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TITLE

APPARENT POLEWARD MOTION OF ONSETS OF AURORAL ABSORPTION EVENTS

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Apparent poleward motion of onsets of auroral absorption events

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A study is made of nighttime auroral radio absorption events observed by riometers in the latitude range of $\lambda = 67–76°$. Individual events are shown to extend over this range with a tendency to occur later at higher latitudes. If the observed onset delay time is interpreted as a poleward expansion of the disturbance, the corresponding average velocity is 0.8 km/s. This velocity is consistent with the poleward motion observed during visual auroral substorms. The absorption events are compared statistically with energetic electron events detected by the Alouette I satellite.

Introduction

At high latitudes, most sporadic radio-wave absorption is considered to be caused by the ionization produced by energetic particles as they are precipitated into the atmosphere. There are two main types of disturbances, the polar cap events which are associated with solar protons impinging over the whole polar cap region and auroral absorption events which are concentrated at auroral latitudes and are thought to be produced mainly by energetic electrons. The two types of absorption are usually easily separable.

The auroral absorption events have been divided into two subgroups, nighttime and daytime events (see, for example, Morozumi 1965). The nighttime events are of shorter duration (about one hour). They tend to start abruptly and have an irregular spiky appearance. By contrast, the daytime events start slowly, vary smoothly, and last for hours. The abrupt features of the nighttime auroral absorption have been shown to be correlated with the sudden increases in auroral luminosity known as "breakup" (Ansari 1964; Parthasarathy and Berkey 1965; and Morozumi 1965). Although less is known about auroral absorption at latitudes higher than the auroral zones, Hargreaves *et al.* (1964) showed that there were two maxima in the occurrence of events at the South Pole ($\Lambda = 74.5°$), with one of the maxima just before magnetic midnight and the other before magnetic noon. The short duration and spiky appearance of the events making up the nighttime maximum suggests that they belong to the group of breakup associated events (see, for example, Hartz and Brice 1967).

The present work is a preliminary study showing that on some occasions nighttime auroral absorption can be identified at approximately the same time at widely separated stations and that, on the average, the onset of absorption is later at the higher-latitude stations. If the difference in onset time is assumed to be due to poleward motion of the high-latitude border of the disturbance, the observations are consistent with the morphology of auroral substorms described by Akasofu (1964). According to Akasofu, an auroral substorm starts with an abrupt brightening of a quiet arc (the breakup phase), followed by a rapid poleward expansion of the area of auroral activity. If electron precipitation associated with the substorms is caused by electrons originating in the tail of the magnetosphere as is currently thought, their morphology may be interpreted in terms of magnetospheric effects.

Observations

Data used in the study were obtained from 30-Mc/s riometer records at Coral Harbour ($\Lambda = 76°$), Frobisher ($\Lambda = 75°$), Churchill ($\Lambda = 71°$), and Cape Jones ($\Lambda = 67°$). Locations of these stations are shown in Fig. 1. An example of the effect being studied is shown in Fig. 2, in which tracings of the records are reproduced. Absorption in decibels increases downward from the quiet background level, which is approximately the level prior to the occurrence of the event at each station. There had been no absorption at any of the stations for at least 9 hours prior to the onsets between 00 and 01 U.T. on October 25, 1963. This in itself suggests that the four stations are observing the spatial and temporal characteristics of one disturbance. In addition, the very similar appearance of the records at Coral Harbour and Churchill suggests that one source is responsible for the effect

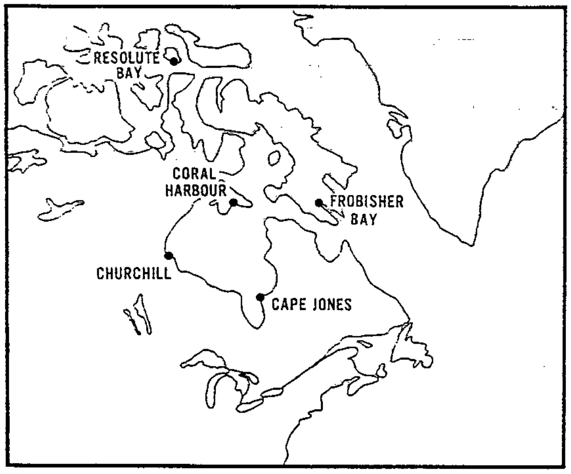

FIG. 1. Map showing the location of stations referred to in the text.

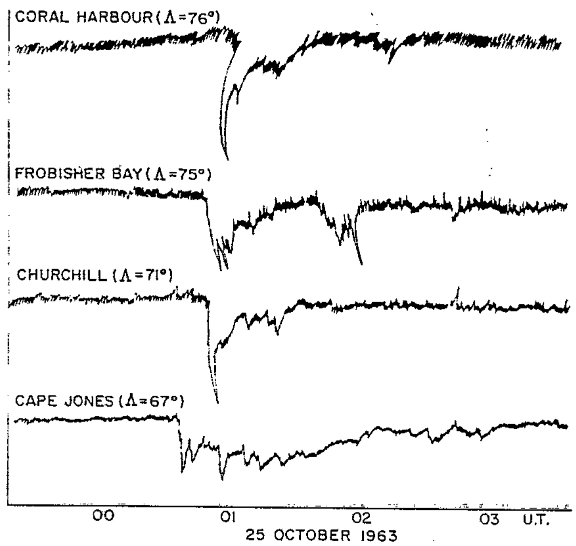

FIG. 2. An example of an abrupt onset radio-wave absorption event seen on riometer records from four stations ranging in invariant latitude from 67 to 76°. From the onset times there is an apparent northward motion. Local time at the stations is 1900–2000.

seen at the two stations. Although the appearance is less similar at Frobisher and Cape Jones, the sequence of onset times is consistent with the interpretation that all four stations are observing one disturbance. Onset times are 0035 U.T. at Cape Jones, 0049 at Churchill, 0050 at Frobisher, and 0055 at Coral Harbour. Times are accurate to ±2 minutes in this case. Thus the event is seen first at Cape Jones, the most southerly station, then at about the same time at Churchill and Frobisher, and 5 minutes later at Coral Harbour, the most northerly station.

In the first part of the study, a comparison was made between times of onsets of events occurring at Coral Harbour and Churchill. In the second part, individual events were selected which could be identified on records from at least three of the four stations. The basic data were well-defined events occurring at Coral Harbour during the period from January 1 to the middle of November 1963. Onset times and durations were recorded for 139 events. The times of onsets were then compared with the Churchill riometer records from which well-defined events were selected if they were associated with the Coral Harbour onsets. A Churchill event was assumed to be associated if it started within an hour of the Coral Harbour onset. In the case of multi-onsets at Churchill, the closest major onset was selected; in ambiguous cases, no selection was made. In more than a dozen cases features were sufficiently similar to offer convincing evidence that the coincidence of the events at the two stations was not due to chance. At least two-thirds of the events had spiky abrupt features at one station or the other. Figures 3 and 4 are included to show other characteristics of the events selected at Coral Harbour. In Fig. 3, which shows the distribution in local time of the onsets, the events are seen to occur predominantly before local midnight. The shaded area indicates the number of events at Coral Harbour with which a Churchill event was associated, as

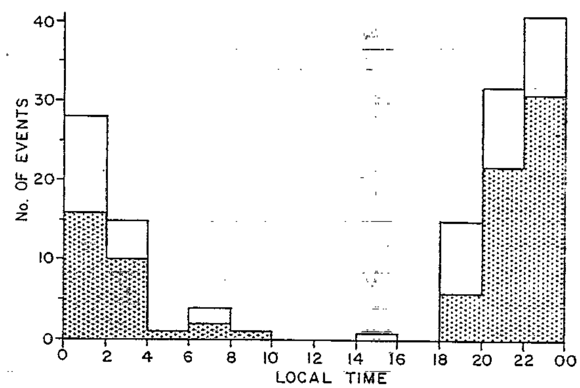

FIG. 3. Distribution in local time of onsets of well-defined events occurring at Coral Harbour during the period January 1–mid-November 1965. The shaded area shows the number of events at Coral associated with an event at Churchill.

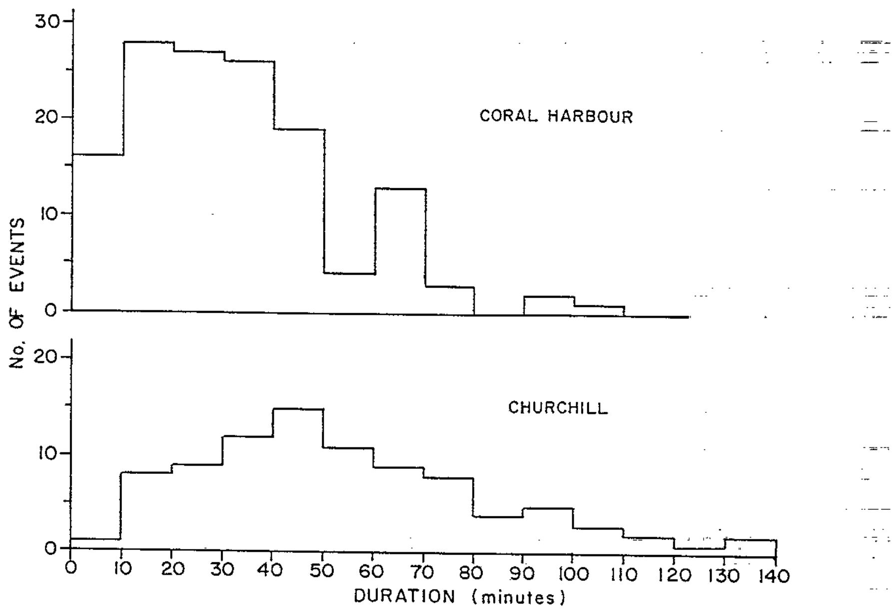

FIG. 4. Durations in minutes of the events occurring at Coral Harbour and at Churchill.

defined above. Two-thirds of the events (90) are seen to be so associated. Of those not uniquely associated, 15 could be ambiguously associated and 14 had a duration of 10 minutes or less. Figure 4 gives the distribution of durations of the Coral Harbour and associated Churchill events. The end of an event was defined to be the time at which the absorption recovered to the preevent level, or until another event started. This definition tends to give a lower limit for the duration. The median duration is about 30 minutes for the Coral Harbour events and 45 minutes for the Churchill events.

The onset time differences between Coral Harbour and Churchill events are plotted in a histogram having 10-minute time intervals, as shown in Fig. 5. It is obvious from the figure that the majority of the events occurred later at Coral Harbour, with a median time delay of 15 minutes (quartile range 3–28 minutes). Assuming direct travel from Churchill to Coral Harbour, such a time delay would correspond to a velocity of motion of about 0.9 km/s (range 0.5–4.6 km/s) or, if motion perpendicular to magnetic shells is assumed, the corresponding median velocity would be 0.8 km/s (range 0.4–3.9 km/s).

To determine the extent of the events and relative times of onset, records from the four stations were compared. During the period May–October, 1963, 17 of the events which had previously been selected could be identified with little ambiguity from the records of at least three of the four stations. Although the number of events is limited, the order of onsets tends to confirm the Churchill–Coral Harbour comparison. The results are set out in Fig. 6, where the events are ranked according to their order of onset, i.e., at Cape Jones 10 of the 14 events

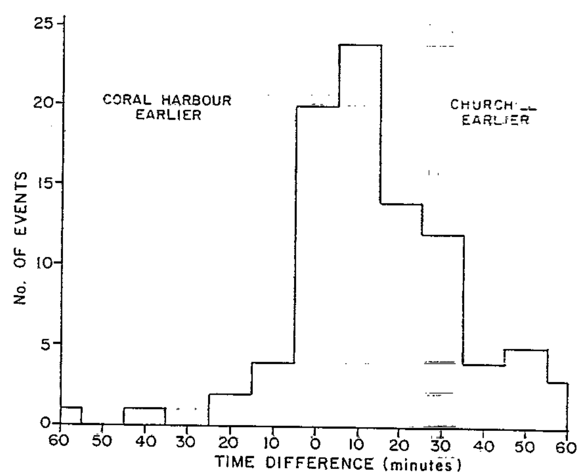

FIG. 5. The differences in onset times of events occurring at Churchill and Coral Harbour.

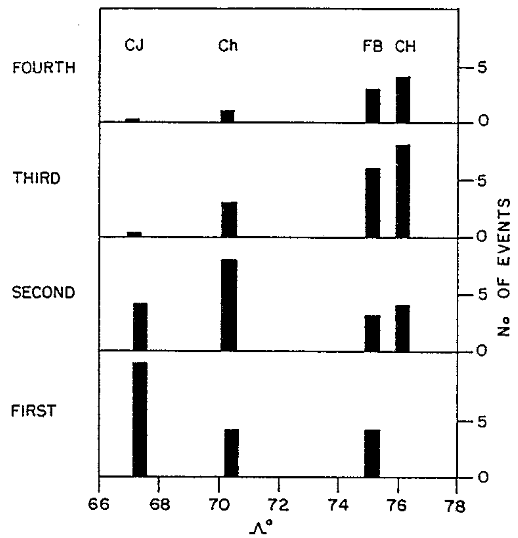

FIG. 6. Numbers of events observed at three or four stations, ranked according to the relative time of onset at each station. The numbers of events are plotted according to the invariant latitudes of the stations.

observed started either at the same time as or earlier than at the other stations. From the figure, it is apparent that there is a strong tendency for the events to occur later at higher latitudes.

Discussion

From the observations reported here, it is apparent that some nighttime auroral absorption events can be identified at stations separated by 9° invariant latitude extending northward to $\Lambda \backsim 76^\circ$ (and even on occasions to Resolute Bay at $\Lambda \backsim 84^\circ$). There is an apparent northward motion of the high-latitude boundary of the events which is shown statistically in Fig. 5, and which can be seen quite convincingly in individual events. The local time of maximum occurrence of the Coral Harbour events, their duration, plus the northward expansion, and the fact that two-thirds of the events had the abrupt onset feature all combine to suggest that the events selected are from the population of breakup associated auroral absorption events. Such motion is consistent with the expansion phase of auroral substorms described by Akasofu (1964). He quotes a northward velocity range of 0.3–1.6 km/s, similar to the velocities determined above from the motion of the high-latitude boundary of auroral absorption from Churchill to Coral Harbour. Apparent motion of events has been shown elsewhere for absorption events seen at Cape Jones and Churchill by Brice and Jelly (1967), who showed that, on the average, nighttime onsets at Cape Jones preceded onsets at Churchill (north and west of Cape Jones) by 10 minutes.

From instances such as those shown in Fig. 2, in which the details of the event at Churchill are reproduced at Coral Harbour at a different time, it appears that there is an actual motion of the source. In many cases, however, features of the disturbance are not recognizably similar at the various stations, even though from time considerations it appears likely that the same disturbance is being observed. Considering the median duration of the events (45 minutes at Churchill and 30 minutes at Coral Harbour) and the 15-minute time delay of the Coral Harbour onsets, it seems probable that the precipitation is usually continuous at Churchill during the period in which it is observed at Coral Harbour. Thus it seems likely that precipitation is continuous over the region between the two stations (5° in latitude) for at least 30 minutes. This would be more consistent with an expansion of the disturbance or a complex source rather than with an actual motion of a single source.

Several authors (Axford 1966; Piddington 1960) have suggested that the source of auroral substorms lies in the neutral sheet in the geomagnetic tail region. Although the method whereby the particles are accelerated and injected into the vicinity of the earth has not been clearly established, according to one proposal particles are energized by merging of the oppositely directed field lines on either side of the neutral sheet. To fit the observations, these field lines would have to correspond to auroral latitudes such that the accelerated electrons would be injected from the tail regions into the auroral zones. The occurrence of aurorally associated phenomena at magnetically conjugate points in the night hemisphere suggests that this may be the case (Westcott 1966). The poleward motion of the substorms would correspond to merging of the field lines in the tail attached to successively higher geomagnetic latitudes.

McDiarmid and Burrows (1965) have reported observations of intense sporadic fluxes of electrons of energies $\geqslant 40$ keV detected by the

Alouette I satellite (1 000-km orbit) at high latitudes at night. They suggested that such electron fluxes, which they referred to as "spikes", probably produced the absorption events reported by Hargreaves *et al.* which maximized before midnight at the South Pole, as referred to above. This suggestion would seem to apply to the events that are reported here and which are considered to be similar to the South Pole events.

An attempt was made to compare the electron spikes reported by McDiarmid and Burrows with individual absorption events, but the comparison was not conclusive because the satellite was seldom in the immediate vicinity of any of the riometer stations when the spikes were detected. However, the phenomena may be compared statistically. Both the electron fluxes and the absorption events maximized before local midnight. The electron fluxes occurred from $\Lambda = 68$–$83°$. The absorption events appear in a similar latitude range. The latitudinal extent of individual events can also be compared. According to McDiarmid and Burrows, the electron spikes are typically less than 2° wide in latitude. From the discussion above, it would appear that absorption frequently extends at least from Churchill to Coral Harbour, a separation of 5° in latitude. From the example shown in Fig. 1, it extends from Cape Jones to Coral Harbour, 9° in latitude. Thus, it seems that, on the average, nighttime absorption events at high latitudes have a greater spatial extent than the intense electron fluxes detected by Alouette I. If the absorption is due to electrons (as is commonly thought), there must be an explanation for the spatial difference. Either the absorption represents the slow decay of ionization produced by the 40-keV electrons or most of the absorption in the events reported here is produced by electrons other than those in the spikes. Because of the irregular appearance of most of the events, unlike a decay, the latter explanation seems more probable. Possibly the intense fluxes of electrons $\geqslant 40$ keV account for the narrow absorption spikes as seen in Fig. 1.

In summary, it has been shown that nighttime auroral absorption events tend to have an apparent motion from the auroral zone towards the pole. This motion ($\sim$0.8 km/s) is consistent with the northward motion of visual aurora described by Akasofu. It appears that for the average nighttime event, electron precipitation is continuous over the invariant latitude range from 71 to 76° for at least half an hour.

Acknowledgment

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