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HIGH-FREQUENCY RADIO-WAVE BLACK-OUTS AT MEDIUM AND HIGH LATITUDES DURING A SOLAR CYCLE[1]

C. COLLINS, D. H. JELLY, AND A. G. MATTHEWS

ABSTRACT

Recent studies at the Defence Research Telecommunications Establishment, Ottawa, comparing v.h.f. riometer and h.f. ionosonde data for the International Geophysical Year, have shown that the two types of absorption events, 'polar cap' and 'auroral', can be identified in the occurrence patterns of ionosonde black-outs. A study based on this comparison has been made of all black-outs observed at a number of medium- and high-latitude ionosonde stations during the period 1949 to 1959. It has been found that the two kinds of absorption events show markedly different variations during the 11 years. Several other temporal and spatial features of the phenomena are also discussed.

INTRODUCTION

The complete absorption of high-frequency radio waves in the disturbed ionosphere is a well-known phenomenon. The effect, commonly termed 'black-out', has been the subject of both detailed and synoptic investigations in several countries over the past twenty years. One of the first advances in this field was made by Wells (1942), who showed the close association between short-duration black-outs and magnetic bays at College, Alaska. Later statistical studies (Lindquist 1951; Agy 1954*a*, *b*; Cox and Davies 1954) indicated some of the large-scale temporal and spatial characteristics of the black-out events. Meek (1952), in his studies of arctic ionospheric disturbances, also described some of the gross features of the absorption phenomena and showed the close association between black-outs and other manifestations of the high-latitude disturbances. A summary of the early work in this field has been given in the comprehensive review published by Little, Rayton, and Roof (1956).

Much of this work was based on the black-out reports from vertical-incidence ionospheric sounding stations. The results led several workers to suggest that there might be more than one kind of black-out condition although no classifications were adopted. This was perhaps due to the nature of the ionosonde black-out data which gave only a qualitative picture of the absorbing regions. More recently, quantitative investigations of the absorption phenomena have been made by a number of groups using measurements of cosmic noise at very high frequencies (20–60 Mc/s). The results of these investigations have confirmed the belief of the earlier workers by showing that the high-latitude absorption events are mainly of two kinds. These are now generally termed 'polar-cap absorption' and 'auroral absorption'.

Several of the polar-cap absorption events have been reported in detail (Bailey 1957, 1959; Hakura, Takenoshita, and Otsuki 1958; Reid and Collins

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1959; and others). In their paper, Reid and Collins divided the abnormal absorption events into three classes depending on the characteristics of the cosmic noise records and on the association with magnetic and auroral activity. The classes were designated as types 1, 2, and 3. Type 1 referred to the well-known sudden ionospheric disturbance (SID). The authors did not consider this type of event relevant to their study, and, since Cox and Davies (1954) have shown that SID's during the 4-year period 1949–52 did not contribute significantly to medium- and high-latitude black-outs, the phenomenon will not be discussed in this paper. Type 2 produced a characteristically irregular trace on the riometer records and the events were easily identified. They occurred at both Ottawa and Churchill, although not always simultaneously, and they often coincided with the occurrence of visible aurora and local magnetic activity. It is probable that these events were similar to the short-duration black-outs studied by Wells. This type 2 is now known as auroral absorption. Although there is considerable evidence to show that there is a type of absorption occurring at geomagnetic latitudes where visible aurora is usually observed (about 55 to 75 degrees) the precise relationship between the radio and the optical phenomena is not yet understood and the term 'auroral' must be used with some caution. In the present paper it is used in conjunction with 'absorption' and 'black-out' to designate occurrences closely associated in time with magnetic disturbances in or near the zone of visible aurora.

Type 3 absorption has been more clearly defined. It began a few hours after the start of a large solar flare and produced a much smoother variation on the riometer records than did the auroral type. It persisted for a number of days and showed a much greater intensity during the day than during the night. No magnetic disturbance was associated with the early hours of an event although a large magnetic storm usually occurred 10 to 30 hours after the start of the absorption. The absorbing region, it was subsequently learned, extended over most of the polar cap (Hakura *et al.* 1958) and hence the name 'polar-cap absorption' came to be associated with it. It is considered to be mainly a high-latitude phenomenon although, as results from the present study show, the effects are frequently observed at geomagnetic latitudes as far south as Winnipeg (59.6°).

Both these types of absorption are detected by the h.f. ionosondes and can be identified if the cosmic noise measurements are used to interpret the vertical-incidence ionosonde measurements. There are two obvious advantages in this procedure. First, since many more years of ionosonde data than cosmic noise data are available, the combination of the two makes possible the determination of the long-term variations of the events observed on the cosmic noise records. Second, the h.f. black-out, which is at best a crude measure of abnormal absorption, now possesses more physical significance for the statistical and synoptic studies of ionospheric disturbances. The procedure is only justified, however, if a close correlation can be established between the results obtained by the two kinds of observations. This point is considered in detail in the following section of the paper.

In the present study of black-out occurrences both ionosonde and cosmic noise measurements have been used and the foregoing classifications from the v.h.f. studies have been applied to the analysis of the h.f. black-out data. All black-out occurrences at a number of Canadian ionosondes for the period 1949 to 1959 have been considered. This 11-year period was sufficiently long to reveal significant differences in the large-scale temporal features of the two kinds of black-out, suggesting that they might be associated with different types of disturbances on the sun.

ANALYSIS OF DATA

Data for the study were collected at the stations listed in Table I. The h.f. ionosondes were conventional instruments and their characteristics have been

TABLE I
Co-ordinates and time zones of stations

	Geographic		Geomagnetic	
Station	Latitude north ϕ°	Longitude west λ°	North Φ°	L.M.T. °W
Alert	82.6	62.6	85.0	75
Eureka	80.0	85.9	86.5	75
Resolute Bay	74.7	94.9	82.9	90
Clyde River	70.5	68.6	81.9	75
Baker Lake	64.3	96.0	73.7	90
Churchill	58.8	94.2	68.8	90
Meanook	54.6	113.3	62.0	105
Winnipeg	49.9	97.4	59.6	90
Ottawa	45.4	75.7	56.9	75
Agincourt	43.8	79.3	55.0	75

described in detail in the Canadian I.G.Y. program (Meek 1957). The cosmic noise recorders were situated at Ottawa and Churchill, and operated on frequencies close to 30 Mc/s. Techniques of equipment operation and methods of data reduction have been described by Little and Leinbach (1958) and Reid and Collins (1959). The analysis of the data will be described in two parts, one dealing with polar-cap black-outs and the other with auroral black-outs.

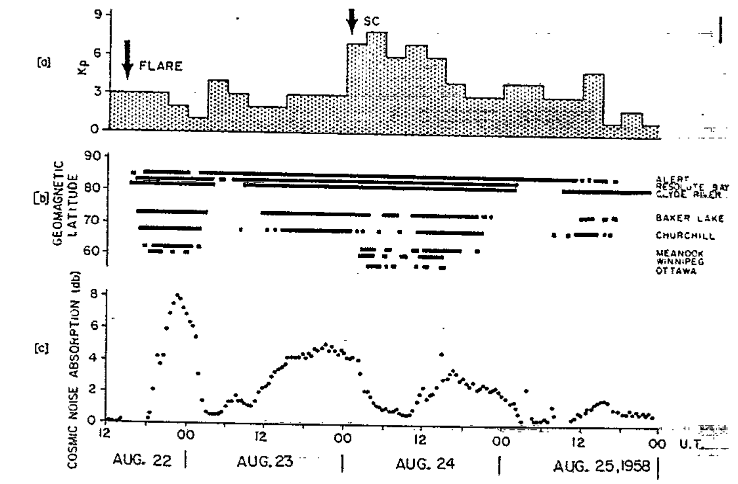
(a) Polar-cap Black-out

The first step in the analysis was a comparison of polar-cap absorption events identified from the riometer measurements and those selected independently from ionosonde black-out occurrences. The I.G.Y. period was selected because data from all the stations were available for most of the period. Auroral and polar-cap absorption events were identified directly from the riometer records. It was found that the Churchill riometer in the 18-month period had detected 15 disturbances involving polar-cap absorption greater than 2 db. Some of these included short periods of auroral absorption in the later parts of the disturbances. No definite occurrence of polar-cap absorption was found on the Ottawa records, although auroral absorption was observed at that station quite frequently.

An independent examination was then made of the ionospheric data from eight stations—Resolute Bay, Baker Lake, and Ottawa for the full I.G.Y. period, and Eureka, Alert, Clyde River, Churchill, and Meanook for 1958. At these stations sweep-frequency soundings were made at 15-minute intervals and recorded in the usual way on f-plots. All black-outs of more than 3-hours' duration were plotted according to the geomagnetic latitude of the station and as a function of universal time (U.T.). It was then found that almost all the black-out occurrences were arranged in a number of distinctive periods of about 2 to 5 days. These black-out groupings showed marked similarities and were clearly separated by relatively long intervals containing no black-out. The starting and finishing times of these absorption events could be determined easily in most cases and 14 of these discrete events were found. A comparison then showed that the 14 long-enduring black-out periods selected from the ionosonde data corresponded to 14 of the 15 polar-cap absorption events identified from the Churchill riometer.

A further examination was made of the ionosonde data for the period of 22 to 25 September 1958, which had not exhibited the distinctive pattern in the black-out plots although the cosmic noise absorption had reached a value of 4 db. It was found that, during this period, the minimum frequencies reflected from the ionosphere at the northern stations were 5 to 6 Mc/s higher than the monthly median. This indicated a large increase in absorption. But the critical frequencies during the day were also found to be unusually high, 8 to 10 Mc/s. This would effectively extend the range of the ionosonde and the absorption was not sufficiently intense to cause a black-out at the higher frequencies.

An examination was also made of the magnetic activity during the 14 black-out events, and histograms of the planetary indices, K_p, were drawn on the latitude–time plots. The disturbance which occurred on 22–25 August 1958 is shown in Fig. 1 and is typical of the polar-cap events which showed both polar-cap and auroral absorption. For ease of comparison half-hourly cosmic noise absorption values (c) in decibels for Churchill are also shown. Black-out occurrences are plotted for stations listed in Table I. Planetary K_p indices at the top of the figure indicate the degree of magnetic activity. The occurrence of the solar flare that was probably associated with the event is shown at the approximate time as is that of the magnetic sudden commencement (S.C.). The S.C. appears to follow the increase in the K_p index but this is due only to the coarseness of the K_p. The flare lasted from 1417 to 1717 U.T. and was described by the Dominion Observatory, Ottawa, as being of importance 3 and having heliographic co-ordinates 21° N. and 8° W. The first evidence of a black-out is seen to follow the start of the flare by about 3 hours and to precede the onset of the magnetic disturbance by about 32 hours. The black-out is almost continuous at Alert, Resolute Bay, and Clyde River, a fact that is attributed to the ionosphere always being sunlit at northern latitudes in August. Baker Lake and Churchill show daytime black-out and nighttime recovery. The black-out at Ottawa, which begins with the increase in magnetic activity and occurs irregularly at night, is more likely to be due to auroral absorption than to the polar-cap type.



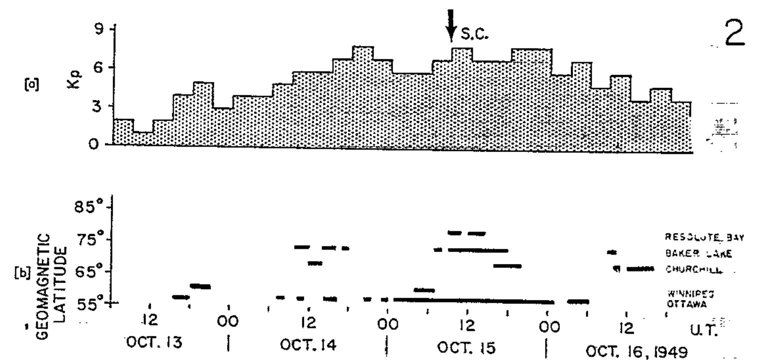


FIG. 1. Disturbance on 22–25 August, 1959, involving polar-cap and auroral absorption; (*a*) 3-hour planetary magnetic index K_p, (*b*) 15-minute black-outs observed at eight ionosonde stations, (*c*) variation in cosmic noise absorption at Churchill.

FIG. 2. Disturbance on 13–16 October, 1949, involving only auroral absorption; (*a*) 3-hour planetary magnetic index K_p, (*b*) hourly black-outs observed at five ionosonde stations.

The black-outs at Winnipeg and Meanook occurring on 22 August coincide with the beginning of polar-cap absorption and are probably of that type. Those occurring on 24 August, accompanied by an increase in K_p, are probably of the auroral type. The smoothness of the Churchill cosmic noise absorption indicates polar-cap type with the few irregularities (e.g. at 1430 on 24 August and 0300 on 25 August) being due to auroral type. It should be noted that there are no means of identifying the two types from the ionosonde data alone, but from the known characteristics of the phenomena one would expect only polar-cap absorption before the start of the magnetic disturbance. The simultaneous occurrence of the two types of absorption made it necessary to adopt a new term for the 14 long-enduring black-out periods identified in the ionosonde data. These will be referred to as 'polar-cap black-outs' in the remainder of this paper.

Most of the 14 polar-cap black-out events presented the same general configuration of black-out occurrences as that shown in Fig. 1. It was felt that these patterns possessed sufficiently distinctive characteristics to permit their identification in earlier ionosonde data and the study was extended to the rest of the 11-year period (1949–1959).

Prior to the I.G.Y. most ionosondes took measurements for only a few minutes on the hour. The occurrence of black-out at the time of these hourly measurements was recorded in the f_{min} data sheets by the symbol B. This provides only a short sample of ionospheric conditions during an hour but, because of the large number of observations taken in the 11-year period, such measurements are adequate for a synoptic study of this kind. All B's were plotted as in Fig. 1 from the monthly f_{min} tabulations for Resolute Bay, Baker Lake, Churchill, Winnipeg, and Ottawa. Several criteria were adopted for identifying the polar-cap black-out events. The black-out had to occur at more than one of the most northerly stations. It had to last more than 3 hours and be reasonably continuous for the duration of the disturbance. The lower latitude stations where the black-out might be discontinuous had to show some day–night variation. The pattern of occurrences for all the stations considered together had to show the same general configuration as presented in Fig. 1. Black-outs which did not satisfy these conditions were considered to be spurious or due to auroral absorption. In a few cases the variations of K_p were also used to confirm the selections. These criteria proved to be quite adequate and some 40 polar-cap black-outs were found to have occurred during the solar cycle. These events have been listed in Table II. In almost all cases the events were easily identified. There is a slight uncertainty about the exact number because a few of the long-enduring disturbances may have consisted of two or more overlapping events. These questionable cases are indicated in Table II.

(b) Auroral Black-out

After the periods of polar-cap black-out had been eliminated from the data a selection was made of all the B's in the rest of the 11-year period which were believed to be due to auroral absorption. In order to identify these auroral B's some criterion had to be adopted for their selection. This was necessary because the symbol B denotes only the absence of an echo from the ionosphere. The failure to detect an echo is usually due to the presence of an absorbing region but it may on occasions also be due to interference or very low critical frequencies of the reflecting region. An examination of the critical frequencies at some of the stations showed that many of the B's did not signify real increases in absorption, particularly in years of low sunspot number. It was not considered practicable, however, to examine all the original records near the times of black-out. Such a procedure would be very laborious and would introduce a large subjective element into the analysis. It was therefore decided that the auroral B's should be selected only if they occurred during a magnetically disturbed period.

Reference has already been made to Wells' study relating black-outs and magnetic bays. From observations at Saskatoon, Meek (1953) has published other detailed accounts of this association of h.f. absorption and magnetic

TABLE II

Polar-cap black-outs identified

Year	Duration	Approx. starting time (U.T.)	Comments
1949	Jan. 23–26	1200	
	Apr. 11–14	1400	
	May 10–13	2000	
	June 4–7	1800	
	Aug. 3–8	1200	Possibly 2 events
	Nov. 19–21	1200	
1950	Feb. 2–3	0200	
	Feb. 22–24	1200	
	Mar. 27–29	1000	
	May 27–31	a.m.	Possibly 2 events
1951	Mar. 7–15	1600	
	Apr. 2–9	1600	
	June 11–19		Possibly 2 events
	Oct. 27–29	0800	
1952	No well-defined events		
1953	Mar. 2–4	1800	Weak, indefinite
1954	No events		
1955	No events		
1956	Feb. 23–25	0600	
	Mar. 11–14	1600	
	Aug. 31–Sept. 2	1800	
	Nov. 13–15	1400	
1957	Jan. 21–23	1500	
	Apr. 4–6	1200	Weak
	June 20–26	1800	Possibly 2 events (second starting on 22)
	July 1–5	1200	Possibly 2 events (second starting on 3)
	Aug. 27–Sept. 4	1400	Possibly 2 or 3 events
	Sept. 21–23	1200	
	Oct. 21–22	1400	
1958	Feb. 10–11	p.m.	
	Mar. 14–15	2200	
	Mar. 25–28	1200–1600	
	Apr. 10–11	1400	
	July 7–10	0600	
	Aug. 16–18	1200	
	Aug. 22–25	1600	
	Aug. 26–27	a.m.	
1959	May 11–17	a.m.	
	July 10	1000	
	July 14–17		
	July 17–20		

NOTE: Starting times are estimated from beginning of black-out at several stations and are not an accurate measure of the starting time of each event.
Possible weak events: 1955, Jan. 17–18; 1956, Apr. 27–28.

disturbance. Davies and Hagg (1955) have reported a pronounced correlation between nighttime ionospheric absorption on 2.0 Mc/s at Prince Rupert, and the local 3-hour range magnetic K index for values of K greater than 4. Heppner, Byrne, and Belon (1952) have reported that some parts of the visible aurora at College were often accompanied by black-outs. It is almost certain that there would also be some magnetic activity at the time of such aurora. It therefore seemed reasonable in the present study to select the auroral black-outs by some level of magnetic disturbance. Since it cannot be shown that auroral black-outs are invariably accompanied by an increase in magnetic activity this method of selecting the data might reduce the total number of listed auroral black-out occurrences. This effect should be negligible, however, and most spurious black-out occurrences which were due only to the absence of a reflecting region should be excluded by this process. The criterion adopted was that the K index given by the nearest magnetic observatory should be greater than 3 in the 3-hour interval in which the black-out occurred. Indices from Agincourt, Meanook, and Resolute Bay were used although the data from Resolute Bay were available only for the years 1952–55. K was chosen for the purpose rather than the planetary index K_p as the former was considered to be more sensitive to local ionospheric disturbance. K_p, which indicates world-wide disturbance, has been plotted in Fig. 1 because black-outs from a number of stations have been shown.

Although many of the black-outs attributed to auroral absorption were randomly distributed, some did form distinct patterns. An example is shown in Fig. 2 for the disturbed period 13 to 16 October 1949. The magnetic activity is high. There are, however, no long-enduring black-outs at the high-latitude stations. The black-out occurrences are more sporadic and of shorter duration than during polar-cap black-outs and they are more frequent at Churchill, Winnipeg, and Ottawa. It can be seen that the general configuration of black-out occurrences is quite different from that shown in Fig. 1.

RESULTS OF SYNOPTIC SURVEY

The temporal variations of the absorption phenomena were examined in two ways. For the polar-cap black-out events both the number of events and the number of B's making up the events were considered. In the case of auroral black-outs the periods designated as polar-cap black-outs were excluded because it was impossible to identify with certainty the type of absorption responsible for the black-out after the magnetic storm had started. In some of the figures all the occurrences of B's have been shown except those making up the polar-cap black-out events, that is, all auroral B's and all the spurious B's rejected by the criterion of magnetic activity. These have been shown for several reasons which should be clear from the following descriptions of the figures.

(a) Secular Variation

The distribution by years of the 40 polar-cap black-outs is given by the histogram in Fig. 3. Shown on the same plot is the variation of the annual mean sunspot numbers published by the Central Radio Propagation Laboratory, Boulder, U.S.A. The close agreement of the two plots indicates that the occurrence of disturbances with polar-cap absorption is closely associated with the mean level of solar activity. Although the number of occurrences is too

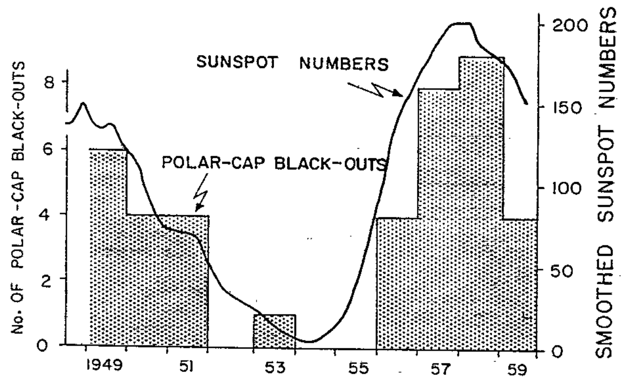


FIG. 3. Distribution of polar-cap black-outs during the sunspot cycle 1949–59.

few for a satisfactory statistical analysis, there is some indication that the outline of the histogram lags by about a year with respect to the sunspot number curve.

Yearly totals were also compiled of the numbers of B's comprising the 40 polar-cap black-outs at Resolute Bay, Baker Lake, Churchill, and Winnipeg. These have not been reproduced here since the shape of the histograms was similar to that shown in Fig. 3. Some indication of the latitude dependence was, however, apparent in these histograms, with Resolute Bay having the greatest number of hourly black-outs and Winnipeg the least.

The secular variation of the auroral black-outs at five of the stations is shown in Fig. 4. For ease of comparison the sunspot number curve has been drawn on the Churchill and Winnipeg histograms. The dotted areas show the yearly totals of auroral B's. The plain areas denote the number of B's rejected by the criterion of magnetic activity. The years for which K indices were not available from Resolute Bay have been shaded with diagonal lines. Φ denotes the geomagnetic latitude of the station. The vertical columns denoting the occurrences at Baker Lake and Winnipeg for 1959 have been drawn narrower than the others. In March 1959 the Baker Lake ionosonde was closed down and in September 1959 the transmitter power at Winnipeg was reduced from 10 kw to 1 kw. This loss of data was unfortunate but it does not seriously affect the results. It will readily be seen that there is some agreement between the outline of the histograms and the curve of solar activity. The variation in the black-out occurrences shows a definite lag on the variation in the sunspot number. Since these histograms are drawn to a common vertical scale they also show the relative frequency of occurrence of the auroral black-outs at the various stations. It can be seen that Baker Lake reported the fewest occurrences while Winnipeg observed the greatest number.

(b) Seasonal Variation

The histogram in Fig. 5 shows the seasonal variation of the polar-cap black-out events. Although the limited number of events does not allow much weight

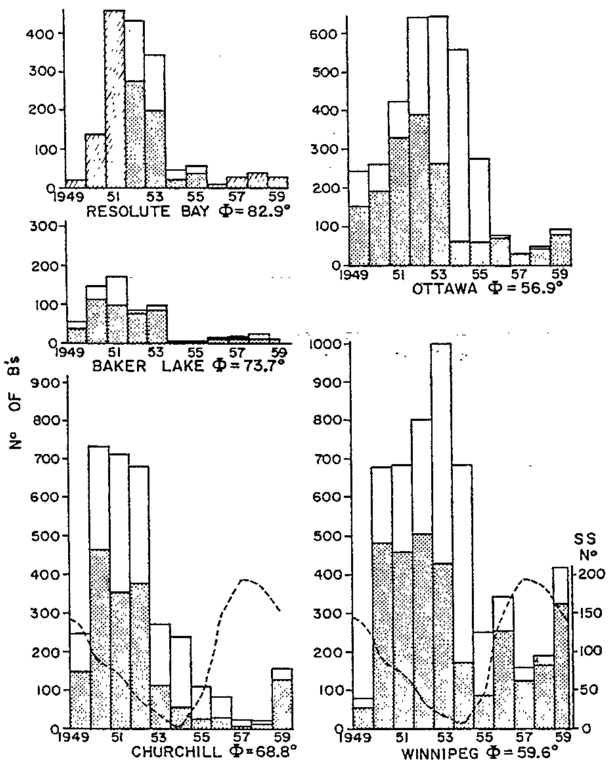


FIG. 4. Distribution of yearly totals of B's at five stations during the solar cycle 1949–59, excluding periods of polar-cap black-out. Solid line histogram, all black-outs. Dotted areas, auroral black-outs. Diagonal line areas, periods for which K index was not available. Broken line, monthly mean sunspot numbers. Φ, geomagnetic latitude.

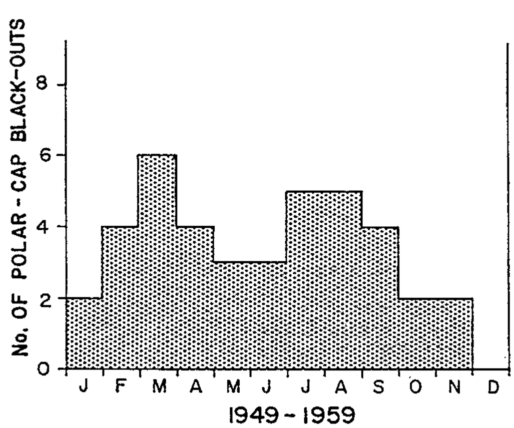


FIG. 5. Distribution of monthly totals of polar-cap black-outs for the years 1949–59.

to be attached to the result, the distribution does suggest slight increases in the occurrence somewhat before the equinoxes. It is perhaps interesting to note that throughout the 11-year period there were no events of this kind in December.

The seasonal variation for the number of B's at Churchill and Ottawa is shown in Fig. 6. Part (a) gives the monthly total of the B's comprising the

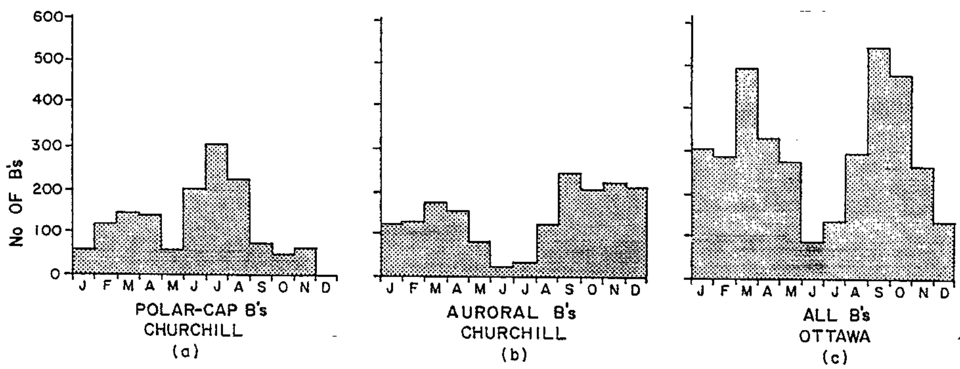


FIG. 6. Distributions of monthly totals of B's; (a) polar-cap black-outs at Churchill, (b) auroral black-outs at Churchill, (c) all B's at Ottawa, periods of polar-cap black-out included.

polar-cap black-outs at Churchill. This shows a maximum during the summer months. In contrast to this the distribution of auroral B's for that station (b) shows a pronounced minimum for the summer months. It might be suggested that the summer maximum in the first histogram might be due to the occurrence of auroral black-outs which could not be extracted from the data. This seems unlikely, however, since the distribution of all black-outs for Ottawa also has a minimum about June and July as shown in (c) and no data were rejected for that station. It is well known that the polar-cap absorption is more intense when the lower ionosphere is sunlit and the maximum in the polar-cap distribution is probably due to the longer periods of sunlight at the higher latitudes during the summer. Plots were also made of the occurrences at the other stations. The histograms for Baker Lake and Winnipeg are similar to those shown in Fig. 6(a) and (b). For Resolute Bay, where the black-outs are mainly of the polar-cap type the histogram in part (a) predominates and the remaining black-outs show no significant seasonal variation. For Ottawa, which is south of the polar-cap absorption region for all but the most intense disturbances, one obtains a distribution of auroral B's which is very similar to but slightly smaller than the histogram given in part (c).

(c) *Diurnal Variation*

Diurnal variations for the auroral black-outs at each of the five stations were derived by totalling the number of B's for each hour during September and October for the 11 years. These have not been reproduced here since they differ only slightly from those already published by Cox and Davies (1954).

The hours (local mean time) of maximum occurrence at Ottawa, Winnipeg, Churchill, and Baker Lake were 0300, 0600, 0700, and 0800 respectively. No significant peak was found in the plot of the occurrences at Resolute Bay.

(d) 27-day Recurrence Tendencies

In order to examine the data for 27-day recurrence patterns, an index was compiled using three categories according to the number of B's during the day: (1) no B's, (2) 3 hours or less, and (3) greater than 3 hours. Polar-cap black-outs from Churchill were plotted on one graph, all other B's from the same station on another plot. The inclusion of all B's both auroral and spurious (but excluding those making up the polar-cap black-outs) in this second plot was necessary in order to permit a comparison to be made with the magnetic data. Since auroral B's had already been selected on the basis of magnetic activity, an index compiled only from auroral B's could not be expected to give any meaningful results when compared with an index of magnetic activity. The daily sum of K indices from Meanook were plotted in the same manner with a 3-division scale: (1) $K < 20$, (2) $20 \leqslant K \leqslant 30$, (3) $K > 30$. Figure 7 shows the 11-year plots of these magnetic and black-out daily indices. International 27-day intervals beginning with solar rotation number 1582 have been used with a repetition of the first 6 days at the end of each horizontal line. Part A of the figure gives the magnetic activity as observed at Meanook. The years of high and low activity are immediately apparent in the general configuration of the plot and the long sequences of recurrent magnetic storms (1950–54) which have been investigated by Bhargava and Nagvi (1954) are also clearly evident. It can readily be seen that there is a marked difference in the general appearance of the plot for the years in which activity is declining (1950–54) and increasing (1955–58).

Parts B and C of Fig. 7 show the daily black-out indices for Churchill for the 11-year period. C indicates only the polar-cap black-outs. Here again the years of high and low activity are clearly evident although there seems to be little difference between the periods of increasing and decreasing activity. In part B all black-out occurrences were considered other than those shown in part C. Part B therefore includes auroral black-outs and those black-outs which were believed to be spurious. This section of the diagram exhibits quite a different pattern of variation. There is no clear minimum in the black-out occurrences (part B) around 1954 at the time of minimum magnetic activity. The most striking feature perhaps is the obvious similarity between the general configurations of the magnetic and black-out indices for the period 1950–54 even though part B is made up from all except polar-cap black-out occurrences. In spite of some contamination of the ionosonde data due to low critical frequencies, the 27-day recurrent sequences show up quite clearly in the plots of the black-out indices. In contrast to this it can be seen that parts A and B of the figure for the period 1956–59 are quite dissimilar. During these years the increase in magnetic activity was quite clearly not accompanied by an increase in the occurrence of auroral black-outs. This confirms the conclusion already drawn from Fig. 4. The inclusion in part B of the short periods of auroral black-out from the polar-cap black-outs in part C would not change the general features of these parts of the figure.

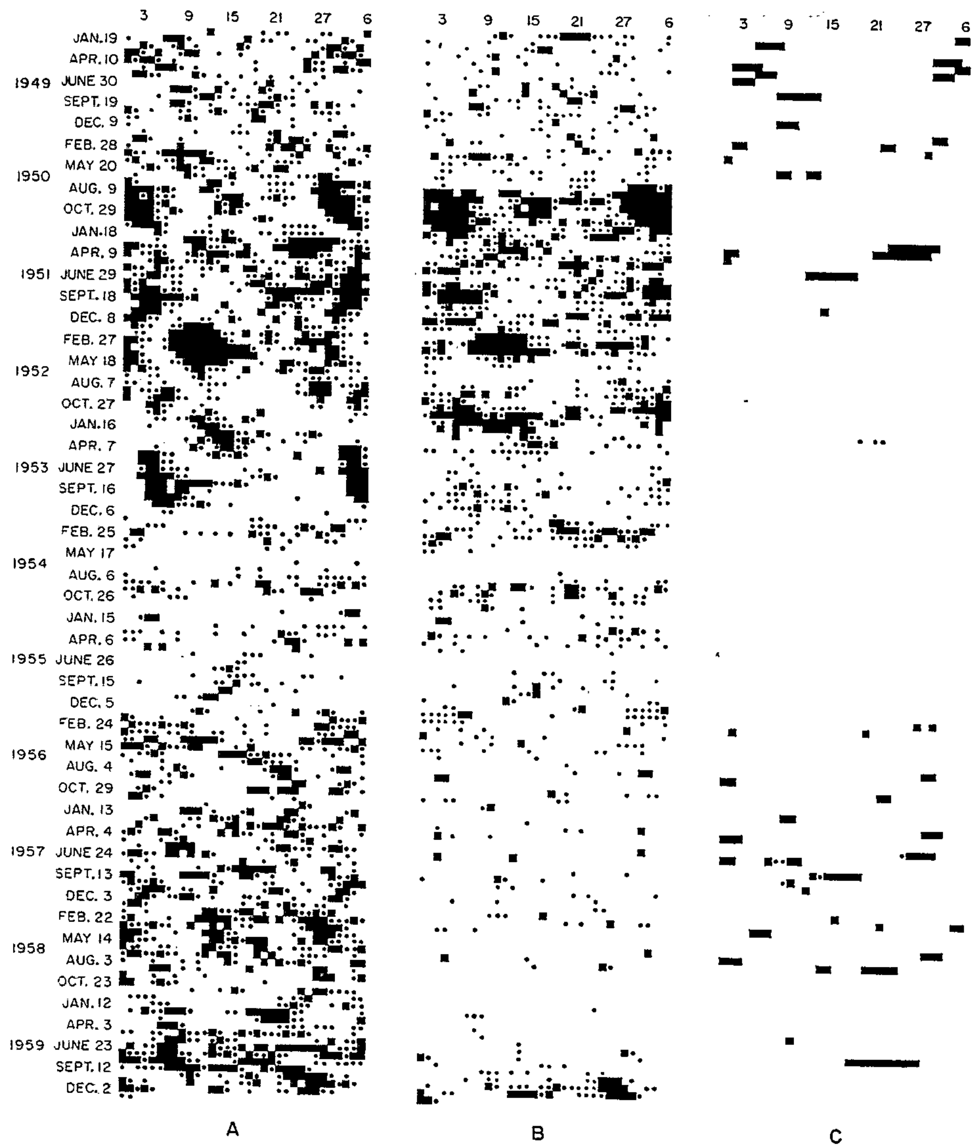


FIG. 7. 27-day recurrence time patterns; (A) magnetic activity at Meanook, (B) all black-outs at Churchill, excluding polar-cap black-outs, (C) polar-cap black-outs at Churchill.
Absorption index: □ daily sum of hourly B's = 0; ● daily sum of hourly B's $\leqslant 3$; ■ daily sum of hourly B's > 3.
Magnetic index: □ daily sum of K values < 20; ● daily sum of K values $20 \leqslant K \leqslant 30$; ■ daily sum of K values > 30.

(c) *Latitude Dependence of Auroral Black-outs*

In order to display the latitude dependence of auroral black-outs some of the results from Fig. 4 have been shown in a different way in Fig. 8. In this plot the number of auroral black-outs has been shown as a function of geomagnetic latitude for every other year starting with 1949. It will be seen that

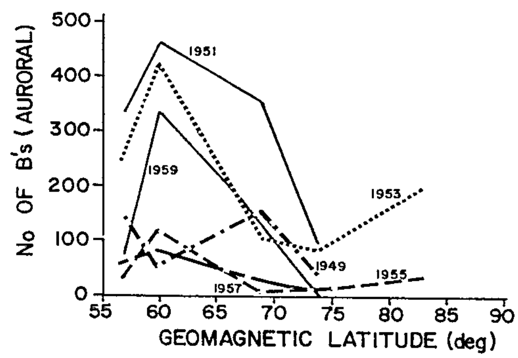


FIG. 8. Yearly totals of auroral B's shown as a function of geomagnetic latitude for alternate years from 1949 to 1959.

a maximum in the number of auroral B's occurs at Churchill only in 1949. For all other years the peak occurs at Winnipeg. Plots of all B's (excluding polar-cap black-outs) produce curves giving a very similar result.

DISCUSSION

An earlier statistical study by Agy (1954*a*), based on h.f. propagation between geomagnetic latitudes 45 and 65 degrees along the 90th meridian, presented evidence for a narrow auroral absorption zone centered about the latitude of maximum occurence of visual aurora. Cox and Davies examined the occurrence of all B's at Resolute Bay, Baker Lake, Churchill, and Winnipeg for the years 1949–1952 and found a pronounced peak in the frequency of occurrence at Churchill. Although a close comparison cannot be made between the present study and the earlier ones it is felt that the results presented here suggest a somewhat different picture of the absorbing regions.

Some appreciation of the latitude variations of the absorption can be obtained from the yearly totals in both Fig. 4 and Fig. 8. It should be remembered, however, that polar-cap black-outs have been excluded from the plots in both figures and the curves in Fig. 8 represent only the numbers of auroral B's. The inclusion of the B's comprising the polar-cap black-outs would certainly change the shape of some of the histograms and curves but only for the higher-latitude stations. For Resolute Bay, where polar-cap black-outs account for 85% of the black-out occurrences during years when the sunspot number is greater than 100, the number of B's would be increased and the outline of the histogram would follow the sunspot curve closely. A somewhat similar condition obtains for Baker Lake. For Churchill the yearly totals of all B's do show the effect of the polar-cap black-outs but the general agreement with sunspot variation is poor. For Winnipeg and Ottawa the B's during polar-cap black-out events form a small part of the total observed. Totalling all black-out occurrences would therefore present a different picture of the latitude dependence at only the northern stations. South of Baker Lake there would still seem to be an extensive absorbing region. It seems likely that there is a maximum in this region but the present results would not lead one to expect a 'narrow' absorption zone. From the curves in Fig. 8 one sees that during 1949 the peak did occur at Churchill but for some years there were as many B's recorded at Winnipeg as at Churchill and for other years there were more.

It may be argued that the method of selecting the data is entirely responsible for this somewhat different picture. It is known, however, that the two types of absorption discussed here often occur simultaneously. A specific event of this kind has been described by Reid and Collins from riometer measurements at Churchill. It seems likely that similar conditions occur at Baker Lake and Winnipeg. This simultaneity of the two types cannot be detected in the ionosonde data and therefore the most meaningful way of presenting the synoptic picture of auroral black-outs is to exclude the periods when polar-cap absorption is known to occur.

Some consideration must also be given to the effect of the magnetic activity criterion on the relative frequency of occurrence of B's for the different stations. Fel'dshstein and Kurdina (1958) have shown that the general character of the magnetic field variation is essentially the same over a distance of 180 km along the meridian and over a distance of 300 km in longitude in regions near the auroral zone. It can thus be assumed that the Agincourt K index is a good measure of the magnetic disturbance at Ottawa 370 km away. Whitham and Loomer (1956) have shown that there is a high degree of correlation between the K indices for Meanook and Baker Lake; these stations are separated by a distance of approximately 1500 km. However, the distance between Meanook and Winnipeg is slightly less than the distance between Meanook and Churchill. This and the latitudes of the stations may cause some weighting of the Winnipeg B's when the Meanook K index is used as the criterion. It is felt, however, that this is not an important factor. If one assumes the most unfavorable conditions for Winnipeg, that all the doubtful cases of black-out should be rejected for Winnipeg and none for Churchill, the general picture of the latitude dependence is changed only slightly and then only for a part of the 11-year period.

The decrease in the occurrence of auroral black-outs north of Churchill seems to persist throughout the solar cycle and agrees with the results from earlier studies. It is difficult, however, to account for the black-out occurrences at Resolute Bay which are shown in Fig. 4. It seems possible that a large number of these auroral black-outs at Resolute Bay are short-lived polar-cap black-outs and that the true auroral black-outs may occur very infrequently north of Baker Lake. Although these black-outs occurred frequently on many consecutive days during 1950–52, they were short-duration events which did not meet the criteria laid down for the selection of the polar-cap black-outs; nevertheless, it may be that they are indeed manifestations of very weak polar-cap black-outs. Similar conditions were obtained for Baker Lake and Churchill, to a lesser extent. K indices from Resolute Bay were available for only 4 of the 11 years, and so they could not be applied in the selection of auroral black-outs at this station. However, it is unlikely that such a selection could be justified by the arguments presented earlier, since very little is known about the association of magnetic and ionospheric disturbances at very high latitudes. It is even questionable whether it is meaningful to refer to these black-outs as 'auroral'. Visible aurora occurs very infrequently at Resolute Bay. Several workers have postulated an inner auroral zone and Lassen (1959) has recently described a region of visual aurora at geomagnetic latitudes of approximately 75 to 80 degrees but there is as yet no evidence for associating this aurora with the very high latitude black-outs. Reid (1960) has reported that riometer measurements at Thule ($\Phi = 87$ degrees) showed a complete absence of auroral absorption during the I.G.Y. These were years of high solar activity. It may be that only during years of declining solar activity are the auroral black-outs detected at very high latitudes. At such times the short-duration absorption events may be due to a combination of the two kinds of black-outs. A meaningful interpretation of the Resolute Bay 'auroral' black-outs must be based on the riometer data now being collected.

Because of the coarseness of the ionosonde measurements little can be said about the extent of the polar-cap absorption region. While no polar-cap black-outs were observed at Ottawa, about half of these events were accompanied by black-outs at Winnipeg before the time of sudden commencement. These were of much shorter duration that at the higher-latitude stations. Since Ottawa and Winnipeg differ in geomagnetic latitude by only 2.3 degrees this result suggests a rather sharp southern boundary for the polar-cap absorbing region and tends to confirm what is already known about the spatial extent of the phenomenon (Reid and Leinbach 1959).

Although much more than 11 years of data is required for the determination of the secular variation of these absorption phenomena an interesting comparison can be made between the variations presented here in the yearly totals of the two kinds of black-out. It is perhaps not surprising that one finds such close agreement between the sunspot numbers and the occurrences of polar-cap black-out since the polar-cap absorption is almost always associated with the occurrence of large solar flares, which, in turn, are associated with large and active sunspot groups. On the other hand the disagreement between the sunspot number curve and the yearly totals of auroral black-outs is quite striking. It is possible that the dependence of the black-out condition on F-region critical frequency is contributing to this result. However, the monthly median noon values of f_0F_2 are known to follow the smoothed sunspot number variations very closely. Any significant dependence of the black-out condition on critical frequencies should have produced a marked increase in the occurrence of black-outs at the time of sunspot minimum (1954). This was clearly not the case. It might also be suggested that changes in data-scaling procedures and modifications to equipment during the past 11 years may be factors affecting the number of black-outs reported. Again it is felt that these are minor considerations. Although noise-level measurements are not available from the ionosonde stations, transmitter powers have been kept the same and the sensitivities of the sounders are considered to be reasonably comparable. The fact that all the histograms in Fig. 4 have the same general shape lends weight to the argument that this secular variation of the auroral black-outs is real and has a physical rather than an instrumental cause. It is also felt that the secular variation of auroral *B*'s as shown in Fig. 4 is not seriously affected by the omission of the auroral black-outs which occurred during polar-cap black-outs. The variation in the yearly totals of all auroral *B*'s at Ottawa (times of polar-cap black-out included) was found to be very similar to that shown by the histogram in Fig. 4.

Since nearly all measures of visible solar activity correlate well with the variations of sunspots it is difficult to suggest an optical feature of the sun which might be associated with the occurrence of the auroral black-outs. In this respect it is interesting to recall the work of Babcock and Babcock (1954). These authors have presented evidence for the existence of both general and localized solar magnetic fields and discussed the importance of these in relation to the emission of corpuscular streams from the sun. In a more recent paper Babcock (1959) has given a further description of the variations in polarity and intensity of the general solar field. When the field was first detected in 1952 it showed a polarity reversed to that of the earth. This was maintained through the years of sunspot minimum until some time between March and July, 1957. At that time the south polar field reversed its sign. The sign of the north polar field remained unchanged until November, 1958, when it rather abruptly became negative. Although there is no evidence to suggest that the two phenomena are related, it is interesting to note that it was just about this time that the auroral black-out occurrences reached a minimum.

It is well known that the solar features during the period of declining spot activity are not the same as during the period of increasing activity. Terrestrial phenomena also exhibit different behavior in different parts of the solar cycle. Large magnetic storms recur at 27-day intervals more frequently in years of decreasing sunspot numbers than in the years when the numbers are increasing. Similar recurrence tendencies have been observed at these times in the occurrence of visual aurora. Such conditions were certainly in evidence during the period 1950 to 1953. The 27-day recurrence pattern which can be seen in the 11-year plot of the daily black-out index, and the maxima about 1950–53 in the histograms in Fig. 4, strongly suggest that auroral black-outs and polar-cap black-outs must be associated with different basic conditions on the sun. It is during the years of decreasing spot activity that the solar *M* regions reach the peak of their activity (Chapman and Bartels 1940). Little seems to be known, however, about these *M* regions although Abetti (1957) has pointed out that such regions may be identified with the filament prominences. The same author has also suggested that the very active coronal regions which have no counterpart disturbances in the photosphere or chromosphere may be connected in some way with the *M* regions. Babcock and Babcock (1954) have suggested that the occasional extended magnetic areas of only one outstanding polarity, which they term unipolar magnetic (UM), may be identified as the *M* regions. Whatever their nature it seems certain that these regions play an important role in the generation of the low-energy particles believed to be responsible for ionospheric disturbances in the vicinity of the auroral zone. It may thus be that the auroral type of absorption is more closely associated with the solar *M* regions than with the flares and sunspots.

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