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On the Geomagnetic Pulsation Pc (Part II) —Middle- and Low-Latitude Pc 3—

by

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Abstract

Continuous observations of magnetic pulsations with periods from 1 to 100 sec have been carried out by induction magnetometers at the middle- and low-latitude three stations in Japan. The dynamic behaviors and the latitudinal distributions of the pulsation have been investigated by means of both analog and digital dynamic spectrum methods. Some preliminary results about Pc3 pulsations are given.

1. Introduction

The pulsation Pc3 is one of the typical magnetic pulsations observed in middle and low latitudes. Since Stewart (1861) and Terada (1917), the pulsations have been investigated by many research workers (Hatakeyama, 1938; Kato and Watanabe, 1957; Yanagihara, 1960; Kurusu and Yanagihara, 1960; Kawamura et al., 1961; Saito, 1964; Hirasawa, 1966; Saito, et al., 1969; under others). Morphologically, Pc3 is a dayside phenomenon with broad occurrence maximum around noon. The average amplitude of Pc3 is of the order of 0.1 gamma in low geomagnetic latitudes and its amplitude becomes larger with increasing latitude. However, its meridian study which covers from the polar regions to the equator is infrequent and Pc3 observed in high latitudes is not sufficient compared with that in low latitudes. Thus, it is not yet well known whether the low latitude Pc3 has a common source with the higher latitude one or not.

The period of Pc3 shows a dominant daily variation. Its period is longer in the daytime that in the nighttime during sunspot maximum years (the inverted U-type), while it shows reverse tendency during sunspot minimum years (the U-type) (e.g. Saito 1969). Recently the magnetic field fluctuations in the Pc3 period range have also been observed in the magnetosphere (Cummings et al., 1969, 1972). Cummings et al. reported that those fluctuations were usually observed in daytime with a clear occurrence peak between 12h and 15h LT.

Several theoretical models of the Pc3 generation mechanism have been proposed. One of them is the barrier theory, which illustrates that Pc3 pulsations are excited as hydromagnetic oscillations in the layer between the maximum Alfvén phase velocity region and the ionosphere (Watanabe, 1959). Li, Prince et al. (1964) calculated the power spectra of the earth's magnetic field fluctuations basing on the assumption that the lower exosphere and the ionosphere play the role of a sort of filter for hydromagnetic waves. They have shown that the hydromagnetic waves in the Pc3 frequency range are effectively transmitted from the exosphere toward the earth. Recent model of the Pc3 excitation is the standing Alfvén oscillations of a local field line excited by the Kelvin-Helmhortz instability on the magnetopause (Hasegawa et al., 1974; Southwood, 1975). This model seems to be favorable at least for the Pc3 observed near the plasmapause (Fukunish et al., 1974 a.b.).

Though Pc3 is observed very frequently in middle and low latitudes, no satisfactory theory about low-latitude Pc3 generation mechanism has been proposed. In the present paper the dynamic behavior of the low-latitude Pc3 is analyzed in comparison with the results derived from the previous investigations.

2. Experiment and Data Analysis

Magnetic pulsations (ULF) have been observed continuously by means of induction magnetometers at middle- and low-latitude Japanese stations: Memambetsu, Kanoya and Chichijima. The locations and the geographic and geomagnetic coordinates of these stations are shown in Fig. 1 and Table 1, respectively. It should be noted that Memambetsu and Chichijima are located on almost the same geomagnetic

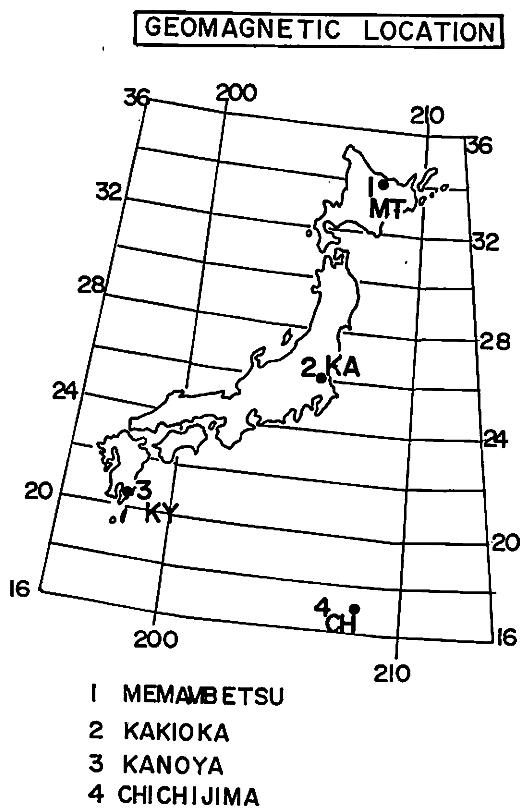

Fig. 1. Geomagnetic location of the stations which are used in this paper.

Table 1 Recording station locations.

Station	Geographic latitude	Geographic longitude	Geomagnetic latitude	Geomagnetic longitude
Memambetsu	43°55′N	144°12′E	34.0°	208.4°
Kakioka	36°14′N	140°11′E	26.0°	206.0°
Kanoya	31°25′N	130°53′E	20.5°	198.1°
Chichijima	27°05′N	142°11′E	17.1°	208.9°

meridian (~208°).

Block diagrams of ULF observing systems are illustrated in Fig. 2(A). Main part of the system consists of sensors, filters, d.c. amplifiers and a data recorder. As shown in Fig. 2(A), the observing system at Chichijima is somewhat different from

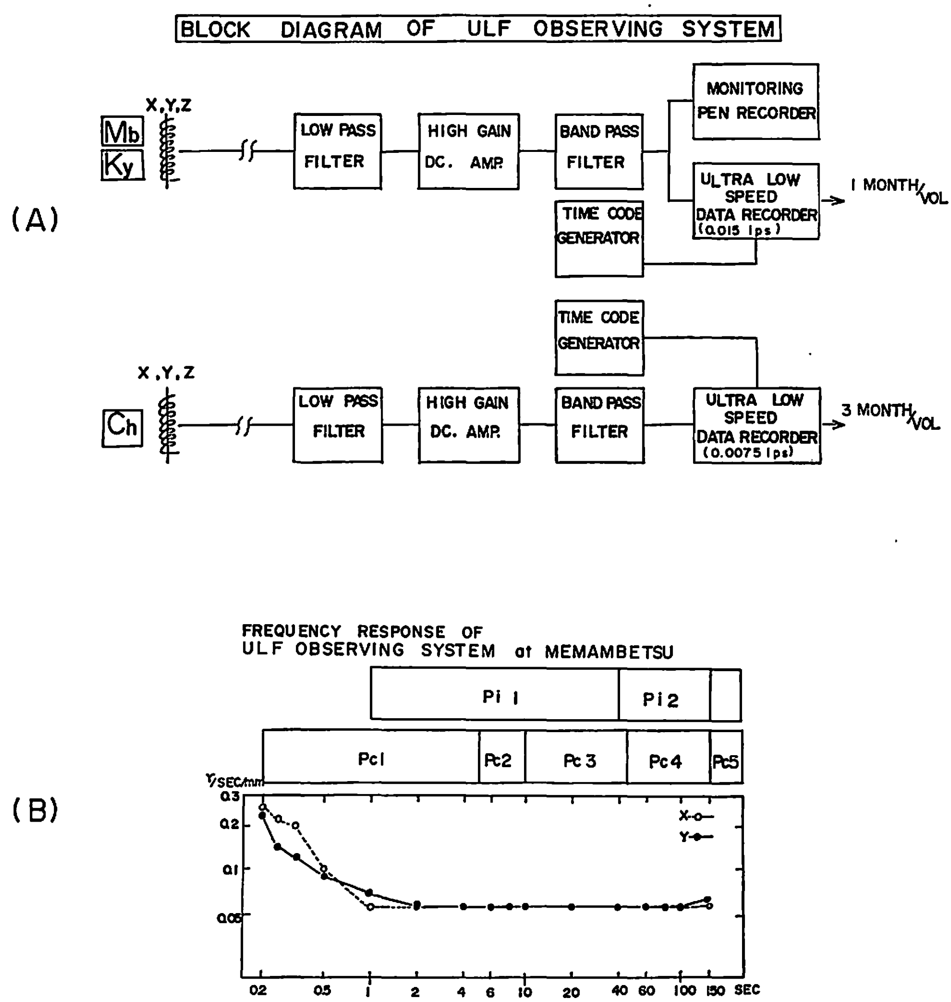

Fig. 2. (A) Block diagrams of the ULF observing system.
(B) Sensitivities of the ULF observing system at Memambetsu.

those at the other two stations. At Memambetsu and Kanoya additional pen recorders are installed for the international cooperative quick report of geomagnetic pulsations. X, Y and Z components of the pulsations are detected by three orthogonal sensors which consist of solenoidal coils and high μ metal cores. Undesirable 50 Hz (or 60 Hz) noise and its higher harmonics caused by the commercial power lines are eliminated from the sensor output by means of an input low-pass filter. The filtered signals are amplified to a sufficiently high voltage for the data recorder. The amplifier in use is Model 147 null detector manufactured by the Keithley Instruments Corporation. It is a chopper type low-noise high-gain d.c. amplifier. Passing through an active band-pass filter, the amplified signals are recorded on magnetic tape by the data recorder.

The data recorder is an ultra-low speed FM analog tape-recorder designed by the TEAC Corporation. The recording speeds are 0.015 ips at Memambetsu and Kanoya, and 0.0075 ips at Chichijima. The recorder has seven channels and three of them are used for three orthogonal components of the pulsations. Besides this, TTL BCD time code from a time code generator is simultaneously recorded on a remaining channel of the same recorder to identify each observing time (hour and day). The frequency response curves of X and Y components at Memambetsu are illustrated in Fig. 2(B). Similar response curves have also been obtained at Kanoya and Chichijima. For detailed descriptions on these equipment, refer to Kawamura et al. (1976).

The pulsations recorded on magnetic tape at each station are analyzed at Kakioka. The ULF analyzing system at Kakioka is illustrated in Fig. 3. The system consists of a tape reproducer and two analyzing apparatuses, one is a sonagraph for analog data and the other is a minicomputer with accessories for digital data. As a reproducer, Model R-510 FM data recorder manufactured by the TEAC Corporation is used. Selectable reproducing speeds are the following six: 1.875, 3.75, 7.5, 15.0, 30.0 and 60.0 ips. Step up of the original frequency can easily be carried out by simply choosing an appropriate speed. Maximum step up ratios are 8000 and 4000

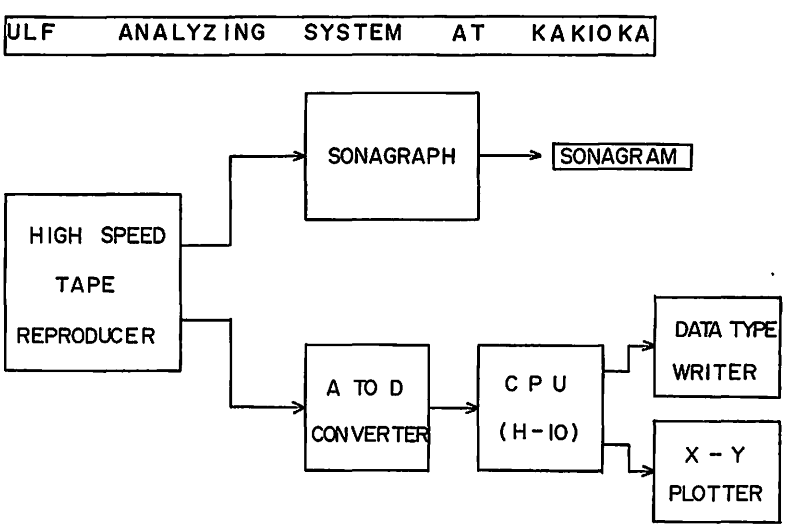

Fig. 3. ULF analyzing system at Kakioka.

for Chichijima and for the other two stations, respectively.

The sonagraph is Model SG-07S manufactured by the Rion Corporation. It has the following three full scale frequency ranges; 30-2500 Hz, 85-8000 Hz and 250-24000 Hz. The minicomputer is HITAC 10 whose core memory is 8K words. Sonagraph methods have successfully been applied to the ULF spectrum analyses by several research workers (Saito, 1960; Hirasawa et al., 1966; Saito, 1967; Kawamura, 1970). The results of such spectrum analyses have shown clear physical structures of the magnetic pulsation.

Digital dynamic spectra of some typical events are also computed by use of a fast Fourier transform algorithm (FFT). In this method, analog data are converted into digital ones at 1.5 sec intervals and then punched on paper tapes in a computer compatible format. Next' the digital data are weighted by the Gaussian window function and the Fourier coefficients of the time series are computed.

Fig. 4(A) shows a test signal which consists of five sine waves, whose amplitudes and periods are different from each other. The test signal X(t) is given by the following equation and shown in Fig. 4 (A). $X(t)=10.0\sin(2\pi/150\cdot t)+5.0\sin(2\pi/105\cdot t)+17.7\sin(2\pi/75\cdot t)+2.0\sin(2\pi/50\cdot t)+20.0\sin(2\pi/35\cdot t)$.

Its autopower spectrum computed by means of the FFT method is shown in Fig. 4(B). In the figure the abscissa and the ordinate represent frequency (mHz) and power (γ^2/Hz), respectively. The spectrum shows clearly the original five components, and their spectral powers are proportional to the original ones. Our simple preliminary test suggests that the FFT method is satisfactory for the spectrum analysis of continuous wave trains like Pc3.

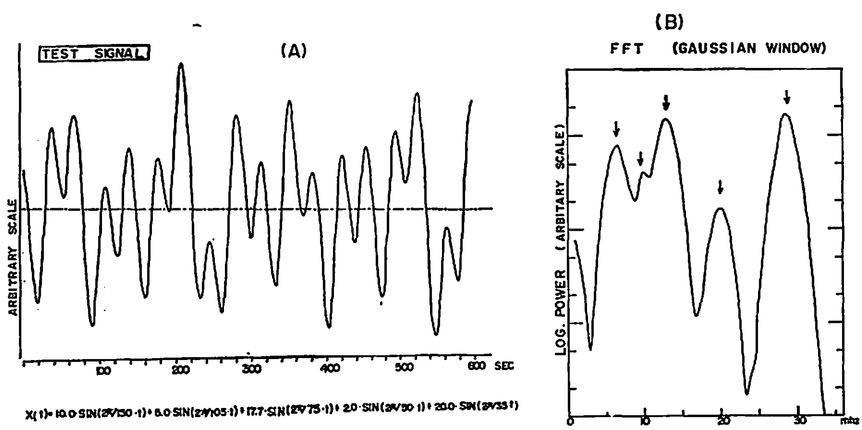

Fig. 4. (A) Traces of the signal made for a test of the FFT method.
(B) The digital power spectra of the test signal.

3. Results of Investigation

Various types of Pc3 pulsations are simultaneously observed at our three stations. In order to make clear the dynamic behaviors of the pulsations and temporal changes in their latitudinal distributions, corresponding sonagrams at the three stations have been investigated. A number of days on which Pc3 was most active in the period from April 1975 to May 1976 are selected for the present analysis.

Fig. 5 shows an example of sonagrams of Pc3 pulsations observed simultaneously at three stations on February 3, 1976. As shown in these sonagrams, there are some sharp spectral bands of period between 20 and 40 sec almost throughout the day. At Memambetsu a relatively narrow band with almost constant period of about 20 sec appears around 03h. Moreover another band of about 40 sec occurs around 05h and then these two bands change into a rather broad band at about 09h. Similar temporal variation of the spectral band in the same time interval may also be seen at the other two stations. It is suggested that the Pc3 may frequently consist of several period bands. Such a tendency has also been pointed out by Saito et al. (1969). At Memambetsu a relatively broad spectral band appears distinctly around 13h, while it is not clear at Chichijima. Though it is difficult at the present stage to discuss in more detail why this band is clear only at Memambetsu, such an interesting latitudinal dependence will be worthy of notice for the study on the physical state of the ionosphere or the lower plasmasphere.

Fig. 6 shows another example of Pc3 pulsations observed simultaneously on May 3, 1976 at the three stations. In this case a narrow band with period of about 40 sec appears around 04h and then this band is rapidly activated around 05h. At Memambetsu, two spectral bands are clearly found. The center periods are about 10 sec and 20 sec, respectively. The presence of pulsations with shorter periods at Kanoya is doubtful and they are not observed at Chichijima. On the other hand, the longer period one is also clear at the other two lower-latitude stations.

Such a tendency is illustrated again in the next example. Fig. 7 shows very intense Pc3 pulsations observed simultaneously on February 18, 1976, at both Memambetsu and Chichijima. In this case the event appears around 05h and then

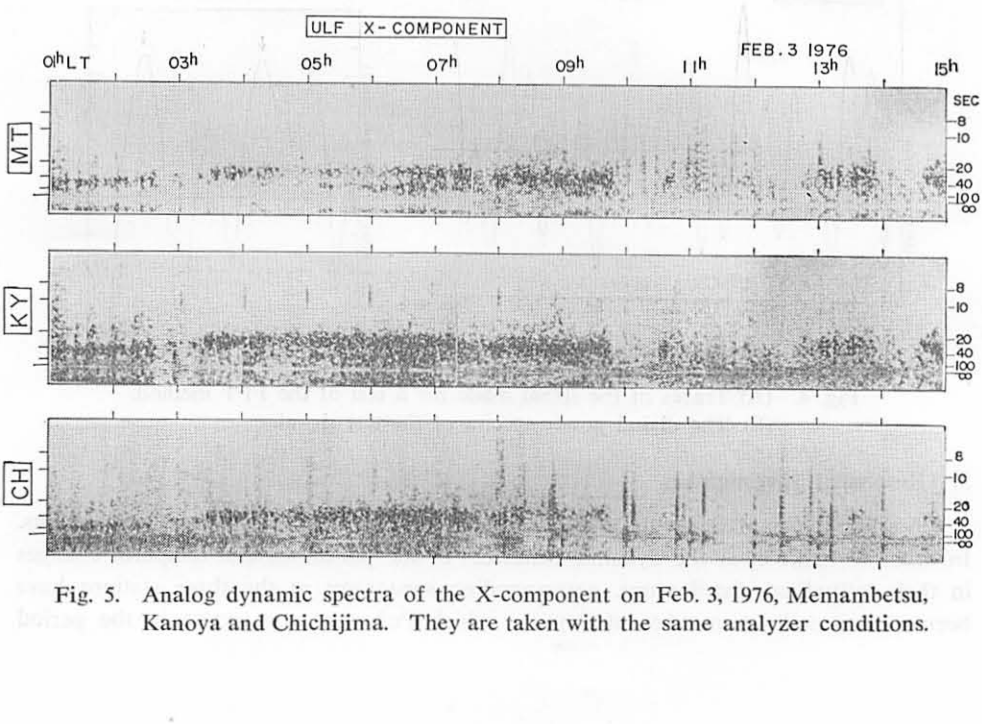

Fig. 5. Analog dynamic spectra of the X-component on Feb. 3, 1976, Memambetsu, Kanoya and Chichijima. They are taken with the same analyzer conditions.

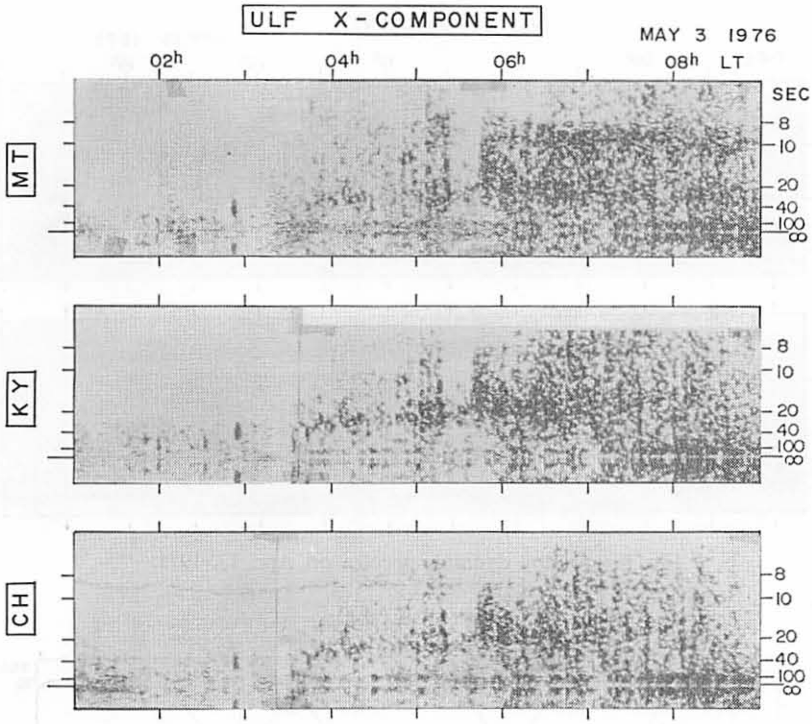

Fig. 6. Analog dynamic spectra on May 3, 1976.

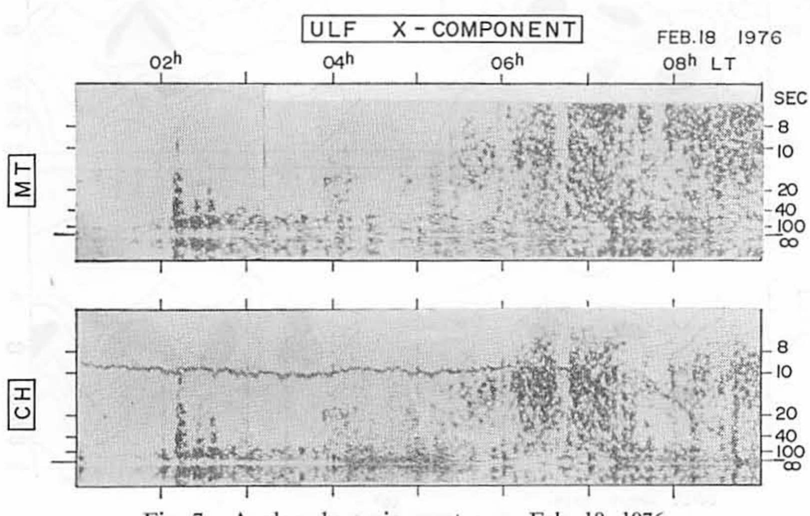

Fig. 7. Analog dynamic spectra on Feb. 18, 1976.

increases its intensity rapidly. However, it seems that their spectral behavior differs between these two stations. Concerning the Pc3 during from 06h to 08h, the shorter period band of about 8 sec is dominant at Memambetsu, while the longer period one

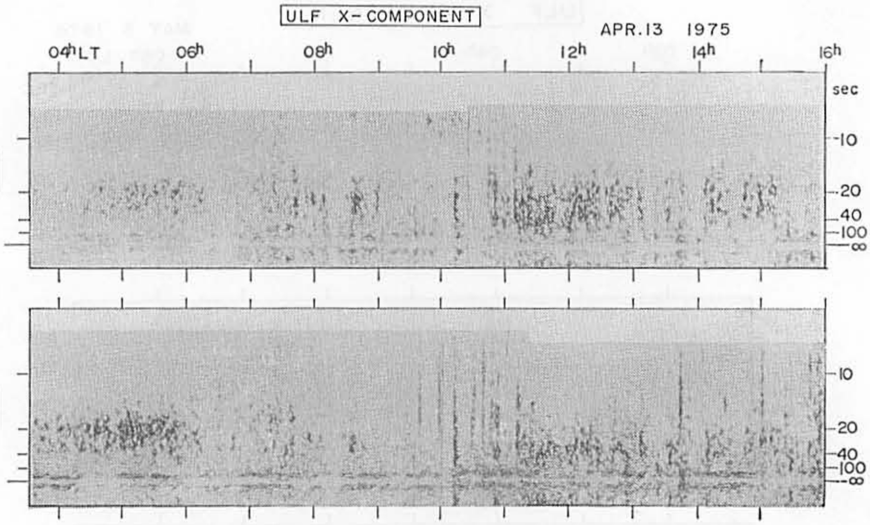

Fig. 8. Analog dynamic spectra on Apr. 13, 1975.

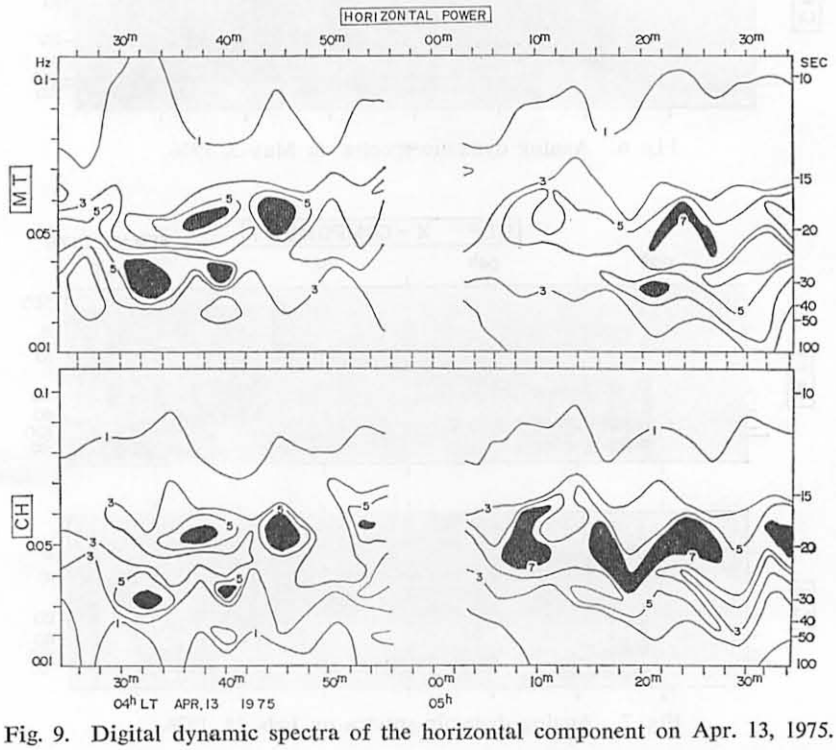

Fig. 9. Digital dynamic spectra of the horizontal component on Apr. 13, 1975.

with 10-20 sec is more clear at Chichijima. An interesting result will be derived from the above events shown in Fig. 6 and Fig. 7. That is, there is a Pc3 whose source exists at rather lower latitudes. Fig. 8 shows two remarkable Pc3 events observed simultaneously at Memambetsu and Chichijima on April 13, 1975. The activity of an event during from 11h to 15h is higher at Memambetsu, while another event with period of about 20 sec in the interval from 04h to 06h is distinctly predominant at a lower-latitude station, Chichijima. The fact shows that the source is at least nearer to Chichijima than to Memambetsu. Thus the existence of the low latitude origin Pc3 is strongly suggested.

Quantitative analysis using much digital data is desirable in order to ascertain the above-mentioned interesting facts more completely. For this purpose, a digital spectrum method is used in addition to the sonagraph one. As mentioned in the previous section, this digital method is sufficiently reliable and effective to investigate a possibility of the low latitude origin Pc3. Digital dynamic spectra at both Memambetsu and Chichijima are computed for the Pc3 event during from 04h to 06h LT on Apr. 13, 1975 shown in Fig. 8. Fig. 9 shows the spectra in the interval from 05h 02m to 05h 32m LT. The spectra in 6.6-minute intervals are continuously computed every 2.6-minute by sliding the time interval. The analyzing frequency range is 0.01-0.1 Hz (T=100-10 sec).

In Fig. 9 the spectra for the horizontal component are computed. One of the interesting results in Fig. 9 is that in this interval the Pc3 pulsations with period of about 20 sec are more predominant at the lower-latitude station. The Pc3 in Fig. 9 has several spectral bands and the temporal variations of these bands are, in general,

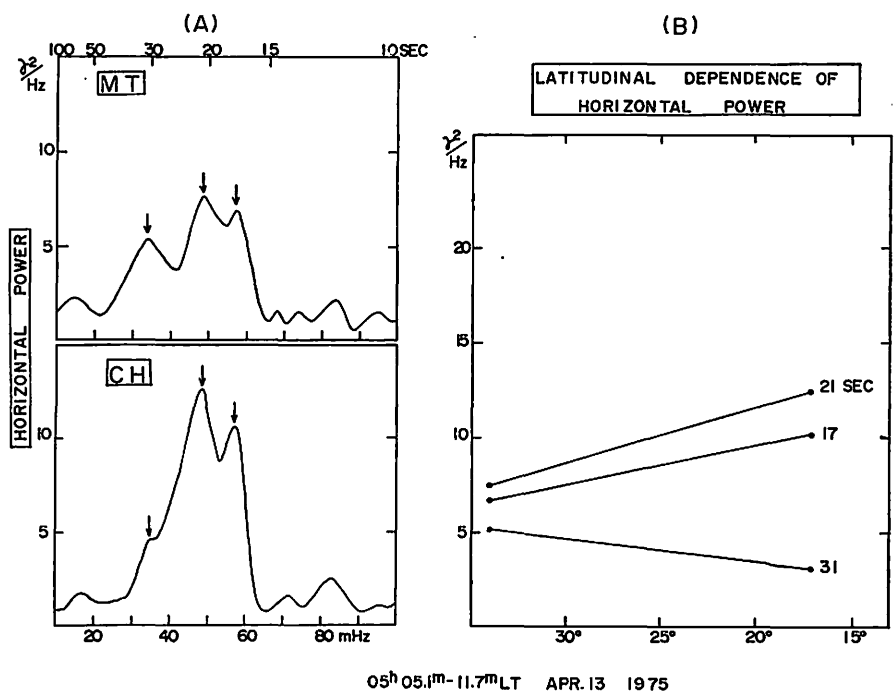

Fig. 10. (A) Horizontal power spectra in the interval 05 h 05.1 m–11.7 m LT on Apr. 13, 1975.
(B) Latitudinal dependence of the spectral peak amplitudes.

similar at the two stations. The individual power spectra in the interval from 05h 05.1m to 11.7m are illustrated in Fig. 10(A). At both stations three peaks are found at about 31, 21 and 17 sec, respectively. As shown in Fig. 10(B) the 31-sec spectral band is more predominant at Memambetsu, while the other two bands are more intense at Chichijima than at Memambetsu. At the present stage, it is difficult to discuss the origin of the low latitude Pc3 in a statistical context. However, it should at least be deduced from the above results that the source of several Pc3's discussed in this section exists at low latitude.

4. Summary

Analog and digital dynamic spectrum analyses of the ULF at the three middle- and low-latitude stations in Japan are carried out and the following interesting results are obtained:

(1) The power spectrum in the Pc3 period range has usually several dominant peaks.

(2) The spectral powers of the above peaks frequently show some different latitudinal dependence by the period.

(3) For several Pc3 events with the period of about 20 sec, their intensities are at least larger at Chichijima ($L=1.09$) than at Memambetsu ($L=1.45$).

Although we cannot sufficiently confirm whether the interesting features of the above-mentioned band have a significant physical meaning or not, it seems that there is a possibility of such a low latitude origin Pc3. These problems will statistically be investigated as well as by case studies by the authors in near future.

In the future investigation, some other stations in higher latitudes and the equatorial region should also be taken into account, if available, for more sufficient illustration of the latitudinal dependence of the spectral powers. The Pc3 phase differences among the stations shall also be analyzed both individually and statistically. It is well known that ground conductivity anomalies (e.g., Price, 1968) and the proximity of a station to the seacoast affect the observed characteristics of the ULF in some way. We shall attempt to investigate the behaviors of the disturbing vectors in relation to the process of the earth's induction.

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Pc 型地磁気脈動(第二報)

— 中低緯度 Pc 3 —

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概　　要

中低緯度の3観測点において誘導磁力計による地磁気脈動（周期1秒～100秒）の連続観測が実施された。その資料について，スペクトル解析を行い，スペクトルの時間変化及び緯度効果が吟味された。本文においては Pc 3 型脈動についての前期的な解析結果を報告する。