ERRATA

Page	Line	Read	For
49		Introduction	Introdution

Earth-Current Pulsations Observed at Kakioka

By KAZUO YANAGIHARA

摘　要

柿岡において1934年から1953年までの20年間に観測された地電流の脈動について分類の必要性を考慮に入れて，その頻度の日変化，年変化，年々変化，27日再帰性，一般の地磁気擾乱の活動度との関連，汎世界的出現と地方時に依存する頻度日変化との関係等を調べた．

§ 1. Introdution

Since as early as 1859[1], various investigations have been done on pulsations of geomagnetic field or earh-currents. They are based mainly on statistical results because of so scanty data that any definite world-wide distribution of the field has not yet been obtained. The results of these statistical works have lead to various kinds of statements and opinions according to their different basis of data, and some of them are out of harmony with the others. This inconsistency may appear invitably when "pulsations" cover all of the periodical variations of periods less than several minutes, even apart from the difference in instrumental characteristics or locality of observing stations, because pulsations are to be classed.

The recognition of a distinctive group of pulsations has become convincible (Angenheister 1954, Scholte and Veldkamp 1954, Troyickaya 1955, Yanagihara 1956) [2],[3],[4],[5] in addition to the group of giant pulsations, distinguished from the other pulsations for their characteristic regional appearance. The most typical appearance of the now distinguished group is recognized as p s c. They occur most frequently on night hours, as they are sometimes called "night- or evening-pulsation". In contrast with this, there may be "day-pulsation" which has its diurnal frequency maximum in daytime (Utashiro 1949, Troyickaya 1955)[6],[4], but the detailed discussion of it is hardly done for their various and unsettled statistical peculiarities.

The numbers of the specified pulsations counted on the record are seriously controlled by the method of measurement. In fact, oscillations of a shorter period are found more numerously on the record by the induction-variometer than on the records of the magnetic field intensity itself. Those of a longer period, however, can be more frequently found on the ordinary magnetogram. Earth-current records play an intermediate role

The mean period of the "night-pulsations", say 90 seconds, is somewhat longer than the "day-pulsations", but the amplitude is not so great that only a few of them are recognizable on the ordinary magnetogram in middle or low latitudes. In earth-current record, however, such a pulsation may be one of the most conspicuous variations in night hours. Hence, it is possible to obtain their statistical characteristics based on the long series of data by ordinary electrograms of earth-currents without increasing sensitivity and paper speed.

One of the statistical results based on the 20-year's data of earth-currents observed at Kakioka was given in the preliminary report (Yanagihara, 1955)(5). More extensive and detailed statistics and discussions will be given in the latter sections.

§ 2. Pulsations of the earth-currents observed at Kakioka (data used)

As already mentioned, in ordinary earth-current records variations of shorter or moderate periods, from one minutes up to several hours, are predominant; for example, bay-disturbances, variations with solar flare, irregular or oscillatory fluctuations during storms and pulsations. The sensitivity of the ordinary record has been adjusted generally so as to equalize the range of diurnal curve nearly to that of ordinary magnetogram, and the paper speed as 15 mm/hour.

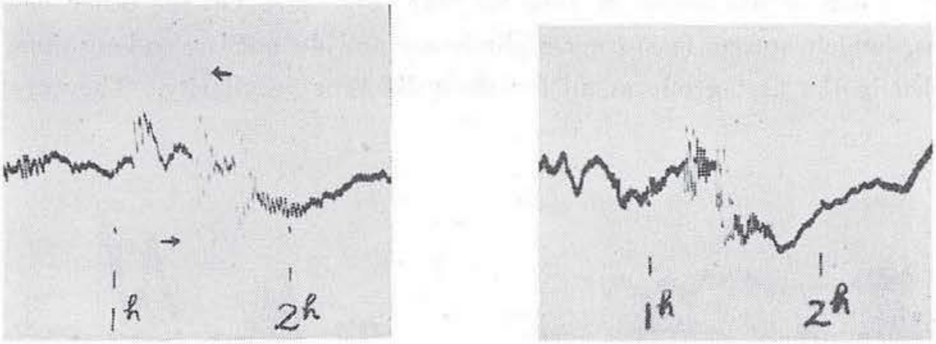
Generally speaking, the pulsations have not so large amplitude, but they are found rather conspicuously on the records, especially on magnetically calm days, because of their rather regular oscillating character. Their occurrences on calm days are well known, but it is not only due to the lack of the other conspicuous variations that pulsations are found often on magnetically calm days. Their occurrences appear to be more favourable in the year of low solar activity. This is an important clue to the present study, and some preliminary works on the said subjects have been published. (5)

After the examination of long series records of earth-currents and the temporary quick-run records available, it was found to be necessary for pulsations in middle or low latitudes to divide them into two groups, at least.

(1) The first group is the "night-pulsation" above mentioned. The night pulsations are often accompanied by bay-disturbances (psc). But the rather typical ones of night pulsation are found semetimes also on the records with no other conspicuous disturbances. At the same time of the occurrences of these pulsations, bay-disturbances or polar storms often appear in higher latitudes, when the corresponding disturbances are not recognizable on the magnetograms or earth-current records at Kakioka. This is well harmony with the result of Scholte and Veldkamp (1955)(3), which shows that the pulsation which was recorded in Europe in the absence of

a bay-disturbance was accompanied in Canada by the beginning of a local storm. It may be true that when a pulsation is found at any place with no other distinct variations, a local storm occurs at some other places, probably at high latitude.

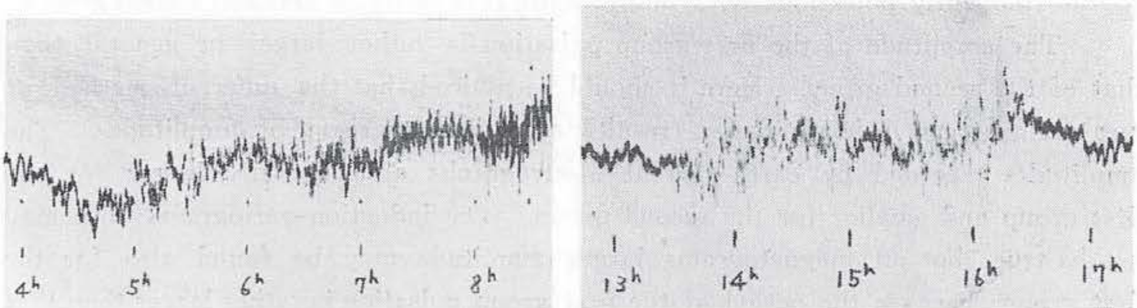
The typical form of this kind of pulsation is a damped oscillation which lasts from few minutes up to one hour (Fig. 1). Rather isolated occurrences are also familiar, as stressed by Troyickaya, (1955)[4]. They are well observable not only on the quick-run records but also on the ordinary records.



a) Sep. 30, 1945 b) Feb. 17, 1953

Fig. 1. Examples of pulsations (the first group).

(2) The second group is the pulsation which may be called "day-pulsation". Its most distinct hours of occurrence is found in early morning of storm times or of several succeeding days after main disturbed period of a storm. It is distinguished from the first group (night-pulsation) by its peculiarity of prolonged continuous waves on the records in contrast with damped oscillations of the night-pulsations (Fig. 2). Some of the day-pulsation was often recorded also in daytime as well as in early morning, when the noticeable storm or disturbance could not be recognized. Hence, it is somewhat suspicious that they all are included in the same second group.



a) Sep. 4, 1947 b) July 29, 1946

Fig. 2. Examples of pulsations (the second group).

The mean period of the first group pulsation, measured from crest to crest, is somewhat longer than that of the second group. From this point of view, Terada roughly divided pulsations into two groups and showed that the group of longer periods 1.5~2.5 minutes predominates in night hours, whereas the other group of shorter periods 0.5-1 minutes is more frequently found in daytime (Terada, 1917)[7].

The classification said above does not mean that the first group occurs in night hours only and the second group does in daytimes only. An example of the pulsation occurred in daytime, whose peculiarity makes it to belong to the first group, is shown in the record of June 8, 1942 (Fig. 3). On the other hand some pulsations, which appear in stormy night hours and do not last so long time, cannot be included in the first group at all for their different peculiarity. They are obliged

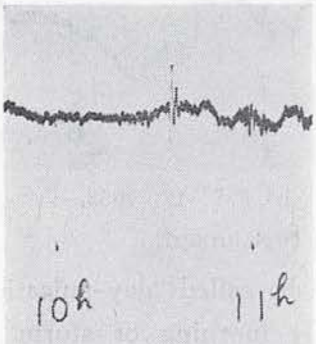


Fig. 3. An example of the first group pulsation occurred in daytime. June 8, 1942

Fig. 4. An example of pulsation occurred in stormy night hours. Oct. 28, 1951

to be included in the second group which has rather vague character. But properly speaking, they may be distinguished from the two groups said above as the third group (Fig. 4). On the transition period from day to night or vice versa, there appear frequently pulsations with intermediate peculiarity of first and second groups.

The amplitude of the first group pulsation is rather larger in general than that of the second group. Here it should be noticed that the different method of measurement can deduce different results as for comparison of amplitudes. The amplitudes recorded by earth-current electrographs are generally larger for the first group and smaller for the second group. On induction-variograms this may not be true, but on magnetograms larger amplitude may be found also for the first group, bacause the period of the first group pulsation is rather larger than that of the second group. It is well known that the ratio of amplitude of earth-current variation to that of corresponding magnetic variation is in proportion to $1/\sqrt{T}$, on the average, where T is the period of the variation.

Pulsations with larger amplitude than a threshold value, which is suitably decided here, may belong mostly to (1) group. And if these pulsations only are chosen, any statistical investigation of (1) group pulsation may be carried out without introducing any mistake due to self-sufficient decision as to classification of pulsations. In this case, it is not evitable, of course, that the data contain the other kinds of pulsations than (1) group. But the percentage of such chances is as small as to be negligible, provided the threshold value is suitable. As such a threshold value, 20 mV/km is adopted for the earth-current pulsations at Kakioka, where 20 mV/km is approximately the same as the range of diurnal variation. The frequency of pulsation may be represented by the numbers of the hour interval in which the pulsation of maximum amplitude over the threshold value, 20 mV/km, is found on the record. In the following, the term "frequency" will be used in place of this numbers, and any statement will be confined to the first group only except the section 7 and the remarked cases. The total numbers of such hour interval which are chosen are 2155 for 20 years, 1934–1953.

§ 3. Diurnal variation of frequency

Mean hourly frequencies for 20 years, 1934–1953, are shown in Fig. 5. As it is expected, the frequency is very high in night hours, and its maximum is found near local midnight. The mean level of the curve is not zero in daytime, being mainly due to pulsations occurred in storm times. Similar noise level may exist in night hours because some pulsations, which may be counted in the third group, are often found during stormy night hours. These two noise levels are likely to be of the same order. Slight increase over the noise level near noon or in forenoon is somewhat distinct.

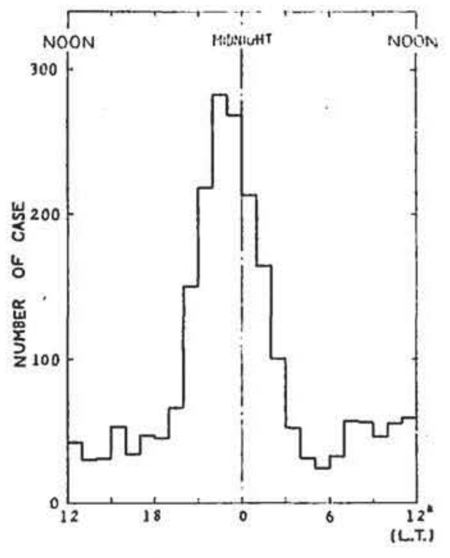


Fig. 5. Mean diurnal variation of frequency for 1934–1953.

The results obtained above are well harmony with the results of Scholte and Veldkamp and Angenheister gained from the data of (1) group pulsation observed at some other localities of the world. They point out that the maximum frequency occurs near *local* midnight, though someone reports the frequency curve depending on the *universal* time (Troyickaya, 1955). The hour of maximum frequency, however, may depend slightly on longitudes, and this subject will be discussed in the next paper.

§ 4. Seasonal, annual and 11-year variations and recurrence tendency

The annual variation and the change in annual means of frequency were outlined in the previons report by means of the number of day on which some pulsation occurred with the amplitude over 20 mV/km. The same variations are calculated again on the frequency criterion defined in § 2 and shown in Figs. 6 and 7. They are nearly the same as those in the previous report. That is to say, the change of annual mean frequency from year to year is in inverse proportion to the solar activity, whereas the annual variation shows the maximum frequency in equinox as well as the general geomagnetic activity. The frequency for sunspot minimum years is higher than that for sunspot maximum years by the ratio of 4 or 5. Though this factor 4 or 5 seems to be somewhat large, but it is a likely supposition that the amplitude may be suppressed with increasing ionospheric conductivity for sunspot maximum years. It is interesting that the variation of annual mean frequency of giant pulsations is also anti-parallel with that of the solar activity (Sucksdorff, 1939) [8]. The range of annual variation is about the same as the mean monthly frequency.

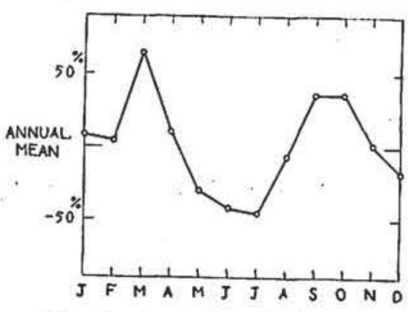


Fig. 6. Annual variation of frequency.

If the ionospheric conductivity controls considerably the frequency of pulsation observed through the manner of screening effect or so, the diurnal variation of frequency should depend upon the season considered. But the diurnal variations of percentage frequency for winter, equinox and summer are not so different each other. Fig. 8 shows for 3 seasons the hourly percentage of frequency, in which the mean level during daytime is not comprised. In spite of this minor opposition, screening or self-impedance effect of the ionosphere influences doubtlessly upon the observed amplitude or frequency of pulsations.

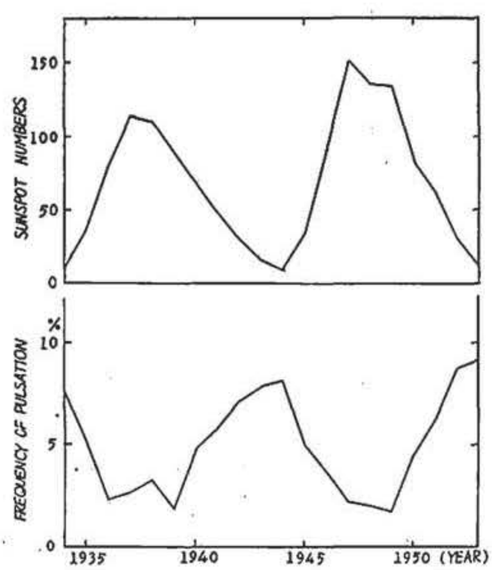


Fig. 7. Annual mean frequency of pulsation and sunspot numbers, 1934-1953.

Geomagnetic activities show the well-known 27-day recurrence tendency, but the occurrence of pulsations does not show any recurrence tendency during up to 40 succeeding days as shown in Fig. 9. As it is seen in the figure, conservation of high frequency is also not found. Occurrence of any pulsation in a day does not affect whether a pulsation appears in the following day or not. To interpret these two inclinations, opposed to those of general geomagnetic activity, it must be taken into consideration that for the present case the pulsations of rather larger amplitude only are used. Recurrent (27-day) or repeated (successive day) pulsations may have smaller amplitudes, and can escape from our data adopted. Actually, repeated occurrences of pulsations can be found sometimes on succeeding days as well as bay-disturbances.

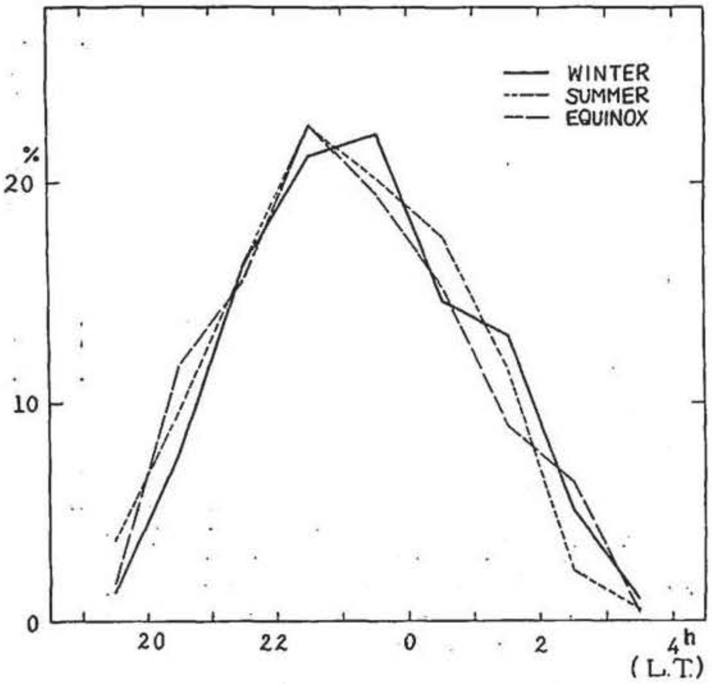


Fig. 8. Diurnal variations of hourly percentage of frequency for three seasons. Mean level during daytime is deducted.

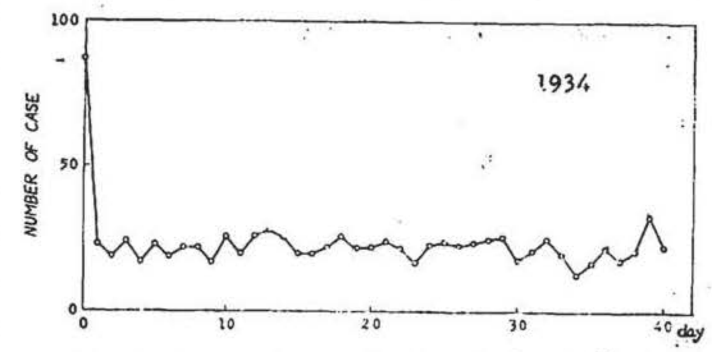


Fig. 9. Average frequencies for 40 days following a set of days on which pulsations occurred in 1934.

§ 5. Relation between pulsations and general disturbances

The annual mean frequency of pulsation is controlled by solar activity in such a manner as to make the frequency in solar active years lower than that in quiet years by the ratio, 1/4 or 1/5, whereas pulsations are oftenly accompanied with bay or baylike disturbance. To examine the relation between pulsations and general geomagnetic disturbances the well-defined Kp-index is used, firstly, for the expression of general level of geomagnetic activity. Fig. 10 shows the frequency of Kp-indices

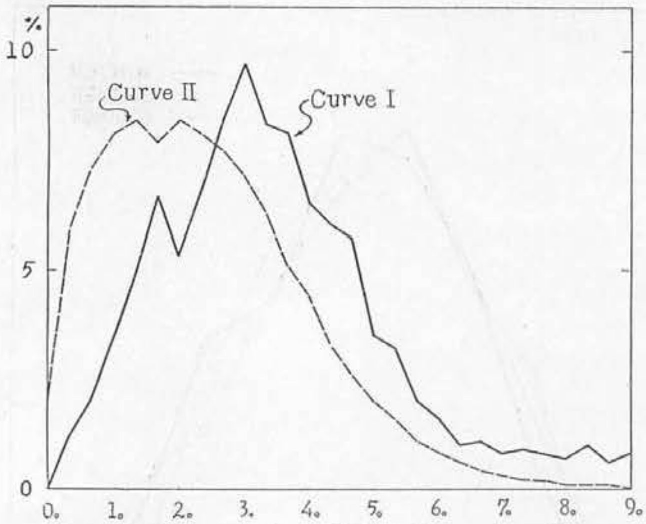


Fig. 10. Frequencies of Kp-index assigned for the interval in which the pulsation is found (Curve I, full line) and for the whole three-hour-interval during the period, 1937-1952 (Curve II, broken line).

assigned for the interval in which the chosen pulsation is found (Curve I). The frequency of Kp-indices assigned for the whole three-hour-interval during the period, 1937-1952, is also shown in the figure (Curve II). In the Curve I, the frequency increases with increasing geomagnetic activity up to its maximum at $Kp=3_0$, and then decreases gradually. At $Kp=3_0$, the Curve II is in the decreasing stage.

In view of these Curves I and II, geomagnetic field is slightly disturbed at the time of occurrence of pulsation, and this may be due to accompanied bay or baylike disturbance. Even when the Kp-index is very low at the time of occurrence of pulsation, in some regions of auroral zone, probably nearest to the observing station (Kakioka, here), some peculiar disturbance may be recognizable. For example, at 11 h May 8, 1951 (U. T.), a baylike disturbance was recorded at College, Alaska(9) for $Kp=1_0$, and at just the time of its opening a pulsation was found at Kakioka (Fig. 11). Pulsations occur also during the entirely quiet interval on the same record or on the available auroral zone data, but the lack of high latitude data along or near the 135°E meridian, on which Kakioka is situated, restrain us from fully concluding.

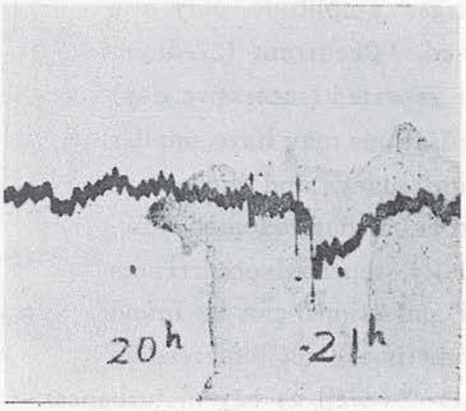


Fig. 11. May 8, 1951

Diurnal frequency curves of pulsation are altered somewhat by levels of background Kp. Fig. 12 shows these curves for $Kp=0_0-2_+$, 3_--4_+, 5_--6_+ and 7_--9_+. The first curve, for $Kp\leqq 2_+$, shows the frequency maximum at about 23.5 h (L. T.) and symmetrically decreases towards day-side. At a glance this symmetric variation is remarkable. The maximum of frequency approaches towards earlier hour with increasing activity, except the curve for $Kp\geqq 7_+$ which is derived from the scanty data.

§ 6. World-wide appearance and local time control

It is fairly well-known that the pulsations occur simultaneously almost all over the world in contrast with the regional appearance of giant pulsations. Fig. 13 shows an example of the pulsation observed at Kakioka at just the same time of the occurrence of pulsation reported by Toledo Observatory (Lat 39° 53′N, Long. 4° 03′W)[10]. On the other hand, there is a conspicuous variation of frequency at an individual station in the course of a day. This contradiction may be removed if the diurnal variation of frequency is considered to be due to the depression of amplitude in daytime. In this point of view, many examples of regional appearance of pulsation must be found for the small amplitude, together with the world-wide appearance for high intensity. For the (1) group pulsation which occurred in daytime at Kakioka, the example shown in Fig. 13 is a most representative one. 12 percent of the pulsations listed in the annual report of earth-currents at Toledo, 1951[10], are clearly found simultaneously on the earth-current records at Kakioka, but 75% of them can not be entirely recognized. The rest is barely found at Kakioka.

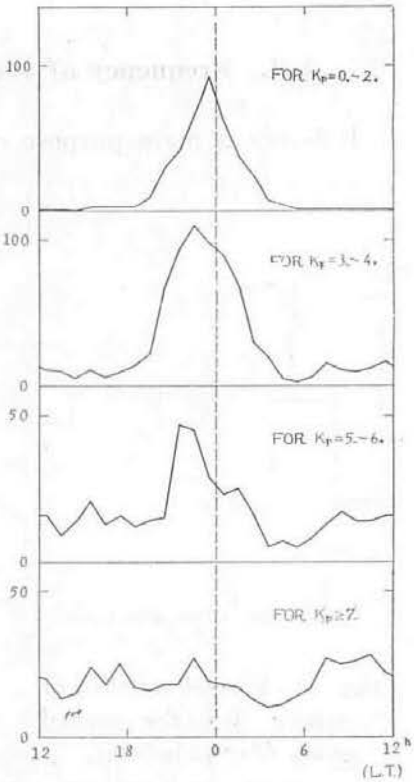


Fig. 12. Diurnal variations of frequency for $Kp=0_0-2_+$, 3_--4_+, 5_--6_+ and 7_--9_0.

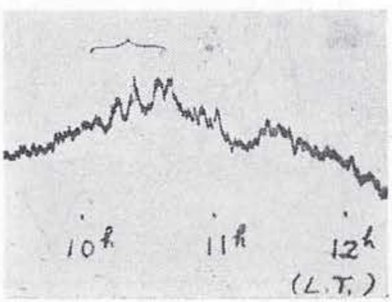


Fig. 13. a) Kakioka

Fig. 13. b) Toledo

Fig. 13. Apr. 10, 1951

§ 7. Frequency of second group pulsations ("day-pulsation")

It is not a main purpose of this paper to make a study of the second group pulsations, but for the sake of contrast with the first group some brief statistical descriptions of the second group pulsation will be added as follows. Diurnal, annual and 11-year variations of activity on the second group are given here. Differing from the case of the first group pulsation, maximum amplitude in one hour interval is used as the measure of activity for the diurnal variation. Means of these maximum amplitudes for each three-hour-interval during the first days of the main magnetic storms which occurred in the period from Mar. 1947 to July 1948 are shown in Fig. 14. In addition to the general tendency of increased activity in daytime, the appearances of two maxima in the morning and evening are interesting, especially with a remarkable magnitude of the former. Then, frequencies in five-hour-interval from 7h to 12h (L. T.) are used as the measure of activity for the annual or 11-year variation, where frequency means the same number as used in the preceding sections. Fig. 15 shows the annual and 11-year variations thus calculated.

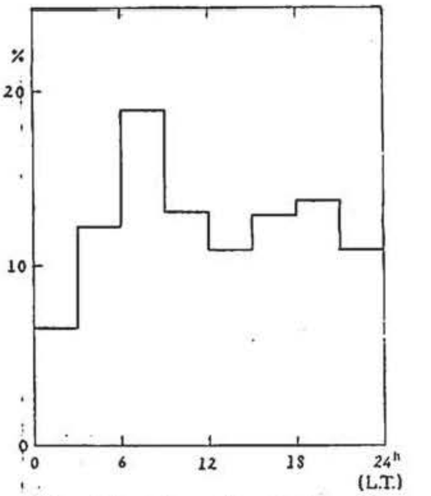


Fig. 14. Diurnal variation of activity for the second group (day-pulsation).

The curve of annual variation shows the maxima in spring and autumn as in the case of first group pulsation or general geomagnetic activity. The spring maximum, however, is very conspicuous in this case. The year-to-year change of

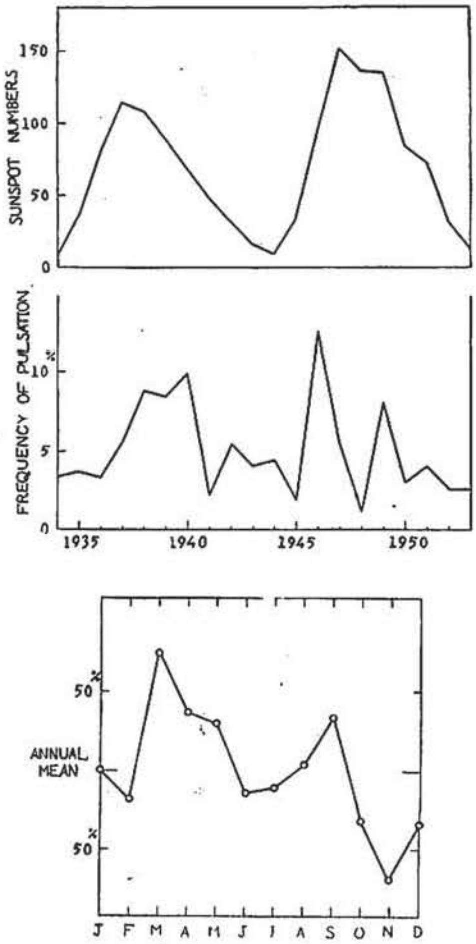


Fig. 15. Annual variation and year-to-year change for the second group (day-pulsation).

frequency is very different from the case of the first group.

§ 8. Conclusion

Earth-current pulsations observed at Kakioka during 20 years from 1934 to 1953 are examined. It is ascertained that two groups of pulsation must be distinguished, that is, first and second groups in § 2. Their statistical peculiarities based on the long continued series of data are made clear. Some of them, for example, diurnal variations of frequency, are about the same as the recent results reported on this old subject taking into consideration the necessity of classification. The diurnal variation of frequency depends on local time, showing the conspicuous predominance of occurrence in night hours. If it depends on the universal time as said by Troyickaya, the maximum of frequency must be found at 3.5 h (L. T.) at Kakioka, but the observed fact is not so.

Much more numerous finding of pulsations on the record during the geomagnetically quiet years than disturbed years, are now clearly shown in the frequency change with the anti-parallel variation to that of the solar activity. On the other hand, each individual pulsation appears to be related to some geomagnetic disturbance, and then the pulsations are found rather frequently during the slightly disturbed period. This apparent contradiction may be removed by taking into consideration the depression of the amplitude of pulsation due to the high ionospheric conductivity during the active years. A similar depression of the amplitude in daytime may be also the cause of the diurnal variation of frequency. A possible explanation of these depressions of the amplitude may be given by considering the ionospheric screening or self-impedance effect.

References

(1) Stewart, B. (1861) : Phil. Trans. London, 423-30
(2) Angenheister, G. (1954) : Gerl. Beitr. Geophys., **64**, 108
(3) Scholte, J. G., and J. Veldkamp(1955) : Journ. Atmos. Terr. Phys., **6**, 33
(4) Troyickaya, V. A. (1955) : T 174 R, Defence Research Board, Canada, Mar., 1955 (translated in English by E. R. Hope)
(5) Yanagihara, K. (1956) : Memo. Kakioka Mag. Obs. **7**, No. 2, 27
(6) Utashiro, S. (1949) : Journ. Geomag. Geoelec., **1**, No. 2, 59
(7) Terada, T. (1917) : Journ. College Sci. Imp. Univ. Tokyo, **37**
(8) Sucksdorff, E. (1944) : Terr. Mag., **44**, 157
(9) U. S. Department of Commerce, Coast and Geodetic Survey. (1951) : Magnetograms and Hourly Values, College, Alaska, 1951
(10) Observatorio Central Geofisico de Toledo. (1951) : Corrientes Teluricas, 1951