Auroral-Zone Geophysical Events and their Relationship to the Magnetosphere

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Abstract: Studies were made of inter-relations among VLF-ELF-ULF radio noises, ionospheric absorption, geomagnetic variations and aurora at the South Pole, Byrd and Eights Stations, Antarctica. Semi-diurnal peaks in the above geophysical parameters were found: these peaks occurred within a few hours before magnetic noon and others a few hours before magnetic midnight. A geophysical event which takes place in the day sector is called a D (day) event and night sector an N (night) event. The N event is similar to AKASOFU's substorm. One N event consists of three phases called N-1, N-2 and N-3. Early in the evening the N-1 is the major part of the N event. In mid-evening, three phases co-exist. The N-3 is the dominant feature of the late evening N event. Observations made by the Injun III satellite showed that VLF hiss (main feature of the N-1) was observed at the boundary and beyond the region of trapped electrons in the dark sector. VLF chorus (main feature of N-3) was observed in the closed lines of force.

From the above observations, we suggest that the physical characteristics of auroral zone are asymmetric with respect to the day-night major axis. VLF hiss and band-type aurora are the main features of the evening side (N-1). VLF chorus, ionospheric absorption, ULF and patchy and surface-like aurora are characteristics of a post-midnight region (N-3). The break-up (N-2) is the transition between N-1 and N-3.

I. Introduction

Measurements of geophysical disturbances at the South Pole (MOROZUMI, 1962, 1963) revealed that many of the disturbances displayed semi-diurnal characteristics with one peak near magnetic noon and the other near magnetic midnight. Additional evidence is also reported by HARTZ and BRICE. MOROZUMI (1965) called the disturbance occurring during the day side a "D" event and the one on the night side an "N" event. The "N" event is similar to AKASOFU's (1964) auroral substorm; however, the word "event" is used here in a more general sense to cover both day and night disturbances. Several authors (ANSARI, 1964; BARCUS and ROSENBERG, 1966; MOROZUMI, 1966a, for example) investigated these day and night patterns on the basis of one or two geophysical parameters. However, in our research we compare more than six geophysical parameters, which enables us to define event characteristics more completely.

As a result of the recent work (MOROZUMI, 1965), a night event is further divided into three phases (N-1, N-2, and N-3). Figure 1 shows an example of such a night event observed at Byrd Station, which is located in the southern auroral zone. Parameters recorded here are indicated on the left side of the chart. In particular, the channel 1 is VLF of 1 kc/sec with a bandwidth of 100 cps. We identify this channel as a chorus channel; whereas channels 2 and 3 are for a VLF broad band of 1-25 kc/sec. Signals recorded here are identified as hiss. The channel 4 records 30 Mc/sec riometer output. An increase in absorption is in the upward direction on the chart. The channels 5, 6 and 8 record the ULF output (.01~5 cps), and channel 7 records the Z component of the ELF (3~30

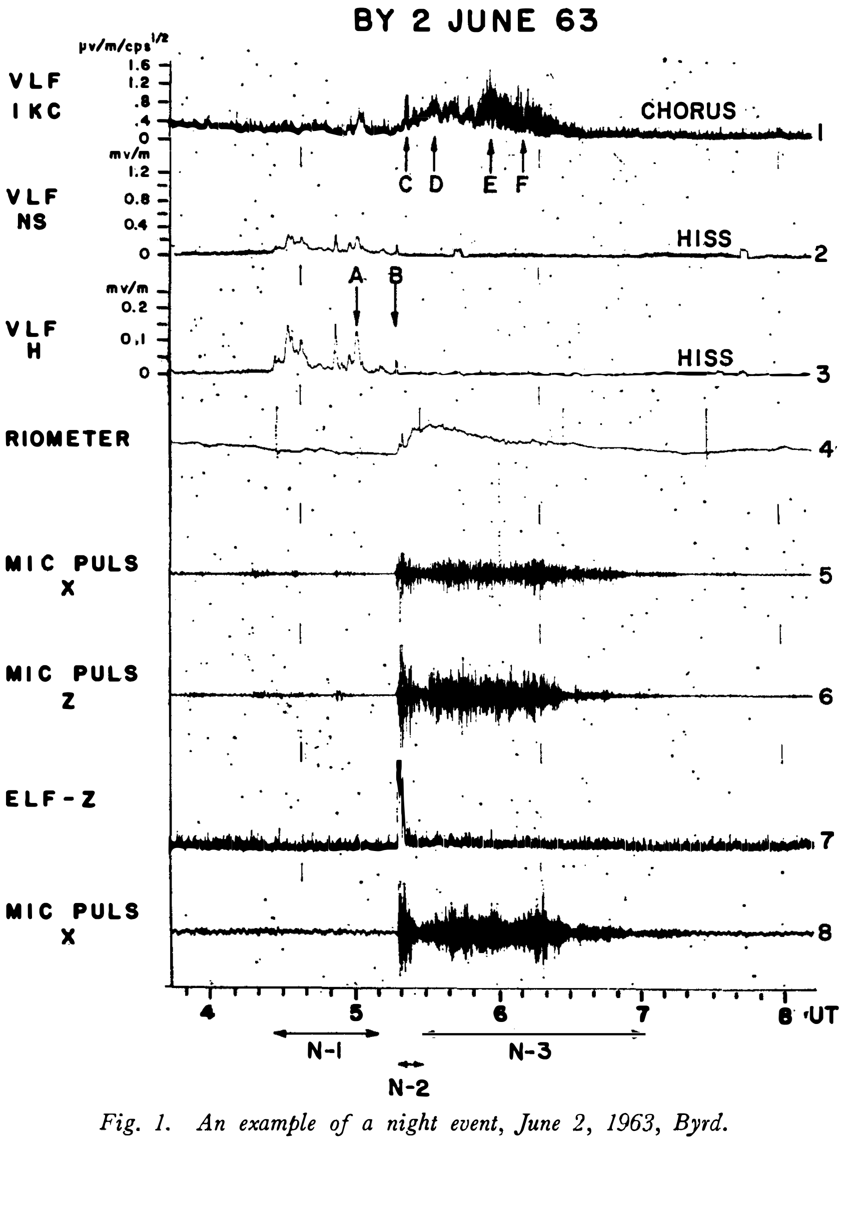

Fig. 1. An example of a night event, June 2, 1963, Byrd.

cps) output. The N-1, N-2, and N-3 phases of the event are indicated by the double headed arrows at the bottom of the chart. Note that the VLF hiss occurs during the N-1 phase (channels 2 and 3). VLF chorus, ULF noise, and ionospheric absorption are the main features of the N-3 phase (channels 1, 4, 5, 6 and 8). The N-2 is the transition between the above two phases. ELF burst is indicative of the N-2 phase (channel 7).

An example of a day event is shown in Fig. 2. Channels 1, 2 and 3 record various components of a wide band (1~25 kc/sec) VLF signal. Channel 4 is the riometer output. Channel 5 is the 1-kc/sec VLF chorus. Channel 6 is the Z component of the ELF output. The last two channels record ULF noise. The ionospheric absorption, VLF chorus, and ULF are the main features of the D event (channels 4, 5, 7 and 8).

The purpose of the present paper is to report further details of the D and N events. The paper describes (i) temporal characteristics such as the local time dependent nature of the events; (ii) the spatial distribution of the events inferred from the records taken at the South Pole, Byrd, and Eights, Antarctica; and (iii) the seasonal variation of the phases. The satellite Injun III VLF and particle records are compared with our ground records. Finally, a magnetospheric model inferred from this study is discussed.

In this paper we use invariant time, which is based on the invariant latitude, whereas the classical magnetic time is based on the dipole system.

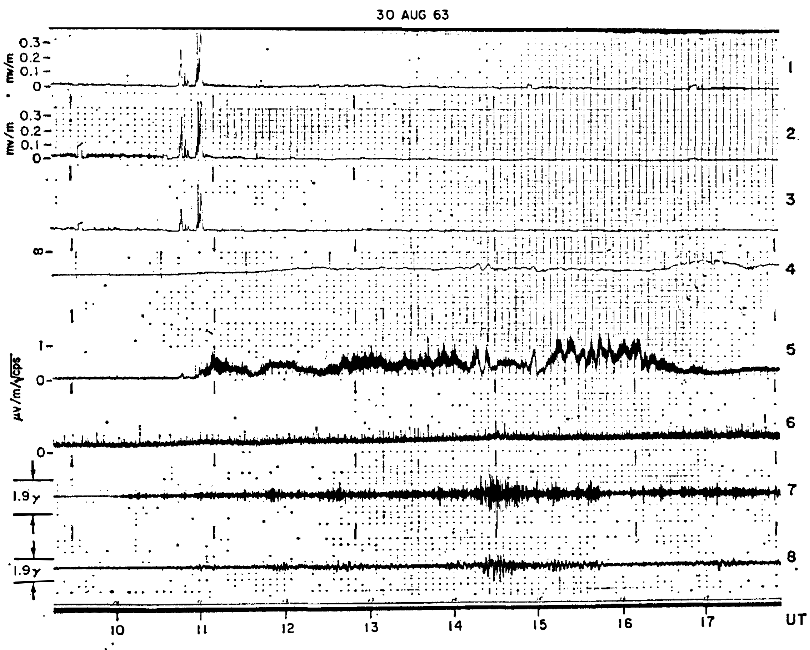

Fig. 2. An example of a day event, August 30, 1963, Byrd.

II. Characteristics of Events

The sequence of N and D events such as shown in Figs. 1 and 2, was discussed by MOROZUMI (1965). We report here the local time dependent characteristics of the events.

1. Night event

An N event has three phases: N-1, N-2, and N-3. However, depending on the time of the day and on the geographical location of the station, a certain phase may either be more clear and distinct from the rest or it may even be missing entirely. In such a case we will call that N event by its most distinctive phase. For example, if the N-1 phase is the dominant feature of a particular N event, then we will call that N event an "N-1 event". However, in a practical case, several N events could overlap. We then call this collection of N events, which has a clear beginning and ending, an "event".

Let us demonstrate these points in Fig. 3, which shows data recorded at Byrd. In the figure, channels 1 and 2 are VLF hiss records. Channel 3 records the auroral light (5577 Å). Channel 4 is the riometer output. Channels 5 and 6 are the ULF signals. Channel 7 records the ELF noise, and the last channel records the VLF, 1-kc/sec chorus. We should note here that invariant midnight is at 0520 UT. The VLF hiss starts at about 0100 UT and ends at 0312 UT. These are the N-1 events. There are three small N-2 phases recognizable at 0203 UT, 0237 UT, and 0305 UT. Therefore this event consists of three N-1 events. The events between 0400 and 0500 UT are N-2 events. The clearest N-2 phase is seen at 0426 UT. The event observed from 0510 UT to 0800 UT is the N-3 events. There is a weak N-1 phase observed from 0510 UT to 0539 UT.

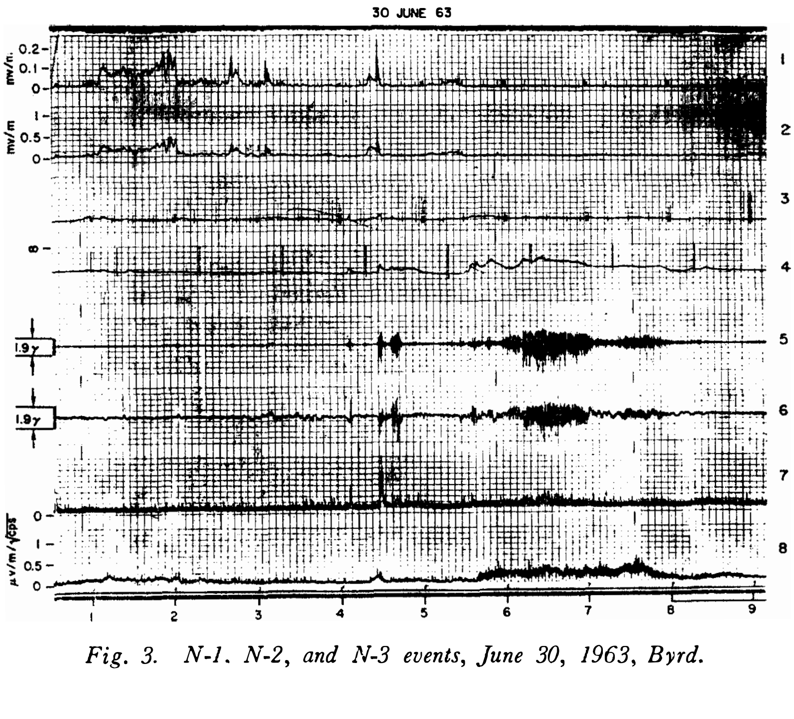

Fig. 3. N-1, N-2, and N-3 events, June 30, 1963, Byrd.

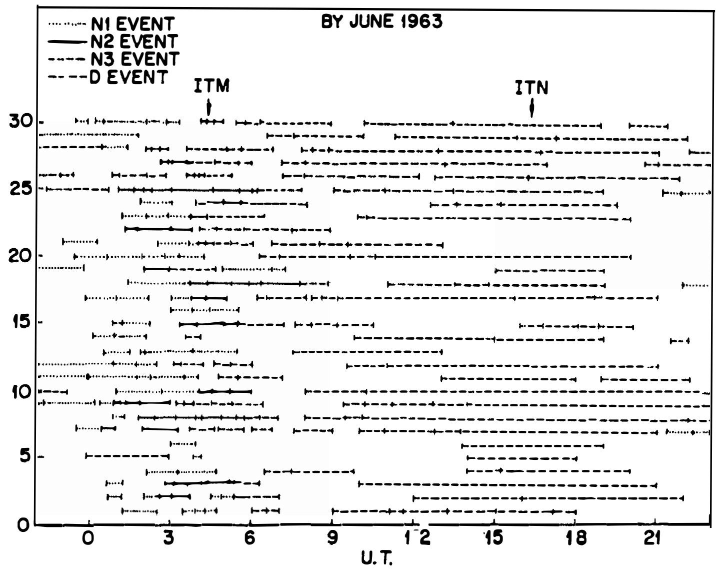

Fig. 4. Duration of events, June 1963, at Byrd Station.

Figure 4 shows the distribution of the duration of the above-explained events over the month of June, 1963, at Byrd Station, Antarctica. One event is marked between two heavy tick marks. Thin tick marks between heavy tick marks indicate the beginning of the N-2 phase of the N event or the beginning of impulsive micropulsation (ULF) noise. The letters ITM and ITN on the top of the figures stand for the invariant time midnight and the invariant time noon. Early during the invariant time evening (23~02 UT), most of the events consist of N-1 events, which are shown by dotted lines. At about 2300~0000 invariant time, most of the events consist of N-2 events (solid lines). We observed more N-3 events (broken lines) in the post-midnight period. This effect is shown statistically by MOROZUMI (1965).

We used VLF hiss to measure the N-1 phase. During the N-1 phase, the ionospheric absorption is usually lower than a few db at 30 Mc/sec (HARANG and LARSEN, 1964). The ionospheric attentuation appears to give a lower cutoff intensity of the VLF hiss. During the N-3 phase and the D phase, the absorption is considerably high. However, the VLF emissions are mostly chorus (500 cps~3 kc/sec), and the attenuation at these frequencies does not appear to alter our measurements significantly.

2. Day event

The thin tick marks in Fig. 4 during the N-3 and D events mark times of outstanding impulsive changes in ULF signals observed during the events. During the D events we observed VLF chorus (MOROZUMI, 1965), riometer absorption (MOROZUMI, 1966b, c), ULF of the Pc type (JACOBS and WRIGHT, 1964), and very low auroral luminosity (MOROZUMI, 1966b). It has been shown that the D events and the N-3 events have many characteristics in common (MOROZUMI, 1965).

III. Spatial Distribution of Events

Now we will discuss the spatial distribution of the events. The N-1 zone is a "local-time" sector where we predominantly observe N-1 events at a particular station. The N-2 and N-3 zones are similarly defined. The N zone is the sum of the N-1, N-2, and N-3 zones, and the D zone is the "local-time" sector where we observed the D events.

Data from the South Pole, Byrd, and Eights Stations, Antarctica, were used here to determine the extent of the events in local-time and latitude. For this purpose the data obtained from Byrd in 1963 (MOROZUMI, 1965) are appropriate. Since the same parameters as Byrd were not available at other stations, events at Eights and Pole are determined from various parameters which are the closest to the Byrd definition of phases. At the Pole station, the VLF hiss occurrence was used to define N-1. The phase N-2 was taken from the aurora curve (MOROZUMI, 1963). The occurrence frequency of auroral diffused surfaces, glow and pulsating surfaces are characteristics of the N-3 event (MOROZUMI, 1966b). Therefore, we used the above parameters to represent the N-3 events at Pole. The day occurrence of the ionospheric absorption was used to define the D event. The records at Pole were obtained in 1960. VLF hiss, chorus and ULF correlation charts were available at Eights in 1963 and various events were derived from MOROZUMI's definition of phases (MOROZUMI, 1965). The width of the distribution of these events is taken to be the interval between two thirds of the maximum distribution of that event. According to MCILWAIN's B-L coordinate system, the location of the estimated magnetic pole is at 75°S and 126°E (SHARP *et al.*, 1966) and the invariant local time is computed with respect to it. Since various parameters observed at Eights and Pole are not the same as those observed at Byrd, we used small letters to indicate Pole and Eights events in the illustrations (*e. g.*, n-1, n-2, n-3, and d).

The N-1 zone is shown in Fig. 5. The triangles on the lines denote the times of maximum distribution. The outer circle refers to the locus of the Eights Station ($\Lambda=60°$). The time of the maximum distribution of the N-1 events (indicated by open triangles) varies depending on the location of the station. However, the distribution of N-1 events tends to become longer at the high-latitude station. This pattern is consistent with the recent VLF hiss plot obtained by JØRGENSEN (1966). In Fig. 6 the distribution of the N-2 events is plotted. The distribution of the N-3 events is plotted in Fig. 7. In Fig. 8 we plotted the D zone. Note in Fig. 8 that the distribution of the maximum D events is at about 1030. Therefore, the D events could be called a forenoon phenomena. It is important to note that D event-like phenomena are observable early in the evening at Eights. Then in Fig. 9 we plotted all the phases together. In order to compare the difference between a classical magnetic dipole time and invariant time, we plotted Fig. 10 according to the dipole coordinates and time. The outer circle refers to the magnetic latitude 60°. Note a change in the peak time of events. They shifted early by one hour or so.

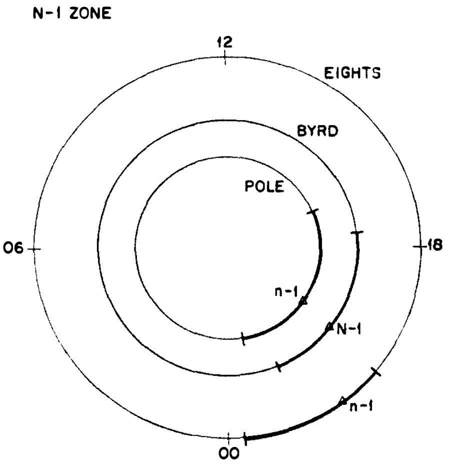

Fig. 5. *N-1 zone at Pole, Byrd, and Eights.*

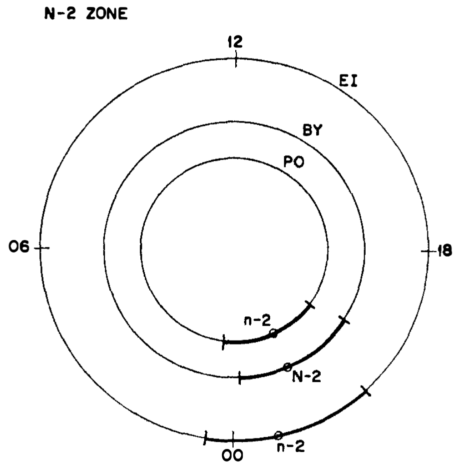

Fig. 6. *N-2 zone at Pole, Byrd, and Eights.*

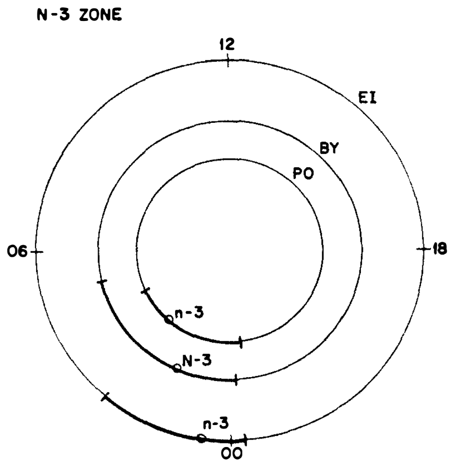

Fig. 7. *N-3 zone at Pole, Byrd, and Eights.*

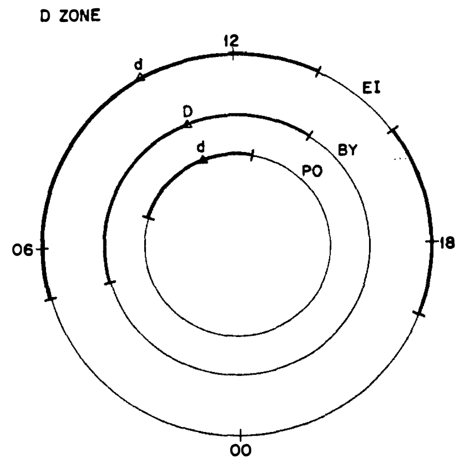

Fig. 8. *D zone at Pole, Byrd, and Eights.*

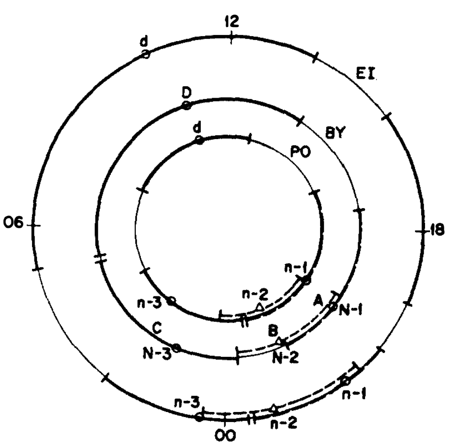

Fig. 9. *All disturbance zones at Pole, Byrd, and Eights.*

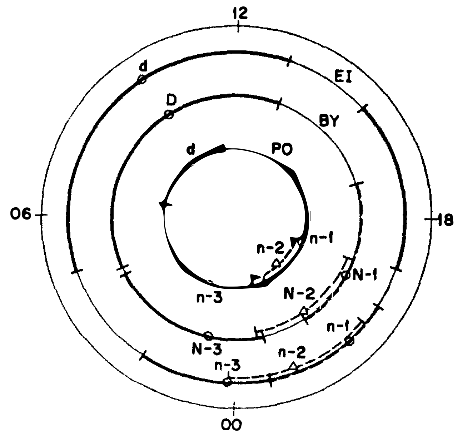

Fig. 10. *Same as Fig. 9 but in a dipole coordinate system.*

IV. Seasonal Variations

In the previous section we have shown the local time distribution of events at high latitudes. We will study next the monthly variation of the peak distribution of events. Records for this purpose are available from Byrd Station only (MOROZUMI, 1966b). The peak distribution time of the events is plotted in Fig. 11 as a function of months (May through October) in 1963. The letters W. S. and S. E., along the abscissa, are abbreviations of the winter solistice and the spring equinox, respectively. Note that in June the time interval between the N-1 peak and the N-3 peak is about 5 hours. However, in October, the time interval between the N-1 peak and the N-3 peak is only 3 hours. We also should note here that the peak times of the events shift as much as three hours.

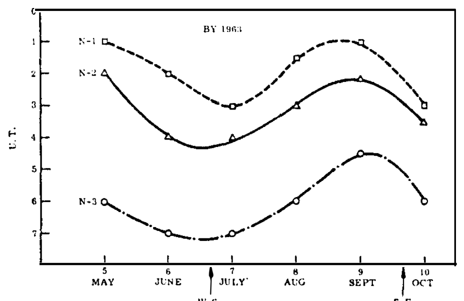

Fig. 11. Seasonal variation of the maximum distribution of N-1, N-2, and N-3 events at Byrd, 1963.

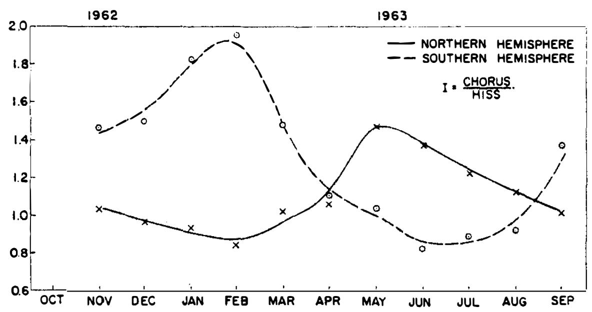

Fig. 12. The ratio of chorus to hiss intensity at Byrd and Great Whale River.

Since we used VLF emissions as a major parameter to define various event characteristics, we examined the seasonal variation of the VLF hiss and the chorus intensities. In order to avoid the effect of the change in the instrument sensitivity in the data analysis, we used the ratio of the average intensity of chorus to hiss for a month to show a quantity, I. The plot of the quantity, I, in both hemispheres is shown in Fig. 12. In the southern hemisphere, I is high during the austral summer months and the I is low during the austral winter months. Figure 11 is in agreement with the results of MOROZUMI and HELLIWELL who have shown that the hiss intensity is higher during winter months than summer, and that chorus intensity is higher during summer months than during winter.

V. Relationship between Satellite and Ground Observations

A relationship between VLF and counting rate of trapped electrons recorded by Injun III satellite is shown in Fig. 13. In order to facilitate the direct comparison with the previous records, we took the direction of the increase in time to be from the right to the left on the abscissa. The direction of the decreasing L value is therefore from the left to the right for this north-bound satellite data. In Fig. 13, VLF hiss of frequency higher than 4 kc/sec, is observable from the

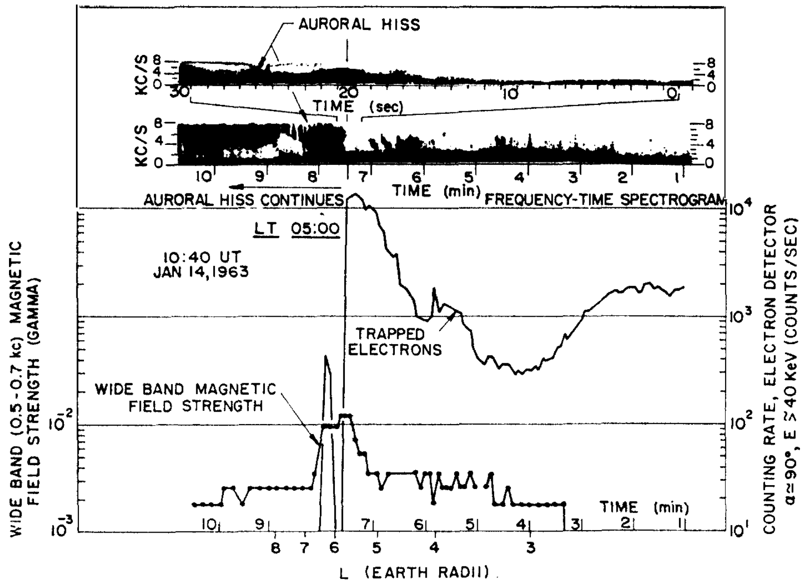

Fig. 13. Injun III record of VLF and trapped particles, January 14, 1963.

high latitude until about L=8. The intensity of this hiss increased as the L value became smaller. VLF hiss observed at 7>L>6 is a wide band noise of frequency 1 kc/sec to 8 kc/sec, which is the upper limit of the frequency response of the instrument. There is an order of magnitude increase in the wide band magnetic field strength at L=5.8. The intensity of the trapped electrons suddenly increased by three orders of magnitude here. It is important to note here that VLF hiss intensity suddenly decreased at the boundary of 40 keV trapped electrons. The counting rate of trapped electrons decreased until about L=3. VLF chorus-like emission is particularly strong at 5>L>4.

In general, a spatial survey by Injun III (GURNETT, 1964) showed that the VLF hiss region exists beyond the latitude of 40 keV electron trapping in the dark sector of the magnetosphere (beyond L=6 in Fig. 13, for example). A similarity exists between this VLF hiss and other phenomena observed on the outside of the electron trapping boundary and the initial phase of a night event (N-1, Fig. 1). A spectrum of VLF hiss pointed out by arrow A in Fig. 1 is shown above line A in Fig. 14. Note the similarity of this spectrum with the wide band hiss noise seen in Fig. 13. The hiss observed at 5:19 (arrow B in Fig. 1) showed a different spectrum from the one observed during the N-1 phase (expanded spectrum B, Fig. 14). The N-2 phase and the phenomena observed at the trapping boundary in Fig. 13 are somewhat similar. The N-2 phase is related to the break-up of the aurora (MOROZUMI, 1966b). It is important to note here that the VLF hiss stopped at the trapping boundary (Fig. 13), and this is typical of the Injun III observations in the dark portion of the magnetosphere (GURNETT, 1964).

The N-3 in Fig. 1 is the post break-up stage of the aurora. Note a large increase in the ionospheric absorption in Fig. 1 and the sudden increase in the

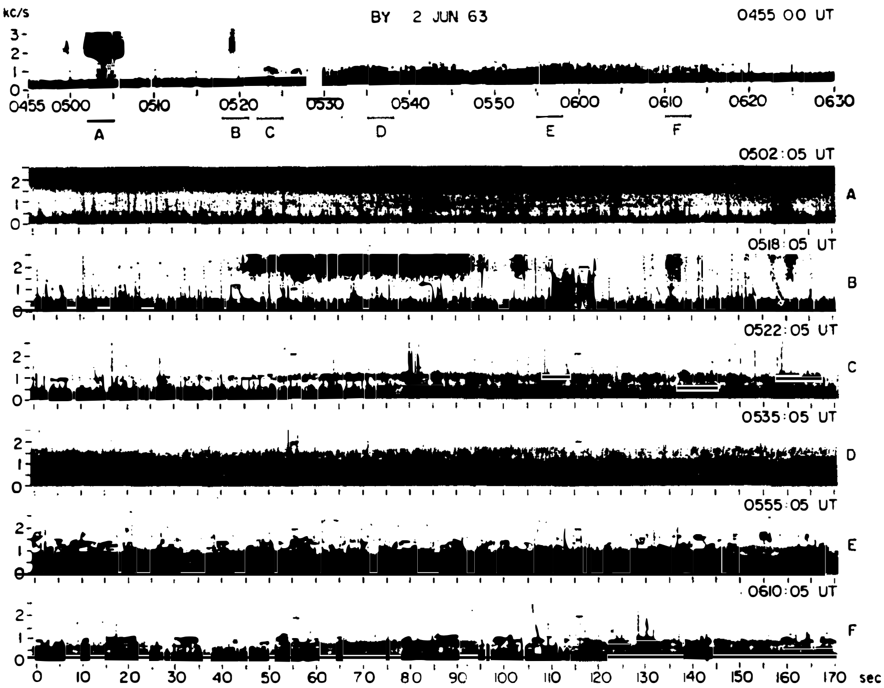

Fig. 14. VLF spectrum, June 2, 1963, Byrd.

trapped particle count in Fig. 13. VLF chorus was observed throughout the N-3 phase (the top channel in Fig. 1). The spectra of VLF chorus indicated by arrows C, D, E, and F (Fig. 1) are shown above lines C, D, E, and F in Fig. 14. Aural comparisons of this N-3 chorus and the chorus-like emission observed at the satellite at 5>L>4 (Fig. 13) showed that they are practically the same kind as far as the ear can distinguish. Further, a comparison of VLF spectra of Fig. 13 with the VLF spectra at the top of Fig. 14 shows further indications of the over-all resemblance of the observations made on the satellite and at the ground station.

VI. Discussion

The Injun III record (Fig. 13 for example) showed that VLF hiss is observable at the outside of the electron trapping and VLF chorus was observable near the electron trapping region. From the above observations, we first constructed a simple model which is shown schematically in Fig. 15 (a). The heavy circle is the 40 keV electron trapping boundary. The dark shaded area is the VLF hiss zone and light shaded area is the VLF chorus zone.

Taking the diurnal variation of VLF hiss and chorus on the ground into consideration, we eliminate the morning sector of VLF hiss and evening sector of VLF chorus to construct Fig. 15 (b). Essentially Fig. 15 (b) is a simplified version of Fig. 9. Fig. 15 (b) shows a clear asymmetry between the evening side and the post-midnight side of the 40 keV electron trapping boundary. VLF hiss is generated mainly near the outside of the evening boundary and VLF chorus

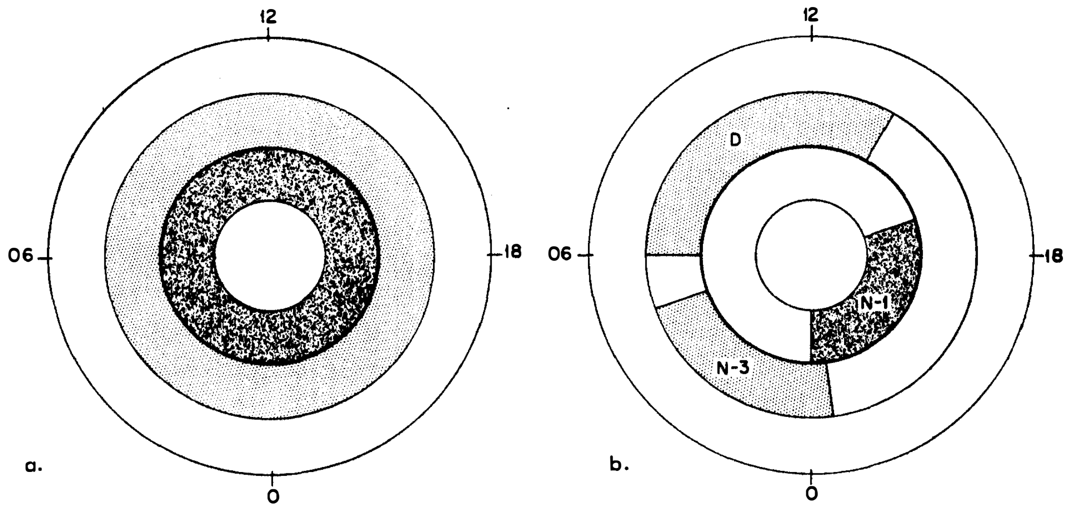

Fig. 15. Schematic diagram of VLF hiss and chorus zones.

is generated mostly near the inside of the post-midnight boundary and the forenoon portion of high-latitude region. This aforementioned pattern is considered to be fixed with respect to the earth-sun geometry. The earth rotates under this pattern.

Let us trace the locus of the Byrd Station under this pattern in Fig. 9. The second circle from the outer one in Fig. 9 is the locus of the Byrd Station. When Byrd enters the N-1 zone (A, for example)the occurrence of an N event manifests the N-1 phase most strongly. Therefore, an observer at A sees this N event as an N-1 event. About an hour before midnight, should an N event take place, Byrd can observe the effect of N-1 and N-3 equally. This transition phenomena between N-1 and N-3 is called the N-2 (at B). Late in the evening, Byrd is under the closed lines of force again (marked C). An evening event observed here should show an intense N-3 and moderate N-2 and a weak N-1. In the morning Byrd enters the excited zone of closed lines of force. This is the D zone. Phenomena observed here are the D events. It is very important to note here that the sequence (N-1, N-2, and N-3) of events is a temporal variation. The magnitude of phases is dependent on the location of the observer when the event takes place (spatial variation).

Studies of the seasonal variation of the phases, although not complete, show that the time interval between the N-1 and the N-3 changes in value depending upon the time of the year. This implies that the location of the trapping boundary described in this note changes. Therefore, measurements of the phases on the ground enable us to infer the motion of the trapping boundary.

A multichannel correlation recorder (measuring VLF hiss, VLF chorus, riometer and ULF, all with calibrations), located around the northern and southern aurora zones about 1000 km apart, together with latitudinal distribution of about 500 km apart, starting at the geomagnetic pole to 50 degrees of colatitude together with an earth satellite (measuring VLF, cosmic noise, particle flux, and magnetic-field variations) will be one of the most effective systems to study spatial and temporal variations of the day and night events described here. Such an investigation will help understand not only individual phenomenon like VLF but also more complex processes like auroral substorm and other magnetospheric processes.

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