 open, 6 closed; 6 open, 6 closed; 18 open, 6 closed; 6 open, 6 closed.

6 June to end of season
27 open, 3 closed; 3 open, 3 closed; 27 open, 3 closed; 3 open, 3 closed.

While 12 sec. is a fairly satisfactory exposure time for a wide range of intensities of aurorae, in the alternately short and long sequence the short exposure will prevent saturated negatives for intense displays and the long exposure will register faint aurorae. In the 27-sec. to 3-sec. sequence, the long exposure is particularly useful for recording diffuse surfaces, which are usually weak. The short, 3-sec. exposure registers well only for very intense forms; it arrests a great deal of the movement in these forms and greatly improves the contrast. Also this short exposure is useful if one requires to follow the movement of bright features in the less intense forms.

In Plate VI, figs. 106–114, nine consecutive frames of the 27-sec. to 3-sec. sequence are printed. The display is particularly intense and rapidly moving. In such a display the maximum performance of the camera is required, and the particular value of short exposures is well illustrated.

The photographic records must be used in conjunction with the visual notes. Mainly because of the length of exposure time, the film does not always show clearly which auroral form is present, e.g. rayed arcs (RA) and homogeneous arcs (HA) are easily confused, and also a small amount of cloud or moonlight can make a misleading impression on the photograph. The film is capable of supplying details of individual displays, particularly with regard to time and position, and shows slow movements which might not be detected by the visual observer, but for a statistical analysis the complete visual records are far superior.

The photographic records have also been deposited permanently, in both negative and positive form, at I.G.Y. World Data Centre C, the Department of Natural Philosophy, University of Edinburgh. They may be consulted there after prior application.

4. Magnetic Observations

The magnetic records were obtained with two sets of standard La Cour magnetographs, one of normal sensitivity and the other insensitive for the recording of storms. The following are the average scale values for the year:

Normal H:	$7 \cdot 09$ γ/mm.	Insensitive H:	$35 \cdot 70$ γ/mm.
D:	$0 \cdot 93$ min./mm.	D:	$5 \cdot 00$ min./mm.
V:	$6 \cdot 85$ γ/mm.	V:	$37 \cdot 20$ γ/mm.

The time scale was 15 mm./hr. with time marks, fixed and moving, every ten minutes. In the magnetogram reproductions given at the end of this report there has been a reduction in scale to approximately one-third of their original size. Time marks have been given at hourly intervals only and the positions of the base lines and traces have been altered to give maximum clarity.

The sign convention for both normal and insensitive records is as follows:

H increases up the page
D increases westerly down the page (mean $D = 1 \cdot 5°$ W. of N.)
V ($= |Z|$) increases down the page. Z is negative in the Southern Hemisphere.

Where small magnetic effects are being considered, the mean quiet-day curve for the appropriate month has been sketched in with a broken line at the correct estimated level.

II. ANALYSIS OF VISUAL OBSERVATIONS

1. Distribution of Observations

Although observations commenced on 1 March and ended on 11 October, the nights near the beginning and end of this season were suitable for observing only the most intense overhead displays, because of the continuous twilight. Table I, which gives the distribution of observations, is therefore based on the period from 24 March to 20 September.

In this table the period 1800–1900 U.T., for example, refers to observations at 1815, 1830, 1845, 1900 U.T. In one hour during any night, therefore, the maximum possible frequency of occurrence is 4; in the case of Table I this is the maximum number of clear observing periods.

In Table I, lines *a*, *b* and *c* may each be used where appropriate to derive percentage frequencies of occurrence of auroral features, line *c* being used on the assumption that cloud, moonlight and other obscuring factors are randomly distributed throughout the night.

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	12
a			17	41	57	65	69	74	75	69	61	57	59	66	69	67	53	30	13	3	
b			25	49	65	73	77	85	91	89	80	75	76	77	77	75	61	36	16	4	
c	48	232	353	460	547	628	688	720	720	720	720	720	712	658	587	503	407	295	147	5	

a. The number of clear, dark periods.
b. The number of clear, dark periods plus the number of clear, moonlit periods when the moonlight did not obscure the aurora.
c. The numbers of periods when the sun was more than 12° below the horizon.

2. FREQUENCY OF AURORAE

Frequencies are given in Table II. For the purposes of this table an overhead aurora is defined as that occurring within 60° and 120° above the southern (geomagnetic) horizon.

TABLE II

FREQUENCY OF AURORAE ON CLEAR, DARK NIGHTS

Period (hr. U.T.)	18	19	20	21	22	23	24	01	02	03	04	05	06	07	08	09	10	11	12
a	13	33	51	61	64	65	69	67	61	57	59	65	68	65	49	27	12	2	
b	0	0	0	1	3	3	6	9	8	10	13	13	17	15	8	2	0	0	
c	76	80	89	94	93	88	92	97	100	100	100	99	99	97	93	90	92		
d	0	0	0	2	4	4	8	13	13	18	22	20	25	22	15	8	0	0	

a. Total number of nights on which the aurora was present.
b. Total number of nights on which the aurora was overhead.
c. Percentage frequency of the aurora (using Table I, line *a*).
d. Percentage frequency of overhead aurora (using Table I, line *a*).

Lines *c* and *d* are plotted graphically as Figs. 3a and b respectively. It is clear that the peak auroral activity, particularly overhead activity, occurs between 0200 and 0800 U.T.

Over all clear, dark periods the aurora is present for 93 per cent of the time and is in the overhead position for 11 per cent of the time.

This latter figure may also be expressed in the way in which auroral frequencies are generally given. From 24/25 March to 19/20 September, it was possible on 142 of the total 180 nights to determine whether or not the aurora was in the overhead position at least once during the night. The aurora was observed overhead on 47 of these nights, i.e. on 33 per cent of possible nights.

3. AURORAL FORMS IN THE ANALYSIS

The term quiet arc here refers to stable, regularly formed arcs, which may have been homogeneous or have had weak, diffuse rays. A glow which was definitely known to have been the upper part of an arc below the horizon is considered in the analysis as a quiet arc, but such forms were comparatively rare at Halley Bay. However, the faint auroral light on the southern horizon, which often preceded the formation of an arc but had neither the typical bow shape nor distinct borders, is not considered here as a definite auroral form. Nevertheless, this faint light which seems to be peculiar to the auroral zone, is taken to indicate the presence of the aurora for the purposes of the analysis in the previous section.

Under clear, dark conditions when there was no auroral light visible, it was nearly always possible—if well-adapted to the dark—to observe a very faint interference ring through the filters, but this was not considered to indicate the presence of the aurora.

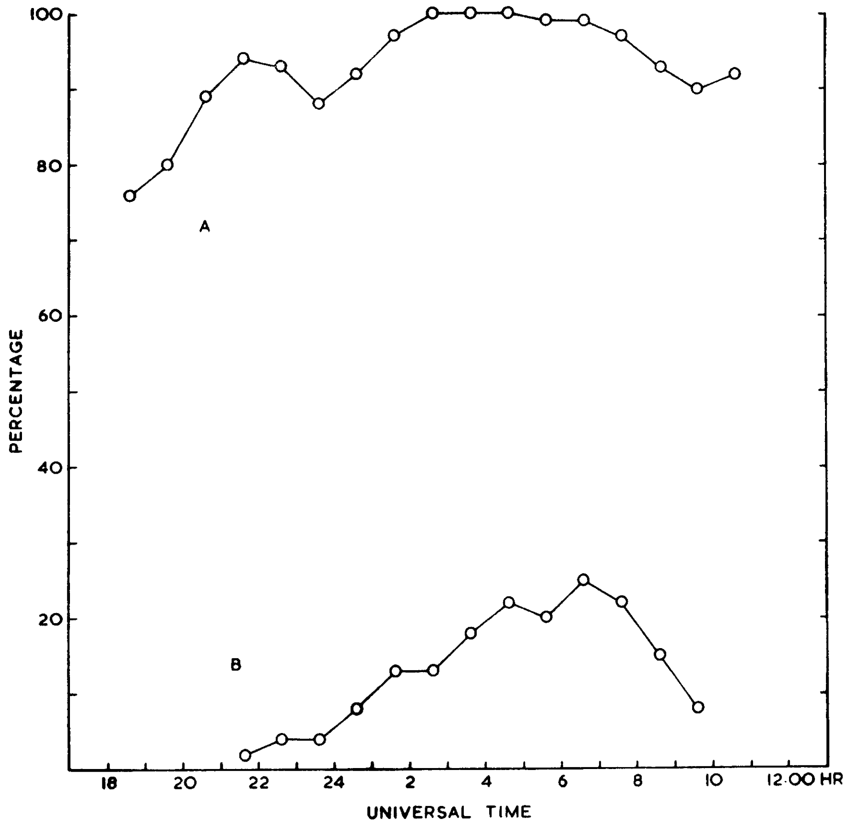

FIGURE 3

Percentage frequency of occurrence of aurorae under clear, dark conditions.

a. All aurorae.
b. Overhead aurorae.

In the following analysis diffuse surfaces and diffuse rays are considered together. They generally appeared at the same time, in association with flaming (F), over large areas of the sky, and at times the distinction between the two forms was very fine. The term drapery (D) is not used in the analysis, as such forms could be included with rayed bands (RB) or a series of diffuse rays. Coronae (C) were most often made up from diffuse rays and surfaces and are not treated separately in the analysis.

During 1959 no activity was observed that could definitely be classified as pulsating (P). Pulsations—or rather, what appeared as pulsations—were observed only in association with F forms and were seen mainly near the magnetic zenith. They could therefore be explained as F forms in which the characteristic motion towards the zenith was obscured by the effect of perspective. The form described in the *Photographic Atlas of Auroral Forms* as pulsating arcs (PA) was not observed during 1959. In the analysis, therefore, P and F forms are considered together as F (p. 15-17).

When flaming begins, diffuse arcs or surfaces extending along the geomagnetic parallels to the north of the main arc appear to be lit up by waves of intensification which begin from the main arc and move from south to north along the geomagnetic meridian with a very regular period. In the later stages, surfaces and diffuse rays are scattered all over the sky north of the main arc system which generally becomes distorted. Waves of intensification are seen towards the zenith; these commence in the south and then move north with decreasing activity. There appear, therefore, to be two distinct wave motions: one acts towards the zenith and on individual auroral forms, and the other is caused by the spreading of this activity from south to north (similar to the regular commencement of F) in a roughly periodic manner. Typical periods are approximately 0·2 sec. and 5 sec. respectively. Auroral forms which are north of the magnetic zenith also show the motion towards their local zenith, but this is difficult to observe except in the case of longer rays and great activity. Occasionally the break-up into diffuse forms precedes the commencement of F activity.

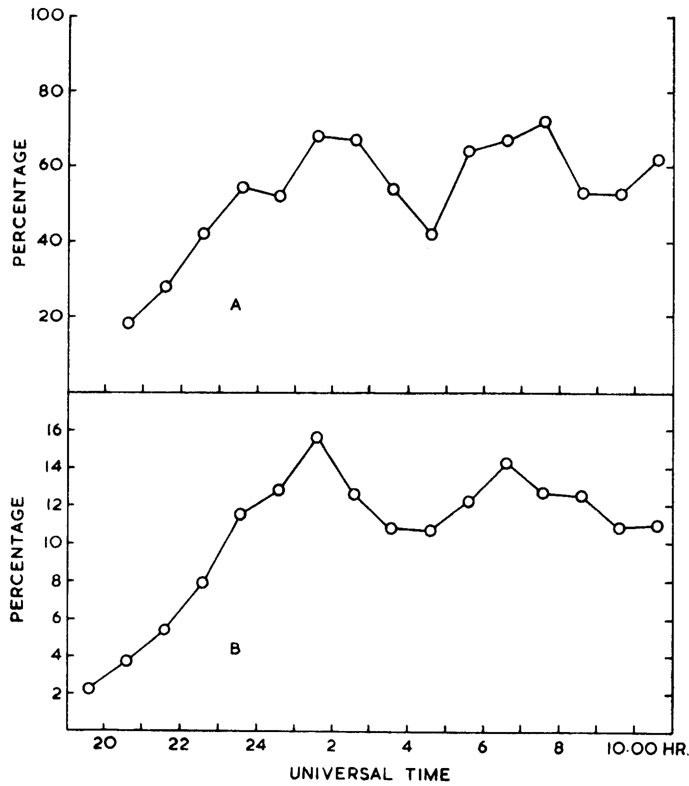

FIGURE 4

Percentage frequency of occurrence of quiet arcs.

a. Under clear, dark conditions.

b. Under all conditions darker than nautical twilight.

There is also an eastward movement of surfaces and diffuse rays. This is relatively slow and, although it was not detected visually because of its confusion with F, it is very clearly seen when the all-sky film is projected at speed. These movements were investigated at Halley Bay during 1956 (Evans, 1959).

Another characteristic motion consisted of rapid east-west undulations, which for convenience are referred to below as "undulating activity". It occurred most frequently on rayed arcs (RA) or rayed bands (RB) and took the form of "ripples" or sometimes rows of rays moving rapidly along the arc or band. The undulations moved with apparently equal frequency either towards the east or towards the west, and occasionally in both directions at the same time.

Undulating activity is examined in detail on p. 19 and 21-25. For moderately intense displays it is seen to be a particular form of the phenomenon sometimes referred to as "break-up", i.e. the disintegration of the quiet-arc system immediately preceding the most active phase of the display, and separating the evening and morning phases of a display.

Undulating activity was frequently accompanied by a deep red-violet coloration along the lower borders. The only other colour noted was a distinct red, occurring mainly on long rays and sometimes on diffuse surfaces. This is type A coloration, 6300 Å, the atomic oxygen forbidden line. No differentiation between white and green coloration was made because the latter generally became more apparent, superseding the former, as the aurora became more intense.

4. Quiet Arcs

a. *Frequency*

The frequency of quiet arcs is given in Table III, and lines *b* and *d* are plotted as Figs. 4a and b respectively.

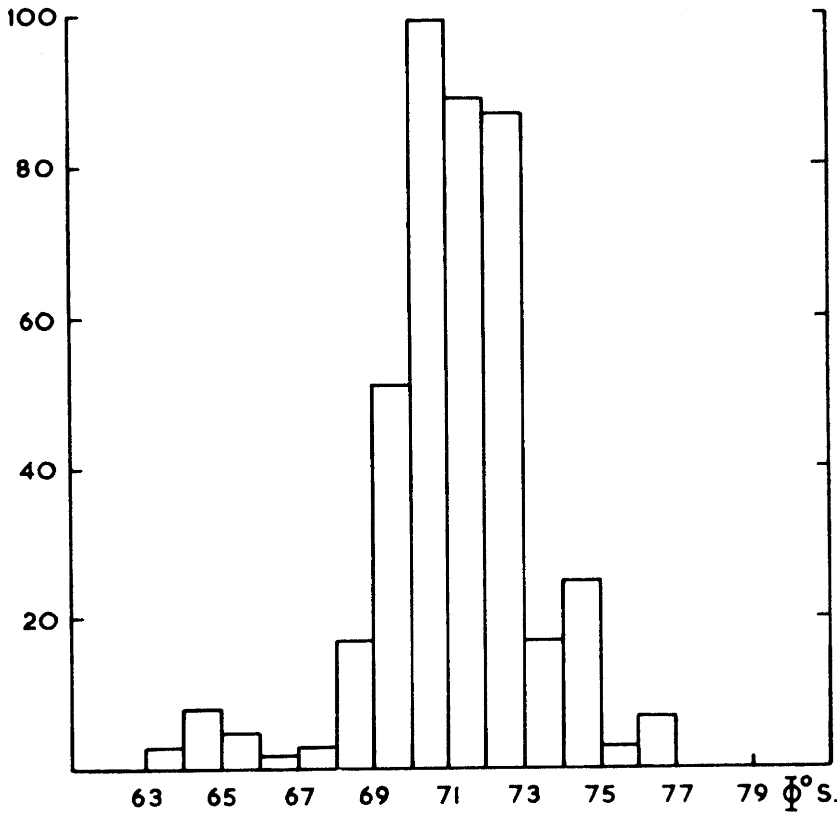

FIGURE 5

Number of occasions on which quiet arcs were observed in each degree of latitude under clear, dark conditions.

TABLE III

FREQUENCY OF QUIET ARCS

Period (hr. U.T.)	18	19	20	21	22	23	24	01	02	03	04	05	06	07	08	09	10	11	1200
a	3	1	10	18	29	40	39	47	41	31	25	42	46	48	28	16	8	1	
b			18	28	42	54	52	68	67	54	42	64	67	72	53	53	62		
c	3	10	20	34	54	83	92	112	91	78	76	81	84	64	51	27	13	2	
d		2·2	3·7	5·4	7·9	11·5	12·8	15·6	12·6	10·8	10·7	12·3	14·3	12·7	12·5	10·8	10·9		

a. Total number occurring on clear, dark nights.
b. Percentage frequency in clear, dark periods (using Table I, line *a*).
c. Total number occurring on all nights.
d. Percentage frequency when the sun was more than 12° below the horizon (using Table I, line *c*).

It is seen that the frequency of quiet arcs builds up to a maximum at ~0200 U.T. (local midnight). This is followed by a decrease in frequency and another maximum at ~0700 U.T. Quiet arcs are still visible in the morning sky and persist into twilight.

b. *Elevation*

Table IV gives the number of quiet arcs with lower borders within each elevation range and shows their variation in time. The approximately equivalent geomagnetic latitude (assuming a mean height of 100 km.) is given on the extreme right. This table uses an hourly period different from that used in

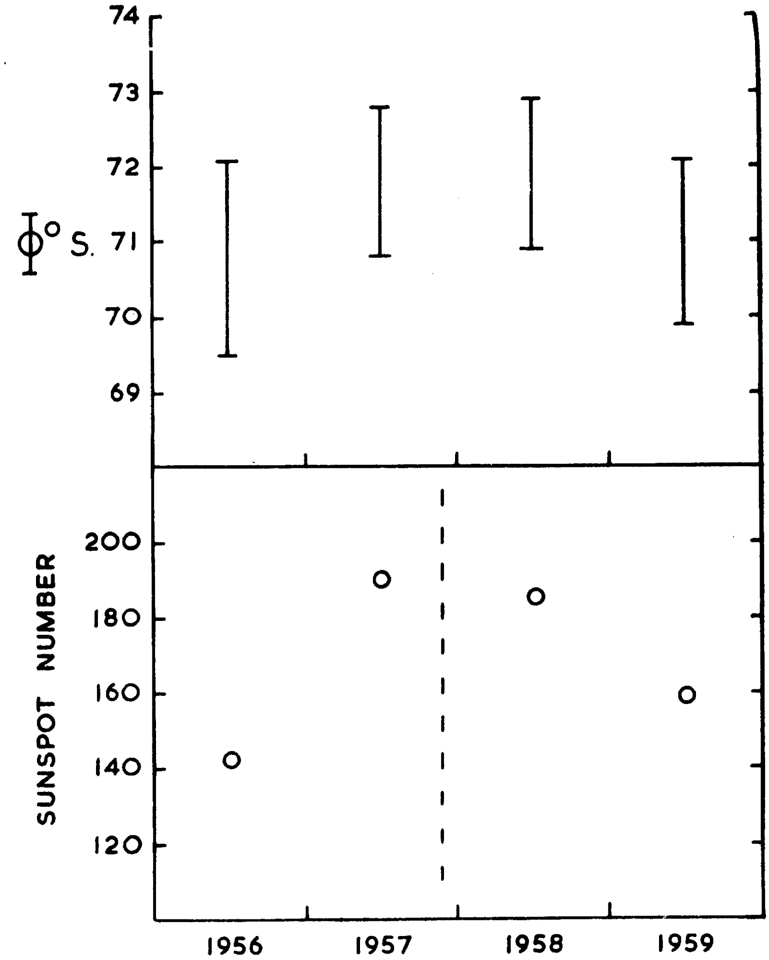

FIGURE 6

Median latitudes of quiet arcs, with interquartile ranges, for each year compared with annual mean daily relative sunspot numbers. The broken line indicates the time of maximum in the sunspot cycle.

Table I, e.g. period 22/23 refers to observations made at 2245, 2300, 2315 and 2330 U.T. Only clear, dark nights have been used.

Fig. 5 has been produced from the totals column on the right of Table IV and shows that the distribution is quite narrow, which agrees with the distributions obtained in 1956, 1957 and 1958 (Evans and Thomas, 1959). It is interesting to compare the median latitudes of quiet arcs for each year. In Fig. 6 the median latitudes are plotted with their interquartile ranges and the mean daily relative sunspot numbers for each year are also plotted.

There is a shift towards higher latitudes during the years of sunspot maximum. More accurate information about this shift should be obtained by continuing the observations of quiet arcs for several more years. However, at this stage, it is interesting to note the changes in the Van Allen zones of radiation

TABLE IV

NUMBERS OF QUIET ARCS AND THEIR VARIATION IN ELEVATION WITH TIME

Period (hr. U.T.)	17/18	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	*Totals*	Φ (degrees)
Elevation (degrees)																				
Glow								4	1	2									7	76
1				2		1													3	75
2					5	2			1				1	4	4	4	4		25	74
3				2	1	4	1	5						4					17	73
4–5					1	5	7	6	9	3	4	3	7	12	16	9	3	2	87	72
6–7		2		2	3	9	7	8	7	4	3	5	10	11	11	5	1	1	89	71
8–10	1	1	1	6	3	4	8	5	12	7	10	11	15	10	2	1	2		99	70
11–15				1	5	7	4	6	2	1	2	9	10	3	1				51	69
16–23					1	2	5	1	1	3		1		3					17	68
24–40						1	1			1									3	67
41–90								2											2	66
91–140								1	2	2									5	65
141–157										6	2								8	64
158–165										1	2								3	63
Median latitudes (degrees south)				70·9	71·5	71·4	70·8	71·5	71·1	70·1	70·5	70·4	70·8	71·7	72·2	72·4	72·7			

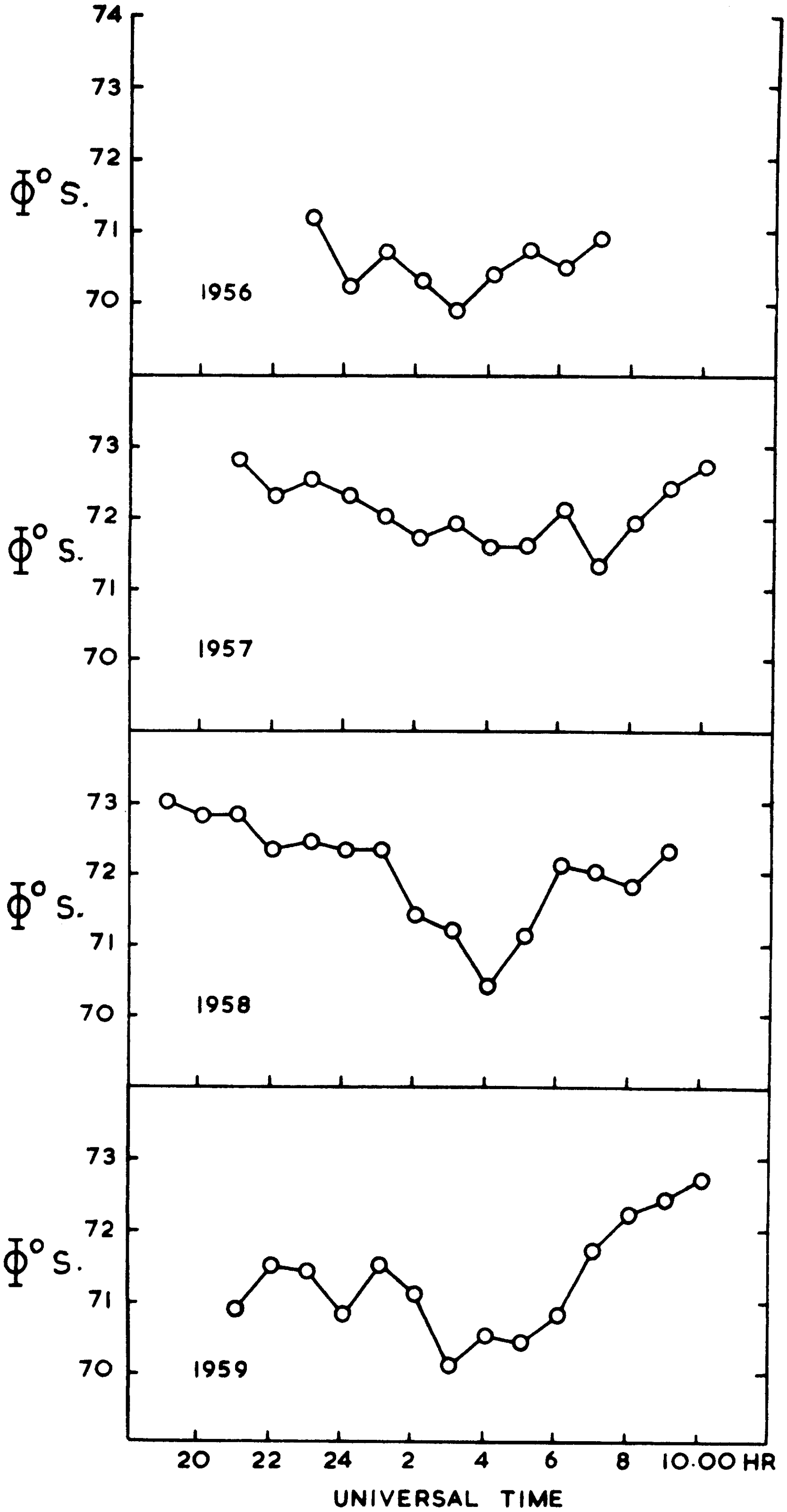

FIGURE 7

Variation throughout the night of median latitudes of quiet arcs for each year.

from 1958 to 1959 (Arnoldy, Hoffman and Winckler, 1960). These changes seem to confirm the proposition that the position of the "horns" of the Van Allen zones controls the quiet-arc zone (Paton, 1960).

A point also worth noting here is that since quiet arcs shift to lower latitudes as sunspot minimum is approached, the number passing overhead at Halley Bay is considerably increased—thus mitigating one of the disadvantages of the station.

In Fig. 7 the median latitudes of quiet arcs for each year are plotted against time. The general shape of each curve is consistent with a time of occurrence of minimum latitude between 0200 and 0600 U.T. 1958 shows most markedly a steady advance to minimum latitude and 1959 a steady retreat from it. The time of occurrence of minimum latitude coincides with the minimum occurrence of quiet arcs (Fig. 4) and the maximum occurrence of overhead activity (Fig. 3). This is to be expected because, as an arc moves equatorwards and overhead activity increases, the arc is likely to become distorted and to be replaced by other forms.

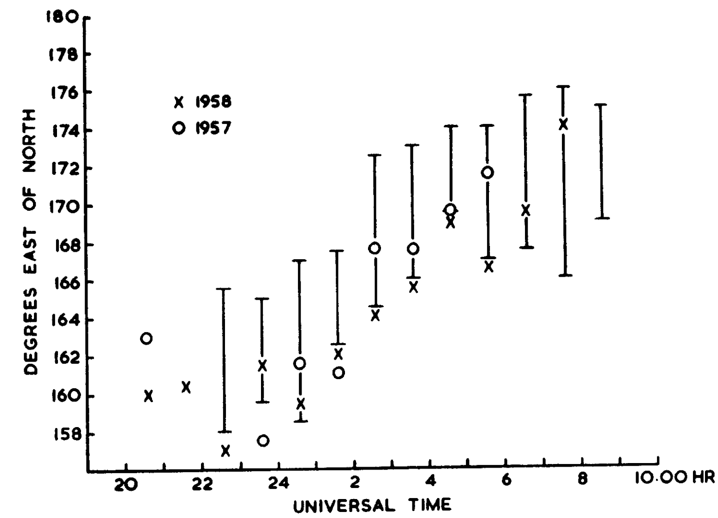

FIGURE 8

Variation throughout the night of mean bearings of centres of quiet arcs with quartile ranges, for 1959. Values for 1957 and 1958 are also shown.

c. *Bearing*

Mean true bearings of quiet arcs which occurred in 1959 are given in Table V.

The variation of mean bearing with time is plotted in Fig. 8 with the quartile range. As the quartile range is large, only 0·5° units are used. For periods outside those plotted, observations are too infrequent for accurate means to be derived from them.

TABLE V

MEAN TRUE BEARINGS OF QUIET ARCS (1959)

Period (hr. U.T.)	22	23	24	01	02	03	04	05	06	07	08	0900	
a		161·6	162·1	162·9	165·0	168·6	169·5	171·9	170·4	171·7	171·1	172·0	
b		3·7	2·8	4·2	2·7	4·0	3·4	2·2	3·6	4·0	4·9	2·9	
c		20	25	21	26	17	15	21	29	31	17	13	

a. Mean bearings.
b. Quartile range of mean bearings.
c. Number of observations.

The mean bearings for 1957 and 1958 are also plotted in Fig. 8. These earlier bearings are seen to be slightly but consistently more easterly than those of 1959, but the rate of change of bearing throughout the night is similar in each of the three years.

Table VI gives the number of quiet arcs occurring throughout the whole period 2215–0900. As there is no difference in distribution between lines *a* and *b*, line *a* is adopted as representing the true distribution and is plotted as a histogram in Fig. 9.

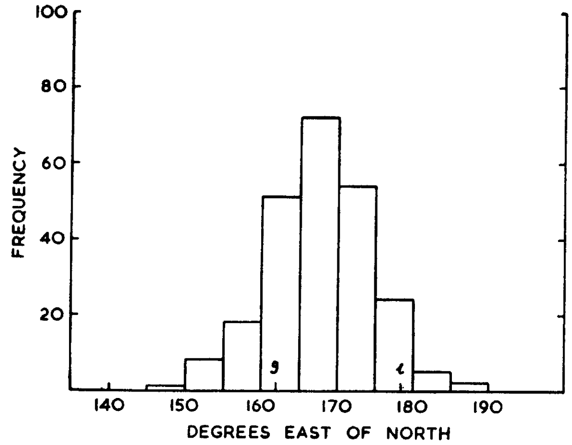

FIGURE 9

Total number of occasions on which quiet arcs were observed within a certain range of bearing.

TABLE VI

NUMBERS OF QUIET ARCS

Bearing (degrees)	140	145	150	155	160	165	170	175	180	185	190
a		0	1	8	18	51	72	54	24	5	2
b		0	0	5	13	33	56	38	17	2	1

a. Total number within a given range of bearing.
b. Total number with bearings measured to nearest degree.

The directions of geomagnetic and local magnetic south are indicated by *g* and *l* respectively. The mean bearing is nearer to the direction of geomagnetic south than to local magnetic south, but the influence of the geomagnetic field is not so apparent as it was in 1958 (Evans and Thomas, 1959), the mean bearing in 1959 being some 3° more westerly. However, too much significance should not be placed on this small difference, since any estimation of the position of the centre of a quiet arc is necessarily somewhat subjective and the observations were made by different observers in each year.

In this analysis of the bearings of the centres of quiet arcs, use has been made of all the observations regardless of the observing conditions at the time. Contrary to what would be expected in the case of elevation of quiet arcs, this procedure should not bias the results of the analysis.

5. SURFACES AND DIFFUSE RAYS

a. *Frequency*

Table VII gives the frequency of surfaces and diffuse rays. Figs. 10a and 10b are graphical representations of Table VII, lines *c* and *d*, respectively.

TABLE VII

FREQUENCY OF SURFACES AND DIFFUSE RAYS

Period (hr. U.T.)	22	23	24	01	02	03	04	05	06	07	08	09	10	11	1200
a	1	2	2	10	12	19	21	16	22	23	19	9	2		
b	1	2	4	11	12	24	38	43	37	42	35	18	2	1	
c	1	2	2	11	15	25	28	21	29	31	31	25	13		
d	0·1	0·3	0·6	1·5	1·7	3·3	5·3	6·5	6·3	8·3	8·6	6·1	1·4		

a. Number observed in good conditions (clear dark and clear moonlit nights).
b. Number observed in all conditions.
c. Percentage frequency in good conditions (using Table I, line *b*).
d. Percentage frequency in all conditions (using Table I, line *c*).

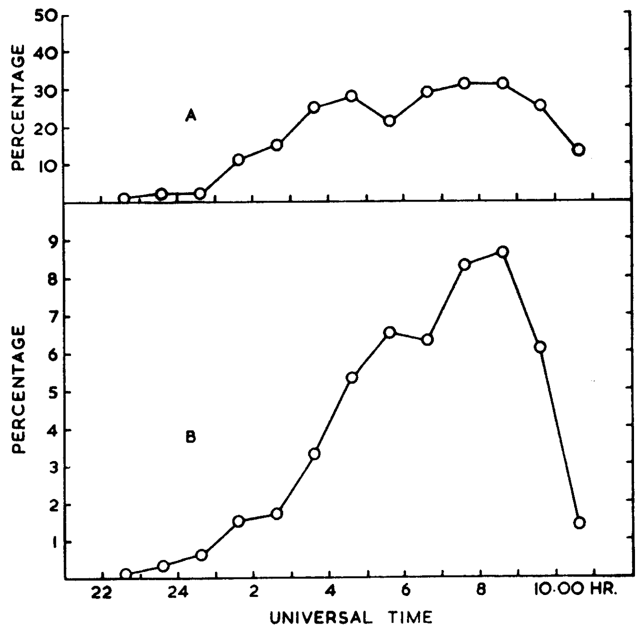

FIGURE 10

Percentage frequency of occurrence of surfaces and diffuse rays.

a. Under clear conditions, dark or with some moonlight.
b. Under all conditions darker than nautical twilight.

b. *Elevation and brightness*

In Fig. 11b mean elevations rather than mean latitudes are given because of the uncertainty in height of these auroral forms.

Surfaces and diffuse rays are clearly features of the post-midnight* aurora, their brightness and elevation decreasing as the morning progresses.

6. FLAMING

Table VIII gives the frequency of flaming. Line *b* is shown graphically as Fig. 12.

A comparison of Figs. 10 and 12 shows the very close relationship between diffuse surfaces and diffuse rays and the presence of flaming.

* When used in this context, "midnight" does not signify a time to the nearest minute, but rather a very approximate period within an hour or more of local midnight.

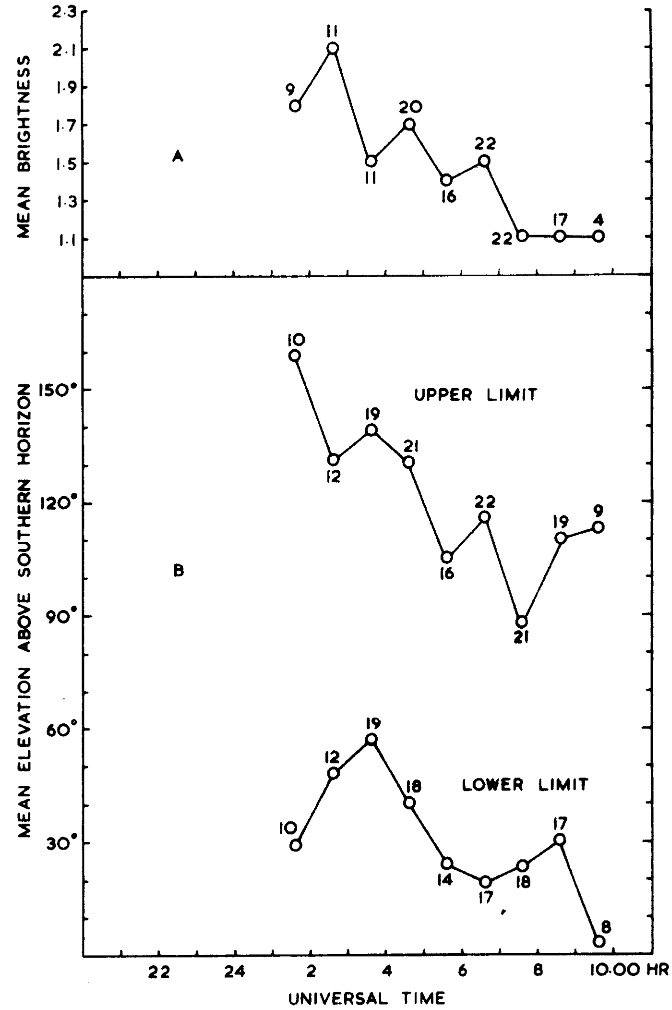

FIGURE 11

Surfaces and diffuse rays.

a. Mean brightness throughout the night.

b. Mean elevation throughout the night.

The numbers above the curves indicate the number of observations used in deriving the means.

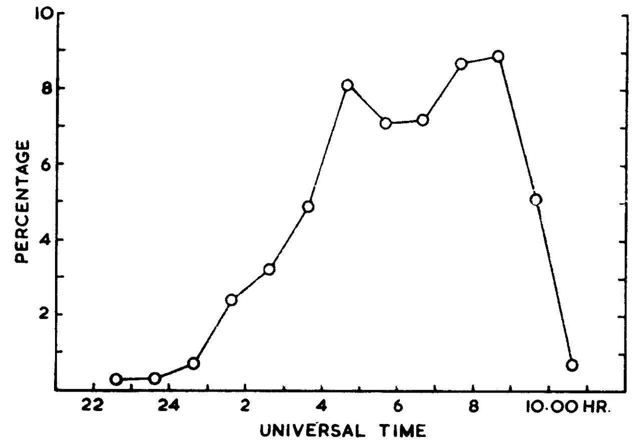

FIGURE 12

Percentage frequency of occurrence of flaming under all conditions darker than nautical twilight.

TABLE VIII

FREQUENCY OF FLAMING

Period (hr. U.T.)	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
a	2	2	5	17	23	35	58	47	42	44	36	15	1
b	0·3	0·3	0·7	2·4	3·2	4·9	8·1	7·1	7·2	8·7	8·9	5·1	0·7

a. Number of occurrences under all observing conditions.
b. Percentage frequency of occurrences (using Table I, line *c*).

7. OTHER FORMS

This part of the analysis excludes quiet arcs and surfaces and diffuse rays; it includes rayed bands (RB), homogeneous bands (HB), rays (R) and active homogeneous arcs (HA) or rayed arcs (RA).

a. *Frequency*

Table IX gives the frequency of these forms. Fig. 13 is line *b* plotted graphically.

These active forms are seen to be mainly a post-midnight phenomenon, but not so exclusively as are surfaces and diffuse rays.

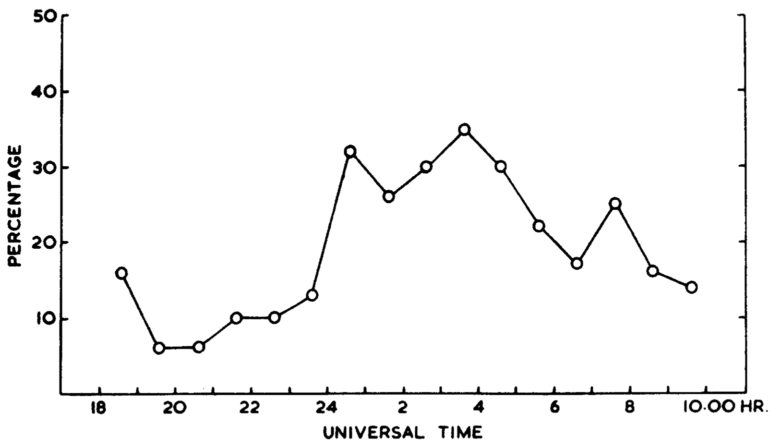

FIGURE 13

Percentage frequency of occurrence of other forms under clear conditions, dark or with some moonlight.

TABLE IX

FREQUENCY OF OTHER FORMS

Period (hr. U.T.)	17–18	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	2	4	3	4	7	8	11	29	23	24	26	23	17	13	19	10	5	0
b		16	6	6	10	10	13	32	26	30	35	30	22	17	25	16	14	

a. Number of occurrences under clear conditions, dark or with some moonlight.
b. Percentage frequency of occurrences (using Table I, line *b*).

b. *Elevation and brightness*

In Fig. 14b mean elevations rather than mean latitudes are given because of the uncertainty of the height of these auroral forms.

Maximum elevation occurs between 0300 and 0600 U.T. Mean brightness decreases steadily from 2200 U.T.

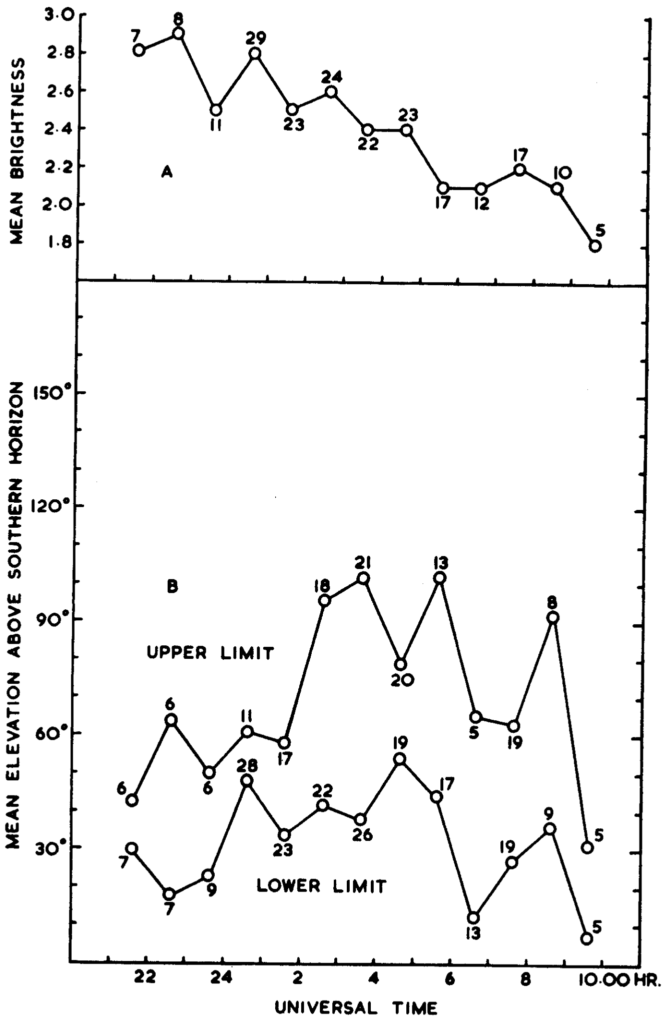

FIGURE 14

Other forms.

a. Mean brightness throughout the night.

b. Mean elevation throughout the night.

The numbers above the curves indicate the number of observations used in deriving the means.

8. COLOUR

As stated on p. 8-9, the distinction between green and white coloration was very fine. The two colours noted here are red type A, and a deeper red or red-violet coloration.

a. *Red Type A*

This colour appears mainly on long rays and sometimes on diffuse surfaces, although in this latter case the colour is generally less distinctive. On one occasion, 15/16 July, during the evening twilight, this red colour appeared very clearly over a homogeneous arc which was rapidly moving and formed part of an exceptionally brilliant display. The number of occasions on which this red coloration appeared is plotted against time in Fig. 15. Normally, type A coloration occurs during great activity and is influenced by twilight.

b. *Red-violet*

In Table X the first column gives all the times of occurrence of east–west or west–east undulations as described on p. 8; the symbol (RV) indicates when these movements were accompanied by the red-violet coloration. Red-violet coloration occurred only in the presence of undulating activity. In the second column K_s' values are given, where K_s' = the sum of the K-indices between 1500 U.T. on one day to 1500 U.T. on the following. The reason for using K_s' rather than K_s is that K_s' expresses more accurately the activity during night time (see p. 21).

TABLE X

Time (U.T.)	K_s'	*Date*
0130 (RV)	8	5/6 June
0230 (RV)	11	5/6 July
0115 (RV)	13	9/10 June
0230	14	7/8 Aug.
0445	15	21/22 July
0230	17	6/7 July
0130 (RV), 0200	18	27/28 Sept.
2315	20	13/14 Sept.
0345 (RV)	20	1/2 Aug.
0300, 0315 (RV)	22	23/24 June
0030	26	5/6 Sept.
0815 (RV)	26	28/29 June
0045 (RV)	28	24/25 Sept.
2315, 2330, 0015 (RV)	30	8/9 April
2215, 2230 (RV), 2245 (RV)	31	4/5 Sept.
0130 (RV), 0330 (RV)	43	15/16 July
2130 (RV), 2145 (RV), 0315 (RV)	48	16/17 Aug.

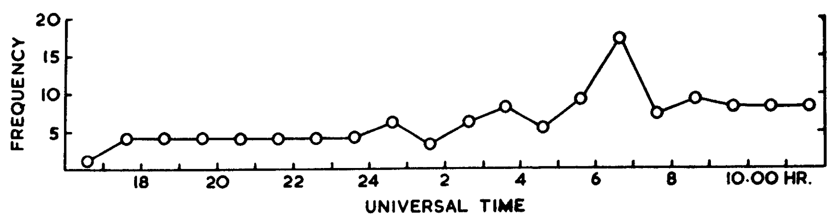

FIGURE 15

Number of occasions on which red, type A, coloration was observed under all conditions darker than nautical twilight.

At least for lower values of K_s', the red-violet coloration and typical accompanying movements occur close to the midnight period. This type of auroral activity seems to separate the evening and morning features of a display. For a further discussion see p. 22.

Table X emphasizes that this type of activity is of short duration.

9. SEQUENCE OF AURORAL FORMS

The pre-midnight period is characterized by the gradual build up of the quiet-arc form then, approximately at midnight, rays develop and sometimes there is moderate band activity. The rayed activity is often accompanied by rapid undulations along the arc (the lower border of which is no longer regularly shaped) and the typical red-violet coloration. Homogeneous arcs (HA) then re-form and move northwards. On the most typical nights flaming commences between 0400 and 0700 U.T., firstly in a regular manner above the arc then, latterly, in an irregular manner on surfaces and diffuse rays. These surfaces and diffuse rays generally form the northern limit of a display, even in large displays when many other forms are present (compare Figs. 11b and 14b). Flaming activity decreases as the morning progresses and the surfaces and diffuse rays recede southwards. The quiet arc then re-forms, its bearing now being more westerly, i.e. 162° (approx.) at 2200 U.T. and 172° (approx.) at 0900 U.T. The quiet-arc zone, as shown in Fig. 5, is narrow in comparison with the range of other auroral features, being confined to a belt of 2 degrees of latitude as defined by the interquartile range.

In the larger displays this sequence is not strictly followed (see p. 29-30). Such displays are characterized by the appearance of active homogeneous arcs (HA) or rayed arcs (RA), which are broad and have many fibres and move rapidly northwards. Rayed bands (RB), homogeneous bands (HB) and long intense rays also appear, and redness of type A may be seen. All these forms may occur at any time during the night, often appearing in the evening period. Rapid east–west or west–east undulations and the red-violet coloration also occur frequently in the evening. Flaming (F) and diffuse rays and surfaces, however, remain characteristically morning phenomena, even during these very big displays.

Most of the characteristics of this sequence are shown clearly in the preceding analysis.

III. RELATION OF AURORAE TO MAGNETIC DISTURBANCE

1. Mean Diurnal Variation of *K*

Magnetic disturbance of significant magnitude was always accompanied by the appearance of the aurora, and for *K*-index greater than 4 the aurora was generally in the overhead position. However, the converse was not always true, and some forms of the aurora (e.g. low, quiet arcs and intense, isolated rays) were not accompanied by significant magnetic disturbance.

The lower limit of the range of disturbance, in gammas, against the corresponding *K*-index for Halley Bay is as follows:

K	0	1	2	3	4	5	6	7	8	9
γ	0	20	40	80	160	280	480	800	1,320	2,000

The mean *K*-indices for each month are given in Table XI, the means having been obtained by adding together the individual *K*-indices.

Table XI

MEAN *K*-INDICES

Period (hr. U.T.)	0–3	3–6	6–9	9–12	12–15	15–18	18–21	21–24
January	1·7	1·7	1·9	1·8	1·8	1·8	2·2	2·2
February	2·4	3·1	2·8	2·3	2·1	2·1	2·2	2·5
March	2·2	2·4	2·4	1·7	1·5	1·2	1·7	1·9
April	2·6	1·9	2·1	1·6	1·0	0·7	1·3	2·0
May	2·4	2·6	2·1	1·7	1·0	0·7	1·1	1·7
June	2·2	2·3	2·1	1·7	0·8	0·7	0·8	1·6
July	3·5	3·4	3·1	2·4	1·7	1·4	1·7	2·5
August	2·9	2·8	2·8	1·9	1·4	1·1	1·5	2·1
September	3·5	3·3	2·8	2·5	1·6	1·5	2·1	2·8
October	2·2	2·9	2·4	1·8	1·3	1·2	2·0	2·3
November	2·6	2·6	2·6	2·1	1·9	1·8	2·3	2·4
December	2·3	2·5	2·5	2·3	1·8	2·3	2·6	2·4
Year (1959)	2·55	2·63	2·46	1·97	1·50	1·38	1·79	2·21

Within the limits of sensitivity of a three-hour range index such as *K*, the diurnal variation is seen to have the same form for all months. The means for the whole year are plotted in Fig. 16.

The peak magnetic activity takes place between 0200 and 0600 U.T. It is for this reason that K_s' is used as described on p. 19.

On comparing Figs. 3 and 16, the maximum magnetic activity is seen to coincide with 100 per cent frequency of occurrence of aurorae between 0200 and 0500 U.T.; the maximum overhead activity is not very sharply defined but occurs at 0630 U.T. approximately. Fig. 4 shows very clearly how quiet arcs are replaced by other forms between 0200 and 0600 U.T., and Fig. 7 indicates a minimum latitude at this time for any quiet arcs which do occur.

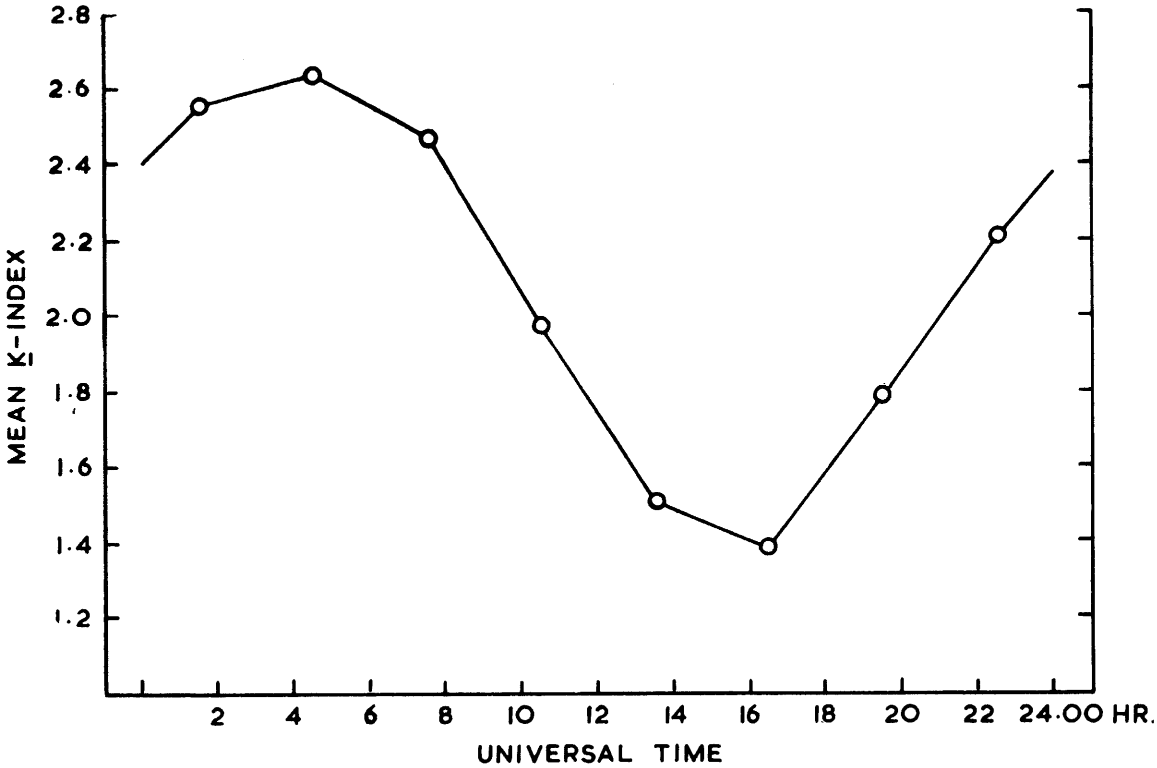

FIGURE 16

Annual mean of the daily variation of magnetic activity as expressed by the *K*-index.

Figs. 10 and 12 show clearly how the growth of flaming (F), diffuse surfaces and diffuse rays is also related to maximum *K*. The maximum frequency of F and the diffuse forms occurs at 0800 U.T. approximately, some time after maximum *K*, but it is significant that the diffuse forms show a decrease in elevation and brightness after the time of maximum *K* (see Fig. 11).

The maximum frequency of occurrence of auroral forms other than arcs and surfaces, takes place at 0400 U.T. approximately (Fig. 13), and the maximum elevation occurs at about 0500 (Fig. 14). However, there is a fairly steady decline in brightness from 2300 U.T. approximately, which does not seem to fit the average magnetic activity. A partial explanation is that when active forms, i.e. other than quiet arcs, appear before the midnight period, magnetic activity for that night is much higher than average (see Table X) and the pattern of disturbance is less regular.

2. OCCURRENCE OF UNDULATING ACTIVITY AND RED-VIOLET COLORATION

Before referring to the magnetograms reproduced in this report, it is necessary to explain some of the descriptive terms which will be used. Originally, the term "magnetic bay" was used to denote a simple departure from and later return to the mean value of the magnetic element on which the bay occurred; this event generally took place under relatively quiet conditions. Recently, there has been a tendency to describe all magnetic disturbance in terms of series of individual, sometimes overlapping, bays (Meek, 1953; Heppner, 1954), and the term "bay" has thus lost much of its original meaning. In this present study the term "bay" will be reserved, as formerly, for more regular deviations from the mean value. The term "displacement" will be used for most other deviations. The signs of both bays and displacements will be described as increasing or decreasing, and westerly or easterly.

As explained earlier, the term "midnight" refers to a period near local midnight, 0146 U.T., of about two hours duration or longer.

A study has already been made of the change with time of the magnetic disturbance vector at Halley Bay during 1957 and 1958 (MacDowall, 1959). The signs of "bay-like" disturbances for H and V were examined and it was found that, on average, there was a reversal of sign near 2400 U.T., changing from H and V increasing to H and V decreasing. This variation with local time was shown to be present even in the case of confirmed world-wide magnetic storms commencing at different times in the day.

A similar pattern was observed in 1959. The element D showed much less systematic behaviour than either H or V, the disturbance being oscillatory rather than bay-like, but in general the sign of the disturbance was westerly in the evening and easterly in the morning.

This disturbance pattern is to be expected when Chapman's idealized current systems are considered, i.e. assuming Halley Bay to be situated equatorwards of the auroral zone electrojets (Chapman and Bartels, 1940, chapter 9). Chapman's analysis is based on forty moderate magnetic storms, as recorded by different observatories as evenly distributed over the world as possible; for high southern latitudes the pattern is mainly inferred. On the $DS+Dst$ system there is an eastward flowing electrojet in the evening and a stronger westward electrojet in the morning. Such strong currents would cause the disturbances observed at Halley Bay. The variation of the element D is explained by the fact that these currents flow in a geomagnetic east–west direction, i.e. along the line from 252° to 72° (true). Meridian currents, which have only a small effect on H and V would explain the many exceptions to the general behaviour of D. Chapman also analyses the current systems occurring in individual storms; the main difference between these and the idealized or average patterns is one of phase. Hence the period of changeover from increasing to decreasing bays is expected to be variable from night to night, as was observed.

On p. 19 it was suggested that undulating activity and red-violet coloration occurred during the separation period between the evening and morning features of a display, at least in moderate displays. A brief account is given below of the auroral and magnetic activity on each night that this particular type of activity took place. Reference should be made to Table X.

*5/6 June: 0130 U.T. (RV); Magnetogram No. 5**

An arc remained low on the southern horizon throughout the night and there was very little difference in auroral character between the morning and evening periods. Maximum brightness occurred during the period around 0130 U.T. Maximum elevation was reached at 0315 U.T. and was followed by some double arc activity with weak rays. More weak rays were observed at 0900 U.T.

Deviations from the quiet-day variation in the elements H and D were hardly significant, but in the case of V, a slight increasing displacement changed to decreasing. The time of this reversal was not sharply defined, because of the small magnitude of the effect, but it took place between 0130 and 0300 U.T.

5/6 July: 0230 U.T. (RV); Magnetogram No. 7

There was some slight cloud which marred observations. Before 0230 U.T. all that could be observed was a faint auroral light on the southern horizon. From 0230 U.T. the arc moved slightly northwards (to elevation 10°) and became intense enough to be distinguished as HA. The arc receded southwards from 0330 U.T. until it faded at 0715 U.T.

Immediately before 0230 U.T. magnetic conditions were quiet. Earlier, in the evening, there were small increasing displacements in H and V. After 0230 U.T. these changed to decreasing displacements which were most clearly observed in the case of V. The element D became more westerly.

9/10 June: 0115 U.T. (RV); Magnetogram No. 6; Plate III, figs. 57–65

Before 0115 U.T. this display was characterized by the formation of HA1 8° from auroral light on the southern horizon, the elevation increasing until the undulating activity commenced. Immediately after

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

0115 U.T. there was band and double arc activity low in the south. Flaming began at 0320 U.T. and ended at 0530 U.T., during which time diffuse surfaces extended well to the north. The arc re-formed at 0545 U.T. at 10°, then receded southwards fading slowly in the morning sky.

From 0115 U.T. approximately, magnetic activity gradually increased to maximum disturbance at 0400 U.T. approximately, when the sign was clearly *H* and *V* decreasing and *D* easterly. Before 0115 U.T. the sign of the disturbance was very uncertain but could be distinguished in the case of *H* and *V* as slightly increasing.

7/8 August: 0230 U.T.; Magnetogram No. 15

Before 0230 U.T. there were arcs low on the southern horizon, first formed at 2315 U.T. from faint auroral light. There was some double arc activity and also some deep folds tending to bands. After 0230 U.T. observing conditions rapidly worsened but it was possible to say that the aurora did not pass overhead.

In the evening there were small bays with *H* and *V* increasing and *D* westerly. From approximately 0230 U.T. the sign of the displacement changed very slowly until near 0600 U.T., but there was then a definite movement with *H* and *V* decreasing and *D* easterly.

21/22 July: 0445 U.T.

Observing conditions were too poor to give details of the display, but the aurora did not at any time reach the overhead position.

During the period around 0445 U.T., *H* and *V* maintained a slight decreasing displacement while *D* changed from a westerly to an easterly displacement.

6/7 July: 0230 U.T.; Magnetogram No. 8

Before 0230 U.T. there was faint auroral light in the south with HA2 16° forming at 2400 U.T. for a brief period. After 0230 U.T. there were bright arcs in the south ~10° until 0345 U.T., and then faint auroral light until it became cloudy at 0500 U.T. The display remained in the south with a distinct brightening at 0815 U.T.

In the evening there were slight, increasing displacements in *H* and *V*. From 0230 U.T. there was a definite change to decreasing bays. The behaviour of *D* was not systematic.

27/28 September: 0130 U.T. (RV); Magnetogram No. 23

Observations were difficult because of continuous twilight. Activity was observed to begin quite suddenly at 0115 U.T. with an interference ring in the south growing into HA3 20°. Undulating activity started at 0125 U.T. and remained until 0150 U.T., during which time there were many folds along the arc. Afterwards there was some double arc activity. The display seemed to be moving overhead at 0250 U.T.

At 0127 U.T. there was a sharp westerly bay in *D*. A change of sign of the displacements of *H* and *V* began with sharp decreasing bays.

13/14 September: 2315 U.T.; Magnetogram No. 20

Observations were again difficult because of twilight. Auroral forms were distinguished from 2315 to 0530 U.T., with maximum activity at 0515 U.T. in the form of RB2–3 45°. Activity was confined well to the south.

Before 2315 U.T. there was a large bay on all three elements, *H* decreasing, *V* increasing, *D* westerly. 2315 U.T. marked the onset of another smaller bay with *H* increasing, *V* increasing, *D* oscillatory.

1/2 August: 0345 U.T. (RV); Magnetogram No. 12; Plate V, fig. 81

From 2315 to 0030 U.T. there were arcs in the south. At 0035 U.T. these arcs began to move overhead. The sky was overcast from 0035 to 0315 U.T. but the interference ring indicated overhead activity, and when the cloud cleared at 0315 U.T. there was a broad HA overhead. After 0315 U.T. there was band activity then flaming from 0415 until 0730 U.T. Plate V, fig. 81 illustrates a new HA forming near the overhead position at 0032 U.T., before the main reversal of magnetic disturbance.

The change from *H* and *V* increasing to decreasing occurred at 0145 U.T. during the cloudy period. At 0342 U.T. there were sharp movements on all three elements, like *ssc**, which marked the beginning of intensified decreasing bays in *H* and *V*.

23/24 June: 0300 U.T., 0315 U.T. (RV)

Moonlight made observations difficult. There was overhead activity nearly all night with bands and broad arcs. 0300 and 0315 U.T. did not appear to be significant times in the display, but in the intervening period there were sharp movements on all three elements: *H* decreased further; *D* moved easterly after oscillatory movements; *V* showed an increasing displacement during a decreasing bay. The aurora was overhead during this period.

5/6 September: 0015 U.T.; Magnetogram No. 19

There was overhead activity, consisting of bands and broad arcs, throughout the night. Flaming commenced at 0105 U.T. The undulating activity occurred at 0017 U.T. and was of very short duration.

Magnetic disturbance was complex at 0017 U.T. when the aurora was overhead. A series of rapid movements began in *H* which tended to make *H* begin to decrease; *D* changed from westerly to easterly displacement. On *V* there was a short, sharp, increasing bay superimposed on a decreasing bay, which had begun at 2330 U.T.

28/29 June: 0815 U.T. (RV); Plate IV, figs. 66–79; Plate V, fig. 80a

There had been overhead activity from 0430 U.T. when flaming first commenced. 0800 U.T. marked the beginning of a northward surge, which culminated at 0825 U.T. in the formation of a corona from a red RB between 10° and 144° elevation. After this, the aurora receded to the south.

There was a clear reversal of sign of disturbance of *V* from increasing to decreasing at approximately 0130 U.T., during a cloudy period. At 0750 U.T., approximately, there were large, sharp movements of all three elements, *H* and *V* decreasing and *D* easterly.

24/25 September: 0045 U.T. (RV)

Observing conditions were too poor to give details of this display.

At 0045 U.T. the displacements of *H* and *D* changed sign by sudden impulses—*H* to decreasing, *D* to easterly. The element *V* changed from increasing to decreasing displacement, although there was a sharp increase before the main change.

8/9 April: 2315 U.T., 2330 U.T. (RV), 0015 U.T. (RV); Magnetogram No. 1; Plates II and III

The main occurrence of undulating activity was at 0012 U.T. when it extended over the whole sky. Before this, the display consisted mainly of several broad homogeneous arcs (HA) moving overhead. From 0012 U.T. there were intense rayed bands (RB) mainly in the south. At 0145 U.T. there was a movement northwards and an arc remained in the north until 0445 U.T. when flaming commenced and diffuse surfaces moved into the magnetic zenith.

At 0010 U.T. there were large, sharp movements on all three elements. *H* changed from a moderate increasing displacement to a large decreasing displacement; *D* was oscillatory; *V* decreased further—already undergoing a decreasing displacement.

4/5 September: 2215 U.T., 2230 U.T. (RV), 2245 U.T. (RV); Plate VI, figs. 106–14

The display developed rapidly from 2045 U.T. The undulating activity occurred from 2210–2225 U.T. as the aurora moved to the overhead position. There was a very rapid movement of RB back to the south at 2245 U.T. From 2300 U.T. the aurora was seen as HA in the north and faint auroral light in the south. From 2400 U.T. cloud obscured all auroral features but the interference filter indicated an overhead display until at least 0600 U.T. The plates, which were taken at 18-sec. intervals between each frame, illustrate the very rapid changes of the aurora at that time and the rapid break-up before receding southwards.

The magnetic events are difficult to interpret because of the rapid movement of the aurora. Between

2215 and 2245 U.T., *V* changed with a sharp movement from increasing to decreasing displacement. The elements *H* and *D* maintained the sign of their displacements, increasing and westerly respectively, and underwent rapid oscillations. The main change of sign of disturbance in *H* occurred about 0100 U.T. by which time the sky was clouded over.

15/16 July: 0115 U.T. (RV), 0330 U.T. (RV); Magnetogram No. 11

This display was very intense. The undulating activity at 0118 U.T. took place at about the time of change in *H* from increasing to decreasing displacement. The pattern is otherwise confused.

16/17 August: 2130 U.T. (RV), 2145 U.T. (RV), 0315 U.T. (RV); Magnetogram No. 16

Observations were made difficult by moonlit cirrus. The display was very intense, and mainly overhead. When undulating activity first occurred at 2130 U.T., *H* underwent the first of many sharp decreasing displacements after a moderate increasing displacement. *V* and *D* simultaneously underwent sharp displacements, decreasing and easterly respectively, although these represented no significant change in the disturbance pattern. The pattern is otherwise confused.

This rather extensive survey of all the occasions on which undulating activity and red-violet coloration occurred, indicates that this type of activity marks the onset of a new active phase in the auroral display and magnetic disturbance pattern. It also shows that, at least for most moderate displays, it frequently occurs during the period between the evening and morning phases of a display, during the change from one sign of magnetic disturbance to the reverse.

3. Effect of Quiet Arcs

Investigations have been carried out on the association between the aurora and the electric currents in the ionosphere, which flow along the direction of the geomagnetic parallels and manifest themselves as magnetic disturbances (Stagg and Paton, 1939; Heppner, 1954). There is strong evidence of a close spatial association of these currents and the aurora.

Most of the correlations attempted have been concerned with quiet homogeneous arcs, as these forms are the most easily explained in terms of simple current systems. There has been very little work of a rigorously systematic, quantitative nature. A large number of quiet homogeneous arcs have been observed from Halley Bay and they could be used for a statistical analysis of magnetic effect in relation to brightness, elevation and time of occurrence. However, a full analysis of this kind is not attempted here, partly because all the magnetic data required are not yet readily available, and also because Halley Bay in this respect is not quite ideally situated. Quiet arcs occur mainly at an elevation of about 7° (Fig. 5) and their magnetic effect is so small as to be almost indistinguishable against the quiet-day variation. Quiet-day variation is slight in high latitudes, particularly during the winter period, but even so it is uncertain whether the mean quiet-day curve for the month is valid on any one day; there is still greater uncertainty regarding the quiet-day level, although the correct form of the variation is known. The method of finding the effect of the quiet arc by comparison with the quiet-day curve, assumes that the derived quiet-day curve represents the variation when there is no arc present. In view of the high percentage frequency of occurrence of the aurora, such an assumption is unlikely to be completely valid. The monthly quiet-day curves used in these reproduced magnetograms have been derived by drawing the smoothest possible trace through all quiet periods.

5/6 June is a unique example of a night when the display consisted of very stable arcs. These occurred from 2300 to 0930 U.T., their elevation varying only very slightly from 6° above the southern horizon during the whole night. Magnetogram No. 5 shows very little systematic displacement from the quiet-day curve in either *H* or *D*. On the other hand, the element *V* shows a small but significant displacement which is increasing in the evening and decreasing in the morning. That *V* alone should be so affected is typical of a distant electric current, such as one near to the position of the quiet arc.

There are many examples in the magnetic records of this change of sign of the disturbance due to a quiet arc. However, Magnetogram No. 5 shows clearly how a small error in estimating the quiet-day level can affect the accuracy of any attempts to measure the disturbing vector. In Table XII a survey is made of the magnetic effects caused by simple movements in the elevation of quiet arcs. The movements selected are all those which were clearly observed and during which the arc retained its regular shape. Such a survey gives limited information about the associated currents, without the error due to uncertainty regarding the quiet-day level which would be incurred in attempting to find the absolute magnetic effect of a stationary arc. The magnetic variations are quoted to the nearest two gammas or half-minute of arc, and have been corrected for the quiet-day variation at the time. Where the magnetogram is reproduced in this report its number is given in the date column.

TABLE XII

MAGNETIC EFFECTS CAUSED BY SIMPLE MOVEMENT IN THE ELEVATION OF QUIET ARCS

a. Records of Northward Movements

Time (U.T.)	*Movement*	*Date*	*V Variation* (gamma)	*H Variation* (gamma)	*D Variation* (minutes)	*Remarks*
2130–2230	HA2 11° → HA1–2 18°	9/10 April (2)*	+90	+60	W 14	
2200–2215	HA3 4° → HA3 6°	25/26 July	+20	+36	W 3	Sharp movements
2200–2300	HA1 7° → RA2 13°	14/15 April (3)*	+50	+ 8	W 3·5	
2300–2350	HA1–2 6° → HA3 8°	9/10 May	+14	−14	W 2·5	
2315–0030	HA1–2 7° → HA2–3 18°	1/2 August (12)*	+34	+66	W 1	
0015–0045	HA1 8° → HA1–2 15°	9/10 June (6)*	− 6	Zero	W 1·5	
0115–0230	HA1 6° → RA2–3 10°	7/8 July (9)*	− 2	− 4	Zero	
0500–0545	HA2 7° → HA2 12°	5/6 August	+48 (following small bay −50)	+64 (following small bay −30)	E 7·5	
0530–0645	HA1–2 10° → HA2–3 18°	2/3 August (13)*	−86	−118	Zero (following small bay W 7·5)	F commenced shortly afterwards
0700–0745	HA1–2 10° → RA2 15°	25/26 June	−48	−88	E 11·5	F commenced shortly afterwards

b. Record of Southward Movements

2345–2400	HA2–3 17° → HA2 12°	2/3 September	−20	− 6	Zero	
0515–0900	HA2–3 9° → HA2 3°	15/16 June	+30	− 4	E 2·5	
0545–0700	HA2 10° → HA1–2 5°	9/10 June (6)*	+28 (following small bay −10)	− 8 (following small bay −28)	Zero (following small bay W 5)	
0600–0945	HA2 12° → HA1–2 6°	31 May/1 June (4)*	+72	+70	E 3·5	
0630–0715	HA2 20° → HA1–2 10°	4/5 July	−20	+28	E 11·5	

* Magnetogram number (see end of report).

As stated in the previous section, the magnetic variation for northward movements is in the same direction as that of the beginning of bays and other disturbances; the reverse is true for southward movements. Assuming that the current which causes the magnetic disturbance moves with the quiet arc, Table XII (particularly XIIa which includes more data) shows clearly that the direction of this current is different in the evening and morning periods. If this current flows along the direction of the quiet arc, then the pattern observed is explained by an eastward current in the evening and a westward current in the morning. The pattern is similar to that discussed in the previous section. The important point to be emphasized here is that these oppositely directed currents exist in the presence of the same auroral form.

As has been pointed out on p. 3, quiet arcs seldom pass overhead at Halley Bay. Not once during 1959 was a simple, isolated arc observed moving from south to north through the overhead position, so that it was not possible to observe the interesting ΔZ reversal, which would be present if an east–west current moved with the arc (Stagg and Paton, 1939).

The following is a survey of the few cases in which the aurora was observed well to the north.

8/9 April: Magnetogram No. 1; Plate III, figs. 48 and 49

Between 0200 and 0500 U.T. the aurora was well to the north, at approximately 20° elevation above the northern horizon, in the form of an arc of varying intensity. During this period the element *V* showed an increasing displacement of 100 gammas at maximum.

5/6 September: Magnetogram No. 19

During the period 0005–0055 U.T. there was an arc of varying intensity and position, between 30° and 90° above the northern horizon. This phase of the display coincided well with a sharp increasing bay superimposed on a larger decreasing bay in the element *V*.

18/19 September: Magnetogram No. 21; Plate VI, figs. 115–118

As Plate VI, fig. 115, shows, for a short period near 0220 U.T. there was an arc at approximately 30° above the northern horizon; this coincided well with a brief increasing displacement in *V*, when near that time the disturbance vector was such as to decrease *V*. Plate VI, figs 116–118, show a surge of diffuse surfaces from the south to the north, which took place between 0400 and 0410 U.T. There were sharp movements on all three elements, but *V* showed a decreasing tendency.

All four plates are confused by moonlit cloud.

21/22 September: Magnetogram No. 22; Plate VI, figs. 119–122

The plates show a northward surge of diffuse surfaces to form RA at 20° above the northern horizon during the period 0330–0430 U.T. This movement to the north coincided well with a reversal of the magnetic disturbance vector from *V* decreasing to *V* increasing, which commenced at 0340 U.T. and was complete by 0430 U.T.

All four plates are confused slightly by a twilight glow, which was becoming more intense.

On all these occasions there was a very active and varied display. Even so, the above evidence indicates that when the aurora is to the north of the observer, the sign of the displacement of *V* is the reverse of that expected when the aurora is to the south.

4. Typical Displays

9/10 April: Magnetogram No. 2

As twilight faded the arc appeared at 2130 U.T. in the south, coinciding with an increasing bay in *H* and *V* and also in *D* which was mainly easterly. The magnetic elements returned to normal as the arc receded southwards after its maximum elevation at 2230 U.T. A very low quiet arc remained until 0215 U.T. when RB 2–3 appeared. At 0220 U.T., approximately, sharp bays occurred on all three elements, *H* and *V* decreasing and *D* westerly. After 0230 U.T. fog unfortunately became thicker and obscured the sky. The magnetic activity of this night was preceded by a well formed *ssc* (confirmed) at 1829 U.T. The main phase of the storm was marked by a large bay at approximately 0600 U.T., *H* and *V* decreasing and *D* easterly. As this bay decayed there were rapid oscillations of large amplitude on all three elements, which are typical of the later stages of magnetic storms, with confirmed sudden commencements, at Halley Bay.

14/15 April: Magnetogram No. 3; Plate IV, figs. 54–56

From 2115 to 2245 U.T. there was HA1–2 moving from 8° to 12° elevation. This accompanied an increasing bay in *H* and *V*. After 2245 U.T. there was some rayed activity and the arc tended to become a band, remaining low in the south. At 0045 U.T. all that was observed was an indistinct auroral light in the south. At 0103 U.T. there was HA3 low in the south, and RA2 63° which was moving overhead. This RA2 became HA1–2 114° at 0111 U.T. and faded out in the magnetic zenith; this is clearly illustrated in the all-sky photographs. At 0059 U.T. the sign of the bay reversed sharply to *H* and *V* decreasing and *D* easterly. This reversal was coincident with a new phase in the auroral display.

9/10 May

The period 2300–0630 U.T. was characterized by quiet arcs low in the south. At 2350 and 2400 U.T. these arcs suddenly reached brightness 3, and a small but distinct increasing bay occurred in *V*. At 0645 U.T. slight rayed activity was observed and from 0715 to 0800 U.T. there were high diffuse surfaces, a corona being formed at 0745 U.T. The display ended at 0830 U.T., as quiet arcs in the south, with the increasing brightness of twilight. The active period from 0700 to 0800 U.T. was accompanied by a decreasing bay in *H* and *V*.

31 May/1 June: Magnetogram No. 4

Slight increasing displacements in *H* and *V* ended when a bay commenced at 2325 U.T. with *H* and *V* decreasing and *D* easterly. Observing conditions were not too favourable at this stage, but a corona formed from diffuse rays could be seen between 2345 and 2400 U.T. while at 2355 U.T. a sharp enhancement of the bay movements occurred. Flaming was observed between 0030 and 0100 U.T. The bay ended at about 0120 U.T. The quiet arc then moved very slowly northwards to a maximum elevation of 12° at 0600 U.T. and receded slowly to 6° at 0945 U.T. *V* gradually decreased to a minimum at 0535 U.T. and then gradually increased. There was no significant trend in either *H* or *D*.

9/10 June: Magnetogram No. 6; Plate IV, figs. 57–65

The quiet arc was first formed as HA1 8° at 0015 U.T. from indistinct auroral light on the southern horizon. The arc rose to 15° at 0045 U.T. and the brightness increased to 2–3. *D* showed a small but definite westerly movement, *V* decreased very slightly. At 0115 U.T. there was undulating activity and red-violet coloration on RA3–4 11°, which became RB3 at 0130 U.T. *D* moved more westerly; *H* was oscillatory, then decreased; *V* increased for a brief period, then decreased. The arc re-formed with some double arc activity. *H* continued to decrease and *D* to become westerly; *V* oscillated slowly. The commencement at 0320 U.T. of flaming and overhead surfaces was accompanied by the beginning of large, sharp bays on all three elements, with *H* and *V* decreasing and *D* easterly. The flaming surfaces gradually receded southwards from 0445 U.T. and the flaming ended at 0530 U.T.; this period marked the decay of the large bay. A quiet arc, receding slowly from HA2 10° at 0545 U.T. to HA1–2 5° at 0700 U.T., was accompanied by a slow increase in *V* to its normal value. Plate IV, figs. 57–65, illustrate clearly the development of flaming, although there was a recession southwards from 0345 U.T. This recession is more apparent photographically than it was visually, as the film does not record the northernmost surfaces which were visible only during intensification by periodic flaming.

1/2 August: Magnetogram No. 12; Plate V, fig. 81

The arc first formed at 2315 U.T., as HA1–2 7°. It moved to HA2–3 18° at 0030 U.T. and was accompanied by bays on all three elements, *H* and *V* increasing and *D* westerly. At 0035 U.T. a second arc was observed, forming overhead in an unusual manner as seen in Plate V, fig. 81. Unfortunately it became cloudy at this stage, but it was possible to ascertain that overhead activity continued. At 0145 U.T. there were new large bays on all three elements; *D* was initially easterly then oscillatory, and *H* and *V* changed to decreasing bays. Undulating activity and red-violet coloration at 0345 U.T. were preceded at 0343 U.T. by sharp enhancements of the bay movements, similar to *ssc* or *si*. Flaming was observed from 0415 to 0715 U.T.

2/3 August: Magnetogram No. 13; Plate V, figs. 82–90

Although there was a reversal from increasing to decreasing bays in *V* at about 0200 U.T., *H* and *D* continued in decreasing and westerly bays respectively. At the time, the display took the form of arcs in the south, and the peak of the bay which occurred at 0345 U.T. coincided with maximum elevation of the arcs. The commencement of flaming at 0645 U.T. was accompanied by large bays on all three elements, *H* and *V* decreasing and *D* easterly. As the activity faded, all three elements returned to their normal values. Plate V, figs. 82–90 cover a period from 0645 to 0800 U.T. and show clearly the development and decay of flaming.

7/8 August: Magnetogram No. 15

From 2315 to 0215 U.T. activity was confined well to the south, mainly as quiet arcs, occasionally tending to bands, during which time *D* was oscillatory and *H* and *V* (especially *V*) showed increasing displacements. At 0218 U.T. there was undulating activity and red-violet coloration on RA3 9°. Afterwards, there was so little activity that it could not be distinguished because of slight cloud. From 0600 U.T. there was HA1–2 near 10° and all three elements commenced bay movements, *H* and *V* decreasing and *D* easterly.

These few examples of typical displays show that the following features are characteristic of most aurorae and their accompanying magnetic effects. Small bays or displacements occur in the evening as the quiet arc is formed; later, in the morning, there are much larger bays with flaming and overhead activity. Also, a discontinuity in the auroral display is observed to coincide with the change of sign of the disturbing vector (i.e. from small increasing bays or displacements to large decreasing bays), the time of changeover generally occurring near local midnight but varying considerably. However, these are only broad generalizations to which there are many exceptions: for example, the sign of the magnetic disturbance in the evening is often uncertain.

It is interesting to compare the above observations with those made from similar northern latitudes, such as those from College, Alaska ($\Phi = 64 \cdot 6°$ N.) during the two winters, 1950–51 and 1951–52 (Heppner, 1954). In his report Heppner considers only the simplest (horizontal) element and attempts to describe all auroral displays and magnetic disturbance in terms of two basic patterns which differ from each other only slightly. The present writer would not classify auroral displays so rigidly, but there is a striking similarity between Heppner's proposed patterns and the southern displays seen from Halley Bay. Heppner suggests that when several bays or displacements occur in one night, the onset of each is accompanied by a new phase in the auroral display. This is clearly verified in the many examples already quoted from Halley Bay. A change in *H*, from small increasing bays or displacements to large decreasing bays, takes place near midnight; at about the same time there is an enhancement of auroral activity as the morning phase of the display commences. Another particularly good example, which was observed on 8/9 April (Magnetogram No. 1), is described below.

5. Large Displays

8/9 April: Magnetogram No. 1; Plates II and III

The display was first observed at 2215 U.T. as twilight faded. Until 2355 U.T. activity was varied but chiefly consisted of homogeneous arcs, several of which were present at the same time, passing overhead to the north. At 2355 U.T. there was a single arc in the north which developed short rays at 0007 U.T. This was followed by a surge of activity from the north-east, and at 0014 U.T. the entire sky was covered with RB4 forming a corona. Undulating activity and red-violet coloration were extensively present. This very active period was accompanied by rapid oscillations in *D* and a sharp decreasing movement in *V*, while *H* changed sharply from increasing displacement to a large decreasing bay (*bs*). Intense, rayed activity continued high in the south until there were movements to the north at approximately 0100 and 0200 U.T., after which the display took the form mainly of a quiet arc in the north. While the aurora was in the north, the displacement of *H* and *D* tended to return to normal, while *V* changed from a decreasing to a slightly increasing displacement. The next significant part of the display occurred at approximately 0500 U.T., when a flaming corona was formed from diffuse rays and surfaces. This phase of the display lasted until twilight at 0700 U.T. There were simultaneous bays on all three elements, *H* and *V* decreasing and *D* mainly easterly, but they were markedly less sharp than at 0012 U.T. There was battery failure in the magnetic recording lights just after 0600 U.T., but the *H* trace may still be followed. Plates II and III, all at 12-sec. film exposure, illustrate this display.

14/15 July and 15/16 July: Magnetograms Nos. 10 and 11

In Magnetogram No. 10 the sensitive trace is reproduced mainly to illustrate how a very intense storm was superimposed on more moderate disturbance. Unfortunately, because of moonlight and drifting snow observing conditions were not favourable, but between 0300 and 0400 U.T. several broad HA2–3 were observed passing overhead; these coincided with the main phase of the early disturbance. Before 0800 U.T. all that could be observed was an interference ring in the south, then between 0800 and 0815 U.T. very active overhead flaming commenced. By 0845 U.T. a very intense red corona, formed from long rays, could be observed in spite of deteriorating observing conditions. The new phase of the auroral display coincided with an *ssc* (confirmed) at 0802 U.T. The intensity of the storm was so great that the normal magnetogram soon became unreadable.

Magnetogram No. 11 gives the insensitive recordings. The auroral display was seen again at 1715 U.T. on 15 July as soon as twilight faded. The magnetic storm had meanwhile continued throughout the twilight period. Immediately after the *ssc* at 0802 U.T. on 15 July, there were huge displacements of all three elements, *H* and *V* decreasing and *D* easterly. The red type A coloration which then commenced, lasted through the next night, and overhead auroral activity was almost continuous. The conditions were so disturbed that it was impossible to correlate any particular outburst of auroral activity with any significant disturbance. However, it is worth noting that in the case of *H* the displacement was generally decreasing for the morning period and increasing for the evening period.

A careful watch was kept during the next two nights. Drifting snow completely obscured the sky but it was possible, with the aid of the interference filter, to establish that on 16/17 July there was very little auroral activity but that on 17/18 July a very intense display took place. Also on 17/18 July there was a magnetic storm of intensity comparable with that which occurred on 15/16 July.

16/17 August: Magnetogram No. 16

Moonlit cirrus made observing conditions difficult. From 1900 U.T., as twilight faded, the interference ring was observed. An *si* at 2131 U.T. coincided with the movement into the overhead position of HB4 and the commencement of undulating activity and red-violet coloration. The next most active phase of the aurora was at 0315 U.T. when C4, formed from long rays, was observed with undulating activity and red-violet coloration; this was coincident with an *si* in all three elements. The two *si* were of the same sign, *H* and *V* decreasing and *D* easterly.

A characteristic feature of these intense displays is that the main phase still takes place on the morning side of midnight (as in the case of less intense displays) and is accompanied by a large decreasing displacement in the element *H*.

6. SPECIAL EXAMPLES

5/6, 6/7 and 7/8 July: Magnetograms Nos. 7, 8 and 9

From the magnetic records at Halley Bay there are many examples of close similarities in the patterns of disturbance on two, and sometimes three, consecutive nights. Similarities in auroral patterns are less abundant simply because observing conditions were seldom favourable for an extended period of several nights. However, one outstanding example of this phenomenon of repetition was observed at 0230 U.T. on the three consecutive nights 5/6, 6/7 and 7/8 July.

On 5/6 July, before 0230 U.T. all that could be observed through some slight haze in the south was a faint auroral light. At 0230 U.T. there was a very distinct HA3 at 10°. At 0232 U.T. the lower border became irregular, rays appeared and there was undulating activity with slight red-violet coloration. HA had re-formed by 0245 U.T. and then remained, gradually becoming fainter and lower until HA1–2 4° at 0700 U.T.

On 6/7 July there was again thin cloud in the south. Before 0230 U.T. there was a very low, faint arc in the south. This arc intensified and moved northwards for a very brief period at 2400 U.T., becoming HA2 16°. At 0230 U.T. there was a definite intensification to RA2–3 10° with undulating activity. This became HA2 at 0245 U.T. and remained until 0345 U.T., when the structure of the arc became so broad that it could no longer be distinguished as an arc but only as faint auroral light in the south. This remained until twilight.

On 7/8 July, HA1 could be distinguished from 0115 U.T. onwards. This very faint arc remained until 0225 U.T. At 0230 U.T., RA2–3 appeared at a slightly greater elevation of 10°, with the rays moving along the arc from the west. RA had become HA again by 0235 U.T. At 0245 U.T. there was HA2 at 8°. and this form remained with gradually decreasing elevation and occasional slight band activity. At 0445 U.T. rays developed and there was slight flaming up to 36° at 0500 and 0515 U.T. Flaming again took place at 0830 and 0845 U.T. up to 32°. Otherwise, the display remained as a low, faint arc in the south until twilight.

On all three magnetograms, the element V shows a smooth decreasing bay or displacement starting from 0230 U.T. and sharper movements later at 0300 U.T. approximately. There are similar movements on H and D but the time of commencement is not so well defined.

There are many, more striking examples of repetition in other magnetic disturbance patterns; sometimes entire patterns for the whole night are almost identical with one another, except for a shift in time of an hour or so. The observing conditions seldom allowed a complete record to be made of the auroral activity on these nights, but there must often have been even more remarkable examples of repetition in auroral activity than that given above.

6/7 August: Magnetogram No. 14; Plate V, figs. 91–94

The magnetogram is reproduced because very favourable conditions allowed the all-sky camera to record the fading out of a quiet arc. The plates show the gradually diminishing intensity and decreasing elevation. Plate V, fig. 92 records some slight flaming activity, detected visually up to 34°, which sometimes occurs in the dying phases of a display.

The magnetogram is very interesting. It is seen that the period 0655–0740 U.T. is that in which the elements H and V are finally recovering from a decreasing bay, while D is undergoing a very small easterly bay. The return to a normal value is very clear in the case of V and is delayed in comparison to the other elements. This phenomenon, the late recovery of the element V, was often observed in other magnetograms; it is typical of the effect of a distant linear current of diminishing magnitude. This particular example strongly suggests a direct correlation between the intensity of an auroral arc and the magnitude of the currents in the ionosphere which accompany the appearance of the arc.

1/2 September: Magnetogram No. 18; Plate V, figs. 95–98; Plate VI, figs. 99–105

Plate V, figs. 95–98 and Plate VI, figs. 99–102, illustrate how an arc moved northwards to a position near the magnetic zenith and underwent a remarkable deformation from west to east. As the deformation moved along the arc it was accompanied by flaming. Finally there were flaming diffuse rays and surfaces over the whole sky as illustrated in Plate VI, fig. 102.

The magnetic disturbance during this deformation was such that there was a large bay with H decreasing and D easterly. V showed no significant displacement or bay; such behaviour is typical of an electric current near the overhead position.

On the same night there was a northward surge of the aurora between 0530 and 0600 U.T., well recorded by Plate VI, figs. 103–105. The accompanying magnetic effect was a decreasing bay in H and V, with D westerly.

24/25 August: Magnetogram No. 17

There was a well formed, rather small bay on all three elements with a sharp beginning at 2319 U.T. and an abrupt end at 2329 U.T., H and V increasing and D westerly. From 2215 until 2345 U.T. the aurora was observed under very clear conditions. From 2215 to 2230 U.T. there was a faint auroral light low in the south, tending to HA1. At 2235 U.T. HA1–2 2° formed distinctly and advanced northwards to HA2 4° at 2245 U.T. and HA2–3 6° at 2300 U.T. There was a double arc at 2315 U.T., HA2–3 10° and HA1–2 (new) 6°; and at 2330 U.T. there was a single homogeneous arc HA2–3 4°, accompanied by rays R1–2 which extended upwards from 15° to 46° above the entire length of the arc. At 2345 U.T. there was a faint auroral light on the southern horizon with rays R1–2 extending up to 35° on the east side only.

The rays at 2330 U.T. were very well formed with extremely sharp outlines and the lower edge of the rays appeared separated from the homogeneous arc. The magnetic bay (*bs*) was clearly associated with their formation.

IV. CONCLUSIONS

IT is again emphasized that these conclusions are based on and apply only to observations from a single station, i.e. Halley Bay, near to the southern auroral zone.

The main findings of this investigation are summarized below.

1. The analysis given in section II (p. 5–20) has established that a certain recurrent pattern can be discerned in most auroral displays, despite the complexity of the phenomenon. The sequence is as follows: quiet arcs in the south until the period around midnight; then a discontinuity with rapid undulations along the arc or moderately intense rayed bands; an advance northwards and the commencement of flaming, overhead activity and the break-up into diffuse forms; finally, the re-formation of the arc and a recession southwards. The examples from section III (p. 21–25 and 27–29) show that the elements *H* and *V* change from small increasing bays or displacements to decreasing ones at the same time as the discontinuity in the auroral display, and that there are large bays coincident with flaming and overhead activity. The element *D* is often oscillatory, but generally changes from westerly to easterly displacements, similarly to *H* and *V*. The magnetic disturbance pattern is explained by atmospheric electric currents to the south of the station in the geomagnetic east–west direction, easterly in the evening and westerly in the morning; meridian currents, which may or may not be closely associated with the main current, would explain the less regular behaviour of the element *D*. This pattern is very closely analogous to those observed from similarly high latitudes in the Northern Hemisphere.

2. In section III (p. 25–27 and 30–32) the data supports that of previous investigations which have demonstrated a close spatial association between quiet arcs and the atmospheric electric currents which produce a displacement of the magnetic elements from their mean values. However, a feature of these currents is that there is a reversal of the sign of the disturbance, similar to that mentioned above, even when the same auroral form (i.e. the quiet arc) is present. As far as the present writer knows, this reversal in the presence of the same auroral form has not been emphasized before.

3. The undulating activity, to which frequent reference has been made, is a very distinctive motion. It occurs most often when a quiet arc develops rays and the undulations move to the east or west or, as frequently happens, in both directions at the same time. Recently, it has been shown (Evans, 1960) that movements of auroral features with a large east–west component, produce a magnetic effect which may be explained in terms of a net transport of negative charge in the direction of the movement of the luminous features. This undulating activity has all the characteristics of a mixture of two opposing movements, and it seems significant that it should occur so frequently near the time of reversal of the sign of the magnetic disturbance.

4. With the more intense, large-scale displays the basic patterns of auroral and magnetic activity are not followed so strictly. Generally, there is a rapid development of the display in the evening and there are rays and bands which are often accompanied by extensive red type A coloration. However, the main phase of activity still takes place in the morning and is characterized by a large decreasing displacement of the element *H*.

5. Careful observation of flaming motion has shown that this does not consist simply of regular movements of "waves of light upwards one after another in the direction of the magnetic zenith" as described in the *Photographic Atlas of Auroral Forms*. The whole motion is irregular and often nearly obscured by other active, associated motions.

6. The Halley Bay results, which cover the four years 1956–59, show that the position of the quiet-arc zone moved to higher latitudes during years of sunspot maximum. This shift is consistent with the suggestion that there is a direct geometrical relationship between the position of the quiet-arc zone and the position of the "horns" of the Van Allen zones of radiation.

7. Observing conditions seldom allow details of auroral displays to be obtained for a series of consecutive nights, and it is therefore probable that the repetition of patterns of auroral and magnetic activity on consecutive nights is more common than was previously supposed.

V. ACKNOWLEDGEMENTS

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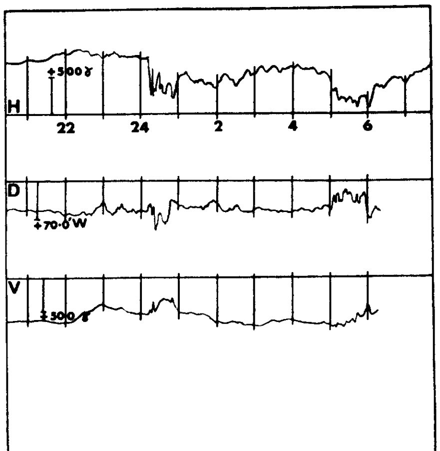
MAGNETOGRAMS Nos. 1-6



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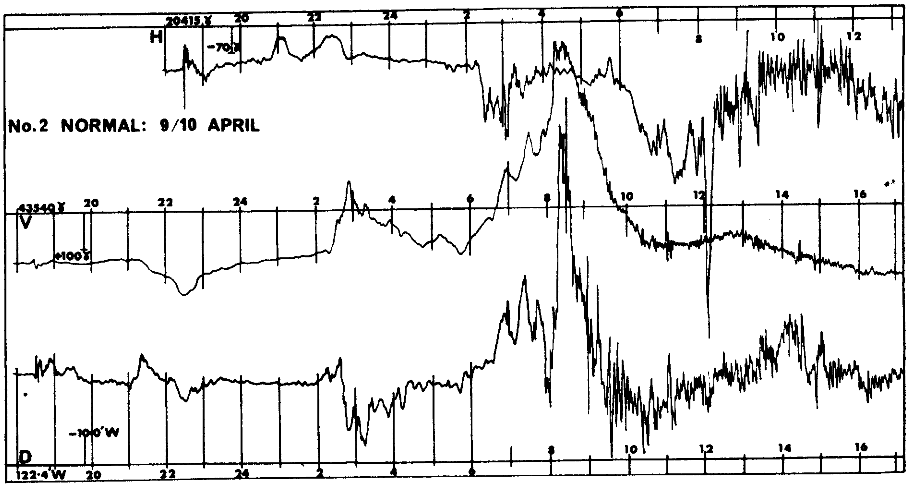

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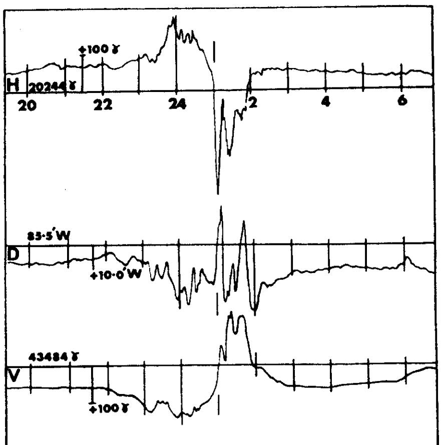

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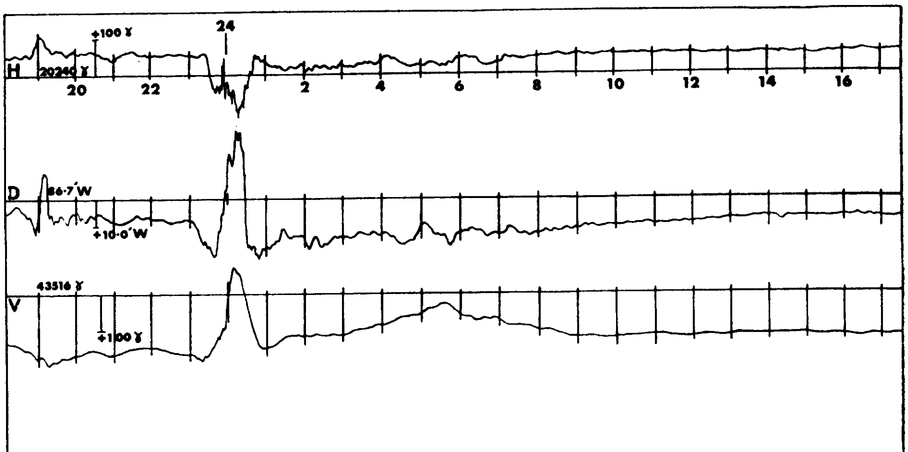

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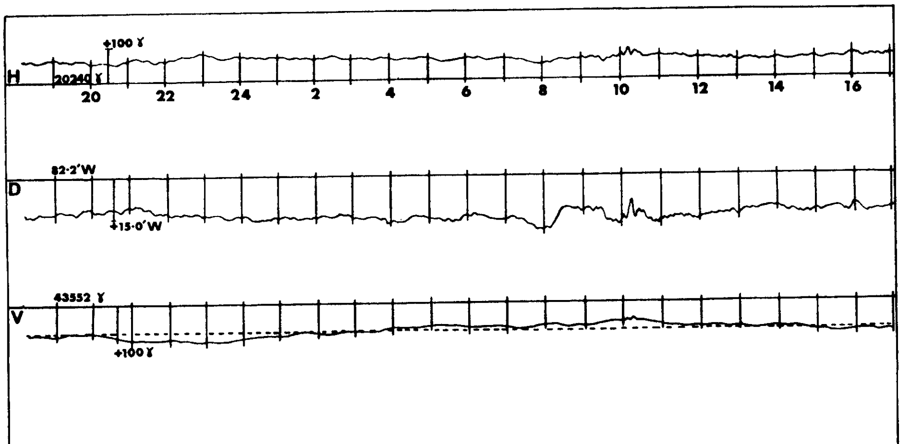

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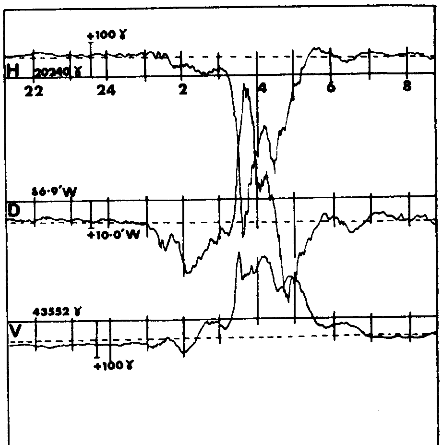

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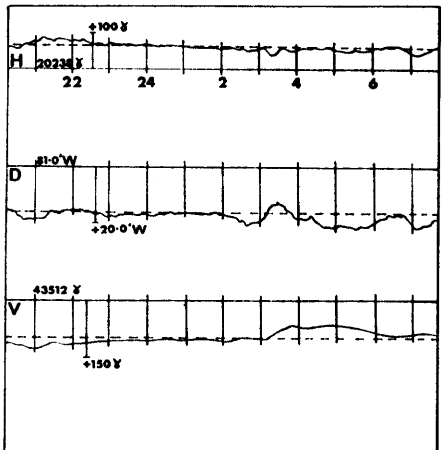

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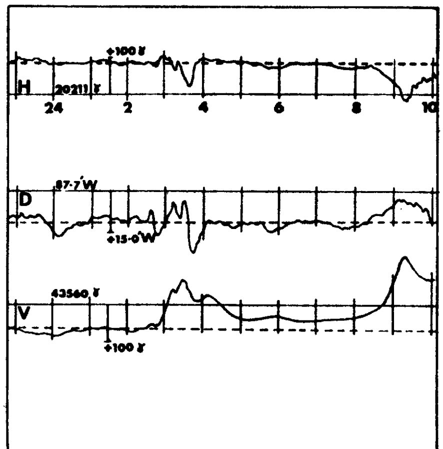

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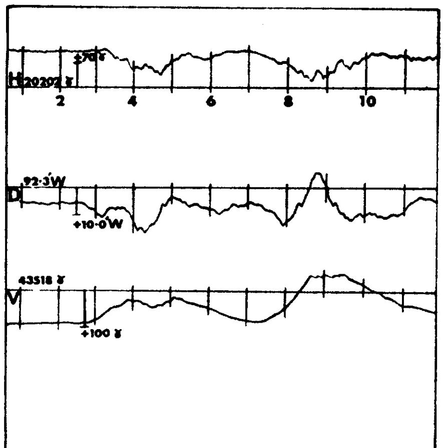

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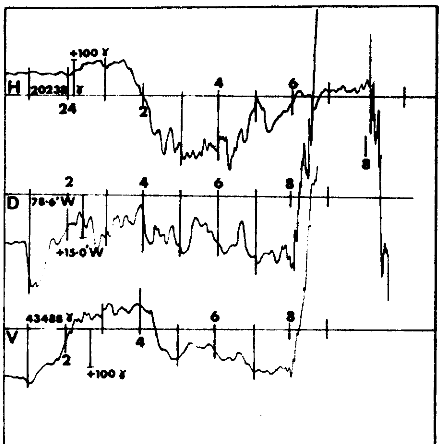

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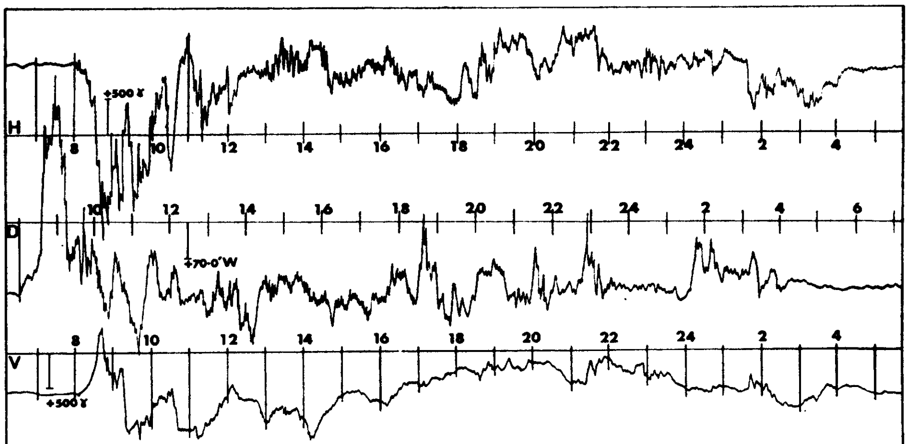

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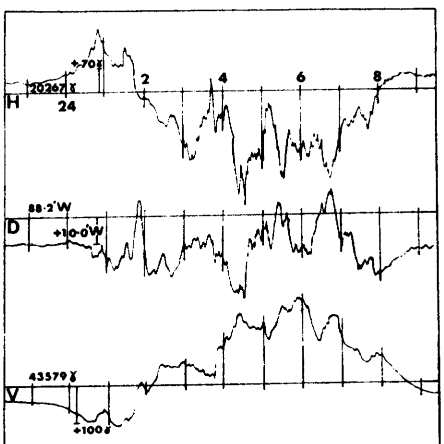

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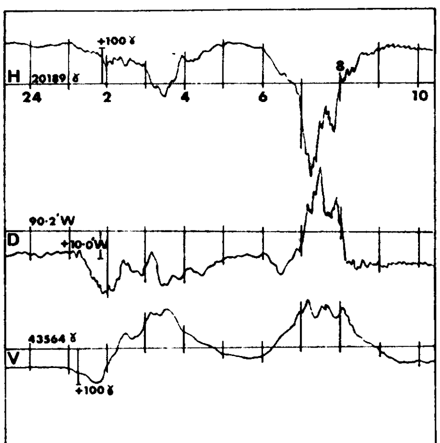

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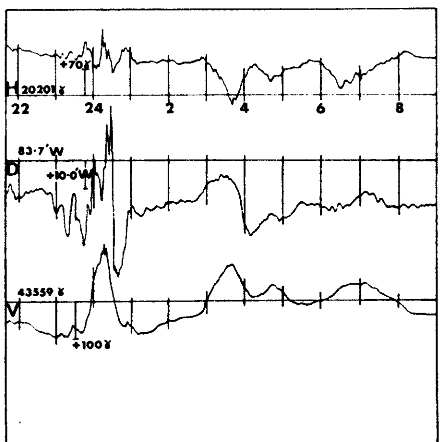

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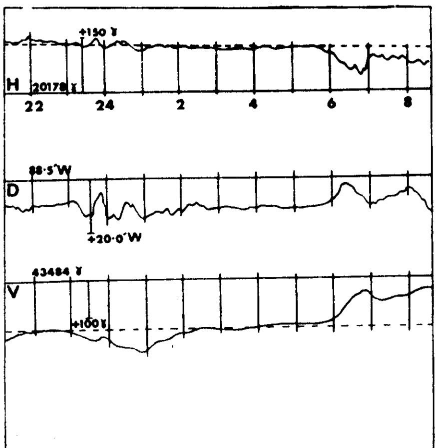

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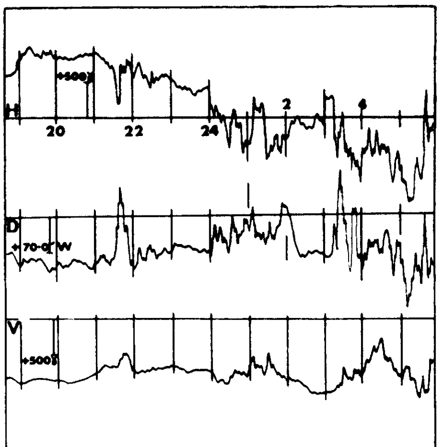

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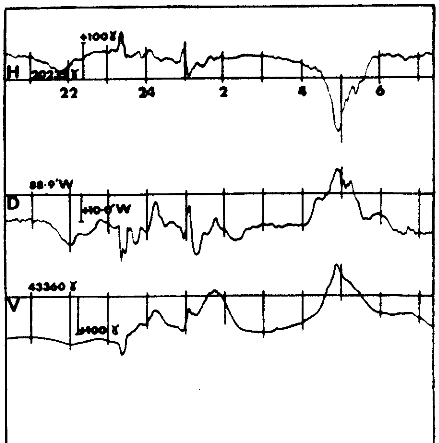

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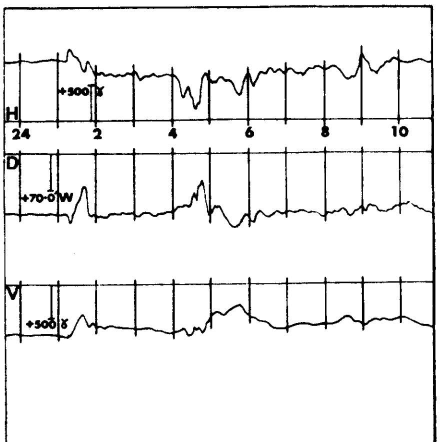

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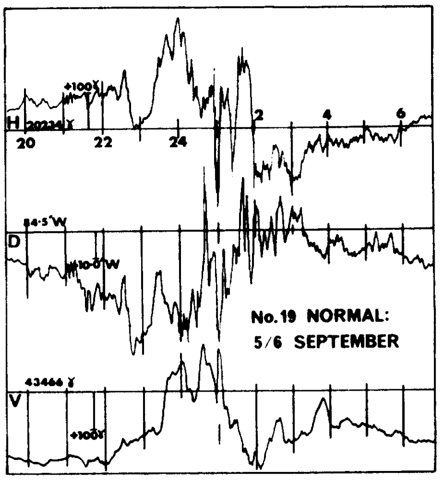

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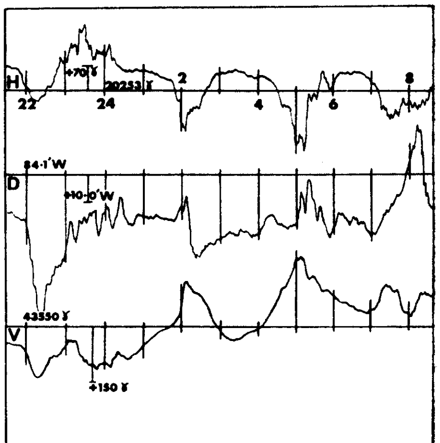

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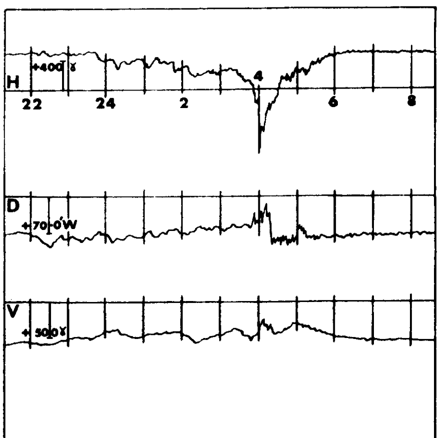

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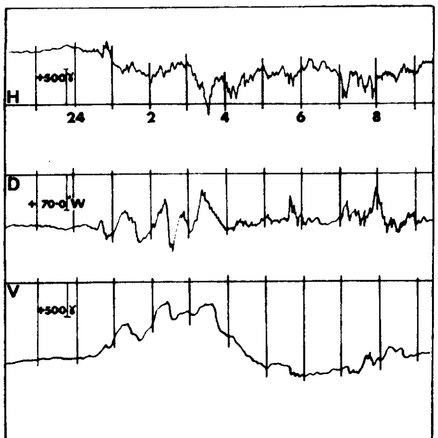

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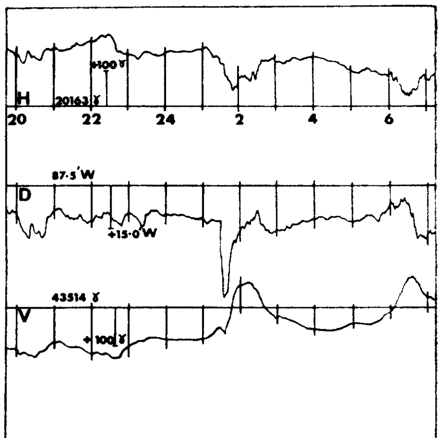


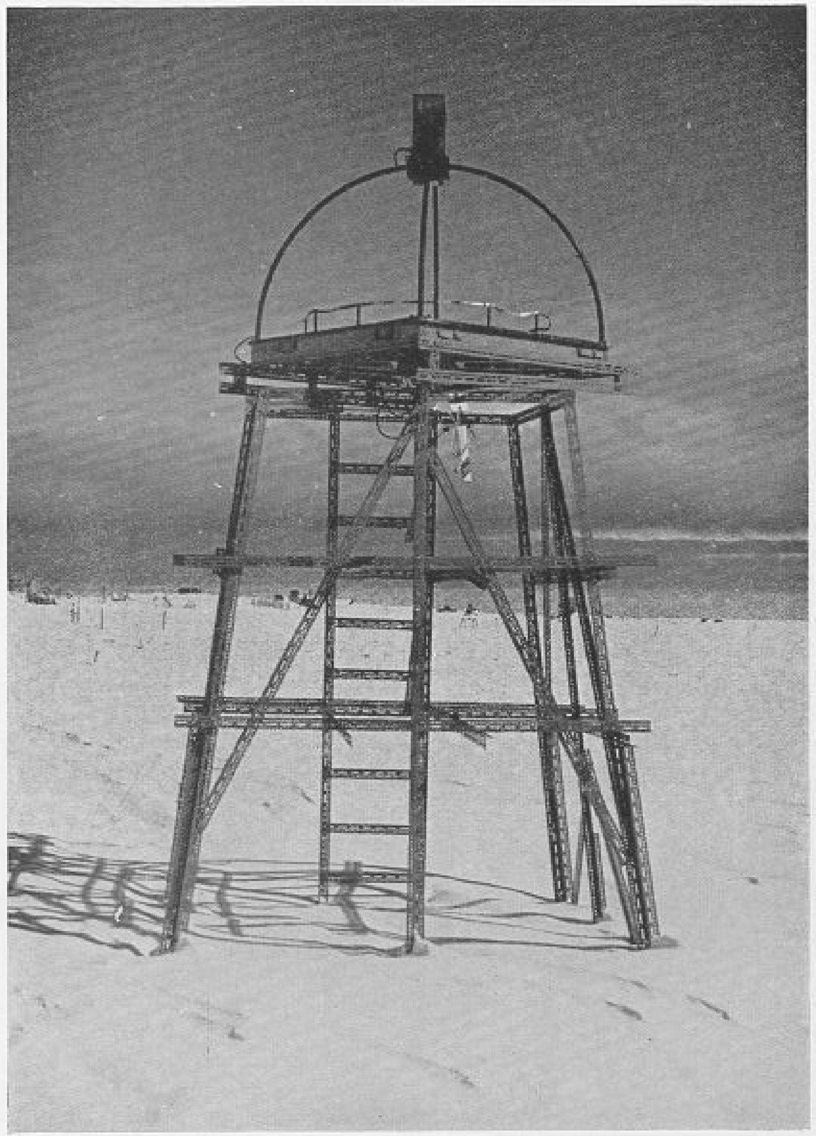
No.23 NORMAL: 27/28 SEPTEMBER

PLATE I

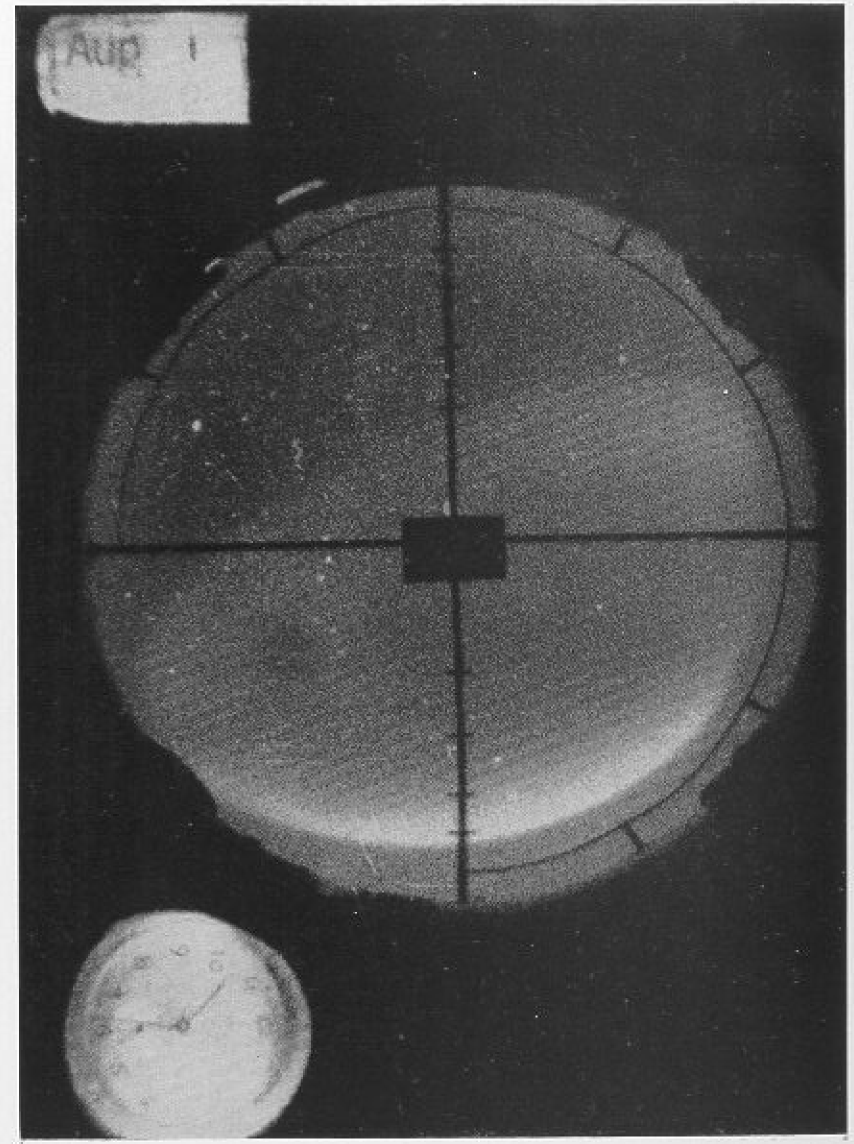
a. The all-sky camera and mounting (see also Fig. 2). The British observatory at Halley Bay, covered by snow, is seen in the foreground.

b. One exposure of the all-sky film. The double date is shown in the upper window and an illuminated watch, set at U.T., in the lower. All elevation markers are clearly shown in the mirror at 20°, 30°, 45° and 60° on the support legs which hold the camera box in the centre. The 10° ring extends for 270° around the horizon and is supported by additional azimuth indicators at 30° intervals. The top of the photograph is north, and east is towards the right, so that the bearing of the centre of the arc is approximately 10° east of south.

The exposure of 27 sec. is long enough to record a few of the brighter stars and the Milky Way may be traced extending in the north–south direction, to the west of centre, even through the brightness of a faint aurora.



a



b

PLATE I

PLATES II–VI

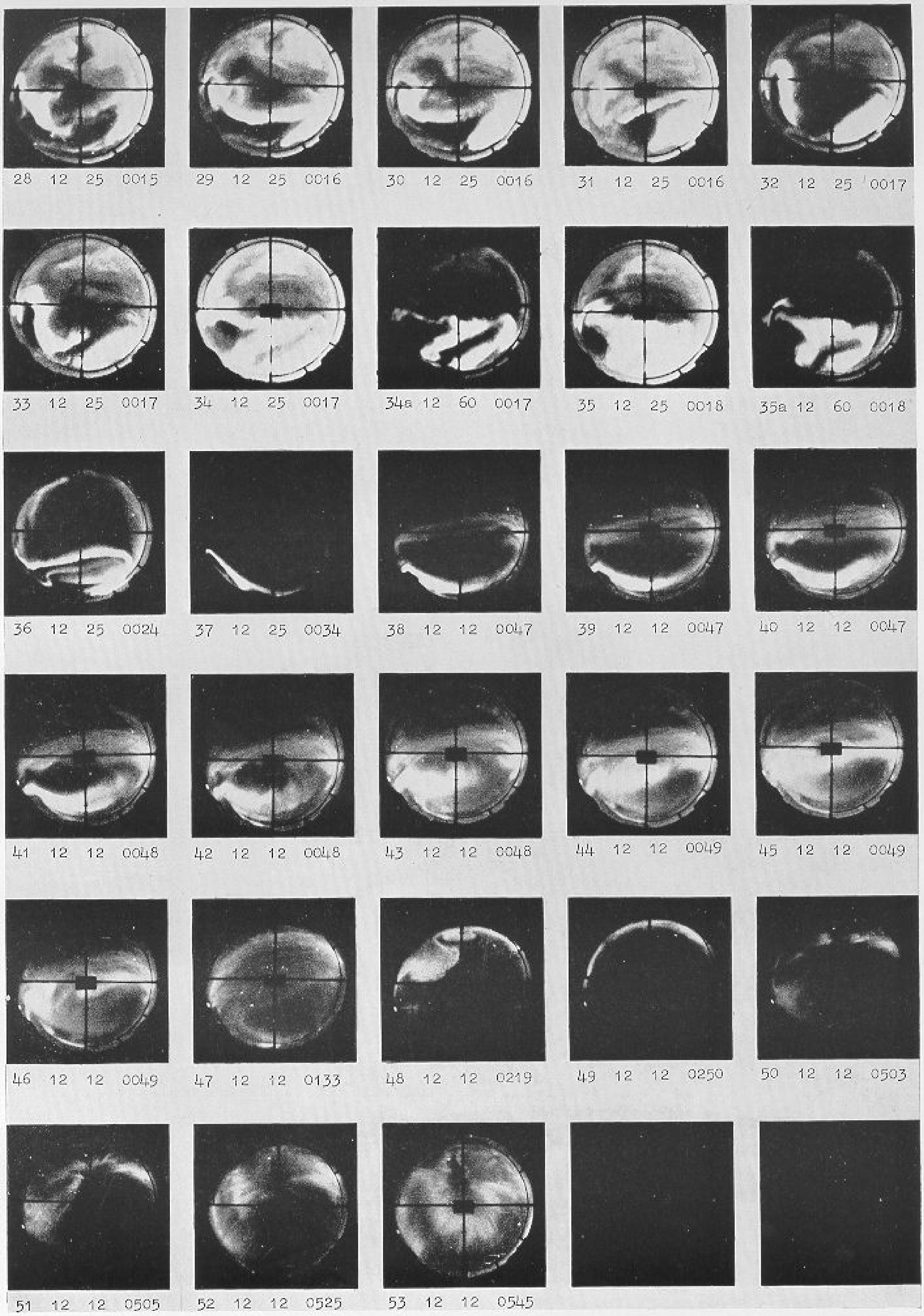
Positive prints taken from single frames of the all-sky camera negative film, processed and printed to produce the maximum contrast. Because of differences in contrast between one negative and another, it was necessary to vary the time of exposure when printing, but the aperture of the enlarging lens was kept constant so that some comparison is still possible. For comparison, selected frames are reproduced twice at different exposure times.

The date and time, which normally appear on each frame (see Plate Ib), 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 to the nearest minute—in that order.

The following prints have been made from consecutive frames of the negative film: 3–13, 17–35, 38–46 and 106–14.

The following prints have been made from alternate frames of the negative film, i.e. with the exposure times centred at 36-sec. intervals: 71–9.

See note facing Plate II



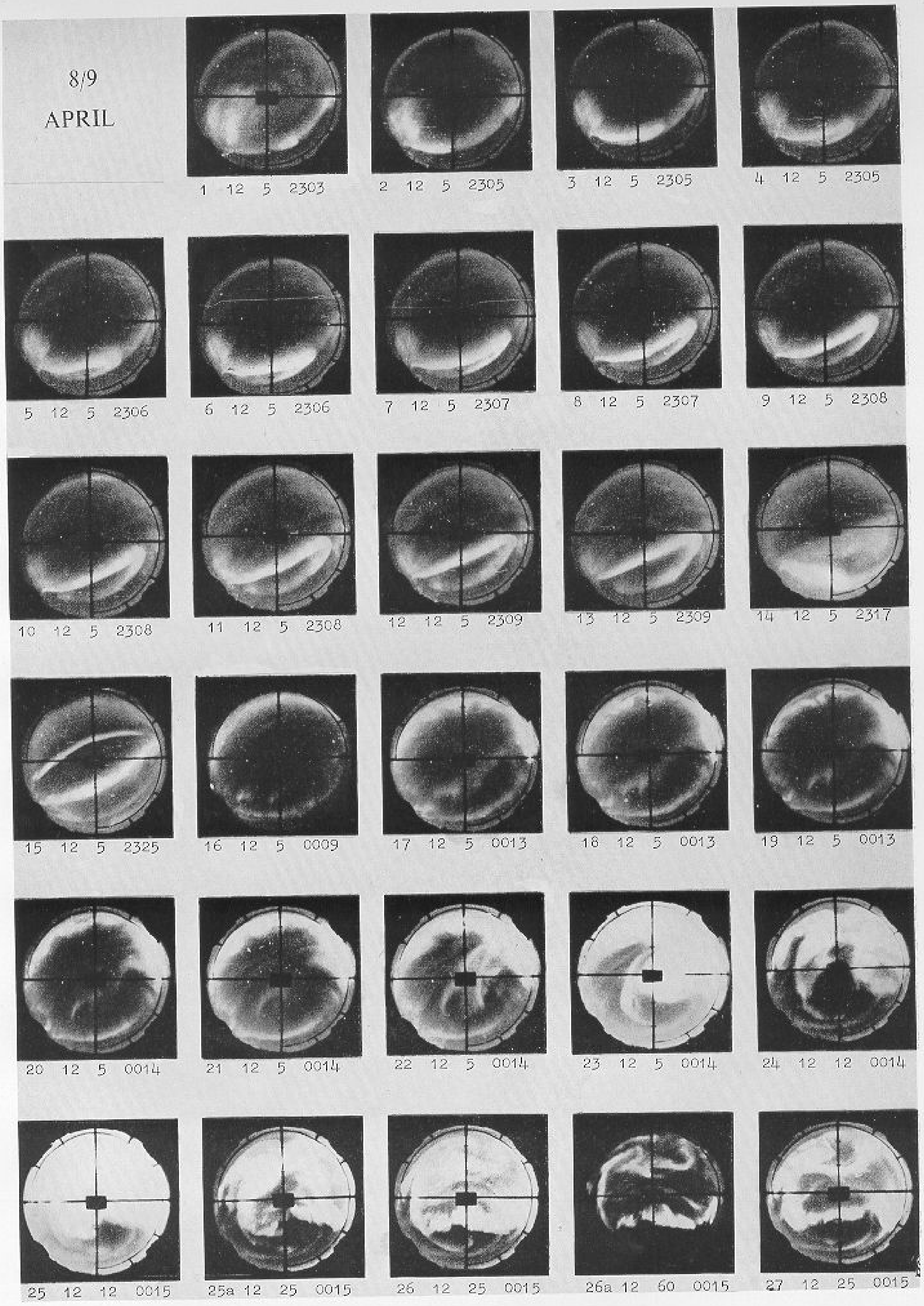
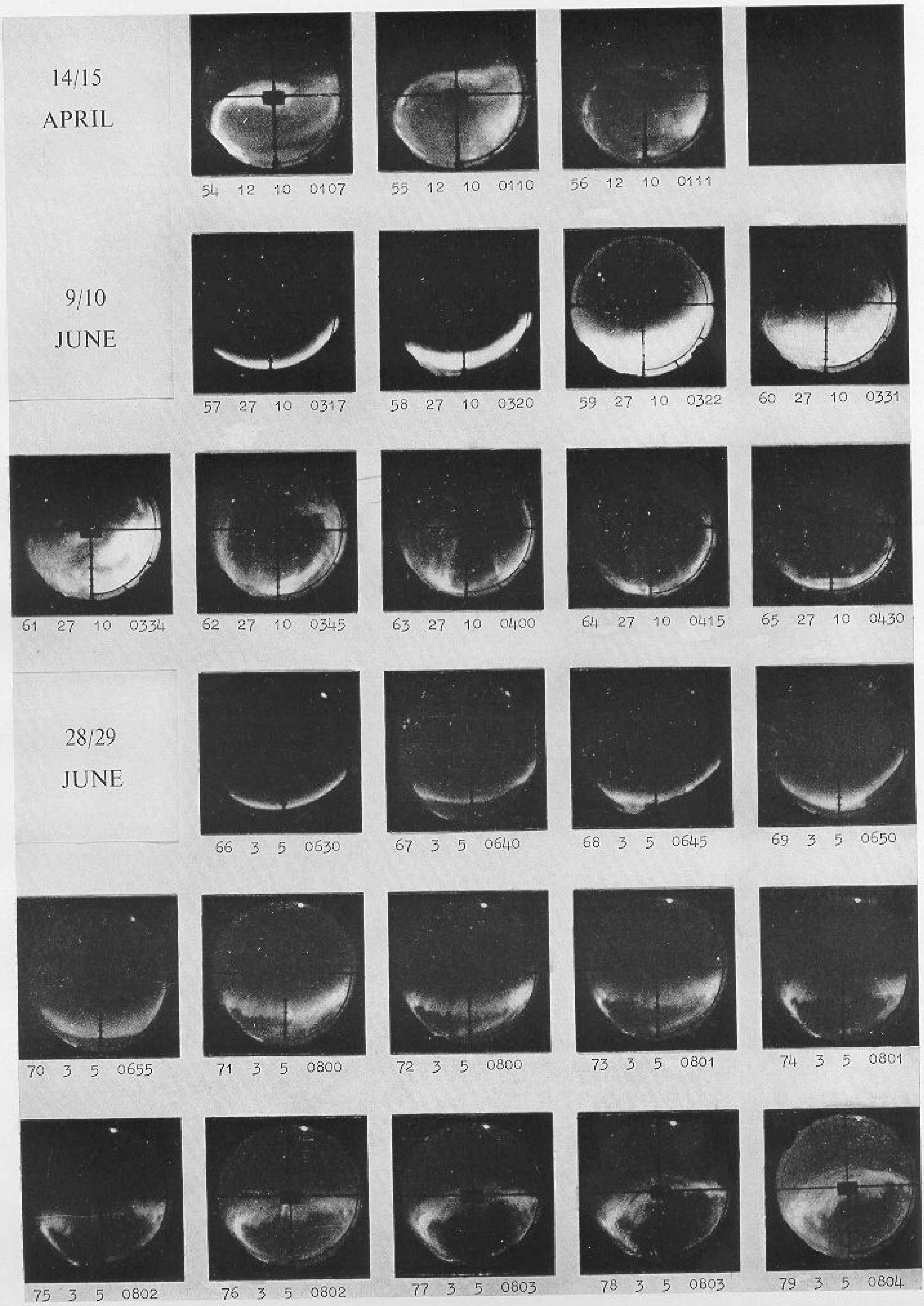
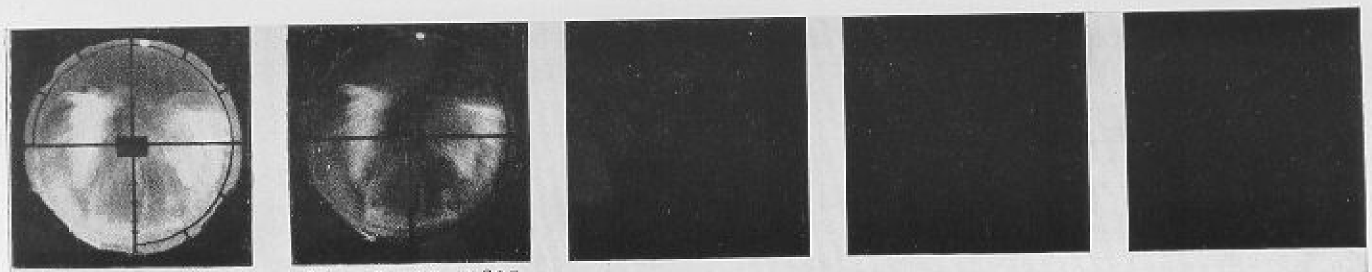

8/9
APRIL
1 12 5 2303
2 12 5 2305
3 12 5 2305
4 12 5 2305
5 12 5 2306
6 12 5 2306
7 12 5 2307
8 12 5 2307
9 12 5 2308
10 12 5 2308
11 12 5 2308
12 12 5 2309
13 12 5 2309
14 12 5 2317
15 12 5 2325
16 12 5 0009
17 12 5 0013
18 12 5 0013
19 12 5 0013
20 12 5 0014
21 12 5 0014
22 12 5 0014
23 12 5 0014
24 12 12 0014
25 12 12 0015
25a 12 25 0015
26 12 25 0015
26a 12 60 0015
27 12 25 0015

PLATE IV

See note facing Plate II

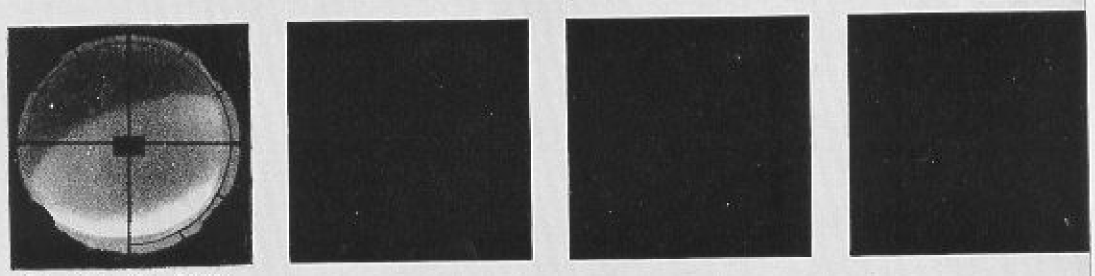


See note facing Plate II



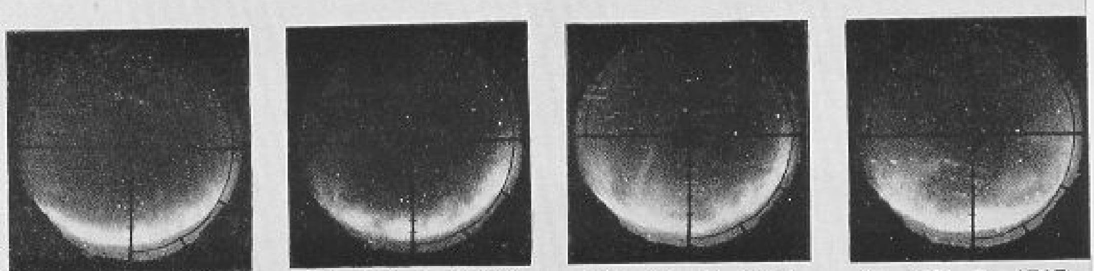
80 3 5 0825 — 80a 3 10 0825

1/2 AUGUST

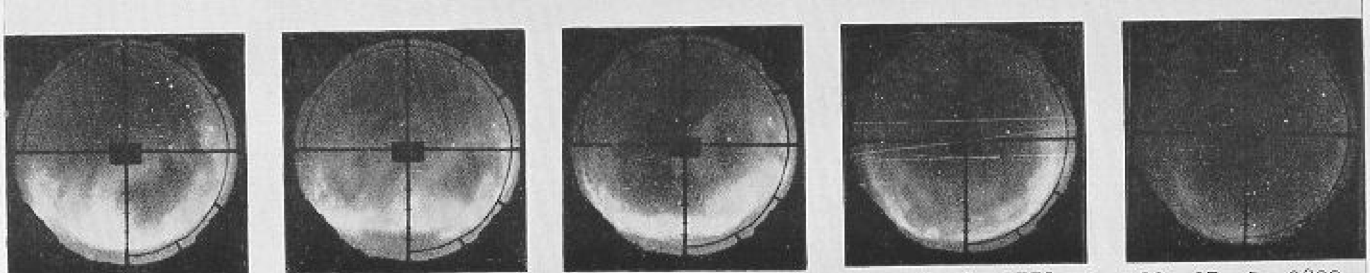


81 27 5 0032

2/3 AUGUST

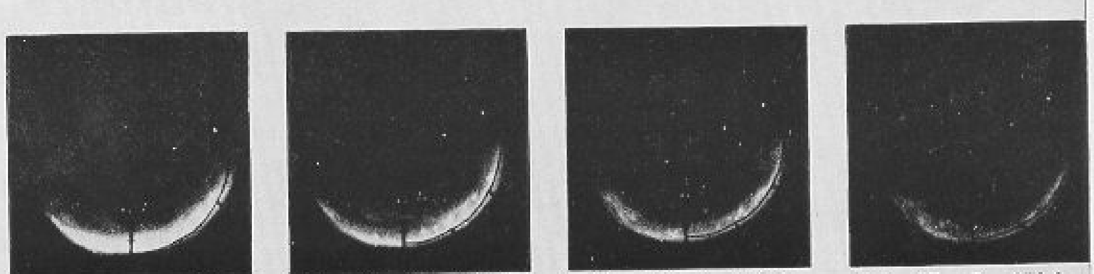


82 27 5 0645 — 83 27 5 0655 — 84 27 5 0700 — 85 27 5 0707



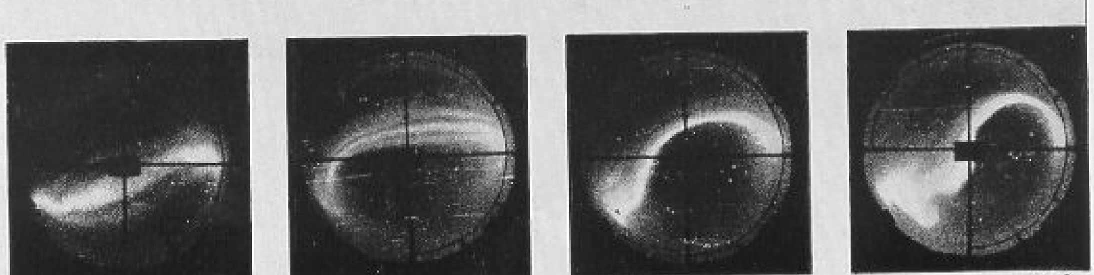
86 27 5 0711 — 87 27 5 0715 — 88 27 5 0720 — 89 27 5 0730 — 90 27 5 0800

6/7 AUGUST



91 27 5 0655 — 92 27 5 0710 — 93 27 5 0720 — 94 27 5 0740

1/2 SEPTEMBER



95 27 12 0320 — 96 27 5 0345 — 97 27 5 0400 — 98 27 5 0406

See note facing Plate II