DISTURBANCE DAILY VARIATION OF EARTH CURRENTS AT KAKIOKA

by

Kazuo YANAGIHARA

Translated from
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E.R. Hope
(with Translator's Comments)

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Note of Thanks

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Kazuo YANAGIHARA

1. Summary

Results of earth-current observations at Kakioka, up to the year 1945, have been published in Annual Report form. The quiet-day diurnal variation has been worked out and published for a period of eleven years (one sunspot cycle). In the present paper, we shall discuss the disturbance daily variation.

Our earth-current quiet days are selected on the basis of the electrograms; they may differ somewhat from the international calm days for the terrestrial magnetic field, or from the quiet days selected from the magnetograms at the same observatory. This is due mostly to the following two factors.

i) During thunderstorms ... generally speaking, the approach of clouds carrying an electric charge ... extreme disturbances may be set up in the earth currents. For this reason, days with such storms have been rejected, in the interests of a symmetrical selection of quiet days.

ii) Even when the terrestrial magnetic field is quiet, the earth currents may show considerable fluctuations whenever short-period variations are prominent. This effect is particularly conspicuous at Kakioka, where actual momentary values are used as hourly values. Nevertheless, the days selected from the electrograms and the days selected from the magnetograms do not show any serious discrepancy, and in both cases the mean daily variations are in fair agreement [2]. For instance, in the years 1941-1945 the five days per month selected at Kakioka as earth-current quiet days, thus a total of 300 days, include 260 of the international ten calm days for the magnetic field, and 179 of the international five calm days.

The situation is about the same for the disturbed days.

2. Disturbance daily variation at Kakioka

Fig. 1 shows the quantity designated as S_A, namely the diurnal earth-current variation for all days (designated as S) less the quiet-day variation (designated as S_q), as observed at Kakioka during the eleven-year period 1934-1944. The north-south component has an extremely small range of variation (this includes S_q) as compared with the east-west component; for this reason we shall deal chiefly with the east-west component. As may be seen from the graph, there is a well-marked secondary minimum at about 10 hrs. local time, so that the curve as a whole has a double-maximum form. This result is not in agreement with the magnetic field data, so long as we regard $S_D = S_d - S_q$, the disturbance daily variation of the magnetic field, as being a wave of period one day [3] and if we take it that $S_A = S - S_q$ represents some steady percentage of S_D. If we now try deriving S_D for the earth-currents, with results as in Fig. 1, here too we see that there is a minimum, and that it occurs at the same hour. Not only this, but the shape of the S_D curve is in excellent agreement with the S_A curve, aside from the fact that the amplitude is 2 1/2 times as great. Thus it seems that no great error would be caused by using S_D and S_A interchangeably. Moreover, the agreement between S_A and S_D is about the same in each and every year, though we inevitably have less smoothness of the curves as compared with the eleven-year means. In the breakdown by seasons or by years, S_D is rather more irregular than S_A. Hence in what follows we shall use S_A instead of S_D.

The left-hand part of Fig. 2 shows a tripartite seasonal breakdown of S_A; for winter (November, December, January, February), for summer (May, June, July, August), and for spring and autumn (March, April, September, October). If we examine these seasonal S_A curves with respect to the secondary minimum at around 10 hrs. we see that in the sequence winter/summer/equinox this minimum becomes shallower (though the absolute value of the minimum rises), and that the two maxima approach each other. In the spring and autumn equinoctial periods, the maxima and minima in the daytime hours are obscured, forming rather a flat maximum region.

Now if a breakdown is made by sunspot number (right-hand side of Fig.2), that is, for mean S_A at sunspot minimum (1934, 1944), mean S_A over the eleven-year period, and mean S_A at sunspot maximum (1937, 1938), the results, in this order, agree exactly with the winter/summer/equinox sequence of the seasonal breakdown. The sequences winter/summer/equinox and sunspot minimum/mean/maximum correspond precisely to the progression of disturbance magnitudes. The degree of disturbance may be shown in terms of the mean daily range, as in Table 1.

Table 1

	Winter	Summer	Equinox	Sunspot-min. years	Means for 11 years	Sunspot-max. years
Daily maximum range, mV/km (EW-Component)	68.2	75.2	87.5	63.3	77.0	84.4

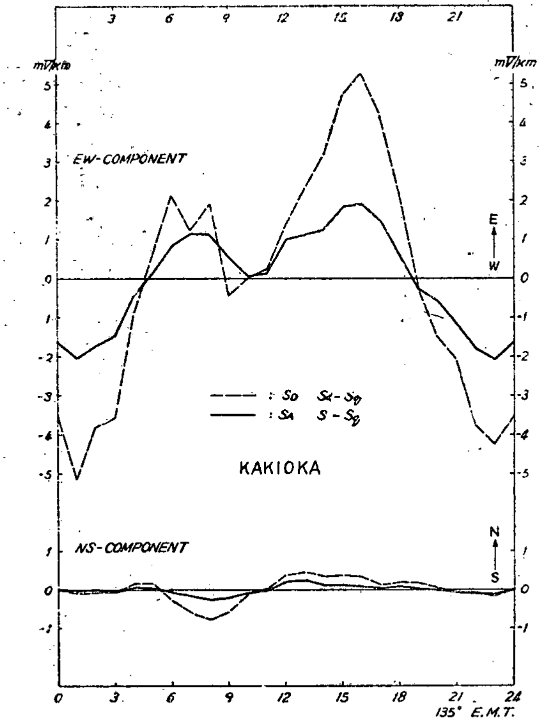

Fig. 1 Disturbance daily variation of earth-current at Kakioka, mean values for 1934-1944, $S_A=S-S_q$ (full line) and $S_D=S_d-S_q$ (broken line)

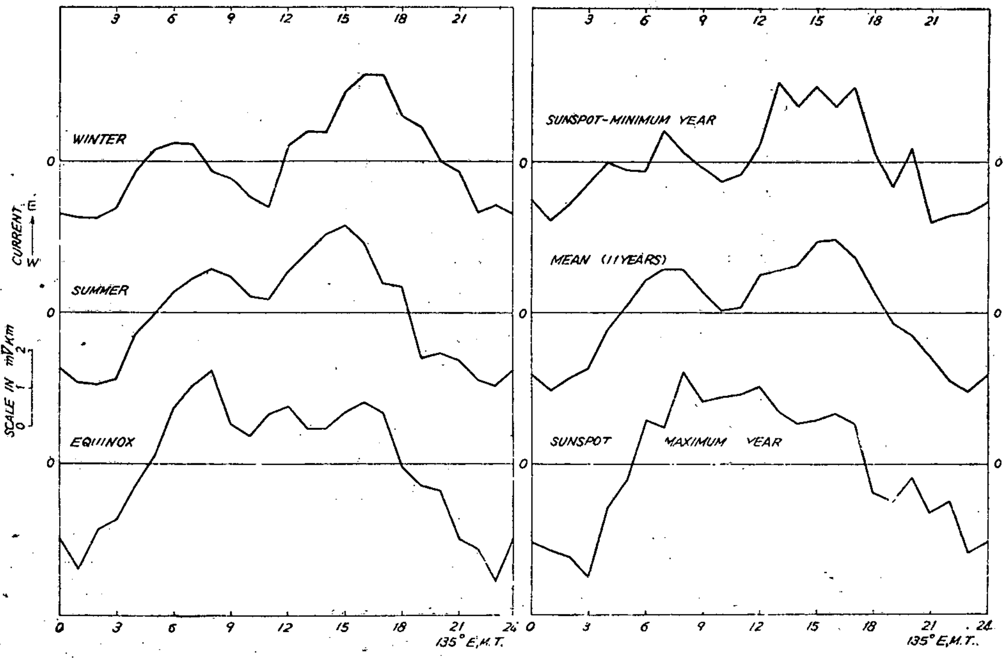

Fig. 2 Changes of disturbance daily variation of earth-current at Kakioka, eastward component, 1934-1944. Winter, Summer and Equinox (left) and Sunspot-minimum years, 11 years and Sunspot-maximum years (right).

Again, if the monthly mean values of S_A at 10 a.m. are averaged at increasing levels of the monthly means of the daily range, the results are as in Table 2. (Monthly mean values of the daily range less than 50 mV/km and greater than 90 mV/km have been rejected, the number of instances being small.)

Table 2

Monthly mean values of daily maximum range, mV/km	50-60	60-70	70-80	80-90
Mean values of $S-S_q$ at 10h, mV/km	-4	+1	+3	+7
Number of months	18	34	31	22

Looking at the matter in this way, we see that with progressively higher levels of disturbance the minimum around 10 a.m. seems to become filled in, although two distinct maxima (Fig. 1) do appear in S_D, a quantity which is calculated from the most disturbed days ... a quite contradictory result.

In Fig. 3 we give the harmonic dial analyses of S_A by seasons and by sunspot minimum, maximum and 11-year mean, showing the diurnal terms [waves]. The diurnal term varies in a relatively regular manner according to the sequences winter/summer/equinox and sunspot minimum/11-year mean/maximum, the amplitude-variation being prominent. The semi-diurnal term also, of course, has a variation, but the amplitude is not as prominent as in the diurnal term.

The apparent filling-in of the 10 a.m. minimum as the above-mentioned sequences progress from winter to summer to equinox, or from sunspot minimum to mean to maximum, would seem to be due to the marked increase of the diurnal wave amplitude which accompanies the said progressions.

If in the seasonal variation and the sun-spot cycle variation of S_A there is a contribution from the semi-diurnal term, but a small one as compared with the diurnal term's contribution, then there is no reason why the 11-year mean of $S_D = S_d - S_q$ should not have a second minimum at about 10 hrs., just as does S_A. Or we could say that the semi-diurnal wave does not appear or disappear according to the disturbance magnitude but merely seems to do so, on account of the seasonal variation (etc.) of the diurnal wave. (If S_D bears some constant proportion to S_A in both the diurnal and semi-diurnal wave, then we may take it that the same thing holds for the seasonal variation, etc.)

3. S_D at other observatories and S_D at Kakioka

W. J. Rooney [2, 4] has frequently stated that the earth-current S_D, like S_D of the terrestrial magnetic field, is basically a diurnal variation.

Since the results here obtained are markedly at variance with this, let us reexamine the data for other observatories. Rooney derived S_D primarily for Watheroo (1924-1928) but also for Ebro, Huancayo, Tucson and other places. At the time (1933) there was only a short run of the Tucson data available for him to use, and he therefore obtained no clear results; for this reason we have now calculated S_A from the data [5] for an 11-year period (Fig. 4). From the EW and NS components, separately examined, it looks as though all we have is a diurnal variation with a flat maximum and minimum, but when we turn to the vector diagram, noticeable bays show up at 12-18 hrs. and 3-7 hrs. (both of these in local time). Moreover, even in Rooney's results for Watheroo [2], where, it has been stated, the variation is mainly diurnal, we find quite well-marked bays at 1-5 hrs. and 16-20 hrs. (local times). These bays mean that in both cases there is a considerable semi-diurnal term.

It seems then that this fact (the existence of a sizable semi-diurnal term in the earth-current S_D) must be put down, not as a local feature at Kakioka, but rather as a world-wide phenomenon. Moreover, in contrast to Kakioka where the hourly earth-current values are given as the momentary values at the actual times /of observation/, at Watheroo and Tucson the means for the hour are used, and if this is taken into account, the fact that the above-said variation shows up more distinctly at Kakioka than at Watheroo or Tucson may be duly explained as an accumulation of shorter-period variations.

That the variation-component of earth-current corresponds in the main to that of the terrestrial magnetic field is a fact which has been repeatedly demonstrated. Moreover, since we have defined our earth current variations S_D and S_A as differences of mean diurnal variations for [sets of] days graded according to the degree of [magnetic field] disturbance, it is hard to believe that they should contain any terms unrelated to the terrestrial magnetic field. Of course our classification of days according to disturbance-level ... that is, our selection of quiet days and disturbed days ... is based on the electrograms, but as explained in Section 1 it does not essentially differ from a distribution on a magnetogram basis.

Now as regards S_D of the terrestrial magnetic field, we are not raising the question of terms other than the diurnal term, but it seems decidedly worth-while to mention the following fact. In connection with the /magnetic field/ declination, it is stated [6] that S_D as given by Chapman [3] for five latitude-zones exhibits a flat minimum part ... which is perhaps as much as to say that there is, just as in our results, a secondary maximum (of east declination) occurring at about 12 hrs.

If our secondary minimum or semi-diurnal term occurs through an accumulation of shorter-period variations, then it is quite likely that it will not be so clearly expressed in the terrestrial field as in the earth currents. The shorter-period variations might be due to increasing ionization in some parts of the auroral zone, setting up disturbance fields of dipole form.

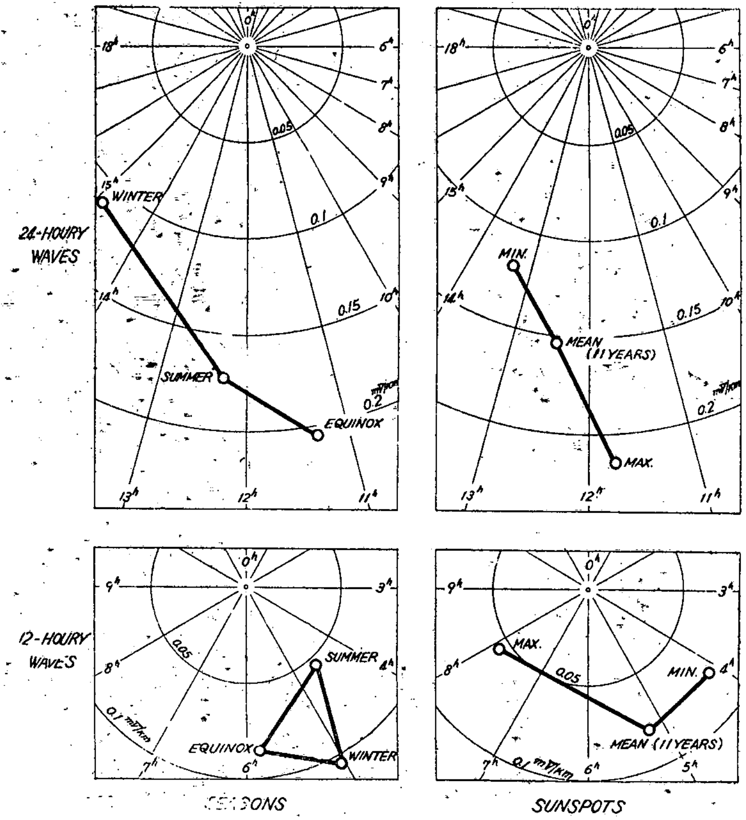

Fig. 3 Harmonic dials for diurnal (24-hourly) and semi-diurnal (12-hourly) sine-waves in the disturbance daily variation of eastward component of earth-current at Kakioka $S_A = S - S_q$, 1934-1944. Winter, Summer and Equinox (left) and Sunspot-minimum years, 11 years and Sunspot-maximum years (right).

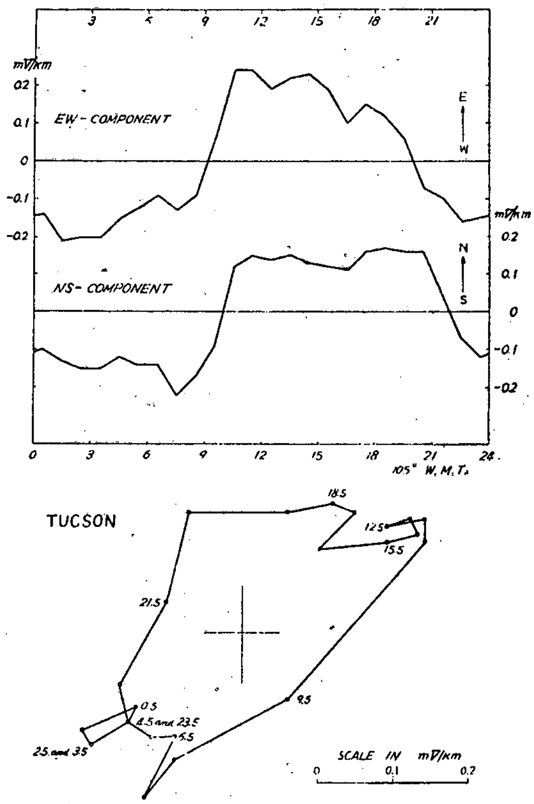

Fig. 4 Disturbance daily variation of earth-current at Tucson, $S_A = S - S_q$, mean values for 1932-1942.

4. Conclusions

Hourly earth-current data at Kakioka have been edited up to the year 1945, and the S_q data for an eleven-year period (1934-1944) have been published in the Annual Report. Availing ourselves of the opportunity thus presented, we have derived S_D and S_A. We find that in addition to the well-known diurnal wave, there is a secondary minimum at about 10 hrs.; a clearly manifested semi-diurnal term. We also have derived the seasonal variation and the variation relative to the sunspot cycle, and here found the amplitude-variation clearly recognizable in the diurnal term, but not clear in the semi-diurnal term.

The occurrence of this secondary minimum or semi-diurnal term is not a local phenomenon, confined to Kakioka. It also shows up quite distinctly in the mean S_A for an eleven-year period at Tucson, and a similar tendency may be seen in Rooney's data for S_D at Watheroo. Moreover, in the terrestrial magnetic field too the same tendency may show up in the S_D variation of the declination. This semi-diurnal term may be conveniently explained as an accumulation of relatively short-period variations.

All the material for this paper has been taken from work carried out in connection with the compilation of the Annual Report. The author particularly wishes to express his gratitude to Technical Officers Ichiro NIIDA and Tsuneo YOKOUCHI, who have been working on the production of the 11-year summary, and to our lady assistants.

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TRANSLATOR'S COMMENTS

on Yanagihara's "Disturbance Daily Variation of Earth-Currents at Kakioka"

E. R. Hope

In the attempt to relate some of the phenomena discussed in [1], [1a] and in [3], the translator's attention was drawn to the Kakioka earth currents, by reason of the markedly small N-S component of variation at that station. Earth-current polar diagrams generally exhibit a large diurnal loop of variation, which is no doubt to be associated with atmospheric tides and auroral-zone currents. Superimposed on this there are minor variations or irregularities, which might have the same source as the diurnal term, or might be due to entirely distinct causes. If at Kakioka the principal variation forms not a loop but almost a straight line, which happens to lie in the E-W direction,* then it is conceivable that the small N-S component might sort out for us any superimposed features which do not have the same source as the main diurnal variation.**

From Fig. 1 of the translated paper, it will be seen that some such effect does exist, particularly in S_D, though the translator was unable to draw any immediate conclusions from it. However, two points of interest emerged from study of this paper. They suggest that a similar investigation of the data for other stations (a general investigation which the translator is in no position to undertake) would be rewarding.

Connection with Suckdorff's and Troyickaya's Micropulsations

In [1], the translator pointed out that Troyickaya's "Type I" continuous oscillations (micropulsations), as detected in the terrestrial magnetic field (vertical component) at stations in Central Asia, exhibit two distinct minor peaks (see Fig. 3), which correspond very closely, in GMT, with the peaks of Sucksdorff's two classes, A and B, of giant micropulsations at Sodankylä, Finland (see [2], page 166).

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* It appears, however, from the data in [5] that the direction which the principal variation takes is chiefly determined by the effect of the seacoast.

** The reason for enquiring into such superimposed influences at stations in the Bering Sea sector will be understood from [4].

	Class A (GMT)	Class B (GMT)
Sodankylä, at sunspot maximum	00-01	05-06
Sodankylä, at sunspot minimum	01-02	08-09
Coinciding with:		
Troyiçkaya's peaks, Central Asia	00-01	06-07 *

Suksdorff's two classes are based on a certain difference in character of the micropulsations (see [2] page 159). Pulsations of Class A occur between 20 hrs and 6 hrs GMT; and exhibit a decided maximum which shifts slightly with the sunspot cycle, as shown.¶Pulsations of Class B appear between 02 hrs and 17 hrs GMT; the maximum is blunter than that of Class A, and not so well marked. Suksdorff calculates its mean position as 7.5 hrs GMT, but shows it as varying by three hours with the sunspot cycle (from 05-06 to 08-09).

In Troyiçkaya's graph the corresponding peak is in an intermediate position (06-07), as we should expect, since her data are for 1951-1952 only; that is, for a period midway between sunspot maximum and minimum. **

We suggest that the wide variation is due to the presence of <u>two</u> peaks of B-class oscillations (compare Suksdorff's graph, curve B, page 166 of [2]), each of which varies independently, and mainly in amplitude, with the sunspot cycle (and probably with the seasons too). That is, there are really three peaks, as follows

<u>1</u>	<u>2</u>	<u>3</u>
00-02	05-06 or slightly earlier	08-09 or slightly later

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* Wrongly given as 08-09 in [1].

** Moreover, Troyiçkaya's data (Fig. 3, right-hand side) would seem to span one of the equinoxes, at which time the micropulsations are much stronger than in summer or winter (see [2], graph on page 168), and the B-class pulsations, according to Suksdorff, have <u>two</u> peaks, the first of which corresponds exactly with Troyiçkaya's peak (06-07 hrs GMT). "At the equinoxes there are two preferred times, 6^h to 7^h and 10^h to 11^h, where the most maximum amplitudes lie." (Suksdorff, [2] page 166.)

Fig. 1. See Fig. 1 of Yanagihara's paper.

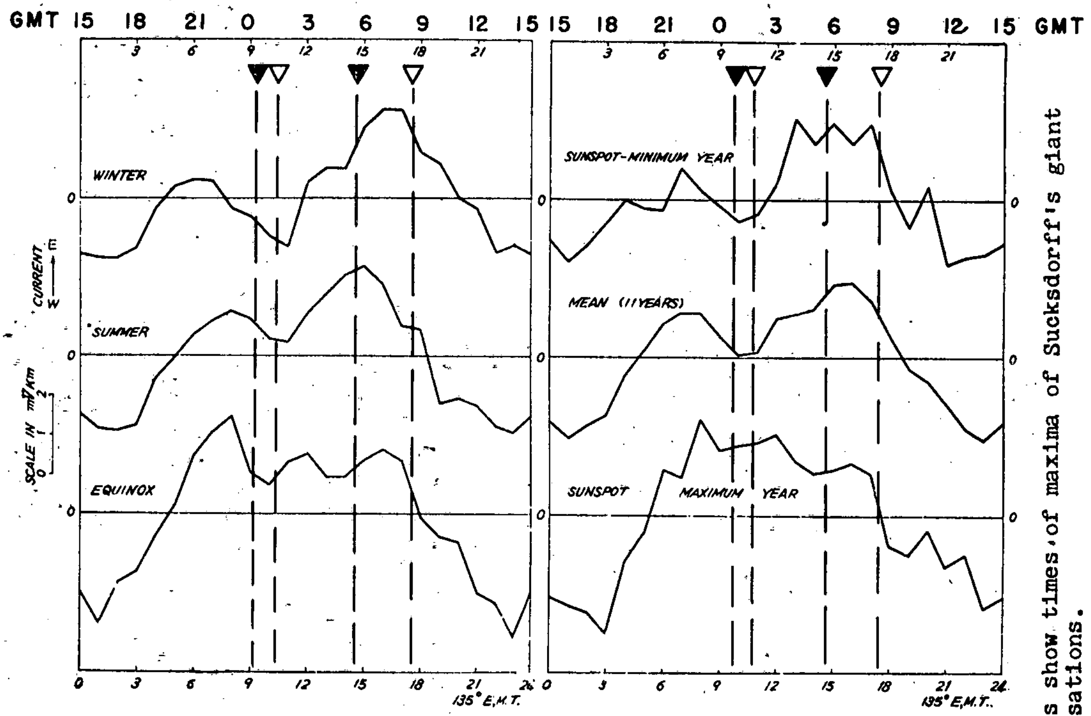
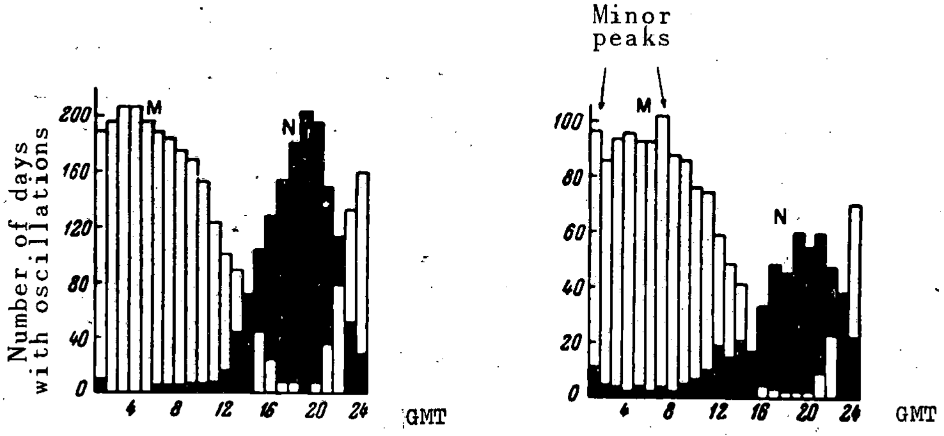


Fig. 2 Changes of disturbance daily variation of earth-current at Kakioka, eastward component, 1934-1944. Winter, Summer and Equinox (left) and Sunspot-minimum years, 11 years and Sunspot-maximum years (right).

Triangles show times of maxima of Sucksdorff's giant micropulsations.

▲, at sunspot maximum.
△, at sunspot minimum.



In earth currents.
(Dec. 1951 to Aug. 1952)

In magnetic field,
vertical component.
(Six months, 1951).

Fig. 3. White: Troyickaya's continuous oscillations
Black: Troyickaya's oscillatory bursts.
M and N show local midnight and noon.

At sunspot maximum the 05-06 peak predominates; at sunspot minimum, the 08-09 peak. The times may really be somewhat farther apart, because Sucksdorff's maxima at 05-06 and 08-09 are for the sum of the two peaks (at different times).

Now these peaks, at the proper hours GMT, seem to appear as dips in Yanagihara's curves of the disturbance daily variation of the earth currents at Kakioka.

In Fig. 1 of Yanagihara's paper here translated, both the S_A and the S_D curves exhibit a pronounced dip in the period 0-3 hrs GMT (9-12 hrs local time), a dip which Yanagihara calls the secondary minimum, but which we shall regard as a secondary maximum (of westward variation). The Greenwich time of this maximum agrees with that of the first Sodankylä and Central Asian peak. Slight but distinct dips may also be detected at about 14 hrs and 19 hrs local time, though they lie on the steep slopes of the curve; the Greenwich times are about 05 hrs and 10 hrs.

Yanagihara's Fig. 2, which we have reproduced with the GMT position of the Sucksdorff peaks marked, permits a more detailed comparison.

It will be seen that in all six curves the dip corresponding to the first peak is very distinct; too distinct to require much comment. A slight shift with the solar activity cycle may be seen, in the direction noted by Sucksdorff; also a seasonal shift.

The 05-06 peak appears, slightly early, as a pronounced sag in the "Sunspot Maximum" curve (ut Sucksdorff); in the "Sunspot Minimum" curve it is small; it is seen as a plateau in the "Mean (11 years)" curve. In the "Equinox" curve it is seen as a very prominent dip, and in the "Winter" curve as a plateau; in the "Summer" curve it is absent.

The 08-09 peak appears, persistently late (10 hrs GMT*), as a marked dip in both the "Sunspot Maximum" and "Sunspot Minimum" curves. It is seen more or less distinctly in all the seasonal curves.

The agreement is therefore excellent between Sucksdorff's and Yanagihara's data, which are for entire, but different, sunspot cycles (1914-1938 and 1934-1944 respectively). The agreement with Troyiçkaya is satisfactory, indeed surprisingly so, if we consider the fact that her data are for only a portion of a single year.

All the temporal correspondences noted are in terms of Greenwich time, as is the case with the other phenomena discussed in [1]. That is, the underlying mechanism must depend in some manner on the attitude of the geomagnetic poles with respect to the sun.

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* Cf. previous footnote.

The picture at Kakioka may be summed up as follows. In the disturbance daily variation as extracted by Yanagihara, there is a diurnal wave with its (westward) maximum near to local midnight (thus coinciding with the Night Maximum of Magnetic Activity). At around 10 hrs local time (01 hr GMT), there is Yanagihara's secondary maximum, smaller, but well marked everywhere except in the "Sunspot Maximum" curve. It is followed by another seasonally variable dip which may be of equal or even greater depth (cf Fig. 2, "Equinox" and "Sunspot Maximum" curves). A third dip appears on the downslope of the diurnal curve. The first of these features is very stable in size and in position, exhibiting only a moderate variation with the sunspot cycle and with the seasons. It corresponds to the maximum of Sucksdorff's Class-A micropulsations. The second and third dips, corresponding to Sucksdorff's Class-B micropulsations, have pronounced variations, both with the sunspot cycle and with the seasons.

We conclude that the special classes of micropulsations detected by Sucksdorff and by Troyiçkaya, which develop in the geomagnetic field at certain definite periods of the GMT day, are phenomena accompanying the well-marked minor peaks of westward earth-current variation at Kakioka. The pulses of energy responsible for the earth-current peaks seem to be more sharply delimited in time than are the micropulsation peaks; that is, the micropulsation peaks are broader, and in particular the B-class micropulsations spread over the whole space between Peaks 2 and 3, producing the effect of a single peak at an intermediate time.

There may be a connection between Yanagihara's secondary maximum and the "axis maximum" [3], pages 19 and 23), but the nature of the latter is not yet clear enough to warrant much comment. See also [4].

It is to be noted that both Sucksdorff's and Troyiçkaya's peaks of micropulsations or continuous oscillations were detected in the geomagnetic field. Troyiçkaya's earth-current diagram (left-hand part of Fig. 3) does not show them. The fact that they show up in Yanagihara's earth-current plots must be attributed to the extraction of the disturbance daily variation (S_A or S_D). Presumably a similar analysis of the earth-currents at Troyiçkaya's Central Asian stations would reveal the peaks, since they were detectable in the geomagnetic field in that region (at Alma Ata).

The obvious question now is whether anything similar is revealed by Yanagihara's plot of the disturbance daily variation of the earth currents at Tucson, Arizona. From Fig. 4, here reproduced with the position of the Sucksdorff micropulsation peaks marked, we see that the picture is very different from Fig. 2. There does seem to be a feature at 00-01 hrs GMT, corresponding to the first Sucksdorff peak; it is distinct, but very small as compared with the deep inflexion in the Kakioka curves. The reader may judge for himself whether the other peaks are represented.

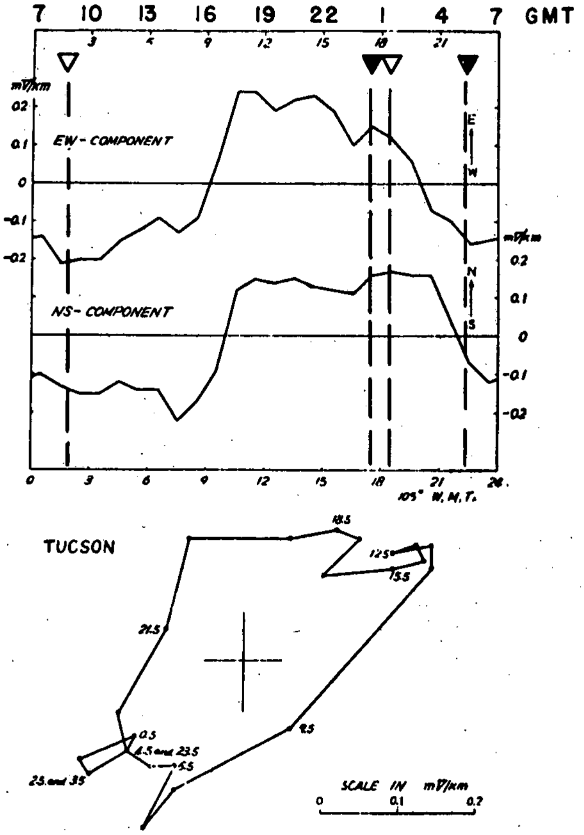

Fig. 4 Disturbance daily variation of earth-current at Tucson, $S_A = S - S_q$, mean values for 1932-1942.

Now micropulsations are most frequently detected in the vicinity of the auroral zones. The association with the earth-current peaks at Kakioka suggests that the forces responsible for the latter emanate from the auroral zones. If so, a variation with latitude is to be expected ... but Kakioka and Tucson do not differ much in latitude.

The most obvious difference between the two stations is that Tucson is in mid-continent, while Kakioka is close to the more highly conducting ocean.

Passage of "Morning Maximum" Wave at Tucson

For Tucson, Arizona, the quiet-day and all-days polar diagrams of earth currents and magnetic disturbance [6] generally exhibit a large oval of diurnal variation, with a small "epicycle" centered at about 0.5 hrs local time. The polar diagram of the disturbance daily variation as calculated by Yanagihara (Fig. 4) has a very different shape. The bay at 11.5 to 17.5 hrs (18.5 to 0.5 hrs GMT) and the "epicycle" at 23.5 to 4.5 hrs (6.5 to 11.5 hrs GMT) do not concern us, but there is another prominent feature which does.

Between 6.5 hrs and 7.5 hrs local time the curve, turning at more than a right-angle to its previous course, makes a sharp excursus south-southwest; during the next hour it completely recovers.

The Greenwich time of the maximum excursion is therefore about 14.5 hrs, and this suggests an explanation: namely, the passage of the spiral wave of corpuscular precipitation which causes the Morning Maximum of Magnetic Activity [3]. If the Soviet isochrons of Fig. 5 are extrapolated, it appears that Tucson will lie between 12 and 14. That is, the spiral will pass Tucson at some time not too remote from 14.5 hrs GMT.

It therefore seems probable that on magnetically disturbed days the precipitation-spiral of the Morning Maximum extends far to the south, and becomes detectable at Tucson as the passage of a quite sharp-fronted earth-current wave.

The discrepancy in time is no doubt explained by the different data; the Soviet isochrons are probably a mean for all days. On disturbed days, it is very unlikely that the spiral would not be displaced.

Compare also Vaughn Agy's radio blackout isochrons ([4], Fig. B, left-hand side) which, as we have pointed out, are the southward extensions of the Soviet magnetic disturbance isochrons. Here, however, we cannot expect better agreement, because Agy's data are for a short and recent period in the solar activity cycle and (in Fig. B) for the summer months only.

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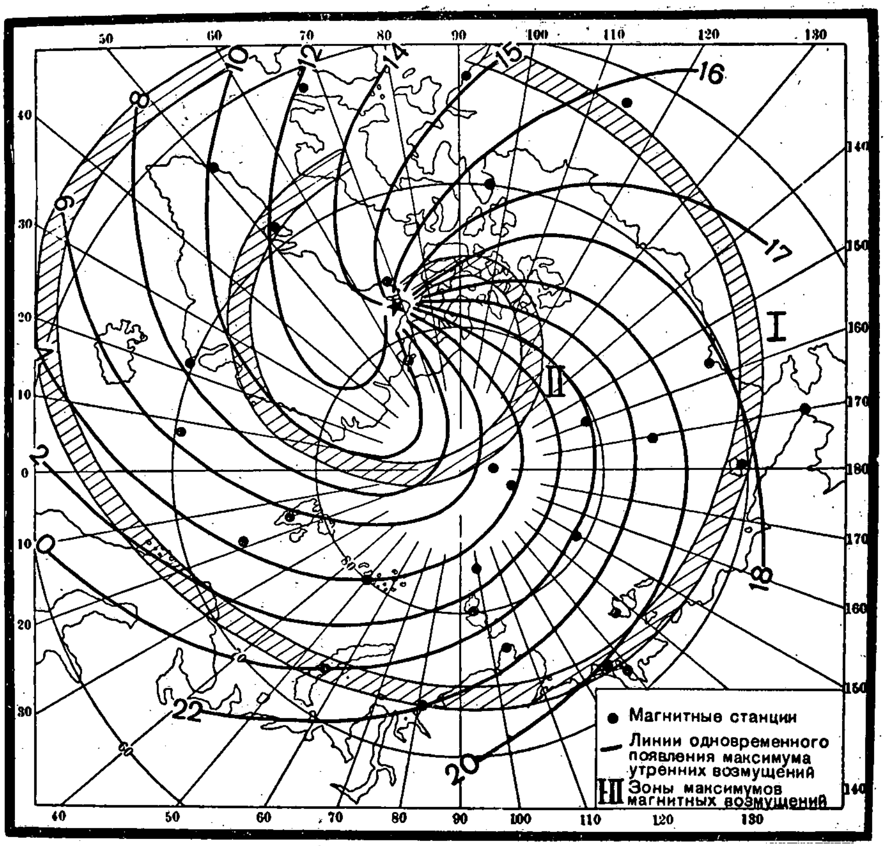

Fig. 5. Spiral isochrons of Morning Maximum of Magnetic Disturbance (from Russian source, [3]). The Figures shown against each spiral are the hours GMT.