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Some Characteristics of Geomagnetic Pulsations at Frequencies Near 1 c/s[1]

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This is a report of some particular characteristics of unique natural electromagnetic field variations in the frequency range of 3.3 c/s to 0.15 c/s observed at the earth's surface. The signals usually exhibit a rising frequency fine structure but variations are observed. The midperiod and emission element recurrence period of an event are linearly related. The bursts of activity usually last about 1/2 hr, but a gross recurrent pattern may persist, on rare occasions, as long as 12 hr. Pulsations associated with field lines reaching the greater radial distances occur near the noon meridian; midfrequencies are lower at this time. Signals are generally not simultaneous at most high latitude stations in the same hemispheres, but the world level of high activity usually persist for several days. Although no seasonal or 27-day solar controlled periodicity was observed the emissions are more likely to occur during high solar activity and in the week following large major magnetic disturbances. No ionospheric effects associated with the field variations were clearly found. Although no great difference in the number of events was noticed for high and middle latitudes, there was a scarcity of such signals at the equator. Conjugate point stations show uniquely similar activity. There may be an alternation of the fine structure between stations in opposite hemispheres on the same earth's magnetic field line. In the high latitudes, the magnetic flux density vector of the emission appears to describe a plane perpendicular to the earth's field line, polarized in a counter clockwise sense, and elliptically elongated in the N–S direction.

1. Introduction

This report concerns itself with natural electromagnetic field variations in the frequency range of 3.3 c/s to 0.15 c/s which have been observed at the earth's surface. Such pulsations, whose amplitude-time trace seems to have a rather "regularly and mainly continuous character" have been named group "pc 1" by a recent IAGA resolution[2] and have been referred to occasionally by such terms as "pearls" and "hydromagnetic emissions." Herein, we will use the words pc 1, pulsations, and emissions interchangeably.

This paper represents some of the studies carried on by the Ultra Low Frequency Group of the National Bureau of Standards Central Radio Propagation Laboratory. Its purpose is to give an orderly resumé of the present level of observational knowledge concerning a unique electromagnetic phenomenon in the limited frequency band. No speculation on the nature of the extraterrestrial origin of these emissions will be attempted. The paper will emphasize the need for more definitive experimental studies of particular aspects of the observable geophysical pulsation characteristics.

Although an historical review is also not intended as part of this paper, it should be recalled that the magnetic flux density fluctuations described herein were first reported by Sucksdorff[3] and Harang[4] in 1936 and have been a part of the world scientific literature since that time. The recent surge of interest in the phenomenon had its genesis in the IGY and has been stimulated, lately, by the realization of space minded geophysicists that the energy propagates through the magnetosphere and, therefore, must relay information of this region to the earth's surface.

2. Data Sampling

The magnetic flux density vector was measured with large, 2 m diam loop antennas of 8 and 16 thousand turns. A single antenna, oriented in the magnetic N – S axis direction, was used at each site except during the polarization studies when three mutually orthogonal loops were employed. The received signals were amplified, multiplied by an inverse function of frequency, limited to a narrow pass-band ("high channel") peaking at 1.5 to 2.0 c/s with −20 dB points at about 0.3 and 7.0 c/s, then recorded on charts mov-

[1] Paper presented at the ULF Symposium, Boulder, Colo., 17–20 August 1964.

[2] IAGA Resolution No. 13, XIII General Assembly of IUGG, Berkeley, Calif., August 1963.

[3] Sucksdorff, E. (1936), Occurrences of rapid micropulsations at Sodankyla during 1932 to 1935, Terrest. Magnetism Atmospheric Elec. **41**, 337–344.

[4] Harang L. (1936), Oscillations and vibrations in magnetic records at high latitude stations, Terrest. Magnetism Atmospheric Elec. **41**, 329–336.

ing at a 6 in./hr speed. On occasions, the amplified signal from the antenna was recorded on magnetic tape having a slow transport speed of 0.01 in./sec.

The maximum signal amplitude in each 5 min interval was scaled for activity appearing in the "high channel" but unaccompanied by activity in the next lower record frequency band. This method excluded the "structureless" irregular pulsation activity of another type which has been associated with auroral ionospheric absorption and luminosity events. For periods when magnetic tape records were available, the continuous spectral "rayspan" displays of data were obtained by analysis of tape played back at several thousand times the recording speed. Frequency information was obtained from these presentations. All scalings were placed on punched cards and handled by standard computer techniques.

Table 1 lists the eight stations used in the study with general information regarding their location and the data sampling periods. Several items should be noted in this table. The general termination date for the study near the early part of 1964 represents a time when most stations had been changed to a newer, frequency modulated, magnetic tape recording system. Macquarie was only operated for the 3 months indicated. The range of maximum radial distances for earth's magnetic field lines associated with the station varies from about 2.4 to 7.2 earth radii, (r_e). Baie St. Paul-Eights, Great Whale River-Byrd, and College-Macquarie represent three conjugate station pairs in order of decreasing conjugate location accuracy. Kiruna, Great Whale River, and College represent three widely spaced northern auroral zone stations.

TABLE 1

Code	Station and data period	Geographic		Geomagnetic		Conjugate location geographic		Maximum radial distance (r_e)
		Latitude	Longitude (W)	Latitude	Longitude (W)	Latitude	Longitude (W)	
KI	Kiruna, Sweden, 27 November 1962–5 May 1964	67.8 N	339.6	65.3 N	244.1	58.7 S	296.2	5.45
GW	Great Whale River, Canada, 9 February 1963–16 November 1963	55.2 N	77.5	66.6 N	11.2	80.2 S	115.0	7.00
CO	College, Alaska, USA, 12 December 1961–10 February 1964	64.9 N	148.0	64.7 N	103.5	57.0 S	165.0	5.58
QU	Baie St. Paul, Quebec, Canada, 18 April 1963–5 May 1964	47.3 N	70.3	58.7 N	0.7	75.4 S	78.5	4.01
BO	Boulder, Colo., USA, 28 November 1962–20 February 1964	40.0 N	105.0	48.9 N	43.1	54.5 S	132.0	2.37
MQ	Macquarie Island, Australia, 19 December 1961–28 February 1962	54.5 S	201.0	61.1 S	116.9	65.2 N	165.3	5.41
EI	Eights Station, Antarctica, 15 December 1963–8 February 1964	75.4 S	77.2	63.9 S	4.1	47.3 N	70.1	4.00
BY	Byrd Station, Antarctica, 5 April 1963–25 December 1963	79.6 S	120.0	70.4 S	24.0	55.5 N	79.5	7.19

3. Appearance of the Data

What one might call a typical event for the class of emissions represented in this study is illustrated in the figure 1 spectral display. Not unusual is the more complex event type shown in figure 2. The rising frequency fine structure (positive slope df/dt) has a regular recurrent rate of period, T_{rec}, and a characteristic midperiod, t_{mid} (or midfrequency f_{mid}). Often a fanlike fine structure with a progressively decreasing slope is observed, figure 3, and on rare occasions a negative slope event like figure 4 is found. Not too unusual are events with faint or no indication of fine structure (fig. 5). Although the emission generally appears singly of less than 1 hr duration, regular recurring emissions lasting for 3 to 12 hr have been observed. Figure 6 illustrates three of these cases where the event midfrequency is constant, gradually increasing, and gradually decreasing. In these "rayspan" displays, a mirror image of the events is shown beneath the zero frequency base line. The occasionally apparent dark spreading of this base line indicates aurorally associated field fluctuations of another type.

The amplitude-time display of the characteristic event is illustrated in figure 7. The top part of the figure shows 40 min of the handsome "bead-on-a string" type envelope that led to the early "pearl" name; an expanded 10 min of this sample in the lower part of the figure resolves the individual oscillations. Amplitude variations may show both the individual bursts of emission characteristic of figure 1 as well as the "beating" of several instantaneously overlapping emissions of slightly different frequencies typified by figure 2. This fact must be remembered in assigning proper significance to the measured "amplitude" of an event or to the recurrence period of the amplitude maxima.

4. General Characteristics

Events of the type discussed above have been observed in the broad frequency range from 0.15 to 3.3 c/s at all stations. A linear relationship between the structure recurrence period T_{rec} and the mid (or average) period of the emission t_{mid} seems to be a typical feature. The best fit to these 145 scaled events, sampled from August, 1963 to February, 1964, at College, Alaska, shown in figure 8 is

$$T_{rec}\ (\text{sec}) \doteq 86 t_{mid}\ (\text{sec}).$$

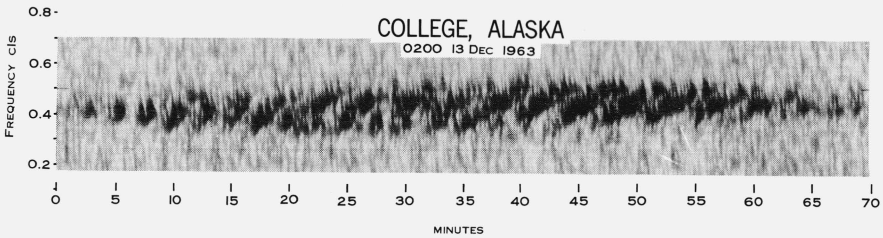

FIGURE 1. *Representative event from College, Alaska, December 13, 1963.*

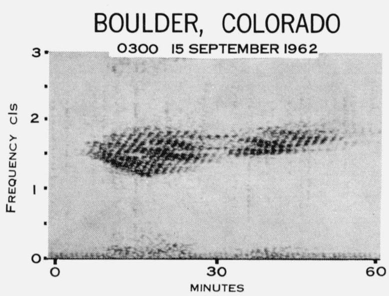

FIGURE 2. *Complex event with overlapping structure from Boulder, Colo., September 15, 1962.*

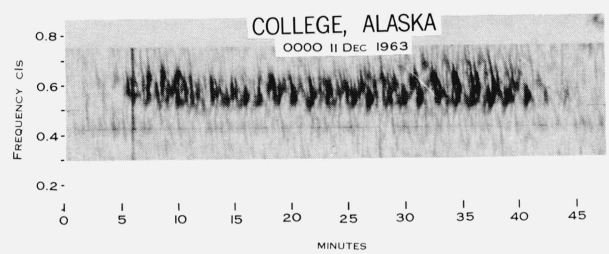

FIGURE 4. *Negative slope structure in event at College, Alaska, December 11, 1963.*

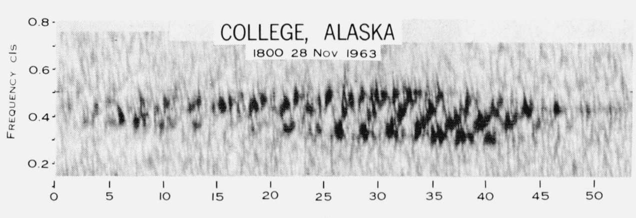

FIGURE 3. *Fanlike structure event from College, Alaska, November 28, 1963.*

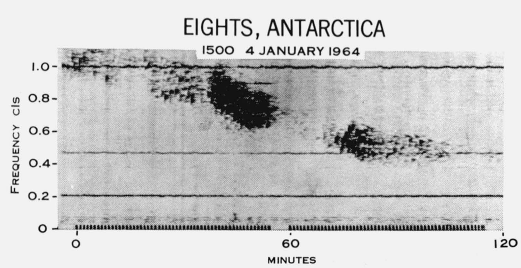

FIGURE 5. *Unstructured event at Eights Station, Antarctica, January 4, 1964.*

The duration of an emission seems independent of the station location. Figure 9 shows the percentage of 1,102 events at Kiruna, Sweden, which last at least the number of minutes indicated. Fifty percent of the events have a duration of at least 35 min. Figures 1 and 2 are of this type. Only 10 percent persist for 2 hr (fig. 6 types are less frequent than this). In figure 10, we show the percent of time events were recorded above indicated levels of intensity for three-month groups of data at Kiruna, Sweden. The magnitude and duration of events varies greatly through the seasons at all stations. Below 10 milligamma, the decreasing ability to discriminate signal within the site noise level enhances the negative slope of the curves. Assuming that an event lasts 35 min (fig. 9), these graphs imply that between 12 to 49 emissions might be expected to occur above 10 milligamma in an average month.

The long duration events of figure 6 often indicate an activity recurrence of a half to 1 hr but no autocorrelation of this period appears in the analysis of all Kiruna data of figure 11. To search for a possible, solar related, 27-day recurrence pattern in the activity, we prepared figure 12, an autocorrelation plot for all

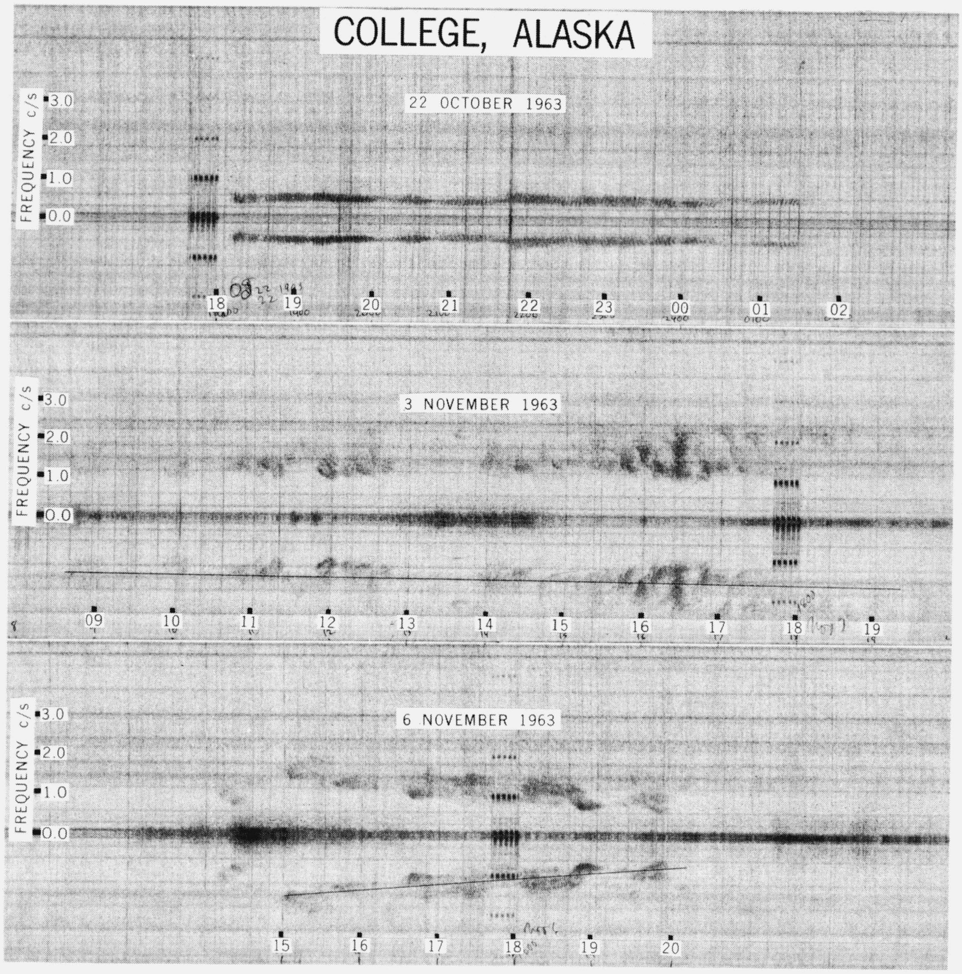

FIGURE 6. *Long duration events at College, Alaska, showing cases in which the midfrequencies remain constant, rise slowly, or decrease slowly.*
In this display, a mirror image of the event is shown beneath the zero frequency base line. The UT hour is indicated.

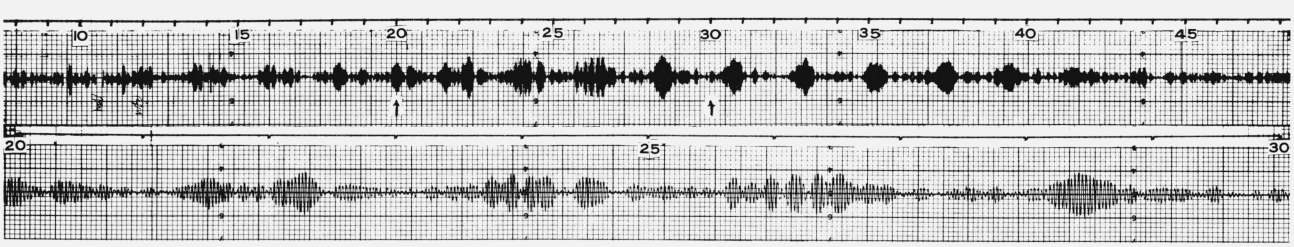

FIGURE 7. *Example of amplitude variation for event at Macquarie Island from 0008 to 0048 on February 10, 1962 (upper trace).*
An expanded 10 min of the upper record appears as the bottom trace.

the Kiruna data using daily indices obtained as the average of the eight, 3 hr indices derived from the average of the three maximum 5-min values scaled in each hour. No significant recurrence pattern was found at any station from 0 to 30 days.

The polarization of the vector signal has not been thoroughly investigated at all stations at this time; nevertheless, some of the three orthogonal field component measurements made at College in August 1962, may well be indicative of the signal propagation characteristics. Figure 13 is a scaled representation of the end point trace of the magnetic flux density vector in each of three planes and in space for about four oscillations during maximum amplitude excursions. The field vector lies essentially in a plane perpendicular to the magnetic field line (dashed line in fig. 13) and rotates in a counter-clockwise sense viewed into the earth along a field line. The vector plane is elongated in a general geographic north-south direction. Several scaled vector examples indicate the same

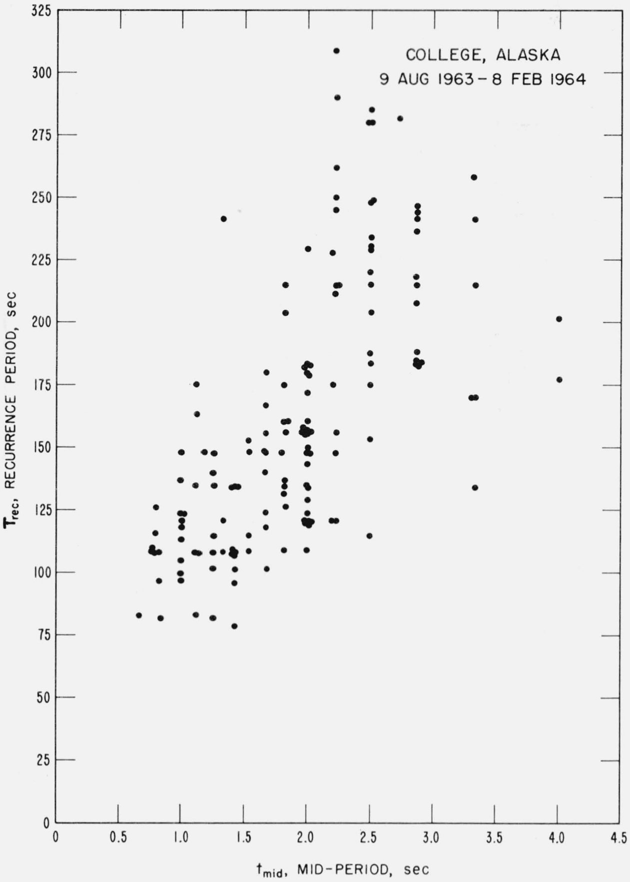

FIGURE 8. *Distribution of recurrence periods for 145 events of given midperiods at College, Alaska, from August 1963 to February 1964.*

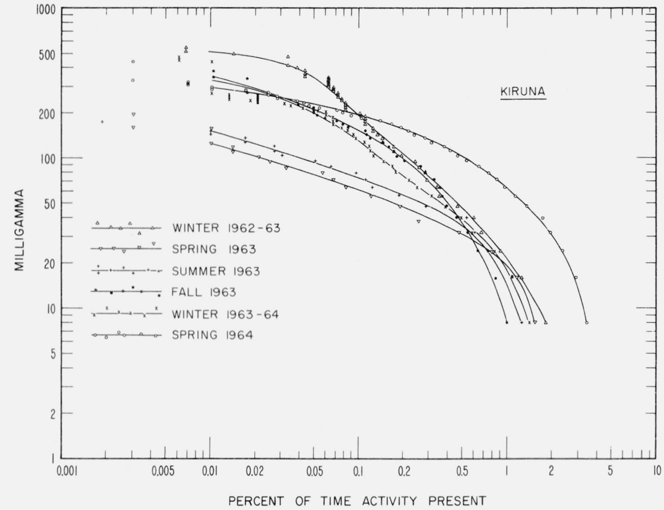

FIGURE 10. *Percent of time for events recorded above indicated levels of magnetic flux density for seasonal groups of data from Kiruna, Sweden.*

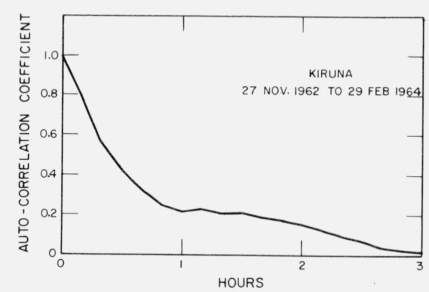

FIGURE 11. *Autocorrelation coefficient for 5-min data samples at Kiruna, Sweden, to 3 hr.*

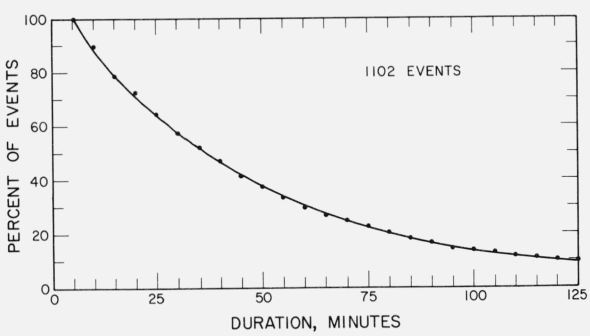

FIGURE 9. *Percentage of 1,102 events lasting at least the times indicated at Kiruna, Sweden, from November 1962 to May 1964.*

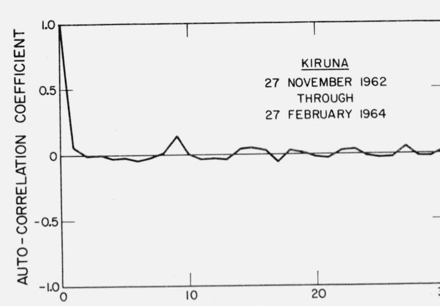

FIGURE 12. *Autocorrelation coefficient for daily values of activity at Kiruna, Sweden, to 30 days.*

general features although the plane occasionally degenerates to a line and the rotation sense may briefly reverse. Beating between simultaneous elements of the rising frequency (fine structure discussed in sec. 3) may readily confuse the polarization picture. For example, it may easily be shown that two of the rising frequency emissions like those shown in figure 2, whose magnetic flux density vectors are elliptically

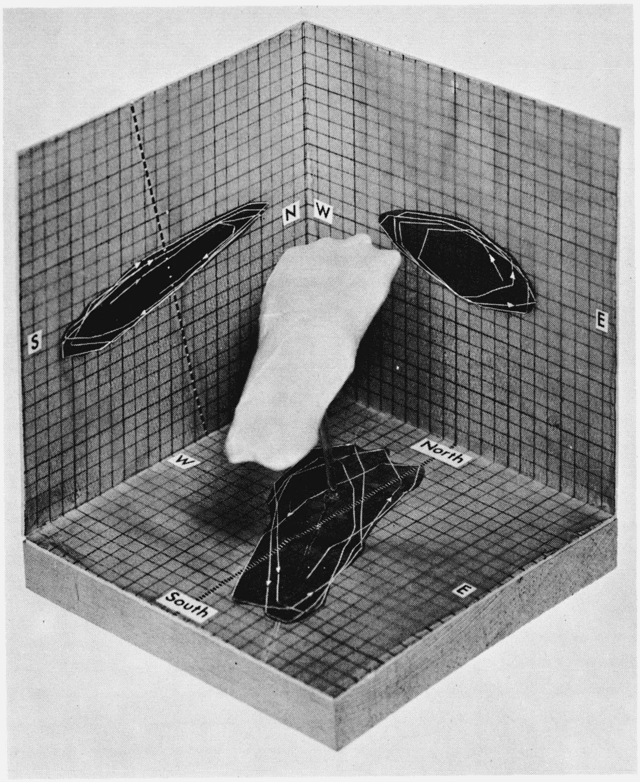

FIGURE 13. *Trace of magnetic flux density vector in three planes and in space for 4 oscillations during maximum amplitude excursion at College, Alaska, on August 16, 1962 at 0330 UT.*

plane polarized with the same field vector rotation sense, but with slight differences in the direction of the major axes, may at times seem to give a linear degeneration of the vector plane and then briefly reverse the rotation sense. Through the cyclic change lasting a beat period, for the major portion of time and larger amplitudes, the ellipse described by the summation vector displays the same polarization sense and average axial direction of the two composite elements. Figure 13 probably represents a typical vector plane and rotation sense for a rising frequency element at high latitudes. One determination of the signal polarization at Boulder has shown an extreme range of variability.

5. Worldwide Features

Each station displays its own characteristic diurnal occurrence pattern. No seasonal variation is presently indicated. For each conjugate station pair, the diurnal occurrence graph alined best when the two related stations were arranged on a similar time scale (such as UT). However, the best order for arranging data from all stations occurred when a local time was used for each site. In figure 14, we show the station diurnal activity curves plotted to approximate a view down on the North Pole with the hourly activity pattern displayed along an equatorial radius corresponding to each station (table 1). To do this, the average local time at a station and its conjugate location (table 1) was taken to be the approximate local time at the equatorial location of the geomagnetic field line connecting the two surface sites. Evidence, presented in succeeding paragraphs, that the signals do travel on the field lines, encourages the radial field display of the emissions with respect to the sun direction in this way. Note the high signal occurrence near the noon meridian along the outer field lines and the westward, early morning, occurrence at smaller radii.

Figures 15 and 16 illustrate a similar diurnal variation in midfrequency of the events for College and Boulder in local time. These values were scaled from the rayspan displays of the magnetic tape recordings. The College data of figure 15 were separated on the basis of observability of recurrent fine structure. The slight difference in these two occurrence patterns seems to result from the fact that at the time of general minimum activity the events, being fainter, make it more difficult to detect structure. The Boulder data, figure 16, were not separated into structured and unstructured types. The distribution shows a greater spread of frequencies in this sample but a local time, diurnal distribution similar to that at College with low frequencies near 1600 local time and high frequencies near 0400 local time. Note that the occurrence maxima for these samples happen near 0300 local time at Boulder and near 1400 local time at College. It appears, then, that higher frequencies are observed on the early morning side of the earth and minimum frequencies near the afternoon meridian. The earlier time appearance of occurrence maxima with smaller radii shown in figure 14 doesn't seem to be accompanied by a similar shift in midfrequency. Station reports of averaged higher frequencies at lower latitudes probably results from the appearance of local occurrence maxima at different times with respect to a fixed local time diurnal midfrequency pattern.

In figure 17, long duration events for College during the period August 1963, through February 1964, are plotted. The same typical diurnal midfrequency pattern of figures 15 and 16 is followed. In other words, the regularly occurring emissions lasting for 3 to 12 hr rise, fall, or remain constant in midfrequency in a fashion commensurate with the local time at the observing station.

One should note now, that the linear relationship of the midperiod, t_{mid}, with the fine structure recurrence period, T_{rec}, implies a diurnal variation of T_{rec} in keeping with figures 15, 16, and 17 showing the longer recurrence periods near the afternoon meridian.

We have seen in figure 10 an illustration of the variability of activity level for the typical station. Figure 18 indicates what may be expected for stations of varying latitudes using data scaled from the chart records during the sampling period indicated in table 1. The differences in average signal activity level between stations at middle and high latitudes seem to be within the range of variation one might expect at any one station; no latitude dependence is found here. Nevertheless the activity has been reported

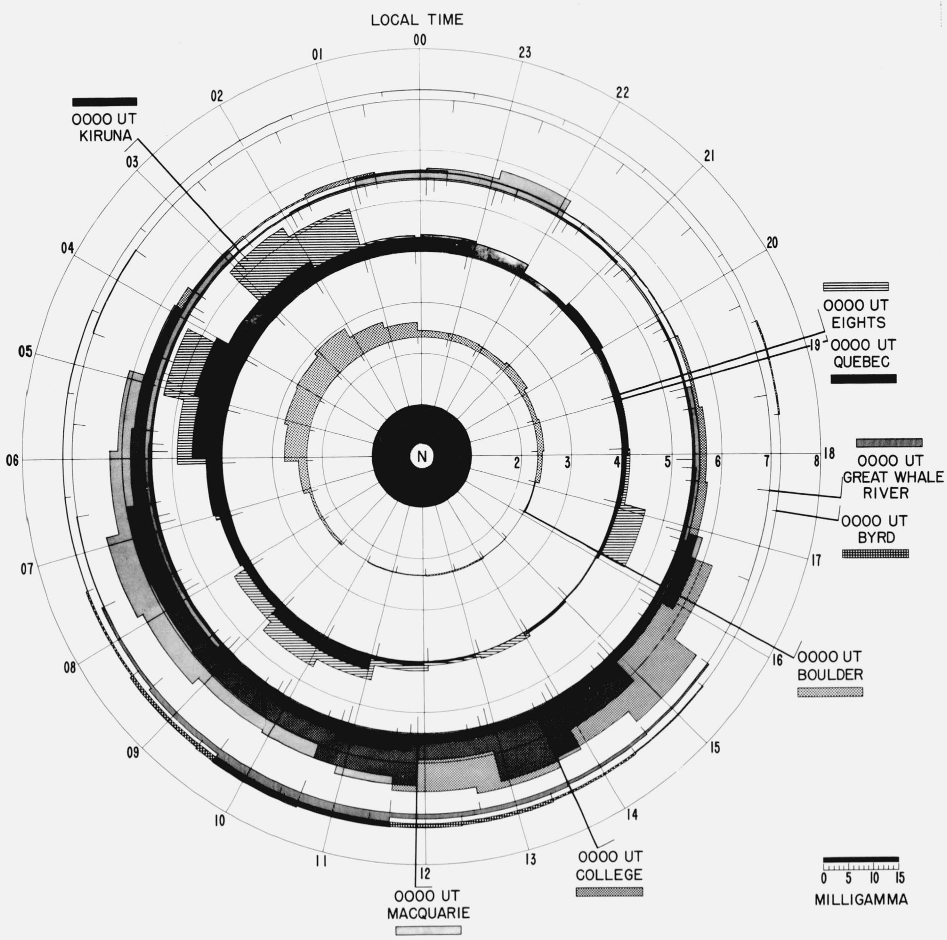

FIGURE 14. *Station diurnal activity viewed in the equatorial plane at radii corresponding to the field line connecting to the station.*

The average local time at each site and its conjugate (table 1) was taken to be the approximate local time of the magnetic field line at its equatorial location. The UT hour for each station graph is indicated.

to be a minimum at the equatorial station at Jicamarca, Peru and at the polar station near Thule, Greenland. In a brief Alaskan program of August 1962, with stations at College and Fort Yukon separated by about 226 km, the data indicated a general coherence of the events over this distance but significant differences in signal appearance were not unusual. The cross-correlation function is essentially zero for pairs of northern latitude stations in table 1 indicating that the signal coherence has about disappeared for the usual event at distances of the order of 1000 km (Great Whale River to Baie St. Paul). At middle and low latitudes, identical signals have been reported by other workers over distances as great as 5,000 km. Perhaps, this is another indication of a changing behavior of the signal at the lower latitudes. A systematic study of the extent of a signal as a function of distance at various latitudes is certainly needed.

Only between conjugate station pairs were significant activity correlations obtained. Figure 19 shows the lead-lag cross-correlation diagrams for hourly activity (sum of twelve, 5 min values centering on the hour) at our three sets of stations using all available data. For each pair, the maximum coefficient of about 0.4 to 0.5 was reached near the zero offset hour. In figure 20, we show a closer view of the cross correlation between conjugate stations for 5 min scalings plotted by months. Still the maxima occur close to zero time offset. The highest correlation of about 0.85 was obtained for the Quebec-Eights pair in December of 1963. These stations are not only the pair nearest to the exact computed conjugacy, but are closer to each other in local time than the other two and at a lower latitude. A significant, secondary, 0.4 correlation peak of Macquarie before College by about 2.3 hr. is in the wrong direction to be related to the local time difference between these stations.

In the three sections of figure 21, we used only the 5-min scalings at times when both stations had measureable activity and we divided the events in 6-hr Universal Time groups. In the Quebec-Eights plot, the coefficient at zero offset was always large.

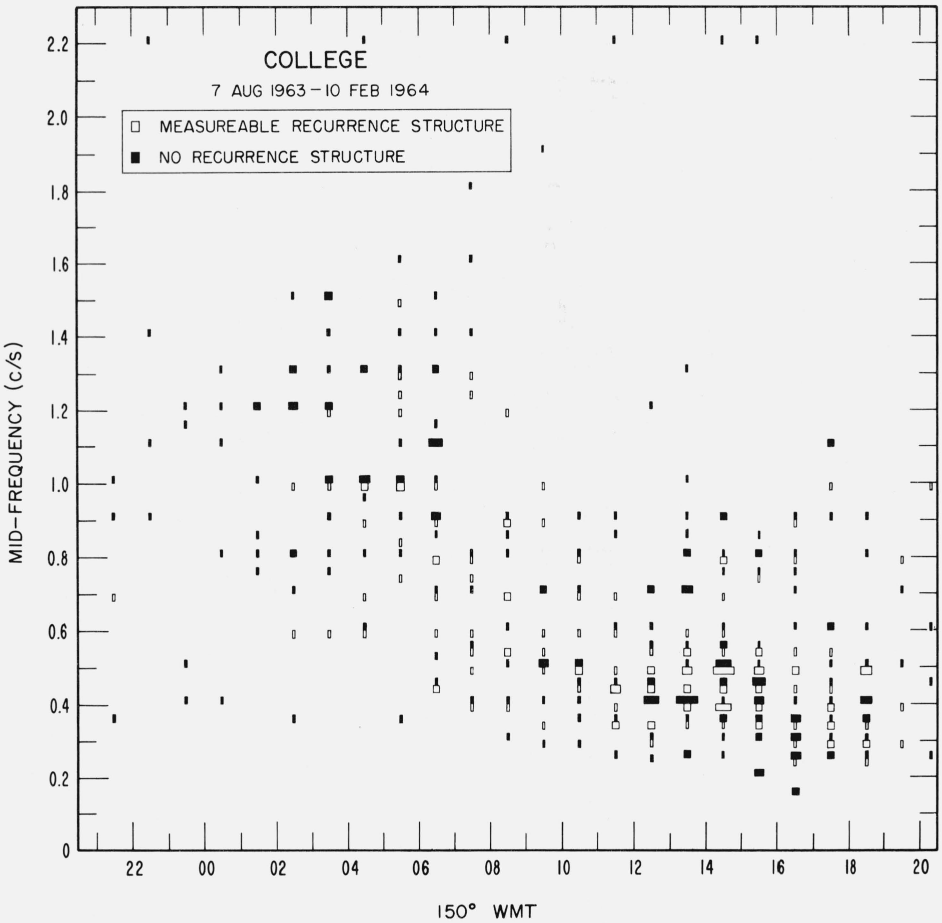

FIGURE 15. *Diurnal variation of midfrequency of events at College, Alaska, from August 7 1963, to February 10, 1964, separated for apparent presence and absence of recurrent fine structure.*

There were insufficient data for an 1800 to 0000 UT plot. The lowest value of 0.65 was obtained in the 0600 to 1200 hr group—the predawn hours of local maximum activity for the stations. The second peak at +1 hr may be significant; it is a shift in the direction (QU before EI) of the local time difference. The local (QU) evening, premaximum occurrence hours of the 0000 to 0600 group gave the highest zero offset, correlation coefficient of about 0.94.

The Great Whale-Byrd Stations have a correlation coefficient of about 0.5 during the period of declining activity, 1800 to 0000. A low value is shown during the period of maximum occurrence, 1200 to 1800, consistent with the other conjugate station data. It is not certain what may be responsible for the unsymmetrical lead-lag plot of the 1200 to 1800 data; the number of data samples is certainly small. There was insufficient available information to prepare the graphs for the two remaining 6-hr intervals.

Looking at the College-Macquarie plot in figure 21, we see a significant correlation at zero offset for the 0000 to 0600 group. This time group again represents the peak and declining part of the local occurrence period. The 1200 to 1800 group shows a fair indication of a high zero offset correlation between stations for this period of small and rising activity occurrence. The small negative cross correlation at zero offset shown in the 1800 to 0000 group was a time of sustained high occurrence of activity at the two sites; an unexpected effect but similar to that experienced in the other conjugate station data. There were insufficient samples for significant cross correlation during the 0600 to 1200 period.

The unique appearance of identical signals simultaneously at stations with conjugate locations and not at other world locations establishes the emissions as a magnetospheric field line phenomenon. Figures 22, 23, and 24 serve to illustrate a typical conjugate case in which successive magnifications of an event are present in sequence. On the compressed scale illustrating the period from 0000 UT September 9 to 2400 UT September 17, 1963 (fig. 22), note the similar appearance of the two events on September 13; yet, there seems to be an earlier emission at Great Whale and some higher frequency structure at Byrd. Slight differences in the tape recording speed at the two sites

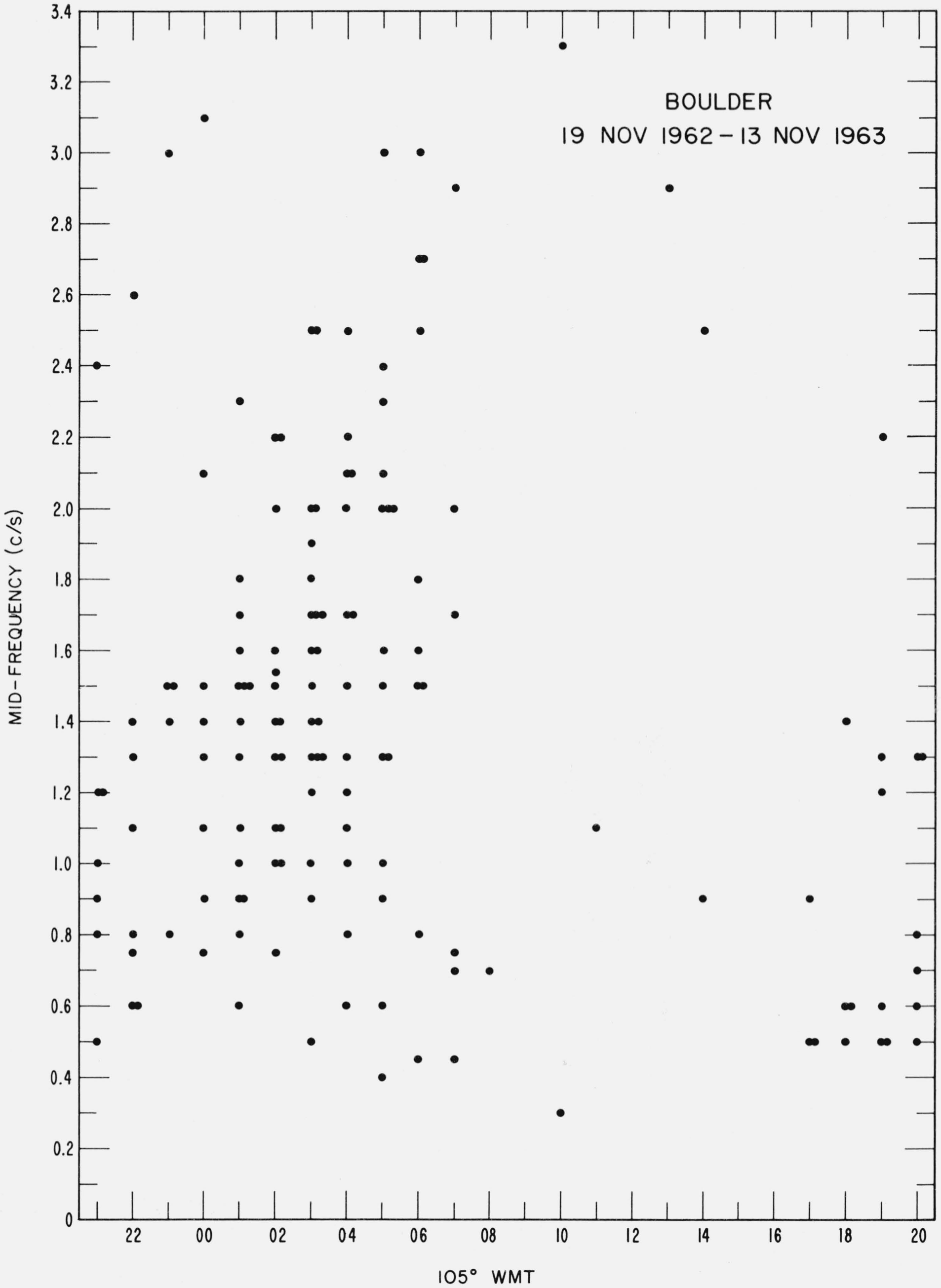

FIGURE 16. *Diurnal variation of midfrequency of events at Boulder, Colo., from November 19, 1962 to December 5, 1963.*
Data not separated for presence or absence of fine structure as in figure 15.

determined by the local 60 c/s power sources give slightly different expansions on the two displays here. The intermittent heavy traces at 0.067, 0.5, and 1.0 c/s are calibration markers. Figure 23 shows an expanded view of the September 13 data from 1230 to 2130 UT with the timing markers indicated. There is a remarkable similarity in the fine details of these events recorded at the conjugate station pair. By scaling expanded views such as that shown in figure 24, it was possible to show an alternate appearance of the individual emission bursts at the two stations. There was no similar activity at our other stations during this event; however, at College and Quebec we did detect emissions later, between 2300 September 13 and 0100 September 14, whereas at Boulder there was some activity between 0400 and 0500 on Septem-

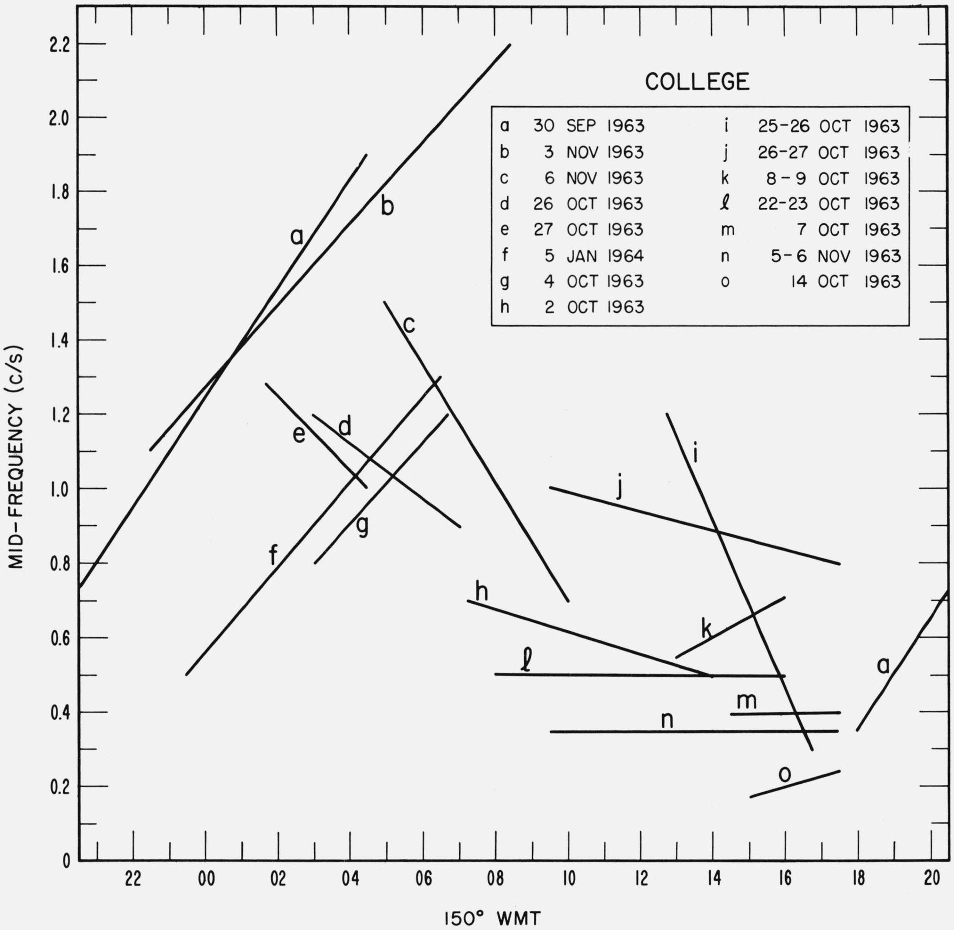

Figure 17. *Diurnal variation of long duration events of figure 6 type for College during period of August 1963 through February 1964.*

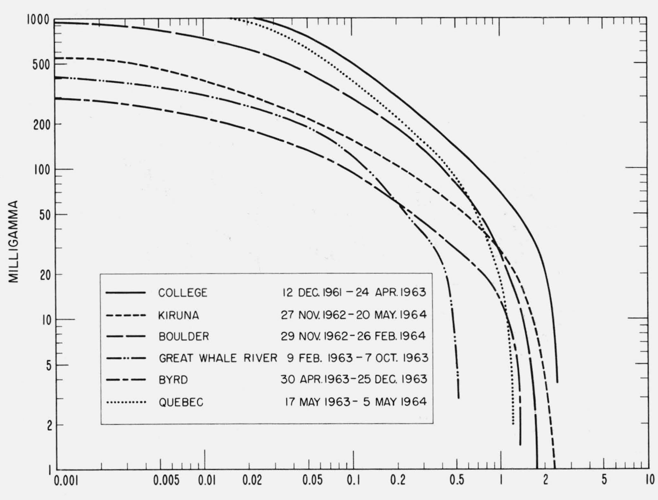

Figure 18. *Percent of time events recorded above indicated levels of magnetic flux density for all data at the stations indicated.*

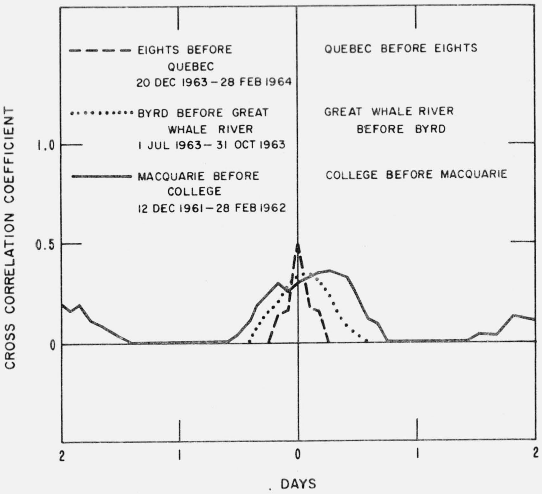

FIGURE 19. *Cross-correlation diagrams for hourly activity at three sets of conjugate stations for lead and lag periods extending to 2 days.*

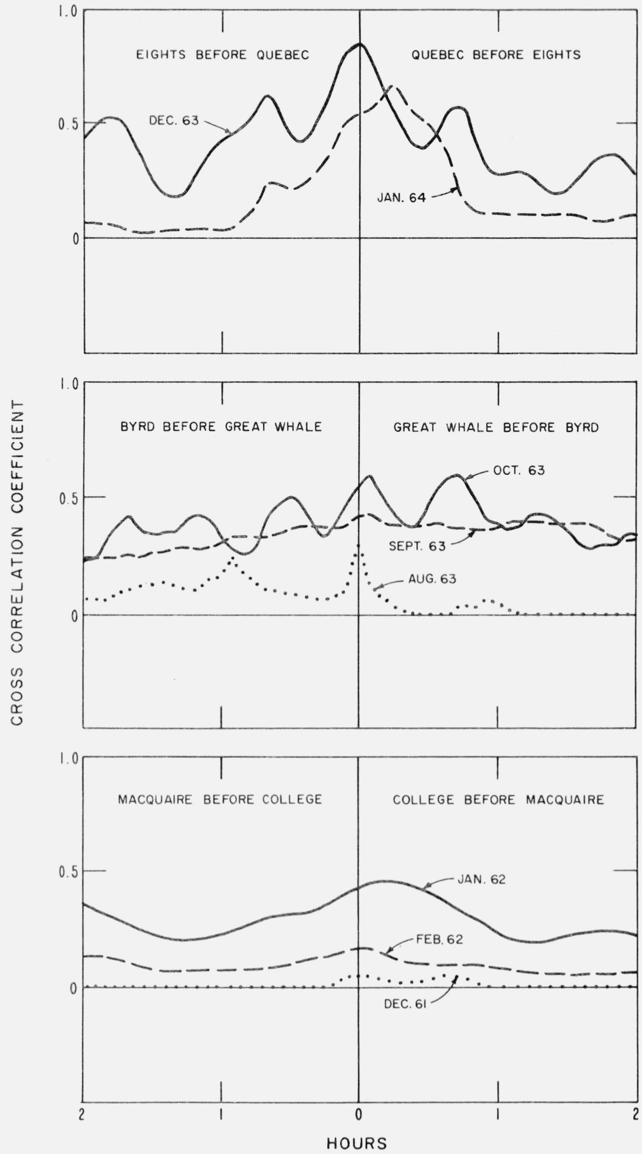

FIGURE 20. *Monthly cross-correlation diagrams for 5-min scalings at three sets of conjugate stations for lead and lag periods to 2 hr.*

ber 14. Figure 25 shows the amplitude trace corresponding to figure 23; there are obvious shortcomings in identifying the discrete similarities of the events with such displays of the data. A cross-correlation function obtained from amplitude scalings has limited value in presenting the unique similarities of the signals.

From the hourly values of activity in milligamma at each station a 24-hr average is obtained which may serve as a daily activity value for the station. A "world" activity index is constructed from these by averaging the reporting stations' values, realizing the shortcomings of such a procedure when station locations were sproadically operated and were not selected for the purpose of obtaining an average global picture. No 27-day solar rotation periodicity was evident in the stations' daily values or in the "world" activity level. In figure 26, the daily activity values are plotted for the period from January 1962 through May 1964. Times when three or more stations were averaged to obtain the daily index are indicated. Note that the high activity usually appears in groups of 2 to 5 days. There are months of enhanced activity as well as relatively quite months; no seasonal pattern is apparent.

6. Relationship With Other Phenomena

One of the first efforts usually attempted with geophysical events of this type is to search for a relationship with the geomagnetic disturbance index, *K*. We saw in figures 12 and 26 that no solar periodicity is apparent in the data. When local 3-hr activity values were matched to magnitudes of *K* indices for the College station in a lead-lag cross-correlation attempt, no relationship was indicated. On figure 26, for the period when data were available from three or more ultra-low-frequency stations, we also plotted the daily sum of *Kp* values, the dates of sudden commencement magnetic storms (SCMS) and the values of Zürich sunspot numbers. A good many of the pc 1 peaks seem to occur during periods of high sunspot numbers. There is no apparent relationship of our indices with the SCMS. We see, too, that the emission peaks appear to follow maxima in the *Kp* values. To look at this last feature more closely, the pc 1 daily values were averaged for 20 days following dates on which the daily world magnetic index, *Ap*, exceeded specific threshold values (fig. 27). Here we see evidence that the emission activity, on the average, is enhanced 4 to 10 days following the larger magnetic disturbances.

To investigate a possible relationship of the events with ionospheric phenomena, our data were compared

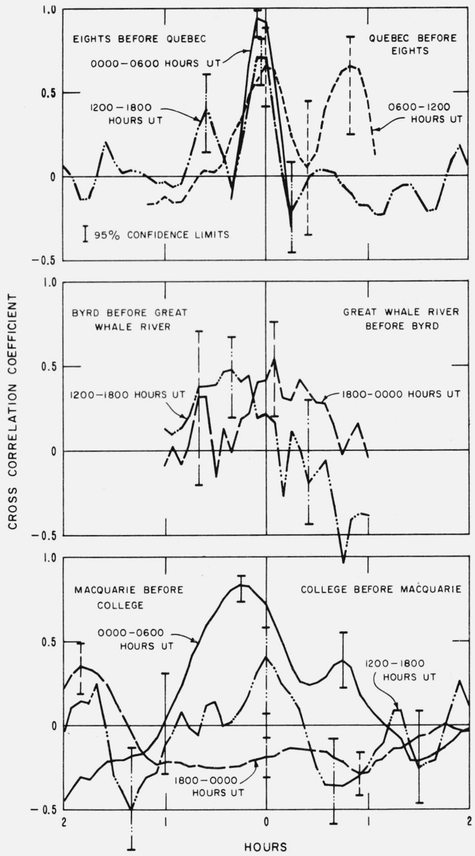

FIGURE 21. *Cross-correlation diagrams for 5-min scalings of all data divided into 6 hr UT groups when both stations of a conjugate pair had measurable events for lead and lag periods to 2 hr.*
Ninety-five percent confidence belts are indicated.

with some ionospheric sounder scalings and with cosmic noise absorption measurements. Such studies should indicate relationships of the pc 1 phenomena to the *D*, *E*, and bottom of the *F* regions in the local ionosphere. Using a sample period of January 1 to April 29, 1963, at College, Alaska, no significant correlations were found between the hourly or daily values of the emissions and the magnitudes of f_{min}, f_0F_2, or f_0E_s for lead and lag periods up to 24 hr and 15 days, respectively. For the period April 14 to December 31, 1963, at Baie St. Paul, Quebec, our data were compared to hourly average of 5-min scalings for the 30 Mc/s absorption. Again, no cross correlation was found for lead and lag periods up to 24 hr. Only on one emission occasion did we see absorption starting and ending with the event. In figure 28, hourly pulsation activity index levels at this station for 4 days following indicated hourly threshold values of cosmic noise absorption near 30 Mc/s are shown. Once the absorption exceeded the threshold size, 96 succeeding hourly pc 1 values were contributed to the averaging which was then normalized to a value of 1.0 taken as the maximum attained during the 4 days; a second occurrence of the same threshold during this period was excluded from the summation. With higher values of absorption, a more difinite diurnal occurrence of absorption is evidenced which surely arranges the pc 1 magnitudes of figure 28 producing the daily peaks in this presentation. From the succeeding days' data, we would expect an echancement at the first few hours of activity in the 1.0 dB threshold plot; this missing peak may be the only slight evidence for a suppression of pulsations by the absorption. The general enhancement several days following the high threshold onset day is possibly related to the increase of activity several days after a magnetic storm (fig. 27) and the established relationship of absorption to large magnetic disturbances.

The midfrequency variation shown in figures 15 and 16 as well as some of the initiation and ending times of the long duration events of figure 17 could be related to the day-night ionospheric changes.

Four other negative results are worth mentioning here. There seems to be no particular relationship between the pulsations reported in this paper and the auroral-type geomagnetic pulsations which have been closely associated with enhanced ionospheric currents and electron density. No auroral luminosity variations have been related to these pulsations. VLF emissions observed at several identical sites show no unique correlation to the pc 1 events. Auroral zone observations of electron precipitation (from balloon measured bremsstrahlung) or proton bombardment (by balloon borne neutron counters) at times of the presence and absence of the pulsation emissions have shown no interrelationship of the phenomena.

7. Concluding Remarks

In summary, these particular features of the pulsations in the 0.15 to 3.3 c/s range seem to be of principal importance. There is usually a rising frequency fine structure but variations are observed. The midperiod and emission element recurrence period of an event are linearly related. The bursts of activity usually last about ½ hr, but a gross recurrent pattern may persist, on rare occasions, as long as 12 hr. Pulsations associated with field lines reaching the greater radial distances occur near the noon meridian; midfrequencies are lower at this time. Signals are generally not simultaneous at most high latitude stations, but the world level of high activity usually persists for several days. Although no seasonal or 27-day solar-controlled periodicity is observed, the emissions are more likely to occur during high solar activity and in the week following large major magnetic disturbances. No associated ionospheric effects have been clearly found. Although no great difference in the number of events is noticed at high or middle latitudes, there is a scarcity of signal at the equator and poles. Conjugate point stations show uniquely similar activity. There may be an alternation of the fine structure for stations close to the same earth's magnetic field

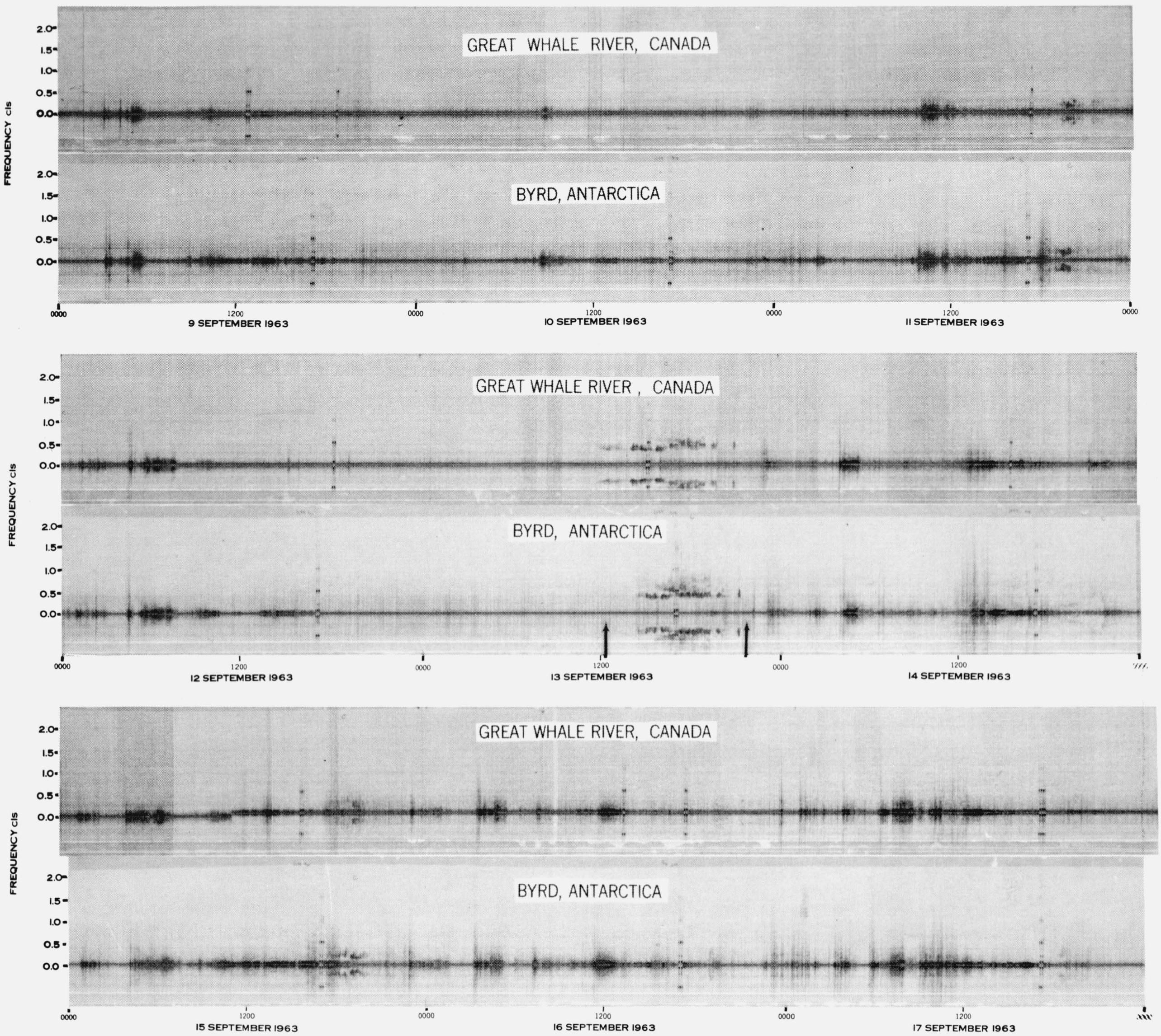

FIGURE 22. *Rayspan spectral display of conjugate data for Great Whale River and Byrd Stations during the period from September 9 to 17, 1963.*

In this display, a mirror image of the event is shown beneath each zero frequency base line. The heavy marks at 0.067, 0.5 and 1.0 c/s are calibrations.

line in different hemispheres. In the high latitudes, the magnetic flux density vector of the emission appears to describe a plane perpendicular to the earth's field line, polarized in a counter clockwise sense, and elliptically elongated in the N−S direction.

The following experimental programs seem necessary at this time: (1) a more complete study of the characteristics of the "ideal" long duration events which seem to display most of the features of the resonant emissions, (2) an investigation of the magnetospheric dependence of the signals at locations tied to such critical regions of the magnetosphere as the geomagnetic pole, the leeward-fold of the magnetopause, the auroral zone, and the trapped particle belt as well as at selected conjugate points and at the geomagnetic equator, (3) studies of the polarization features as evidence of propagation modes at the various world sites, in particular as a function of latitude, (4) an investigation of the special cases of dissimilar behavior at conjugate sites, and (5) a more complete evaluation of the reception of similar events

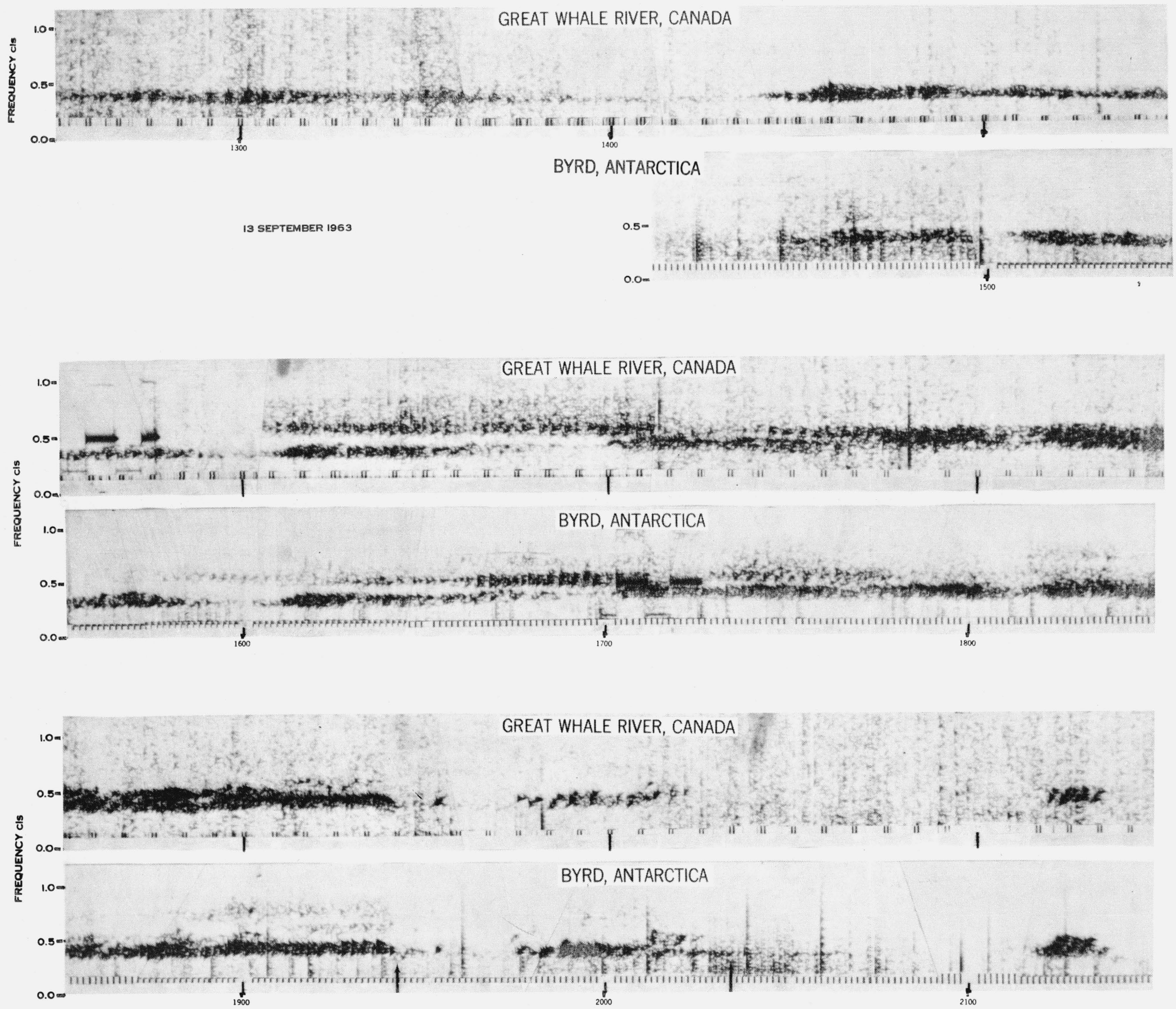

FIGURE 23. *Spectral display of conjugate data for Great Whale River and Byrd Stations during September 13, 1963; an expansion of part of figure 22.*

The local time markers appear at the bottom of the trace. The heavy marks at 0.067, 0.5, and 1.0 c/s are calibrations.

over varying surface distances to resolve the recurrence period versus latitude problem.

We express our sincerest gratitude to the great number of organizations and people who have contributed so very much to the success of the extensive observational programs. The Antarctic Stations were made possible by the Antarctic Program Office of NSF as part of the NBS Conjugate Point Program Contract GP–1824. The two Canadian Stations resulted from the excellent help of the Canadian National Research Council. Kiruna Geophysical Observatory in Sweden graciously contributed data from that auroral zone station as part of a pleasant cooperative scientific effort. At College, Alaska, we are indebted to the Geophysical Institute there for splendid assistance through September 1963, and after that date, to the U.S. Coast and Geodetic Survey Magnetic Observatory adjacent to the University of Alaska. Our thanks for the Macquarie Island measurements are given to the ANARE Office of the Department of External Affairs of the Commonwealth of Australia.

We must give credit to a number of outstanding individuals who have assisted in the program over the years: P. Law and F. Jacka at Melbourne; R. R. Brown at Berkeley; B. Hultgvist and A. Egeland at Kiruna; M. Sugiura, J. Dawson, and J. Townshend at

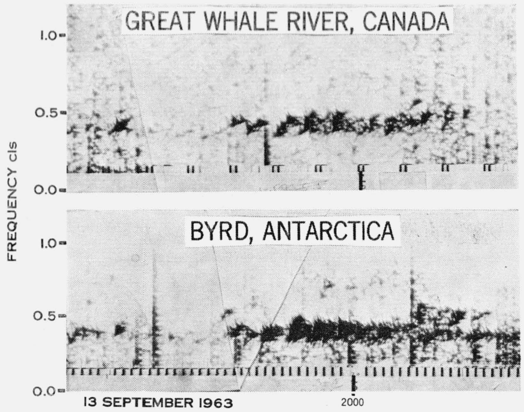

FIGURE 24. *Spectral display of conjugate data for Great Whale River and Byrd Stations during September 13, 1963; an expansion of part of figure 23.*

The local time markers appear at the bottom of the trace.

(Figure 26 is given on next page.)

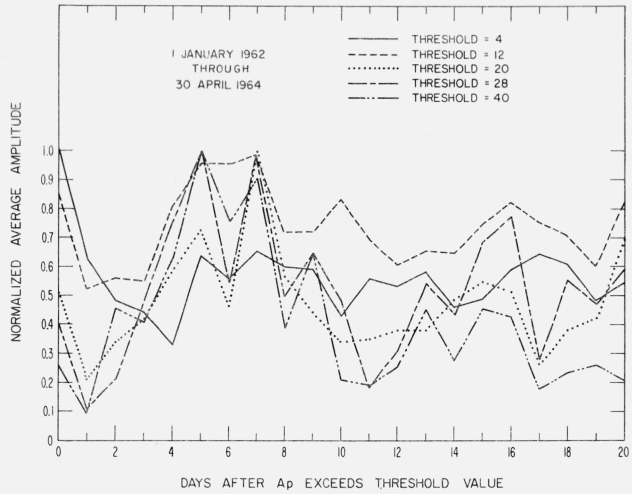

FIGURE 27. *The pc 1 daily values averaged for 20 days following the dates on which the daily world magnetic index,* Ap, *exceeded specific threshold values.*

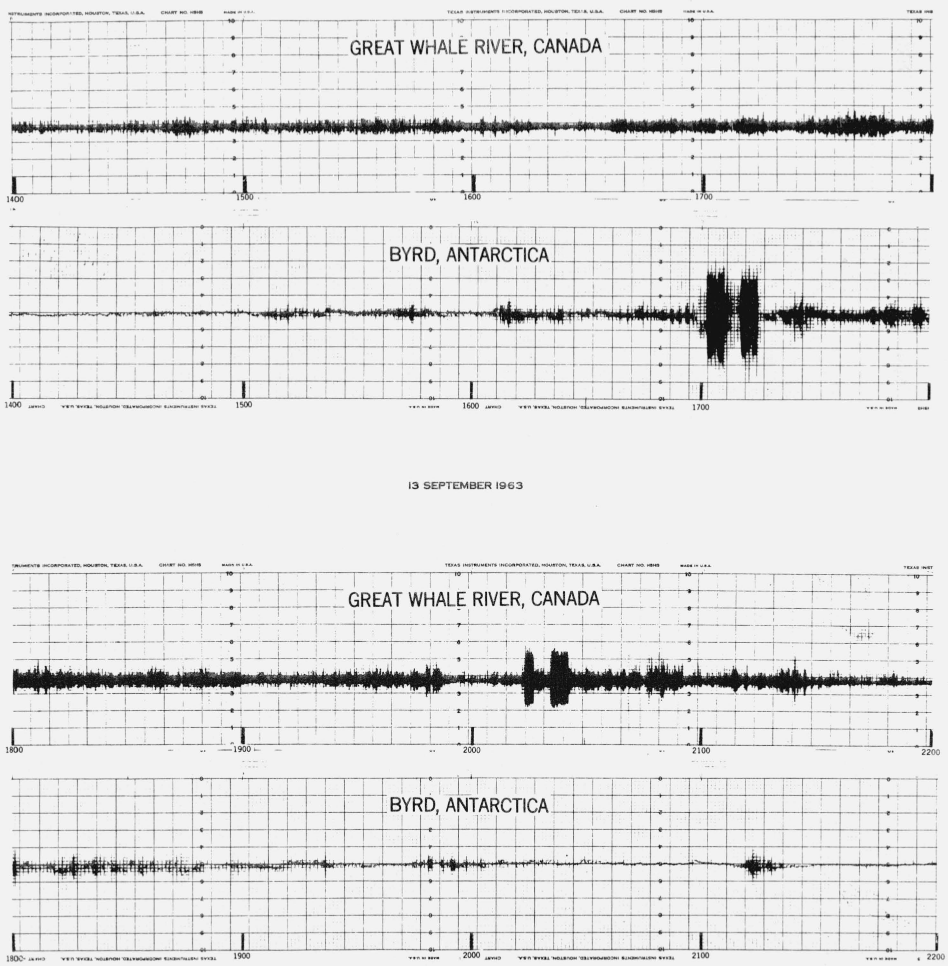

FIGURE 25. *Amplitude trace corresponding to event shown in figure 23 for Great Whale River and Byrd Stations during September 13, 1963.*

The vertical bars near 1700 and 2030 are calibration markers.

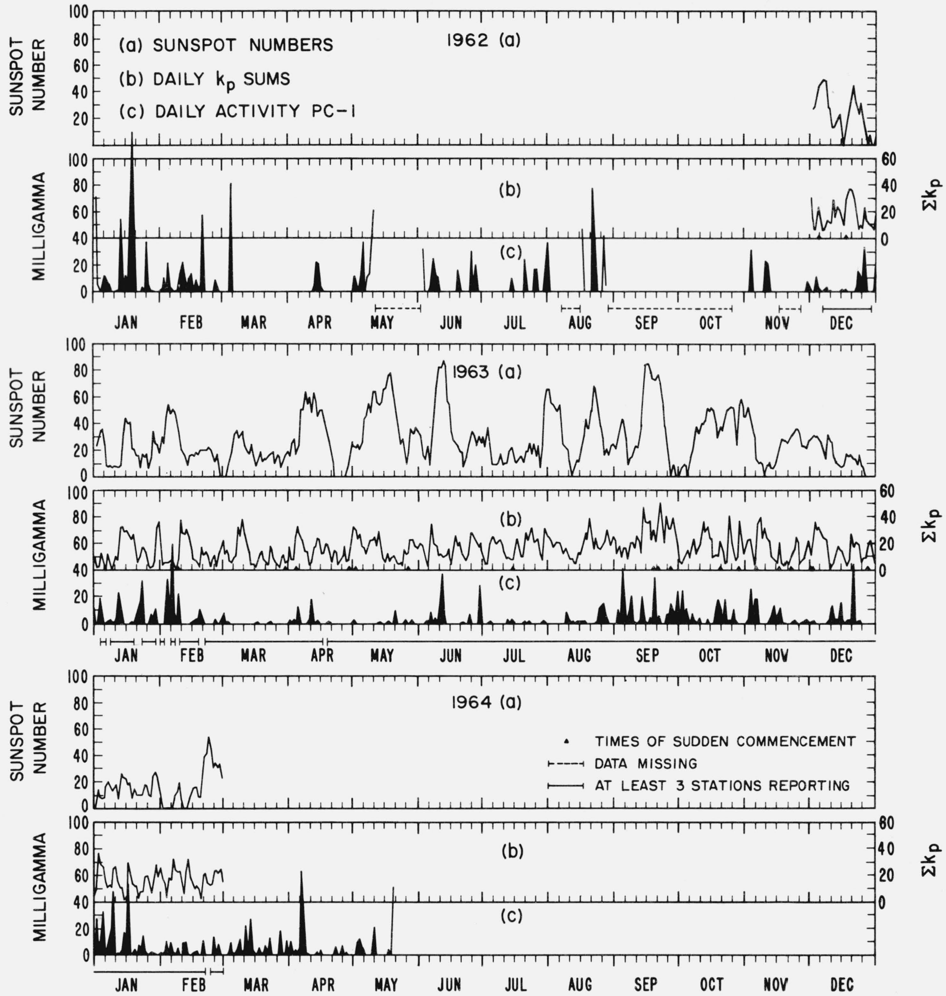

FIGURE 26. *The pc 1 daily world activity values from January 1962, through May 1964.*

Times when three or more stations were averaged are indicated. During this period the daily sum of *Kp* values, dates of sudden commencement magnetic storms, and values of Zürich sunspot numbers are also shown

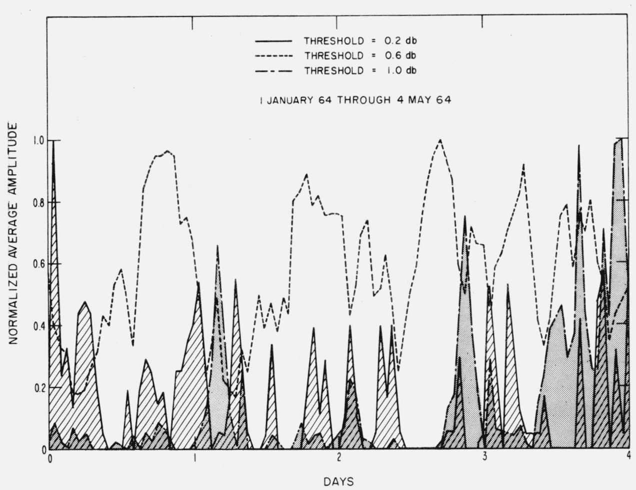

FIGURE 28. *Hourly activity index levels at Baie St. Paul, Quebec, for 4 days following specific hourly threshold values of 30 Mc/s cosmic noise absorption in dB.*

College; D. Wasmundt, D. Vance, J. Pope, and D. Littlefield at Boulder; and D. Webster, S. Maagoe, and D. Lewis, who maintained the Antarctic sites. For the phenomena comparison studies H. Sauer of NBS contributed the riometer data and Miss V. Lincoln of NBS supplied the solar terrestrial activity information.

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