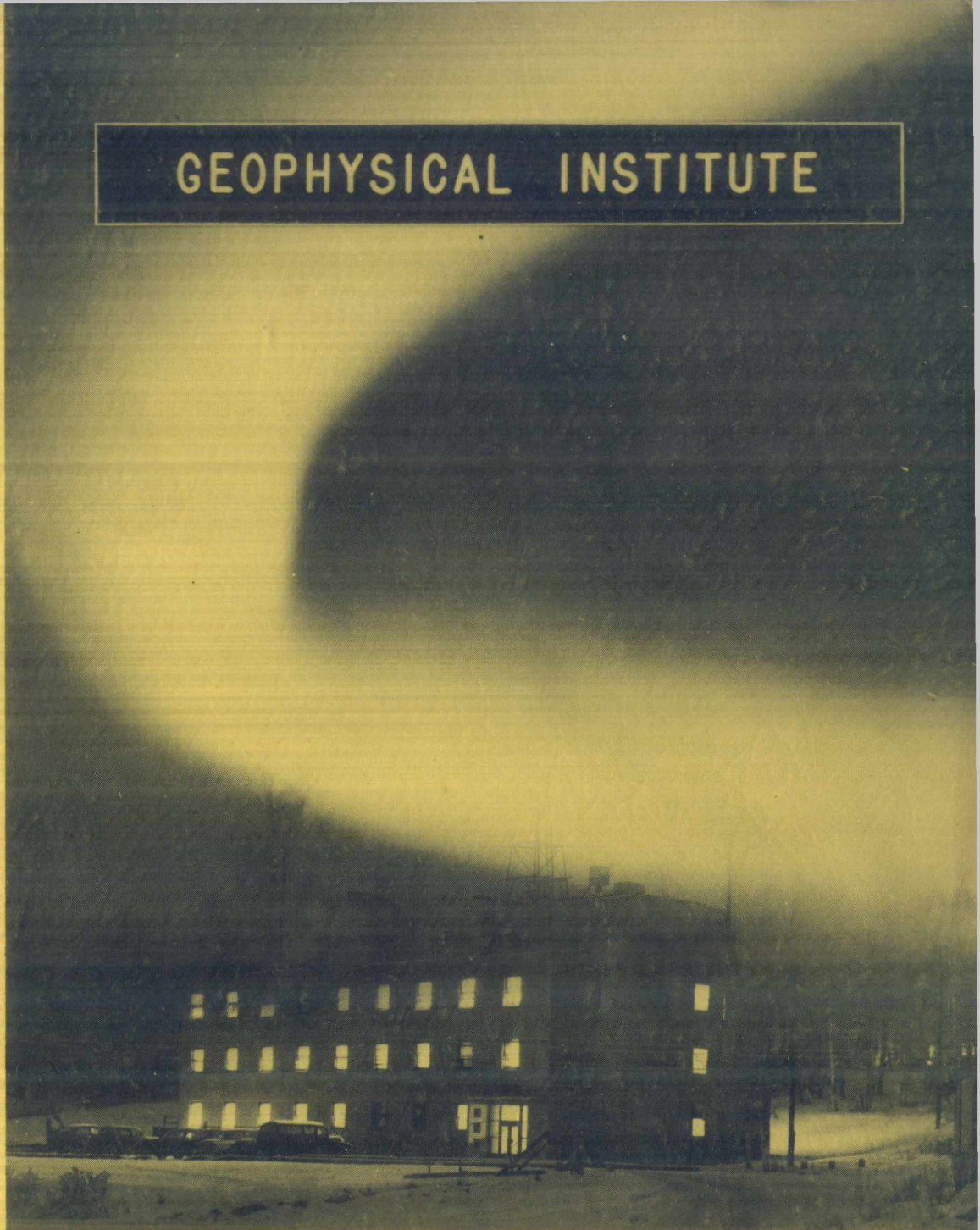


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RAPID FLUCTUATIONS IN EARTH-CURRENTS AT COLLEGE

by

V. P. Hessler and E. M. Wescott

Scientific Report No. 1

Air Force Cambridge Research Center

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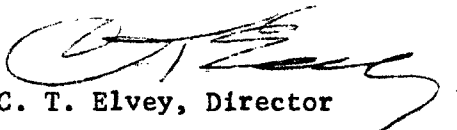
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C. T. Elvey, Director

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Rapid Fluctuations in Earth-Currents at College

ABSTRACT

An unusual type of earth-current variation is regularly observed in the College records. The phenomena consist of more or less regular fluctuations with range from a few mv/km to more than 1000 mv/km, and periods ranging upwards from 6 seconds. The fluctuations may continue from a few minutes to several hours. They have a strong diurnal variation at College with a broad maximum at 0600 local time. The fluctuations also occur at a site about 100 km southeast of College, but are not observed at Barrow. Thus these rapid fluctuations display characteristics quite different from the previously classified magnetic and earth-current continuous pulsations, pc's, and train pulsations, pt's. Special equipment was devised to count and record the period of the fluctuations on a continuous basis. Typical rapid fluctuation traces and charts showing their activity patterns are presented.

Introduction

The term "earth-current rapid fluctuation" as used herein applies to the more or less regular variation in the earth-current with periods ranging approximately from 1 to 60 seconds. The lower limit is set by the Brown and Esterline-Angus recorders which the upper value is purely arbitrary. The term fluctuation is chosen in preference to oscillation or pulsation because of its connotation of an irregular variation to either side of the quiet day trace.

Magnetic pulsations were observed as early as 1861 and they were recorded in the program of the First Polar Year. These pulsations have been under continual study since. With the advent of electronic apparatus the frequency range of recording magnetometers has been extended to include any desired frequency band. The IGY program included an extensive study of the magnetic pulsation spectrum up to 50 cycles/sec.

In contrast to the above, very little earth-current rapid fluctuation data are available, particularly at geomagnetic latitudes in the region of the auroral zone. It is observed that the College earth-current records display much more structural detail than the magnetograms, and that the earth-current rapid fluctuations are always much more pronounced than the corresponding magnetic pulsations. Thus the earth-current records contain information concerning ionospheric charge motion and inhomogeneities which may not be discernable in the magnetograms.

Equipment

Geographic location of electrode field - The electrode field is located a few hundred feet to the west of the Geophysical Institute building at College. The College geographic coordinates are $64^{\circ}51'$ N and $147^{\circ}50'$ W, and the geomagnetic coordinates are $64^{\circ}37'$ N and $256^{\circ}30'$ E.

Stray electric fields - The electrodes are installed in a wooded area with no d-c circuits anywhere in the vicinity. Welding operations during extension of the campus heating system has sometimes resulted in interference, but these traces are very distinctive and not to be confused with earth-currents. The 60 cycle power system and a local radio station produce a d-c voltage at the output of the transistor amplifiers. However, it has been possible to eliminate this interference completely by proper filtering at the amplifier input. The above mentioned a-c sources have no observable effect on the trace of the Brown Electronik recorders.

Electrodes - The electrode field consists of three electrodes, West (W), Common (C), and South (S). The South and West electrodes are located geographically south and west of Common respectively, with C-S and C-W spacings of 300 ft. The electrodes consist of 25 ft of old lead covered telephone cable buried to a depth of 30 inches in loess soil. The chemical potential is low and very constant except for changes which occur during the spring break-up.

Lines - All electrode lines are terminated in the woods in a junction box at the Common electrode. The line from the junction box to the instrumentation in the Institute building is a 4-conductor shielded cable, thus avoiding possible electromagnetic pick-up.

Recorders - The Brown Electronik recording potentiometers used in this study have a full scale range of 5 mv and a response rate of 4 seconds for full scale travel. The 5 mv range makes it necessary to insert an attenuating network between the electrodes and the recorders. This network also includes a centering circuit for adjusting the recorder pen to mid-scale under quiet

day conditions. The Brown recorders are normally operated at a full scale range of 1200 mv/km. As mentioned above some of the records are also taken with Esterline-Angus recorders powered with transistor amplifiers.

Cycle counting equipment - This equipment consists of a 10-point stepping relay, a clutch driven microswitch, and an operations pen attached to the Brown recorder. The microswitch is closed as the pen drive starts upscale and opens as it starts downscale. Thus within the sensitivity of the equipment, the stepping relay advances one step for each cycle of fluctuation regardless of its amplitude or the position of the pen on the scale, and the operations pen makes a pip for each 10 cycles. At the 1200 mv/km range the counting equipment is sensitive to earth-current variations with a range of 5 mv/km at any part of the potentiometer scale. Tests with a low frequency function generator show that the equipment will count and record fluctuations of the above range up to a frequency of 1 cycle/sec (the maximum observed frequency to date is 10 cycles/min, i.e., 1/6 cycle/sec).

Records and Scaling

Rapid fluctuation records - Several examples of the Brown recorder N-S earth-current traces for College showing rapid fluctuations are given in Fig. 1. Note the record of the cycle counting equipment above each trace. Very often the disturbances at College are so active that the pen paints the record as observed on the 10 February 1958 trace at 2000 UT. There is no possibility of determining the frequency or period of the fluctuations of such a disturbance from the trace. The 11 February 1958 trace indicates the magnitude which is

sometimes attained by the rapid fluctuation. Maximum frequency has never been observed during periods of maximum amplitude activity. Compare, for example, the cycle counting record for the 2000 hour on 10 February 1958 and for the 0100 hour on 11 February 1958 in Fig. 1. There is a tendency for disturbances to start with large amplitude fluctuations of low frequency and shift to lower amplitude and more rapid fluctuations. The 4 March 1958 record is a fair example of this phenomenon.

Rapid fluctuation at College - selected days - Fig. 2 presents the number of cycles of earth-current fluctuations during each hour for ten selected days. The records are scaled by counting the number of pips in each hour and multiplying by 10.

Rapid fluctuation activity - February 1958 - The records were scaled as explained for Fig. 2 and the results presented graphically in Fig. 3. The points represent fluctuation frequency versus hour of the day. Grouped points represent several occurrences during the month of a given frequency at a given hour of the day. For example, there were three instances of 100 cycle/hour fluctuation during the 0800 hour in the month of February 1958. Note that a frequency of 120 cycle/hour corresponds to a period of 30 seconds.

Diurnal variation in rapid fluctuations - The records for September through December 1957 were scaled subjectively for rapid fluctuation amplitude, according to the following procedure. Any case in which the pen painted the record even for a few minutes was considered an instance of rapid fluctuation for that hour and the estimated amplitude (range in mv/km from the lower envelope to the upper envelope) of the rapid fluctuation was recorded. In this scaling the amplitude of any low frequency disturbance which occurred during the hour was ignored. The average hourly values of rapid fluctuation amplitude for each of the four months scaled were calculated and are presented in Fig. 4.

The March-June 1958 N-S earth-current records were scaled for cycles per hour according to the procedure used to determine the data for Fig. 3. Average hourly values of rapid fluctuation frequency were calculated for each of the five months and are presented in Fig. 5.

Diurnal variation in amplitude and frequency activity - The average values of earth-current amplitude activity for the month of February 1958 given in Fig. 6 were determined in a manner similar to that used in scaling magnetic K-indices. The hourly range is taken as the difference between the greatest positive and negative departures from an arbitrarily assigned zero trace (the diurnal variation is negligible in comparison with disturbances at College). The cycles per hour frequency activity curve is the February curve of Fig. 5 replotted with the amplitude activity curve to show the relative diurnal variation. The graphs of Fig. 7 correspond to Fig. 6 except that five-month averages are presented and the amplitude activity scaling is based on 3-hour instead of 1-hour periods.

Rapid fluctuation frequency and period - The cycle counter record was scaled for "instantaneous" frequency by determining the time between pips, corresponding to 10 cycles and assuming a constant frequency during the interval. The eight 3-hour sections of earth-current trace of Fig. 1 were scaled and fluctuation frequencies are plotted in cycles/min in Fig. 8. Note that 10 cycles/min correspond to a 6-second period. The 6-second period is the most rapid fluctuation that has been scaled from the records. However, visual examination of the records indicates that the scaled value must be very nearly the maximum that has been recorded. This does not, of course, imply that more rapid fluctuations

do not occur in the earth currents. It should be recalled that the minimum range of fluctuation which was recorded by the equipment was 5 mv/km.

The data for the eight 3-hour intervals of rapid fluctuation activity of Figs. 1 and 8 were analyzed for frequency of occurrence of fluctuation with periods from 6 to 38.4 seconds. The results are presented as a frequency distribution histogram, Fig. 9. The non-integral class widths are due to the scaling procedure. The records were scaled to the nearest 1/50th inch which results in 1.2 second steps for the period of the fluctuations. The histogram is presented not as the characteristic frequency distribution of the phenomena but rather as an indication of the distribution which may occur during periods of considerable rapid fluctuation activity. Additional data will be scaled and a complete analysis of the frequency distribution curve will be presented in a future report.

The modal class as determined from the peak of the histogram is 10.8 seconds. It may be of interest to note that this is very close to the 11.3 second arithmetic mean of all periods scaled in the range 6 to 18 seconds. The arithmetic mean of all periods in the range 6 to 38.4 seconds is 12.6 seconds.

The positive skewness of the distribution is due essentially to the nature of the variable. Let us consider an assumed situation in which rapid fluctuations of period corresponding to each of the class intervals occurred for equal lengths of time during the epoch under consideration. Evidently the frequency of occurrence of each class would be inversely as the period and a j-type distribution would result. This theoretical curve would actually be a hyperbola. Thus the general form of the distribution to the right of the modal class is clear. There are two possible explanations for the rapid drop to the left of

the modal class. The higher frequency fluctuations may not occur, but it seems more likely that the sharp cut-off may be due to a rapid decrease in amplitude of higher frequency fluctuations. It should be recalled here that the equipment was capable of recording fluctuations down to 1 second period at an amplitude of 5 mv/km or greater. It is of interest to note the duration of activity at the various periods. The frequency of occurrence of the modal class is 98 and thus the total duration of 10.8 second period rapid fluctuation activity in the 24 hour epoch is 176 minutes ($98 \times 10.8 \times 10/60$). The total duration of activity in the range 8.4 to 14.4 seconds is over 13 hours. Again it must be recalled that 3-hour intervals of considerable activity were selected.

The extent of the rapid fluctuation which may occur is further illustrated by consideration of the data of Fig. 5. For the seven most active hours of the day during February and March the number of cycles per hour averaged 180 which corresponds to an arithmetic mean period of 20 seconds. The February-June average for these same hours is 130 cycles/hour or an arithmetic mean period of 27.7 seconds. The greatest number of cycles recorded in one hour was 510 which corresponds to an arithmetic mean period for the hour of 7.1 seconds. This disturbance occurred on 20 February 1958 at 00 UT.

Rapid fluctuation at College and at Barrow - Fig. 10 shows two College earth-current records with major rapid fluctuations. These are typical disturbances which occur quite frequently at College. The corresponding records for the receiver site at Barrow show essentially no indication of the rapid fluctuations. The geomagnetic coordinates of Barrow are 241.25°E and 68.5°N . Note also that the sensitivity of the Barrow record is approximately twice as great as the College record. This difference in the fluctuation activity in the

College and Barrow records was noted early in the investigation and has been observed throughout the study. The difference is not one of instrumentation because the equipment at the two sites is identical. Furthermore, the time marks and sudden commencements on the Barrow records indicate the ability of that equipment to respond to voltage impulses.

Discussion

Comparison of earth-current rapid fluctuations with geomagnetic pulsations - Two types of geomagnetic pulsations related to this study are defined by the IAGA, Special Committee No. 10 (1957). Pulsations designated "pt" are defined as a phenomenon consisting of several series of oscillations, each series of oscillations lasting 10 to 20 minutes, the whole phenomenon lasting for periods of not more than about one hour. Pulsations designated "pc" are defined as pulsations having a considerable element of continuity, having periods between 10 and 40 seconds, lasting a number of hours. The report does not mention magnitudes but Kato and Watanabe (1957) state that pc amplitudes are of the order of $1/10 \gamma$ and pt amplitudes of several tenths of a γ . Presumably these figures are for middle latitude observations.

Apparently disturbances which can truly be designated as pc or pt occur simultaneously over most of the earth. Obayashi and Jacobs (1958) present simultaneous records of geomagnetic pulsations at a group of observatories including Tromso, College, and Tucson. No scales are given but from the writer's familiarity with College magnetic records the College pt's must be of the order of several γ 's in magnitude. However, periods are given and the College pt's as reported generally range from 150 to 300 seconds.

The question now arises as to the manner in which these earth-current rapid fluctuations may be related to the magnetic pt's.

A preliminary analysis of earth-current and magnetic amplitude activity at College shows a close correlation in the actual values of mv/km and γ . The maximum earth-current disturbance, not rapid fluctuation, recorded in these studies at College is 3600 mv/km and the College magnetic K-index scale for 9 is $>2500 \gamma$. The correlation coefficient for the February 1958 College K-indices and the College earth-current "E-indices" is over 0.9. For this correlation the College earth-current 3-hour amplitude activity scalings were converted to "E-indices" through the College K-index schedule but substituting mv/km for γ .

The above suggests that earth-current pt's at College might be expected to have a range of perhaps 10 mv/km. Referring now to Fig. 1, we observe that the range of fluctuations under discussion herein are 1 to 2 orders of magnitude greater than expected values of pt's. Fig. 4 shows that even the average fluctuation range for the six most disturbed hours during September, November, and December was about 30 mv/km.

Fig. 10 indicates that the College earth-current rapid fluctuations are a highly localized phenomena in comparison with the world wide pt's. Only two examples of simultaneous College and Barrow records are given in Fig. 10 but these are typical of many records observed during nearly three years of continuous recording. The Barrow records always show disturbances during rapid fluctuation at College but never any major rapid fluctuation.

The monthly reports of the Onagawa Magnetic Observatory at Sendai, Japan report pt's or other special activity during six of the eight periods of rapid fluctuation activity shown in Fig. 1.

From all of the above it seems quite likely that the earth-current rapid fluctuations are associated with the same general ionospheric disturbance as the magnetic pt's. However, they differ so much in form, period, and relative amplitude that it seems the earth-current rapid fluctuations should be classified as a separate phenomenon.

Comparison with other earth-current pulsation studies - Troyickaya (1955) observes two types of earth-current fluctuations which she terms "persistent" type oscillations and "burst" type oscillations.

Troyickaya's "persistent" type oscillations are so related in form and frequency to the magnetic pc's that they must stem from the same ionospheric activity. It would seem reasonable to term these oscillations "earth-current pc's." The rapid fluctuations of this report are definitely not pc's. However, the College earth-current records quite often do display continuous nearly sinusoidal oscillations having a range of less than 5 mv/km and a period of about 30 seconds. It should be recalled that the sensitivity of the College equipment was set to record major disturbances and thus did not count these earth-current pc's. Equipment is now being operated at greater sensitivity for the purpose of studying this phenomenon.

It is of interest to note that it is much simpler to set up equipment to record earth-current pc's of a few mv/km than magnetic pc's of $1/10 \gamma$ amplitude.

Troyickaya's (1955) "burst" type oscillations seem to display all of the characteristics of magnetic pt's. She shows simultaneous records almost identical in form for Alma Ata and Vilkiya, two stations separated by 4000 km. She also shows records very similar in form for several stations including locations

in Sicily, Venezuela, and the U.S.A. As in the case of the magnetic pt's these earth-current pt's bear very little resemblance to the rapid fluctuations of this report.

The major point of Troyickaya's paper is her conclusion that the earth-current pc's and pt's tend to occur diurnally at mutually exclusive hours, and that their occurrence is based on universal rather than local time. Her chart shows occurrence of pt's building up rapidly from 1200 to a maximum at 1800 to 1900 and dropping to nearly zero at 2400, all UT. Unfortunately only one chart is given, presumably for Alma Ata, but one gathers from the Hope translation that a similar curve based on UT would be obtained from, say, Vilkiya observations. This conclusion was at such variance with the usual nighttime increase in activity that one would anticipate succeeding studies directed toward a check of Troyickaya's conclusions. Ohchi (1957) prepared pt frequency distribution histograms from scalings of the 1950-1952 Toledo and Kakioka earth-current records and the Cheltenham and Sitka magnetic records. The Kakioka records were scaled for pt's of >3 mv/km amplitude, but no information concerning limits is given for the other scalings. The frequency distributions show a maximum of both earth-current and magnetic pt activity at or shortly before local midnight. Indeed if one rescales Troyickaya's "burst" type chart to local time (assuming the data are for Alma Ata) her data correlate equally well with the four observatories studied by Ohchi. Another earth-current pulsation study made by Yanigihara (1957) seems to substantiate Ohchi's results. Yanigihara presents a chart of "mean diurnal variation in frequency for 1934-1953" of earth-current pulsations at Kakioka. This chart shows only one major peak centering at about 2300 local time or 1400 UT. However, the nature of the fluctuations is not discussed so it is not possible to determine certainly whether this result is at variance with Troyickaya's conclusion.

Ohchi (1957) concurs with Troyickaya that pt's may occur simultaneously over large areas but adds that amplitudes are not the same from place to place.

On the basis of the above evidence it seems the more likely that earth-current pt's most commonly occur at or shortly before local midnight.

The above discussion presents another important distinction between earth-current pt's and rapid fluctuations. The diurnal variation in earth-current rapid fluctuation (rf) activity at College is evident in all of the data presented in Figs. 3, 4, 5, 6, and 7. It is perhaps most readily observed in Fig. 5 which shows a broad maximum centering at about 1600 UT, which corresponds to 0600 local time. A comparison of Fig. 5 with Ohchi's and with Yanigihara's charts shows that the rf activity (at College) tends to lag the general pt activity in local time by six hours.

Diurnal variation in amplitude and fluctuation frequency activity at College - Often an earth-current disturbance will start with large amplitude long period variations and gradually shift to more rapid fluctuations of lesser amplitude. The 4 March 1958 disturbance shown in Fig. 1 is a fair example. This observation is substantiated by the curves of Figs. 6 and 7 in which the monthly and 5-month amplitude activity curves rise toward a maximum well ahead of the frequency activity. It is of some interest in this connection to note that Ohchi (1957) found the > 20 mv/km pt's to have a maximum frequency of occurrence about one hour earlier than those of < 20 mv/km.

Generation of earth-current rapid fluctuations - No satisfactory explanation of the generation of the rapid fluctuations is suggested by the current auroral and magnetic storm theories. However, the search for possible theoretical explanations of the phenomenon suggests questions which must be answered by an

adequate theory of the phenomenon. Are the earth-current rapid fluctuations generated by changing ionospheric currents or by moving charge configurations? What is the height and horizontal distribution of the generating ionospheric activity? Is the rapid ionospheric activity generated by solar or terrestrial influences?

The question of electromagnetic versus electrostatic induction of the rapid fluctuations arises because of the relative magnitude of the earth-current and magnetic activity. From Faraday's law, the ratio of amplitude of the earth-current fluctuations to magnetic fluctuations should be proportional to the frequency. However, the earth-current rapid fluctuations seem much too large to be accounted for even on the basis of the increased frequency. This question will be considered in detail in a future report.

The fact that the rapid fluctuations appear in the College records and not in the Barrow records indicates that the rapidly changing ionospheric currents or charge configurations are much closer to College than to Barrow and thus low in the ionosphere. Preliminary analysis of earth-current records taken at Shaw Creek, a site located 100 km eastward from College and at about the same geomagnetic latitude, indicates that the rapid fluctuation activity corresponds with the College activity. The above suggests the need for future observations at widely separated sites, along and perpendicular to the auroral zone.

The rapid ionospheric activity may be caused by irregularities in the solar corpuscular stream. Let us consider the magnitude of such irregularities which would be required to produce rapid fluctuations of 10-second period. The velocity of 48 hour transit time particles is 8.65×10^5 meters/sec, and thus the

length of the required irregularity is 8650 kilometers. According to one auroral theory (Bennett 1958) such irregularities, if produced at the sun, could probably be maintained even in a proton stream of 48 hour transit time.

A theory of the rapid fluctuations based on corpuscular stream irregularities must include a mechanism whereby their effect may be concentrated in a small region or narrow band of the lower ionosphere. A discharge theory of the aurora by Reid (1958) postulates the conduction of corpuscular radiation effects to ionospheric levels by what might be considered an electric circuit. First, it is considered that incoming particles produce a difference of potential between two magnetic field lines. Since ionic conductivity parallel to the field lines is much greater than in the perpendicular direction, the two field lines will in effect constitute a transmission line with a broad termination at some level in the lower ionosphere at which the perpendicular conductivity becomes greater than the parallel conductivity. Thus a mechanism is provided for conducting extra ionospheric disturbances to lower ionospheric levels in the polar regions. However, we must still account for the selective action by which the rapid fluctuation is produced at College and not at Barrow. The difference in the maximum heights of the Barrow and College dipole field lines is nearly 2 earth radii, the Barrow line reaching to 6.4 radii and the College line to 4.5. The Van Allen radiation chart shows large changes in this range of heights. If we postulate the generation of a fluctuating potential at the 4.5 radii height by corpuscular stream irregularities which is not produced at the 6.4 radii height, the occurrence of rapid fluctuations at College and not at Barrow would follow from Reid's (1958) theory.

This discussion of the generation of earth-current rapid fluctuations is intended to suggest possible approaches to the development of a theory. The development of a satisfactory theory will await further observation, analysis, and ingenuity.

Summary

Rapid fluctuations in earth-currents with range > 5 mv/km and periods from 6 to say, 30 seconds occur frequently at College.

The ranges of the rapid fluctuation are commonly as much as 300 mv/km and sometimes > 1000 mv/km.

Generally there is a correspondence between range of the fluctuations and period, the largest fluctuations corresponding to the longer periods.

During eight 3-hour intervals of rapid fluctuation activity the average period was 12.6 seconds.

There is a pronounced diurnal variation in rapid fluctuation activity with a broad maximum occurring at about 0600 local time and a minimum at 1800 local time.

Rapid fluctuations of the type observed regularly at College are either not observed or very small at Barrow.

Amplitude activity generally precedes frequency activity at College by a few hours.

The rapid fluctuations (rf) differ in so many respects from pt's that it seems desirable to classify them as a separate form.

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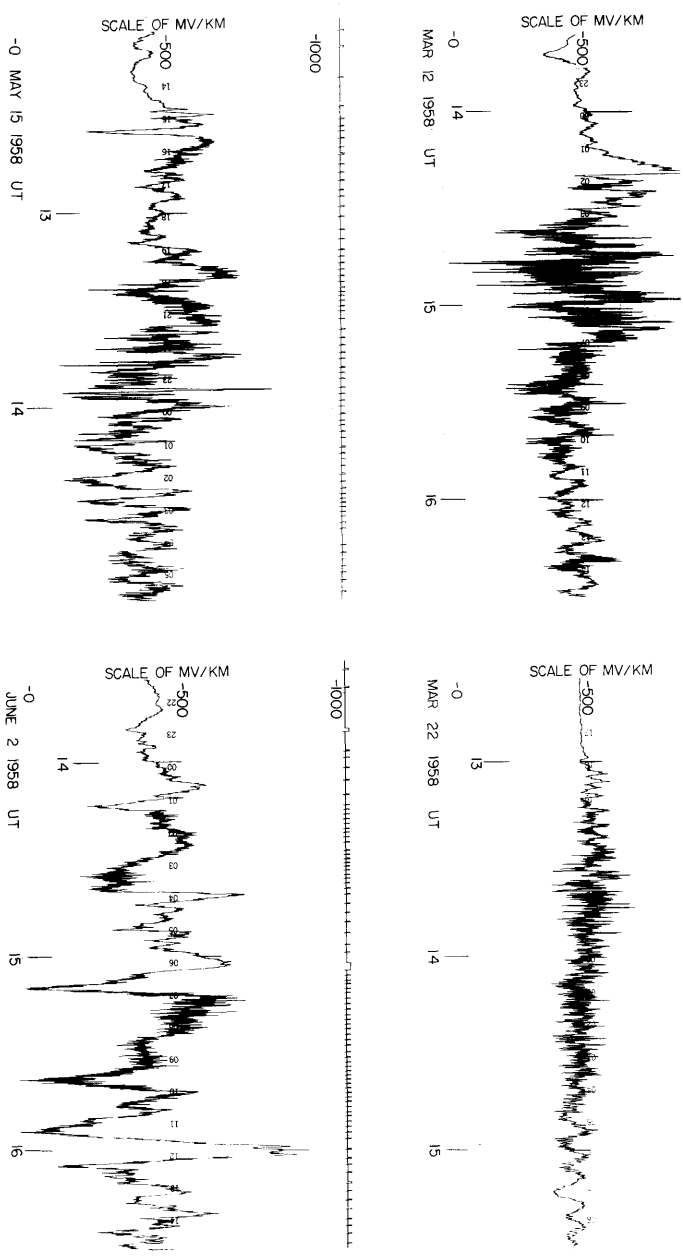


Fig. 1. Earth-current Rapid Fluctuations at College.

-1000

SCALE OF MV/KM

-0

FEB 10 1958

UT

13

14



-1000

SCALE OF MV/KM

-0

FEB 10 1958

UT

20

21



-1000

SCALE OF MV/KM

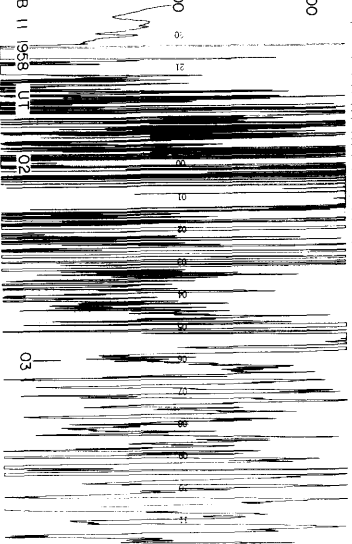
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FEB 11 1958

UT

02

03



-1000

SCALE OF MV/KM

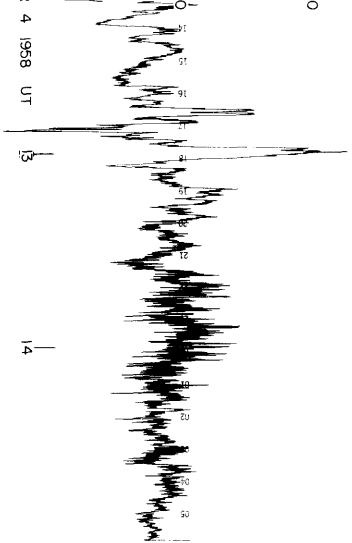
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MAR 4 1958

UT

13

14



-1000

-1000

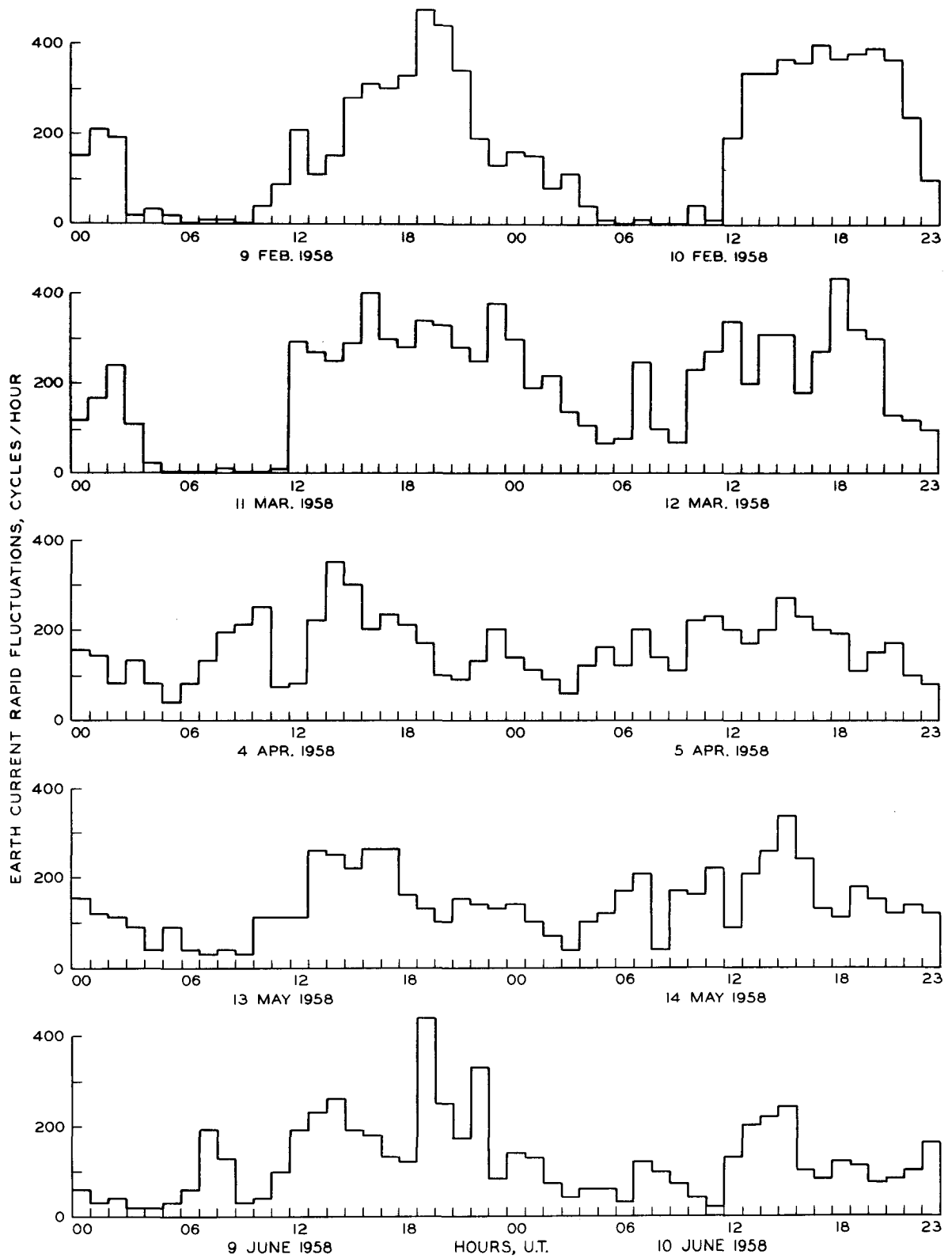


Fig. 2. Rapid Fluctuations at College, Selected Days.

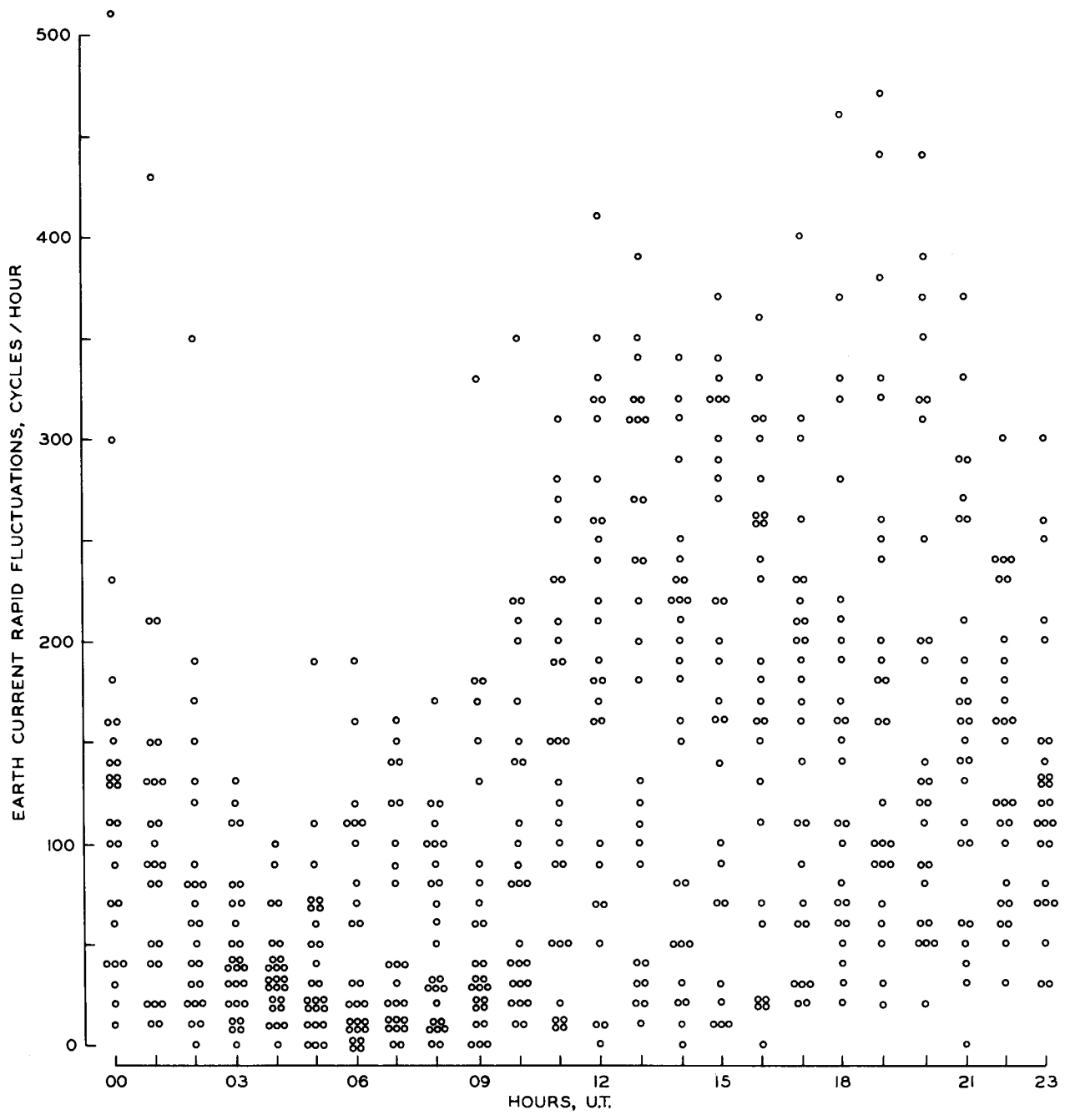


Fig. 3. Rapid Fluctuation Frequency at College, Hourly Values Feb 1958.

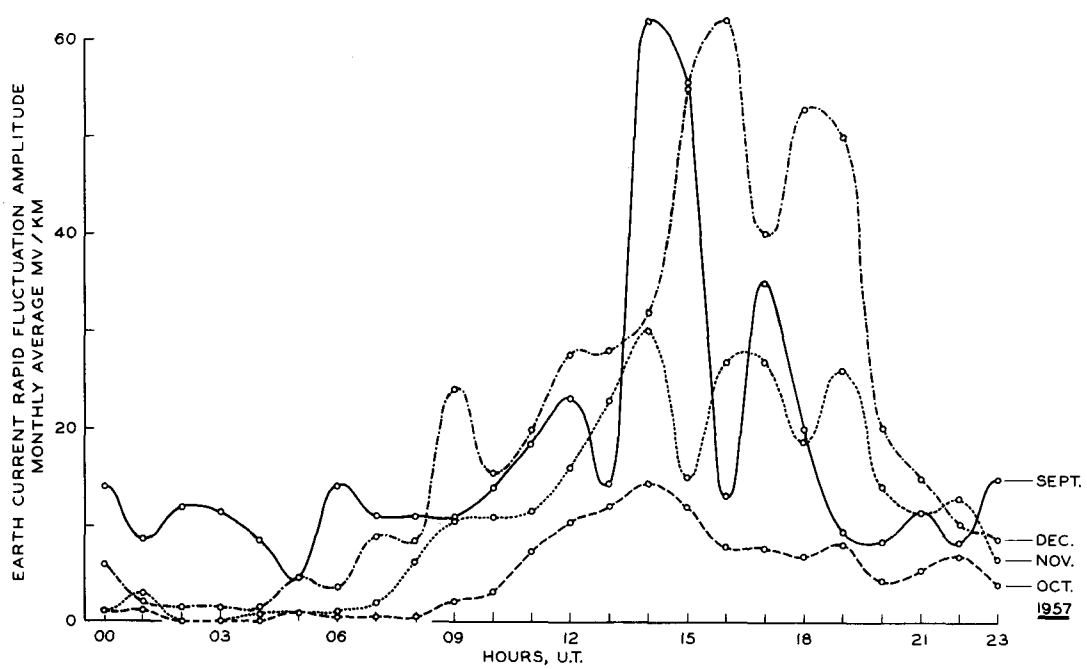


Fig. 4. Rapid Fluctuation Amplitude at College.

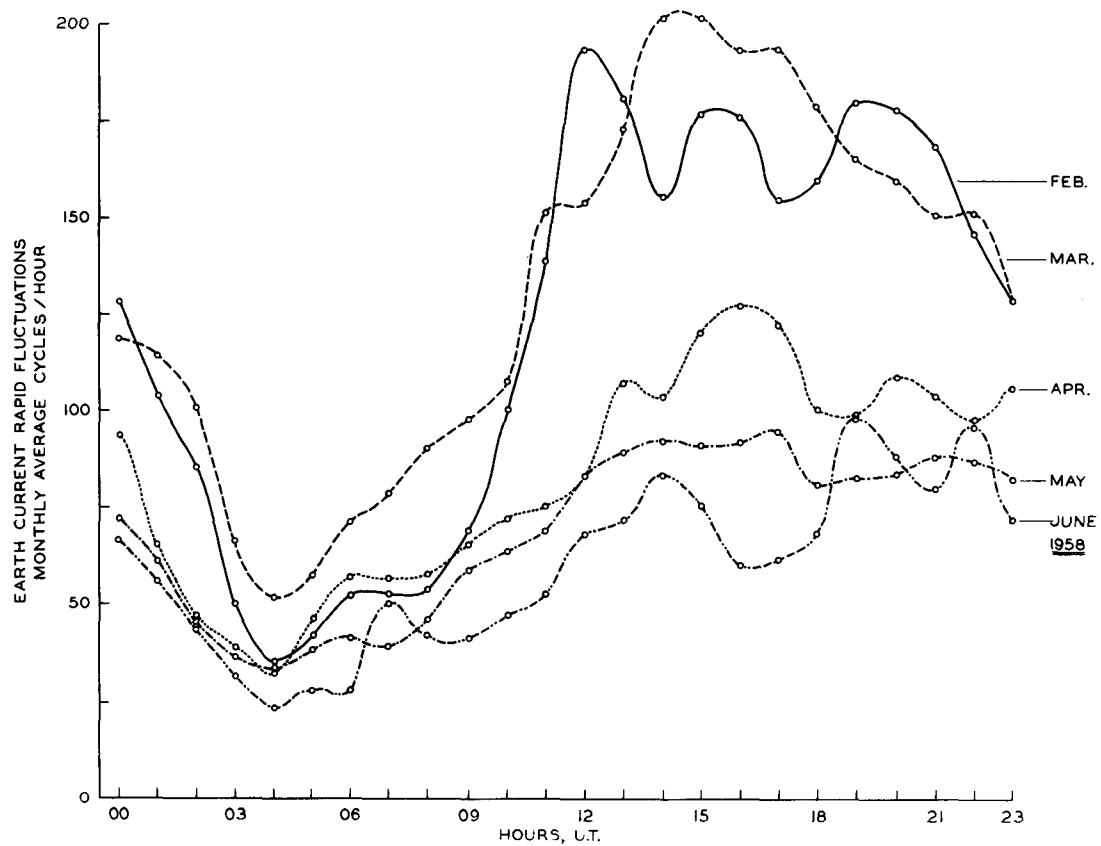


Fig. 5. Rapid Fluctuation Frequency at College.

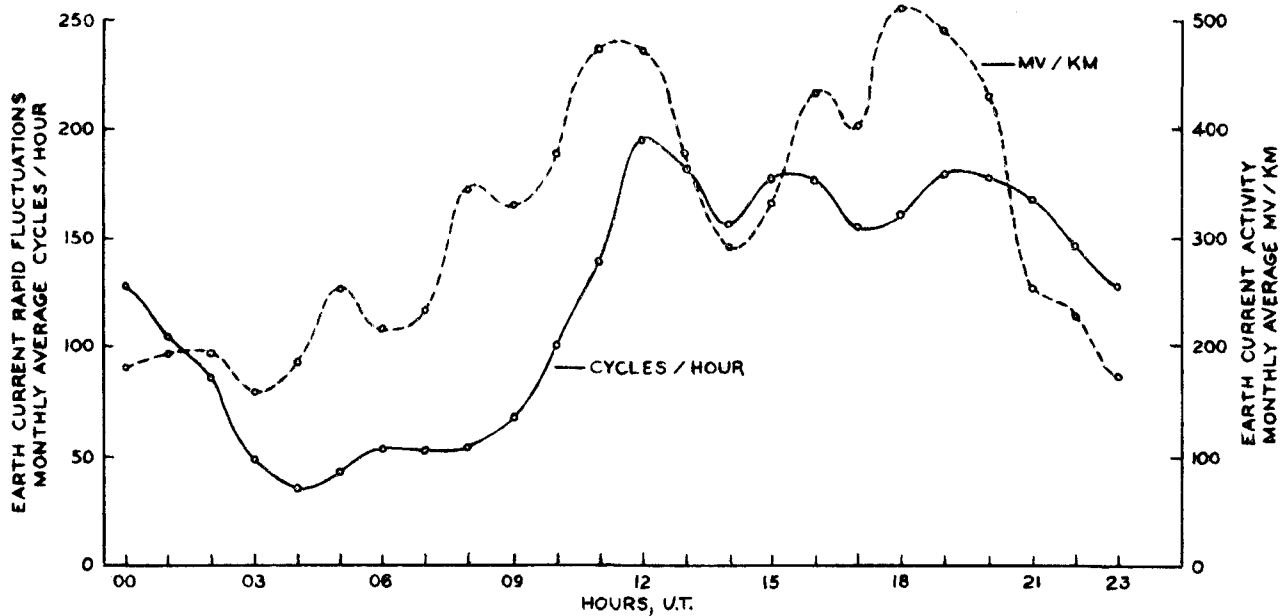


Fig. 6. Rapid Fluctuation Amplitude and Frequency Activity at College, Feb 1958.

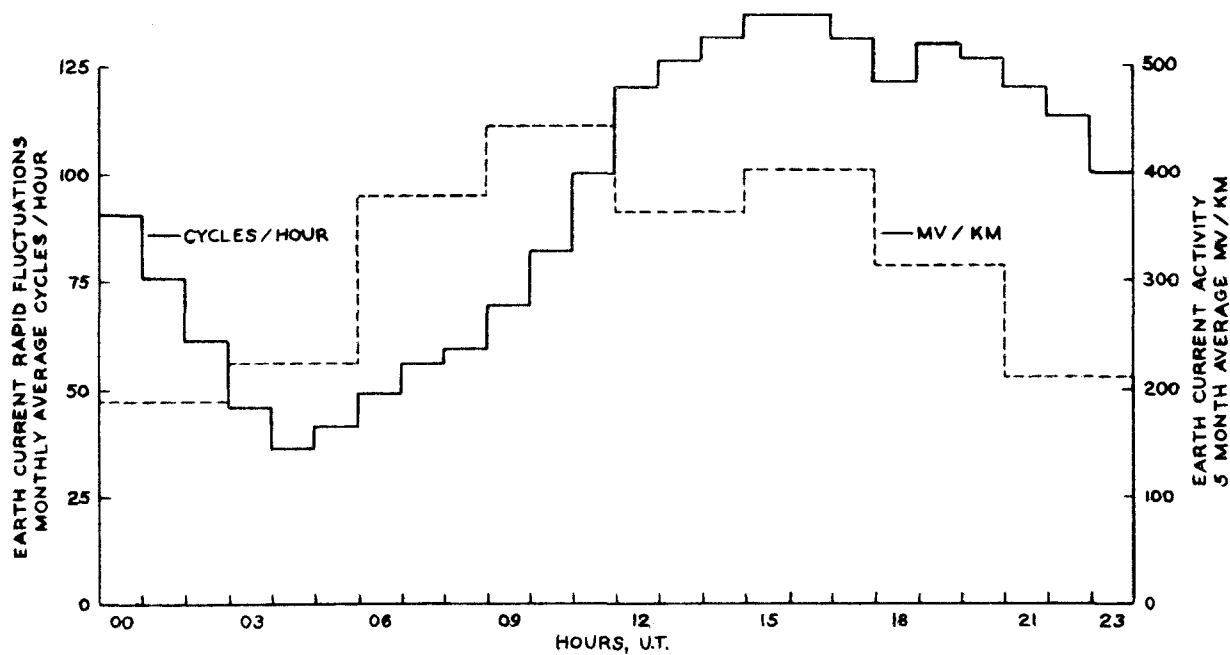


Fig. 7. Rapid Fluctuation Amplitude and Frequency Activity at College, Feb-June 1958 Average.

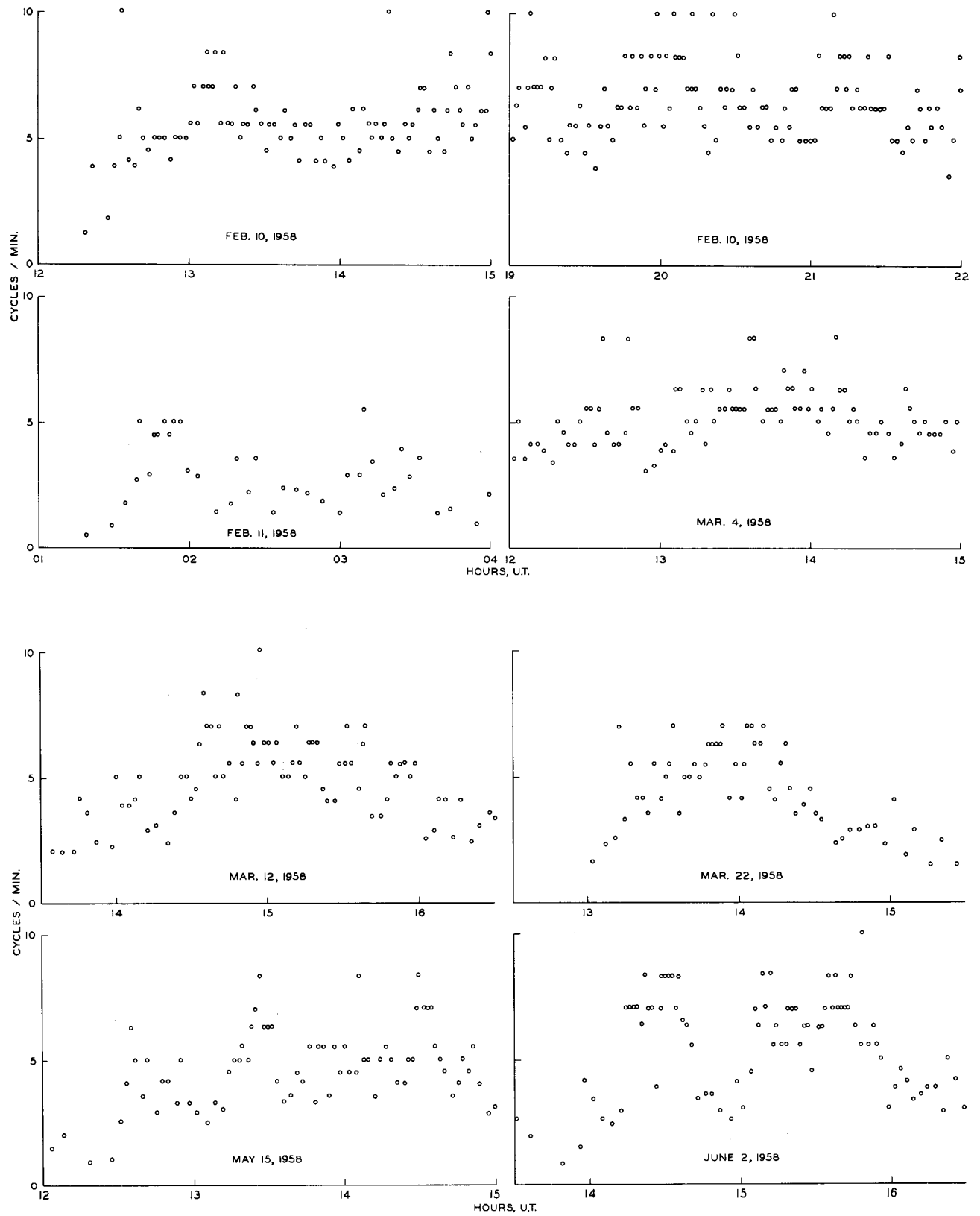


Fig. 8. Rapid Fluctuation Frequency at College, Selected Storms.

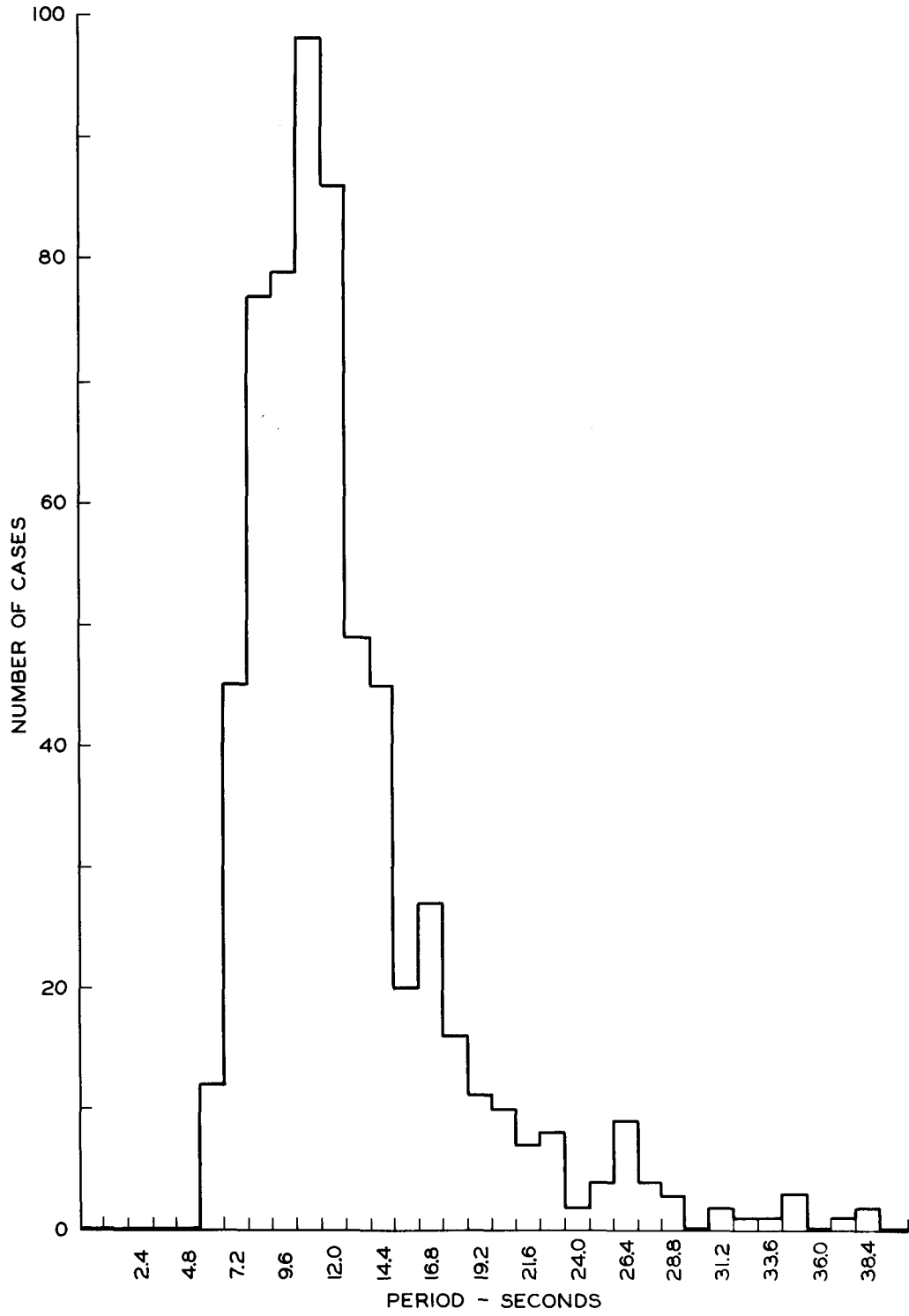


Fig. 9. Period of Rapid Fluctuations.

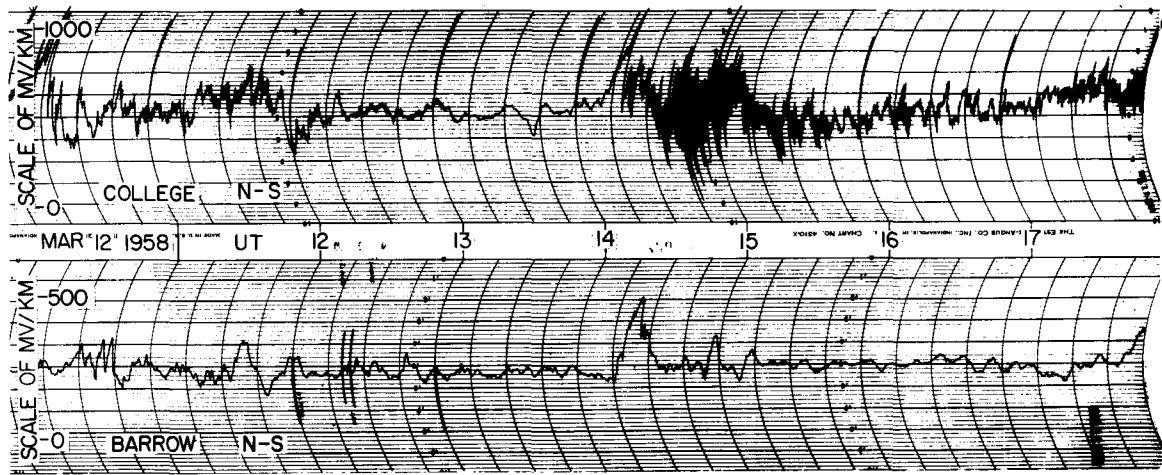
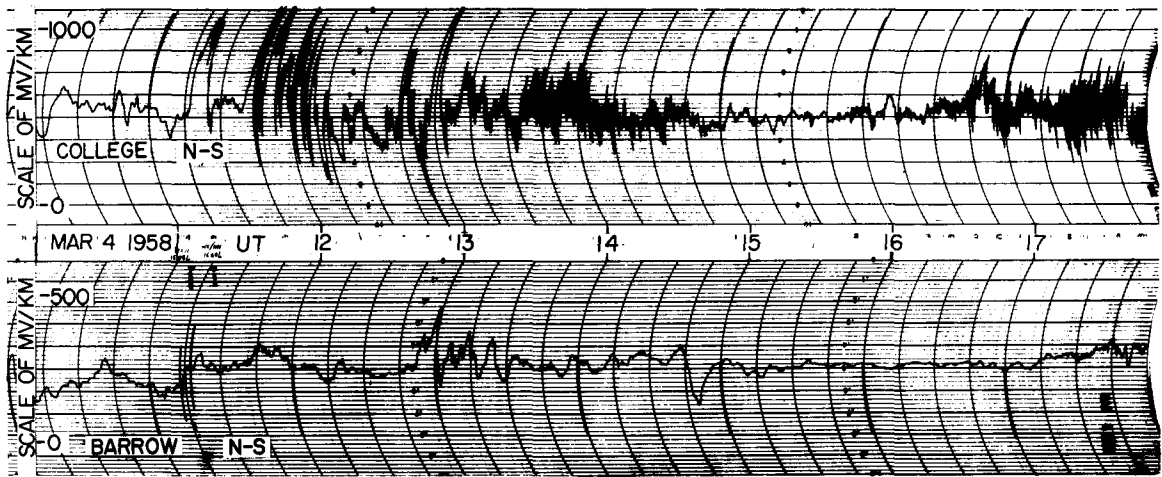


Fig. 10. Comparison of Rapid Fluctuations, College and Pt Barrow.