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ANALYSIS OF AURORAL OBSERVATIONS, HALLEY BAY, 1961 AND 1962

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ABSTRACT

THE visual and photographic methods of recording auroral forms and characteristics at Halley Bay are described, and the data collected during 1961 and 1962 are analysed.

Seasonal variations are investigated, and show some indication of a 27·3-day recurrence cycle. The diurnal variations of the various auroral forms are also examined. It appears from this investigation that the aurora will almost certainly be seen from Halley Bay between 0400 and 0500 U.T., provided that the sky is clear and dark.

The eccentric arc zone of Evans and Thomas (1959) is found to fit the observations reasonably well if Mayaud's "equatorial plane coordinates" (Mayaud, 1960) are used, but a curve similar in shape to Alfvén's theoretical curve (Alfvén, 1955) may be better than the circle used by Evans and Thomas.

The elevation of aurorae seen from Halley Bay is shown to be correlated with the state of the magnetic disturbance, and the results for homogeneous arcs are found to agree very well with those obtained by Jacka (1953). Some correlation is found between the aurora and certain ionospheric parameters, such as the maximum frequency of sporadic E (f_o), the blanketing frequency of sporadic E (f_b), and the height of the F layer. It is also found that during flaming aurorae there is invariably ionospheric blackout, and that during active aurorae sporadic E (particularly auroral and slant type) is usually present unless there is ionospheric blackout.

Aurorae which occurred at Halley Bay during the major magnetic storms of 1961 and 1962 (Laurie and Finch, 1962, 1963) are summarized, and all-sky photographs are used where available.

Investigation of the change in pattern of aurorae at Halley Bay between 1956 and 1962 shows that there has been an increase in the number of diffuse surfaces and a reduction in the number of active rayed forms, and also that there has been some change in the general diurnal pattern over these years. Auroral behaviour recorded at Halley Bay, during the years 1956 to 1962, appears to agree quite well with that observed in high northern latitudes as described by Lassen (1963).

Aurorae occurring at Halley Bay are compared with those reported from the vicinity of the Antarctic Peninsula, and from positions in the Northern Hemisphere near to the point theoretically conjugate to Halley Bay. There is some, although by no means complete, agreement between the auroral forms seen in the two hemispheres. An investigation of the equatorward extent of aurorae in the Northern and Southern Hemispheres, shows that there is a marked tendency for aurorae to move equatorwards simultaneously in the two hemispheres.

CONTENTS

I. INTRODUCTION

THIS report deals with auroral observations carried out by the author during the Antarctic winters of 1961 and 1962. In analysing the records, use is made of the simultaneous magnetic and ionospheric observations.

1. THE POSITION OF HALLEY BAY

The geophysical observatory at Halley Bay, Coats Land, was established by the Royal Society in 1956 in preparation for the International Geophysical Year (1957–58). A full programme of geophysical observations was carried out during the I.G.Y., and the station was then taken over by the Falkland Islands Dependencies Survey (since renamed the British Antarctic Survey). Observations have been continued without interruption.

Halley Bay is situated at the edge of the southern auroral zone (Fig. 1) as defined in the *International Auroral Atlas* (Paton and Jacka, 1963). This zone is based on the parameter θ_3 introduced by Bond and Jacka (1962) who suggested that the maximum probability of occurrence of overhead aurorae is at $\theta_3 = 22 \cdot 5^\circ$, and defined the auroral region as extending $7 \cdot 5^\circ$ on either side of this line. The probability of overhead aurorae according to θ_3, as given by Bond and Jacka (1962), is shown in Fig. 2. From Fig. 1 it is evident that if the lower borders of auroral forms are taken to be at 100 km., the field of view from Halley Bay extends south to a value of θ_3 of 20°. Thus, although the frequency of overhead aurorae is fairly low at Halley Bay, aurorae can be seen near the southern horizon on almost every clear dark night.

For simplicity, and for comparison with results from previous years, the analysis in this report is given in terms of geomagnetic latitude. The south geomagnetic pole is at 78·5°S., 111°E. in geographical coordinates, and the geomagnetic coordinates of Halley Bay are 65·8°S., 24·3°E., the zero geomagnetic meridian being that passing through the geographical pole.

The position of the observatory is interesting. From Halley Bay there is almost 18° difference between the directions of the geomagnetic pole and the magnetic dip pole, the geomagnetic pole being 160·9° east of geographical north, and the dip pole 178·5° east of north. The station is also theoretically very well situated for the study of diurnal variations in the aurora, for not only is it at the outer edge of the auroral region, but it is also geographically a long way south (the geographic coordinates are 75°31′S., 26°40′W.) and is therefore dark throughout most of the day during the winter months. In practice, however, since most of the aurorae at Halley Bay occur near the southern horizon where cloud is prevalent, the data available for investigation of diurnal variations are severely limited.

2. VISUAL OBSERVATIONS

Visual observations of the aurora were made from a hatch in the roof of the new living hut which had been built in the autumn of 1961. An elevation-azimuth indicator, made up from a Meteorological Office alidade, was fixed permanently to the south side of the hatch and fitted with a small heater to keep it free from frost. For the forms appearing in the north, a hand alidade was used. On nights when the aurora was obscured by cloud, drift or moonlight, a pair of Fabry-Perot interference filters, transmitting the 5577Å "auroral green" line of monatomic oxygen, were used to detect displays. For convenience, these filters were fitted into a pair of goggles.

Observations were made on each quarter-hour of Universal Time when the sun was more than 12° below the horizon, but were more frequent during active displays. They covered the whole of this period, except near mid-winter when the number of hours involved was too great for one observer. Observations in previous years had shown that aurorae very rarely occurred at Halley Bay before 2000 U.T., and so in 1961 during the darkest months they were started at 2000 U.T. However, to ensure that no occurrences were being missed because of the late start, 1962 observations during the darkest months were begun

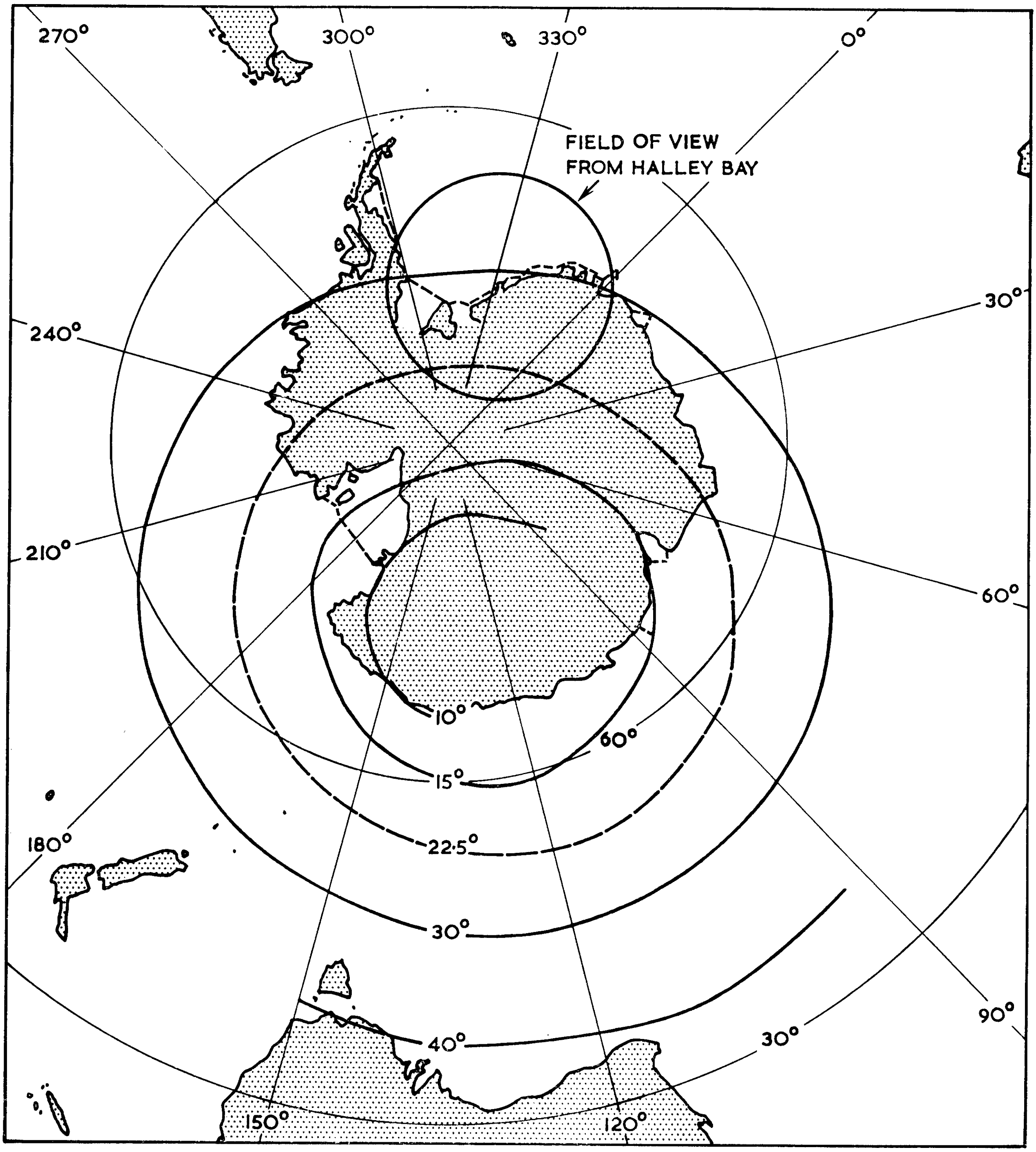

FIGURE 1

The southern auroral region. (Reproduced from the *International Auroral Atlas*, 1963.)

at 1800 U.T. They normally finished at 0900 U.T., but if a display was still visible at this time, observations were usually continued until it was obscured by twilight.

The auroral forms were classified according to the system given by Störmer in the *Photographic Atlas of Auroral Forms*. (The one exception is given on p. 8.) The brightness was estimated in accordance with the following international brightness index:

0 — Sub-visual
1 — Brightness of the Milky Way
2 — Brightness of moonlit cirrus
3 — Brightness of moonlit cumulus
4 — Very bright, giving a ground illumination of the order of full moonlight

Intermediate values of brightness (e.g. 1–2) were also used; 0–1 was used for aurorae which were fainter than the Milky Way.

Elevations and azimuths of the highest point of the lower borders of quiet arcs, and the maximum and minimum elevations of other forms were measured. When isolated diffuse surfaces, rays or bands occurred, their azimuth and elevation were measured together with the azimuth and elevation of any peculiar folds within arcs or bands. If only a fragment of an arc was visible, the azimuth of the terminating point was measured. The observer was provided with a master switch with which to extinguish the numerous outside lights around the station, so that they did not interfere with the visual observations.

3. Photographic Observations

a. *Black and white photography*

Black and white photographs were taken of the whole sky, using an Alaskan type all-sky camera which was mounted on a steel tower at about 11 ft. above the snow surface (Sheret, 1963, plate Ia).

The camera consisted of a Paillard Bolex H 16 cine camera with Switor f/1·4, 50-mm. lens, which was focused at 3·25 ft. on to a convex mirror. The camera was placed in a heated box above the mirror, and supported by four legs which were orientated roughly north, south, east and west. (During 1961 the bearing of the northern leg was 2·5° west of true north, but in 1962—following reconstruction of the tower—this bearing was 0·5° east of north.) A small box underneath the mirror contained heaters, and also a watch and a date-wheel which were intermittently illuminated by small neon bulbs. The watch and date-wheel showed through perspex windows in the lid of the box, and were photographed with the mirror. The north—south support legs had elevation markers at 20°, 30°, 45° and 60°, and in addition there was a ring running for 270° around the mirror marking 10° elevation; this was supported by small legs at 30° intervals (Sheret, 1963, fig. 2).

During March and April 1961, the box beneath the mirror also contained a timing mechanism which consisted of a 60 c./sec. synchronous motor controlling two micro-switches. The first micro-switch activated a solenoid attached to the firing arm of the camera, and the second illuminated the neon bulbs. The synchronous motor revolved once every 72 sec. (since the power supply was at 50 c./sec.), lighting the neon bulbs once per revolution and giving the following exposure sequence:

Frame 1 — 27-sec. exposure
3-sec. delay
Frame 2 — 3-sec. exposure
3-sec. delay
Frame 3 — 27-sec. exposure
3-sec. delay
Frame 4 — 3-sec. exposure
3-sec. delay

At the beginning of May 1961 the timing system was changed and a new mechanism, with a 50 c./sec. synchronous motor, was installed inside the hut instead of in the box at the camera tower. This facilitated maintenance, and the 50 c./sec. motor, with its one revolution per minute, was also much more convenient. The exposure sequence for the rest of 1961 was:

Frame 1 — 23-sec. exposure
2-sec. delay
Frame 2 — 3-sec. exposure
2-sec. delay
Frame 3 — 23-sec. exposure, etc.

The camera was operated only on clear dark nights when there were aurorae above 10° elevation, as aurorae below this elevation were distorted by the optics of the system.

For the 1962 season the timing was changed to one exposure of 10 sec. each minute, and the camera was run throughout all clear dark nights. An extra micro-switch, incorporated into the timing mechanism, extinguished the outside lights for each 10 sec. period and left them on for the remainder of the time. (In 1961 the lights had been extinguished throughout each camera run, but this caused too much inconvenience to other base members when the 1962 timing was adopted.)

During 1961, the film used was Ilford HP3 (200 A.S.A.), which was developed to near finality in ID 33. (Development time was 15 min. at 20°C.) In 1962, Kodak Tri-X developed for 15 min. at 20°C. in ID 19 was used in order to obtain more contrast and finer grain.

b. *Colour photography*

A Voigtländer Prominent 35-mm. camera, with 50-mm. f/2 lens, was used for the colour photography. The camera was mounted on a wooden tripod just outside the hatch from which the visual observations were made. Unfortunately, in very cold weather the wind-on mechanism of the camera froze up, and it was necessary to take it inside after each exposure to thaw it out.

The film used throughout was Kodak High-Speed Ektachrome (160 A.S.A.), and this was processed with E-2 (improved) processing chemicals. Later, in the 1962 season, this film was rated at 320 A.S.A. and given an extra 3 min. in the first developer. (Normal developing time is 10 min.) The colours obtained from this extra development were all perfectly acceptable, although no attempt was made to adjust the pH value of the colour developer as is recommended by Kodak (Kodak pamphlet No. E-39).

Various exposures were tried during 1961 and 1962, ranging from 5 to 40 sec. at f/2. It was found that with an aurora of brightness 2–3 or 3, the best exposure was about 15–20 sec. at f/2, rating the film at 320 A.S.A.

II. ANALYSIS OF VISUAL OBSERVATIONS

1. Observations Used in the Analysis

The observations used in this analysis are those which were made between the hours of nautical twilight, i.e. when the sun was more than 12° below the horizon (Table I). The first night of the year on which the sun was more than 12° below the horizon was 13/14 March, and the last night was 30 September/1 October. Within the limits of twilight, if the sky was clear and the moon less than half full, any aurora present could be seen by the observer. As cloud, drifting snow, fog and moonlight often obscured the aurora, the records are also analysed using only clear dark periods (i.e. sky clear and moon less than half), and in the case of active forms the analysis also uses all clear nights, as moonlight does not obscure the brighter and more discrete forms. In general, the same trends are found in each analysis, although there is, of course, a much higher percentage frequency of occurrence when only clear dark periods are considered.

The observations were made on the quarter-hours of Universal Time, thus during any night the maximum number of occurrences in one hour is four. The four observations considered in each hour are those at quarter past, half past, quarter to, and on the hour. Thus, the period 16/17 U.T. refers to the observations at 1615, 1630, 1645 and 1700 U.T. Table I gives the number of periods, in these various categories, which are used in the analysis of diurnal variations.

As very bright aurorae could be seen outside the twilight hours defined above, a more irregular watch was kept before 13/14 March and just after 30 September/1 October.

2. Seasonal Variations of the Aurora

Of the 202 nights, during each year, when the sun was more than 12° below the horizon for part of the night, 26 were clear and dark in 1961 and 21 in 1962 (although 9 in 1961 and 6 in 1962 had a little cloud for part of the night). Of the 26 clear dark nights during 1961, there were only 3 during which no aurora was seen, and these were all nights on which the sun was more than 12° below the horizon for only about two or three hours. In 1962, the aurora was seen on all clear dark nights.

TABLE I

DISTRIBUTION OF OBSERVATIONS

Period (hr. U.T.)		17	18	19	20	21	22	23	24	01	02	03	04	05	06	07	08	09	10	11	1200	
	a	135	281	388	487	574	650	711	757	794	808	799	772	733	675	601	517	422	323	200	33	
1961	*b*			19	63	140	153	187	178	186	170	189	181	173	159	137	96	83	65	22		
	c			11	44	99	111	127	117	120	109	120	116	109	106	92	69	65	49	21		
1962	*b′*		30	133	153	185	210	202	189	192	187	198	200	193	189	198	148	140	82	25	1	
	c′		23	95	92	122	141	130	123	125	126	132	139	135	151	157	110	114	66	25	1	

a. The number of quarter-hour periods when the sun was more than 12° below the horizon.
b, b′. The number of clear periods (dark and moonlit).
c, c′. The number of clear dark periods.

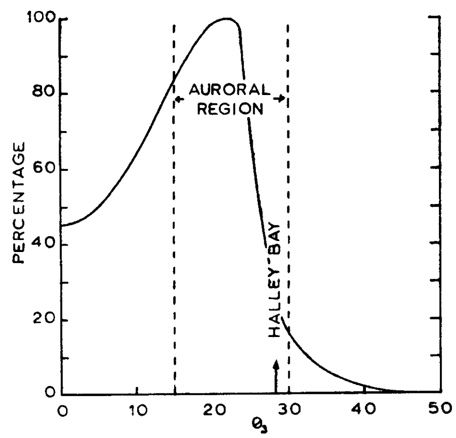

FIGURE 2

Frequency of occurrence of aurorae in the auroral region. (Reproduced from Bond and Jacka, 1962.)

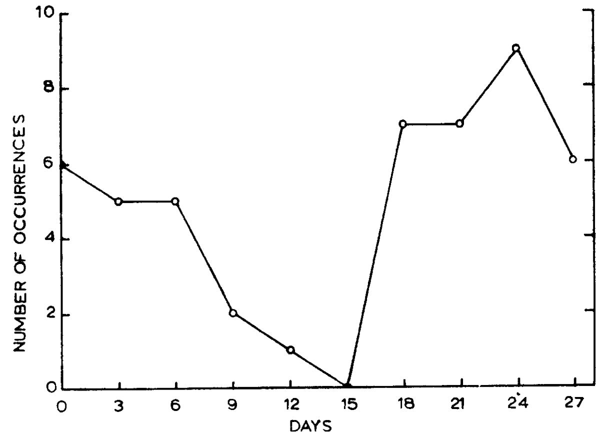

FIGURE 3

The 27-day cycle of aurorae occurring above 100° elevation at Halley Bay.

An auroral watch was kept during 210 nights in 1961 and 223 nights in 1962; auroral forms were seen on 104 in 1961 and 96 in 1962. In addition, unidentifiable auroral forms were seen, or detected by means of the interference filters, on a further 41 nights in 1961 and 26 nights in 1962. The sky was completely obscured by cloud or drifting snow on another 46 nights in 1961 and 64 nights in 1962, and it is therefore likely that the aurora occurs at some time during every night within this period. This is what we would expect from the field of view from Halley Bay shown in Fig. 1, and from the probability distribution in Fig. 2.

The aurora was seen overhead (i.e. with elevation greater than 60°) on 40 nights during 1961 and 32 nights in 1962, i.e. on 24·4 per cent of all nights on which observations were possible in 1961, and on 20·1 per cent in 1962. These frequencies agree with the frequency of overhead aurorae at Halley Bay suggested by Fig. 2.

Fig. 3 shows that there is some indication of a 27·3-day period running through the results of these two seasons. The two years were divided into 82-day periods, then the last day in each period was discarded and the remaining 81 divided into three periods of 27 days. The number of days on which the aurora was seen near the magnetic zenith (above 100° elevation from the southern horizon) were then recorded for each position in the period. To smooth out the curve three days were taken at a time. The results are plotted in Fig. 3. Dividing the years into 26-, 28- and 29-day periods gave no such variation, although there was some indication of the variation when divided into 27-day periods. This result agrees well with that obtained by Dixon (1939) who analysed aurorae seen in Scotland between 1858 and 1938, and suggested that a 27·3-day period ran right through the whole 80 years.

3. Auroral Forms Used in the Analysis

Following Blackie (1964), the auroral forms have been divided into three main groups. These are:

i. Quiet forms, which include homogeneous arcs and glows.
ii. Active forms, which include rayed arcs, rayed bands, isolated rays and homogeneous bands.
iii. Diffuse surfaces, including the form frequently seen at Halley Bay, when diffuse surfaces and rays intermingle.

Coronae are considered as being in group ii, since they are usually the occurrence of one of the forms of this group in the magnetic zenith.

Two forms were seen during 1961 and 1962, which had not previously been reported from Halley Bay. These were pulsating arcs, and a system of multiple arcs or bands. This latter form is not described in Störmer's *Photographic Atlas of Auroral Forms* (1951), but is referred to in the more recent *International Auroral Atlas* (Paton and Jacka, 1963). For the purposes of analysis, the multiple arcs or bands are included in group ii and, as there were only a few, the pulsating arcs are treated separately.

4. Positions and Diurnal Variations of the Various Forms

Both local and geomagnetic midnights are used in this analysis. Local midnight, when the sun is in the geographic meridian opposite to that of the station, is at 0147 U.T. at Halley Bay; geomagnetic midnight, when the sun is in the opposite geomagnetic meridian, is at 0303 U.T.

TABLE II

DIURNAL FREQUENCY OF ALL AURORAE AND OVERHEAD AURORAE

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	11–1200
1961	*a*	2	11	36	71	101	156	217	288	339	417	355	354	283	216	170	138	73	23	1
	b	0·7	2·8	7·4	12·4	15·5	21·1	28·7	36·3	42·0	52·2	46·0	48·3	42·0	35·9	32·9	32·7	22·6	11·1	3·0
	c		1	9	28	55	75	74	91	93	102	100	105	100	68	57	53	35	5	
	d		9·1	20·5	28·3	49·5	59·0	63·2	75·8	85·3	85·0	86·3	96·4	94·4	73·9	82·6	81·6	71·5	23·8	
	e			2	3	5	5	8	9	11	7	5	8	3	2	3	4	4	4	
	f			4·5	3·0	4·5	3·9	6·8	7·5	10·1	5·8	4·3	7·3	2·8	2·2	4·3	6·2	8·2	19·0	
1962	*a′*	9	46	58	85	147	204	256	264	284	305	303	298	287	248	196	141	90	24	
	b′	3·2	11·9	11·9	14·8	22·6	28·7	33·8	33·3	35·1	38·2	39·2	40·7	42·5	41·2	37·9	33·4	27·8	12·0	
	c′	6	29	35	58	86	96	102	108	115	127	121	135	147	123	100	71	40	10	
	d′	26·1	30·5	38·1	46·7	61·0	73·8	82·8	86·4	91·3	96·3	87·0	100·0	97·3	78·4	91·0	62·3	60·6	40·0	
	e′						3	1	8	22	12	13	12	11	2	5				
	f′						2·3	0·8	6·4	17·5	9·1	9·4	8·9	7·3	1·3	4·5				

a, a′. Number of quarter-hour periods, in which the sun was more than 12° below the horizon, and aurorae were observed with or without interference filters.
b, b′. Percentage frequency of all aurorae (using Table I, line *a*).
c, c′. Number of clear dark periods in which aurorae were observed.
d, d′. Percentage frequency of aurorae in clear dark periods (using Table I, lines *c* and *c′*).
e, e′. Number of clear dark periods in which overhead aurorae occurred.
f, f′. Percentage frequency of overhead aurorae in clear dark periods (using Table I, lines *c* and *c′*).

a. *All aurorae and overhead aurorae*

Table II shows the frequency distributions of aurorae during 1961 and 1962; Table II, lines *b* and *b'*, are plotted in Fig. 4. The maximum occurrence was at about 0300 U.T. in 1961, and at 0600 U.T. in 1962, but if clear dark periods only are considered (Fig. 5) the maximum occurred between 0400 and 0500 U.T. in both 1961 and 1962, and during that hour the aurora was almost certain to occur. Even on the night with least aurora during the two seasons, there was an occurrence from 0415 to 0515 U.T.: this was 25/26 June 1962, when diffuse surfaces of brightness 1 were seen below 10° elevation in the south. Fig. 5 is probably more representative than Fig. 4 of the true diurnal variation of aurorae occurring near Halley Bay.

The diurnal variations of overhead aurorae for 1961 and 1962, given in Fig. 6, indicate a maximum at local midnight. It seems likely that the increase in percentage frequency shown by the 1961 results after 0700 U.T. is completely unreal, and is caused by the fact that there were only a few observations after this time.

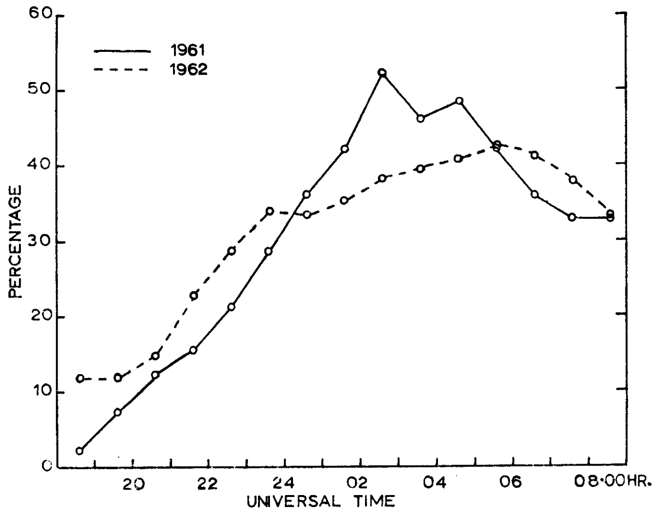

FIGURE 4

Occurrence of all aurorae (when the sun was more than 12° below the horizon).

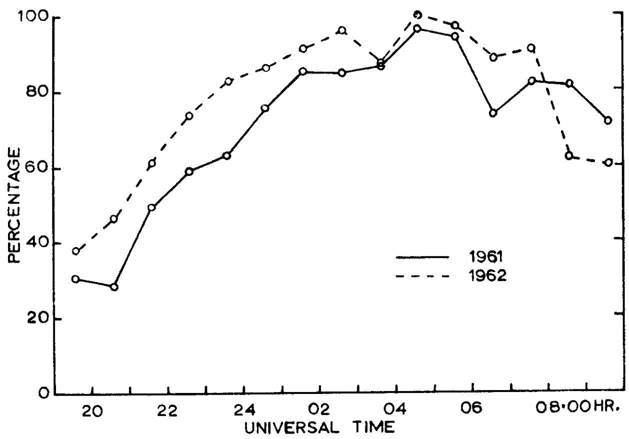

FIGURE 5

Occurrence of all aurorae (in clear dark periods).

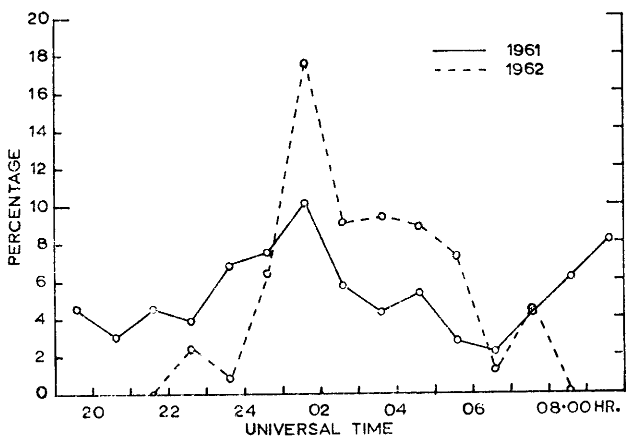

FIGURE 6

Occurrence of overhead aurorae (in clear dark periods).

TABLE III

DIURNAL FREQUENCY OF HOMOGENEOUS ARCS

	Period (hr. U.T.)	17	18	19	20	21	22	23	24	01	02	03	04	05	06	07	08	09	10	1100
1961	*a*			2	18	28	44	61	74	62	85	88	81	71	42	39	31	5		
	b			4·5	18·2	25·2	34·6	52·1	61·7	56·9	70·8	75·8	74·3	68·0	45·7	56·5	47·7	10·2		
	c			7	18	31	53	101	106	107	138	130	113	111	62	50	35	5		
	d			1·4	3·1	4·8	7·5	13·3	13·2	13·3	17·3	16·8	15·4	16·4	10·3	9·7	8·3	1·5		
1962	*a′*	1	19	24	32	58	55	68	58	53	65	75	78	98	81	55	24	10	4	
	b′	4·3	20·0	26·1	26·2	41·1	42·3	55·3	46·4	42·0	49·2	54·0	57·8	64·9	51·6	50·0	21·0	15·2	16·0	
	c′	1	19	25	37	76	70	88	92	97	112	101	113	140	95	65	28	12	4	
	d′	0·4	4·9	5·1	6·5	11·7	9·8	11·6	11·6	12·0	14·0	13·1	15·4	20·8	15·8	12·6	6·6	3·7	2·0	

a, a′. Number of occurrences in clear dark periods.
b, b′. Percentage frequency in clear dark periods (using Table I, lines *c* and *c′*).
c, c′. Total number of occurrences.
d, d′. Percentage frequency in all periods (using Table I, line *a*).

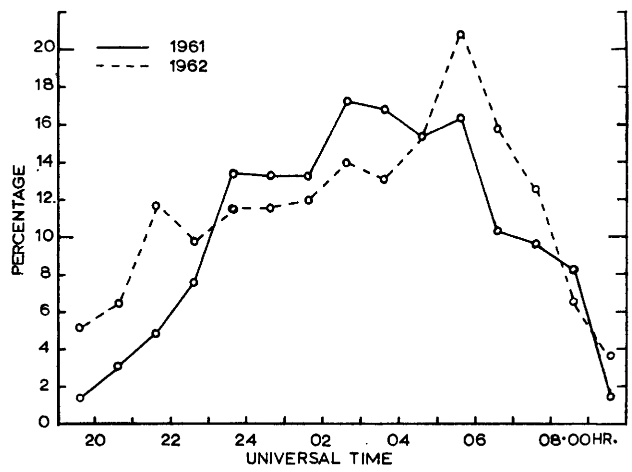

FIGURE 7

Occurrence of homogeneous arcs (when the sun was more than 12° below the horizon).

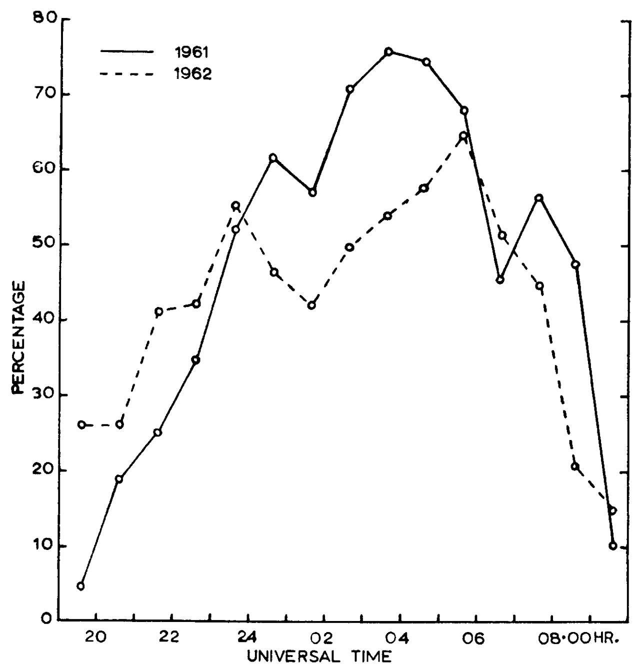

FIGURE 8

Occurrence of homogeneous arcs (in clear dark periods).

TABLE IV

NUMBERS OF HOMOGENEOUS ARCS AND THEIR VARIATION IN ELEVATION WITH TIME: 1961

Period (hr. U.T.)	17/18	18/19	19/20	20/21	21/22	22/23	23/24	00/01	01/02	02/03	03/04	04/05	05/06	06/07	07/08	08/09	09/10	10/11	*Total*	*Φ* (degrees)
Elevation (degrees)																				
½																			—	76
1					1	2	2	2		2	2	1				2			14	75
2					4	1	5	6	3	4	4	2		3	13	14	2		61	74
3				1	2	5	4	8	7	8	6	2	3	4	20	9	2		81	73
4–5				10	11	13	17	23	24	21	19	25	29	20	9	6			227	72
6–7				4	8	8	8	8	8	14	22	16	17	9					122	71
8–10				2	4	6	9	13	17	22	27	21	15	5					141	70
11–15			1		1	4	7	9	4	9	11	6	3	2			1		58	69
16–23							3	2		3	3	4	1	1					17	68
24–40					2		5			2	1	2							12	67
41–90								2	1	2	1								6	66
91–140							3	1			1								5	65
141–157			1					1											2	64
158–165						2													2	63
166–							1	1											2	
Total			2	17	33	41	64	76	64	87	97	79	68	44	42	31	5		750	
Median latitude (degrees south)				72·1	71·9	71·8	71·4	71·8	71·9	71·1	70·9	71·1	71·6	72·1	73·4	73·4				

TABLE V

NUMBERS OF HOMOGENEOUS ARCS AND THEIR VARIATION IN ELEVATION WITH TIME: 1962

Period (hr. U.T.)	17/18	18/19	19/20	20/21	21/22	22/23	23/24	00/01	01/02	02/03	03/04	04/05	05/06	06/07	07/08	08/09	09/10	10/11	*Total*	*Φ* (degrees)
Elevation (degrees)																				
½				1															1	76
1					1	1	1								1				4	75
2			3	1	1	2	2		1			1		1	3	3			18	74
3		3	4	3	4	4	7	3	1				2	5	12	2			50	73
4–5			6	16	16	22	31	19	14	10	8	9	22	27	23	16	9	4	252	72
6–7		3	2	3	10	14	15	17	13	17	22	27	25	28	12	3			211	71
8–10		3	2	8	14	10	9	6	12	17	25	30	35	13					184	70
11–15				1	2	10	9	8	5	13	15	10	14	5					92	69
16–23	1	2	6	1	1	4	8	6	2	8	4	2							45	68
24–40				1				2		1	1								5	67
41–90					1														1	66
91–140			1					1	3										5	65
141–157			1					3	3										7	64
158–165					1					1									2	63
166–					1														1	
Total	1	11	25	35	52	67	82	65	54	67	75	79	98	79	51	24	9	4	878	
Median latitude (degrees south)		70·9	71·8	72·1	71·3	71·4	71·7	71·3	71·3	70·3	70·5	70·7	70·8	71·5	72·4	72·5				

[*Facing page 10.*

Table VI

BEARINGS OF HOMOGENEOUS ARCS: 1961

Bearing (degrees E. of true N.)	*Period* (hr. U.T.)																		Total
	17/18	18/19	19/20	20/21	21/22	22/23	23/24	00/01	01/02	02/03	03/04	04/05	05/06	06/07	07/08	08/09	09/10	10/11	
136–140			1					2											3
141–145					1	1				1									3
146–150			1			1			2			1	1						6
151–155				1		1	3	2	2										9
156–160				1	5	8	18	13	7	15	5	5	2	1					80
161–165				5	16	20	24	37	33	45	49	28	10	7	3	2			279
166–170				3				4	7	16	20	28	35	13	8	6	2		142
171–175						1		1	3	3	5	9	12	17	14	9			74
176–180						1		1	1	3	3		3	2	6	5	2		27
181–185										1		1							2
Total			2	10	22	33	45	60	55	84	82	72	63	40	31	22	4		625
Mean bearing				164·1	161·9	167·1	165·1	162·7	164·0	165·6	167·0	167·1	169·3	168·2	173·0	173·0	175·0		

Table VII

BEARINGS OF HOMOGENEOUS ARCS: 1962

Bearing (degrees E. of true N.)	*Period* (hr. U.T.)																		Total
	17/18	18/19	19/20	20/21	21/22	22/23	23/24	00/01	01/02	02/03	03/04	04/05	05/06	06/07	07/08	08/09	09/10	10/11	
136–140																			—
141–145									1										1
146–150					2							1							3
151–155	1		3					1	1										6
156–160			2	4	8	7	4	4	1		1		1						32
161–165		3	4	4	23	24	19	13	12	9	10	3	2	2					128
166–170		5	10	18	18	15	22	29	22	33	44	28	33	14	2				293
171–175		4	1	6		2	4	4	6	6	13	26	28	30	21	8	3		162
176–180						2	3	1	1	4	3	11	17	22	17	10	1	3	95
181–185									1	1		1	4		1	1	2		11
186–190											1				1	3	1		6
Total	1	12	20	32	51	50	52	52	45	53	72	70	85	68	42	22	7	3	737
Mean bearing		168·9	164·5	167·6	164·1	165·3	167·1	167·2	167·4	169·5	168·2	171·4	174·2	176·2	178·2	181·6	181·6	182·0	

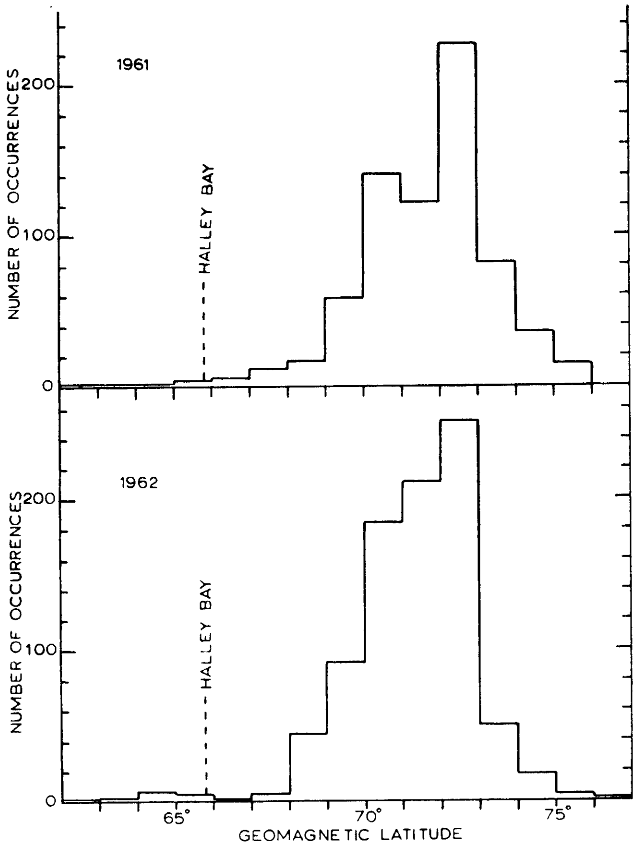

FIGURE 9

Number of homogeneous arcs occurring in each degree of geomagnetic latitude (in clear dark periods).

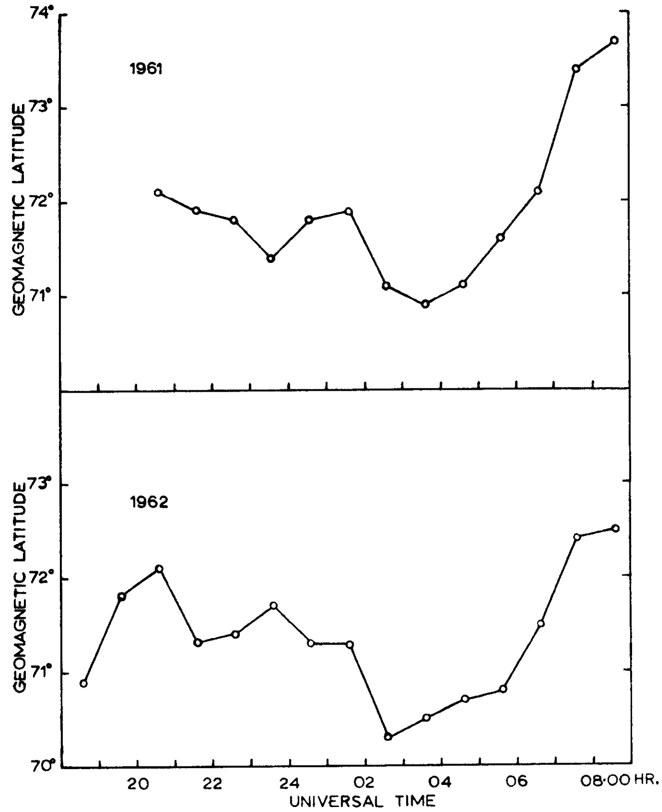

FIGURE 10

Hourly median latitude of homogeneous arcs (in clear dark periods).

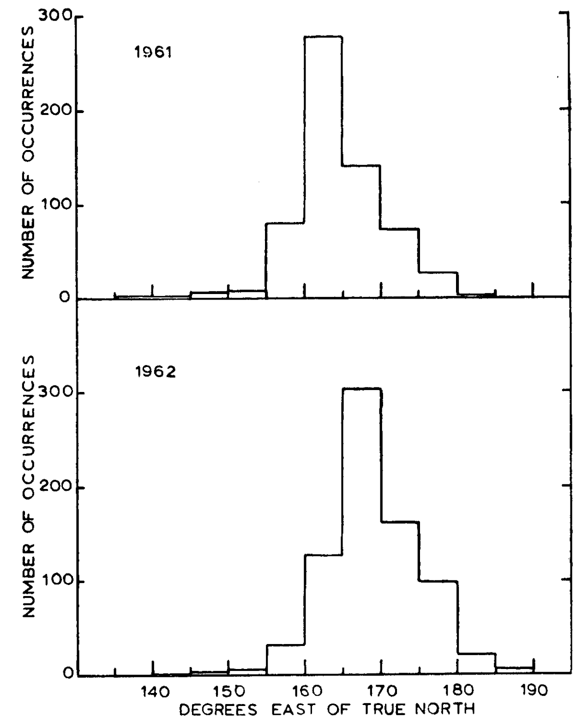

FIGURE 11

Distribution of centre bearings of homogeneous arcs (in clear dark periods).

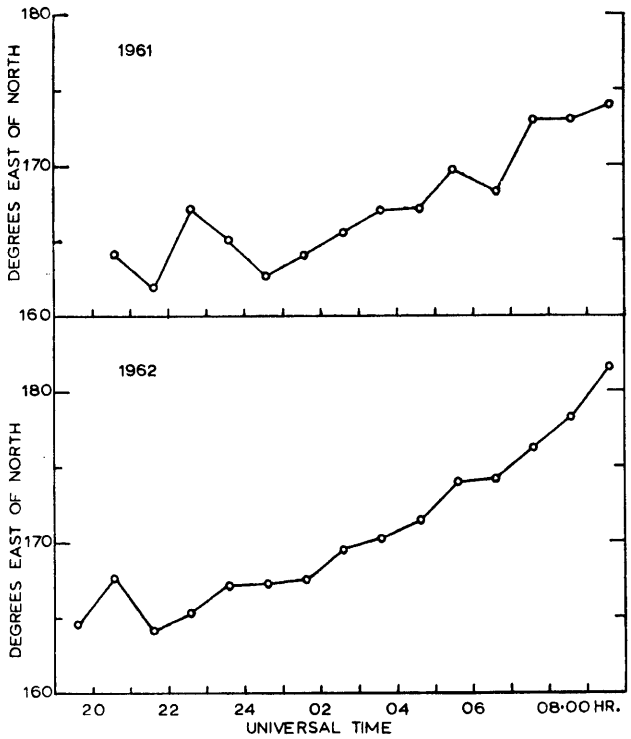

FIGURE 12

Hourly mean centre bearings of homogeneous arcs (in clear dark periods).

b. *Quiet forms*

i. *Homogeneous arcs.* Because of their stability these forms are very easy to measure and therefore to analyse.

Diurnal frequencies of homogeneous arcs for 1961 and 1962 are given in Table III, and the percentage frequencies are plotted as Figs. 7 and 8. The diurnal pattern appears to have changed from 1961 to 1962; the maximum frequency of occurrence was near geomagnetic midnight in 1961, and between 0500 and 0600 U.T. in 1962, and both years showed another possible maximum at about 2400 U.T. Changes in diurnal variation from 1956 to 1962 are given on p. 39 and 41.

The latitude position of homogeneous arcs is estimated by measuring their elevation and assuming that the height of their lower borders is 100 km., as they are roughly perpendicular to the geomagnetic meridian through Halley Bay. Tables IV and V give the number of homogeneous arcs occurring in each clear dark quarter hour, in each degree of geomagnetic latitude. The histograms in Fig. 9, which give the latitude distribution for 1961 and 1962, show that the maximum number of arcs occurred between geomagnetic latitudes 72°S. and 73°S. The median positions were 71·8°S. geomagnetic latitude in 1961 and 71·2°S. geomagnetic latitude in 1962. 50 per cent of arcs occurred between 70·4°S. and 72·8°S. in 1961, and between 70·1°S. and 72·2°S. in 1962. Fig. 10 shows the diurnal variations in the median positions for the two years.

Tables VI and VII give, for each hour of Universal Time (in clear dark periods only), the frequency of centre bearings in each 5° interval east of geographic north. The histograms in Fig. 11 show a very marked maximum frequency between 165° and 170° east of north. The mean position of centre bearings was 166·6° east of north in 1961 and 170° east of north in 1962. The diurnal variations of the mean centre bearings are given in Fig. 12.

It appears from Figs. 10 and 12 that homogeneous arcs generally remain almost stationary before local midnight, but between local and geomagnetic midnights there is an equatorward movement accompanied by a westward drift. The westward drift continues after geomagnetic midnight, but the equatorward movement is then reversed to a slower poleward movement.

Fig. 13 gives the diurnal variation of the mean brightness of homogeneous arcs, and shows that there is a slight increase in average brightness through the night until about 0400 U.T. There appears to be a sudden fall off in brightness after 0600 U.T., but the figures for intervals 0800–0900 and 0900–1000 U.T. in 1962 are suspect because of the small number of observations.

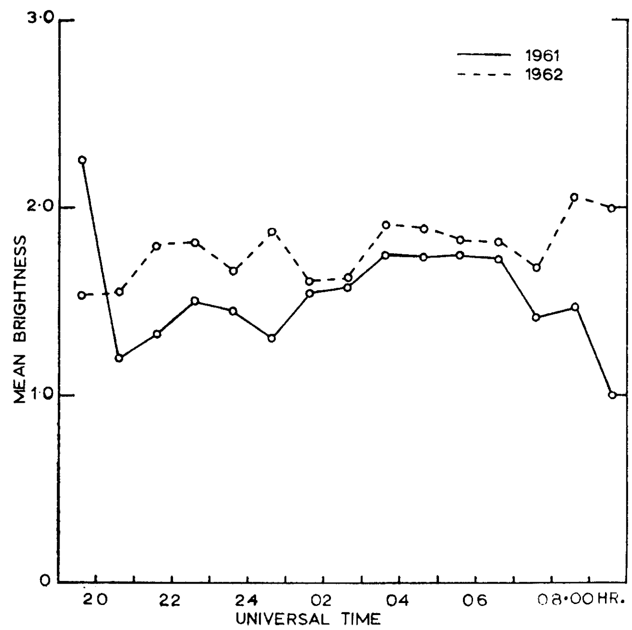

FIGURE 13

Mean brightness of homogeneous arcs (in clear dark periods).

ii. *Glows.* This classification includes faint glows on the horizon, which are probably other forms just below the horizon, and the glow which extends over quite a large part of the sky. This latter form is defined as a "veil" in the new *International Auroral Atlas* (Paton and Jacka, 1963).

Table VIII gives the occurrence of glows under all conditions and under clear dark conditions, for 1961 and 1962, and Fig. 14 shows the diurnal variation of the percentage frequency of occurrence. It can be seen that there is an early evening maximum, and then a much smaller maximum late in the morning. The evening maximum is caused by the horizon glows which precede the formation of homogeneous arcs, and there may be, as Störmer (1955) suggests, homogeneous arcs just below the horizon.

The mean brightness of glows is fairly constant throughout the night (Fig. 15). They are apparently much fainter than any of the other forms considered in the analysis (Figs. 13, 19 and 22).

TABLE VIII

FREQUENCY OF GLOWS

Period (hr. U.T.)		17	18	19	20	21	22	23	24	01	02	03	04	05	06	07	08	09	10	1100
1961	*a*				2	17	20	5	3	2	4	1	1				3	6		
	b				2·0	15·3	15·7	4·3	1·3	0·9	3·3	0·9	0·9				4·6	12·2		
	c				3	20	28	6	10	12	10	1	1		2	1	4	9		
	d				0·5	3·1	3·9	0·8	1·3	1·5	1·3	0·1	0·1		0·3	0·2	0·9	2·8		
1962	*a′*	3	6	4	11	12	6	5	3	3	1	1			1	3	3			
	b′	13·1	6·3	4·3	9·0	8·5	4·6	4·1	2·4	2·4	0·8	0·7			0·6	2·7	2·6			
	c′	3	6	4	13	14	9	5	3	3	7	7			1	3	3			
	d′	1·1	1·5	0·8	2·3	2·2	1·3	0·7	0·4	0·4	0·9	0·9			0·2	0·6	0·7			

a, a′. Number of occurrences in clear dark periods.
b, b′. Percentage frequency in clear dark periods (using Table I, lines *c* and *c′*).
c, c′. Total number of occurrences.
d, d′. Percentage frequency in all periods when the sun was more than 12° below horizon (using Table I, line *a*).

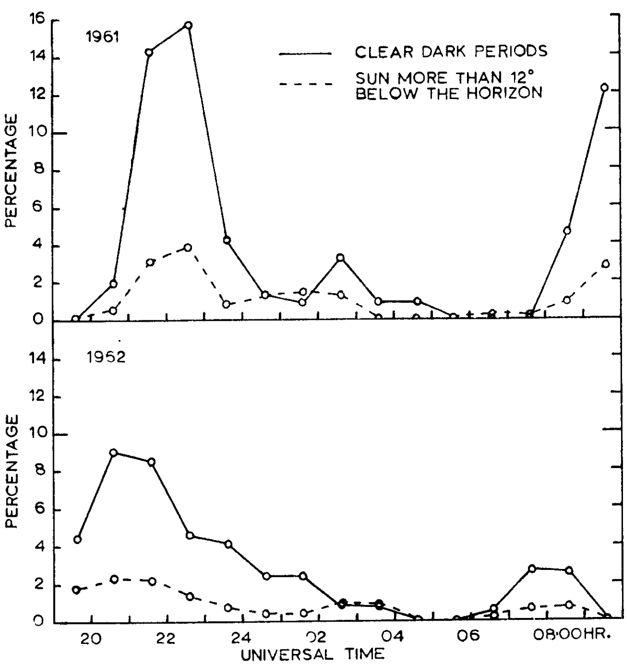

FIGURE 14
Occurrence of glows.

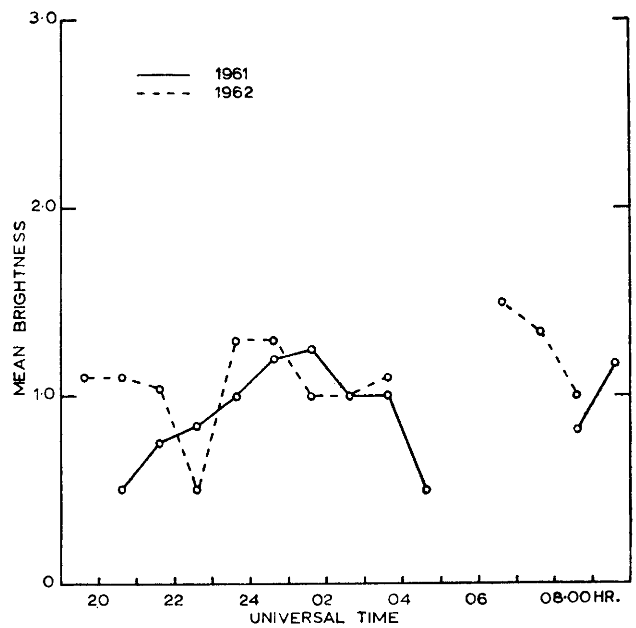

FIGURE 15
Mean brightness of glows.

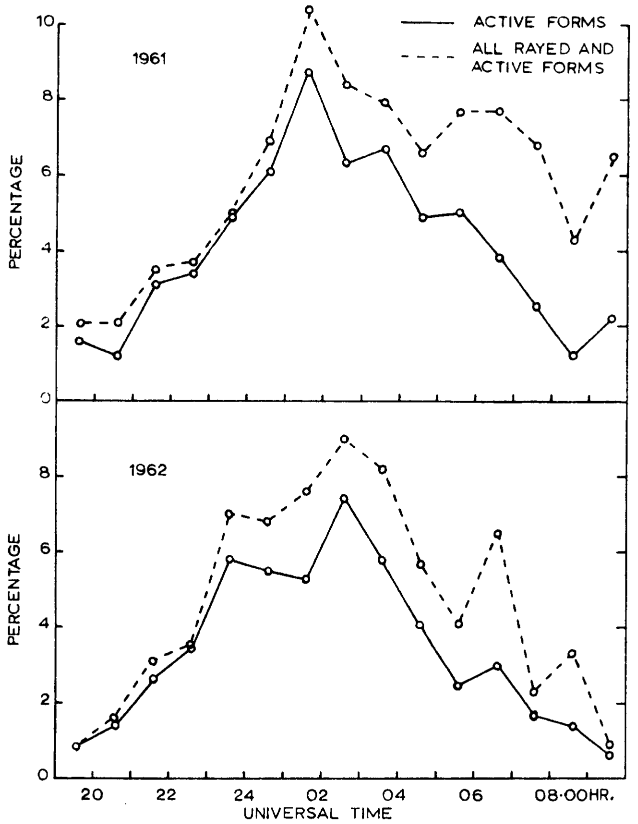

FIGURE 16

Occurrence of active forms (when the sun was more than 12° below the horizon).

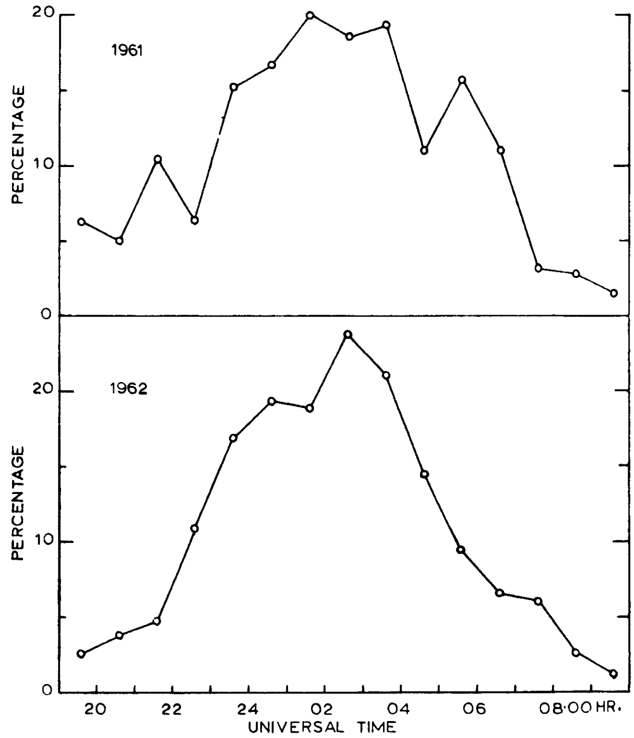

FIGURE 17

Occurrence of active forms (in clear periods).

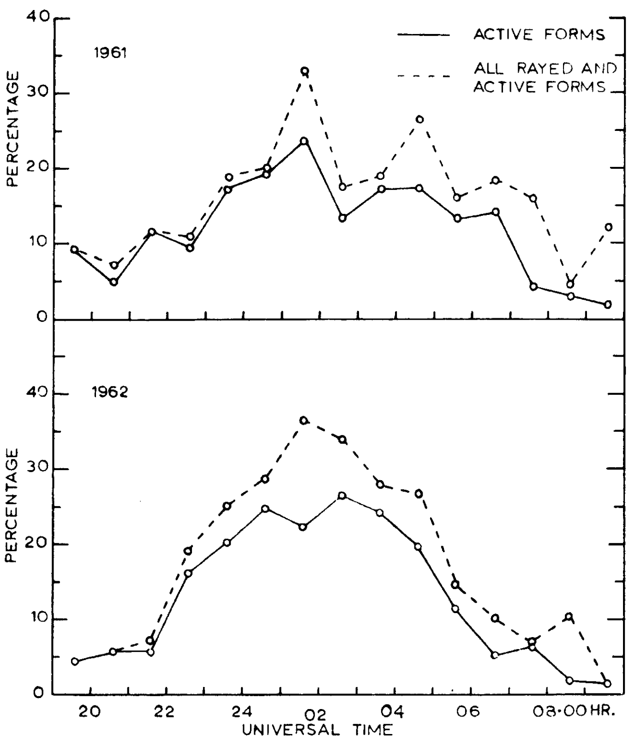

FIGURE 18

Occurrence of active forms (in clear dark periods).

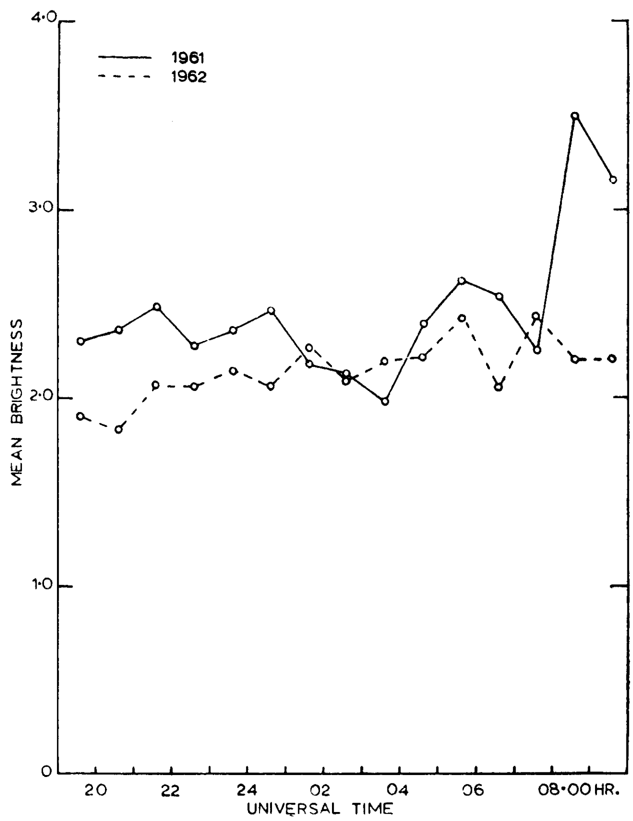

FIGURE 19

Mean brightness of active forms (in clear dark periods).

TABLE IX

FREQUENCY OF ACTIVE FORMS

Period (hr. U.T.)		17	18	19	20	21	22	23	24	01	02	03	04	05	06	07	08	09	10	11	00
1961	*a*			1	4	5	13	12	20	23	26	16	20	19	14	13	3	2	1	2	
	b			9·1	9·1	5·0	11·7	9·5	17·1	19·2	23·8	13·3	17·2	17·4	13·2	14·1	4·3	3·1	2·0	9·5	
	c			1	4	7	16	12	27	31	34	35	36	19	25	15	3	3	1	2	
	d			5·3	6·3	5·0	10·5	6·4	15·2	16·7	20·0	18·5	19·3	11·0	15·7	11·0	3·2	2·8	1·5	9·1	
	e			2	8	7	20	24	37	48	70	50	52	36	34	23	13	5	7	4	
	f			0·5	1·6	1·2	3·1	3·4	4·9	6·1	8·7	6·3	6·7	4·9	5·0	3·8	2·5	1·2	2·2	2·0	
1962	*a′*			3	4	7	8	21	25	31	28	35	34	24	17	8	7	2	1	2	
	b′			3·2	4·4	5·7	5·7	16·1	20·3	24·8	22·4	26·5	24·4	17·8	11·3	5·1	6·4	1·8	1·5	8·0	
	c′			3	4	7	10	22	32	37	35	49	42	28	18	13	9	3	1	2	1
	d′			2·3	2·6	3·8	4·8	10·9	16·9	19·3	18·7	24·8	21·0	14·5	9·5	6·6	6·1	2·1	1·2	8·0	100·0
	e′			3	4	8	17	24	44	44	43	59	45	30	17	18	9	6	2	2	
	f′			0·8	0·8	1·4	2·6	3·4	5·8	5·5	5·3	7·4	5·8	4·1	2·5	3·0	1·7	1·4	0·6	1·0	

a, a′. Number of occurrences in clear dark periods.
b, b′. Percentage frequency in clear dark periods (using Table I, lines *c* and *c′*).
c, c′. Number of occurrences in clear periods (dark and moonlit).
d, d′. Percentage frequency in clear periods (dark and moonlit) (using Table I, lines *b* and *b′*).
e, e′. Total number of occurrences.
f, f′. Percentage frequency in all periods when the sun was more than 12° below horizon (using Table I, line *a*).

TABLE X

FREQUENCY OF DIFFUSE SURFACES

Period (hr. U.T.)		17	18	19	20	21	22	23	24	01	02	03	04	05	06	07	08	09	10	11	00
1961	*a*				7	9	9	12	7	12	15	20	16	24	26	32	28	23	25	3	
	b				15·9	9·1	8·1	9·8	6·0	10·0	13·8	16·7	13·8	22·0	23·8	34·8	40·6	35·4	51·0	14·3	
	c				8	12	16	20	15	35	51	50	39	63	54	68	69	50	43	10	1
	d				1·6	2·1	2·5	2·9	2·0	4·4	6·3	6·3	5·1	8·6	8·0	11·3	13·3	11·8	13·3	5·0	3·0
1962	*a′*		2	4	8	11	19	31	31	23	50	42	40	63	54	51	53	50	33	4	
	b′		8·4	4·2	8·7	9·0	13·5	23·8	25·2	18·4	39·7	31·8	28·8	46·6	35·8	32·5	48·1	43·8	50·0	16·0	
	c′		2	4	9	16	26	39	36	30	56	54	64	84	70	73	67	54	43	6	
	d′		0·7	1·0	1·8	2·8	4·0	5·5	4·8	3·8	6·9	6·8	8·3	11·5	10·4	12·1	13·0	12·8	13·3	3·0	

a, a′. Number of occurrences in clear dark periods.
b, b′. Percentage frequency in clear dark periods (using Table I, lines *c* and *c′*).
c, c′. Total number of occurrences.
d, d′. Percentage frequency in all periods when the sun was more than 12° below horizon (using Table I, line *a*).

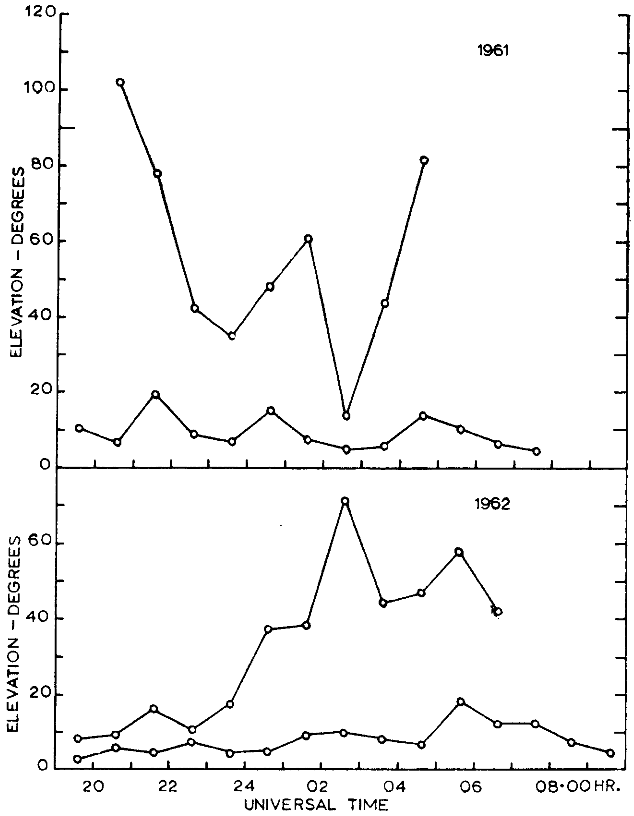

FIGURE 20
Mean upper and lower limits of active forms (in clear dark periods).

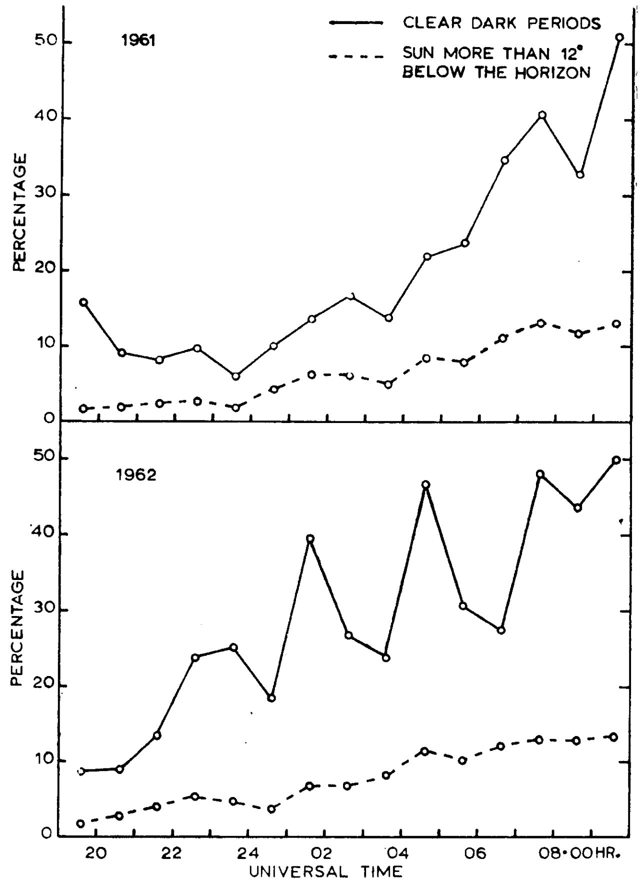

FIGURE 21
Occurrence of diffuse surfaces and rays.

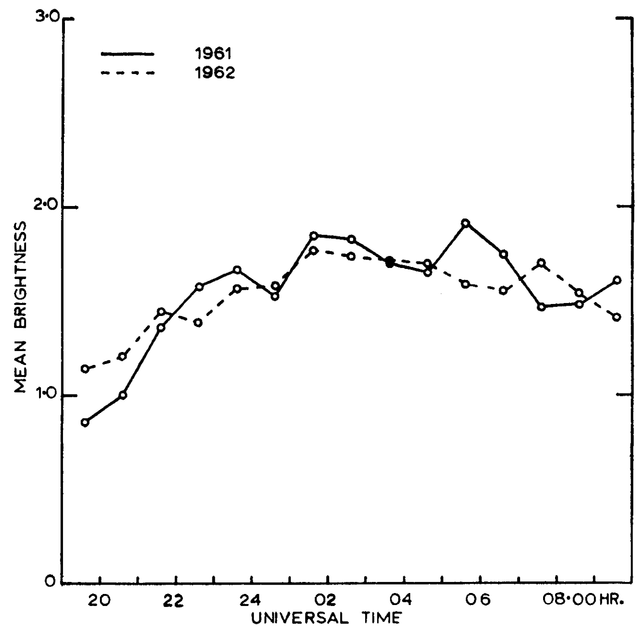

FIGURE 22
Mean brightness of diffuse surfaces and rays (in clear dark periods).

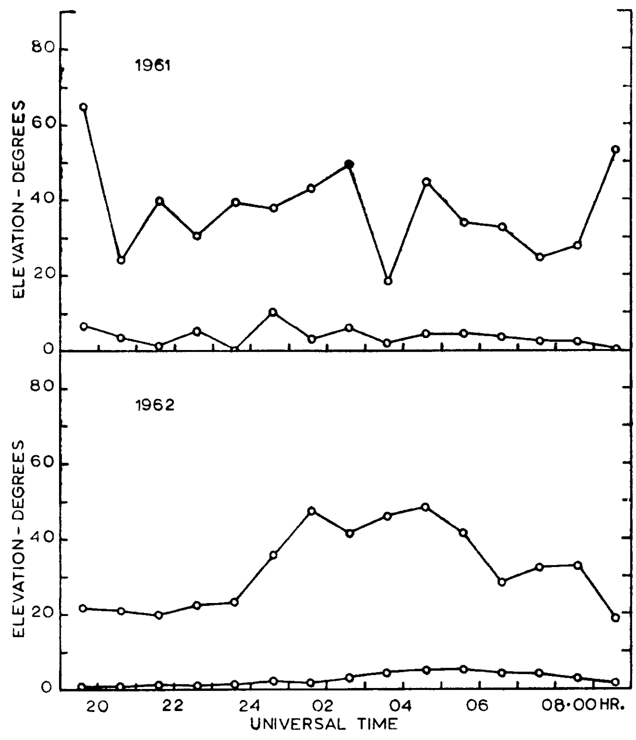

FIGURE 23
Mean upper and lower limits of diffuse surfaces and rays (in clear dark periods).

c. *Active forms*

Table IX gives the frequencies of occurrence of active forms for the three different sky conditions, and the percentage frequencies are plotted in Figs. 16, 17 and 18. The three graphs all suggest a broad maximum of activity extending two hours on each side of local midnight. The broken lines in Figs. 16 and 18 show the frequencies if rays, which occurred with diffuse surfaces, are included with the active forms.

Figs. 19 and 20 show the mean brightness and mean maximum and minimum elevations of active forms throughout the night. There seems to be no particular pattern as far as the elevations are concerned, and the brightness appears to be fairly constant throughout the night. The mean brightness is mostly between 2 and 2·5 and is, therefore, much greater than for any of the other forms.

d. *Diffuse surfaces*

As can be seen from Fig. 21, surfaces are a morning feature of the aurora at Halley Bay. They usually appear just above a homogeneous arc, then the arc disappears leaving only the surfaces, although sometimes the arc apparently breaks up into surfaces without the surfaces appearing first. They have about the same average brightness as homogeneous arcs, i.e. between 1·5 and 2 throughout most of the night (cf. Figs. 13 and 22), and reach their maximum elevation between 0200 and 0500 U.T. (Fig. 23). The values in the early evening and late morning are unreliable because of the small number of observations.

The actual and percentage frequencies of occurrence used in Fig. 21 are given in Table X.

e. *Flaming*

This is not really a separate form but is an upward movement of waves of light over diffuse surfaces or diffuse surfaces and rays, towards the magnetic zenith. Its occurrence with diffuse surfaces is somewhat varied, sometimes being coincident with the first appearance of diffuse surfaces but more often starting afterwards, sometimes appearing and disappearing intermittently.

Flaming is a morning feature of the aurora at Halley Bay, and is seen only occasionally before 2400 U.T. Table XI gives the frequencies of occurrence throughout the night, for 1961 and 1962. The percentage frequencies are plotted in Figs. 24 and 25 for all conditions when the sun was more than 12° below the horizon and for clear dark conditions, respectively.

TABLE XI

FREQUENCY OF FLAMING

	Period (hr. U.T.)	17	18	19	20	21	22	23	24	01	02	03	04	05	06	07	08	09	10	11	00
1961	*a*								1		4	1	2	13	6	15	15	9	14	3	
	b								0·9		3·7	0·8	1·7	11·9	5·7	16·3	21·8	13·8	28·6	14·3	
	c			1	4		1	2	2	6	18	9	27	36	29	36	34	23	29	14	3
	d			0·3	0·8		0·2	0·3	0·3	0·8	2·2	1·1	3·5	4·9	4·3	6·0	6·4	5·4	9·0	7·0	9·1
1962	*a′*									5	10	10	18	33	28	14	19	26	6		
	b′									4·0	7·9	7·6	12·9	24·4	18·5	8·9	17·3	22·8	9·1		
	c′									5	10	15	24	37	36	23	31	26	9		
	d′									0·6	1·2	1·9	3·1	5·1	5·3	3·8	6·0	6·2	2·8		

a, a′. Number of occurrences in clear dark periods.
b, b′. Percentage frequency in clear dark periods (using Table I, lines *c* and *c′*).
c, c′. Total number of occurrences.
d, d′. Percentage frequency in all periods when the sun was more than 12° below horizon (using Table I, line *a*).

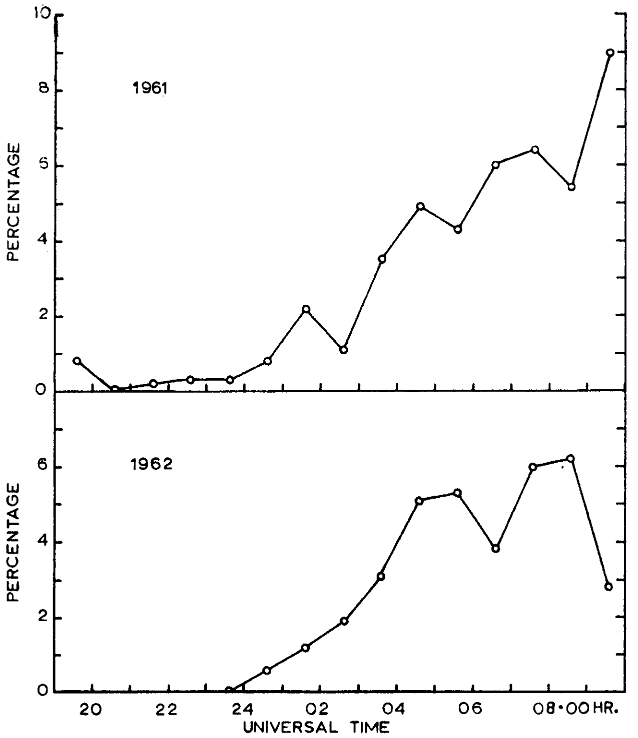

FIGURE 24

Occurrence of flaming (when the sun was more than 12° below the horizon).

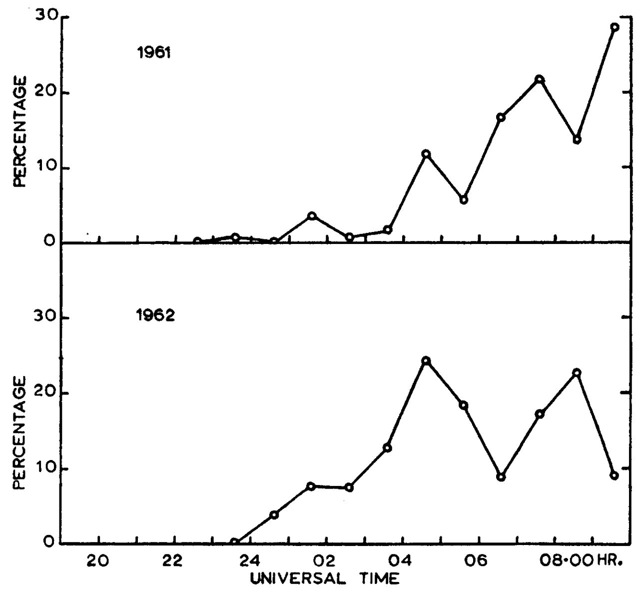

FIGURE 25

Occurrence of flaming (in clear dark periods).

TABLE XII
FREQUENCY OF RED AURORAE

Period (hr. U.T.)			17	18	19	20	21	22	23	24	01	02	03	04	05	06	07	08	09	10	1100	Total
1961	*a*			1	1	2	5	11	11	17	16	23	20	20	16	15	10	6	8	2		184
	b								5	1	3	3	1									13
1962	*a′*							2	2	10	7	3	6		1	1						32
	b′						1		5	7	2	2			1							18

a, *a′*. Number of occurrences of red type A.
b, *b′*. Number of occurrences of red type B.

f. *Red coloration*

There are two types of red coloration: red type A which is a high altitude feature appearing in the middle or near the top of auroral forms, and red type B which appears as a red lower border particularly in rayed arcs. Type A consists of the 6300 Å and 6364 Å bands of atomic oxygen, whereas type B is from the red bands of molecular nitrogen. Type A often appears purple because of mixing with the blue of ionized nitrogen, and both types sometimes appear orange because of mixing with the normal green (5577 Å) of atomic oxygen.

Table XII gives the number of quarter-hour periods during which red coloration occurred in each hourly period during 1961 and 1962, and Fig. 26 shows the percentage frequency of red type A. From Table XII it can be seen that, with only three exceptions, all red type B occurred between 2300 and 0300 U.T., and Fig. 26 shows that red type A tended to occur after about 2100 U.T., and reached a maximum frequency at about local midnight.

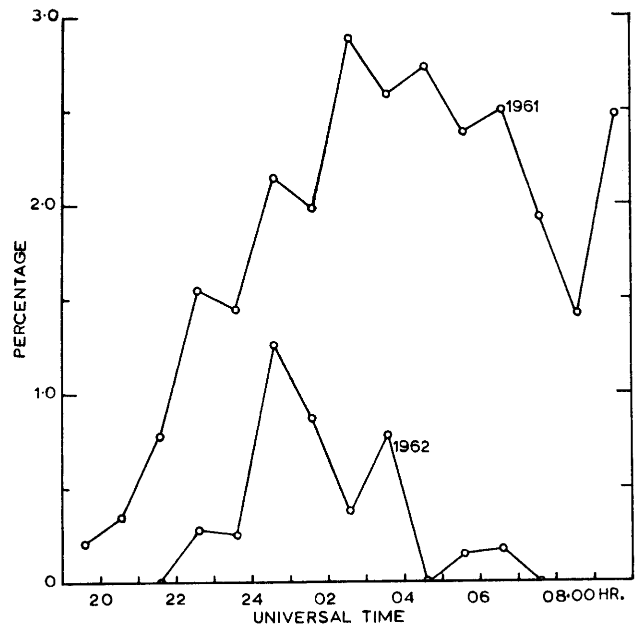

FIGURE 26

Occurrence of red type A coloration (when the sun was more than 12° below the horizon).

g. *Pulsating arcs*

Pulsating arcs had not previously been seen from Halley Bay, and were seen on only three occasions during 1961 and not at all in 1962. It is possible that they occurred during previous years, but were not observed because of their very short duration.

Of the three seen in 1961, the first occurred towards the end of the big display on 14/15 April. There was considerable cloud and flaming rays could just be detected. At 0330 U.T. two pulsating arcs of brightness 3 suddenly appeared overhead, and at the same time red coloration appeared in the rays. The arcs were green and red and pulsated with a period of a few seconds. They lasted only about 30 sec., so that had they not appeared just on the quarter-hour they would probably have been missed altogether. The second pulsating arc occurred in completely different circumstances. There had been a homogeneous arc at fairly constant elevation (between 7° and 10°) but varying brightness (2–3), from 0245 U.T. on 7/8 June. For a short time around 0500 U.T. this arc appeared to pulsate with a period of 3–4 sec., and at the time of the pulsations was of brightness 3 and at 9·5° elevation. The third pulsating arc appeared in the magnetic zenith near the beginning of the big display on 21/22 June. Although there were diffuse surfaces in the south at the same time, there was no flaming. The arc was of brightness 3–4 and had green and red coloration. It was first seen at 0215 U.T. and by 0230 U.T. it had settled into a green homogeneous arc of brightness 2, but by this time it was covered by thin cloud which had gradually spread from the south.

h. *General diurnal pattern of aurorae at Halley Bay*

Auroral displays at Halley Bay generally start either with a homogeneous arc or with a glow on the horizon which soon becomes a homogeneous arc. The arc usually remains fairly stationary until local midnight, but then sometimes breaks up into active forms for a short time. After this, the homogeneous arc forms again and appears to drift westwards with a simultaneous latitude change, as described on p. 12, and later in the morning breaks up into diffuse surfaces which are accompanied by flaming.

This general pattern is typical of a fairly quiet night. When there is a big display, active forms are seen throughout the night, and on exceptionally quiet nights only homogeneous arcs and/or diffuse surfaces are seen.

III. ASSOCIATION OF THE AURORA WITH MAGNETIC AND IONOSPHERIC DISTURBANCE

1. Statistical Analysis

a. *Association with magnetic disturbance*

Table XIII shows that there is close correspondence between the maximum elevation of the aurora at Halley Bay, during any particular night, and the maximum value of the local magnetic index, *K*, for that night. The lower limits of the *K*-indices for Halley Bay are given in Table XIV.

The geomagnetic latitude position of the centres of homogeneous arcs are compared with the planetary magnetic index, *Kp*. This is done by finding the median latitude of the arcs for each value of *Kp*. In order to provide a sufficient number of observations in each class, use has been made of all the homogeneous arcs seen in clear dark periods during the years 1957 to 1962.

These medians are plotted against *Kp* in Fig. 27 and show very good linear dependence. Also plotted in Fig. 27 are the results of a similar analysis carried out by Jacka (1953), using observations made from Macquarie Island (geomagnetic coordinates 60·7°S., 243·1°E.) between May 1950 and April 1951. If the values for $K = 0$ and $K = 1$ are ignored because of the small number of observations in these classes, then the slope of the straight line derived from Jacka's results is the same as that obtained from the Halley Bay results. Comparison of the actual geomagnetic latitudes of the two sets of results shows that there is only about 0·5° latitude difference between the best straight line through each set of results.

b. *Association with ionospheric disturbance*

The occurrence of sporadic *E* and ionospheric blackout, as recorded by the ionosonde at Halley Bay, are compared in Table XV with the coincident occurrence of the different auroral forms. Only four types of sporadic *E* were recorded during the night hours, and these are the ones described in the *Annals of the International Geophysical Year*, Volume 3, as follows:

r (retardation): non-blanketing *Es*
f (flat): showing no increase of height with frequency
s (slant): a steadily rising, diffuse trace
a (auroral): gradually rising lower edge, with diffuse echo above

Also in Table XV, the occurrence of spread *F* is compared with the occurrence of the various auroral forms. There are too few occurrences of type *r* sporadic *E* to allow analysis of this type of *Es*. Table XVI gives the expected number of occurrences of each type of aurora with blackout, and with each of the other types of sporadic *E*. These figures were obtained from the totals of the various auroral forms, blackout and sporadic *E* given in Table XV, assuming that there is an even distribution throughout the classes.

Table XIII

VARIATION OF ELEVATION OF THE AURORA WITH LOCAL MAGNETIC INDEX

*Local K-index**	*Maximum Elevation* (degrees)						*Total*
	0–5	5–10	10–20	20–60	60–120	>120	
0–1	3	7	3		1		14
2–3		18	26	21	3		68
4–5		4	20	17	26	11	78
6–7		1	2	6	12	14	35
8–9					2	3	5
Total	3	30	51	44	44	28	200

* Maximum value during night.

By comparing Tables XV and XVI, the following conclusions may be drawn:

1. Active forms are associated with the occurrence of blackout and sporadic *E* types *a* and *s*.
2. Diffuse surfaces are associated with blackout.
3. Auroral *Es* occurs slightly more frequently than would be expected when there are only homogeneous arcs present.
4. When there is no aurora, or merely a glow, auroral and slant type *Es* occur very infrequently.

Table XV shows that flaming is usually accompanied by ionospheric blackout, and that spread *F* tends to be associated more with quiet aurorae than with active forms or diffuse surfaces.

TABLE XIV

THE LOWER LIMITS OF THE *K*-INDICES FOR HALLEY BAY

K	0	1	2	3	4	5	6	7	8	9
γ	0	15	30	60	120	210	360	600	990	1,500

TABLE XV

OCCURRENCE OF VARIOUS AURORAL FORMS WITH SPORADIC *E* AND IONOSPHERIC BLACKOUT

Aurorae	*r*	*f*	*a*	*s*	*No Es*	*Blackout*	*Spread F*	*Total*
Active aurorae	1	30	13	19	7	35	11	103
Diffuse surfaces	3	53	11	21	25	94	26	200
Homogeneous arcs only	6	124	32	24	85	47	105	300
Glows or nothing	1	85	4	5	64	57	63	215
Flaming	2	8			3	41	3	54
Total	13	279	61	73	179	200	225	760

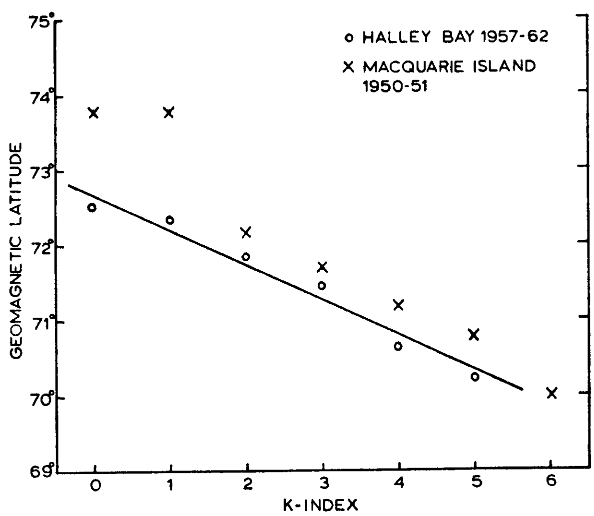

FIGURE 27

Variation of the median position of homogeneous arcs with the planetary magnetic index, *Kp*. (For Macquarie Island data see Jacka, 1953.)

In Tables XVII and XVIII, the virtual height of the *F* layer is examined in relation to the occurrence of different auroral forms and to auroral brightness, respectively. Inspection of Table XVII suggests that the *F* layer tends to be higher when the aurora is present, and that the greatest heights are associated with active forms and diffuse surfaces. Also, as would be expected from this, Table XVIII shows that there is close correlation between the height of the *F* layer and the brightness of the aurora, giving a value for χ^2 of well over 20, on the hypothesis that there is no connection between height and brightness. Thus, for 4 degrees of freedom this is good enough for the hypothesis to be rejected at the 0·1 per cent level.

TABLE XVI

EXPECTED RELATIONSHIP BETWEEN VARIOUS AURORAL FORMS AND SPORADIC *E* OR BLACKOUT

Aurorae	*f*	*a*	*s*	*No Es*	*Blackout*	*Total*
Active aurorae	37·81	8·27	9·89	24·26	27·11	103
Diffuse surfaces	73·42	16·05	19·21	47·11	52·63	200
Homogeneous arcs only	110·33	24·08	28·82	70·67	78·95	300
Glows or nothing	78·93	17·26	20·65	50·64	56·58	215
Total	279	61	73	179	200	760

TABLE XVII

RELATIONSHIP BETWEEN VARIOUS AURORAL FORMS AND THE VIRTUAL HEIGHT OF THE *F* LAYER

(number of occurrences)

Aurorae	*Virtual Height of F Layer* (km.)			*Total*
	205–300	305–400	>400	
Active aurorae and diffuse surfaces	20	27	10	57
Homogeneous arcs only	49	106	8	163
Glows or nothing	71	24	5	100
Total	140	157	23	320

TABLE XVIII

RELATIONSHIP BETWEEN THE BRIGHTNESS OF THE AURORA AND THE VIRTUAL HEIGHT OF THE *F* LAYER

(number of occurrences)

Brightness	*Virtual Height of F Layer* (km.)			*Total*
	205–300	305–400	>400	
None	62	15	5	82
<2·0	60	85	8	153
⩾2·0	18	57	10	85
Total	140	157	23	320

The brightness of the aurora is correlated with f_b (the frequency below which reflections from higher layers are blanketed by sporadic *E*) in Table XIX, and with f_o (the maximum frequency of the *Es* layer) in Table XX. In both cases low frequencies are associated with no aurora or faint aurorae. This is particularly noticeable in the case of f_b, which was always below 1·5 mc./sec. when there was no aurora.

Table XXI suggests that the maximum frequency of the sporadic *E* layer tends to be higher when the elevation of the aurora is high, and in fact if the elevation is greater than 30° the maximum frequency is usually greater than 3 mc./sec.

TABLE XIX

RELATIONSHIP BETWEEN THE BRIGHTNESS OF THE AURORA AND THE BLANKETING FREQUENCY OF THE *F* LAYER (f_b)

Maximum Brightness	f_b (mc./sec.)				*Total*
	⩽1·0	1·1–1·5	1·6–2·0	>2·0	
None	37	19			56
<2·0	39	51	15	1	106
⩾2·0	11	34	17	21	83
Total	87	104	32	22	245

TABLE XX

RELATIONSHIP BETWEEN THE BRIGHTNESS OF THE AURORA AND THE MAXIMUM FREQUENCY OF SPORADIC *E* (f_o)

Maximum Brightness	f_o (mc./sec.)			*Total*
	⩽1·5	1·6–3·0	>3·0	
None	42	30	14	86
<2·0	74	67	9	150
⩾2·0	34	90	40	164
Total	150	187	63	400

TABLE XXI

RELATIONSHIP BETWEEN THE ELEVATION OF THE AURORA AND THE MAXIMUM FREQUENCY OF SPORADIC *E* (f_o)

Maximum Elevation	f_o (mc./sec.)			*Total*
	⩽1·5	1·6–3·0	>3·0	
None	42	30	14	86
⩽30°	107	151	27	285
>30°	1	6	22	29
Total	150	187	63	400

TABLE XXII

LOCAL *K*-INDICES FOR 14/15 APRIL 1961

Period (hr. U.T.)	18–21	21–24	00–03	03–06	06–09
K	6	7	8	7	7

2. AURORAL ACTIVITY DURING BIG MAGNETIC STORMS

Laurie and Finch, using Hartland Point magnetograms (Laurie and Finch, 1962 and 1963), reported sixteen big magnetic storms in 1961, and seven in 1962. Of those in 1961, four were classified as "great storms", but none of the 1962 storms came into this classification.

In 1961, eight of the sixteen storms occurred during the Halley Bay auroral observation season (three of these being "great storms"), and three of the seven storms occurred during the auroral observation season in 1962. These eleven storms occurred on the following dates:

14/15 April 1961
20/23 June 1961
*13/14 July 1961
17/19 July 1961
*26/27 July 1961
2/3 August 1961
24/27 September 1961
*30 September/1 October 1961
6/10 April 1962
12 September 1962
19 September 1962

* signifies a "great storm".

A summary of the auroral displays which occurred at Halley Bay during these nights is given below, together with brief descriptions of the simultaneous magnetic and ionospheric activity.

All the magnetograms reproduced in this section are from the insensitive magnetometer, and the scale values for the three elements are as follows:

Z — 18·35 γ/mm.
H — 17·65 γ/mm.
D — 2·5 γ/mm.

Z increases down the page, H up the page, and D increases westerly down the page.

The all-sky photographs used in this section and in section V are from the 3-sec. exposure in 1961, and the 10-sec. exposure in 1962, with film development as indicated on p. 6. They have been enlarged using the same standard exposure in all cases.

On *14/15 April 1961* observations began at 2030 U.T. Diffuse surfaces and a homogeneous arc were already present and quickly developed into a rayed arc and a corona, reaching brightness 4 at 2123 U.T. By 2055 U.T. the diffuse surfaces had spread to within 15° of the northern horizon (see Plate I: note twilight in the west at 2055 and 2107 U.T.). The aurora again reached brightness 4 during the whole of the period from 2145 to 2215 U.T., when the most prominent form was an arc (sometimes rayed) which moved from north to south and passed overhead at about 2157 U.T. (Plate I). By 2215 U.T. this arc was breaking up into rayed bands, which receded to the southern part of the sky by 2245 U.T. The aurora near the northern horizon became much brighter at about 2324 U.T., and this brightness increased and spread southwards until, at 2328·5 U.T., the whole sky was covered by rayed bands of brightness 4. The sequence of events and diminishing brightness, up to 0005 U.T., can be seen from Plate I. After 0030 U.T. cloud interfered with observations, but the aurora was detected up until 0700 U.T., and flaming could be seen through the cloud at 0145, 0200 U.T. and from 0300 to 0430 U.T.

The ionospheric results for 14/15 April show f type sporadic E at 2000, 2100 and 2200 U.T., and then blackout for the rest of the night, the values of f_o for 2000, 2100 and 2200 U.T. being 5·1, 6·0 and 3·5 mc./sec., respectively. The magnetogram for this night became much quieter after 0700 U.T.; the local magnetic K-indices for the night are given in Table XXII. The K values show that the magnetic conditions were very disturbed during this active aurora, becoming quieter at 0700 U.T. when the aurora was detected for the last time. The ionospheric results show that there was blackout whenever flaming aurorae occurred, and the sporadic E which was recorded had high values of maximum frequency (f_o) in each case.

On *20/21 June 1961* (Plate II) the aurora was first seen at 2145 U.T., but remained quiet until about 2330 U.T. After this, there was a varied display which reached brightness 4 at 0031 U.T. and then gradually faded to brightness 2–3. The aurora was seen throughout the rest of the night, and although observations were terminated at 0900 U.T., interference rings could still be seen in the twilight. Plate II shows the aurora moving further north up to 0015 U.T.; it reached the northern horizon by 0045 U.T., but unfortunately there are no all-sky photographs for this period. The aurora covered the whole sky until 0300 U.T., when there was a system of multiple arcs just to the north of the overhead position. At 0330 U.T. this had become a homogeneous arc, which merged into the corona that was present before changing back to multiple arcs by 0345 U.T. By 0415 U.T. the multiple arcs had broken up to form rays and diffuse surfaces converging to the zenith from the east and west. By 0430 U.T. these surfaces and rays had become a rayed arc which gradually receded south, reaching an elevation of 38° by 0500 U.T. Further visual observations showed that the arc gradually receded to 15° elevation by 0615 U.T., but cloud made it impossible to follow any later developments.

On *21/22 June 1961* auroral observations were started at 2030 U.T., and even though there was considerable cloud throughout the night a very active display was seen all night, and flaming diffuse surfaces could still be seen when observations were terminated at 1115 U.T. on the 22nd.

On *22/23 June 1961* both cloud and moonlight interfered with observation in the evening hours, but a fairly active display was apparent until about local midnight. After this there were diffuse surfaces until 0300 U.T., and then a homogeneous arc just below 10° elevation which remained until the display ended at 0445 U.T.

The maximum frequencies (f_o), of the sporadic E are given in Table XXIII. It is noticeable that the values of f_o were much higher when the aurora was present overhead; e.g. note the increase from 2·5 to 5·6 mc./sec. between 2400 and 0100 U.T. on 20/21 June, as the aurora passed overhead, and again the decrease from 4·3 mc./sec. at 0500 U.T. to 2·1 mc./sec. at 0700 U.T. as the aurora receded south again.

TABLE XXIII

THE MAXIMUM FREQUENCY (f_o) OF SPORADIC E FOR 20–23 JUNE 1961

(in mc./sec.)

Hr. (U.T.)	20	21	22	23	24	01	02	03	04	05	06	07	08	09	10
20/21 June	0·9	*	*	*	2·5	5·6	B	5·6	5·6	4·3	B	2·1	1·9	1·6	*
21/22 June	5·5	6·4	7·1	7·0	7·0	5·9	7·0	5·9	B	5·3	B	B	B	B	B
22/23 June	B	B	3·7	3·4	3·9	5·3	2·4	*	1·6	*	*	*	*	*	B

B denotes ionospheric blackout.
* denotes that there was neither blackout nor sporadic E.

TABLE XXIV

LOCAL K-INDICES FOR 20–23 JUNE 1961

Period (hr. U.T.)	18–21	21–24	00–03	03–06	06–09	09–12
20/21 June	1	4	8	4	3	3
21/22 June	5	7	7	7	6	4
22/23 June	3	4	4	2	0	0

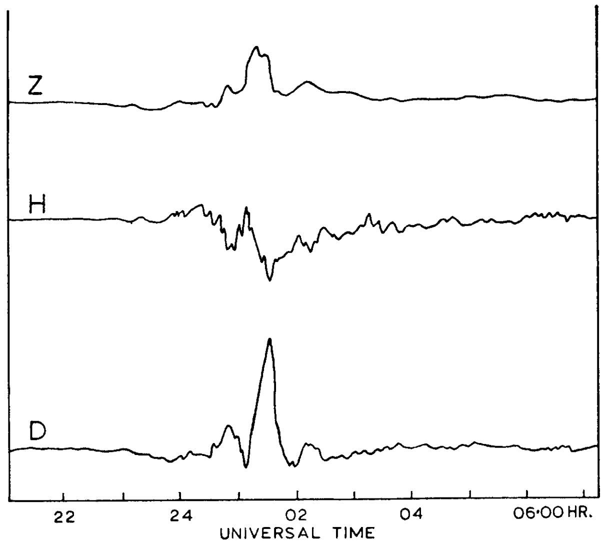

FIGURE 28

Insensitive magnetogram for 20/21 June 1961.

There was also good agreement between auroral activity and magnetic disturbance, as can be seen from the insensitive magnetogram for the night of 20/21 June, which is reproduced in Fig. 28, and from the local magnetic *K*-indices shown in Table XXIV.

The magnetogram shows a bay starting at 2330 U.T., and a further bay superimposed on this from 0030 to 0230 U.T. The start of this superimposed bay corresponds to the sudden increase in brightness of the aurora at 0031 U.T., and the end corresponds to the change of form, from a corona to overhead rayed arcs, which occurred at about 0230 U.T. The beginning of the original bay, as would be expected, had been coincident with the change from quiet to active auroral forms, and the end of this bay was at the time (0600 U.T.) when the aurora returned to a quiet form. It will be noticed from Fig. 28, that the magnetic conditions were most disturbed between 0030 and 0200 U.T., which was the period when the aurora was at its brightest.

The above table gives high *K* values throughout the night of 21/22 June, corresponding to the very active aurora which was present all night; the very high *K* value between 0000 and 0300 U.T. on 20/21 June also corresponds to the active aurora between these hours. Note also the reduction in the value of *K* after 0300 U.T. on 22/23 June, and the simultaneous disappearance of the aurora.

The next big storm, on *13/14 July 1961*, is described by Laurie and Finch as a "great storm". When auroral observations began at 1850 U.T. there was already a rayed arc at 13° elevation, and other base members reported that it had been present, at about this elevation, since at least 1800 U.T. A rayed arc, or sometimes rayed bands, were present at about the same elevation (or lower) until 0100 U.T. At 1910 U.T. there was a homogeneous arc overhead which then moved northwards, reaching a position 30° above the northern horizon by 1930 U.T. (cf. increased activity in *H* and *D* traces of the magnetogram reproduced in Fig. 29). By 1945 U.T. only diffuse surfaces were visible to the north, and at 2015 U.T. there was only the rayed arc in the south which was then at an elevation of 9°. From 2015 until 0100 U.T. there was a varied and active display which gradually became more active, with rays reaching the zenith at 2245 U.T. (Again note the disturbance shown on the magnetogram in Fig. 29.) For a time, after 0100 U.T., only homogeneous arcs and/or diffuse surfaces were seen, and by 0630 U.T. there was only a glow to about 2° elevation; the magnetogram was then fairly quiet (see Figs. 29 and 30). The glow gradually increased again in elevation, and by 0745 U.T. had become a homogeneous arc at about 5° elevation. By 0830 U.T. this arc had developed rayed structure; it increased in elevation and brightness until 0845 U.T. when there was a rayed arc of brightness 3–4 and 20° elevation. The arc then broke up into rayed bands, and by 0846 U.T. there were rayed bands of brightness 4 with rays converging to the zenith. Flaming began at 0852 U.T., and by 0900 U.T. flaming rays were visible. These were seen until 1130 U.T., and interference rings could still be seen when observations were terminated at 1145 U.T. From Fig. 30 it can be seen that the break-up of the rayed arc at 0845 U.T. was coincident with a sudden increase in magnetic activity,

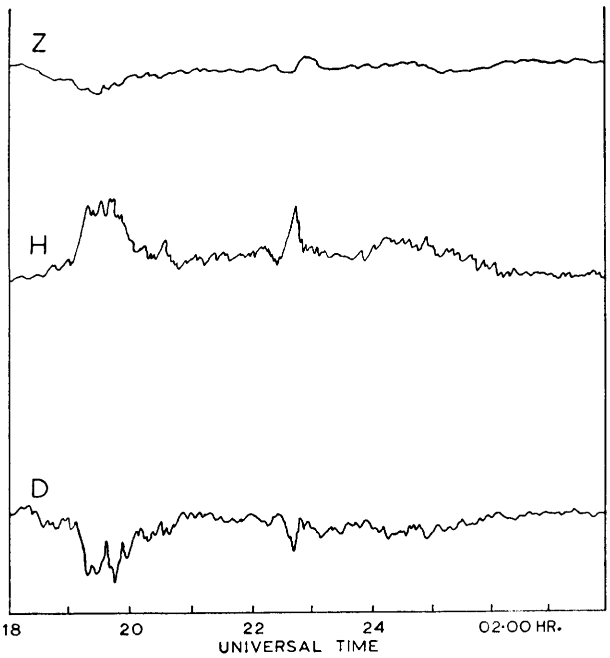

FIGURE 29
Insensitive magnetogram for 13/14 July 1961.

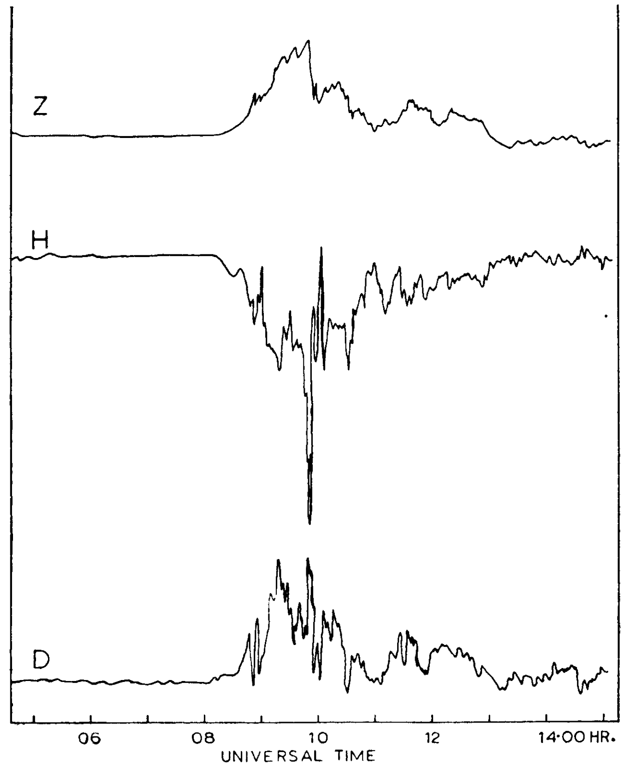

FIGURE 30
Insensitive magnetogram for 14 July 1961.

and that the beginning of this auroral activity at about 0815 U.T. was coincident with the start of a magnetic bay. The pattern of auroral activity can also be seen from the *K* values for the night, which are given in Table XXV.

TABLE XXV
LOCAL *K*-INDICES FOR 13/14 JULY 1961

Period (hr. U.T.)	18–21	21–24	00–03	03–06	06–09	09–12
K	7	6	6	4	7	9

The ionospheric results for 13/14 July give *f* type sporadic *E* at 1800, 1900, 2000, 2400 and 0100 U.T. and then blackout until 0600 U.T., after which there was, unfortunately, a fault in the ionosonde. None of the sporadic *E* was at a particularly high frequency, the maximum frequency (f_o) being about 1·0 mc./sec. in each case.

On *17/18 July 1961*, there was cloud all night at Halley Bay, but interference rings indicated that the aurora was present throughout the night. On the following night, *18/19 July*, there was again some cloud all night, but for much of the time there was only a thin layer through which the aurora could be seen. Other base members reported seeing the aurora between the cloud at 1800 U.T., and when regular observations began at 1900 U.T. there were already flaming rays converging to the zenith. Cloud interfered with the observations until 2400 U.T., but flaming was seen between the cloud during most of the period up to 2300 U.T. At 0015 U.T. there was a rayed band between 8° and 14° elevation, and diffuse surfaces overhead. By 0022 U.T. the band had become a homogeneous arc at 21° elevation, and there were flaming rays and diffuse surfaces overhead. As can be seen from Plate II this changed quickly, until at 0029 U.T. the whole sky was covered by rays and rayed bands of brightness 3. Then the aurora faded quickly, leaving flaming rays and diffuse surfaces at 0033 U.T. Plate II shows the westerly movement which

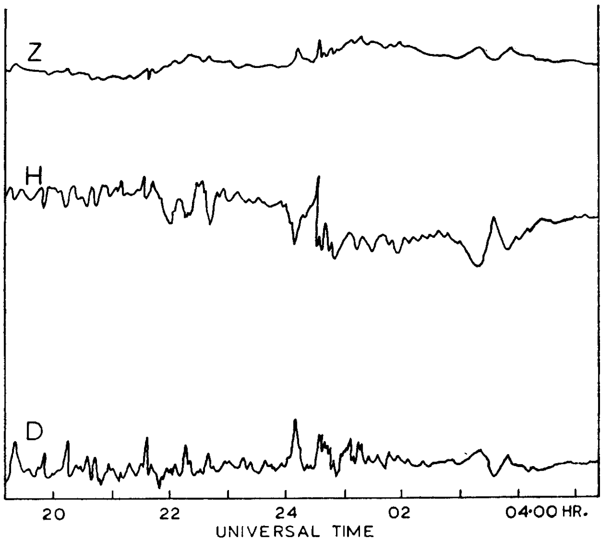

FIGURE 31

Insensitive magnetogram for 18/19 July 1961.

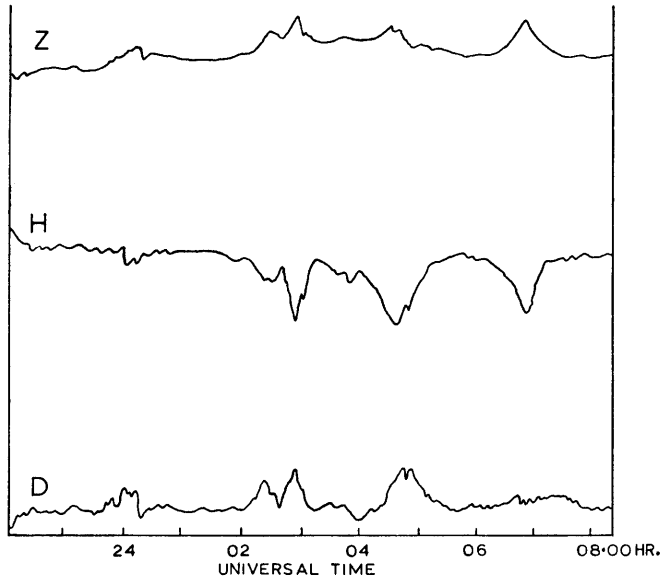

FIGURE 32

Insensitive magnetogram for 24/25 September 1961.

TABLE XXVI

LOCAL *K*-INDICES FOR 17–19 JULY 1961

Period (hr. U.T.)	18–21	21–24	00–03	03–06	06–09
17/18 July	6	6	7	8	8
18/19 July	6	6	7	6	1

occurred at about 0050 U.T., and the magnetogram, reproduced in Fig. 31, shows a rapid change in the *H* component corresponding to the sudden burst of auroral activity near 0030 U.T.

Flaming aurora was seen until 0230 U.T., and then at 0245 U.T. there was a system of multiple arcs stretching from 40° to 120° elevation above the southern horizon. These arcs remained in approximately the same position until about 0325 U.T., when they moved farther north (Plate III). At 0332 U.T. rays appeared above a bank of cloud which was low in the south and these quickly became brighter, with the arcs breaking up into flaming rays and diffuse surfaces by 0340 U.T. Multiple arcs again appeared overhead at 0400 U.T., but gradually receded to the south (30° to 80° elevation at 0415 U.T.) and became a homogeneous arc at 22·5° elevation by 0430 U.T. (Plate III). Flaming rays and diffuse surfaces were seen throughout this period and until 0445 U.T., but by 0500 U.T. the flaming had ceased and there was only a homogeneous arc at 14·5° elevation and diffuse surfaces to about 30° elevation. The cloud now began to spread over the sky again, and only auroral light could be seen between the cloud until 0630 U.T., and then nothing at all.

There was a sudden disturbance on the magnetogram (Fig. 31) at about 0340 U.T. as the arcs broke up, and then gradual quietening as the aurora receded to the south. The *K* values, given in Table XXVI, also show that magnetic conditions became quieter after 0600 U.T. on 18/19 July; the *K* values had been fairly high throughout the preceding two nights.

The ionospheric results showed that there was blackout for most of these two nights, with *f* and *s* type sporadic *E* until 0100 U.T. on 17/18 July, and then occasionally during the rest of the two nights.

On *26/27 July 1961* observations were severely restricted by cloud and moonlight, but interference rings were already visible low in the south when observation began at 2215 U.T. By 2245 U.T. a rayed band

TABLE XXVII

LOCAL *K*-INDICES FOR 26/27 JULY 1961

Period (hr. U.T.)	21–24	00–03	03–06	06–09	09–12
K	6	5	3	9	9

TABLE XXVIII

THE MAXIMUM FREQUENCY (f_o) OF SPORADIC *E* FOR 26/27 JULY 1961

Hr. (U.T.)	22	23	24	01	02	03	04	05	06	07	08	09	10	11	12
f_o (mc./sec.)	1·6	5·4	2·5	5·6	5·9	4·4	2·7	2·3	B	2·2	1·5	B	B	B	B

B denotes ionospheric blackout.

was visible at 8° elevation, and after this there was a very active display which lasted until about 0530 U.T. After 0530 U.T. the interference rings became fainter, and by 0600 U.T. had disappeared altogether. Nothing was seen from 0600 to 0800 U.T., so observations were terminated at 0800 U.T. However, at 0855 U.T. the meteorological observer reported flaming rays and a corona overhead, so regular observations were started again. The aurora continued in the same form until 1100 U.T., and interference rings could still be seen in the twilight at 1115 U.T.

The *K*-indices, given in Table XXVII, are in good agreement with the level of auroral activity seen during the night, and Table XXVIII shows that when sporadic *E* was observed the maximum frequency (f_o) was high whenever there was an active aurora.

Although observation on *2/3 August 1961* was restricted by cloud and drifting snow, it was possible to see that the aurora reached the overhead position only from about 0430 to 0500 U.T., and was by no means as active as during the previous "big magnetic storms" reported by Laurie and Finch. The maximum value of *K* for the night was 5 (between 0300 and 0600 U.T.), and the maximum frequency (f_o) of sporadic *E* was only about 2·3 mc./sec. Sporadic *E* was present from 2400 to 0400 U.T. inclusive, with blackout at 2200 U.T. and for the rest of the night after 0400 U.T.

As can be seen from Table XXIX, the *K*-indices at Halley Bay, during the magnetic storm of *24/27 September 1961*, reached their maximum during the night of 24/25 September; the insensitive magnetogram for this night is reproduced as Fig. 32.

On *24 September* auroral observations began at 2230 U.T., at which time interference rings were detected in the south. Although the sky was moonlit all night a considerable aurora was seen, starting with a homogeneous arc at 2245 U.T. and becoming a rayed arc at 25° elevation by 2315 U.T. At 2330 U.T. the rayed arc was at 8·5° elevation, but rayed bands were beginning to appear up to an elevation of 20°. The rayed arc persisted until it broke up into rayed bands at 0001 U.T., and from 0015 until 0200 U.T. inclusive, observations indicated that there was an arc at between 10° and 15° elevation. By 0215 U.T.,

TABLE XXIX

LOCAL *K*-INDICES FOR 24–27 SEPTEMBER 1961

Period (hr. U.T.)	21–24	00–03	03–06
24/25 Sept.	5	7	7
25/26 Sept.	4	3	3
26/27 Sept.	3	4	5

this had broken up into rayed bands and rays extending to the zenith (cf. the beginning of disturbance on the magnetogram shown in Fig. 32). After this, rays and diffuse surfaces were seen extending to the zenith until they were lost in the twilight at 0315 U.T. Flaming was present at 0300 U.T.; interference rings were detected from the whole sky until 0330 U.T. and then from the southern half of the sky until 0345 U.T.

The ionospheric results for this night give sporadic E from 2200 U.T., except for the blackouts at 0100, 0300, 0400 and 0500 U.T., but the only time when there was a particularly high maximum frequency (f_o) was at 2200 U.T., when it reached 5·5 mc./sec.

On *25/26 September* the sky was completely obscured by cloud and drifting snow until 0300 U.T., and then partly obscured by cloud and moonlight, and no aurora was detected. There was sporadic E from 0100 U.T. but not at very high frequencies, and as can be seen from the above table the maximum K-index for the night was 4.

On *26/27 September* the aurora was first seen in the form of a homogeneous arc at 2400 U.T. This soon gave way to a rayed arc which persisted until 0215 U.T., when it was detected only as interference rings in the moonlight. Rayed bands had appeared below the arc at 0145 U.T. Flaming rays and diffuse surfaces to 45° elevation appeared at 0147 U.T., reaching the zenith at 0200 U.T. Interference rings were seen in the moonlight until 0400 U.T., after which the combination of moonlight and twilight made the sky too bright for observation. There was sporadic E at 0100 U.T., and then blackout until 0500 U.T.

The last "great storm" during the 1961 auroral season at Halley Bay occurred on *30 September/ 1 October* and, although there was twilight and a little fog throughout the night, the aurora was seen in the zenith from 2320 to 0330 U.T. and interference rings were detected until 0415 U.T. All the aurora seen was either of rayed form or was a homogeneous arc at a very high elevation (i.e. at about 10° from the northern horizon), and flaming appeared to be present throughout the night. The maximum frequencies of sporadic E were 1·0 mc./sec. at 2400 U.T., 1·1 mc./sec. at 0100 U.T., 5·3 mc./sec. at 0200 U.T. and 5·7 mc./sec. at 0400 U.T., with blackout at 0300 U.T. The K-indices for the three periods between 2100 and 0600 U.T. were 7, 9 and 8, respectively. Thus, both ionospheric and magnetic results were what would be expected during an active auroral display.

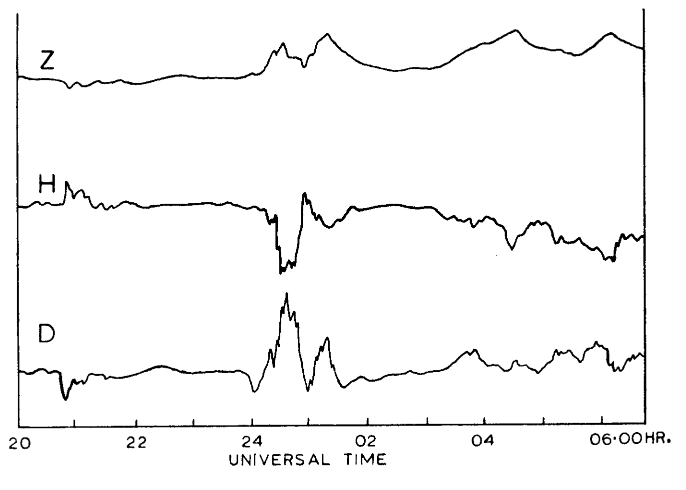

FIGURE 33

Insensitive magnetogram for 6/7 April 1962.

On *6/7 April 1962* thin cloud cover interfered slightly with observations; from 0530 U.T. the cloud became thicker, so that only interference rings were detected. The aurora was first seen at 2052 U.T., in the form of rays to 20° elevation. After this and until 2345 U.T., only faint diffuse surfaces below about 15° elevation were seen. The insensitive magnetogram (Fig. 33) shows a sudden impulse at 2042 U.T., and it is probable that the active aurora which was seen at 2052 U.T. actually started ten minutes earlier.

At 2345 U.T. there was an arc with one ray in the west and rayed bands below the arc. This arc became brighter, and a glow spread to about 60° elevation. Just before 2400 U.T. the arc began to break up into rayed bands in the east (Plate IV), and by 0012 U.T. had broken up into rays which extended to about 45° elevation. Plate IV also shows the aurora spreading northwards after 0015 U.T. and reaching the overhead position by 0026 U.T. Flaming was seen at 0030 U.T. but had ceased again by 0053 U.T., at which time there were two unusual rayed bands to the south (Plate V). There was an active display until 0115 U.T., when faint rays could still be seen in the zenith. By 0130 U.T., however, rays only reached 35° elevation, and by 0200 U.T. only a homogeneous arc could be seen at 16° elevation, considerable cloud by that time interfering with observations below that elevation. The cloud then began to spread and only auroral light could be seen, although rays were observed extending to 45° elevation at 0345 U.T., and a bright arc (3–4) was seen at 29° elevation at 0430 U.T. As the cloud spread only interference rings could be seen, but these persisted until 0700 U.T.

Comparison with the insensitive magnetogram (Fig. 33) shows a disturbance in the D trace just before 2400 U.T., when the arc began to break up into rayed bands, and H and Z became disturbed as the rays extended to 45° elevation at 0012 U.T. The biggest disturbance, which occurred on all traces at about 0030 U.T., corresponded to the time when the aurora spread to the overhead position and flaming became apparent. After this, both the aurora and the magnetic traces were quieter, but there was a big disturbance in the H component at about 0430 U.T. corresponding to the appearance of the bright rayed arc.

On *7/8 April 1962* there was almost complete cloud cover throughout the night, and the only aurora seen was the occasional homogeneous arc below cloud in the south. However, the interference filters showed that the aurora was present from 2100 until 0615 U.T.

On *8/9 April 1962* drifting snow made observation impossible until 0145 U.T., but from 0145 U.T., when the sky became clear and dark, there was a homogeneous arc at just below 10° elevation. This arc persisted until 0615 U.T. and, although there was twilight after this, interference rings indicated that the arc was still present at 0700 U.T.

The aurora was again fairly quiet on *9/10 April 1962* with either a glow or a homogeneous arc from 2145 until 0145 U.T., then diffuse surfaces above the arc until 0307 U.T. The arc had become rayed by 0307 U.T., and at 0330 U.T. there were two arcs—a homogeneous arc at 17° elevation and the western segment of a rayed arc of 4·5° elevation. By 0345 U.T. the aurora was becoming a little more active, with a rayed arc at 10° elevation and rayed bands to 27·5° in the west. These bands changed into diffuse surfaces and rays by 0400 U.T., and by 0415 U.T. the arc had also broken up into diffuse surfaces and rays which extended to 18° elevation. Diffuse surfaces were seen at 0430 U.T., but after this there was only a homogeneous arc at just below 10° elevation, and that had disappeared by 0630 U.T.

The magnetogram for 9/10 April showed a magnetic bay starting just before 0300 U.T., but there appears to have been no change in auroral form at this time. The bay, however, did not show itself on the D trace until just after 0300 U.T., which is the time when the aurora first became active.

Table XXX gives the occurrence of ionospheric blackout, and the maximum frequency (in mc./sec.) of the little sporadic E which occurred. There was a considerable amount of blackout and a very high value of f_o at the beginning of the display on 6/7 April but, apart from the value of 3·1 mc./sec. at 2400 U.T. on 6/7 April and at 0700 U.T. on 9/10 April, the sporadic E did not have very high values of maximum frequency.

TABLE XXX

OCCURRENCE OF BLACKOUT AND MAXIMUM FREQUENCY OF ANY SPORADIC E, 6–10 APRIL 1962 (in mc./sec.)

Hr. U.T.	21	22	23	24	01	02	03	04	05	06	07
6/7 April	6·1	2·3	1·1	3·1	B	B		B	B	B	B
7/8 April	B	B	?	B	B	B	B	B	B	B	B
8/9 April	B		?	B			B	B	B	B	B
9/10 April			B	B	B	B	2·5	2·4			3·1

TABLE XXXI

LOCAL *K*-INDICES FOR 6–10 APRIL 1962

Hr. U.T.	21–24	00–03	03–06	06–09
6/7 April	4	7	6	6
7/8 April	6	5	5	2
8/9 April	4	4	2	3
9/10 April	2	1	3	2

The local magnetic *K*-indices for the four nights 6/7 to 9/10 April, given in Table XXXI, are in good agreement with the level of simultaneous auroral activity.

On the two remaining days when "big magnetic storms" were reported by Laurie and Finch, considerable cloud and drifting snow obscured the sky at Halley Bay. The only aurora detected near these two days, were faint interference rings seen at one observation on each of the nights following the storms—at 2245 U.T. on *12/13 September 1962* and at 0345 U.T. on *19/20 September 1962.*

The above summary clearly shows that any major change in auroral form or activity was accompanied by a major change in magnetic activity.

In addition to these major magnetic storms, there were a further 45 occasions at Halley Bay when weather conditions permitted break-up, from quiet to rayed active forms, to be observed and recorded to the nearest quarter-hour. On two of these 45 occasions, however, there was no apparent change in the Halley Bay magnetogram. The first such occasion was on *13/14 April 1961*, when a homogeneous arc at 0100 U.T. became a rayed arc by 0115 U.T. Although there was nothing definite on the Halley Bay magnetogram, there was a small disturbance on the magnetogram at the Argentine Islands (geomagnetic 53·8°S., 3·3°E.), and M'Bour (geomagnetic 21°N., 55°E.) and San Fernando (geomagnetic 41°N., 71·3°E.) both reported a sudden impulse at 0101 U.T. The second occasion when there was a change to active auroral forms without an associated magnetic disturbance, was between 0115 and 0130 U.T. on *22/23 April 1961.* On this occasion no magnetic disturbance was reported from any station. It should be pointed out, however, that the active auroral form seen at Halley Bay was low in the south (below 10° elevation) and, at the time of its appearance, was of the quite exceptionally low brightness of 0–1. (The average brightness of active forms is given in Fig. 19.)

On a further 8 of these 45 occasions, the Halley Bay magnetograms were already disturbed, and it was difficult to pick out a disturbance associated with the change of auroral activity. On the remaining 35 occasions, however, there was a definite change in the magnetic trace which could be associated with the break-up of the aurora. Of these magnetic changes, 20 were the beginnings of bay-type disturbances, 2 were sudden impulses, and 6 were the beginnings of minor magnetic disturbances. The remaining 7 were in the middle of already disturbed periods, but in each case the disturbance increased at the time of break-up.

These 45 observations thus agree with the conclusions drawn from the major magnetic storms, that when auroral forms become active there is an associated magnetic disturbance except, perhaps, when the active auroral form is exceptionally faint.

As only hourly ionospheric results are available, it is difficult to compare the times of change of ionospheric disturbance with the times of change of auroral forms. However, it appears that an increase in the maximum frequency of sporadic *E* often coincides with a change to active auroral forms, and that blackout, which is very commonly associated with active aurorae, often persists after they have become quiet again.

IV. COMPARISON WITH RESULTS FROM PREVIOUS YEARS

1. Introduction

The observations used in this section are those for clear dark periods only, except in the case of red aurorae and where otherwise stated.

The results of observations made at Halley Bay during previous years have been obtained from the following publications:

1956, 1957, 1958 from Evans, S. and G. M. Thomas. 1960. Visual and Photographic Auroral Observations. (*In* Brunt, D. Ed. *The Royal Society International Geophysical Year Antarctic Expedition, Halley Bay, Coats Land, Falkland Islands Dependencies, 1955–59.* London, Royal Society, 1, 27–54.)

1959 from Sheret, M. A. 1962. Analysis of Auroral Observations, Halley Bay, 1959. *British Antarctic Survey Scientific Reports*, No. 37, 33 pp.

1960 from Blackie, J. R. 1964. Analysis of Auroral Observations, Halley Bay, 1960. *British Antarctic Survey Scientific Reports*, No. 40, 47 pp.

Some data (e.g. on flaming) have also been obtained from the original report sheets.

The results from these seven years' observations at Halley Bay are also compared with the conclusions drawn by Lassen (1963), using results obtained from the Northern Hemisphere between 1882 and 1959. For this comparison, and again in section V, the coordinate system used is that which was introduced by Mayaud (1960). At large distances from the earth's surface the dipole field, on which the geomagnetic coordinate system is based, gives a very good approximation to the actual magnetic field. Nearer to the earth's surface, however, this is no longer true. Thus, for the study of auroral morphology it is probably better to use the more accurate approximations of the equatorial plane co-ordinates introduced by Mayaud.

In Mayaud's system, a point is taken in the geomagnetic equatorial plane. Then, a point on the earth's surface is obtained by following the theoretical dipole field line from this point to its intersection with the earth's surface; this point is called point *A*. Next, the actual field line is followed to its intersection with the earth's surface, and this intersection point is called point *B*. Mayaud now characterizes the actual intersection point *B* by the geomagnetic coordinates of the theoretical intersection point *A*. Thus, the actual and theoretical points are identified with one another by projecting back to the geomagnetic equatorial plane along their respective magnetic field lines, hence the name "equatorial plane coordinates" which Mayaud gives to his system.

Table XXXII

FREQUENCY OF OCCURRENCE OF AURORAE

Year	*Number of Periods**	*Number with Aurorae*	*Percentage Frequency of Aurorae*	*Number with Zenith Aurorae*	*Percentage Frequency of Zenith Aurorae*
1956	934	522	56·0	126	13·5
1957	1,055	946	89·7	255	24·2
1958	1,184	1,170	98·8	337	28·4
1959	945	888	94·0	108	11·4
1960	1,350	930	68·9	156	11·5
1961	1,485	1,051	70·8	83	5·6
1962	2,007	1,509	75·2	89	4·4

* Clear dark quarter-hour periods.

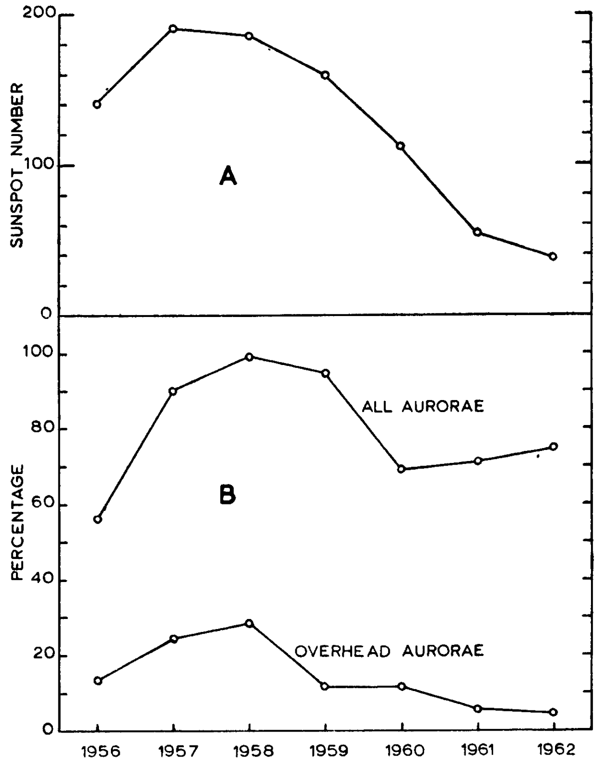

FIGURE 34

A. Mean daily sunspot numbers during period of observation.
B. Percentage frequency of aurorae.

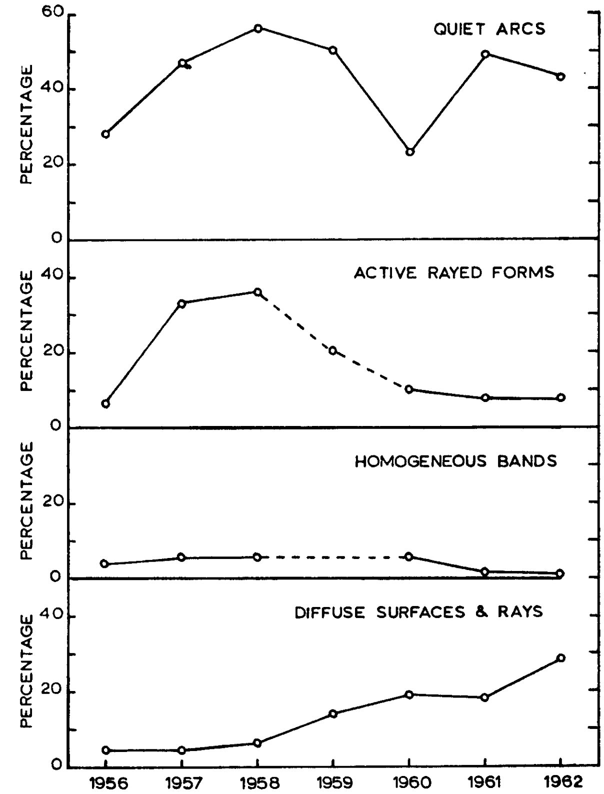

FIGURE 35

Occurrence of various auroral forms.

2. PROBABILITY OF OCCURRENCE OF THE AURORA

In Fig. 34, the mean daily sunspot numbers for the years 1956–62 are compared with the percentage frequencies of all aurorae and of overhead aurorae. The auroral frequencies, together with the actual number of occurrences of aurorae in clear dark periods, are also given in Table XXXII.

Fig. 34 shows a fall in the probability of occurrence of all aurorae after sunspot maximum (1957 and 1958), but a levelling off at about 70–75 per cent from 1960 onwards. The probability of occurrence of overhead aurorae, however, continues to fall as sunspot minimum approaches, which suggests either that the auroral zone is becoming narrower or that the whole zone is receding polewards. The most likely explanation is that the zone is becoming narrower, and the probable cause of this is that active aurorae do not reach such low latitudes as sunspot minimum approaches. It seems unlikely that the whole zone is moving polewards, as the homogeneous arcs seen from Halley Bay occurred in about the same position throughout the seven years of observations. However, Lassen suggests that the auroral zone does recede towards the pole as sunspot minimum approaches, and that there is also some reduction in frequency on the outer edge of the zone. He has produced a schematic diagram of the distributions of auroral frequency across the auroral zone during sunspot maximum and sunspot minimum (Lassen, 1963, fig. 36). For overhead aurorae observed from stations in the latitude of Halley Bay, in equatorial plane co-ordinates, these schematic distributions give an estimated drop in frequency of from 40 per cent at sunspot maximum to 10 per cent at sunspot minimum. As can be seen from Fig. 34, the actual drop at Halley Bay is from 28·5 per cent at sunspot maximum to about 4 per cent at sunspot minimum, which agrees quite well with the suggested distributions.

The changes in the frequency of occurrence of the various auroral forms are given in Table XXXIII and Fig. 35. It can be seen that the frequency of occurrence of quiet arcs decreased after sunspot maximum, but suddenly increased in 1961 before falling again slightly in 1962. The frequency of active rayed forms

TABLE XXXIII

FREQUENCY OF OCCURRENCE OF HOMOGENEOUS ARCS, RAYED FORMS, HOMOGENEOUS BANDS AND DIFFUSE SURFACES

	*Number of Periods**	*Number of HA*	*Percentage Frequency of HA*	*Number of Active Forms*		*Percentage Frequency of Active Forms*		*Number of DS*	*Frequency Percentage of DS*
				R	*B*	*R*	*B*		
1956	934	261	28	40	35	4·3	3·7	46	4·9
1957	1,055	497	47·1	346	62	33	5·9	48	4·5
1958	1,184	665	56·1	428	62	36	5·8	75	6·3
1959	945	473	50			20·2†			14·0†
1960	1,350	307	22·8	137	74	10·1	5·5	256	19·0
1961	1,485	731	49·2	111	20	7·5	1·3	268	18·0
1962	2,007	858	42·7	153	19	7·6	0·9	569	28·4

* Clear dark quarter-hour periods.
† Probability of occurrence in clear dark and clear moonlit periods. The figure for active forms combines the percentage probabilities of rayed forms and homogeneous bands.

fell with the decrease in sunspot number. Diffuse surfaces show a steady increase in frequency of occurrence as the sunspot number decreases. This increase in the frequency of diffuse surfaces, and the increase in the frequency of quiet arcs in 1961 and 1962, are consistent with the levelling off in the frequency of all aurorae seen from Halley Bay. They are also consistent with the continued decrease in frequency of overhead aurorae, as the aurorae seen overhead were usually active rayed forms, whereas quiet arcs and diffuse surfaces were generally confined to the southern part of the sky. It is difficult to say whether there was any real change in the already low frequency of occurrence of homogeneous bands, but there seems to be a slight decrease towards sunspot minimum.

TABLE XXXIV

NUMBER OF OBSERVATIONS OF RED COLORATION

	1956	1957	1958	1959	1960	1961	1962
Type A	1*	57	38	131	17	184	32
Type B	13*	29	10	16†	22	13	18

* During 1956, observations were half-hourly and not quarter-hourly as in succeeding years.
† The colour described by Sheret (1963) as "deeper red or red-violet" is assumed to be type B.

Table XXXIV and Fig. 36 show the total number of occurrences of red aurorae during each year from 1956 to 1962. There does not appear to be any systematic variation of red type A during these years, but some pattern may become evident when observations are available from a longer period. Some of the apparent variations may be subjective errors, as there have been a number of different observers. However, the greater number of occurrences of red type A in 1961 in comparison with 1962, are partly accounted for by the frequent occurrence of red diffuse surfaces which were not seen at all during 1962. Moreover, subjective errors are very unlikely to be significant in a comparison of these two years as all the observations were carried out by the one observer. The number of occurrences of red type B remained approximately the same in each year from 1956 to 1962.

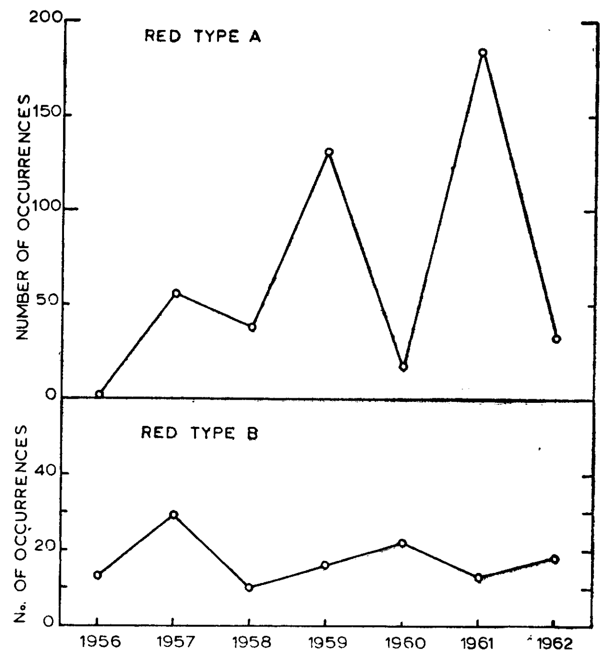

FIGURE 36

Occurrence of red coloration.

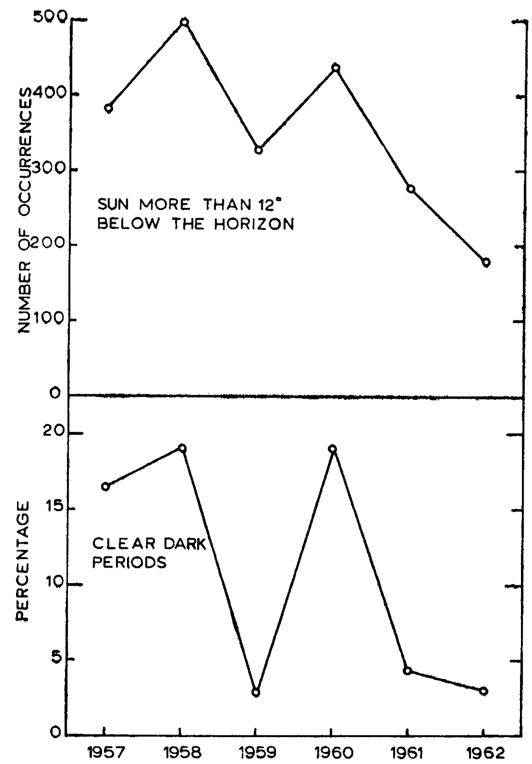

FIGURE 37

Occurrence of flaming.

TABLE XXXV

OCCURRENCE OF FLAMING

	1957	1958	1959	1960	1961	1962
a	384	497	327	435	276	180
b	174	228	27	258	59	62
c	16·5	19·2	2·9	19·0	4·3	3·1

a. Number of occurrences (quarter-hour periods) under all observing conditions.
b. Number of occurrences in clear dark periods.
c. Percentage frequency of occurrence in clear dark periods.

Table XXXV and Fig. 37 give the frequency of occurrence of flaming, for clear dark conditions and for all conditions when the sun was more than 12° below the horizon, during each of the years from 1957 to 1962. In Fig. 37, the graph for clear dark periods is plotted as a percentage frequency of occurrence. Both graphs suggest that there was a decrease in the frequency of flaming as sunspot minimum approached, a minimum in the frequency distribution in 1959, and a subsidiary maximum in 1960. As with red coloration, however, some irregularities in the recorded frequency of occurrence of flaming may be due to subjective errors, since the observations were made by different observers.

TABLE XXXVI

DIURNAL FREQUENCY OF ALL AURORAE

Period (hr. U.T.)	18	19	20	21	22	23	24	01	02	03	04	05	06	07	08	09	10	1100
1956		16	19	17	36	75	72	76	94	95	72	60	40	34				
1957	58	38	37	69	86	92	97	100	96	95	99	100	100	92	100	100		
1958	100	94	86	98	96	96	100	100	100	100	100	100	100	100	100	100		
1959	76	80	89	94	93	88	92	97	100	100	100	99	99	97	93	90	92	
1960			41·6	36·0	45·1	68·5	75·0	81·5	85·7	90·3	90·1	82·2	70·2	61·6	43·7	31·3		
1961	9·0	20·5	28·3	49·5	59·0	63·2	75·8	85·3	85·0	86·3	96·4	94·4	73·9	82·9	81·6	71·5	23·8	
1962	30·5	38·1	46·7	61·0	73·8	82·8	86·4	91·3	96·3	87·0	100·0	97·3	78·4	91·0	62·3	60·6	40·0	

3. DIURNAL VARIATIONS DURING THE YEARS 1956–1962

a. *Diurnal variations of all aurorae*

Table XXXVI gives the diurnal variation of all aurorae seen from Halley Bay during clear dark periods in the years 1956 to 1962, and Fig. 38 gives the percentage frequency in each year. Fig. 38 indicates that in 1956, as sunspot maximum was approaching, the maximum frequency of occurrence was near magnetic midnight;* during sunspot maximum (1957 and 1958) the frequency increased at other times of the night, particularly in the morning, and in 1958 approached 100 per cent throughout most of the night. In 1959, the frequency in the morning and evening began to fall again, leaving a maximum near or just after magnetic midnight. From 1960 to 1962, the diurnal variations were much the same as in 1959, with a maximum frequency just after magnetic midnight and a slightly higher frequency of occurrence in the morning than in the evening.

By using all-sky photographs taken in the Northern Hemisphere during the I.G.Y. (1957–58), Lassen (1963, fig. 13) has produced a polar diagram for the diurnal variation of zenithal aurorae at latitudes above 65°N. (equatorial plane coordinates). From this diagram it is possible to obtain some idea of the diurnal frequency distribution of all aurorae seen from a station situated at 61·9° latitude in equatorial plane coordinates (i.e. the position of Halley Bay). Although the actual numerical values of a distribution so obtained may not be very accurate, the general picture of the diurnal variation will be fairly good. This distribution has been obtained, and is shown by the smooth curve of Fig. 38. There is remarkable agreement between the general shape of this curve and the distribution obtained from the Halley Bay results for 1957, 1961 and 1962. The 1958 and 1959 results from Halley Bay give a curve of the same general tendency, although the actual frequencies for 1958 are higher.

Furthermore, Fig. 38 shows that the Halley Bay results agree with Lassen's conclusions for aurorae seen from a station near the auroral zone during the years just before and just after sunspot maximum. Lassen, using the results from the First International Polar Year (1882–83) and observations made from 1948 to 1950, concludes that aurorae observed from such a station will reach a main maximum frequency of occurrence near magnetic midnight, and a subsidiary maximum in the early morning hours. The results from Halley Bay for the years 1956 and 1959–62 all show this maximum near magnetic midnight, and the 1961 and 1962 results give a slight indication of a further maximum near 0400–0500 magnetic time. In Fig. 39 the Halley Bay results for the years 1956–62 have been smoothed out and plotted as a contour diagram, with contours of equal percentage frequency of occurrence showing the change in diurnal variation of frequency. There is some indication of a maximum at magnetic midnight in 1956, but after sunspot maximum the frequency maximum occurs 1–1·5 hr. later, and there appears to be no

* In equatorial plane coordinates, magnetic midnight is only 12 min. earlier than geomagnetic midnight, so that for the purposes of this analysis magnetic midnight is also taken to be 0300 U.T.

subsidiary maximum. However, this contour diagram demonstrates the agreement between the results obtained from Halley Bay in 1957 and 1958, and the distribution obtained from Lassen's contour diagram (smooth curve of Fig. 38); both sets of results show a gradual rise in frequency of occurrence up to 1–2 hr. before magnetic midnight, and then an almost constant frequency throughout the rest of the night.

TABLE XXXVII

DIURNAL FREQUENCY OF OVERHEAD AURORAE

Period (hr. U.T.)	19	20	21	22	23	24	01	02	03	04	05	06	07	08	09	10	1100
1956		1	3	4	10	15	20	33	39	24	8	7	1				
1957	4	1	6	11	10	18	32	42	42	44	38	28	22	32	23		
1958	10	6	12	20	21	30	44	48	36	31	29	35	25	26	66		
1959			2	4	4	8	13	13	18	22	20	25	22	15	8		
1960		5·5	3·9	4·4	8·9	9·5	19·2	20·6	17·8	21·4	10·4	10·6	9·3	1·6			
1961	4·5	3·0	4·5	3·9	6·8	7·5	10·1	5·8	4·3	7·3	2·8	2·2	4·3	6·2	8·2	19·0	
1962				2·3	0·8	6·4	17·5	9·1	9·4	8·9	7·3	1·3	4·5				

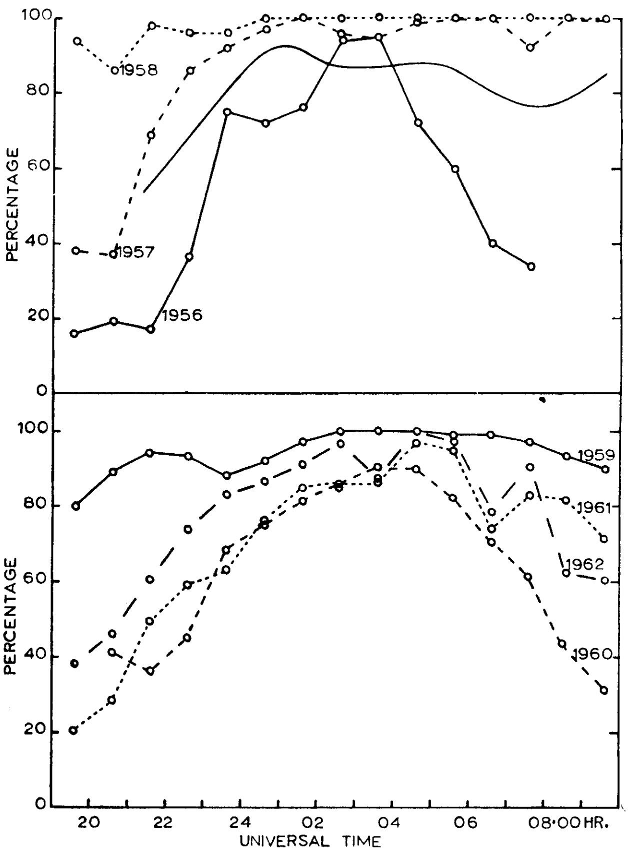

FIGURE 38

Diurnal variations of all aurorae.

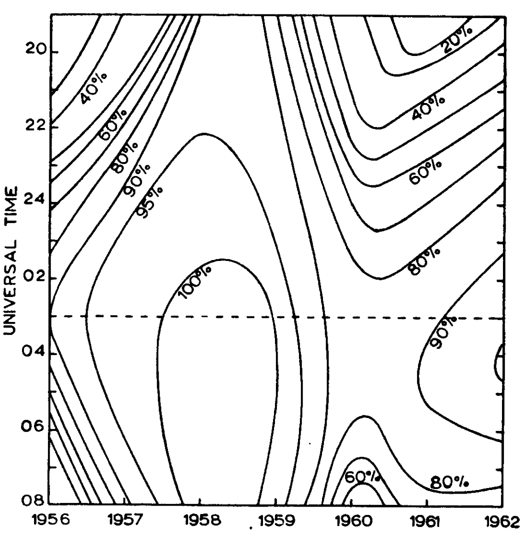

FIGURE 39

Occurrence of all aurorae.

Overhead aurorae at Halley Bay (Table XXXVII; Fig. 40) generally show a maximum at magnetic midnight and a further maximum in the morning hours, although in 1961 and 1962 the first maximum occurred near local midnight rather than magnetic midnight. The morning maximum occurred earlier as sunspot minimum approached. This is shown in the contour diagram, Fig. 41, which has been obtained by smoothing the results of Fig. 40. Fig. 41 suggests that the maximum near local midnight in 1960 is the morning maximum which had moved forward to an earlier part of the night. The maximum which occurred near magnetic midnight at sunspot maximum, moved from just after magnetic midnight in 1957 to just before magnetic midnight in 1958 and disappeared by 1959. It is probable that this very large maximum in 1957 and 1958 has obscured a ridge representing the maximum frequencies, which runs from about 0900 U.T. in 1958 to about 2400 U.T. in 1960–61. These overhead aurorae are, of course, the only aurorae which would be seen from a station a few degrees of latitude north of Halley Bay, thus there is fair agreement with Lasson's conclusion that, for a station near the auroral zone, there would be a maximum near magnetic midnight and a further maximum in the morning hours.

The above discussion shows that the results from Halley Bay agree quite well with the conclusions drawn by Lassen from results obtained in the Northern Hemisphere, but Lassen's conclusions are too simple to describe fully the diurnal variation of the aurora, and particularly the changes in this variation from year to year.

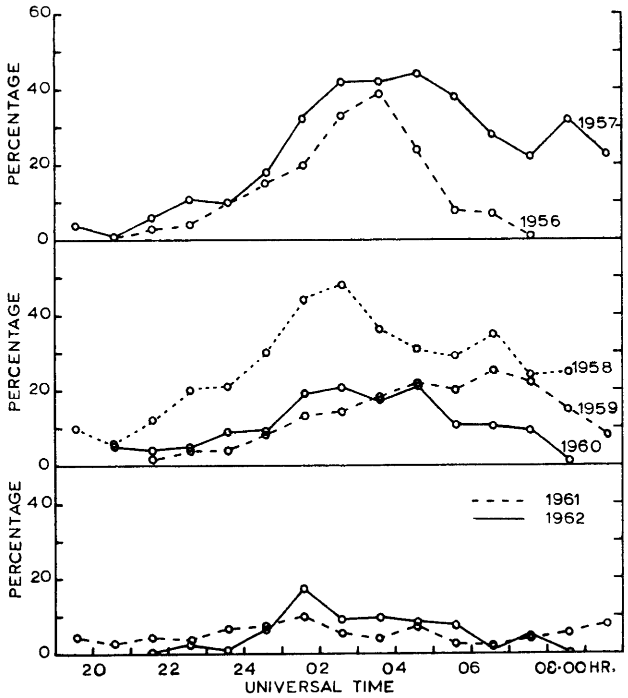

FIGURE 40

Diurnal variations of overhead aurorae.

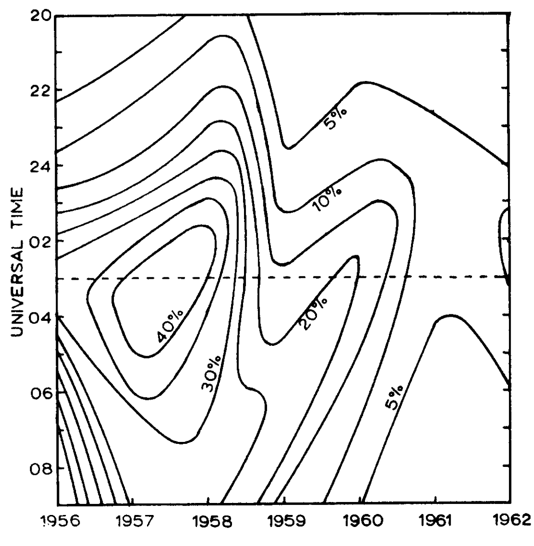

FIGURE 41

Occurrence of overhead aurorae.

b. *Diurnal variations of individual forms*

Tables XXXVIII, XXXIX and XL, and contour diagrams Figs. 42, 43 and 44, give the diurnal variations during each year from 1956 to 1962, for quiet arcs, rayed active forms, and diffuse surfaces, respectively.

Fig. 42 shows that there was a maximum occurrence of quiet arcs near local midnight in 1956. In 1957–58, however, a steep increase of frequency in the evening and a slower increase in the morning produced a bimodal distribution with a minimum near magnetic midnight. This minimum was perhaps caused by active forms taking the place of quiet arcs near magnetic midnight during the years of sunspot maximum. In 1959, the evening maximum occurred later, and the morning maximum only then reached its maximum value. After 1959, both morning and evening maxima fell steeply, and a smaller fall in

TABLE XXXVIII

DIURNAL FREQUENCY OF HOMOGENEOUS ARCS

Period (hr. U.T.)	19	20	21	22	23	24	01	02	03	04	05	06	07	08	09	10	1100
1956		5·8	11·3	10·3	22·2	33·8	42·4	41·0	41·0	33·4	31·6	32·4	32·8	21·4	13·6		
1957	17·7	35·8	35·2	55·8	51·1	60·0	63·2	44·0	40·0	37·0	47·6	44·7	51·5	37·7	39·5	50·0	
1958	64·3	80·0	60·5	70·6	63·4	68·4	65·5	48·5	47·0	42·7	46·0	48·5	55·0	65·4	36·4		
1959			18·0	28·0	42·0	54·0	52·0	68·0	67·0	54·0	42·0	64·0	67·0	72·0	53·0	53·0	52·0
1960			19·5	10·7	16·0	25·8	30·2	28·8	26·2	33·0	36·9	21·9	21·3	10·5	4·7	6·2	
1961		4·5	18·2	25·2	34·6	52·1	61·7	56·9	70·8	75·8	74·3	68·0	45·7	56·5	47·7	10·2	
1962	20·0	26·1	26·2	41·1	42·3	55·3	46·4	42·0	49·2	54·0	57·8	64·9	51·6	50·0	21·0	15·2	16·0

TABLE XXXIX

DIURNAL FREQUENCY OF ACTIVE FORMS

Period (hr. U.T.)	19	20	21	22	23	24	01	02	03	04	05	06	07	08	09	10	1100
1956	0	0·9	0·6	0·5	0·4	6·8	9·0	5·1	11·5	9·0	2·6	2·7	0	0	0		
1957	29·4	0	5·6	11·7	19·8	25·2	28·6	44·0	55·5	43·0	41·7	46·0	40·5	39·6	34·2	16·7	
1958	7·1	15·0	10·3	14·7	27·8	28·7	29·9	53·6	49·0	49·0	51·8	45·5	39·4	34·7	30·3	33·3	
1959*	16	6	6	10	10	13	32	26	30	35	30	22	17	25	16	14	
1960		0	8·3	8·7	8·9	12·0	17·5	15·2	15·1	12·5	8·7	1·4	5·3	9·3	1·6	0	
1961		0	0	0·9	0	7·7	15·0	15·6	9·2	14·7	12·9	9·4	12·0	4·3			
1962	3·2	4·3	3·3	2·1	6·1	8·9	13·6	11·6	15·2	15·8	14·1	7·3	5·1	5·5	0·7	1·2	4·0

* 1959 frequencies are those for clear dark and clear moonlit periods and include occurrences of homogeneous bands.

TABLE XL

DIURNAL FREQUENCY OF DIFFUSE SURFACES

Period (hr. U.T.)	19	20	21	22	23	24	01	02	03	04	05	06	07	08	09	10	1100
1956	0	0	0	0	1·4	1·4	2·6	8·9	8·9	15·4	10·5	4·1	6·2	3·6	0		
1957	0	0	0	0	0	0·9	2·1	5·4	4·4	9·5	4·8	2·6	9·4	5·7	21·0	27·8	
1958	0	0	0	2·3	1·1	0	0	1·0	11·0	11·5	6·4	9·0	12·5	13·5	30·2	55·6	
1959*	0	0	0	0	1	2	2	11	15	25	28	21	29	31	31	25	13
1960		0	0	0	0·9	4·7	6·6	13·6	23·0	26·8	37·9	38·6	33·0	41·9	23·4	18·8	
1961		15·9	9·1	8·1	9·8	6·0	10·0	13·8	16·7	13·8	22·0	23·8	34·8	40·6	35·4	51·0	14·3
1962	4·2	8·7	9·0	13·5	23·8	25·2	18·4	39·7	31·8	28·8	46·6	35·8	32·5	48·1	43·8	50·0	16·0

* 1959 frequencies are for clear dark and clear moonlit periods.

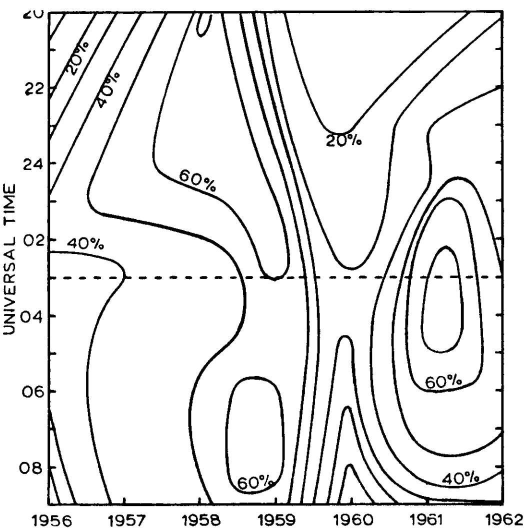

FIGURE 42

Occurrence of homogeneous arcs.

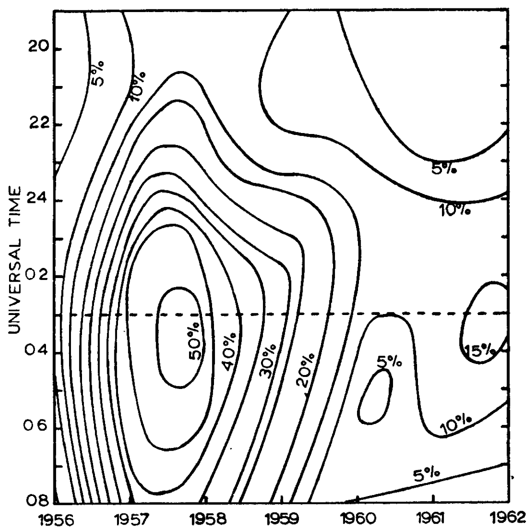

FIGURE 43

Occurrence of rayed active forms.

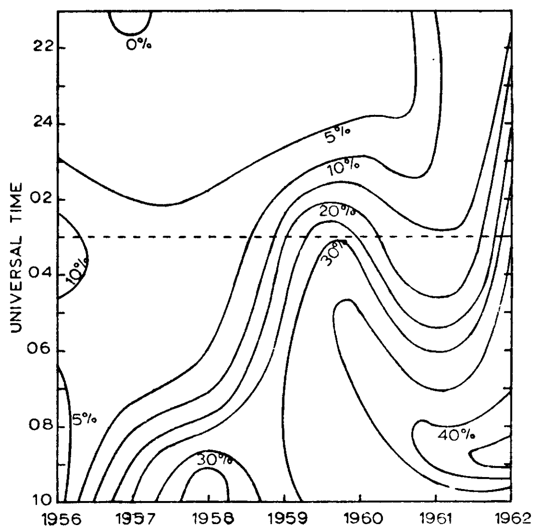

FIGURE 44

Occurrence of diffuse surfaces.

frequency near magnetic midnight left the maximum in 1960 at just after magnetic midnight. The maximum remained just after magnetic midnight throughout 1961, although there was a sudden increase in frequency.

Of the three separate groups of forms considered, the variations of the active forms, shown in Fig. 43, appear to be the most straightforward. A peak occurred in the distribution at about an hour after magnetic midnight in 1958, and this caused the maximum in the diurnal variation to move from about local midnight in 1956 to about 0400 U.T. in 1958, and then back to just before local midnight by 1960. In 1962, a slight increase in frequency at about magnetic midnight caused the maximum to return to magnetic midnight.

The maximum frequency of occurrence of diffuse surfaces at Halley Bay was near magnetic midnight in 1956, but in subsequent years as the frequency increased they became a late morning feature of the displays (see Fig. 44). These surfaces then began to appear at other times of the night, but the maximum frequency remained in the late morning although it changed from after 1000 U.T. in 1957 to about 0600 U.T. in 1960. In 1961 and 1962, the maximum was again between 0800 and 0900 U.T., and there was an increase in frequency in the evening.

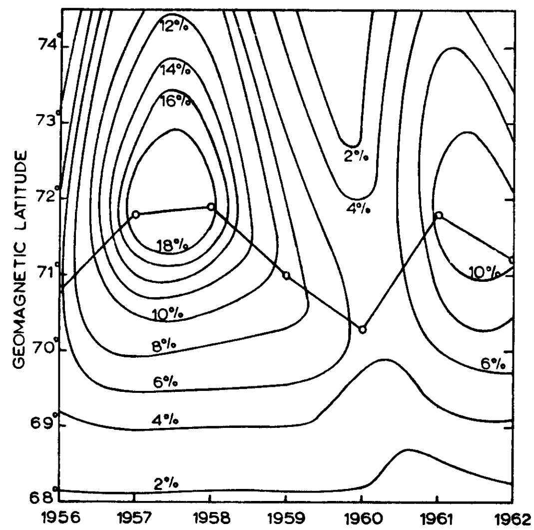

FIGURE 45

Geomagnetic latitude of homogeneous arcs.

4. POSITIONS OF QUIET ARCS

Table XLI gives the frequency of quiet arcs in each degree of geomagnetic latitude, expressed as a percentage of the total number of clear dark periods during each year. The contour diagram (Fig. 45), compiled from these figures, shows that the increase in the number of quiet arcs during sunspot maximum (1957 and 1958) and in 1961 and 1962, occurred mainly as a peak with its maximum at 72°S. geomagnetic latitude. This regional increase in frequency is a more likely explanation of the change of median position of arcs during these years (see Fig. 46a), than is the movement of the whole arc zone suggested by Sheret and Thomas (1961). To illustrate this point, the median positions of arcs, given in

TABLE XLI

GEOMAGNETIC LATITUDE OF HOMOGENEOUS ARCS

Φ (degrees)	1956	1957	1958	1959	1960	1961	1962
<66	1·4	0·8	0·2	1·7	0·2	0·7	0·7
66–67	1·3	0·7	0·2	0·2	0·2	0·4	0·0
67–68	1·6	0·9	0·8	0·3	0·4	0·8	0·2
68–69	1·4	2·3	3·1	1·8	2·6	1·1	2·2
69–70	4·0	4·3	5·5	5·4	4·0	3·9	4·6
70–71	6·5	12·4	9·8	10·5	6·3	9·5	9·2
71–72	4·5	14·0	13·0	9·4	4·0	8·2	10·5
72–73	4·0	28·2	29·6	9·2	3·9	15·3	12·6
73–74	0·9	8·5	8·7	1·8	1·0	5·5	2·5
74–75	0·1	2·9	1·6	2·6	0·1	4·1	2·5
>75	0·3	1·0	0·5	0·3		0·9	0·2

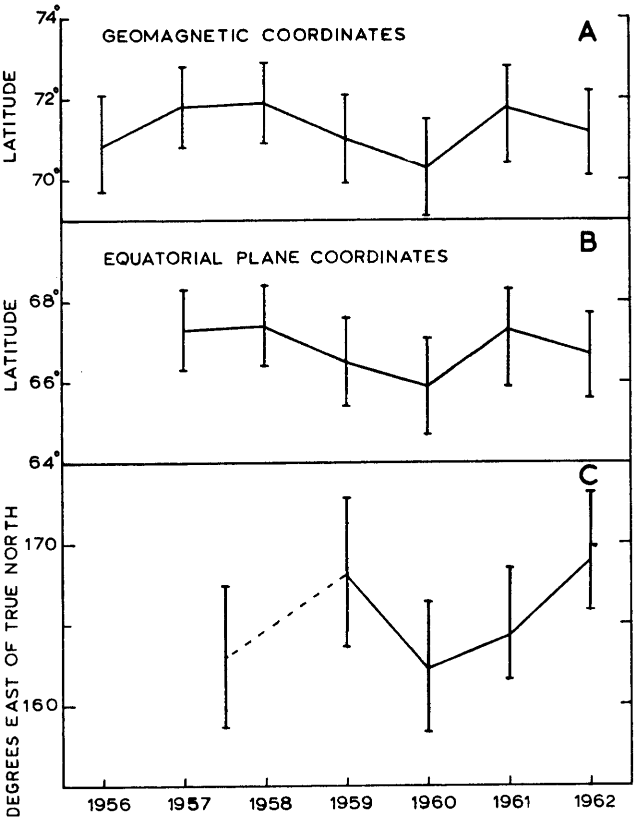

FIGURE 46
Position of centres of homogeneous arcs.

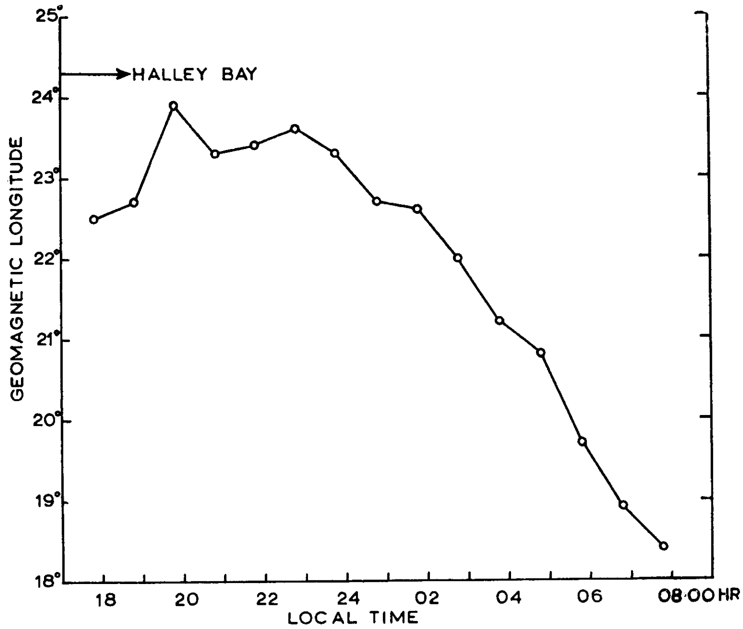

FIGURE 47
Diurnal variation of centres of homogeneous arcs (1956–62) in geomagnetic longitude.

Fig. 46a, have been plotted on the contour diagram of the frequency distribution (Fig. 45).

There appear to be, therefore, three separate groups of homogeneous arcs: the basic arc distribution, which is represented by the distribution in 1960, with its median position around 70·5°S. geomagnetic latitude; the evening and morning arcs which occur during sunspot maximum, with their maximum frequency of occurrence at about 72°S. geomagnetic latitude; and, finally, those appearing near magnetic midnight in 1961 and 1962, again with a maximum frequency at about 72°S. geomagnetic latitude.

Lassen (1963) has suggested that there is "a great concentration of aurora situated on 65° to 70° latitude" (equatorial plane coordinates), and further, that the "quiet arc zone", suggested by Evans and Thomas (1959), is included in this region of great concentration, although of course other forms besides quiet arcs occur in this region. Fig. 46b, which gives the median positions and interquartile ranges of quiet arcs for the years 1957–62 in equatorial plane coordinates, shows that well over 50 per cent of the quiet arcs seen from Halley Bay occur in the region from 65°S. to 70°S. In all years, except 1960, over 75 per cent of the arcs occur in this region.

The median positions and interquartile ranges of the centre bearings of quiet arcs are plotted in Fig. 46c. Unfortunately the data are insufficient to reveal any systematic changes over the years, particularly as no results are available for 1956 and those for 1957 and 1958 are grouped together. Moreover, the azimuth readings were rather approximate, especially in the years 1957–59.

5. QUIET-ARC ZONE ECCENTRIC IN LOCAL TIME COORDINATES

In this section all the quiet arcs, seen from Halley Bay in clear dark periods during the years 1956–62, inclusive, have been grouped together.

Evans and Thomas (1959) suggest that the quiet-arc zone is circular and centred at 2° of latitude from the geomagnetic pole along the 0200 local time meridian. If this is so, the centre bearings of quiet arcs will be expected to lie along the geomagnetic meridian of the observing station at 0200 local time. Fig. 47

gives the diurnal variation of the geomagnetic longitude position of the centres of quiet arcs for the years 1956 to 1962, and shows that throughout the whole night the centres of the arcs were west of 24·3°E., the geomagnetic meridian of Halley Bay. If, however, the centres are given in terms of Mayaud's (1960) equatorial plane coordinates (in which Halley Bay is at 61·9°S., 26·7°E.), their longitude positions are east of 26·7°E. before 0300 local time, and west of 26·7°E. after 0300 local time (Fig. 48b). This is consistent with the model suggested by Evans and Thomas.

Fig. 48a gives the diurnal variation in latitude of the centres of quiet arcs in equatorial plane coordinates, and the positions that would be expected from the model suggested by Evans and Thomas with the centre of the circle displaced 1° from the geomagnetic pole instead of 2°. Similarly, Fig. 48b shows the longitude of the centre of the arcs in equatorial plane coordinates, and the positions that would be expected from the eccentric circle model. Fig. 48a shows very good agreement between the actual results and the model, and agreement would be even closer if the auroral arc zone were assumed to be not circular but similar in shape to the theoretical curve suggested by Alfvén (1955), i.e. further away from the pole than the circular zone at 1800 local time, and much nearer at 0600 local time. The longitude positions in Fig. 48b show the correct trend, but the movements appear to be much greater than would be expected from the model. This may be due to the difficulty of measuring the azimuth accurately or may be because the arc zone is not strictly circular. There does not, however, appear to be any evidence of the discontinuity in the longitude position curve near 0600 local time predicted by Alfvén's theoretical curve.

In general, therefore, there is fair agreement with an eccentric circle model similar to that suggested by Evans and Thomas, but there is some indication that the circle should be replaced in the model by a curve similar in shape to Alfvén's theoretical curve.

Considering now the three arc zones suggested in the previous section, the diurnal variations of the median positions are plotted in Fig. 49. Fig. 49a gives diurnal variation of the basic zone which is based on the results from 1960; this was obtained by converting the results published in Blackie (1964) into

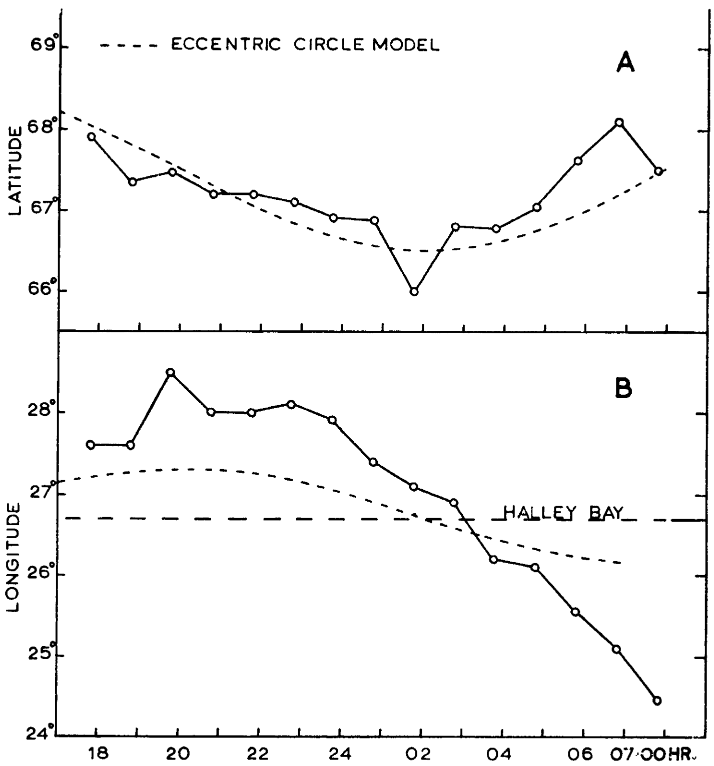

FIGURE 48

Diurnal variation of centres of homogeneous arcs (1956–62) in equatorial plane coordinates.

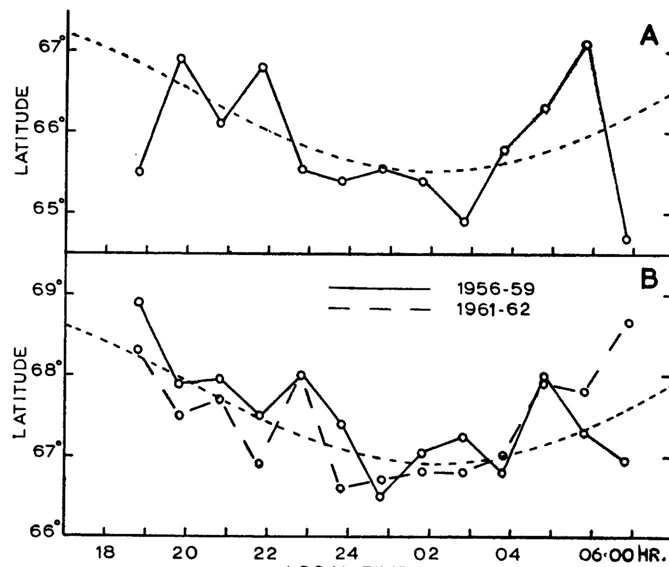

FIGURE 49

Diurnal variations of the three groups of homogeneous arcs.

equatorial plane coordinates. The same diagram gives the curve based on the eccentric circle model, and it can be seen that this shows quite good agreement with Blackie's observations.

The diurnal variations of the median position of quiet arcs, for the years 1956–59 and 1961–62, have been obtained by smoothing out the results and subtracting the arc distributions of the basic 1960 results (also smoothed out) and then adjusting the frequencies for the number of clear dark periods during each hour in 1960, in 1956–59 and 1961–62. The resulting median positions are plotted in Fig. 49b and agree well with the eccentric circle model which is also shown.

The eccentric circle models shown in Figs. 48 and 49 differ only in their radii. The eccentric circle for the 1960 basic arc zone (Fig. 49a) has a maximum co-latitude of 24·5°, and that for the other two periods (1956–59 and 1961–62) has a maximum co-latitude of 23·1°. Thus, for all the years except 1960, two arc zones are superimposed: one has a maximum co-latitude of 24·5° at 0200 local time and a maximum frequency of occurrence at about magnetic midnight; the other has a maximum co-latitude of 23·1° and maximum frequencies in the evening and morning during sunspot maximum, and near magnetic midnight in 1961 and 1962. As has been seen already, if all the arcs are taken together the distribution of the median positions fits an eccentric circle model with a maximum co-latitude of 23·5° at 0200 local time.

V. AURORAE IN GEOMAGNETIC LONGITUDE SECTOR 0°E. TO 120°E.

1. Introduction

In this section, aurorae seen from Halley Bay are compared with the few seen from island stations adjacent to the Antarctic Peninsula. There is also a comparison of the minimum latitude position of simultaneous aurorae in the two hemispheres, and a discussion of particular displays seen by aircraft and shipping near the points conjugate to Halley Bay in both geomagnetic and equatorial plane co-ordinates.

2. Aurorae Reported from the Vicinity of the Antarctic Peninsula

There were only three reports of aurorae from this area during 1961 and 1962, and all three occurred during the big magnetic storms referred to on p. 24. The first was from the Argentine Islands (geomagnetic 53·8°S., 3·3°E.) on 14/15 April 1961, and the other two were from the Argentine Islands and Deception Island (geomagnetic 51·6°S., 6·2°E.) on 30 September/1 October 1961. These stations are at a lower geomagnetic latitude than Halley Bay and, as their field of view is restricted by mountains to the south, aurorae seen from them in the southern sky would be those that appear low in the northern sky at Halley Bay.

It is interesting to compare the photographs and visual observations of the display at Halley Bay on *14/15 April 1961* (Plate I), with the aurora reported from the Argentine Islands. The actual time of commencement of the display at the Argentine Islands is not known, but it is was first observed at 2310 U.T. when there was a single ray in the south-east extending to 50° elevation. Rayed bands were reported to the west from Halley Bay at 2300, 2315 and 2320 U.T., and it is possible that the ray seen from the Argentine Islands was the upper part of one of these. If this is so, its position would be 69°48′S., 54°49′W. geographic, and its highest point at about 800 km. If the lower end of the ray is assumed to be at about the same distance from Halley Bay as its highest point, the lower border would be at a height of about 450 km. The sun was 16·5° below the horizon at 69°48′S., 54°49′W. at the time when the ray was seen, so that any aurora above about 275 km. would have been in sunlight. Thus, this ray may well have been the typical long high ray which occurs in sunlight (Störmer, 1955, p. 130).

At 2329 U.T. the Argentine Islands reported a rayed arc of brightness 4 and 15° elevation, with rays to 55° elevation and a red pulsating surface at 60° elevation. Plate I shows that this was the time when the aurora at Halley Bay was at its brightest and most active, and the visual observation for 2330 U.T. gives flaming and red coloration in rayed bands of brightness 4 which converged to a corona in the zenith.

At 2336 U.T. there was a homogeneous arc at 10° elevation from the Argentine Islands. This arc became rayed at 2345 U.T., and at 2347 U.T. a pulsating surface appeared in the south-south-west, extending to 60° elevation. This could well have been the northern extremity of the aurora seen from Halley Bay (Plate I), which decreased after 2335 U.T., but had increased again by 2345 U.T. Two rayed arcs were reported from the Argentine Islands at 0004 U.T., at 12° and 20° elevation. Although rayed arcs were seen from Halley Bay, they were only at 10° and 35° elevation (see Plate I), i.e. further south than over the Antarctic Peninsula. Plate I shows a kink in the two arcs at their western extremity, so it is possible that to the west of Halley Bay they were in a more northerly latitude. The aurora then faded at the Argentine Islands, leaving only an isolated ray to 30° elevation at 0020 U.T. By this time there was considerable cloud at Halley Bay and all-sky photography had been discontinued, but rays were seen overhead and to the north at 0015 U.T., and diffuse surfaces could be seen overhead at 0030 U.T.

The aurora reappeared at the Argentine Islands for a short time from 0301 to 0312 U.T., in the form of a rayed arc at 8° elevation with rays extending to 40° elevation. Unfortunately, there was still considerable cloud at Halley Bay, but at 0300 U.T. flaming rays could be seen converging to a corona in the zenith, and flaming was seen through the cloud at 0315 U.T.

The other two reports from the vicinity of the Antarctic Peninsula were of aurorae which occurred during the "great storm" of *30 September/1 October 1961*. The Argentine Islands station first reported an aurora at 0301 U.T., in the form of rays extending to 30° elevation as if there was a rayed arc or band just below the horizon, which at the Argentine Islands is at an elevation of about 8°. At Halley Bay there was a rayed arc of 135° elevation, and flaming rays converging to a corona in the zenith at 0300 U.T. If it is assumed that the arc seen at Halley Bay was in the same geomagnetic latitude as the arc or band which was just below the horizon (i.e. between 5° and 7° elevation) at the Argentine Islands, the height of the form would have been between 100 and 120 km. This is a reasonable figure.

By 0315 U.T. there were rays and diffuse surfaces at Halley Bay, and at 0330 U.T. flaming rays converged to a corona, but after this only interference rings were seen, in the north, and these became lost in the twilight at 0415 U.T. At the Argentine Islands a homogeneous band of 10° elevation was seen at 0315 U.T., and this was still visible at 0330 U.T., the display continuing until it was lost in the twilight at 0730 U.T.

At Deception Island the aurora was not seen until 0555 U.T., although it may have been present earlier, by which time the sky at Halley Bay was much too bright for displays to be seen. The display at Deception Island took the form of rays, extending to 50° elevation, which gradually faded until they were last seen at 0611 U.T. This agrees well with the Argentine Islands' report, i.e. an increase in activity at 0545 U.T., with rayed bands extending to 30° or 35° elevation until 0613 U.T., then decreasing activity to 0615 U.T., only a glow remaining at 0617 U.T.

3. MINIMUM LATITUDE OF AURORAE IN THE NORTHERN AND SOUTHERN HEMISPHERES

Table XLII compares the maximum elevation of the aurora at Halley Bay on any particular night, with the minimum geomagnetic latitude from which the aurora was reported, on the same night, from the sector of the Northern Hemisphere between 0°E. and 120°E. geomagnetic. It is confined to the periods

TABLE XLII

POSITIONS OF AURORAE IN NORTHERN AND SOUTHERN HEMISPHERES

Minimum Geomagnetic Latitude in N. Hemisphere	*Maximum Elevation at Halley Bay*				*Total*
	0–10	10–20	20–100	>100	
>70°	11	13	17	7	48
61°–70°	8	9	13	10	42
⩽60°	3	11	16	19	49
Total	22	33	48	36	139

during 1961 and 1962 when auroral observations were being carried out at Halley Bay (mid-March to the beginning of October), and also excludes the period 1 June to 12 July in each year when there are long hours of daylight in the Northern Hemisphere. Any doubtful observations from the Northern Hemisphere have been ignored, i.e. treated as though there were no aurorae visible below 71°N. geomagnetic.

On the hypothesis that there is no connection between the minimum latitude of the aurora in the Northern Hemisphere, and the maximum elevation of the aurora at Halley Bay, Table XLII gives a value of χ^2 of 10·85. This means, that for 6 degrees of freedom, the hypothesis can be rejected at the 10 per cent level, and thus suggests that there is some degree of agreement between the minimum latitude of the aurora in the two hemispheres.

4. Comparison of Particular Displays Reported from Geomagnetic Longitude Sector 15°E. to 35°E.

As most of the northern half of this sector is the western part of the North Atlantic, observations in this area are limited to those made by ships and aircraft, and the only fairly regular observations are those made by the U.S. weather ship at 56°31′N., 51°00′W. geographic. In geomagnetic coordinates this is 67·2°N., 26·1°W., which is not very far from the point theoretically conjugate to Halley Bay in geomagnetic coordinates (Halley Bay is 65·8°S., 24·3°E. geomagnetic). In equatorial plane coordinates (Mayaud, 1960), however, the point conjugate to Halley Bay is 61·3°N., 19·0°W. geomagnetic, which is some way south of the weather ship.

Comparison of the aurora seen at Halley Bay with that seen on an aircraft flight from London to Bermuda on *8/9 April 1961*, shows that there is close agreement between the two. The aircraft crossed geomagnetic longitudes 40°, 30° and 20°E. at a geomagnetic latitude of 65°N., thus passing very close to the point conjugate to Halley Bay in geomagnetic coordinates.

At 0100 and 0115 U.T. a faint diffuse surface was seen at Halley Bay, but nothing was reported by the aircraft at this time. This is not surprising, as the maximum intensity of this surface was 1 and the aircrew would be too pre-occupied to notice such a faint aurora, especially as the aircraft was more than 10° east of the Halley Bay meridian at this time. At 0130 U.T. nothing was seen at Halley Bay, but a homogeneous band at 10° elevation was reported by the aircraft which was still more than 10° east of the Halley Bay meridian. From 0145 to 0300 U.T., however, rayed forms were reported both at Halley Bay and by the aircraft. At 0300 U.T. a change from rayed forms to homogeneous arcs occurred in both places (the aircraft then being at 65°N., 20°E. geomagnetic), and in both there was gradual fading from 0330 U.T. to 0345 U.T. According to the aircraft report the arc had completely disappeared by 0400 U.T., and at Halley Bay, where there was by then complete cloud cover, no interference rings were seen.

On *14/15 April 1961* an aircraft, flying from New York to London, reported an aurora between 0045 and 0215 U.T. from positions between 61°N., 20°E. and 62°N., 30°E. geomagnetic, which is very near to the point conjugate to Halley Bay in equatorial plane co-ordinates.

The early part of this display at Halley Bay is described on p. 45, and although considerable cloud interfered with observation after 2400 U.T., the general picture appears to be the same as that seen by the aircraft. Both reported rayed bands to 15° elevation at 0045 U.T., although these were only to the east in the Northern Hemisphere and between cloud in the west at Halley Bay. It must be remembered, however, that because of the rapid west to east motion, the longitude of the aircraft at the time is not known exactly. At 0115 U.T. the aircraft reported rays converging to 80° elevation, and there were rays converging to a corona in the zenith at Halley Bay. No corona was seen after this at Halley Bay, but rays were seen until the sky became completely obscured by cloud at 0215 U.T. During this period the aircraft reported rays and rayed bands, with flaming starting at 0150 U.T. Flaming was first seen at Halley Bay at 0145 U.T.; it could still be seen when the cloud thinned at about 0300 U.T. and persisted until 0430 U.T., after which interference rings could be seen until 0700 U.T. The aircraft reported that flaming had stopped by 0230 U.T., but started again at 0300 U.T. and carried on until obscured by cloud at 0430 U.T. By 0300 U.T., however, the aircraft was at about 65°N., 40°E., i.e. some distance east of the point conjugate to Halley Bay.

Another aircraft flying from Montreal to Shannon, on the same night, also reported flaming aurora overhead between 0500 and 0700 U.T., from positions 57°N., 350°E., 65°N., 10°E., and 65°N., 30°E. geomagnetic.

Reports from aircraft flying from New York to London, on *8/9 May and 10/11 May 1961*, similarly show some agreement with the aurora seen from Halley Bay.

A rayed arc was reported from 61°N., 30°E. geomagnetic, between 0320 and 0335 U.T. on 8/9 May. At Halley Bay there had been a homogeneous arc from 0045 U.T., but at 0300 U.T. this became rayed, and returned to its quiet form at 0400 U.T. Thus, the rayed arcs occurred at about the same time in the Northern and Southern Hemispheres, and were in about the same latitude position in equatorial plane coordinates.

On 10/11 May the sky was completely obscured by cloud at Halley Bay, but interference rings were detected from 0230 until 0615 U.T. This timing agrees quite well with the report from the aircraft, of an aurora starting at 0300 U.T. in a position 58°N., 30°E. geomagnetic.

On *11/12 June 1961* there appears to have been a much larger auroral display in the Northern Hemisphere than in the Southern. The report from S.S. *Gardenia*, at 57°N., 20°E. geomagnetic, was as follows:

At 0340 U.T.: Rayed arc with rays to 90° elevation.
0430–0508 U.T.: Diffuse surfaces from 15° to 80° elevation.
At 0505 U.T.: Rayed bands of brightness 3–4 below 10° elevation.
0508–0511 U.T.: Rayed bands of brightness 3–4, and rays and diffuse surfaces to 90° elevation.

At Halley Bay, however, there was only a homogeneous arc at 0330 U.T., which persisted until 0530 U.T. At 0500 U.T. there were rayed bands below this arc, which was at 12° elevation, and diffuse surfaces appeared just above the arc at 0515 U.T. By 0545 U.T. the arc had completely broken up into rays and diffuse surfaces, extending to 20° elevation.

As the S.S. *Gardenia* was at a much lower geomagnetic latitude than Halley Bay, there appears to have been a much bigger display in the Northern Hemisphere than in the Southern Hemisphere as observed from Halley Bay.

20/21 June 1961 was another night on which the aurora was different in the two hemispheres, but this time it was much bigger in the Southern Hemisphere. At Halley Bay it was seen from 2145 U.T., and extended into the northern half of the sky from 0015 until 0430 U.T. (all-sky photographs, Plate II). In the Northern Hemisphere the U.S. weather ship U.S.C.G.C. *Barataria*, at 67°N., 26°E. geomagnetic, reported clear sky and no aurora at 2100, 2400 and 0300 U.T.

On *21/22 June 1961* there was a very large display at Halley Bay, but cloud interfered with observations throughout the night. In spite of the cloud, however, a pulsating arc was seen at 112° elevation at 0215 U.T. This arc became quiet and was overhead at 0230 U.T., and at 0330 U.T. was 45° above the northern horizon.

This arc, seen at Halley Bay, was probably equivalent to the homogeneous band rising to 90° elevation, which was reported by a German ship at 59°N., 30°E. geomagnetic, between 0200 and 0430 U.T. There is good agreement here in equatorial plane co-ordinates, as an arc which is overhead at 59°N. would appear at 45° above the southern horizon to an observer at 61·3°N., which is the point conjugate to Halley Bay in equatorial plane coordinates.

Again on *4/5 July 1961*, the aurora seen at Halley Bay was in fair agreement with that seen by an aircraft flying from New York to London via Gander. The aircraft report was as follows:

57°N., 10°E. geomagnetic — 0210 U.T.: Rayed arc of brightness 2 at 10° elevation.
60°N., 20°E. geomagnetic — 0225 U.T.: Rays of brightness 2 to the north-east.
60°N., 20°E. geomagnetic — 0230 U.T.: Rayed bands of brightness 2 to the north-east.
60°N., 20°E. geomagnetic — 0240 U.T.: Diffuse surfaces of brightness 1 to the north-east.
61°N., 30°E. geomagnetic — 0325 U.T.: Diffuse surfaces of brightness 1 to the north-east.
62°N., 40°E. geomagnetic — 0335 U.T.: Flaming in the north-east.

At Halley Bay there was considerable cloud all night, but a rayed arc at 26° elevation could be seen to the south-east at 0215 U.T. In equatorial plane coordinates, this was approximately the latitude of the arc seen at 0210 U.T. in the Northern Hemisphere. Multiple arcs were seen overhead at Halley Bay at 0230 U.T., and diffuse surfaces and rays converging to the zenith at 0245 U.T., the change to diffuse surfaces occurring at about the same time as in the Northern Hemisphere. At 0300 and 0315 U.T. there was a homogeneous arc overhead at Halley Bay, but diffuse surfaces were again seen at 0330 U.T. and flaming started between 0400 and 0415 U.T. This difference in the time of commencement of flaming in the two hemispheres may perhaps be attributed to the difference in geomagnetic longitude between Halley Bay and the aircraft, which was by then about 15° east of the Halley Bay meridian.

On *14/15 July 1961*, M.V. *Woodford*, at 58°N., 20°E. geomagnetic, reported a homogeneous arc at 15° elevation at 0300 and 0630 U.T., with a rayed arc and ray to 50° elevation at 0430 U.T. At Halley Bay interference rings were seen from 0215 U.T. onwards; at 0430 U.T. there were flaming rays overhead and a corona which, together with occasional diffuse surfaces, persisted until lost in the twilight. Therefore, on this occasion too, the timing of the aurora at the two stations was comparable. Moreover, a corona would probably appear as a rayed band or arc if viewed from a lower latitude.

On *16/17 July 1961* the display at Halley Bay rapidly developed from a glow at 2345 U.T., to a homogeneous arc at 0015 U.T., and a rayed arc at 21° elevation with diffuse surfaces to 10° elevation by 0115 U.T. Flaming had started by 0130 U.T., and rays and diffuse surfaces then extended to 90° elevation, with slight red coloration in the diffuse surfaces and the arc at 0145 U.T. Flaming ceased by 0200 U.T., and the aurora gradually became quieter until there were only diffuse surfaces to 15° elevation at 0300 U.T. Then, by 0315 U.T., the form had changed to a homogeneous arc of brightness 2 at 8° elevation; by 0430 U.T. diffuse surfaces had appeared above this arc, and by 0445 U.T. there were again flaming rays and diffuse surfaces.

S.S. *Beaverdell*, at 63°N., 20°E. geomagnetic, first reported a display at 0300 U.T. on 16/17 July, and this took the form of a homogeneous arc of brightness 3 at 25° elevation. By 0400 U.T. the arc had become rayed, and there was flaming to 120° above the northern horizon. Although there was a considerable difference in the time of the onset of flaming in the two hemispheres, the arcs which appeared in the Northern and Southern Hemispheres at 0300 and 0315 U.T., respectively, were in approximately the same latitude, if equatorial plane coordinates are used.

On the following night a display was reported by S.S. *Beaverdell*, then at 63°N., 30°E. geomagnetic, from 0300 to 0500 U.T., and by S.S. *Lakonia*, in about the same position, from 0130 to 0400 U.T. The U.S. weather ship, U.S.C.G.C. *Humboldt*, at 67°N., 26°E. geomagnetic, also reported a display at 0317 U.T. At Halley Bay, however, the sky was unfortunately completely obscured by cloud, but interference rings were detected from 2000 to 0700 U.T., thus indicating an occurrence of the aurora throughout the night.

A few days later, on *24/25 July 1961*, M.V. *Brisbane Star* reported a display, with rays and diffuse surfaces to 18° elevation, from as far south as 38°N., 20°E. geomagnetic. This was from 0715 to 0739 U.T., at which time there was complete cloud cover and moonlight at Halley Bay and nothing was seen. Earlier, between 0100 and 0215 U.T., rayed forms had been visible from Halley Bay even against the moonlit sky, and interference rings had been detected up until 0600 U.T., although there was complete cloud cover from 0445 U.T. onwards.

On *9/10 August 1961* there was a display at Halley Bay throughout the night from 2130 U.T. onwards. Although U.S.C.G.C. *Duane*, at 67°N., 26°E. geomagnetic, reported a rayed arc at 0300 U.T. (when there was a homogeneous arc at Halley Bay), she reported that the sky was clear and dark with no aurora at 0600 U.T.

The following night U.S.C.G.C. *Duane* made exactly the same auroral report, but this time there was better agreement with the Halley Bay observations. At Halley Bay, the sky was partially covered by cloud both at 0300 and 0600 U.T., but rays were seen converging to the zenith above Halley Bay at 0300 U.T.; nothing was seen at 0600 U.T.

On *26/27 August 1961* a rayed arc was seen at 20° elevation from Halley Bay at 2400 U.T., and no aurora was seen in a clear dark sky at 0300 U.T. On *29/30 August 1961*, at Halley Bay, there was a homogeneous arc overhead; diffuse surfaces extended to the northern horizon at 2400 U.T., and rayed bands and rays to the zenith at 0300 U.T. On both of these nights, the U.S.C.G.C. *Cambell* reported from 67°N., 26°E. geomagnetic that the sky was clear and dark with no aurora, so presumably there was a larger display in the Southern Hemisphere than in the Northern, particularly on 29/30 August.

A few days later, however, on *4/5 September 1961*, the U.S.C.G.C. *Cambell* reported diffuse surfaces from 40° to 80° elevation, between 0100 and 0220 U.T., and a rayed arc almost overhead at 0430 U.T. Although there was considerable cloud throughout the night at Halley Bay, auroral light was seen from 0045 to 0300 U.T. and again at 0430 U.T., the timing agreeing quite well with that of the aurora seen by the *Cambell*.

Two ships reported aurorae from this sector of the Northern Hemisphere on the night of *11/12 September 1961*: a French ship at 73°N., 30°E. geomagnetic from 0620 to 0705 U.T., and S.S. *Beaverdell* at 64°N., 30°E. geomagnetic from 0400 to 0500 U.T. The sky at Halley Bay was unfortunately completely cloud-covered all night, but interference rings were detected from 0500 to 0600 U.T.

An aircraft flying from Gander to Prestwick on *13/14 September 1961* made the following report:

60°N., 20°E. geomagnetic — 0147 U.T.: Homogeneous arc at 10° elevation.
61°N., 30°E. geomagnetic — 0245 U.T.: Homogeneous arc weaker.
61°N., 30°E. geomagnetic — 0315 U.T.: Glow.
61°N., 30°E. geomagnetic — 0330 U.T.: Glow getting brighter.
61°N., 40°E. geomagnetic — 0400 U.T.: Sky obscured by cloud.

This compares fairly well in pattern and position, in equatorial plane coordinates, with the aurora seen from Halley Bay. At 0145 and 0200 U.T. there was an arc at 7° or 8° elevation from Halley Bay, which became a glow by 0230 U.T. Nothing could be seen at 0300 U.T., but this could have been due to the cloud which had hampered observation all night, especially as interference rings were detected between 0430 and 0515 U.T.

On *16/17 September 1961* U.S.C.G.C. *Cook Inlet*, at 67°N., 26°E. geomagnetic, reported a homogeneous band of brightness 4 and 85° elevation at 0005 U.T. The latitude position of this, in equatorial plane co-ordinates, compares well with a homogeneous arc of brightness 0–1 and 3° elevation which was seen from Halley Bay at 0015 U.T. This arc remained at Halley Bay until 0430 U.T., and was sometimes as high as 19° and of brightness 2–3; on occasions it appeared as a double arc or a rayed arc. From 0330 to 0400 U.T. it was accompanied by diffuse surfaces in the south-east. At 0305 U.T., however, *Cook Inlet* reported only a glow on the horizon, when at Halley Bay the arc had reached 13° elevation.

Another ship, S.S. *Gardenia*, also reported an aurora from this sector of the Northern Hemisphere on 16/17 September, from a position near 62°N., 15°E. geomagnetic, which is quite close to the point conjugate to Halley Bay in equatorial plane co-ordinates, i.e. 61·3°N., 19·0°E. geomagnetic. The *Gardenia* reported a homogeneous arc from 0100 to 0200 U.T., a glow until 0400 U.T., a rayed arc and flaming diffuse surfaces between 0400 and 0410 U.T., and rayed bands and rays flaming to the zenith from 0410 to 0530 U.T. At 0545 U.T. only a homogeneous band remained, and this gradually faded to a glow by 0730 U.T. Plate III shows the homogeneous arc which was present for most of the night at Halley Bay, and also shows the break-up into flaming rays and diffuse surfaces which occurred between 0430 and 0445 U.T. Rays and diffuse surfaces which extended to the zenith, as did the rays in the Northern Hemisphere, were seen until 0500 U.T., after which they were lost in the twilight, leaving only interference rings. These interference rings became fainter and at 0530 U.T. were only seen low in the south, which indicates that the aurora at Halley Bay receded at about the same time as in the Northern Hemisphere. Other similarities include the increase in activity near 0400 U.T. and subsequent decrease at about 0530 U.T., but the display appears to have been greater in the Northern Hemisphere.

On *17/18 September 1961* a French ship, at 73°N., 30°E. geomagnetic, reported rayed aurorae overhead between 2100 and 0115 U.T., and then considerable cloud. At Halley Bay, the aurora commenced at 0015 U.T. with a homogeneous arc, rayed forms not being seen until 0230 U.T. The difference in the time of commencement may be explained by the fact that the French ship was more than 10° of latitude north of the point conjugate to Halley Bay, in equatorial plane coordinates, and 10° latitude is the approximate field of view for aurorae at 100 km. altitude.

A French ship, at 73°N., 30°E. geomagnetic, also reported a display from 2015 until 0130 on the night of the "great storm" of *30 September/1 October 1961*. This took the form of rayed bands, diffuse surfaces and rays converging to the zenith, sometimes covering the whole sky. At Halley Bay, twilight restricted observations to the few hours between 2320 and 0345 U.T., but within this period the aurora was exactly the same as that reported by the French ship. However, U.S.C.G.C. *Cook Inlet*, at 67°N., 30°E. geomagnetic, only reported a glow to the north at 0305 U.T., which suggests that in the Southern Hemisphere the aurora either extended nearer to the geomagnetic equator or continued longer.

On *23/24 March 1962* U.S.C.G.C. *Cook Inlet*, at 67°N., 26°E. geomagnetic, reported a homogeneous arc of brightness 1 and 45° elevation at 2400 and 0100 U.T., changing to brightness 2 and 30° elevation by 0200 U.T. This was followed by a glow of brightness 1 to 30° elevation at 0300 U.T., and then by

TABLE XLIII

REPORTS OF AURORAE IN NORTHERN HEMISPHERE ON 6/7 APRIL 1962

Source	*C.S. Lord Calvin*	*Aircraft over Gander*	*Aircraft from Montreal to Prestwick*	*U.S.C.G.C. Cook Inlet*
Position (Geomag.)	59°N., 30°E.	60°N., 20°E.	58°N., 30°E. to 65°N., 40°E.	67°N., 26°E.
Time (U.T.)				
2345				G, and R—north
0330			RB_s, R_s (2–3) to 15°	
0430		RB_s, FR_s (3–4) to 10°	↓	
0500		↓	↓	RA overhead
0530		↓	↓	
0545		↓	PRB_s (3) 10° to 90°	
0600	PHB 7° to 17°	↓	↓	
0606		↓	RB_s to 25°	
0700		↓	DAWN	

rays of brightness 2 extending to 45° elevation at 0400 U.T. At Halley Bay there was moonlight all night, but interference rings were detected from 0130 to 0245 U.T., which agrees well with the time of the brightest aurora in the Northern Hemisphere.

On *6/7 April 1962* aurorae were reported from four different sources near the point conjugate to Halley Bay. These are given in Table XLIII. Plate IV shows that although the display at Halley Bay was active at 2345 U.T., when there was a rayed arc at 13° elevation with rayed bands below, it did not extend very far above the southern horizon, nor was it particularly bright. Thus, this may have been similar to the display reported by *Cook Inlet* at 2345 U.T. Later during the night, cloud interfered with observation from Halley Bay, but auroral light was seen between the clouds below 20° elevation at 0330 U.T. and rays to 30° elevation at 0345 U.T. (cf. the aircraft report). This was followed at 0430 U.T. by a rayed arc at 29° elevation, and auroral light seen between the clouds at about 30° elevation from 0445 to 0515 U.T. This arc, which was seen from Halley Bay, was in about the same geomagnetic latitude as the rayed arc reported by *Cook Inlet* at 0500 U.T. Although there was considerable cloud at Halley Bay, auroral light was seen at about 30° elevation from 0445 to 0515 U.T. and interference rings were detected until 0700 U.T. (cf. the aurora seen by the aircraft until 0700 U.T.).

At Halley Bay aurorae occurred throughout the two nights *29/30 May and 30/31 May 1962.* On 29/30 May there were diffuse surfaces to 10° elevation at 0300 U.T., and on 30/31 May a homogeneous arc of 5° elevation at 0300 U.T. followed by a rayed arc of 6° elevation with diffuse surfaces to 13° elevation at 0600 U.T. Meanwhile, U.S.C.G.C. *Bibb,* at 67°N., 26°E. geomagnetic, reported that the sky was clear and dark with no aurora at 0300 U.T. on 29/30 May and at 0300 and 0600 U.T. on 30/31 May. The aurora seen from Halley Bay at 0300 U.T. on both nights was only of brightness 1, so that it is possible that a similar aurora in the Northern Hemisphere may have been missed by U.S.C.G.C. *Bibb.* However, at 0600 U.T. on 30/31 May the aurora at Halley Bay was of brightness 2–3, which indicates that there was definitely more auroral activity in the Southern Hemisphere.

There was also a disparity on *1/2 July 1962,* when U.S.C.G.C. *Coos Bay* reported from 67°N., 26°E. geomagnetic that the sky was clear and dark with no aurora at 0300 U.T. At Halley Bay there was a homogeneous arc at 0245 U.T., but by 0300 U.T. cloud covered the part of the sky where the arc had been seen, and no interference rings were detected.

On *24/25 July 1962* U.S.C.G.C. *Barataria*, at 67°N., 26°E. geomagnetic, reported a rayed arc at an elevation of 20° between 0100 and 0110 U.T. This agrees well, in form and timing, with the rayed arc and rayed bands which developed quickly at Halley Bay at 0055 U.T. and disappeared at 0110 U.T. (Plate V). At Halley Bay the elevation varied considerably but was about 20° from 0102 U.T., which is almost the same geomagnetic latitude as the position of the arc in the Northern Hemisphere. U.S.C.G.C. *Barataria* also reported a rayed arc of 70° elevation at 0315 U.T., but at Halley Bay all that could be seen was a homogeneous arc of 20° elevation.

On *7/8 August 1962* U.S.C.G.C. *Barataria* reported seeing a display from 0050 to 0445 U.T., and that it was overhead from 0050 to 0110 U.T. and again from 0240 to 0445 U.T. Unfortunately, the sky at Halley Bay was completely obscured by cloud throughout the whole of this particular night, but interference rings were detected between 0145 and 0300 U.T.

On *11/12 August 1962* U.S.C.G.C. *Barataria* reported that the sky was clear and dark with no aurora at 0130 and 0300 U.T. Similarly, no aurora was seen at Halley Bay, but there was very bright moonlight which could have completely obscured a faint aurora.

On *16/17 August 1962* U.S.C.G.C. *Coos Bay*, at 67°N., 26°E. geomagnetic, reported red surfaces and rays to 50° elevation from 0130 to 0215 U.T., and then clear dark sky with no aurora for the rest of the night.

At Halley Bay there was moonlight all night and thin cloud cover after 0130 U.T. The aurora was first seen there at 2145 U.T., and rayed forms appeared on and off until 0230 U.T. Interference rings were detected throughout this period and sometimes occurred in the northern part of the sky even when the sky was clear, which suggests that the aurora extended north of Halley Bay. At 0130 U.T. there was a rayed arc of brightness 2–3 and 15° elevation, which changed by 0200 U.T. to rayed bands of brightness 2–3 below 20° elevation. However, by 0230 U.T. the rayed bands were below 6° elevation, and after this there were only interference rings low in the south with one isolated ray to 20° elevation at 0315 U.T. There was, therefore, little similarity between the aurorae in the two hemispheres, except that both became quieter after 0215 U.T.

On *17/18 August 1962* U.S.C.G.C. *Coos Bay*, at 67°N., 26°E. geomagnetic, reported rays of brightness 2–3 from 30° to 80° elevation, and surfaces of brightness 3 to 40° elevation, from 0040 to 0115 U.T. Then, from 0600 to 0630 U.T., there was a violet homogeneous band of brightness 2 and 30°–50° elevation. On the same night M.V. *Redcar*, at 64°N., 30°E. geomagnetic, reported a rayed arc from 2300 to 2400 U.T.

At Halley Bay there was cloud and moonlight throughout the night, but interference rings were detected from 2200 to 2215 U.T., at 2300 U.T. and between 0445 and 0515 U.T. A homogeneous arc, of 10° elevation, was visible from 0530 to 0600 U.T., and was followed by interference rings until 0645 U.T. Assuming that the height of the aurora was 100 km., there was only about one degree of geomagnetic latitude difference between the position of the arc seen at Halley Bay from 0530 to 0600 U.T. and the position of the band seen by U.S.C.G.C. *Coos Bay* half an hour later. This was, however, the only similarity between the aurorae occurring in the two hemispheres on 17/18 August.

On *18/19 August* a homogeneous arc of 8° elevation was seen from Halley Bay at 2345 U.T. By 2400 U.T. this had changed into a rayed arc of 5·5° elevation, with rays extending to 45° elevation. Diffuse auroral light and rays were then seen between cloud until 0030 U.T. In the Northern Hemisphere M.V. *Redcar*, which was still at 64°N., 30°E. geomagnetic, reported a rayed arc with rays extending to 60° elevation from 0005 to 0015 U.T., i.e. at the time at which an arc was seen in the Southern Hemisphere.

On *21/22 August 1962* an aircraft flying from Gander to Prestwick, at 62°N., 30°E. geomagnetic at 0050 U.T. and 63°N., 40°E. geomagnetic at 0145 U.T., reported a rayed arc of 30° elevation with rays to 60° elevation from 0050 U.T. until 0145 U.T. At 0145 U.T. it changed to a homogeneous band of 10° to 15° elevation and a glow on the northern horizon. At the same time the S.S. *Birmingham City*, at 70°N., 30°E. geomagnetic, reported a double homogeneous arc from 20° to 80° elevation between 0050 and 0115 U.T. U.S.C.G.C. *Coos Bay* at 67°N., 26°E. geomagnetic, reported a homogeneous band overhead between 0449 and 0456 U.T.

Plate VI shows the aurora seen from Halley Bay during this period, and an extract from the visual observation data is given below:

0045 U.T.: Corona with rays converging to the zenith from the whole sky.
0100 U.T.: Diffuse rayed arc at 10° elevation, corona and rays converging to the zenith, and a diffuse surface on the northern horizon.

0115 U.T.: Rayed arc at 15° elevation, with corona and rays converging to the zenith. The northern limit is 135° elevation above the southern horizon. Rayed bands below the arc in the south.
0130 U.T.: Rayed arc at 20° elevation, corona with rays converging to the zenith.
0145 U.T.: Multiple arcs from 32° to 112° elevation.
0200 U.T.: Rayed arc at 49° elevation and multiple arcs overhead.

The break-up into rayed bands, rays and diffuse surfaces, which occurred between 0200 and 0210 U.T., is shown in Plate VI.

If a height of 100 km. is assumed, the rayed arc seen by the aircraft in the Northern Hemisphere was in about geomagnetic latitude 64°N., and the rayed arc seen from Halley Bay varied from about 70°S. to 68° geomagnetic. However, as the point conjugate to Halley Bay in equatorial plane co-ordinates is 61·3°N., the latitude positions of these arcs are comparable if equatorial plane co-ordinates are used. The change from rayed forms to more homogeneous forms occurred at about the same time in the two hemispheres. It is almost as if the aurora then became dependent on geomagnetic latitude rather than equatorial plane coordinates for, if a height of 100 km. is again assumed, the homogeneous band seen by the aircraft at 0145 U.T. was in about the same geomagnetic latitude as the multiple arcs seen from Halley Bay.

At Halley Bay, the aurora remained very active throughout the night. No observations were made at the exact time at which the homogeneous band was seen by *Coos Bay*, but those of 0445 and 0500 U.T. both record rayed bands and diffuse surfaces below 30° elevation in the south.

On *22/23 August 1962* the U.S.C.G.C. *Coos Bay*, still at 67°N., 26°E. geomagnetic, reported a clear sky with no aurora at 2400 U.T., but a homogeneous arc of 15° elevation at 0600 U.T. The aurora at Halley Bay apparently did not resemble that seen by the *Coos Bay* for, although there was cloud, auroral light was seen from 2030 to 0030 U.T., and then interference rings were detected up until 0300 U.T. Observations were continued until 0730 U.T., but there was no sign of any further aurora.

On *24/25 August 1962* U.S.C.G.C. *Coos Bay* again reported a display, and although there was cloud at Halley Bay it was possible to see that the general pattern of the display was the same in the two hemispheres.

At Halley Bay there was a glow at 2030 U.T. which became a homogeneous arc by 2145 U.T., but from 2200 U.T. cloud obscured part of the sky and made it difficult to identify the auroral forms. A rayed arc of 9° elevation was seen at 0015 U.T., and then auroral light behind cloud (below 20° elevation) and rays to 50° elevation at 0030 U.T. At 0045 U.T., the aurora in the southern sky was the same as that at 0030 U.T., but there was a homogeneous arc at 60° elevation above the northern horizon.

The *Coos Bay* reported a homogeneous band of 20° elevation from 0015 to 0025 U.T., and rays, from 10° to 80° elevation between 0035 and 0046 U.T. There was a homogeneous band of 80° elevation at 0250 U.T., and this broke up at about 0253 U.T. into diffuse surfaces extending to 45° elevation. At Halley Bay there was a homogeneous arc of 13° elevation at 0245 U.T., and by 0300 U.T. there were diffuse surfaces to 35° elevation and auroral light behind cloud below 10° elevation. The band seen in the Northern Hemisphere is about half-way between the points conjugate to the position of the arc seen from Halley Bay in geomagnetic and equatorial plane coordinates, and break-up occurred at about the same time in the two hemispheres. At 0347 U.T., *Coos Bay* reported diffuse surfaces covering 7/10ths of the sky. At Halley Bay at 0345 U.T., there was only auroral light below 15° elevation, but by 0400 U.T. there were flaming diffuse surfaces extending to 30° elevation. Thus, again, there was some similarity between the aurorae seen in the two hemispheres.

On eight consecutive nights, from *28/29 August* to *4/5 September 1962*, auroral reports were received from the Yacht *Mischief*, sailing between 76°N. and 72°N. geomagnetic. Even though the yacht was at a much higher geomagnetic latitude than Halley Bay, it is interesting to compare the aurorae.

On *28/29 August 1962* the yacht, which was at 76°N., 20°E. geomagnetic, reported a glow to the south from 0115 to 0130 U.T., and diffuse rays in the south from 0215 to 0345 U.T. and again from 0430 to 0445 U.T. From 0500 to 0615 U.T. there was a red and green glow in the south which reached the zenith at 0600 and 0615 U.T. In timing, this aurora agrees very well with that seen from Halley Bay, and the poleward recession occurred at the same time in the two hemispheres, i.e. between 0545 and 0600 U.T.

At Halley Bay the sky was clear and dark, with no aurora until 0030 U.T. At 0030 U.T. there was a little cloud low in the south, and by 0045 U.T. auroral light could be seen through breaks in this cloud. The auroral light had increased slightly in brightness and elevation by 0130 U.T., and then remained more or less the same until 0515 U.T. By 0530 U.T. diffuse surfaces could be seen extending above the bank of cloud to 35° elevation, and at 0545 U.T. flaming diffuse surfaces and rays extended to the zenith. At 0600 and 0615 U.T. there was only auroral light below 20° elevation. At 0630 U.T. there was only auroral light below 20° elevation. At 0630 U.T. only interference rings could be seen in the cloud, and these disappeared by 0645 U.T.

On the following night, *29/30 August 1962*, the Yacht *Mischief* was at 75°N., 30°E. geomagnetic and reported rayed forms in the south from 0100 to 0530 U.T., with rays sometimes extending to 90° elevation after 0400 U.T. On the same night U.S.C.G.C. *Coos Bay*, at 67°N., 26°E. geomagnetic, reported an arc at 80° elevation from 2355 to 0130 U.T., and then auroral light between cloud for the rest of the night.

At Halley Bay there was cloud until 0415 U.T., and the sky was completely obscured from 2300 to 0245 U.T. However, auroral light was seen whenever there was a break in the cloud, and interference rings were detected through the complete cloud cover from 2300 to 0015 U.T. The cloud cleared at 0430 U.T. and revealed a homogeneous arc of 10° elevation which eventually broke up into diffuse surfaces between 0530 and 0545 U.T., diffuse surfaces first appearing above the arc at about 0530 U.T. By 0545 U.T., there was flaming to 30° elevation. No aurora was seen after 0545 U.T., but interference rings were detected in the twilight until 0645 U.T.

Thus, there was a moderately active aurora in both hemispheres, but no detailed comparisons are possible because of the weather conditions.

On *30/31 August 1962* M.V. *Bamburgh Castle*, at 65°N., 40°E. geomagnetic, reported auroral light between cloud at 10° to 20° elevation at 0025 U.T. A homogeneous arc was seen almost overhead at 0045 U.T., and from 0150 U.T. rays and rayed bands, with flaming, covered 5/8ths of the sky. The aurora continued in this form until 0305 U.T., by which time there were a corona and rayed bands in the southern sky. From 0335 U.T. there was a "magnificent display" which finally ended with diffuse surfaces at 0440 U.T. Meanwhile, the Yacht *Mischief*, at 75°N., 20°E. geomagnetic, first reported a glow on the southern horizon at 0045 U.T. This persisted until 0115 and 0130 U.T., when rays were seen extending from the south to the northern sky. From 0145 to 0245 U.T. diffuse rays converged to the zenith from the east and west. At 0400 U.T. rays of brightness 2 covered the whole sky; these changed to a homogeneous band by 0515 U.T. and broke up again into rays, this time in the south-west, at about 0540 U.T.

At Halley Bay (Plate VI) cloud hampered observation until 0500 U.T., but interference rings were detected at 2345 U.T., and by 0045 U.T. auroral light could be seen below 10° elevation. The first definite form was a diffuse arc of 20° elevation at 0230 U.T. By 0245 U.T. this had broken up into three groups of rays and diffuse surfaces, which became brighter by 0250 U.T. and formed multiple arcs by 0255 U.T. (Plate VI). By 0300 U.T. there were multiple arcs from 90° to 135° elevation, and rayed bands just to the south of this. Flaming was seen in the rays and diffuse surfaces which extended to 90° elevation at 0315 U.T., and by 0330 U.T. the multiple arcs had disappeared. The aurora still extended to the zenith at 0330 U.T., but by 0335 U.T. all that remained was auroral light in the cloud below 25° elevation. This continued until 0515 U.T., by which time the cloud had cleared and the aurora had become much more active, with a rayed arc of brightness 3–4 at 45° elevation and diffuse surfaces to 90° elevation. As can be seen from Plate VI, this arc moved northwards, and then at 0530 U.T. began to break up into diffuse surfaces. By 0540 U.T. an arc had formed again in the south, and was accompanied by flaming rays and diffuse surfaces. The whole aurora then became much fainter, but rays could still be seen in the zenith at 0600 U.T.

Although at Halley Bay the display was quite active, it seems to have been far bigger in the Northern Hemisphere, particularly between 0335 and 0440 U.T. However, a break-up into diffuse forms occurred at about 0530 U.T. in both hemispheres.

On *31 August/1 September 1962* M.V. *Bamburgh Castle*, U.S.C.G.C. *Coos Bay* and the Yacht *Mischief*, all reported a display from the part of the Northern Hemisphere conjugate to Halley Bay, but it was less active than during the previous night. *Bamburgh Castle* at 64°N., 30°E. geomagnetic, reported a diffuse surface from 2400 to 0615 U.T. *Coos Bay*, in her usual position at 67°N., 26°E. geomagnetic, reported surfaces to 25° in the north-north-west at 0100 U.T. and a homogeneous arc of 30° elevation to the north-west at 0300 U.T. *Mischief* reported a glow behind cloud to the south-west at 0200 U.T., and a glow from 0400 to 0600 U.T., with one isolated ray to the zenith at 0400 U.T.

At Halley Bay auroral light was seen between cloud low in the south from 2330 to 0145 U.T. By 0200 U.T. there was a glow to 15° elevation, with an isolated ray to 32° elevation. The glow remained until 0400 U.T., by which time it was only just above the horizon. Then cloud again interfered with the observations, and only auroral light could be seen until a homogeneous arc was observed at 0500 U.T. This arc was at about 10° elevation where it remained until last seen at 0615 U.T., diffuse surfaces appearing above it at about 0600 U.T. This very quiet aurora at Halley Bay is in agreement with the aurora seen by the three ships in the Northern Hemisphere, in that it consisted of quiet forms and first appeared at about the same time.

On *1/2 September 1962* the Yacht *Mischief* and U.S.C.G.C. *Coos Bay* again reported a display. *Coos Bay* reported a homogeneous arc which appeared at 60° elevation and brightness 2–3 at 2320 U.T., receded to 30° by 2325 U.T., and remained at this elevation until last seen at 0100 U.T. Another homogeneous arc, this time of 90° elevation and brightness 1, appeared at 0146 U.T. and remained until 0155 U.T. *Mischief*, which was by then at 72°N., 30°E. geomagnetic, did not report a display until 2400 U.T., when there were glows to the east and the west. These persisted until 0200 U.T., with rays to the zenith from the south-west during the last 10 min. The next report from *Mischief* was of diffuse surfaces in the west from 0230 U.T. to 0300 U.T., and then a glow in the north from 0410 to 0500 U.T.

At Halley Bay the aurora started at 2045 U.T. as a rayed arc of 4·5° elevation, and then alternated between diffuse surfaces and a homogeneous arc. At 2315 U.T. there was an arc of 4·5° elevation with one ray in the east and diffuse surfaces to 13° elevation. A homogeneous arc then alternated with diffuse surfaces, until it finally broke up into diffuse surfaces sometime between 0300 and 0400 U.T. The exact time of break-up is not known because after 0300 U.T. part of the sky was obscured by cloud. Diffuse surfaces and rays were seen until 0630 U.T., by which time they extended to 90° elevation, and flaming was seen at 0445, 0530, 0615 and 0630 U.T. Twilight then hampered observation, but interference rings were detected until 0715 U.T.

The arcs seen from Halley Bay were in about the same latitude as those seen from U.S.C.G.C. *Coos Bay*, if they are given in terms of equatorial plane coordinates, but the display appears to have been more active in the Southern Hemisphere.

On *2/3 September 1962* the Yacht *Mischief*, which was still at 72°N., 30°E. geomagnetic, reported a glow to the south through fog between 2400 and 0215 U.T. At Halley Bay there was a moderate display throughout the night, which extended towards the equator after 0145 U.T. The lack of observations from the yacht after 0215 U.T. may perhaps be explained by a comparable equatorward movement in the Northern Hemisphere, subsequent activity being beyond the yacht's range of visibility.

On the following night, *3/4 September 1962*, there was cloud at Halley Bay, but auroral light was seen between the cloud throughout the night. Two reports of aurorae came from near the conjugate point in the Northern Hemisphere: one from the Yacht *Mischief* which reported a display from 2400 to 0140 U.T., and the other from an aircraft flying from New York to London which reported a display between 0025 and 0355 U.T.

By *4/5 September 1962* the Yacht *Mischief* was at 70°N., 30°E. geomagnetic, and reported diffuse surfaces to 90° elevation from 0200 until 0330 U.T. Halley Bay had a homogeneous arc before 0200 U.T., but this changed to diffuse surfaces at 0200 U.T., the arc re-forming at 0245 and 0300 U.T. After this diffuse surfaces persisted until they were finally lost in the twilight at 0615 U.T.

On *9/10 September 1962* there were three reports of displays from the conjugate sector of the Northern Hemisphere, between geomagnetic longitudes 15°E. and 35°E. The first report was from an aircraft flying between 60°N., 20°E. geomagnetic and 62°N., 40°E. geomagnetic, *en route* from Gander to Shannon, which observed a homogeneous arc of 25° elevation from 0230 U.T. This changed to a glow by 0315 U.T., then to a homogeneous arc with one ray in the west and flaming in the east at 0330 U.T. By 0345 U.T. there was a rayed arc at 15° elevation and flaming rays to 45° elevation from the east. By 0415 U.T. this had faded to a glow which was eventually lost in the twilight just after 0430 U.T.

The second report from the Northern Hemisphere was from U.S.C.G.C. *Cook Inlet* at 67°N., 26°E. geomagnetic, which observed an aurora extending to 45° elevation behind cloud at 0305 U.T.

At Halley Bay rayed arcs which were seen from 0215 U.T., became homogeneous at 0315 U.T., and then broke up into flaming rays and diffuse surfaces by 0330 U.T. Although these changed back to a rayed arc of 17° elevation by 0345 U.T., flaming rays and diffuse surfaces occurred again at 0400 U.T. There had been moonlight all night at Halley Bay, and by 0430 U.T. the aurora had faded so that it was only detectable as interference rings. Although the forms were not exactly the same in the two hemispheres, the onset of flaming occurred at about the same time, as did the general reduction in activity. Also the rayed arcs, seen at 0345 U.T. both from the aircraft and from Halley Bay, were at the same latitude position in equatorial plane coordinates.

Also in the Northern Hemisphere, a French ship at 63°N., 30°E. geomagnetic, reported a diffuse surface at 0515 U.T. This changed to diffuse rays by 0530 U.T., and to diffuse surfaces by 0535 U.T. At 0545 U.T. there was an isolated ray of brightness 4 in the north-east, and by 0550 U.T. a homogeneous arc of 20° elevation had also appeared. At 0600 U.T. there was an isolated ray in the west, and by 0610 U.T. a homogeneous band overhead. This broke up at 0612 U.T., leaving diffuse rays for about a minute, and then the aurora disappeared altogether. Meanwhile, at Halley Bay, interference rings were seen until 0530 U.T., when a diffuse arc appeared at about 15° elevation. This arc had become a normal homogeneous arc of 27° elevation by 0600 U.T., and a rayed arc of 22° elevation by 0615 U.T. The last report from Halley Bay was of interference rings seen in the twilight at 0630 U.T. Therefore, once again, the level of activity in the two hemispheres seemed to be comparable and, if equatorial plane coordinates are used, the band seen overhead by the French ship at 0610 U.T. was in about the same latitude position as the arc seen from Halley Bay at 0615 U.T.

The aurorae seen in this sector of the Northern and Southern Hemispheres on *21/22 September 1962* again showed some similarity, flaming apparently commencing at 0230 U.T. in both hemispheres.

An aircraft flying from Montreal to London reported an aurora from 62°N., 10°E. to 63°N., 20°E. geomagnetic, between 0130 and 0305 U.T. At 0130 U.T. there was a rayed arc of 5° elevation with rays to 20° elevation, then at 0230 U.T. there were rayed bands and flaming rays to 50° elevation, sometimes reaching 90° elevation before eventually disappearing in the moonlight by 0305 U.T.

At Halley Bay there was drifting snow all night, but auroral light was seen to 30° elevation at 0230 U.T. This was followed by flaming diffuse surfaces to 90° elevation at 0245 U.T., and flaming rays and diffuse surfaces to 90° at 0300 and 0315 U.T. After 0315 U.T. only interference rings were seen, and these were lost in the twilight after 0430 U.T.

On *23/24 September 1962* M.V. *Aldersgate*, sailing near 62°N., 20°E. geomagnetic, reported an aurora from 0030 to 0500 U.T. At 0030 U.T. there was a glow below 5° elevation, then a glow to 15° elevation from 0200 to 0310 U.T., with rays to 20° elevation between 0300 and 0310 U.T. At 0330 U.T. there was a homogeneous arc of 8° elevation, which became a glow by 0400 U.T. and gradually faded and was last seen at 0500 U.T.

At Halley Bay there was twilight for much of the night, but interference rings were detected at 2145 U.T. and persisted until 0015 U.T. A homogeneous arc of 3·5° elevation appeared at 2400 U.T., and a rayed arc of 3·5° elevation at 0100 U.T., but nothing else was seen until interference rings re-appeared at 0145 U.T. At 0215 U.T. a homogeneous arc of 9° elevation appeared. This changed to a rayed arc of 10° elevation by 0230 U.T., and broke up into diffuse surfaces by 0245 U.T. After 0245 U.T. only interference rings were seen, and these disappeared in the twilight at 0430 U.T. Thus, once again, the level of auroral activity seems to have been comparable in the two hemispheres, even though the forms were not exactly the same.

On *27/28 September 1962* U.S.C.G.C. *Cambell*, at 67°N., 26°E. geomagnetic, reported an aurora between 2340 and 0250 U.T. This aurora reached its maximum brightness and elevation at 0250 U.T., when flaming rays of brightness 3 and 45° elevation were seen. There was cloud all night at Halley Bay, but interference rings were detected at 0230 and 0245 U.T. at about the time when the aurora seen by the *Cambell* was most active.

On *28/29 September 1962* U.S.C.G.C. *Cambell* reported a glow to 45° elevation at 2325 U.T. Unfortunately, twilight prevented observations at Halley Bay until 2345 U.T., but interference rings were seen at 2345 and 2400 U.T.

On *29/30 September 1962* twilight again restricted observations at Halley Bay and it was very difficult to identify particular forms, but interference rings indicated that there was an auroral display at least from 2315 to 0430 U.T. The particular forms that were seen were as follows:

0030 U.T.: Rays converging to the zenith.
0130 U.T.: Rayed arc of 28° elevation.
0145 U.T.: Rays converging to the zenith.
0200 U.T.: Again rays to the zenith, and flaming.

S.S. *Alsatia* at 63°N., 20°E. geomagnetic, reported diffuse rays below 9° elevation, sometimes extending to 25° elevation, from 0030 to 0430 U.T. which agrees well in timing with the aurora seen from Halley Bay. Forms, similar to those seen from Halley Bay, were reported in detail by a French ship at 65°N., 20°E. geomagnetic. They were as follows:

2300 U.T.: Rayed band below 15° elevation in the west.
2315 U.T.: Diffuse surface to 25° elevation.
2330 U.T.: Isolated ray.
2345 U.T.: Rays and rayed bands to 20° elevation.
0030 U.T.: Rayed bands in the north-east.
0100 U.T.: Three diffuse rays near the horizon.
0120 U.T.: Diffuse glow on the horizon.
0130 U.T.: Rayed band to 5° elevation and a ray to the north-east.
0145 U.T.: Diffuse rays.
0300 U.T.: Flaming rays to the north-east with pink and green coloration.
0425 U.T.: Homogeneous band of brightness 3 and 60° elevation.
0455–0515 U.T.: Rays of brightness 2, and a glow.

On the night of *30 September/1 October 1962* M.V. *Bamburgh Castle*, at 63°N., 20°E. geomagnetic, reported an aurora of brightness 4 throughout the hours of darkness. U.S.C.G.C. *Cambell*, however, reported that there was an aurora between 2340 and 0050 U.T., and rayed bands of brightness 4 in the zenith from 0730 to 0750 U.T., but that the sky was clear and dark with no aurora at 0300, 0400, 0500 and 0600 U.T. *Cambell* was in her usual position of 67°N., 26°E. geomagnetic, so that the difference in these two reports is quite surprising.

The sky at Halley Bay was clear but twilit all night, and only faint interference rings were seen from 0100 to 0200 U.T., which agrees more with *Cambell's* observations than those of *Bamburgh Castle*.

On *5/6 October 1962* a rayed arc of about 12° elevation was seen from Halley Bay at 0120 and 0200 U.T., and there were interference rings from 0120 until 0215 U.T.

In the Northern Hemisphere U.S.C.G.C. *Cambell* reported a glow at 2300 U.T., a rayed arc of 55° elevation at 0045 U.T., and a homogeneous band at 40° elevation with diffuse surfaces to the east at 0155 U.T. A French ship, at 58°N., 20°E. geomagnetic, reported a diffuse glow below 10° elevation at 0125 U.T., a homogeneous arc at 0127 U.T., then a rayed arc at 0130 U.T. The arc changed back to a glow by 0145 U.T., but the rayed arc reappeared at 0205 U.T. and was followed by flaming rays of brightness 2 at 0225 U.T. The times of occurrence of the forms seen by the French ship again show similarity with the sequence of events at Halley Bay. However, S.S. *Bristol City*, at 59°N., 30°E. geomagnetic, only reported a glow below 12° elevation from 0200 to 0230 U.T., but this difference may perhaps be due to the difference in geomagnetic longitude.

On *7/8 October 1962* M.V. *Huntingdon*, at 60°N., 10°E. geomagnetic, reported a glow and a homogeneous band in a moonlit sky from 2400 to 0020 U.T.

At Halley Bay there was moonlight all night, but rays were seen to 35° elevation at 0036 U.T. and interference rings until 0215 U.T.

5. Summary of Comparison Between Aurorae Seen in the Northern and Southern Hemispheres

The preceding survey shows that the general level of auroral activity was usually about the same in the two hemispheres, but that it was occasionally significantly different. Comparison of local magnetic *K*-indices for Halley Bay and Lerwick (in the Northern Hemisphere), on the nights when there was considerable difference in auroral activity between the two hemispheres, shows that there was no parallel difference in magnetic activity. On all of these nights the local *K*-indices for Halley Bay and Lerwick always showed the same trends, if not exactly the same numerical values.

The survey also shows that identical auroral forms occur frequently at points which are conjugate in equatorial plane coordinates, and occasionally at points which are conjugate in geomagnetic coordinates. There is also some indication that, in displays in the same geomagnetic longitude, both the break-up into rays and diffuse surfaces and the onset of flaming occur simultaneously in the two hemispheres.

VI. RADIO ECHO OBSERVATION OF THE AURORA

Radio methods were used to study the aurora at Halley Bay during 1962. The equipment was run by J. S. Marsden of Sheffield University, and operated at a frequency near to 70 mc./sec. The aerials used were 3 rhombics orientated roughly south-east, south and south-west. The equipment ran continuously and was switched to each of these aerials in turn, for 4 min. on each aerial.

So far only preliminary results are available, but these appear to be very encouraging. The percentage frequency of occurrence of radio echoes for each hour is given in Fig. 50. In plotting this graph, echoes received during any particular hour have only been counted as indicating the occurrence of the aurora if the equipment was running for a total of more than 30 min. during that hour. In order to get a picture which can be correlated with visual observations only the following hours have been included:

March	2200–0500 U.T.
April	2000–0700 U.T.
May	1900–1000 U.T.
June	1900–1000 U.T.
July	1900–1000 U.T.
August	1900–0800 U.T.
September	2100–0500 U.T.

Comparison of the diurnal variation of radio echoes, given in Fig. 50, with the diurnal variations of the various auroral forms given on p. 39–41, shows that the radio echoes have the same kind of bimodal distribution as the homogeneous arcs seen during 1962. The homogeneous arcs which occurred between 3° and 10° elevation in clear dark periods are plotted in Fig. 50, for comparison, and show remarkable agreement, except perhaps between 0400 and 0900 U.T. This suggests that they were largely responsible for the echoes received by the Halley Bay equipment.

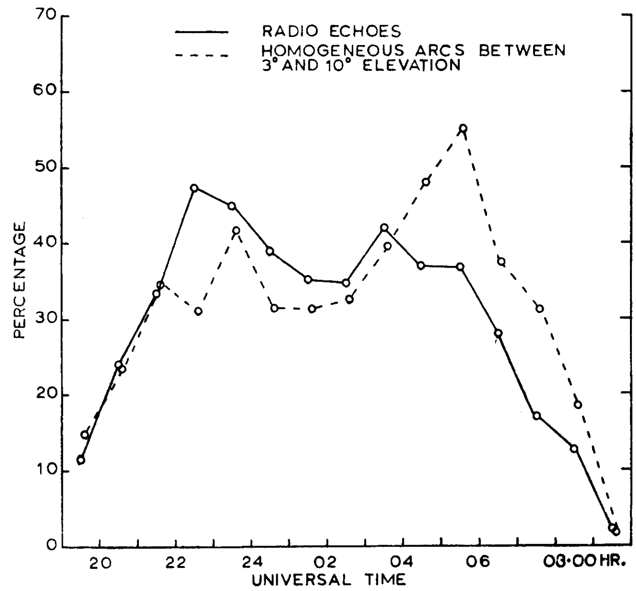

FIGURE 50

Diurnal variation of radio echoes of aurorae.

Marsden (private communication) considers it likely that detailed analysis of the radio echo results will reveal an increase in the percentage frequency between 0400 and 0900 U.T. There may be better agreement between the visual and radio echo results if the radio echo analysis is based on 12-min. intervals (comparable to the quarter-hour intervals used in the analysis of visual observations) instead of hourly intervals.

VII. ACKNOWLEDGEMENTS

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I also wish to record my gratitude to my companions during 1961 and 1962 whose co-operation made the continuous observation of aurorae at Halley Bay possible.

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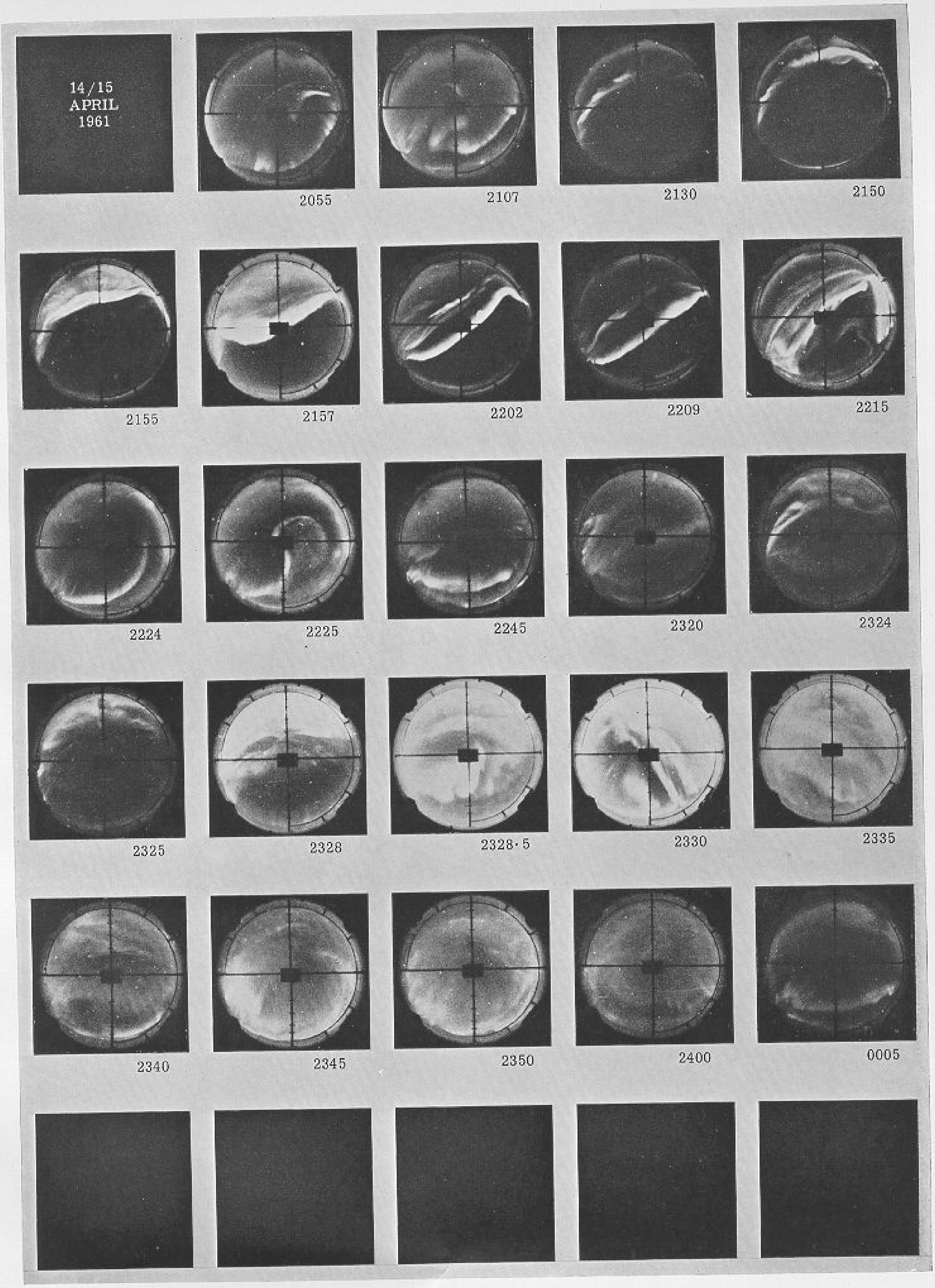
PLATES I–VI

Positive prints taken from single frames of the all-sky camera film, orientated so that north is at the top of the page.

The date appears at the beginning of each sequence, and the time is given below each frame to the nearest minute of universal time. Plate I photographs are all 3·5-sec. exposures, and Plate II photographs taken on 20/21 June 1961 are 23-sec. exposures. All other photographs for 1961 are 3-sec. exposures, and those for 1962 are 10-sec. exposures.


14/15
APRIL
1961
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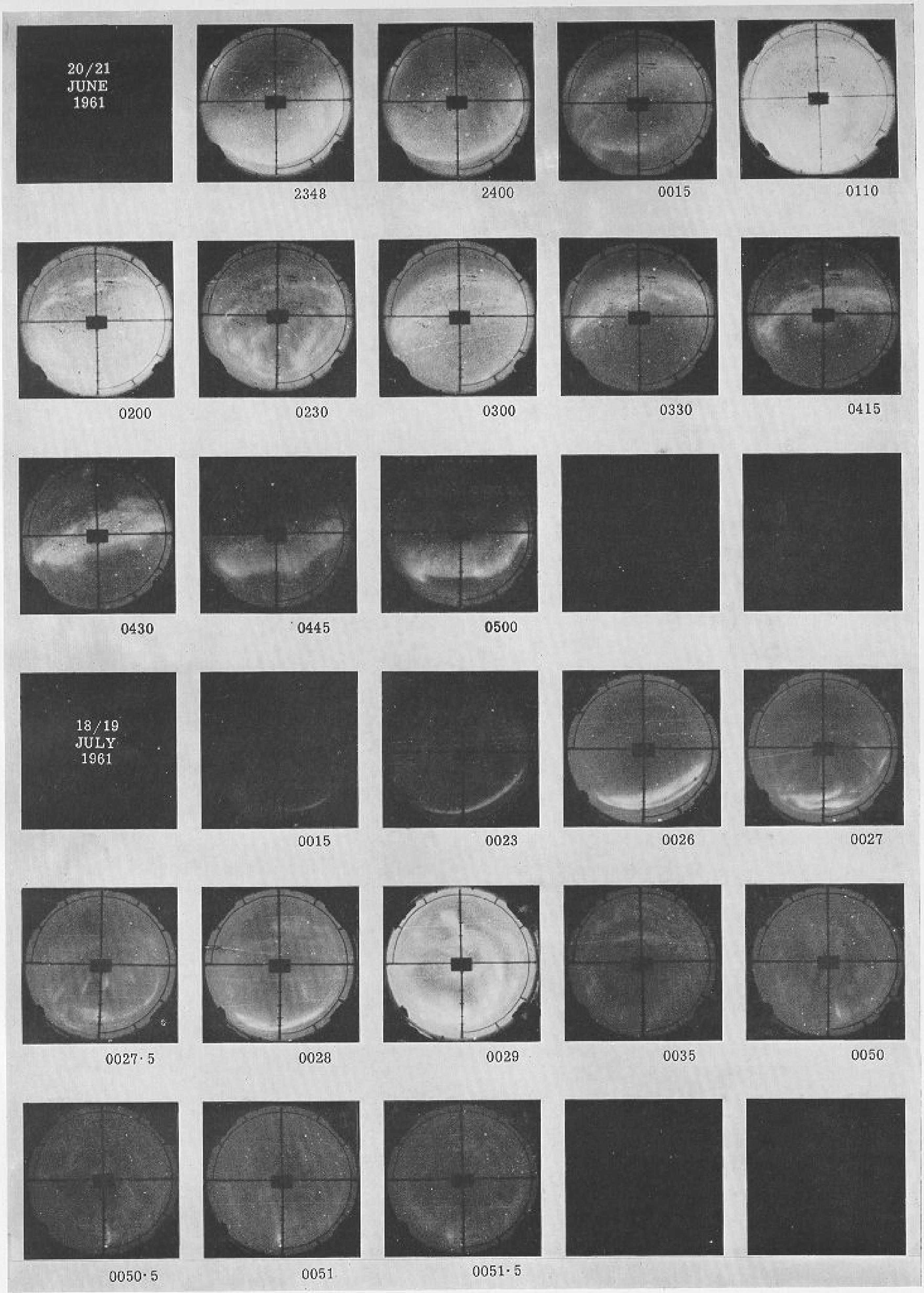
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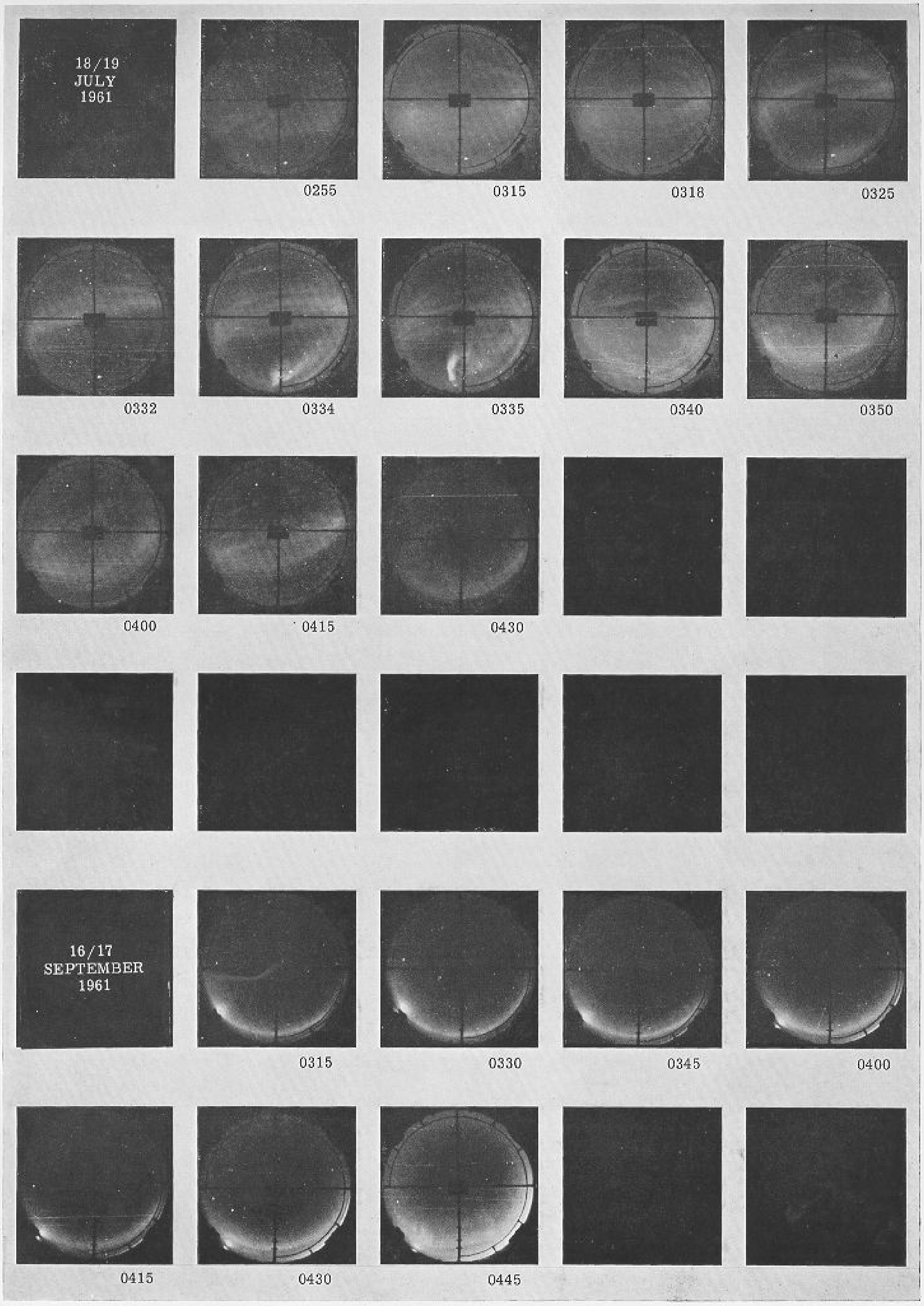
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SEPTEMBER
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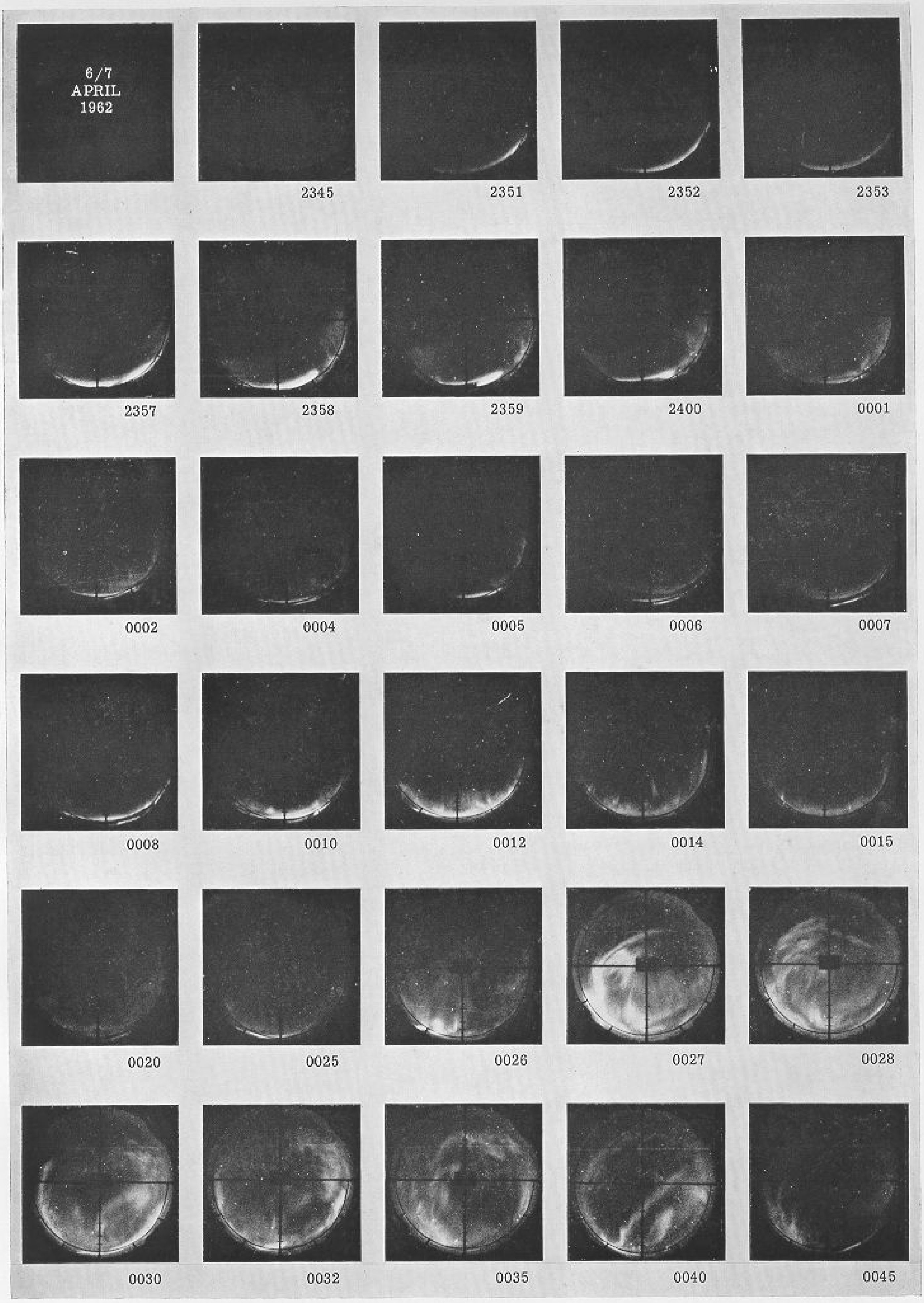
0400
0415
0430
0445


6/7
APRIL
1962
2345
2351
2352
2353
2357
2358
2359
2400
0001
0002
0004
0005
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0007
0008
0010
0012
0014
0015
0020
0025
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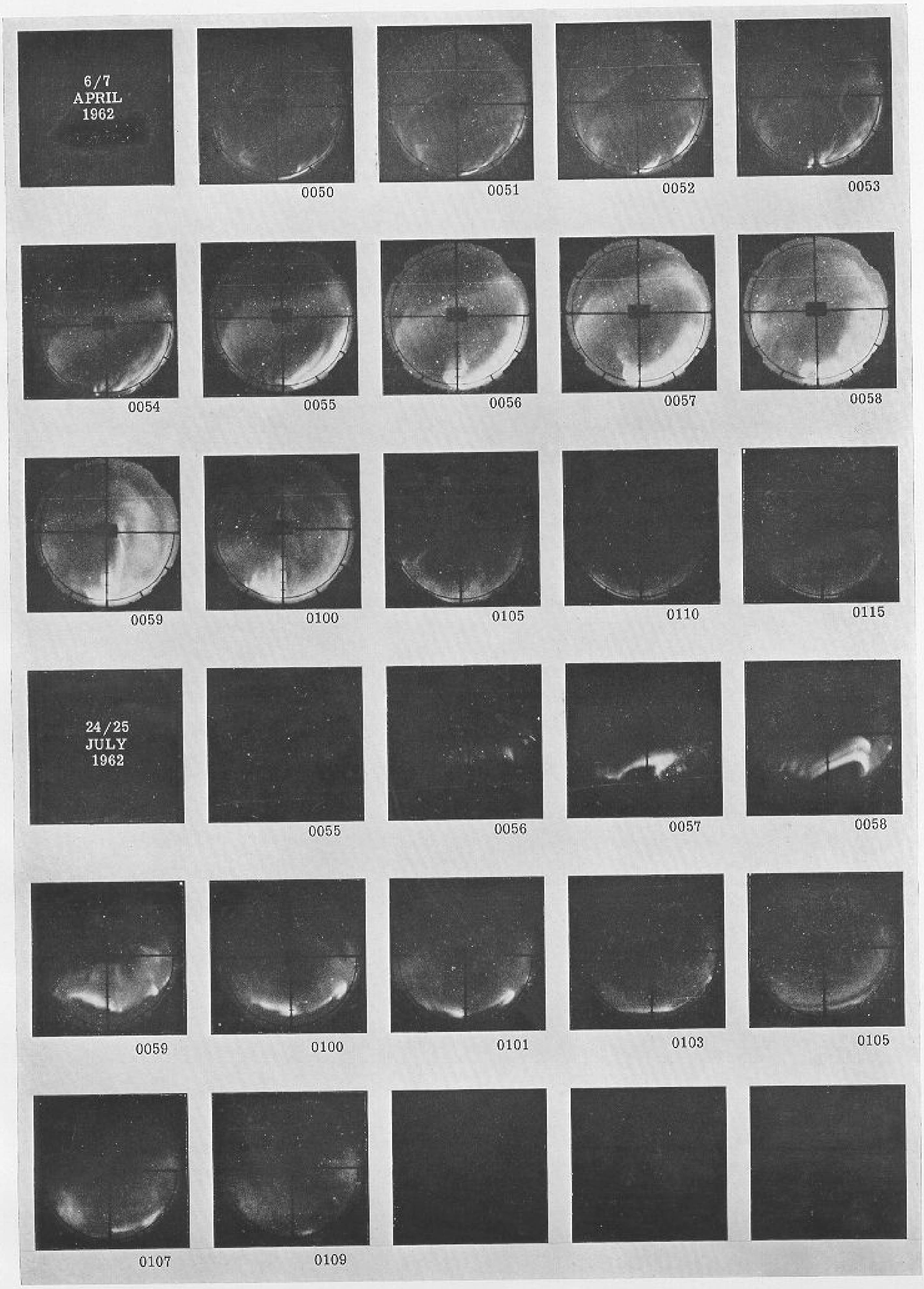
0028
0030
0032
0035
0040
0045

PLATE V


6/7
APRIL
1962
0050
0051
0052
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0054
0055
0056
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0058
0059
0100
0105
0110
0115
24/25
JULY
1962
0055
0056
0057
0058
0059
0100
0101
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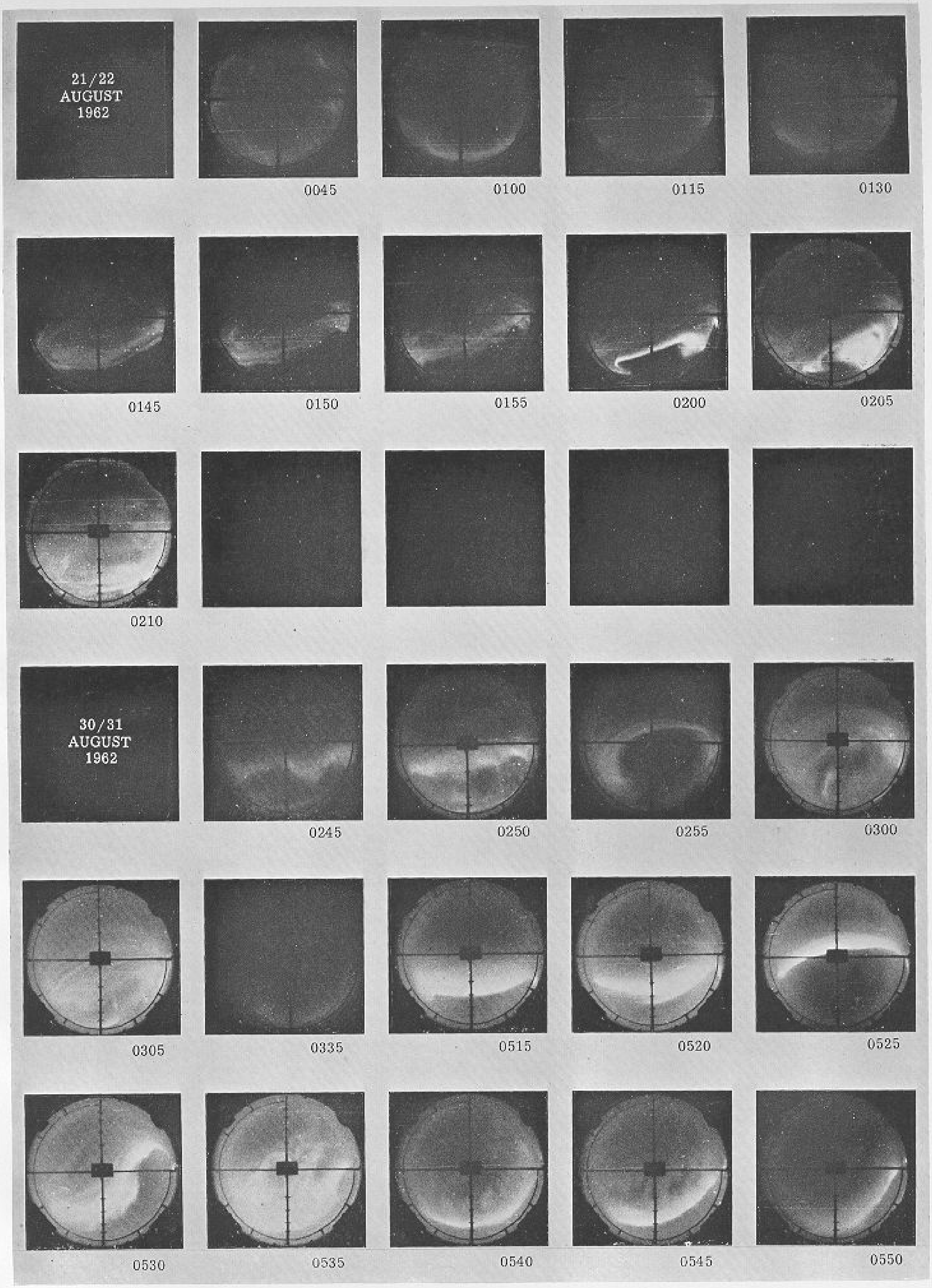
0105
0107
0109


21/22
AUGUST
1962
0045
0100
0115
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0145
0150
0155
0200
0205
0210
30/31
AUGUST
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0245
0250
0255
0300
0305
0335
0515
0520
0525
0530
0535
0540
0545
0550