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Short-Period Geomagnetic Micropulsations with Period of about 1 Second in the Middle and Low Latitudes

By

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CONTENTS

Abstract:—Since the IQSY period, continuous observations of short-period geomagnetic and earth-current micropulsations have been carried out at two observatories, Memambetsu (43° 55′N, 144° 12′E) and Kanoya (31° 25′N, 130° 53′E), in addition to the usual ordinary and rapid-run observations. In the present paper, some characteristics of geomagnetic micropulsations with shortest periods ranging from 0.2 sec to 5 sec defined as pc-1 by IAGA-IUGG nomenclature are investigated, mainly statistically. It seems that the continuous micropulsation may be classified into two or more classes, the most peculiar one being PP, firstly found by Troitskaya's pioneering work (1957). It shows well-known microstructure on the frequency-time display, while for the other classes the microstructures are not so evident.

It seems that the diurnal variation of the occurrence frequency and the mean period, the seasonal shift of the time of maximum occurrence as well as the Kp-dependency of the pulsation are certainly due to the ionospheric attenuation. Existence of the latitude dependency of the amplitude and the structure doubling at the lower-latitude station means the propagation along a path above the ionosphere and also some attenuation ascribed to the penetration through the ionosphere. The difference of the occurrence between the auroral or sub-auroral zone and the low latitudes will be ascribed mainly to the above mentioned two effects.

As the result, it is deduced that the micropulsation is hydromagnetic oscillation of the upper atmospheric origin closely related with magnetic storms.

Particularly, the fine-structured micropulsation will be understood as the hydromagnetic wave bouncing along the magnetic line of force between the conjugate points with a speed of several hundred kilometers per second. The wave perhaps propagates from the auroral or subauroral zone to the lower latitudes almost simultaneously over a wide region through the paths above the ionosphere.

In addition to the continuous micropulsations, a brief description is made on some characteristics of short-period irregular micropulsations having the same range of periods ($\leq$10 sec). Micropulsations may be interpreted as the higher frequency components of either pi-1 or pi-2 with longer periods associated with a geomagnetic storm or bay disturbance.

With examples, the occurrence characteristics of the micropulsations accompanied by geomagnetic storms are shown.

Outline of the measuring apparatus of the pulsations is described.

Introduction

In recent years regular continuous micropulsations with periods of about 1 second have been observed by many workers, in mainly the American zone and USSR. These micropulsations are widely known as the 'pearl-type'. Observations are carried out usually with induction loop coils or earth-current electrodes. Troitskaya (1957) found the 'pearl-beating type pulsation, PP', in USSR zone using the earth current methods. Benioff (1960) observed a sinusoidal form geomagnetic field fluctuation with periods ranging from 0.3 to 2.5 seconds in southern California and named it 'Type-A oscillation'. He found a rough inverse relationship to the solar sunspot cycle. His Type-A oscillation is essentially nocturnal. He pointed out that the occurrence increased rapidly after sunset and disappeared rapidly after sunrise. Kato and Saito (1964) also observed the pearls at Onagawa and showed the peak occurrences were in the night hours, after sunset and before sunrise. Heacock and Hessler (1962) observed pearl-type earth-current pulsations in a period range of 1-5 sec at College, Alaska. It was shown by him that the micropulsation was world-wide event and occurred usually in the daytime. Heacock and Hessler (1965) pointed out the onset of the pearl events immediately after a storm sudden commencement appearing particularly in the afternoon hours, 12-20 LT. Wentworth (1964) showed that the occurrence of the pearl is more frequent by two times or more in the one week following a ssc than in a very quiet period. The author (Kawamura, 1964) and Yanagihara and Kawamura (1964) pointed out that the pc-1 micropulsations observed at Kanoya in the period from March 1 to May 31, 1964 occurred under a rather magnetically calm condition (K$\leq$3), that the rotational sense of the horizontal fluctuation vector was essentially counterclockwise and that moreover the change of the amplitude of constituent pulse was somewhat similar at the two stations but occurrence time of its maximum and minimum differed slightly. Tepley (1964) observed the pearls at four widely-scattered Pacific observatories and showed that the micropulsations with similar microstructures occurred almost simultaneously, that is, with a much shorter time delay compared with the bouncing period between conjugate points at the stations of the same hemisphere. He also showed a 180° phase shift between the two hemispheres. Prior to this investigation Yanagihara (1963) suggested that there was a rough conjugate relationship of PP-envelope between conjugate stations. Tepley *et al.*, (1965) showed some examples of the similarity and the simultaneity of the frequency-time display among widely-scattered stations such as College in Alaska, Palo Alto in California and Kauai in Hawaii. Wentworth (1964) applied to the observed data in southern California the formula given by Karplus *et al.*, (1962) who showed a very large attenuation value of the pc-1 range micropulsations in the ionosphere. And he deduced the signal amplitude at 550 km, the base of the exosphere, from that at the sea level. The author (Kawamura, 1965) showed from analyses of its vibragram that any series of micropulsations could be divided into several sub-series occurring isolatedly or superposedly with durations of about 20-30 minutes. Pope (1964) investigated the polarization of the pearls and showed that the rotational sense was generally counterclockwise and its occasional inversion was ascribed to the superposition of two or more trains. Geomagnetic micropulsations were also investigated morphologically by Hirasawa *et al.*, (1965) using their dynamic spectra obtained at Kakioka, and they classified those into seven types.

So-called pc-1 micropulsations may involve some other classes differing from the pearls but it will be very difficult to classify micropulsations in more detail. So that in this investigation micropulsations are treated without such detailed classification. However the distinct event with a clear fine-structure may correspond to the pearl-type micropulsations.

Some portions of the present paper have been given in two previous brief notes (Kawamura, 1966 and 1967).

1. Measuring Apparatus

For detecting short-period geomagnetic micropulsations, induction loop coil is usually used. In observing micropulsations with periods longer than about 10 seconds, the electromotive force induced in the coil may be measured with a galvanometer with a proper period of several seconds and current sensitivity of the order of 10^{-8} A/mm/m. On the other hand, the observation of micropulsations with periods shorter than about 10 seconds is considerably difficult. Because, the sensitivity of galvanometer decreases in inverse proportion to the square root of its proper period. Generally it seems that the amplitude of the geomagnetic variation decreases as the period of the variation becomes shorter. If the variation of the geomagnetic field is converted into induced electromotive force with a loop coil, it will be expected that the signal of the same order as that with a longer period may be detected. Thus, a galvanometer with the same sensitivity and a shorter period should be used for the present observation of micropulsations. Otherwise it will be necessary either to use a loop coil of a sufficiently large effective area or to amplify the signal by means of a suitable amplifier. As the amplitude of the micropulsations we are interested in is of the order of 10 milligammas, electromotive force induced in the loop coil with an effective area of 10^8cm^2 is at most 1 μV. Actually we use in parallel both ordinary photographic recording and tape recording. The whole device is schematically shown in Fig. 1.

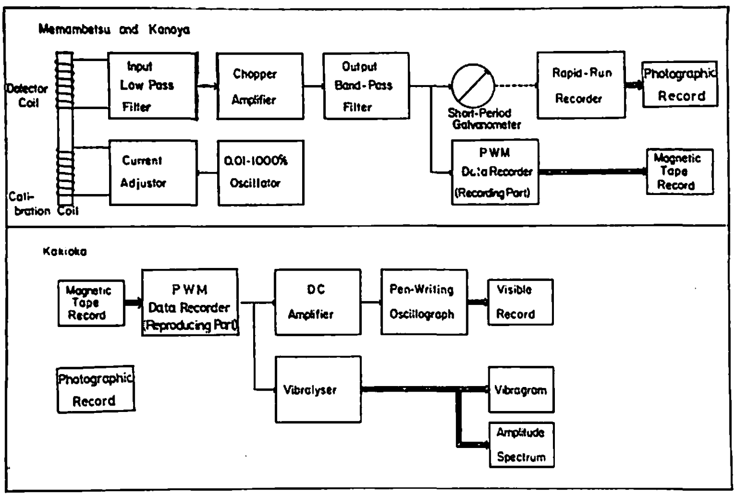


Fig. 1. Schematic diagram of measuring and data-analyzing apparatus for short-period micropulsations, pc-1 and pi-1 (sp).

Air-cored detector coil is desirable for the detector coil because it will be able to maintain the source impedance at a sufficiently small value. However, we have to use a high-mu metal-cored coil in the limited area of our observing sites. The core consists of 100 sheets of thin slender plate of 78% nickel parmalloy with dimensions of 200 cm × 10 mm × 0.1 mm. Between any two adjacent plates a miler film is inserted. Parmalloy, TMC-V, has a evry high permeability (initial permeability: 30,000-70,000). The shape and the dimensions of the core are designed to minimize undesirable effects of the demagnetizing field and the eddy current loss. The measured effective permeability is about 5000 to 6000 which is in agreement with the value deduced from the dimension ratio of the core and the initial permeability. The core is inserted into a PVC pipe. A copper wire is wound on the pipe about 20,000 turns in a spindle shape. The effective area is about 1.0 to $1.2\times 18^8\,\mathrm{cm}^2$ for 1 cps signal. As shown in Fig. 2 the effective area begins to lower from about 10 cps. The fact perhaps shows existence of some undesirable loss due to the eddy current even for our extremely low frequency range.

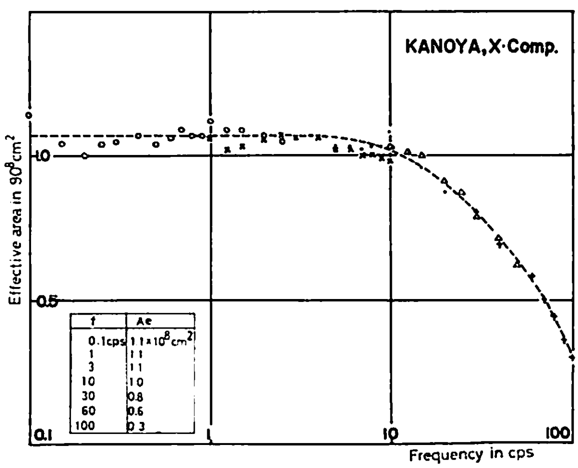


Fig. 2. Frequency response of effective area of the detector coil at Kanoya.

On the middle part of the detector coil a calibration winding of 100 turns is wound. Calibration current of 2×10^{-8} A through it induced in the detector coil an electromotive force equivalent to that for the uniform oscillating magnetic field of about 18 milligammas applied around the detector. To eliminate undesirable troubles due to external electrostatic induction, the coil is shielded with a copper cylinder which is put closely on the inner wall of an outer PVC pipe. The PVC pipe is enclosed water-proof in a large polyethyrene pipe and burried under the ground about 1 meter deep. The position is selected so as to be away from power lines as far as possible.

There are some external noises in various frequency ranges. These noises are mainly due to meteorological phenomena, power lines and other artificial sources. To prevent the amplifier from being saturated by noises which are much larger than the natural signals of geomagnetic micropulsations, the detector coil is connected to the amplifier through an input filter. The filter consists of a derived-M type 50 or 60 cps rejection filter and usual LC type low pass filter.

Some rejection filters were added at Memambetsu in February 1967 for the elimination of undesirable noises due to the radio waves propagating along the earth's surface (Kawamura *et al.*, 1967). As the filtered signal is applied to a low-noise high-gain chopper type amplifier, circuit elements of low impedance have to be used in the filter. TMC-V tape-wound spiral cores are adopted in our choke coil. Noises of 50 or 60 cps are eliminated by about 80 db. Specially-designed noiseless polyethyrene sheath coaxial cable is used as lead wire from the detector to the filter.

The chopper amplifier is Model 149 Milli-microvoltmeter manufactured by Keithley Instruments Inc., USA. The full scale range is adjustable from 0.1 μV to 100 mV according to the amplitude of the signal. We must use usually the amplifier at 10 μV range, as in higher range the frequency response falls. In this case the amplifier responds up to 3 cps or more. The instrumental noise increases as the source resistance increases. In the present case the resistance of the source is of the order of 1 kiloohm and the noise is at most 0.02 μV pp. The fluctuation of 0.02 μV pp corresponds to the field variation of about 0.3 milligammas peak to peak. The input resistance of the amplifier at this range is 1 megohm.

Output of the amplifier is led into two different recording apparatus through a filter. As the filter consists of a variable cutoff band pass filter and a twin-T type 50 or 60 cps rejection filter the most appropriate frequency response can be selected. Since the IGY the observation of micropulsations with periods longer than about 10 seconds is carried out with different equipment at our observing sites, Memambetsu and Kanoya. For the present purpose it is desirable to record only short-period micropulsation: pc-1, pc-2 and shorter side of pi-1, with a seismographic type recorder with small pitch without superposition of other classes with longer periods. The latter classes are, therefore, eliminated by the above-mentioned output filter.

Our principal equipment is a four-channel data recorder of pulse-width-modulation type. It comprises three units, two recording units and one reproducing unit. The recording units are installed at two observing stations. The reproducing unit is installed at Kakioka and used to reproduce the signals of tapes recorded at the stations. Reproduced signals are applied to pen writing oscillograph or frequency analyzer, a vibragraph which is a sort of sonagraph. The tape is driven with a very slow speed of 7.6 mm/sec during observation but speed of reproduction is 7.6 cm/sec or 19 cm/sec. With ordinary seven-inch reel magnetic tapes, twice-a-day exchange is sufficient for continuous observation. When such reproduced signals with raised frequency are applied to the frequency analyzer, we are able to investigate the most detailed microstructure of micropulsations, because the time scale is magnified up to about 4 cm/min. In this case the frequency response of the data recorder is from dc to 100 cps in reproduced signals, while dc-10 or dc-4 cps in the original. Ordinary sonagrams convenient in investigating the changes of frequency and intensity for longer time intervals are obtained by stepping up the ratio of the reproducing frequency to recording frequency with another FM or AM type data recorder. Our pulse-width-modulation type recorder has a fairly high signal-to-noise ratio of about 45 db or more. The input impedance and maximum range are 500 kiloohms and ± 1V pp, respectively. In the IQSY period the filter output is directly fed to the recorder.

Photographic recordings are also carried out with a moving coil galvanometer and a seismograph-type recorder. Photographic record is used as a effective monitor because it is capable of showing the occurrence of micropulsations clearly. That is, we can detect the beginning and ending times, classes, mean period and amplitude of micropulsations directly from this record. The galvanometer has a very short oscillation period of about 0.1 sec and a comparatively high current sensitivity of about 2.7×10^{-7} A/mm/m which are achieved by decreasing the moment of inertia of its suspended system as much as possible, together with the use of special strong magnet. Its coil resistance and critical damping resistance are about 150 and 50 ohms, respectively. In ordinary use the driving speed of the recorder is 30 mm/min. As the pitch of the recorder is only 5 mm, the scale value is adjusted to about 5 milligammas/mm for 1 cps signal. Each half day record of three components, dX/dt, dY/dt and dZ/dt, is registered on the sheet of bromide paper of 42 cm $\times$ 92 cm wound on the recording drum. Two examples of bromide records are shown in Figs. 3 and 4. These figures show the monitoring records of micropulsations observed at Kanoya in about 12h-24h (UT) on January 29 and February 11, 1966, respectively. In Fig. 3 the pc-1 micropulsations of quality B appearing during 1927-2129 UT are recorded together with two preceding series of pc-1 of quality C. In Fig. 4 clear trains of pi-1 occurred during 1412-1440 UT are shown. The oscillations of 1 cps

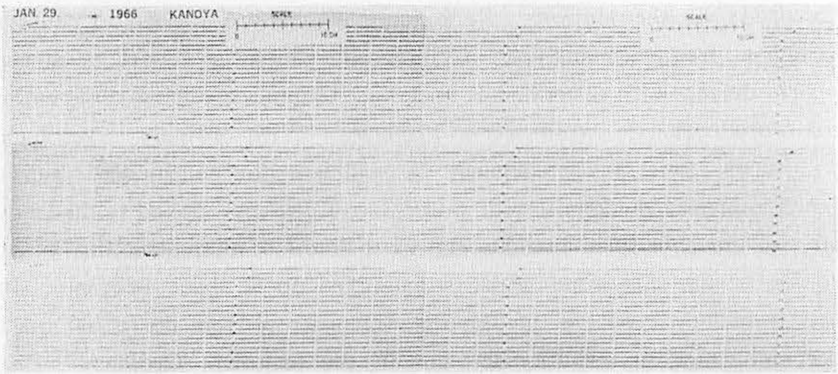


Fig. 3. An example of half-day bromide record registered at Kanoya on January 29, 1966. A distinct series of pc-1 micropulsation is found in 1927-2129 UT, with two weak preceding traces of the micropulsation. The top, middle and bottom traces correspond to X, Y and Z components, respectively.

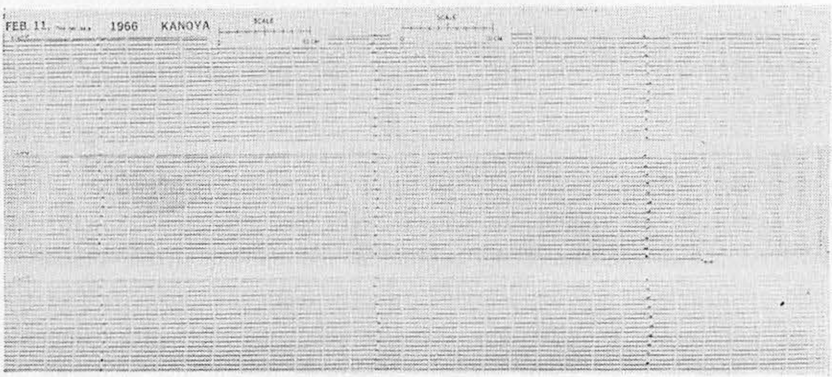


Fig. 4. An example of half-day bromide record registered at Kanoya on February 11, 1966. Clear trains of pi-1 micropulsation are found in 1412-1440 UT.

with constant amplitude recorded after about 10-20 minutes from the starting time of these records are the traces of the calibrating signal. These deflections correspond to the field variations of about 18 milligammas.

The analyzer used here is Model 651A Vibralyzer manufactured by Kay Electric Co., USA. It has three frequency ranges: 5-500 cps, 15-1500 cps and 44-4400 cps. Its analyzing filter bands are 2 cps in narrow band and 20 cps in wide band. In the case of the magnified sonagram with time scale of about 4 cm/min, corresponding to the step-up ratio of the frequency of about 25, the lowest range, 5-500 cps, is employed together with Model 667A Scale Magnifier. The vertical frequency scale is expanded by a factor of 10 with the magnifier. So that the lowest frequency range from dc to 50 cps in this case corresponds to the usual frequency of the distinct pc-1 which is at most 2 cps. In the case of the ordinary sonagram, the frequency is raised once again by 10-20 times, so the output of the data recorder is applied directly to the vibralyzer without passing the magnifier, and frequency-time display of long interval is obtained. Tape records are also converted into visible pen-records with most convenient time scales for the purpose of vector analysis and others. As the noises originating from power lines are very intense compared with the signals of micropulsations with periods of about 1 sec, we designed this measuring apparatus taking account of the signal to noise ratio. The overall instrumental noise is less than 1 or 2 milligammas for 1 cps, even when the input terminal of the input filter is open. The position where the detector coil is burried is chosen so as to minimize external noises. External noises are usually 2 milligammas in the night hours and increase to 5 milligammas in the daytime at both Memambetsu and Kanoya. It seems that the increase of the noise intensity in the daytime is mainly due to that of various

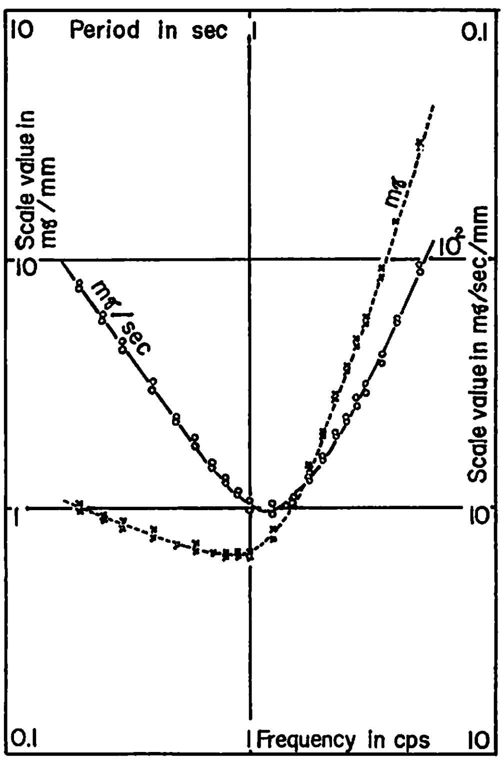


Fig. 5. Overall response curve of the device at Kanoya. In this figure 'round' and 'cross' marks correspond to scale values of two kinds, milligamma/sec/mm and milligamma/mm, respectively.

man-made origins. Natural noises, such as from a thunderstorm in the vicinity exceeds 10 milligammas. The measurements have to be stopped for a while in such severe conditions because excessive noises may damage the measuring circuit. On the other hand, the ordinary double amplitudes of fairly distinct events of the pulsations we are interested in are several ten milligammas at both observing sites. The micropulsations scarecely attain 100 milligammas or more even in the most distinct phenomena. Thus, the overall signal to noise ratio is generally 20 to 30 db.

The overall response curve of our device is illustrated in Fig. 5. This response is measured once a week. The sensitivity for any period is obtained from both the response curve and the calibrating signals of 1 cps which are measured for each tape or bromide paper. The lowering of response at the dc side is due to the dc-cut character of the output filter. In our observation such character is chosen in order to lower the intensity of the micropulsations with longer periods, such as pc-3 and pi-2. If necessary the response at the dc side can be improved by a simple adjusting procedure of the output filter. The overall sensitivity will also be increased without much difficulties. However, it is not so effective to increase sensitivity in the present work, because the accuracy of measurement is not increased by a higher sensitivity but is determined mainly by the signal to noise ratio.

2. Diurnal Variation of the Occurrence Frequency of pc-1

Continuous micropulsations with periods of about 1 sec are detected at Kanoya on 103 days in the two years. Micropulsations occur almost simultaneously at both Memambetsu and Kanoya. On 28 days of these, outstanding phenomena with quality of A or B are observed. The criteria of the quality are as follows:

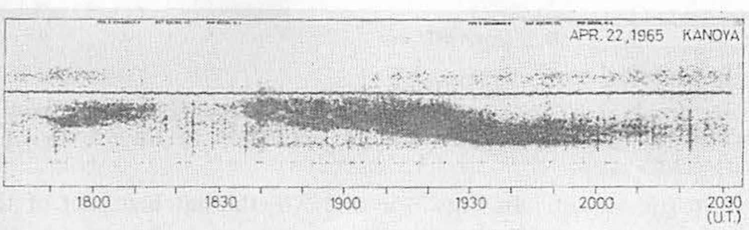
A: Distinct, with double amplitude larger than 20 mγ

B: Clear, with double amplitude larger than 10 mγ

C: Ordinary, small or somewhat doubtful

The data, time interval (beginning and ending times) and quality of the micropulsation, are tabulated in the *Report of Observation on Geomagnetism, Earth-Current and Night Airglow during the IQSY 1964-1965* together with those in the special periods classified by the quality. As to the special periods with quality A or B, the times of occurrence and double amplitudes in milligamma of three components, X, Y and Z are given in the same volume. An example of micropulsations is given in Fig. 6. In this figure a reproduced record of typical

(a)



(b)

Fig. 6. Example of (a) reproduced records and (b) corresponding sonagram of typical pc-1 observed at Kanoya in 1748-2012 UT on April 22, 1965. The reproduced record is shown in the upper and lower halves of Fig. 6 (a), respectively.

pc-1 and the corresponding sonagram are illustrated. Micropulsations are seen from 1748 to 2012 UT on April 22, 1965 at Kanoya. The sonagram shows typical pearl characteristics. The pulsations are divided into two series. The preceding series has a duration of about half an hour. The distinct succeeding series (of quality A) beginning at about 1830 UT has a fairly long duration of about 2 hours. Its largest oscillation appears at about 1932 UT. The double amplitudes of its three components, X, Y and Z, are 50, 35 and 12 milligammas, respectively. The center frequency changes gradually from about 1.5 cps to 1.0 cps and the broadest part of the frequency range extends over about 0.5 cps around the center frequency.

To investigate the diurnal variation of the occurrence frequency, we count hourly numbers of 20-minute periods in which any micropulsation occurs. The diurnal variations in the hourly numbers in the two-year period are shown in Figs. 7(a) and 7(b), for Memambetsu and Kanoya, respectively. The occurrence of micropulsations concentrates in the night hours. Eighty-four percent of the whole are found during twelve hours from 6 p.m. to 6 a.m., and 57% are in the period of six hours from 0 a.m. to 6 a.m. The occurrence frequency has a very distinct maximum at one or two hours before sunrise (at about 4 a.m.). Then, it decreases rapidly and reaches a minimum at about noon. It usually shows a comparatively low level in the daytime. And the occurrence frequency increases

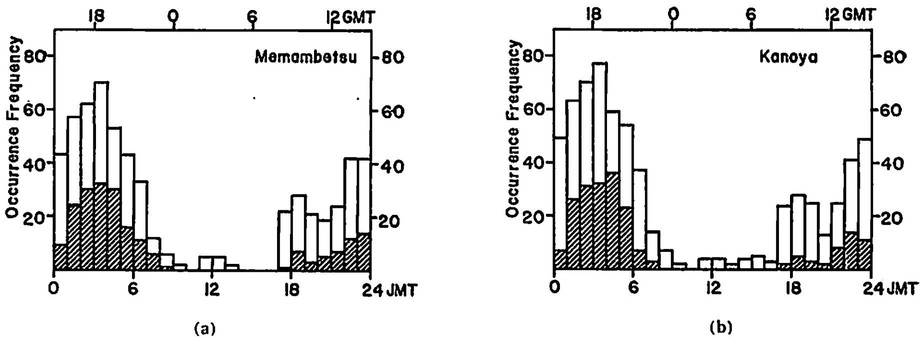


Fig. 7. Diurnal variations of pc-1 observed at Memambetsu (a) and Kanoya (b) during April 1964–March 1966. Variations are represented by the hourly number of 20-minute intervals in which pc-1 cccurs.

gradually from the sunset. In Figs. 7(a) and 7(b) the hatched part of the hourly number means 20-minute periods with quality of A or B. In these figures a secondary small maximum is noticed immediately after sunset. The maximum is somewhat doubtful, because our data are too insufficient for asserting the existence of this secondary maximum. The characteristics of the occurrence fairly coincide with those of PP reported by Yanagihara (1963) who investigated the pulsation using data in the auroral zones. On the other hand, some authors have reported daytime maximum from their observations of micropulsations in the higher latitudes. The difference in the results of various authors may be due to the lack of strict definition and classification. Yanagihara divided the continuous micropulsations with periods of 0.3 to 10 sec observed in the auroral zones into three typical classes: PP, CPlp and CPsp. And he pointed out that PP generally appeared during several hours after sunset and before sunrise. According to him, CPsp with almost the same period as PP appears usually in the sunlit forenoon side. But, such micropulsations are not clearly noticed in our observation in the middle or low latitudes. Only a few indistinct events are observed in the daytime hours, usually of very calm condition, in our stations. Such difference in the manner of appearrance between higher (auroral or sub-auroral) and lower latitudes may be related to the mechanism of the propagation of micropulsations.

As to the diurnal variations of the occurrence frequencies, there is a significant difference between the pc-1 and other continuous micropulsations, pc-2, pc-3 and pc-4, with longer periods. Those with longer periods appear in the daytime usually. In Fig. 8 the mean diurnal variations of these continuous micropulsations with longer periods observed at Kanoya in the IQSY period

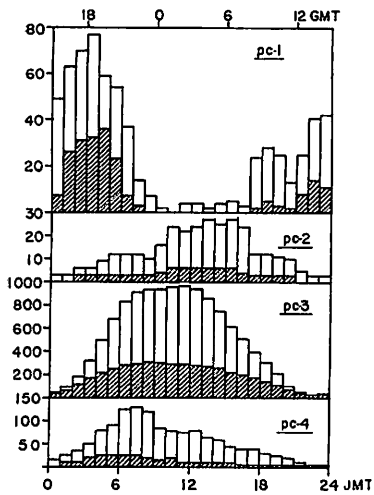


Fig. 8. Diurnal variations of other continuous micropulsations (pc-2, pc-3 and pc-4) with periods longer than that of pc-1. They are shown in comparison with that of pc-1. Data are read from rapid-run magnetograms recorded in the IQSY period (1964-1965) at Kanoya.

(1964-1965) are shown with that of pc-1. These data are taken from *Report of the Geomagnetic and Geoelectric Observations* (1966). As shown in this figure, pc-3 shows a distinct maximum of occurrence about one hour before noon. The time of the maximum occurrence of pc-2 is in the afternoon and a few hours later than that of pc-3. On the other hand, the maximum of pc-4 is in the morning hours.

Some excellent morphological studies on these micropulsations are carried out by Yanagihara (1960) and Saito (1964). Yanagihara investigated statistically and reclassified the micropulsations occurring in the middle latitudes mainly using the data obtained at Memambetsu and Kanoya in the IGY period. He classified regular, continuous micropulsations, with sinusoidal wave form—pc and ps-like pulsations—into two subgroups. According to him one is the oscillation having periods between 10 and 40 sec and the other is the oscillation having periods less than about 10 sec. He named the latter as 'spt' or 'spc', classifying by its duration. He deduced that the micropulsation pc is hydromagnetic standing oscillations under the boundary region of the maximum Alfven wave velocity existing about 3000 km in height. It coincides with Saito's interpretation. Saito classified the continuous micropulsations usually observed in the lower latitudes into two principal classes: pc-2, 3 and pc-4, and pointed out that pc-2, 3 are induced by hydromagnetic standing oscillations below the region of maximum Alfven wave velocity, while pc-4 is caused by hydromagnetic standing oscillations along the geomagnetic field lines. Yanagihara's results of the diurnal variations also show that pc occurs mainly in the daytime and the occurrence frequency has a peak at about 9-10 LT. But he showed that his spc is rather noctural in both calm and stormy conditions and the results may be due to the decrease of the period in the night hours in accordance with the results of Kato and Saito (1959) in the storm time.

Undoubtedly our pc-2 also usually appears in the time of a geomagnetic storm. The fact illustrated by Fig. 9 in which the relation between pc-2 and Kp-index is shown. However, the above-mentioned result of the time of the

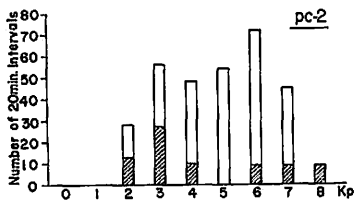


Fig. 9. Kp-dependency of pc-2 occurrence at Kanoya.

maximum occurrence of spc is considerably different from the present results of pc-2. Saito (1964) regarded pc-2 and pc-3 to be a single class, pc-2, 3. And his pc-2, 3 shows a clear noon-type diurnal amplitude variation. It seems that this discrepancy may be due to the fact that 'spc' includes some different kinds of micropulsations with continuous but somewhat irregular forms other than pc-2. The included micropulsations may be either continuous-looking pi-1 occurring mainly in the storm time or non-structured pc-1 with rather longer periods. The pc-1 micropulsation, on the other hand, is obviously nocturnal. However, the occurrence character of the micropulsation in the magnetospheric source region may be considerably different from the above-mentioned diurnal variation on the ground level in the lower latitudes. As will be shown later, micropulsations are generally regarded as hydromagnetic wave guided along the geomagnetic field line. Then, the wave will propagate from the higher to the lower latitudes almost simultaneously over a wide region through the path in the upper part of the ionosphere. It may be able to penetrate the ionosphere in the night side. Namely, it is deduced from the occurrence and the diurnal variation of pc-1 that the daily change of micropulsations observed on the ground is in close connection with the overhead ionospheric electron density. In other words, pc-1 with the shortest period of these continuous micropulsations may strongly be subjected to the ionospheric screening effect, while it seems that other continuous micropulsations with longer periods are hardly affected. This observational fact has been already pointed out by Hirasawa *et al.* (1965) and Nagata *et al.* (1966).

The diurnal variation of the occurrence frequency of pc-1 has some distinct seasonal changes. It shows that the occurrence hours are shortest in summer season and the time of the maximum occurrence shifts to earlier hours. In Fig. 10 the occurrence hours and the time of maximum are shown for both winter (December to January) and summer (June to July). In winter, pulsations appear throughout the day and the maximum occurrence appears at about 6 JST. In summer, micropulsa-

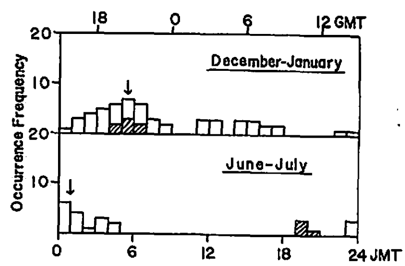


Fig. 10. Occurring hours and times of maximum occurrence of pc-1 in winter (upper half) and in summer (lower half).

tions occur mainly in the shortest night hours and the time of the maximum occurrence shifts to about 1h-2h JST. This fact shows also the existence of the ionospheric screening effect on the diurnal variation of the pc-1 micropulsations.

3. Annual Variation of the Occurrence Frequency of pc-1

The annual variation of the occurrence frequency is also distinct in appearance. In our observation it has two maxima, at spring and autumnal equinoxes. The annual variation of the occurrence frequency (20-minute intervals) at Kanoya is shown in Fig. 11. At Kanoya 64% of the whole events and 74% of the distinct phenomena with quality A or B occur in equinoctial four months (March-April and September-October). Especially, 49% of the distinct phenomena concentrate in March and April. At Memambetsu 59% and 42% of the whole events occur in the same four months and in March-April, respectively. Also 65% and 50% of the distinct phenomena correspond to the above two intervals. On the other hand, only a few events appear in summer. For example, only 6% of the whole pc-1 events occur in June-August at Kanoya. As micropulsations are clearly nocturnal events, it will be expected that the maximum of the occurrence frequency may occur in winter months. Nevertheless in our observation the above obvious annual change is seen. It is deduced that the annual change is related firstly to the source agent of the micropulsation in the outer atmosphere. Therefore, this apparent annual variation is somewhat doubtful. It seems, indeed, that the occurrence of micropulsations is closely connected with the magnetic storm. In two years and one month (March 1964-March 1966) the most frequent occurrence of micropulsations is found in the following four periods:

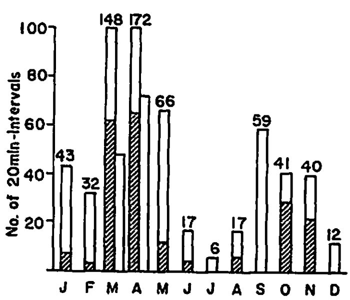


Fig. 11. Annual variation of occurrence frequency (the number of twenty minute intervals) of pc-1.

1) The first part of March to the middle part of April 1964
2) The last part of April to the first part of May 1965
3) The last part of January to the first part of February 1966
4) The middle and last parts of March 1966

Each of these periods followed a rather intense magnetic storm for the quiet sun period. The main characteristics of the preceding storms are tabulated in

Table 1. Main characteristics of geomagnetic storms preceding successive occurrences of distinct pc-1 events observed over several successive nights in the following four periods:
1. The first part of March to the middle part of April 1964.
2. The last part of April to the first part of May 1965.
3. The last part of January to the first part of February 1966.
4. The middle and last parts of March 1966.

In this table K_{max} and R(H) show maximum value of K and maximum range of horizontal component, respectively, observed at Kakioka in the course of the storm. Time is indicated in UT.

Begin			Main phase		Last phase		End		Type	K_{max}	R(H)
					Period 1						
	h	m	day	hr	day	hr	day	hr			γ
Feb. 20	11	36					21	19	ssc		92
Mar. 3	19.2		4	00.7	4	12.6	5	24	sg	5	123
29	14	08					30	22	ssc	5	67
Apr. 1	05.6		1	13.0	1	23.5	3	16	sg	5	87
					Period 2						
Apr. 17	13	13	18	03.2	18	10.1	19	24	ssc	7	278
					Period 3						
Jan. 20	02	03					22	24	ssc*	5	94
					Period 4						
Mar. 13	13.5		13	21.0	14	09.0	14	20	sg	5	155
22	11.8		23	05.8	23	11.2	23	24	sg	7	122
27	19.6		28	06.4	28	12.4	28	24	sg	5	94

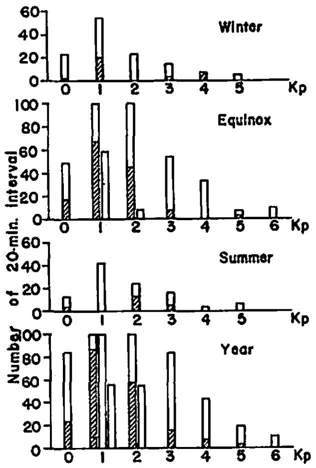
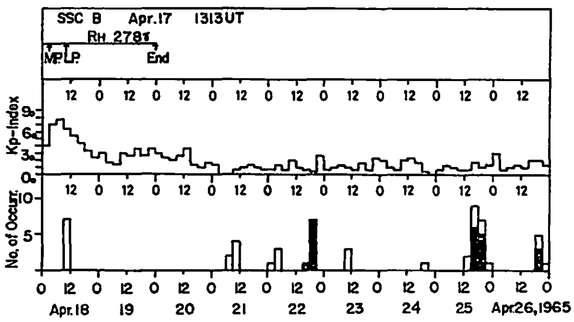


Fig. 12. Occurrence frequency (the number of twenty-minute intervals) of pc-1 for each Kp-value for each season and a full year at Kanoya. Hatched area corresponds to distinct event.

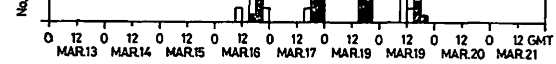
Table 1. The occurence of pulsations in these periods reaches 54% of the whole events and 68% of the distinct phenomena in the same periods at Kanoya. Because these periods are concentrating in March and April, the annual variation of occurrence frequency shows a sharp peak at these months.

Nevertheless most pc-1 micropulsations occur under magnetically calm conditions. In Fig. 12 the occurrence frequency of micropulsations at Kanoya is shown for each Kp-value. In any season micropulsations occur most frequently at Kp=1. Seventy-six percent of the whole events and eighty-one percent of the distinct phenomena appear when $Kp \leq 2_{+}$. In the course of magnetic storms with Kp-values equal to or larger than 5, only

4% of the whole occurs. The occurrence usually continues over a few successive days in a calm period following a rather large storm. It is deduced, therefore, that micropulsations are excited by the high energy particles related to the magnetic storm but its propagation to the sea level in the lower latitudes is obstructed by some mechanisms prevailing in the magnetically disturved condition. Two examples are given in Figs. 13(a) and 13(b). This result coincides with



(a)



(b)

Fig. 13. Two typical examples of successive occurrences of pc-1 over several successive days after a geomagnetic storm. Examples (a) and (b) correspond to ssc on April 17, 1965 and sg on March 13, 1966, respectively. The upper, middle and lower parts in each figure show storm characteristics, Kp-index and occurrence frequency of pc-1 in each three-hour range.

that of Wentworth's investigation (1964). He shows that his hydromagnetic emission is apt to occur in the quiet periods following a magnetic storm, using the Helicorder records observed at California stations during August 1960-July 1963. But our results are very different in the following points from the results of Heacock and Hessler (1965) at College:

1) They usually observe the onset of the pearl-type micropulsation immediately after ssc.

2) They observe their pearl-type micropulsation mainly in the afternoon hours.

It seems that the differences may be due to the mechanism of propagation to the lower latitudes and a difference in the classification, when compared with ours, on regular-continuous and others.

4. Period and Intensity of pc-1

The period of the continuous geomagnetic micropulsations is usually from 0.5 to 5 sec. The number of occurrences of micropulsations in each period is given in Fig. 14. The period of the largest oscillation in a five-minute interval is read off from photographic trace. The hatched part means the number for

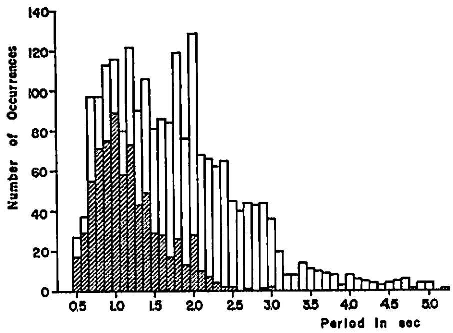


Fig. 14. Occurrence frequency (the number of five-minute intervals in which pulsations occurred) of pc-1. The period is of the largest oscillation read from monitoring record in the five-minute interval. The hatched area corresponds to the distinct event.

the distinct phenomena. The same result is also summerized in Table 2. As shown in these figure and table, micropulsations have periods shorter than 3 sec.

Table 2. The number and percentage of five-minute intervals with periods divided into various ranges, for distinct, indistinct and whole pc-1 events, respectively.

Number and percentage	Range of period (in seconds) ≤2.0	≤3.0	>2.0	>3.0	Whole
Distinct events	700 96%	729 100%	29 4%	0 0%	729 100%
Indistinct events	760 55%	1244 90%	627 45%	143 10%	1387 100%
Whole events	1460 69%	1973 93%	656 31%	143 7%	2116 100%

usually. About 93% of the whole events have such periods and 69% are shorter than 2 sec. Micropulsations with frequencies higher than 2 cps are difficult to be found on a photographic trace, because only the largest oscillations are treated, though weak traces of micropulsations with frequencies higher than 2 cps are frequently found on the sonagram.

The upper limit of the frequency may be related to the ion cyclotron frequency of positive ion constituting the plasma frozen in the magnetic lines of force which propagates micropulsations.

The mean period of the micropulsation is very different between the distinct events and the indistinct phenomena. For the distinct events, the mean period is about 1.2 sec and shorter than that of the indistinct phenomena. It is also affected to some extent by geomagnetic conditions. The average periods are about 1.1 sec and 1.4 sec for $Kp \leq 2_+$ and $Kp \geq 3_-$, respectively. For the distinct event, micropulsations with periods longer than 3 sec are not detected. In the indistinct phenomena, the mean period is about 2.1 sec and is not much dependent on Kp-index. About 96% of the distinct phenomena have periods shorter than 2 sec, while about a half of the indistinct phenomena have periods longer than 2 sec. These relations are shown in Table 3. It is deduced that two or more

Table 3. Average value of dominant period of pc-1 in each five-minute interval classified by Kp-value into three groups: distinct, indistinct and whole events. Figure in brackets shows the number of the corresponding five-minute intervals.

	$Kp \leq 2_+$	$Kp \geq 3_-$	Whole
Distinct events	1.1 sec (610)	1.4 sec (119)	1.2 sec (729)
Indistinct events	2.1 sec (1040)	2.1 sec (347)	2.1 sec (1387)
Whole events	1.7 sec (1650)	2.0 sec (466)	1.8 sec (2116)

classes of the pc-1 micropulsations such as PP, Yanagihara's CPsp and CP1p may also be observed at middle and low latitude stations. On the sonagrams, for example, the distinct events generally show well-known fine structure of PP but, it is not so clear for the indistinct events.

In other words, the distinct events may be mainly the pearls while the indistinct phenomena perhaps include some other kinds such as non-structured pc-1 with periods equal to or somewhat longer than that of the distinct events. This non-structured pc-1 may partly correspond to Yanagihara's 'spc' (1960). An example of sonagram of the non-structured pc-1 is shown in Fig. 15. Micro-

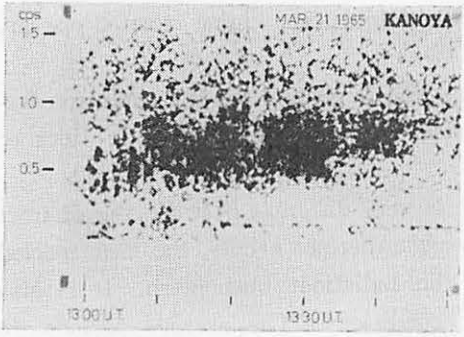


Fig. 15. An example of sonagram of non-structured pc-1 observed at Kanoya on March 21, 1965.

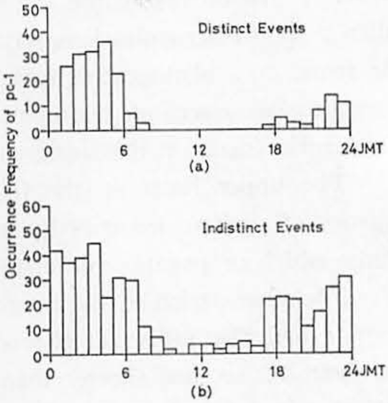


Fig. 16. Diurnal variations of occurrence frequency of (a) the distinct and (b) the indistinct pc-1 events.

pulsations occur under a rather disturved condition ($Kp=3_-$) but do not show the burst-like character as pi-1 on the sonagram. Moreover, as shown in Fig. 16, both distinct and indistinct events are nocturnal, but the daily change of the latter does not show any distinct maximum before sunrise. It seems that the change in the mean period of the distinct events that depends on the geomagnetic condition is also regarded as the effect of attenuation along the path of propagation. On the other hands, the indistinct events with longer periods are perhaps not so influenced by attenuation.

The aspect of the diurnal variation of the occurrence frequency seems to change with the range of its period. For the events with periods shorter than 2 sec, the occurrence is usually limited to the night hours, and its maximum appears before sunrise. As the period of the event becomes shorter, the time of the maximum occurrence nears sunrise. On the other hand, when the period becomes longer than 2 sec, the rate of occurrence in the daytime increases and the time of maximum shifts to the night hours between sunset and midnight. Especially in the events with periods longer than 3 sec, micropulsations occur most frequently just after sunset. This observational fact may reflect the effect of the ionospheric attenuation, because the events with shorter periods may be more subjected to such effect (Fig. 17).

The period of the continuous micropulsations shows a daily change, as is illustrated in Fig. 18. The ordinate shows the hourly mean period which is averaged with the number of occurrences shown in blackets. The period is generally longer in the daytime than in the night time. Dotted line shows the

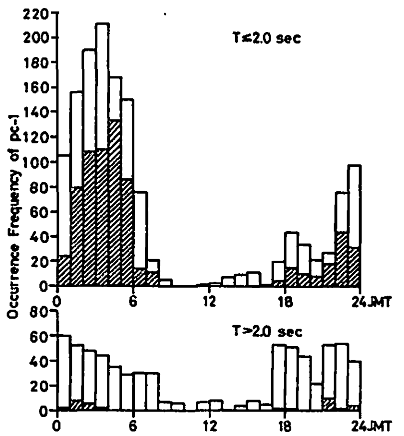


Fig. 17. Diurnal variations of occurrence frequency (the number of five-minute intervals in which pulsations occurred) of pc-1 divided into two groups: the one equal to or shorter than 2 sec and the other longer than 2 sec by the range of period of the largest oscillation in the five-minute interval. Hatched area corresponds to distinct pc-1.

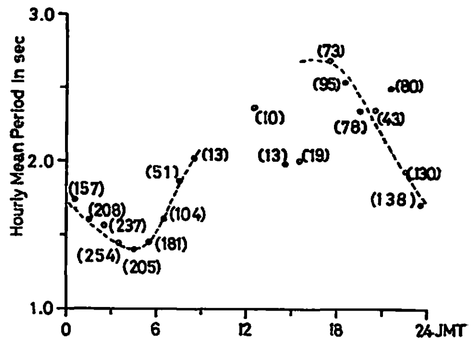


Fig. 18. Daily change of hourly mean period of pc-1. The period is mean value for each one hour of that of the largest oscillation in each five-minute interval. Figure in brackets is the number of the used intervals.

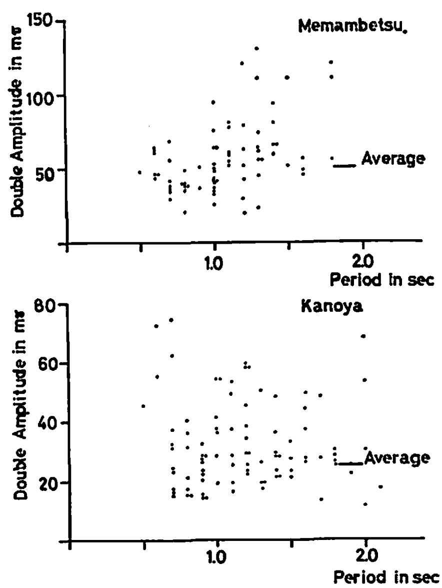


Fig. 19. Largest double amplitudes in milligamma of distinct series of pc-1 observed at Memambetsu (top) and Kanoya (bottom). These are plotted for the corresponding period.

daily change of the hourly mean period. It is somewhat dispersive in the daytime because only a few events occur in this time interval. However, the curve in the night hours is fairly smooth and shows a distinct single maximum and minimum. It shows the longest period at about 18 JST and the shortest at about 5 JST. The period shortens gradually from sunset to sunrise. This closely corresponds to the daily change of the occurrence frequency of micropulsations shown in Fig. 7(a) and Fig. 7(b). It seems that the change reflects the ionospheric attenuation effect on micropulsations.

The double amplitude of the micropulsation is of the order of several ten milligammas. In Fig. 19 the double amplitudes of the distinct events observed at both stations are plotted. The amplitude of Y component is usually small compared with X component. However, Y component frequently exceeds X component in the hours around sunrise at both stations. It is deduced that the equivalent ionospheric overhead current flows in an east-west direction in the midnight hours but changes to a north-south direction in the morning hours. However, Z component is usually too small to be recognized on our monitoring records, except in the case of the most intense events. Z component has an amplitude about one order smaller than the horizontal components.

There is a latitude dependency concerning to the observed signal of micropulsations. The amplitude of detected signals is larger in Memambetsu which is higher than Kanoya in latitude. The mean double amplitudes are about 50 mγ and 25 mγ at Memambetsu and Kanoya, respectively. In addition, only a few evidences of the propagation of micropulsations across the equator known as Tepley's structure doubling (1964) were obtained at the lower latitude station, Kanoya, as will be shown later. But it has not been detected at Memambetsu. Both latitude dependency and structure doubling at the lower latitude station suggest some attenuation of the signal within the wave duct in the upper part of the ionosphere, besides the ionospheric screening effect.

5. Other Characteristics of pc-1, and Discussions

To investigate more-detailed fine structure of the pulsation, two types of frequency-time displays, sonagram and vibragram, are analyzed. Distinct events observed on 19 days and listed in Table 4 are used.

In Fig. 20, a vibragram and a sonagram are shown together with the corresponding reproduced record of the same component (X component) obtained on April 6, 1964. The vibragram is essentially equal to the sonagram except for

Table 4. Distinct pc-1 events observed at Kanoya and used in investigation of their fine structure.

Date	Duration (UT)	Quality	Date	Duration (UT)	Quality
Mar. 2, 1964	1900—1938	B	Apr. 25, 1965	1607—1808	A
	1950—2027	B		1816—1833	B
9	1927—2022	B		1920—1955	B
12	2015—2210	B	26	1854—1934	B
17	1811—1948	A	May 5	1144—1415	B
	1957—2155	B	11	1208—1319	B
Apr. 4	0850—0950	B	Aug. 25	1600—1624	B
	1241—1403	B	Oct. 5	1602—2109	A
	1422—1555	B	Jan. 29, 1966	1927—2129	B
	1626—2100	A	Mar. 17	1923—2259	A
6	1943—2013	A	18	1613—1645	B
15	1610—1740	B		1651—1712	B
	1833—2103	A		1730—1932	B
Aug. 9	1431—1535	B	30	1630—2030	A
Mar. 7, 1965	1731—1907	B			

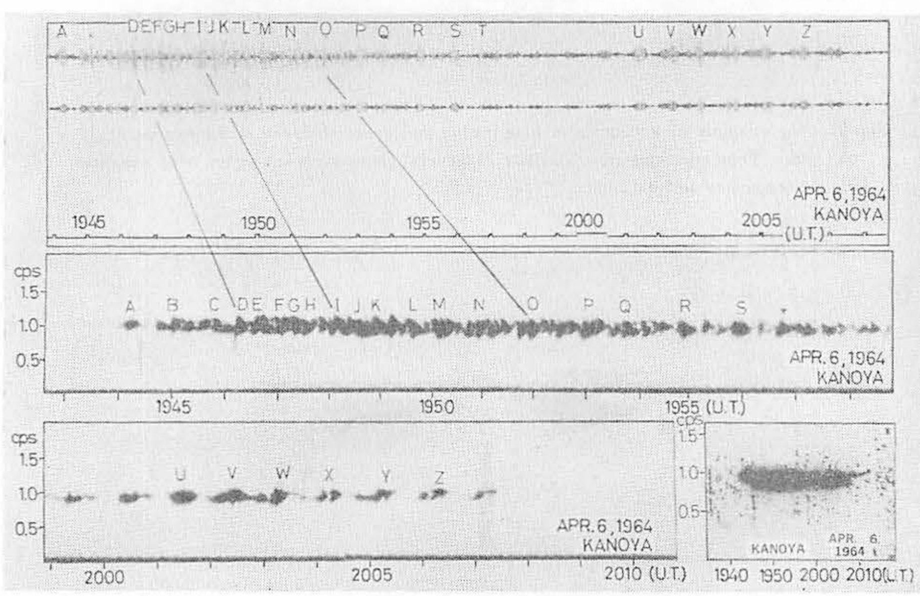


Fig. 20. Simultaneous reproduced record (top), vibragram (middle and bottom-left) and sonagram (bottom-right) of typical pc-1 observed at Kanoya on April 6, 1964. They illustrate clear one-to-one correspondence between each pearl-like envelope on the reproduced record and individual elementary patterns on the vibragram.

the extended time scale. As shown in this figure, the constituent elementary patterns on the vibragram have one-to-one correspondence to the bead-like envelope of the micropulsation on the reproduced record. And the well-known fine structure with rising tone on the sonagram usually consists of a sequence of such elementary patterns.

As shown in Fig. 21, a series of long-lasting micropulsations is interpreted as occasional succession and superposition of several sub-series with different center periods and durations. These durations usually range from about ten to

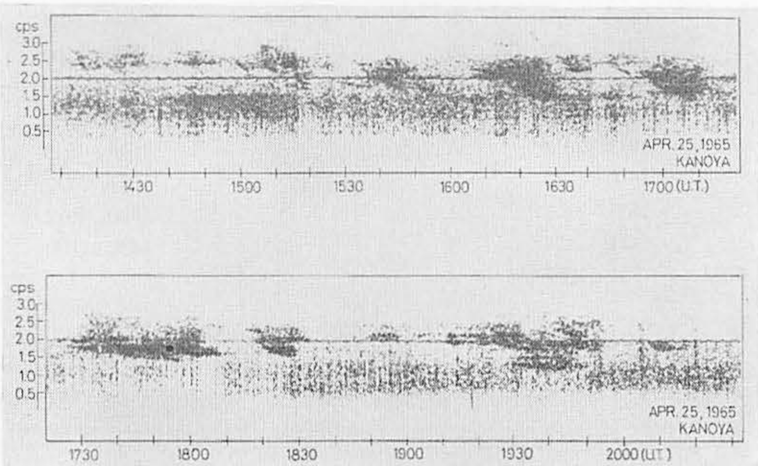


Fig. 21. An example of sonagram of long-lasting pc-1 event observed at Kanoya on April 25, 1965. This micropulsation consists of several elementary sub-series with discrete center frequency and duration.

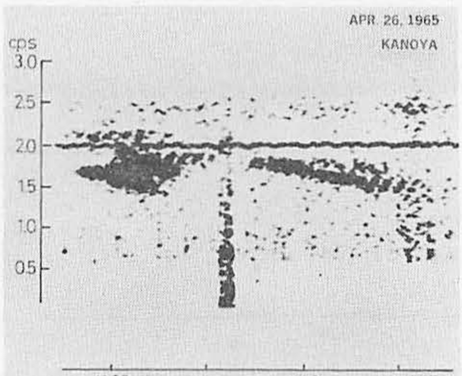


Fig. 22. Discrete trend of center frequency for each sub-series of pc-1, observed at Kanoya on April 26, 1965.

several ten minutes.

The trend of the center frequency of the sub-series usually varies. An example is illustrated in Fig. 22. This event consists of two sub-series.

The center frequency of the sub-series appearing around 19h (UT) has a rather ascending trend but in the following series occurring in 1915-1930 UT, the frequency shows a clear descending trend. Most sub-series have wide-band microstructure. Analyzed more minutely, the structure of the sub-series usually reveals layer structure of considerably narrow bands superposed on the well-known sequence of the rising tone structure. In Fig. 23 an example observed

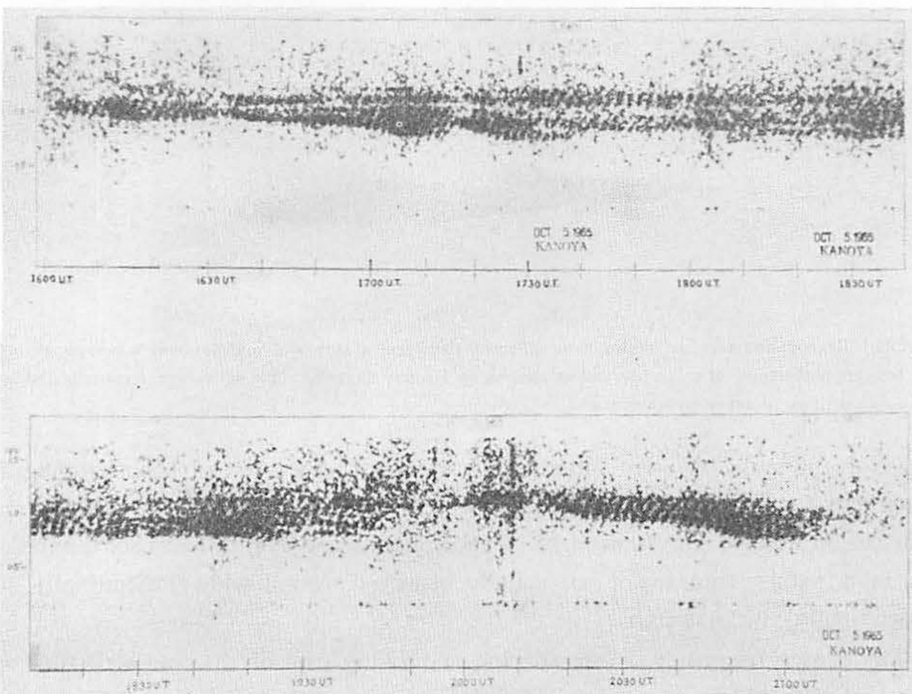


Fig. 23. Layer-structure on sonagram of pc-1 observed at Kanoya on October 5, 1965.

on October 5, 1965 is shown. This event appears continuously for a fairly long period, from 1600 to 2110 UT, and clearly shows succession and superposition of such layer structures. So that the layer structure has a duration shorter than that of the whole series or sub-series.

Individual patterns of microstructure can not always be clearly discerned; in an intense event, particularly, its characteristic microstructure on the sonagram is complicated. An example of such sonagram is given in Fig. 24. The reproduced record shows typical pearl characteristics. It is speculated that such an

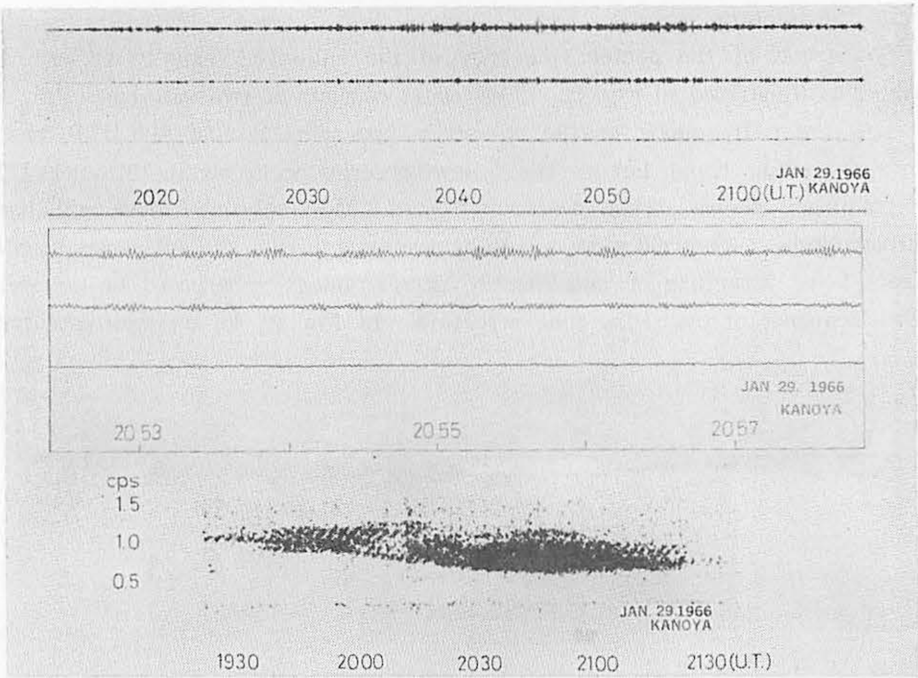


Fig. 24. Reproduced records having two different time scales (top and middle) and a corresponding sonagram (bottom) of pc-1 observed at Kanoya on January 29, 1966. This sonagram is complicated by superposition of layer structures.

intense event veils its own characteristic microstructure by superpositioning its constituent layer structures. In other words, some magnetospheric sources may be in action almost simultaneously in such an intense event, because the pulsation is a rather rare event but usually observed over a wide (latitudinally and longitudinally) surface area.

The center frequency, mean spacing and rising rate of the fine structure are investigated to obtain more detailed information on the pulsation. The center frequency and the mean spacing are mainly read for each layer structure. As the events with complicated structures are many in the present samples, the data are not so sufficient but able to give us rough information on spacing and rising rate.

In Fig. 25 distribution of mean spacing for the 2-year period at Kanoya is shown. The range of the spacing is 50-170 seconds. A distinct peak of the spacing appears at about 100 seconds. If this value corresponds to the bouncing period of the hydromagnetic wave packet guided by the field line between the conjugate points across the equatorial plane at a distance of several earth's radii

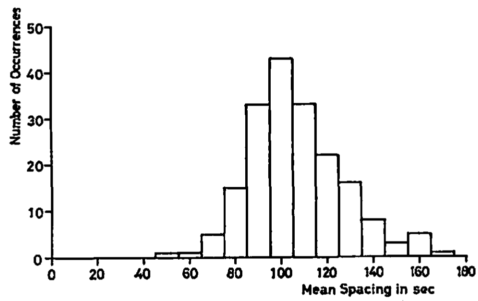


Fig. 25. Distribution of mean spacing (repetition period) of fine structure of the distinct pc-1 event observed at Kanoya.

as pointed out by Jacobs and Watanabe (1964), Obayashi (1965), Wentworth (1966) and others, its bouncing speed will amount to about several hundred kilometers per second or more. This is somewhat higher than other investigater's results, which suggests that the source origins may be nearer to the earth. Besides, the waveform is fairly sinusoidal. These factors—undisturbed wave form and regular, short spacing—may be related to stable inner magnetosphere.

The relation between the mean spacing and the center frequency is very dispersive, as is shown in Fig. 26. Apparently, there is no relation between these two factors. In Fig. 26, × mark means the average value of the mean

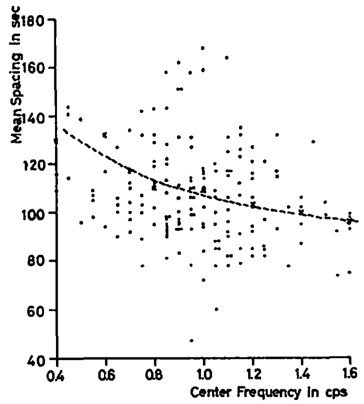


Fig. 26. Relation between center frequency and mean spacing of fine structure of the distinct pc-1. Cross mark shows average value of mean spacing for each 0.2 cps range.

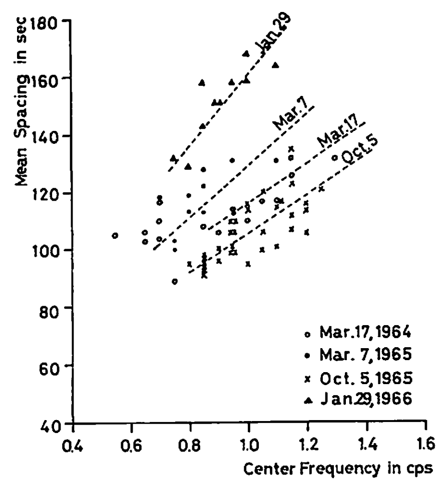


Fig. 27. Examples showing linear relation between mean spacings and the corresponding center frequencies in individual series of pc-1. Four distinct series observed at Kanoya on March 17, 1964, March 7 and October 5, 1965 and January 29, 1966 are used.

spacing for each 0.2 cps interval. It is seen from its smoothed curve that the lower the center frequency is, the longer the mean periodicity becomes. This relation qualitatively agrees with the results of other authors (Heacock and Hessler, 1962; Gendrin, 1963; Schlich, 1963 and Tepley, 1966). The fact does not agree with the generally accepted theory (Jacobs and Watanabe, 1964; Obayashi, 1965). However, there is a favorable evidence for the theory. As to the individual events, it is shown that the micropulsation with a longer frequency has a faster velocity of propagation as illustrated in Fig. 27. This suggests that the cause of the inconsistency is due to other conditions in the magnetosphere. An extreme example is given in Fig. 28. This is a sonagram of the pearls observed

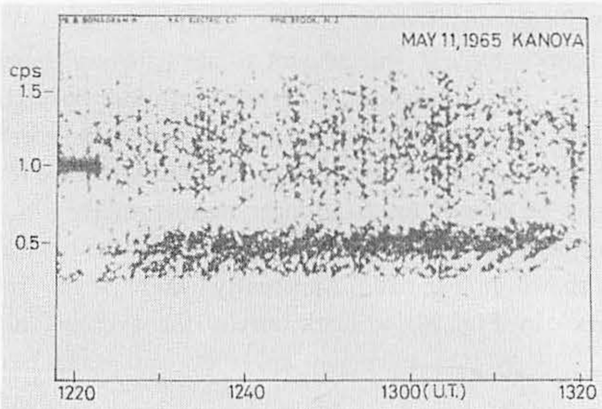


Fig. 28. Sonagram of pc-1 observed at Kanoya on May 11, 1965. This is an example of series having a comparatively low center frequency and a long repetitive period.

at Kanoya on May 11, 1965. It shows a fairly long repetitive periodicity of about 2-3 minutes for its comparatively low center frequency of about 0.5 cps. On the other hand, the event shown in Fig. 20 has a very short repetitive period (about 50 sec) for its center frequency of about 1 cps, a usual value.

The microstructures on dynamic spectrum at Memambetsu and Kanoya are usually very similar. An example is given in Fig. 29. These vibragrams are obtained from records observed at the same time, during 2020-2030 UT on October 5, 1965. It is well illustrated in these vibragrams that both microstructures have the same form, center frequencies and repetitive periodicities but somewhat different intensities (darkness). This fact also shows the propagation along a shorter path in the upper part of the ionosphere, and agrees well with the results of Tepley (1964, 1966) and Tepley *et al.* (1965). They illustrate the similarity of the microstructures in a wider region of the same hemisphere.

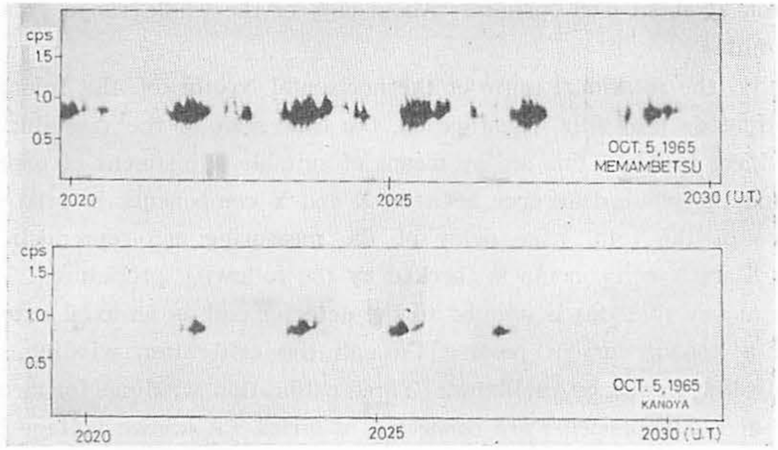


Fig. 29. Simultaneous vibragrams of pc-1 at Memambetsu (upper half) and Kanoya (lower half). This event is observed on October 5, 1965.

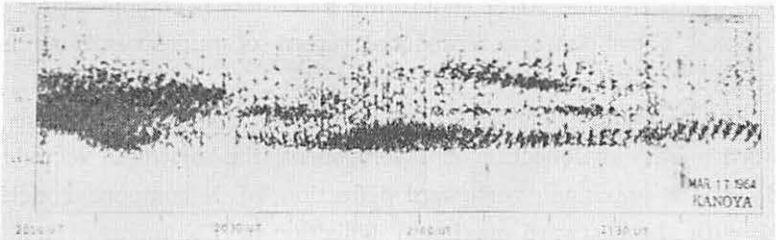


Fig. 30. An example of sonagram of pc-1 showing Tepley's structure-doubling. This is obtained from observation at Kanoya on March 17, 1964.

As shown in Chapter 3, a few examples of Tepley's structure-doubling are observed at the lower latitude station, Kanoya. An example of the doubling is shown in Fig. 30. Most of the frequency-time displays show some sequences of ascending-tone structure with so-called fan-shape. However, the tone changes frequently even in a sub-series. It is somewhat doubtful, therefore, whether the fan-shape is an essential character. But, it seems that the above description is not wholly inconsistent with Obayashi's theory which says that the rising frequency is based upon the dispersive nature of the velocity of the hydromagnetic wave. The sequence with a falling tone is not yet observed in the present work. The ascending ratio is shown in Fig. 31. It

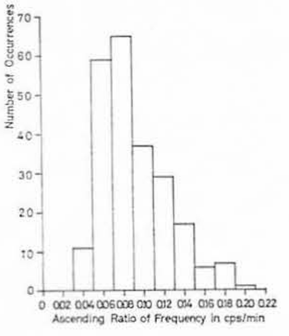


Fig. 31. Rough distribution of ascending ratio of frequency in each rising-tone micro-structure of pc-1.

has a peak at about 0.08 cps/min. About 65% of the whole range from 0.05 to 0.10 cps/min.

Finally, the rotational sense of the horizontal vector of the micropulsation is investigated. For this investigation, the time scale of the reproduced record is magnified to 10-25 mm/sec by means of suitable adjustment of paper-driving speed, and the phase difference between X and Y components is read off. The difference of the total time delay of the measuring and reproducing circuits between X and Y components is checked by the following procedure. The signal with frequency of 1 cps is applied to the detector coil as an axial external field made by a known current passing through the calibration winding, using an extremely low frequency oscillator. Three calibration windings for measurement of X, Y and Z components are connected in series. A known voltage is applied across these three series-connected windings with an oscillator for calibration. If the circuit is well adjusted, the horizontal vector of the calibration field should show linear polarization. After confirming that there is no appreciable difference between X and Y components, reproduced record of micropulsations is investigated.

When the maximum deflection of X component coincides with the eastward or westward maximum deflection of Y component, the horizontal vector is linearly polarized. If the maximum northward deflection of X component delays when compared with the eastward maximum deflection of Y component and the delay is less than half a period, the rotational sense of the horizontal vector is counter-clockwise. If the eastward maximum of Y delays when compared with the northward maximum of X less than half a period, it becomes clockwise.

In Fig. 32 example of the reproduced record with a magnified time scale is

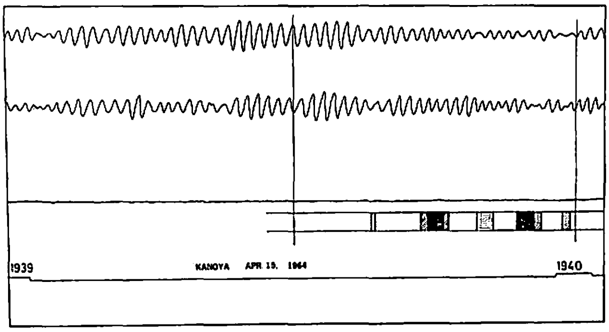


Fig. 32. Magnified reproduced record of X and Y components of pc-1 and the corresponding course of rotational sense of horizontal vector. In this example pc-1 observed on April 15, 1964 at Kanoya is treated.

illustrated. Two curves on the upper half are traces of X and Y components. On the lower half the change of the rotational sense of the vector and the time are shown. Blank and shaded areas correspond to counterclockwise and clockwise rotations, respectively, and hatched area means transitional. In Fig. 33, the actual behavior of the horizontal vector corresponding to the trace in Fig. 32 is

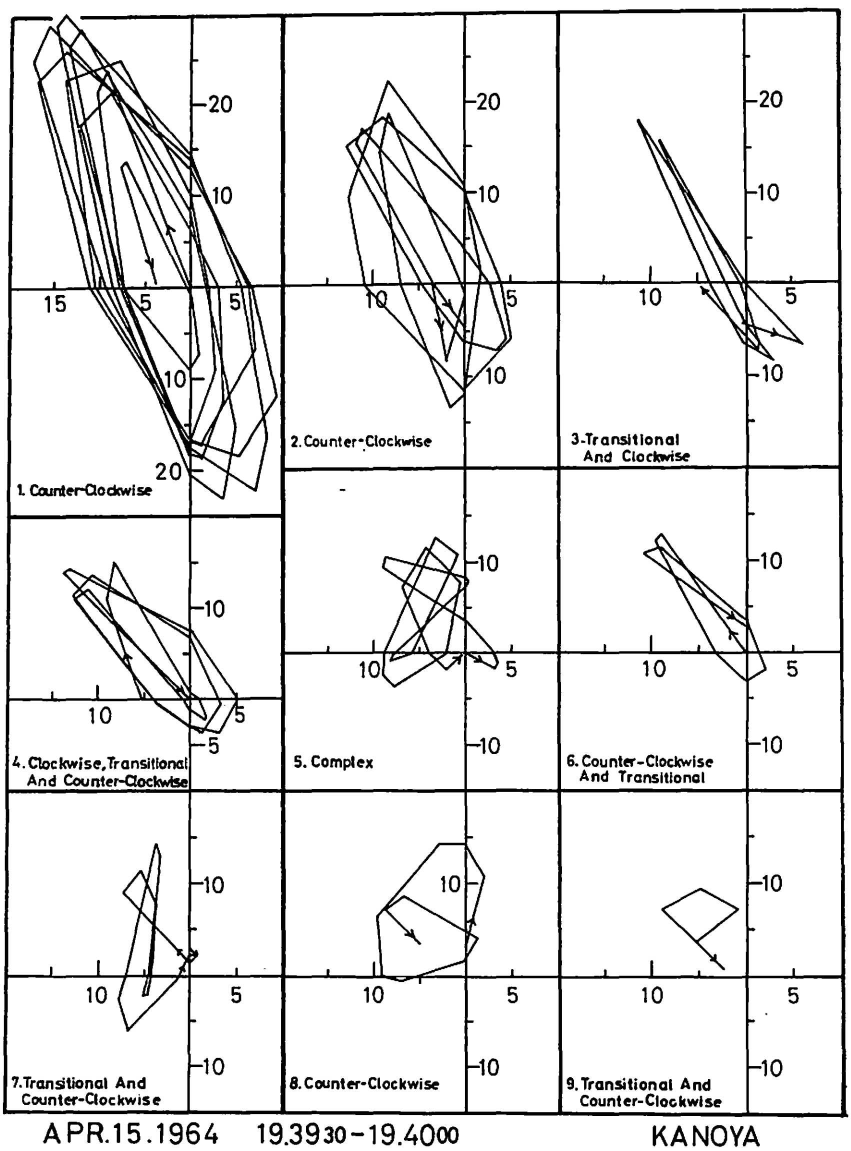


Fig. 33. Actual deviation of horizontal vector corresponding to the trace shown in Fig. 32.

shown. Figs. 34 and 35 are similar to Fig. 32. As shown in these figures, the rotation with counterclockwise sense occurs usually in each loop part of the bead-like oscillation corresponding to the finest structure on the sonagram appearing as a spot. The sense apparently changes to clockwise or transitional (linear)

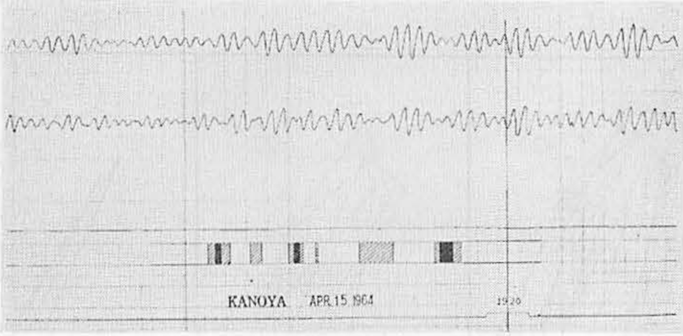


Fig. 34. A magnified reproduced record and the corresponding course of horizontal vector at about 1920 UT of the same pc-1 series as shown in Fig. 32.

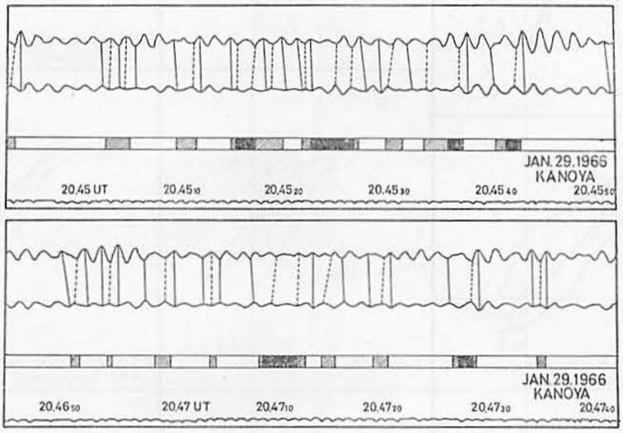


Fig. 35. A magnified record and the corresponding behavior of horizontal vector of pc-1. This is observed on January 29, 1966 at Kanoya.

at around the node. Therefore, it is deduced that the rotational sense of the horizontal vector is essentially counterclockwise and the transition is merely a superficial feature. This result may be understood more easily by Fig. 36. This observational fact suggests that the structured pc-1 should be regarded as hydromagnetic L-wave of proton mode, essentially.

The rotational sense is statistically investigated further concerning the distinct events observed at Kanoya on the following eight days: April 22 and

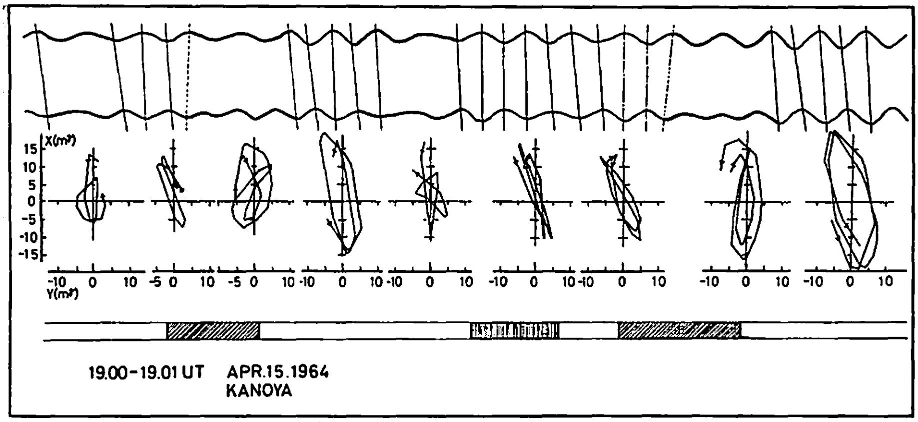


Fig. 36. Reproduced record of the same series as shown in Figs. 32 and 34. Upper and lower traces show X and Y components. Upward directions on both traces are northwards and eastwards. If northern peak of X precedes western peak of Y the sense is counterclockwise (full line). It is clear that the node on the envelope corresponds to transitional part of successive wave packet.

Table 5. The number of five-minute intervals for each rotational sense divided into three groups—clockwise, counterclockwise and linear or mixed—of horizontal disturbing vector of pc-1.

In the upper half (a) the number is tabulated for each range of corresponding center frequency of the regular oscillation. While in the lower half (b) the number is related to the corresponding local time of occurrence. The figures are obtained from typical pc-1's observed at Kanoya on the following eight days: April 22 and 25, May 5 and October 5, 1965, January 29 and March 17, 18 and 19, 1966.

(a)

Frequency in cps / Rotational sense	0.4–0.8	0.8–1.2	1.2–1.6	1.6–2.0	2.0–2.4
Clockwise	0	14	12	21	4
Counterclockwise	31	99	22	5	3
Linear or mixed	0	22	14	8	1

(b)

Time in JST / Rotational sense	00–02	02–04	04–06	06–08	08–20	20–22	22–24
Clockwise	16	25	9	0	0	0	1
Counterclockwise	13	43	69	7	0	13	15
Linear or mixed	8	24	13	0	0	0	0
Whole	37	92	91	7	0	13	16

25, May 5 and October 5, 1965, January 29 and March 17, 18 and 19, 1966. The results are shown in Table 5 and Fig. 37. Particularly in Fig. 37, the relation between the rotational sense and time of occurrence are shown for each period. An interval is selected for each five minutes. The interval is usually a few ten seconds and is that which shows sinusoidal wave form most clearly. The shaded part means the intervals in which the rotational sense is essentially counter-clockwise. Blank and hatched parts correspond to clockwise and linear or complicated polarization, respectively. Though the sense of rotation is still counterclockwise mostly, it tends to change to clockwise or linear polarization. This trend becomes remarkable especially in events with shorter periods. From an example in Fig. 38, it seems that both senses appear, alternately, or it may be interpreted that the polarization is rather linear. These results roughly agrees with Pope's results (1964). It is difficult, however, to explain the alternation in the present work, because our available data are not so much.

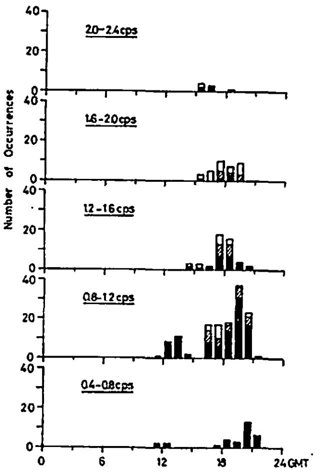


Fig. 37. Occurrence frequency of polarization of pc-1 for each 0.4 cps range for each occurring time. Black area corresponds to counterclockwise (left-handed) polarization. Blank and hatched parts mean right-handed and linear or transitional polarizations, respectively.

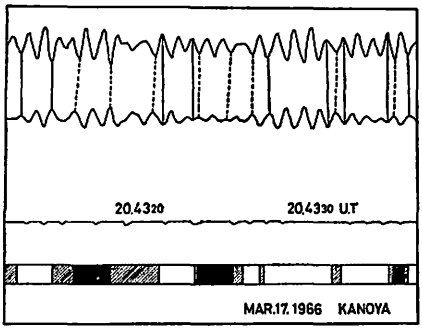


Fig. 38. Magnified traces of X and Y components showing alternation of polarization of pc-1 vector. This is observed at Kanoya on March 17, 1966.

The principal direction of horizontal vector of pc-1 is almost north-southwards in the midnight hours and then changes gradually to northwest-southeastwards. The direction becomes usually to east-westwards in the morning hours. The behavior of the horizontal vector in the daytime hours is yet undetermined, because micropulsations of pearl-type are hardly observable in these hours in the lower latitudes. The occurrence of pc-1 on the ground level shows distinct diurnal variations which roughly correspond to that of the electron density in the overhead ionosphere. So that such ground measurement is insufficient for giving a definite idea on the occurrence of the micropulsation in the magnetospheric source region. The hydromagnetic wave arriving at the ionospheric level in the higher latitudes (auroral or subauroral zone) propagates along the path in the upper part of the ionosphere and penetrates the night ionosphere and reachs the Earth's surface in wide areas almost simultaneously. It is speculated from the above facts that the ionospheric overhead current corresponding to the horizontal magnetic vector flows east-westwards in the midnight hours.

6. Irregular Micropulsation, pi-1 (sp), Appearing in the Same Range of Period as pc-1

Besides the above-described short-period continuous pulsations, there occurs micropulsation pi-1 (sp) with irregular and burst-like characteristics in the almost same range of period. Micropulsations were observed on 322 days and its distinct events appeared on 58 days in a two-year period from April 1964 to March 1966. The numbers of the whole and the distinct events are 653 and 73, respectively. The distinct events are selected by criteria similar to those for pc-1. An example of the reproduced record of micropulsations is shown in Fig. 39, which was

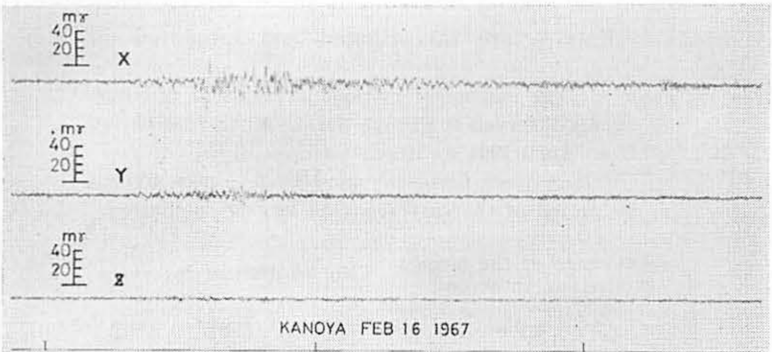


Fig. 39. Reproduced record of pi-1 (sp) observed in the course of a storm on February 16, 1967 at Kanoya.

observed in the course of a magnetic storm on February 16, 1967 at Kanoya. As shown in this figure the micropulsation clearly has an irregular and burst-like nature. The duration of micropulsations is usually several to several ten minutes, fairly shorter than that of pc-1. However, events with considerably long durations are observed at times, especially during a storm. In that case, irregular but continuous waves following noise-burst last for a fairly long period. Since such micropulsations show continuous appearance, it is not so easy to distinguish it from pc-1 on photographic records. In such case, it may be more efficient to use frequency-time display. An example of sonagram corresponding to the above event is shown in Fig. 40. The frequency on the sonagram covers a fairly

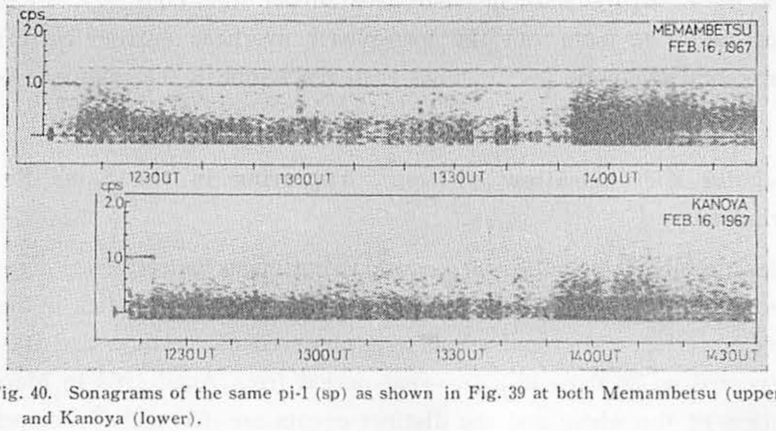


Fig. 40. Sonagrams of the same pi-1 (sp) as shown in Fig. 39 at both Memambetsu (upper) and Kanoya (lower).

wide range. The upper limit of the frequency is usually 1 cps and sometimes reaches 2 cps or more, particularly in the distinct events. The periods of the largest oscillations in the special intervals of the distinct events observed in the two-year period at Kanoya are investigated and tabulated in Table 6. The

Table 6. The number of distinct intervals of pi-1 (sp) events observed at Kanoya during a two-year period from April 1964 to March 1966.
It is given for each 'one-second' range divided by period of the corresponding largest oscillation.

Period-range of the largest oscillation, in second	No. of distinct intervals
≤1.0	5
1.0-2.0	49
2.0-3.0	37
3.0-4.0	33
4.0-5.0	6
5.0-6.0	11
6.0-7.0	14
7.0-8.0	13
8.0-9.0	3
>9.0	5

periop is usually 1-4 seconds but the values may not be so important because their broad fine structures are the most essential character.

The micropulsation is generally accompanied by pi-1, 2 (pi-2) and/or the longer side of pi-1 shown as pi-1 (1p). They correspond to 'pt' in the old nomenclature of IAGA-IUGG. About 65% of the whole and 92% of the distinct pi-1 (sp) events are observed together with pi-1, 2. The same results are already described in the author's earlier paper (Kawamura, 1964). Moreover, about 30% of the whole and 52% of the distinct events are detected in the course of magnetic storms. But 141 events of the whole are independent of pi-1, 2 micropulsations or storms. Two and seven events of them depend on sudden impulses and bay disturbances, respectively, and 43 events appear with either pc-3 or pc-2. (See Table 7.) From these results, the pi-1 (sp) micropulsation may be interpreted

Table 7. Occurrence characteristics of pi-1 (sp) in relation with
(a) geomagnetic storm,
(b) irregular micropulsations, pi-1, 2, with longer periods,
(c) either geomagnetic storm or irregular micropulsations, at least.

(a)

	Distinct events	Indistinct events	Whole events
No. of pi-1 (sp) events	73	580	653
No. of pi-1 (sp) events occurring in storm-time	38	156	194
Percentage of simultaneous occurrences	52%	27%	30%

(b)

No. of pi-1 (sp) events	73	580	653
No. of pi-1 (sp) events occurring simultaneously with irregular micropulsations, pi-1, 2 having longer periods	67	359	426
Percentage of simultaneous occurrences	92%	62%	65%

(c)

No. of pi-1 (sp) events	73	580	653
No. of pi-1 (sp) events occurring in storm-time or with irregular micropulsations having longer periods	71	441	512
Percentage of simultaneous occurrences	97%	76%	78%

as essentially higher frequency components of irregular and burst-like pulsation accompanied by the bay disturbance or irregular but continuous pulsation in the storm period. It seems that this pi-1 (sp) occurring with bay's and storm's pulsations may correspond to Yanagihara's 'spt' and 'spc', respectively.

On the other hand, pi-1, 2 does not always accompany the higher frequency components. In the two-year period, 814 events of pi-2 and 158 events of pi-1 (1p) are observed at Kanoya. The numbers of these distinct events are 346 and 73, respectively. About 40% of the whole events and about 55% of the distinct phenomena of pi-2 accompanied the higher frequency components, pi-1 (sp). About 72% of the whole and about 84% of the distinct events of pi-1 (1p) have pi-1 (sp) components. The results are shown in Table 8. It is deduced that in the case

Table 8. The number and percentage of simultaneous appearances of pi-1 (sp) to (a) pi-2 and (b) pi-1 (lp) observed at Kanoya in a two-year period from April 1964 to March 1966.

(a)

	Distinct events	Indistinct events	Whole events
No. of pi-2 events	346	486	814
No. of pi-1 (sp) events occurring simultaneously with pi-2	190	134	324
Percentage of simultaneous occurrences	55%	28%	40%

(b)

No. of pi-1 (lp) events	73	85	158
No. of pi-1 (sp) events occurring simultaneously with pi-1 (lp)	61	52	113
Percentage of simultaneous occurrences	84%	61%	72%

of distinct pi-1, 2, the higher frequency component, pi-1 (sp) also has a sufficiently large amplitude, while pi-1 (sp) perhaps becomes undetectable in the insignificant pi-1, 2. It is also expected that the diurnal variation of the occurrence frequency of pi-1 (sp)—shown in Fig. 41—may coincide with that of pi-1, 2.

The ordinate of Fig. 41 shows the number of 20-minute intervals in which pi-1 (sp) occurs. This micropulsation is also essentially nocturnal and 84% of them are observed during 6h p.m.—6h a.m., while about 57% appear in the six hours around midnight. About 94% of the distinct phenomena occur in twelve night hours. In Fig. 42 this diurnal variation is compared with those of pi-2 and pi-1 (1p) observed in the same two-year period from January 1964 to December 1965 at Kanoya. The upper, middle and lower diagrams correspond to pi-1 (sp), pi-1 (1p) and pi-2, respectively. The time of the maximum occurrence of each micropulsation of them is also about midnight. The similarity of these diurnal variations also suggests that pi-1 (sp) is the higher frequency components of pi-1, 2.

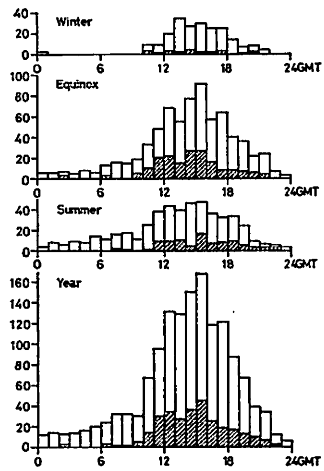


Fig. 41. Diurnal variation of occurrence frequency of pi-1 (sp) for each season and full year at Kanoya. It is shown by the hourly number of 20-minute intervals in which pi-1 (sp) occurs.

The seasonal variation of pi-1 (sp) is shown in Fig. 43. In this period micropulsations also occurred most frequently in the spring equinox. However, it also appeared almost equally from May to September. Yanagihara (1957) investigated the annual variation of the occurrence frequency of pt from the data of earth current observed at Kanoya in a period of 20 years and pointed out that the variation showed equinoctial maximum and summer minimum. We also obtained almost same result for the two-year period. Our result for pi-1 (sp) also well coincide with those for pt (or pi-1, 2), except summer minimum.

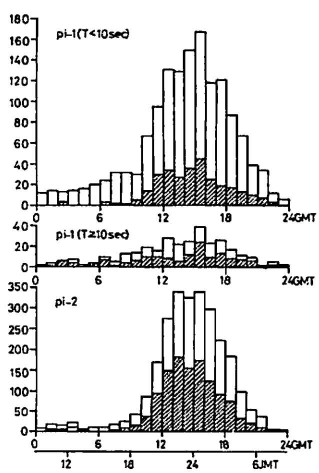


Fig. 42. Diurnal variation of pi-1 (sp) in comparison with those of pi-1 (1p) and pi-2.

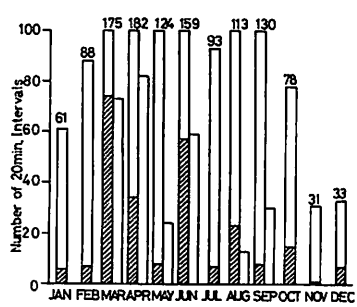


Fig. 43. Annual variation of occurrence frequency (the number of twenty-minute intervals) of pi-1 (sp) at Kanoya.

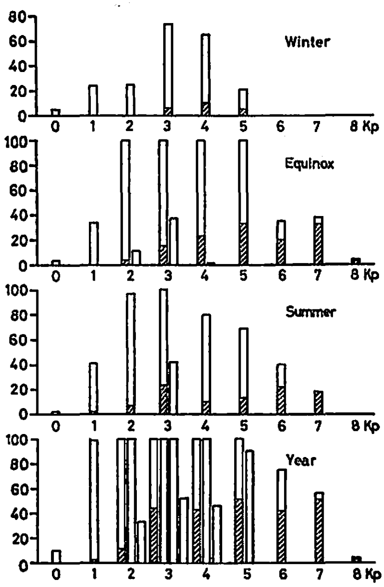


Fig. 44. Kp-dependency of occurrence of pi-1 (sp) at Kanoya.

Finally, the Kp-dependency of the occurrence of pi-1 (sp) is given in Fig. 44. As already shown, the micropulsation generally overlaps pi-1, 2 with longer periods following a storm or bay disturbance, so it appears most frequently under a rather disturbed condition. About 91% of the whole appears in Kp-values larger than 2_-. The result for the distinct events is more clear. Only two 20-minute periods are detected in the calm conditions of $Kp \leq 1_+$.

After all, pi-1 (sp) shows the maximum occurrence in the period range of 1-4 seconds but it is deduced that pi-1 (sp) does not constitute a principal class but is higher frequency components of pi-1, 2, generally overlapping a storm or bay disturbance. Therefore, the diurnal and annual variations and Kp-dependency of the occurrence frequency also coincide with those of pi-1, 2. Its dynamic spectrum shows a burst-like broad band structure having good coincidence for each train of pi-1, 2. Owing to the broad band structure, the wave form is also fairly irregular.

7. Short-Period Geomagnetic Micropulsations and Geomagnetic Storms

As has been described, micropulsations with periods of about 1 second, either pc-1 or pi-1 (sp), have a very close relationship with geomagnetic storms. Typical structured pc-1 in the middle and low latitudes usually appears in a magnetically rather calm condition and, consequently, its relationship with the storm is not so clear. However, the micropulsation should be understood as an magnetohydrodynamic phenomenon related to the enhanced solar wind which is regarded as the cause of the geomagnetic storm, because there are some favorable facts as follows.

1) Successive occurrences of typical structured pc-1 micropulsations usually concentrate during the night hours of several successive days in the quiet period following a storm, in our observation.

2) Some pc-1 events without such well-defined spectral structure as the pearl events are observed in the course of magnetic storms.
3) As pointed out by Heacock and Hessler (1965), the pearl events are directly accompanied by the storm sudden commencements and clearly show daytime maximum of the occurrence in the auronal zone.

It is believed from the conjugate relationship that the micropulsation is the hydromagnetic wave travelling along the geomagnetic lines of force between conjugate points and is related to the behavior of the solar wind particles trapped in the magnetosphere during a storm time. Therefore, various interesting morphological characteristics of the micropulsation observed in the middle and low latitudes should be interpreted as some positive indications which show the existence of the mechanisms attenuating the wave energy during its propagation from the auroral zone to the earth's surface in the lower latitudes. On the other hand, pi-1 (sp) is enhanced in the initial to recovering phases of a magnetic storm. This micropulsation has undoubtedly an 'irregular' wave form but shows a more 'continuous' nature compared with the usual pi-1 accompanied by the bay disturbance. On the other hand, pi-1 (sp) is observed, corresponding to bay-like appearance recorded sometimes on magnetogram during the course of a geomagnetic storm. This micropulsation still maintains the train-type nature of ordinary pi-1, 2 in a more undisturbed condition.

Typical occurrences of short-period micropulsations accompanied by geo-

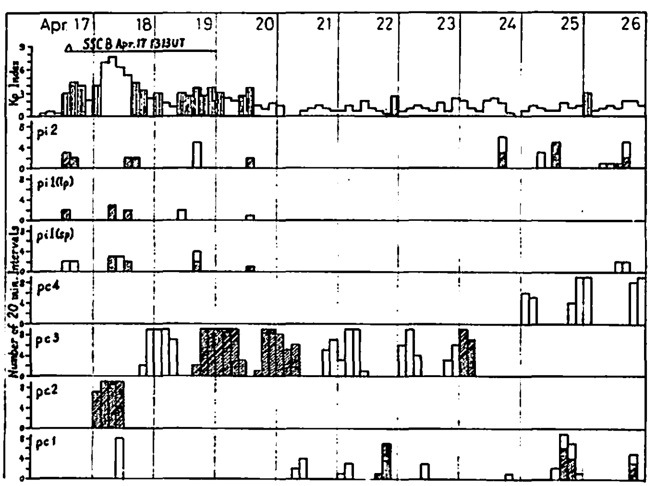
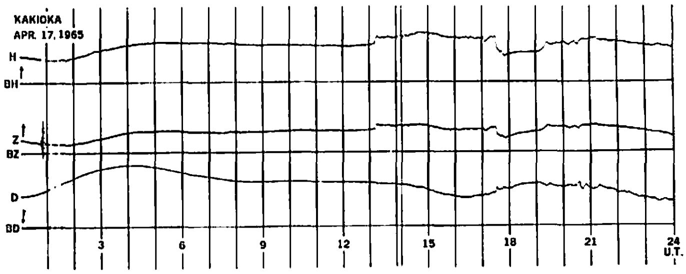


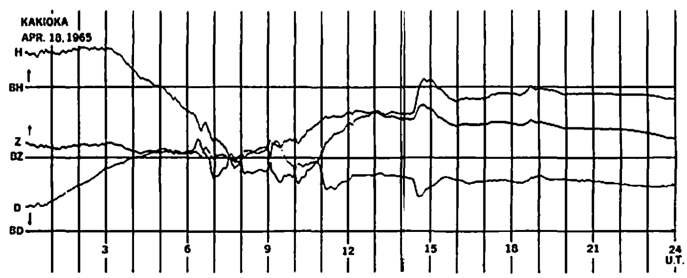
Fig. 45. Change of Kp-index and occurrence characteristics for each class of micropulsations in several successive days following ssc storm on April 17, 1965.

magnetic storms are described in more detail with three representive examples.

The first example is the micropulsations that occurred in a period of several days after a ssc storm on April 17, 1965. The appearance of micropulsations in this period is shown schematically in Fig. 45. In this figure, the uppermost row shows successive Kp-values; the blank, striped and shaded parts correspond to calm ($Kp \leq 2_+$), moderately disturbed ($Kp = 3_- - 4_+$) and stormy ($Kp \geq 5_-$) conditions, respectively. In the second and third row and fifth and sixth row, pi-1 (1p), pi-2 and pc-4, pc-3 recorded on rapid-run magnetograms at Kanoya are shown. The seventh row is pc-2 read from the same record. The forth row indicates the occurrence of pi-1 (sp), and the appearance of pc-1 micropulsation is given in the bottom row. These pi-1 (sp) and pc-1 are observed from the ultra rapid-run magnetograms which are our monitoring records. The hatched areas correspond to their distinct events. This storm is the most intense one observed at Kakioka in the two-year period. The maximum ranges of three components, H, Z and D, are 278γ, 106γ and $15.2'$, respectively. Fig. 46 shows ordinary magnetograms obtained at Kakioka; and (a), (b) and (c) are those on April 17, 18 and 19, respec-

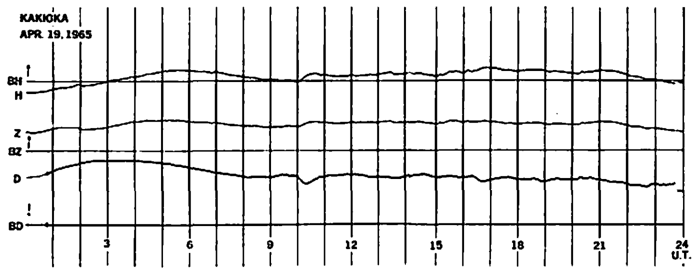


(a)



(b)

Fig. 46. Ordinary magnetograms observed at Kakioka on (a) April 17, (b) 18 and (c) 19, respectively.



(c)

Fig. 46. (Cont.)

tively. In this storm a distinct storm sudden commencement is observed at 1313 UT.

This storm is regarded as 'isolated' one, because several days before the storm we had very low Kp-values. Especially, the Kp-values in four Kp ranges before the ssc are 0_0, 0_+, 1_- and 0_+. It seems that the relation between storm and accompanied pulsations is shown more clearly. In its main and last phases clear irregular but continuous micropulsations are enhanced. In the same period a weak trace of pc-1 is observed, but it is rare that this micropulsation occurs in the active course of geomagnetic storm in our middle and low latitude stations. The continuous micropulsations with period of pc-3 range are successively observed in the last phase and the following several days. The structured pc-1 micropulsations occur in fairly quiet conditions of each night hour of six successive days starting from April 21. The events observed on April 22, 25 and 26 are particularly distinct. In these events it is noticed that the micropulsation has a considerably high mean period. Accompanied by the bay disturbances, ordinary pi-1 (sp) micropulsations are observed with usual pi-1, 2 micropulsations.

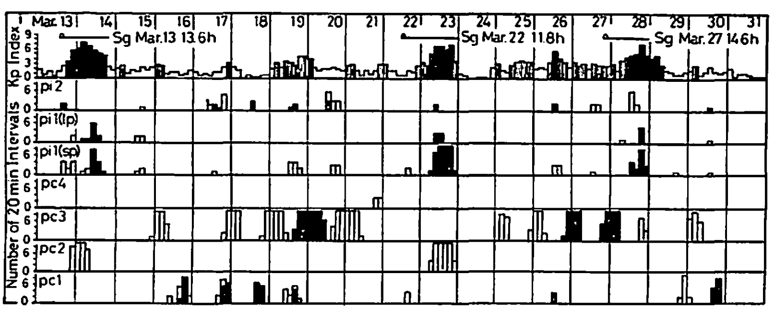
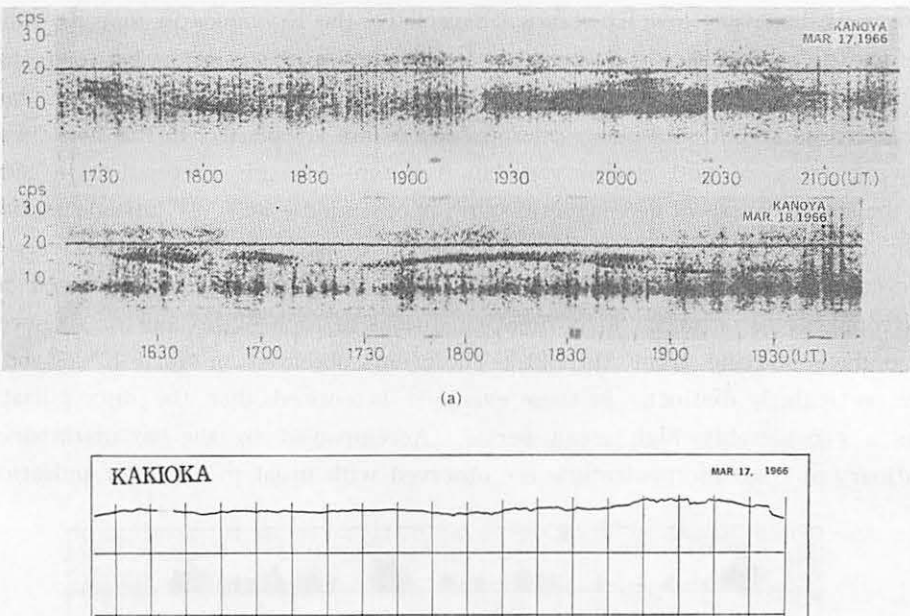
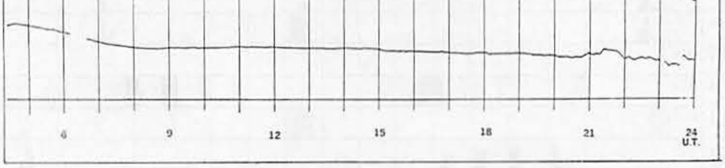


Fig. 47. Change of Kp-index and occurrence charactesistics for each class of micropulsations from March 13 to March 31, 1966 during which three successive storms occur.

In the second example, the micropulsation observed during 13-31 March 1966 are treated. Successively occurring three gradual storms are recorded during this period. The first storm appearing on March 13 is the most intense one, and has the maximum H range of 248γ. The second and the third storms on March 22 and 27 are smaller. In Fig. 47 these miropulsations are shown in connection with the storms and Kp-values. In all these cases the short-period irregular pi-1 (sp) micropulsations with longer durations are observed around the main phases. Continuous daytime micropulsations, pc-3, prevail in their rather disturbed recovering stages following these storms. Overlapping on so-called polar sub-storms, pi-1, 2 and its higher frequency component pi-1 (sp) are sometimes recorded. The well-structured pc-1 events occur usually in rather calm periods after these storms. A typical example is observed for four nights in a row from

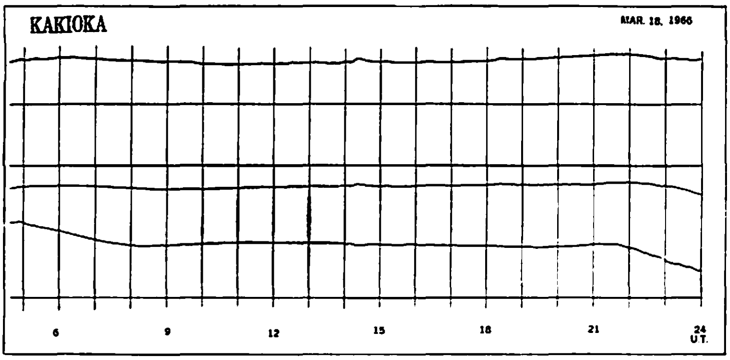


(a)



(b-1)

Fig. 48. Sonagrams at Kanoya and the corresponding ordinary magnetograms at Kakioka of pc-1 on March 17 and 18, 1966.



(b-2)

Fig. 48. (Cont.)

March 16 to 19. Some of the sonagrams and the corresponding ordinary magnetograms are shown in Fig. 48.

In the last example the micropulsations observed in the period from February 15 to March 1, 1967 are shown. A considerably intense ssc storm occurs at 2348 UT, February 15, 1967 and the maximum range of the horizontal component at Kakioka is 256γ. The change of Kp-value and the occurrence of micropulsations in the period are shown in Fig. 49. Throughout all the stages of the

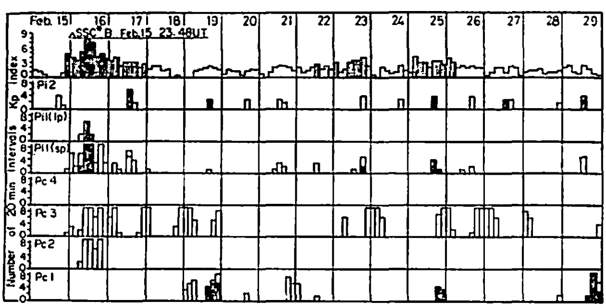


Fig. 49. Change of Kp-index and occurrence characteristics for each class of micropulsations in 15 days following ssc on February 15, 1967.

storm, very distinct and long-lasting storm-type pi-1 (sp) and pi-1, 2 are observed. They are shown in Fig. 50. The upper and lower halves of the figure show the dynamic spectra of the micropulsations at Memambetsu and Kanoya, respectively. After this storm structured micropulsations are observed during four consecutive days starting from February 19. Particularly, on February 19 some weak traces are recorded even in the daytime at Memambetsu. Kp-values in this period are 0, a nearly 'dead calm' condition. But, at Kanoya no clear corresponding trace

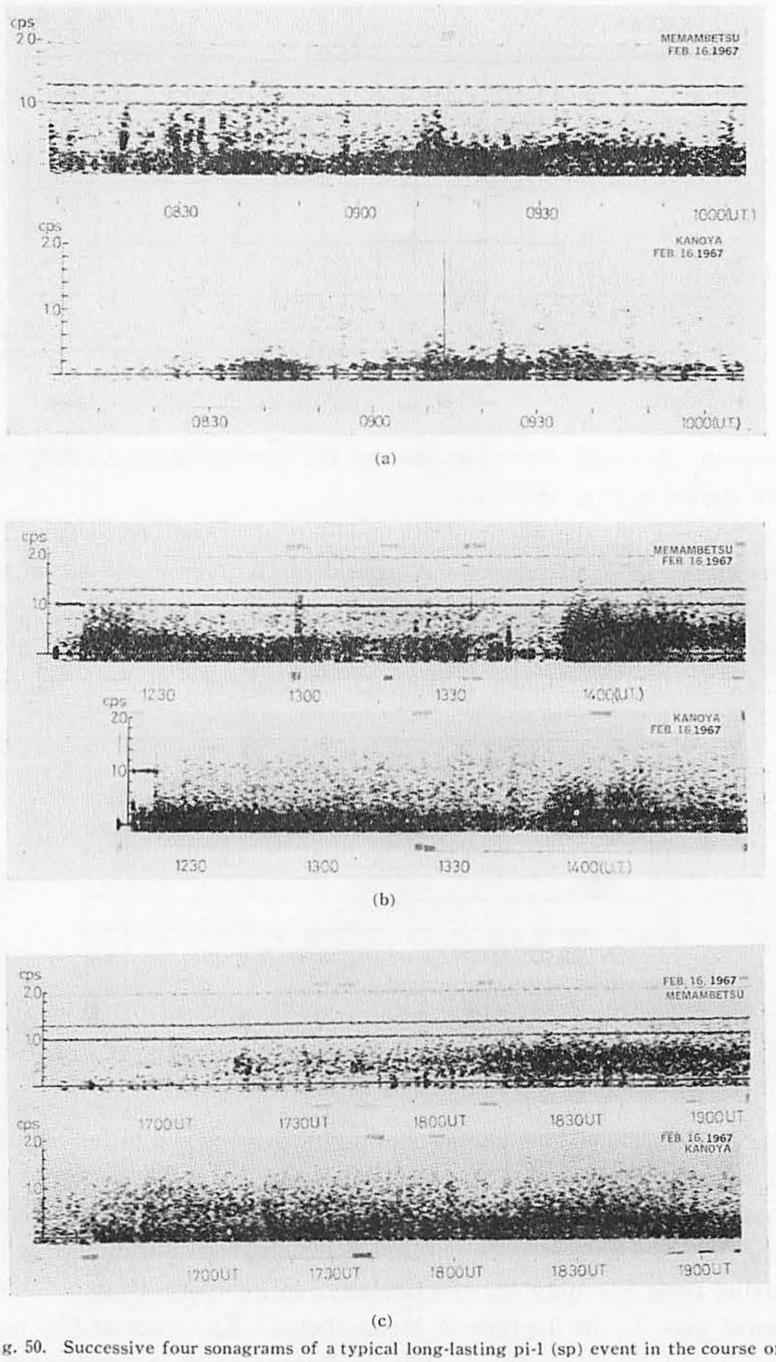
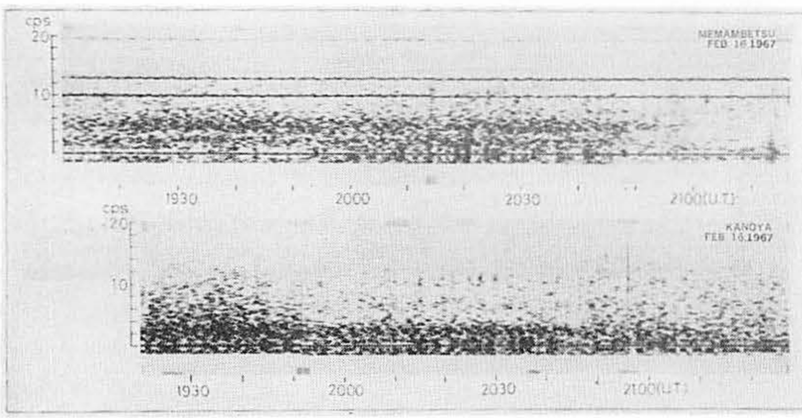


Fig. 50. Successive four sonagrams of a typical long-lasting pi-1 (sp) event in the course of a magnetic storm on February 16, 1967 at Memambetsu (upper) and Kanoya (lower).

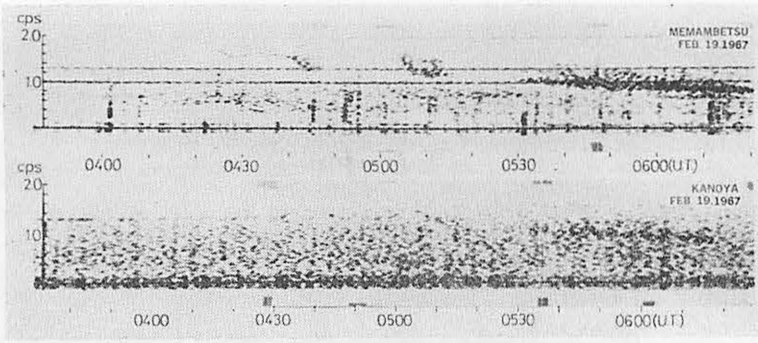


(d)

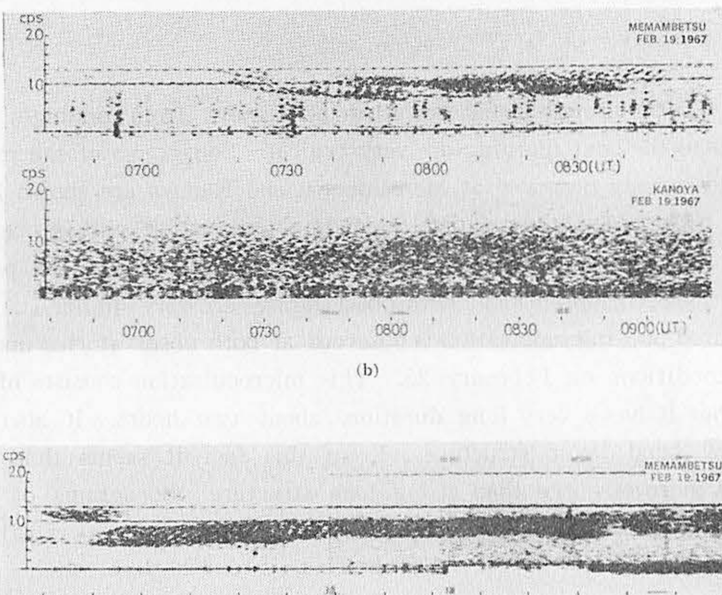
Fig. 50. (Cont.)

is found. The micropulsations recorded at Kanoya from midnight (JST) of February 19 to the next morning are very typical. Sonagrams of the micropulsations simultaneously observed at Memambetsu and Kanoya are shown in parallel in Fig. 51. They also show typical ascending tone nature with proper spacing. Except the above-mentioned slight difference in daytime traces, the patterns of the dynamic spectra obtained at both observatories are very similar. An isolated well-structured pc-1 micropulsation is observed at both observatories under rather disturbed conditions on February 25. This micropulsation consists of only one sub-series but it has a very long duration, about two hours. It also shows a very narrow band layer structure. From this fact it seems that the layer structure is more essential than rising tone structure. Sonagrams of this pc-1 observed at Memambetsu and Kanoya are shown in Figs. 52 (a) and (b), respectively.

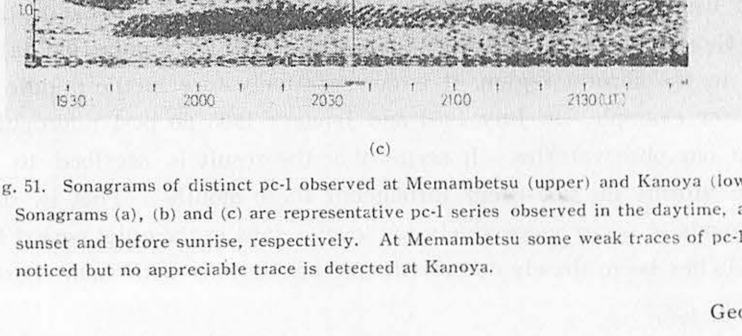
As shown in the above examples, it is very rare that characteristic pc-1 micropulsations appear in the active course of a geomagnetic storm. Micropulsations occur usually under a rather calm condition ($Kp \leq 2_+$) on several days after a storm. Generally it is accepted that while the micropulsation is observed frequently in the auroral region, it is comparatively rare in the middle and low latitudes; for example, in July 1964 and January 1965 no pc-1 micropulsation is observed at our observatories. It seems that the result is ascribed to the fact that active storms do not occur throughout these months. That is, the micropulsation trends to occur successively for several days in the quiet period following a storm. As has been already descrived, micropulsations with such short periods



(a)



(b)



(c)

Fig. 51. Sonagrams of distinct pc-1 observed at Memambetsu (upper) and Kanoya (lower). Sonagrams (a), (b) and (c) are representative pc-1 series observed in the daytime, after sunset and before sunrise, respectively. At Memambetsu some weak traces of pc-1 are noticed but no appreciable trace is detected at Kanoya.

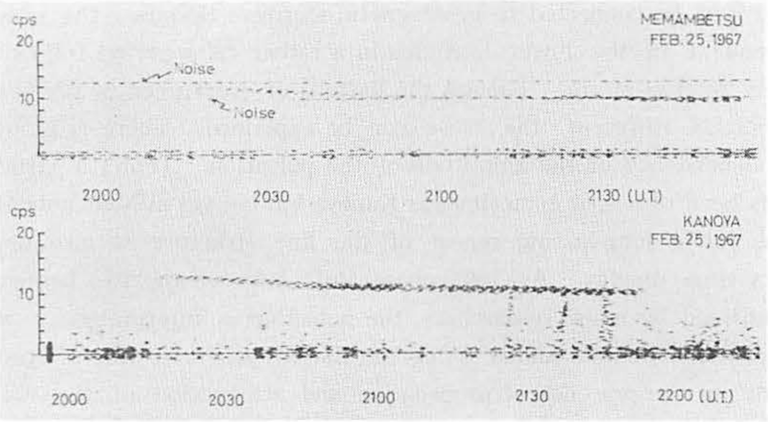


Fig. 52. Sonagrams of clear pc-1 event observed at (a) Memambetsu and (b) Kanoya on February 25, 1967. These sonagrams show typical long-lasting layer structure.

may considerably be subjected to ionospheric screening effect, enough to reveal the characteristic diurnal variation in the occurrence frequency observed on the ground in the lower latitudes. Therefore, it is clear that the sources in the magnetosphere enhanced by a geomagnetic storm are maintained for a fairly long period.

On the other hand, in the active course—the main and last phases—of a storm, irregular but continuous micropulsations with periods of pi-1 range and fairly long duration are enhanced. The micropulsation also shows the same burst-like nature as ordinary pi-1, 2 accompanied by bay disturbance. This micropulsation is perhaps resulted from the penetration of energetic solar wind particles into the magnetosphere. This micropulsation has continuous but spectral characteristics clearly different from that of the structured pc-1 micropulsations.

Concluding Remarks

In the first place, the characteristics of the continuous micropulsations of pc-1 range are statistically investigated. The observational data at two lower latitude stations, Memambetsu and Kanoya, in the IQSY period are used. At least two classes of micropulsations are contained in this range. One is the pearls which show well-known distinctive microstructure. And the other has periods somewhat longer than that of the pearls. The latter is also nocturnal but does not show distinct maxima as the pearls do; its fine structure is not clear.

It seems that the mechanism by which pc-1 micropulsations are triggered or enhanced may be connected to geomagnetic storms. Because, the occurrence is most frequent in the lower latitudes in a rather calm period following a comparatively intense storm. Though the pattern of occurrence in the auroral zone is appreciably different, the cause can be explained. There is an evidence of latitude dependency of the amplitude of the pulsation. Tepley's structure doubling has been observed sometimes at Kanoya but not yet at Memambetsu. Moreover, the fairly long-lasting repeat of the fine structure is also observed on frequency-time display. As 180° phase shift between the two hemispheres has been confirmed by many researchers, the pulsation is interpreted as the hydromagnetic wave packet guided along the Earth's magnetic line of force. These facts indicate the presence of propagation and attenuation of the wave in the ionospheric duct.

Diurnal variations of occurrence frequency and of period as well as seasonal shift of the time of maximum occurrence will be interpreted as the ionospheric screening effect on the pc-1 micropulsation.

Most of long-lasting distinct pearls generally consist of irregular successions or superpositions of several sub-series with durations of a few ten minutes. These sub-series with rather wide bands are likely to show so-called fan-shape structures together with rising tone structures. However, each 'pearl' corresponds very well to the finest structure, 'spot', on the vibragram or sonagram. It seems that the sequence of the spots, or layer structure, is more essential than rising tone structure, because the rising ratio and the mean periodicity is fairly different for each event. These depend on the length of path and mean velocity of hydromagnetic wave.

The 'shorter' repetitive period and 'regular' waveform will suggest that the pulsation is originated in stable inner magnetosphere. It seems that the behavior of the horizontal vector shows that the micropulsation is essentially a hydromagnetic L-wave bouncing between each of the corresponding conjugate pair along geomagnetic field line and propagates through fairly lower atmosphere from the higher (auroral or subauroral) latitudes to the ground in the lower latitudes. The micropulsation is a rather rare event. When the condition is magnetically calm and the station is in the night hemisphere, the micropulsation is observable in the lower latitudes. When, under such conditions, the pulsation is enhanced in the magnetosphere, it will propagate simultaneously over fairly wide areas of the Earth's surface. It is explained, from both the occurrence character in the higher latitudes and the local time dependency due to the ionospheric control in the lower latitudes, that the pearls may occur more frequently in the magnetospheric source region after a geomagnetic storm.

Secondarily, the irregular micropulsation pi-1 (sp) with periods of the same range as pc-1 is investigated. This pulsation occurs mainly under rather disturbed conditions, geomagnetic storm or bay. Particularly in the course of a storm intensely enhanced pulsations are frequently observed. It will be interpreted that the pulsation overlapping on bay is merely a higher frequency component of ordinary pi-1, 2. Its frequency-time display shows clearly well-known trains of noise bursts. So that the diurnal and seasonal variations of the occurrence frequency and other characteristics well coincide with those of pi-1, 2 or pt. Storm-time irregular micropulsations also show similar burst-like nature and broad band spectrum. Their characteristics are, however, somewhat different, in period and duration, from those of bay-time pulsations. The pulsation overlapping on pt shows shorter duration, at most one hour, and a sharp midnight maximum in diurnal variation, while the storm-time micropulsations usually have longer durations continuing for several hours or more. In the former, the higher frequency component is not always detected but the latter is usually characterized by higher frequency component with larger intensity.

It seems that the micropulsations of three different classes are connected, either directly or indirectly, to geomagnetic storms in the lower latitudes. In the most active course of a storm, irregular but continuous micropulsations are observed. It is pointed out by many authors (ex. Saito and Matsushita, 1966) that the continuous daytime micropulsations, pc-2, 3 etc. have a close correlation with a storm. However, they named storm-time pc pulsations with damped-type nature as psc pulsations. Our most interesting pulsation, structured pc-1, is usually observed successively in a rather quiet pericd following an intense geomagnetic storm.

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中低緯度地域における周期1秒付近の短周期地磁気脈動

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中低緯度地域における周期1秒前後の短周期地磁気脈動を連続測定するために，高透磁率コアを用いる誘導型磁場変化測定装置を考案し，それを女満別および鹿屋に，またその解析装置を柿岡に設置し，1964年3月以来，上記周期の地磁気脈動を測定調査している。

本論文では，この測定装置と，主として1964年3月より1966年3月までの約2年間にえられた連続測定資料に基づく中低緯度で観測される周期1秒前後の地磁気脈動の特性に関する統計調査結果について述べ，この脈動の伝播について考察する。

まず第1章では，1秒前後の最も測定困難な周期を有する極微小振幅の地磁気脈動を検出しうるこの測定装置について述べる。中低緯度で高々数十 mγ の微小振幅をもつこの短周期地磁気脈動の検出には，測定装置の内部雑音およびすべての人工的外来雑音を，測定に支障のない量まで低めることが必要である。実際にこの装置では，その綜合雑音量を 2 mγ 以下（実効断面積 10^8cm^2 のループコイルに誘起される周期1秒の起電力に換算して約 0.1 μV 以下）におさえることができた。

第2章では，この装置を用いて，女満別および鹿屋の2点で測定された周期約1秒の規則的連続脈動 pc-1 の出現頻度の日変化について述べ，中低緯度におけるその日変化はその上の電離層の遮蔽効果によって支配されることを示した。

第3章では，この脈動の出現頻度の年変化について述べる。外見上の顕著な変化はその本質ではなく，この脈動は磁気嵐後の静穏期に多く出現する傾向を持つことを示した。

第4章では，この脈動の周期および振幅の特性について述べる。平均周期も出現頻度に良く対比する顕著な日変化を示し，この脈動に及ぼす電離層遮蔽効果によると解釈した。女満別と鹿屋との間で，かなり大きな振巾の相違が認められることは，この脈動の高緯度から中低緯度地上への伝播と，その伝播路における減衰を示している。

第5章では，この脈動の特に顕著なものについて，そのスペクトル微細構造と水平変化ベクトルの振舞いについて調査した結果について述べる。またこの振動の発生域と伝播機構について考察した。

第6章には，pc-1と同じ周期範囲にある不規則脈動に関した同様の統計解析を行なった結果について述べる。この脈動 pi-1 (sp) は，主として磁気嵐または地磁気湾型変化に伴うバースト状不規則脈動 pi-1, 2 (従来の pt) のこの周期帯に属する成分で，その統計的およびスペクトル的特性は pi-1, 2 と良く一致することを示した。

第7章では，これらの脈動はいずれも磁気嵐と密接な関係を持つものであるので，数例の典型的な磁気嵐とそれに続く期間について，磁気嵐の経過とこれら脈動の出現の関係を調査した結果について述べる。

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