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# On the Geomagnetic Pulsation Pc (Part III)
# —Spectral and Polarization Characteristics of Middle- and Low-Latitude Pc 3—

by

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**Abstract**

Continuous observations of geomagnetic pulsations with periods from 1 to 100 sec have been carried out by induction magnetometers at the middle- and low-latitude stations in Japan. Some spectral and polarization characteristics of pc 3 pulsations are mainly investigated by means of both analog- and digital-dynamic spectrum methods. In the present paper, solar-cycle variations and seasonal changes of occurrence frequency and mean period of pc 3 are shown with relation to solar and geomagnetic activities on a statistical basis. Particularly, latitudinal dependencies of both horizontal powers and polarizations of pc 3 are described in more detail as an extensive study in some special intervals.

## 1. Introduction

The geomagnetic pulsation pc 3 is one of the most characteristic 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, 1927; Yanagihara, 1960; Kurusu and Yanagihara, 1961; Kawamura et al., 1961; Saito, 1964; Hirasawa and Nagata, 1966; Sakurai et al., 1969; Kawamura and Kuwashima, 1977 and others). Pulsation pc 3 is a typical dayside phenomenon with a broad occurrence maximum around noon. It usually has an average amplitude of the order of 0.1 nT in lower 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 pc 3 observed in high latitudes is not sufficiently compared with that in low latitudes. Thus, it is not yet known for certain whether the low latitude pc 3 has a common source with the high latitude one or not.

The mean period of pc 3 shows a dominant daily variation. It is longer in the daytime than in the nighttime during sunspot maximum years (the inverted U-type), while it shows a reverse tendency during sunspot minimum years (the U-type) (e.g. Saito, 1969). The magnetic field fluctuations in the pc 3 period range have also been observed in the magnetosphere (Cummings et al., 1969, 1972). They reported that the field fluctuations were usually observed in the daytime with a clear occurrence peak between 12h and 15h LT.

Several theoretical models of the pc 3 generation mechanism have been proposed. One of them is the barrier theory which states that pc 3 are exited as hydromagnetic oscillations in the layer between the maximum Alfvén phase velocity region and the ionosphere (Watanabe, 1959). Prince and Bostick (1964) calculated the power spectra of the earth's magnetic field fluctuations 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 waves in the pc 3 frequency range are effectively transmitted from the exosphere toward the earth. A recent model of the pc 3 excitation is the standing Alfvén oscillations of a local field line excited by the Kelvin-Helmholtz instability on the magnetopause (Hasegawa and Chen, 1974; Southwood, 1975). This model seems to be favorable at least for the pc 3 observed near the plasmapause (Fukunishi and Lanzerotti, 1974a, b).

Though pc 3 is observed very frequently in middle and low latitudes, no satisfactory theory about the low-latitude pc 3 generation mechanism has been proposed. In the present paper, its spectral and polarization characteristic are investigated.

## 2. Observation and instrumentation

Since the IGY, geomagnetic pulsations with periods from about 10 sec to several minutes have been observed continuously at our two magnetic observatories, Memembetsu (MMB) and Kanoya (KNY). Early instruments at these observatories were classical-type induction magnetographs which consisted of air-cored loops, galvanometers, and rapid-run photographic recorders (Yoshimatsu, 1960). In the IQSY

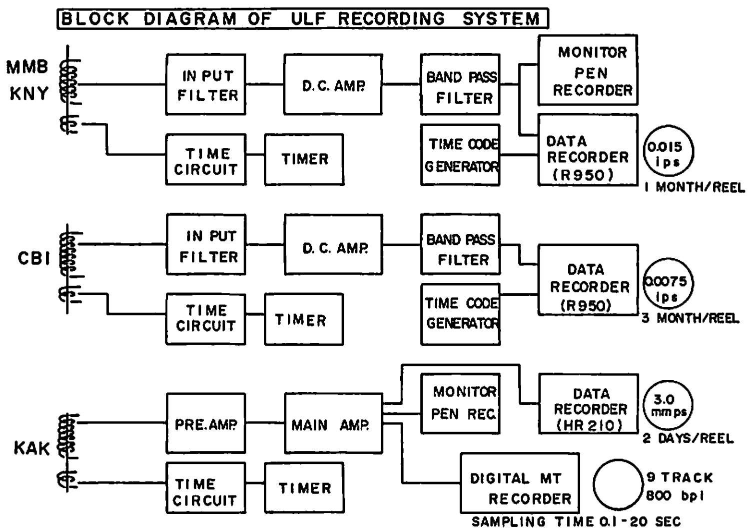


Fig. 1. Block diagram of pulsation observing systems at four observatories, Memambetsu, Kanoya, Chichijima and Kakioka.

period, specially designed induction magnetometers were added to the above magnetographs at these observatories in order to observe pulsations with shorter periods than about 10 sec (Kawamura and Kashiwabara, 1965; Kawamura, 1970). These two types of observing systems have recently been replaced with the present induction magnetometers (Kawamura, 1976a; Kawamura, 1977a). Since 1974, the same new-type magnetometers have also been installed at Chichijima (CBI) station. Block diagrams of these observing systems are illustrated in Fig. 1. Main part of the system consists of three orthogonal parmalloy-cored sensors, filters, chopper amplifiers and an F-M data recorder. As shown in this figure, the system at Chichijima station, which is unmanned,

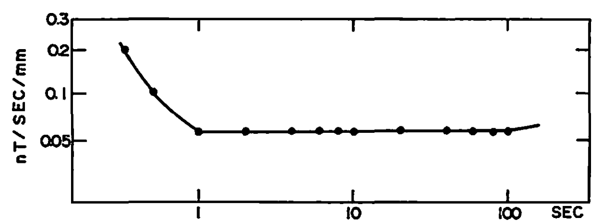


Fig. 2. Overall frequency response curves of the system at Memambetsu.

Table 1. Geographic and geomagnetic coordinates of observatories

| Station | Geographic | | Geomagnetic | |
|---|---|---|---|---|
| | Latitude | Longitude | Latitude | 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 |

is somewhat simplified, compared with those at the other two observatories. There is no monitoring pen recorder at Chichijima. Data recorder at Chichijima is driven at half tape speed of those at Memambetsu and Kanoya. Details of the systems were shown in the previous paper (Kawamura and Kuwashima, 1977). Here only the overall response curves of the system at Memambetsu are given as an example in Fig. 2. It is clear that the sensitivities are sufficiently flat in period range from 1 to 100 sec. Since the IMS, similar observation has been carried out at Kakioka with a more compact instrument of almost the same response character.

Geographical and geomagnetic coordinates of these four observatories, Memambetsu, Kakioka (KAK), Chichijima and Kanoya are shown in Table 1 and Fig. 3. These observatories form a meridian station chain in lower latitudes. Above all, it should be noticed that Memambetsu and Chichijima are located on almost the same geomagnetic meridian (about 208).

The pulsations recorded on magnetic tape by the data-recorder at each observatory are reproduced and analyzed at Kakioka. The block diagram of the analyzing system at

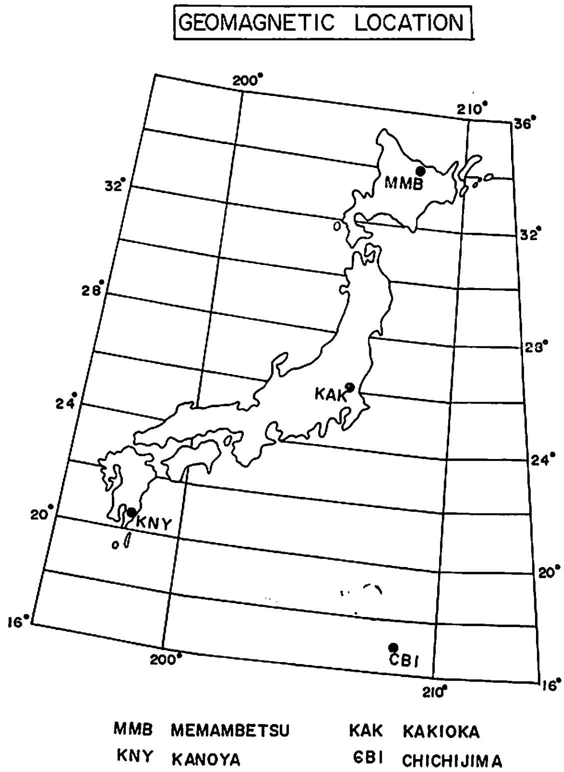


Fig. 3. Locations of the four observatories forming a Japanese station chain.

Kakioka is shown in Fig. 4. Details of the tape-reproducer have already been described in the previous paper (Kawamura and Kuwashima, 1977). As the spectral analyzer, SD-360 Digital Signal Processor with a hard-copy recorder manufactured by the Spectral Dynamic Corporation has been used. The analyzer executes spectrum analysis by the Fast Fourier Transform (FFT) method. A dozen data analysis functions which consist of autopower spectrum, crosspower spectrum, transfer function, coherency function, correlation function and others can be selected. As the sampling ratio is in the range from 50 sec to 3.26 microsec, any signal with frequencies from 0.01 Hz to 150 kHz can be analyzed effectively. Two step-up ratios of 4,000 and 500 are ordinarily used in the present analyses. Direct recording of dynamic spectrum by the hard-copy recorder is carried out with the former higher reproducing speed. On the other hand, the latter, lower speed is applied in cases of analog display on an X-Y recorder of power ratio between two observatories and digital display of frequency and amplitude of each spectral peak calculated by the analyzer. Details of the functions and practical behavior of the analyzer have been described by the present authors (e.g. Kawamura,

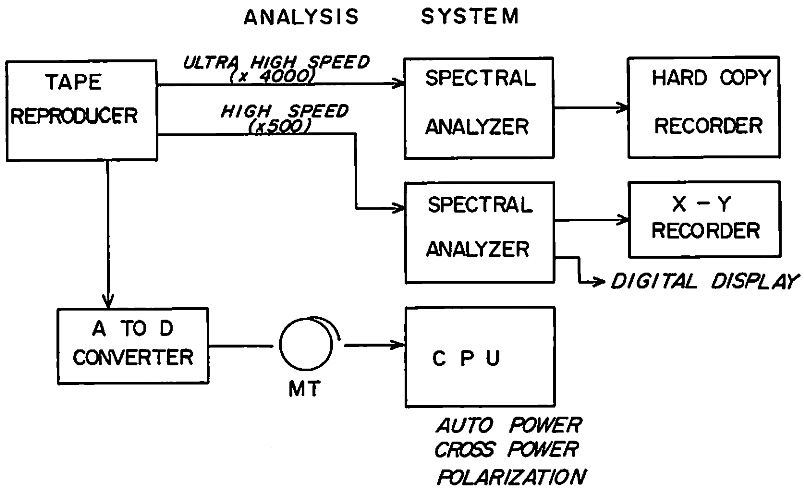


Fig. 4. Block diagram of pulsation analyzing system installed at the Kakioka Magnetic Observatory. But analysis of the polarization characteristics was carried out by a computer system of the National Institute of Polar Research.

1977b). We were fortunately permitted to use the specially designed spectral analysis system for our polarization analysis and others by courtesy of the National Institute of Polar Research. Description of the system has been given by Iwabuchi et al. (1978).

## 3. Solar-cycle variations of occurrence frequency and mean period of pc 3

Since the IGY, time of occurrence, maximum amplitude and mean period for each special interval with quality of A or B (Romañá, 1960) of pulsations recorded on rapid-run induction magnetograms at our observatories have been hand-scaled and reported in successive issues of our year book "Report of the Geomagnetic and Geoelectric Observations (Rapid Variations)". Yearly mean period of regular continuous pulsation pc with period from about 10 to several tens sec (pc 3 in the present criterion) reported in the year books for the period from 1957 to 1967 at Memambetsu is shown in Fig. 5, together with yearly means of both $\Sigma$Kp and Zürich Wolf sunspot number. It seems in this figure that the mean period corresponds well to the $\Sigma$Kp and/or the sunspot number. However, it is well known that there is generally a time lag between solar and geomagnetic activities. Although the sunspot maximum year during these eleven years was the year 1957, the shortest annual mean period was observed in 1960 coinciding with the peak of $\Sigma$Kp rather than the sunspot maximum. The diurnal variation of occurrence frequency of pulsation is given in Fig. 6 for each season of the same interval. There is a distinct occurrence peak just before noon but the seasonal change of the maximum hours is not so clear. In Fig. 7, occurrence frequency

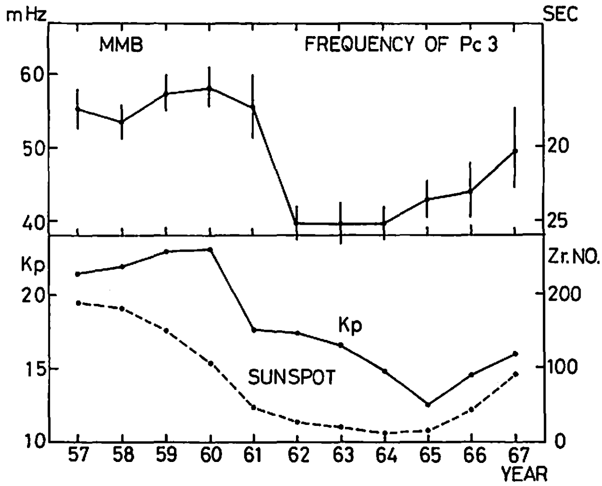


Fig. 5. Relation between long-term variation of pc-3 period and those of both $\sum$Kp and Rz (Zürich Wolf sunspot number).

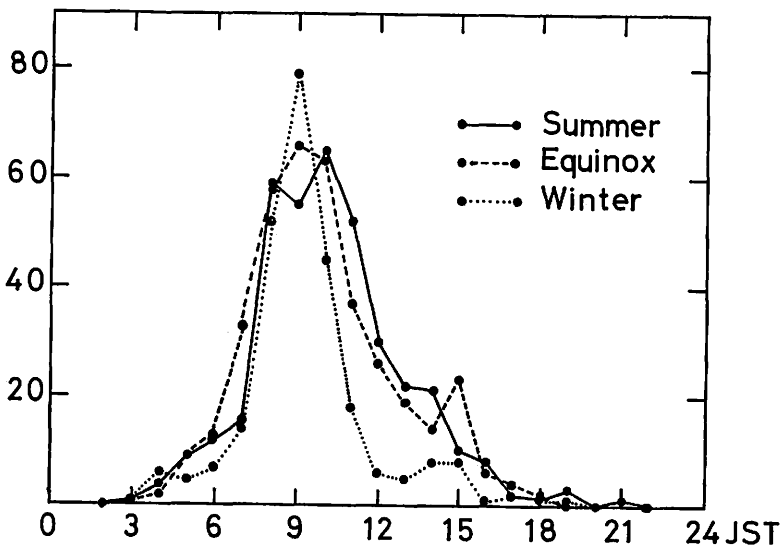


Fig. 6. Diurnal variation of pc-3 occurrence frequency for each season at Memambetsu.

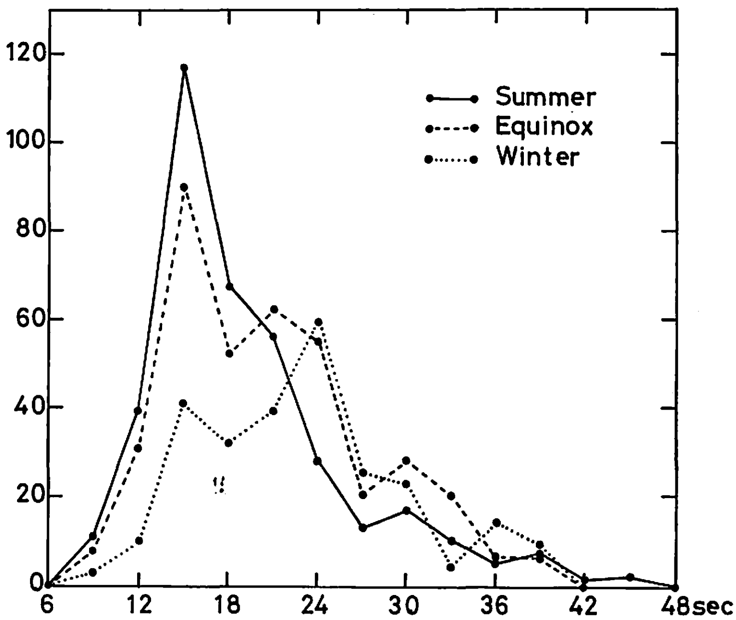


Fig. 7. Distribution of occurrence frequency of pc-3 by its period for each season at Memambetsu.

distribution to period of the pulsation observed at Memambetsu is given for each season in this interval. Namely, the number of pulsation with periods which are in each 3 sec range centered at each value scaled on abscissa is shown as the occurrence frequency. It will be seen that the mean period of pc 3 shifts to shorter side in summer and at equinox than in winter. Dividing these eleven years into two phases of maximum (1957-1961) and minimum (1962-1967) based upon those annual mean sunspot numbers, the above diurnal variation of occurrence frequency and the seasonal shift of the mean period were investigated somewhat in detail. Such diurnal variations of occurrence frequency of pc 3 are shown in Figs. 8a and 8b. It seems that the more the sunspot number is, the more frequent the occurrence becomes. But there is no clear difference of maximum occurrence hours between the maximum and minimum phases. It will be seen in Figs. 9a and 9b that pc 3 periods observed in the maximum phase is in a shorter period range than in the minimum phase. The seasonal shift of the mean period is observed only in the maximum phase. Diurnal variations of the pulsation period for each season in both sunspot maximum and minimum phases are illustrated in Figs. 10a and 10b, respectively. It is also clear in these figures that the daily mean period in the sunspot maximum phase is shorter than that in the minimum phase. In the maximum phase, the diurnal variation in summer shows clear "inverted U-type". But this is not so clear in the other seasons of that phase. It seems that the variation in winter shows rather "U-type". As shown in Fig. 10b

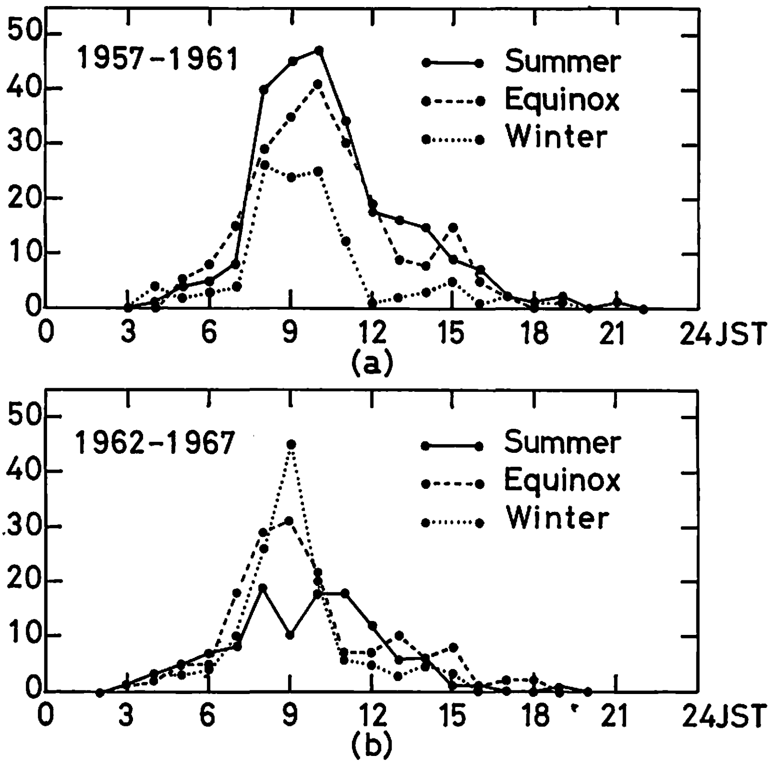


Fig. 8. (a) Diurnal variation of pc-3 occurrence frequency in sunspot maximum phase (1957–1961) for each season at Memambetsu.

(b) Similar variation in sunspot minimum phase (1962–1967).

the occurrence of distinct pc 3 in the afternoon hours was infrequent in this sunspot minimum phase and the diurnal variation in the morning hours showed rather "U-type" characteristics.

The seasonal changes of occurrence frequency and the mean period of the pulsations as well as that of mean $\Sigma Kp$ are summarized in Figs. 11a, 11b and 11c and Table 2. In these figures, full, dotted and broken lines show seasonal changes of occurrence frequency, mean period and mean $\Sigma Kp$, respectively. Figs. 11a, 11b and 11c illustrate the seasonal changes for the two phases, sunspot maximum (1957-1961) and minimum (1962-1967), and the whole period (1957-1967), respectively. Mean $\Sigma Kp$ in variably has its clear maximum at equinox. In the minimum phase, there is no

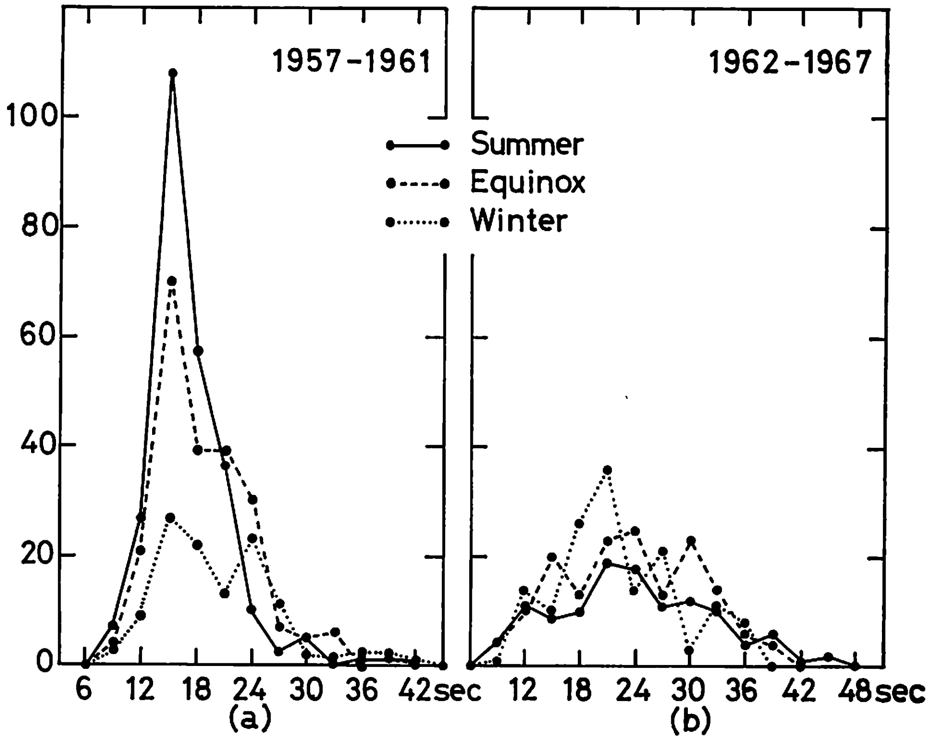


Fig. 9. (a) Distribution of occurrence frequency of pc-3 by its period for each season at Memambetsu in sunspot maximum phase.
(b) Similar distribution in sunspot minimum phase.

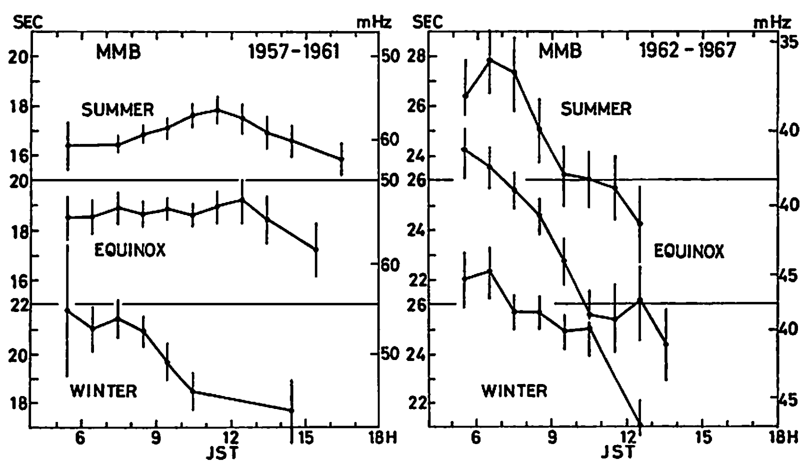


Fig. 10. (a) Daily variation of pc-3 period for each season at Memambetsu in sunspot maximum phase.
(b) Similar variation in sunspot minimum phase.

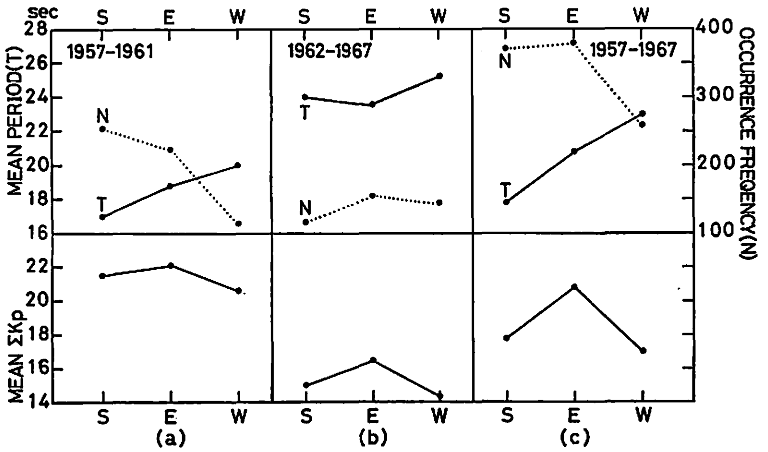


Fig. 11. (a) Seasonal changes of occurrence frequency and period of pc-3 as well as that of mean $\Sigma$Kp at Memambetsu in sunspot maximum phase.
(b) Similar changes in sunspot minimum phase.
(c) Similar changes in the whole interval (1957–1967).

Table 2. Seasonal changes of occurrence frequency, mean period and mean $\Sigma$Kp for each season

| Phase | Season | Occurrence frequency | Mean period (sec) | Mean $\Sigma$Kp |
|---|---|---|---|---|
| Maximum phase | Summer | 255 | 16.98 | 21.56 |
| (1957-1961) | Equinox | 223 | 18.81 | 22.11 |
| | Winter | 115 | 20.03 | 20.62 |
| Minimum phase | Summer | 117 | 24.03 | 15.02 |
| (1962-1967) | Equinox | 155 | 23.54 | 16.45 |
| | Winter | 144 | 25.19 | 14.35 |
| Full interval | Summer | 372 | 19.22 | 17.87 |
| (1957-1967) | Equinox | 378 | 20.75 | 18.88 |
| | Winter | 259 | 22.90 | 17.03 |

seasonal change of the occurrence frequency of distinct pc 3 but the change of mean period corresponds to that of mean $\Sigma$Kp. On the other hand, in the maximum phase the occurrence frequency in summer and at equinox is higher than that in winter. Moreover, the mean period has its minimum in summer so that its seasonal change does not correspond to that of $\Sigma$Kp. The mean period of distinct pc 3 shows a Kp-dependency but it will be pointed out that there is a seasonal change due to some other causes.

## 4. Geomagnetic activity dependencies of pc 3 occurrence

Occurrence frequency of pc 3 observed at Memambetsu in the period from January, 1976 to May, 1978 was hand-scaled from its continuous dynamic spectrum written

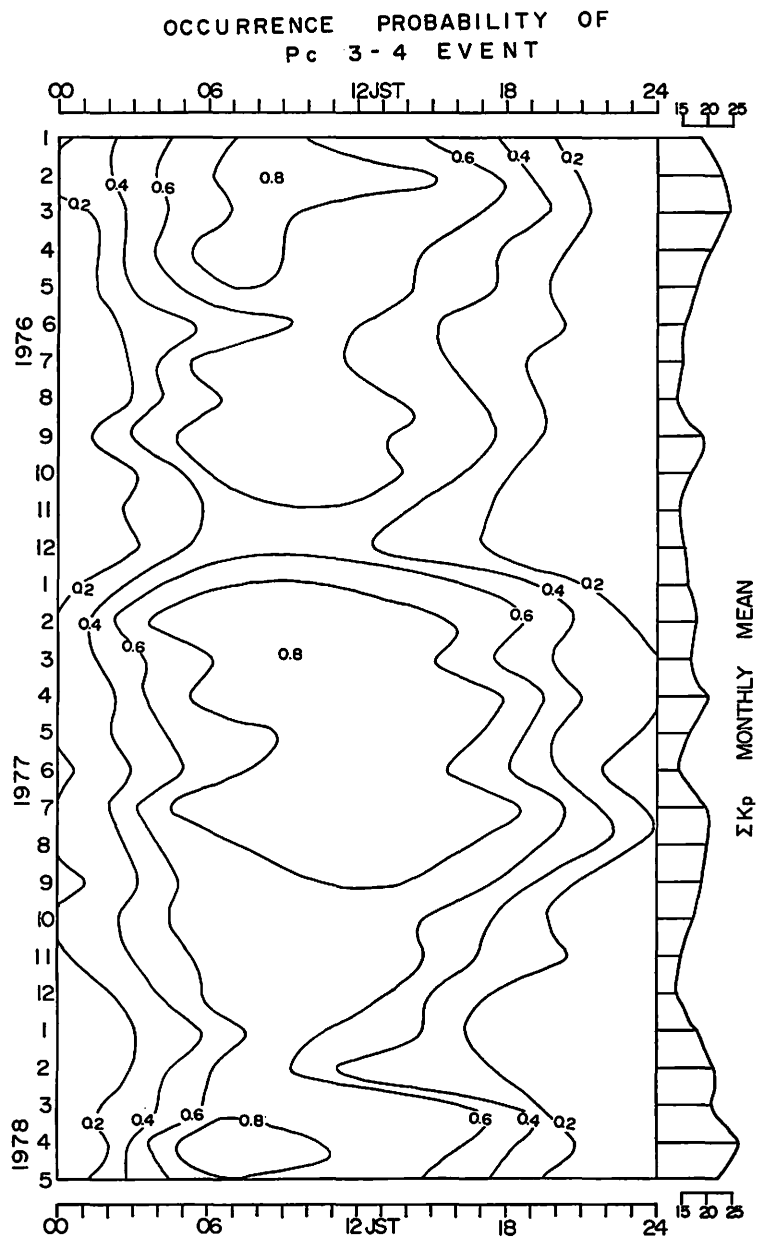


Fig. 12. Contour map showing the monthly ratio of pc-3 occurrences in each hour of the day from January, 1976 to May, 1978 at Memambetsu. Right-hand side diagram of the map shows $\Sigma$Kp monthly mean.

by the hard-copy recorder. The number of one hour interval in which the pulsation pc 3 with longer duration than 30 min. is observed at least in three 10-minute ranges is counted first. A contour map which shows the rate of the number to the total number of days for each month is given in Fig. 12 together with monthly mean $\Sigma$Kp values.

The occurrence frequency of pc 3 has its maximum at equinox. However, in 1977 such a maximum occurs rather in summer (July to August) than at autumn equinox. This corresponds well to the fact that the geomagnetic activity in that year was lower at autumn equinox than in summer. It can be understood as a result of the seasonal variation of geomagnetic activity that the occurrence frequency of pc 3 in middle and low latitudes shows an annual variation.

For each hourly occurrence shown in Fig. 12, the hourly mean period of the pulsation is scaled from the same dynamic spectrum. The hourly distributions of such a mean period in the interval from January to March, 1976, are illustrated by means of contour maps in Figs. 13a and 13b, for geomagnetically rather quiet ($\Sigma$Kp$\leqq$11) and rather disturbed ($\Sigma$Kp$\geqq$30) days, respectively. The mean period for larger $\Sigma$Kp days is shorter than that for smaller days. Moreover, the occurrence maximum for larger Kp days shifts to the earlier hours of the day than that for quiet days.

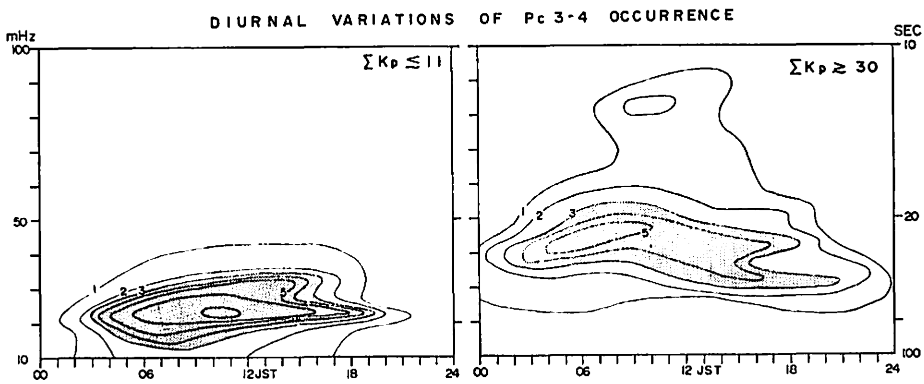


Fig. 13. (a) Contour map showing diurnal variation of pc-3 occurrence frequency at Memambetsu for rather quiet days ($\Sigma$Kp$\leqq$11) from January to March, 1976.
(b) Similar map for rather disturbed days ($\Sigma$Kp$\geqq$30) in the same period.

## 5. Latitudinal dependence of horizontal powers of pc 3

In Fig. 14 ULF dynamic spectra observed at Memambetsu, Kanoya and Chichi-jima on March 16-17, 1976 (JST) are illustrated. It should be noted that time passes away from right to left in this figure. As already described, the overall responses

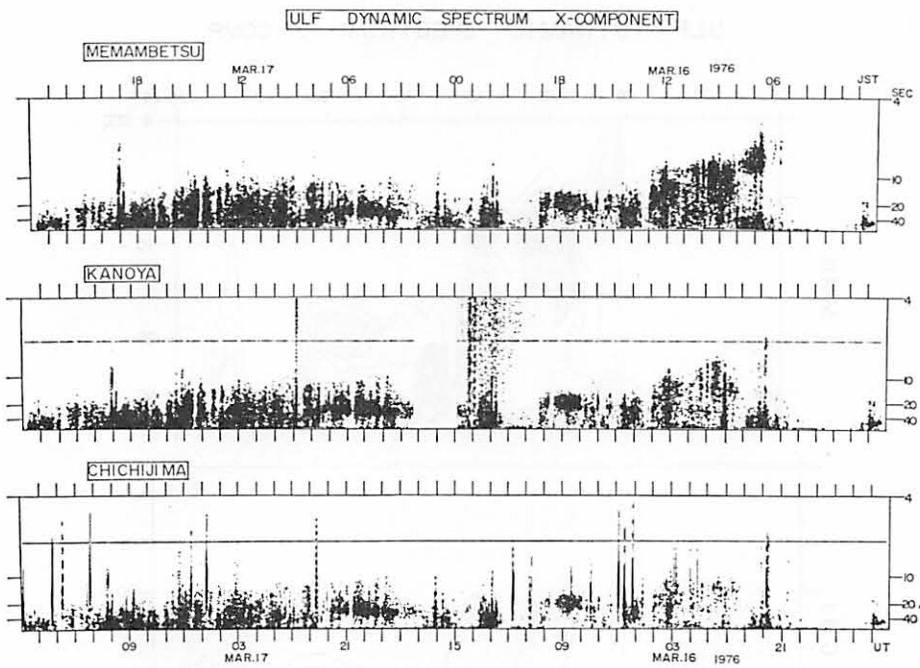


Fig. 14. Dynamic spectra of ULF X component at Memambetsu, Kanoya and Chichijima on Mar. 16–17, 1976.

of instruments are almost the same among these three observatories. So that the powers of the pulsations at any observatory can be compared directly on these spectra with those at another observatory. On these two days distinct pc 3 of long duration has been observed. It will be seen that the pc 3 shows a clear latitudinal dependence. There was sudden enhancement of the pulsation at around 06h on March 16 but its highest frequency part was observed only at Memambetsu which is the highest in latitude of those observatories. In general it seems that the lower the latitude of the observatory the weaker the power of pc 3 becomes. Moreover, the enhanced higher frequency part of pc 3 is apt to be subjected to attenuation in low latitudes. Particularly at Memambetsu a typical "U-type" diurnal variation of the mean period can be seen on March 17, 1976.

In Fig. 15, the dynamic spectra at Memambetsu and Chichijima on March 16 are illustrated by means of contour maps which show residual powers for attenuation of each 5 dB. Namely, the contour of 0 dB is that of the power of pc 3 recorded when no attenuation is applied to it. The hatched area means intense power observed over attenuation of 10 dB. It will first be pointed out that there is a distinct latitudinal dependence of occurrence frequency of such the continuous pulsation. Although at Memambetsu the pulsation components with shorter periods than about 10 sec. have been enhanced at about 06h on March 16, such enhancement has hardly been observed at Chichijima. It seems that the components are, in general, subjected to more intense

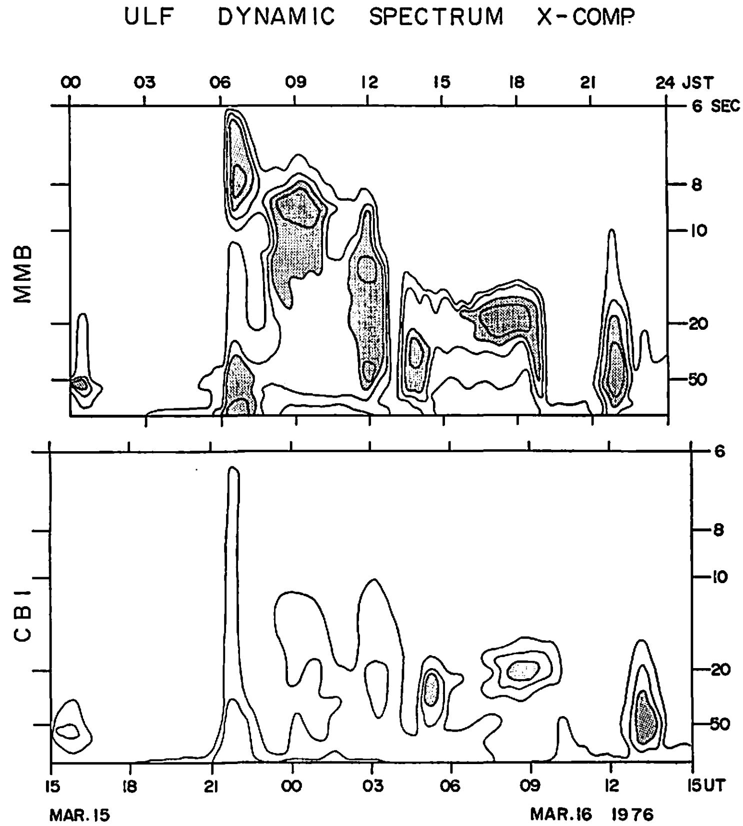


Fig. 15. Contour dynamic spectra of ULF X component at Memambetsu and Chichijima on Mar. 16, 1976.

attenuation in lower latitudes.

In Fig. 16, the ratio of autopower spectra of the $X$ component of pc 3 between Memambetsu and Chichijima is plotted for its corresponding frequency for each hourly spectral peak. The ordinate is the power ratio and the abscissa the peak frequency. As already described, this frequency and power (amplitude) are given directly by the digital display part of SD-360. This figure means that the pulsation has more intense power at Memambetsu than at Chichijima, when the corresponding point is in a lower ratio part than 1.0. As shown in this figure, the power at Chichijima is usually less intense than that at Memambetsu; and the higher the peak frequency is, the smaller the power ratio becomes. Particularly, this ratio shows a smaller value than 0.2 for peak frequency higher than about 100 mHz.

Another example is given in Figs. 17 and 18. Fig. 17 gives the dynamic spectra of geomagnetic pulsations observed at Memambetsu, Kanoya and Chichijima on Feb. 17-

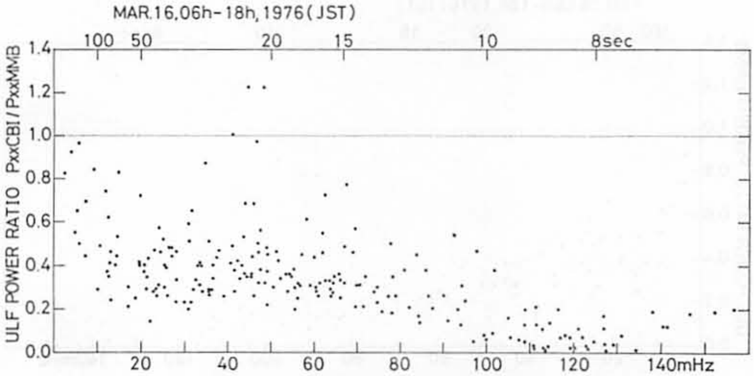


Fig. 16. Auto-power spectrum ratio of pc-3 X components between Memambetsu and Chichijima from 06h to 18h (JST) on Mar. 16, 1976.

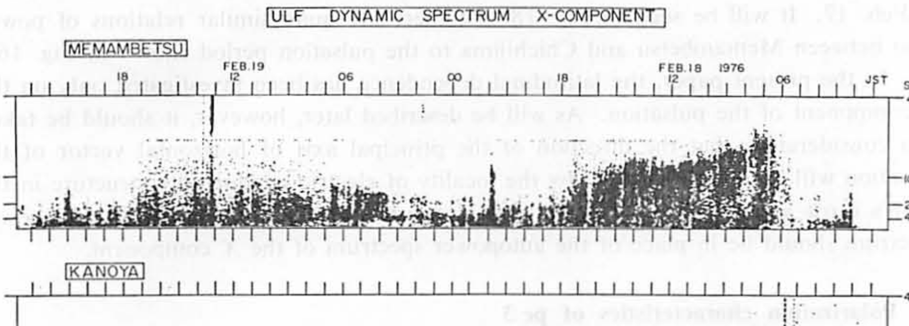


Fig. 17. Dynamic spectra of ULF X component at Memambetsu, Kanoya and Chichijima on Feb. 17–18, 1976.

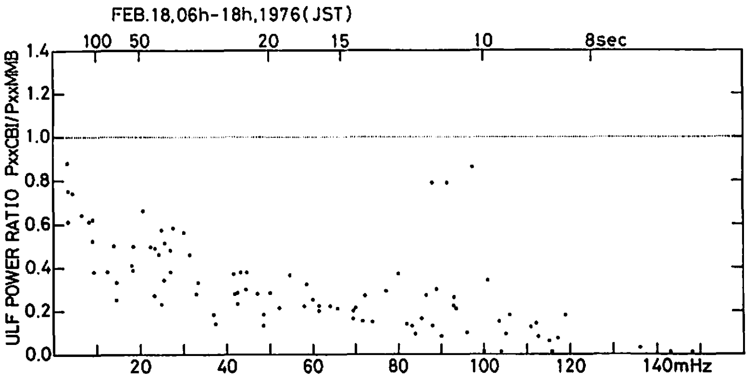


Fig. 18. Auto-power spectrum ratio of pc-3 X components between Memambetsu and Chichijima from 06h to 18h (JST) on Feb. 18, 1976.

18, 1976. Also in this example, clear enhancement with distinct latitudinal dependence of higher frequency components of the continuous pulsation is observed in the daytime of Feb. 17. It will be seen in Fig. 18 that there are quite similar relations of power ratio between Memambetsu and Chichijima to the pulsation period shown in Fig. 16.

In the present paper, the latitudinal dependence has been investigated only on the $X$ component of the pulsation. As will be described later, however, it should be taken into consideration that the direction of the principal axis of horizontal vector of the pulsation will be greatly affected by the locality of electric conductivity structure in the earth's crust and upper mantle. So that in future investigation, the horizontal power spectrum should be in place of the autopower spectrum of the $X$ component.

## 6. Polarization characteristics of pc 3

In Fig. 19 the dynamic spectra of the ULF $X$ component on April 11-12, 1976, at our two observatories, Memambetsu and Chichijima, are illustrated together with the corresponding geomagnetic H traces at three auroral-zone observatories, College, Tixie Bay and Dixon Island, as well as at Kakioka. The arrow on the auroral-zone magnetogram shows the midnight time at each observatory. Continuous pulsations with long duration were observed in the daytime on these two days at Memambetsu and Chichijima. But identification of pc 3 on such a dynamic spectrum is generally not so easy. On the other hand, it is well known that pi 1, 2 is an excellent indicator of a substorm onset (e.g. Sakurai and Saito, 1976). So that for the identification some auroral-zone magnetograms are usually compared with this dynamic spectrum. Corresponding to sharp negative bays at these auroral-zone observatories, clear pi 2 events have been observed around 23h on April 11 at both Memambetsu and Chichijima. These bays were most distinct at Tixie Bay where the time was just midnight. Pi 2 events occurring in the interval from about 19h to 20h correspond well to three successive sharp negative

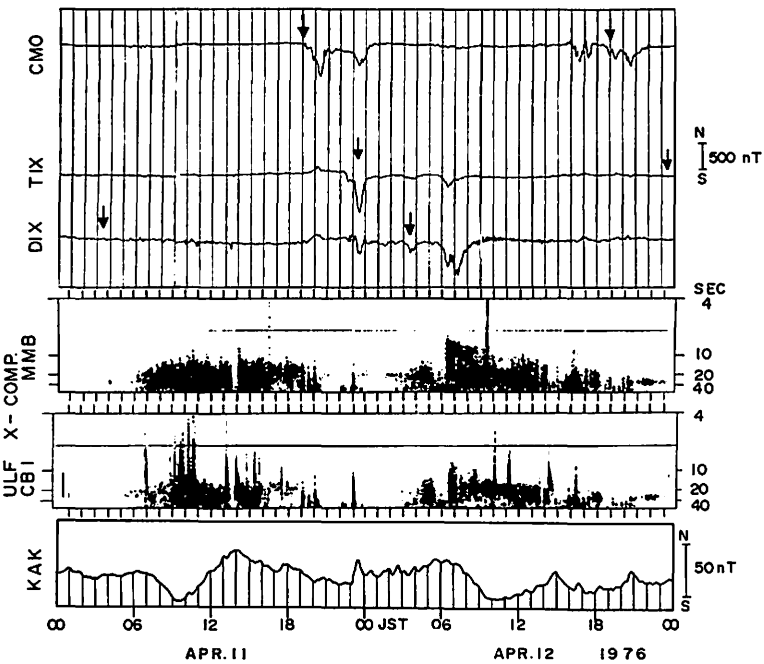


Fig. 19. Dynamic spectra of ULF X component at Memambetsu and Chichijima as well as *H* traces at Kakioka, College, Tixie Bay and Dixon Island on Apr. 11–12, 1976 (JST).

bays at College. It seems that continuous pulsations in the daytime (06h-18h) on April 11 are no doubt pc 3. A similar contour spectrum as in Fig. 15 is also given in Fig. 20. It will be seen in this figure that continuous pc 3 and three successive pi 2 pulsations have been observed throughout the daytime and in the evening hours, respectively. In the present work, we will investigate polarization characteristics of the pulsations on that day.

Firstly we have to describe the procedure of our polarization analysis. As already shown in Fig. 4, reproduced signals converted into digital values with sampling ratio 0.5 sec by an A/D converter are recorded on a digital magnetic tape. These digital data were analyzed by the computer system of the National Institute of Polar Research. As the sampling ratio is 0.5 sec, analyses of the pulsations with longer periods than 1 sec can be carried out theoretically. But in the present work we treat of only pc 3 range (5-100 sec) pulsations, so that signals with a period outside of the range are rejected by means of a filtering technique. Each 2040 digital data corresponding to about 17 min interval is sliced into three equal partially-overlapping units which consist of 1024 samplings (about 8.5 min). Auto- and cross-power spectra are computed by means of FFT method for each unit data and then these data are averaged for each 17 min interval. Spectral smoothing as continuous dynamic spectra is

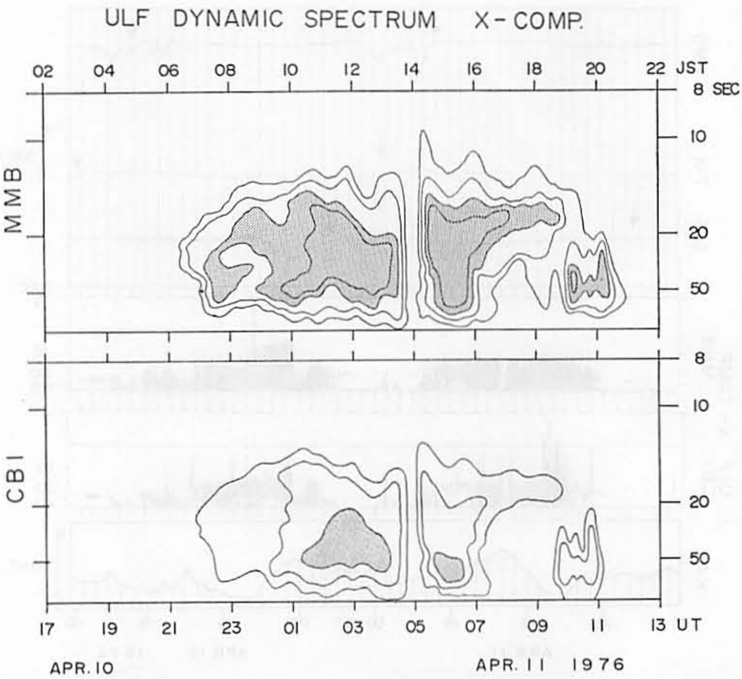


Fig. 20. Contour dynamic spectra of ULF $X$ component at Memambetsu and Chichijima on Apr. 11, 1976.

performed by averaging such spectra successively for 17 min intervals, overlapping them by half. Finally polarization parameters which consist of ellipticity and direction angle of the major axis of the horizontal polarization ellipse are computed from these power spectra for such a successive interval. These computed results are given on a magnetic tape and/or a line printer. The simplified flow chart of our calculation procedure is shown in Fig. 21.

In the present paper, the sign of ellipticity $\varepsilon$ is defined as positive (or negative) when the polarization vector rotates clockwise (or counter-clockwise) along magnetic lines of force. And $\varepsilon=0$ and $\varepsilon=\pm 1$ mean linear and circular polarizations, respectively. Direction angle $\theta$ of the major axis is measured in right-handed sense from the north. So that the direction angle is positive when the major axis is in the north-east sector. And when the axis coincides with the north-to-south direction, $\theta$ becomes zero. $\theta=\pm 90°$ corresponds to the major axis lying east to west. The relations are illustrated in Fig. 22. $X$ and $Y$ axes are taken northwards and eastwards, respectively.

Next, our calculation program was checked by the following test signal:

$$X=10.0\sin(2\pi/77\cdot t)+7.0\sin(2\pi/36\cdot t)+10.0\sin(2\pi/22\cdot t)$$

$$Y=-5.0\sin(2\pi/77\cdot t+60°)+20.0\sin(2\pi/36\cdot t+10°)+6.0\sin(2\pi/22\cdot t-10°)$$

This test signal is superposition of three sinusoidal waves whose periods are 77, 36 and 22 sec, respectively. And these waves shown by the first, second and third terms

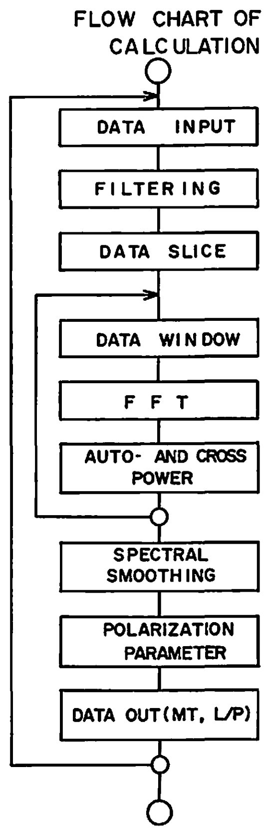


Fig. 21. Flow chart showing calculation procedure of polarization parameters.

in right-hand sides of the above equations correspond to the upper, middle and lower polarization ellipses in Fig. 23.

Crosspower spectrum, ellipticity and direction angle obtained by calculating this signal with our program are given in the upper, middle and lower diagrams of Fig. 24, respectively. Each sharp peak in the cross-power spectrum coincides with the very period of each elementary wave of the test signal. Ellipticity of the first and third waves having clockwise rotational sense is certainly positive and that of the second wave shows undoubtedly negative sense. The direction angle of the second wave whose horizontal vector points almost east-to-west in near 90° and that of the first wave which has a small angle from the north in the northwest sector shows a small negative value. On the other hand the direction angles of the second and third waves whoes major axes are in the northeast sector give no doubt positive values. It was confirmed by this test signal that our calculation program can be applied to the present analysis.

Fig. 25 shows an example of polarization analysis carried out for a pi 2 event observed 1930.4-1947.5 JST on April 11, 1976. The left and right halves of this

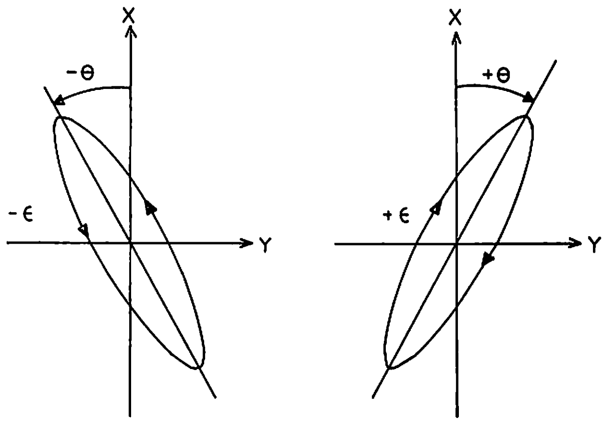


Fig. 22. Definition of signs of polarization characteristics (ellipticity and direction angle of the major axis) in our calculation program.

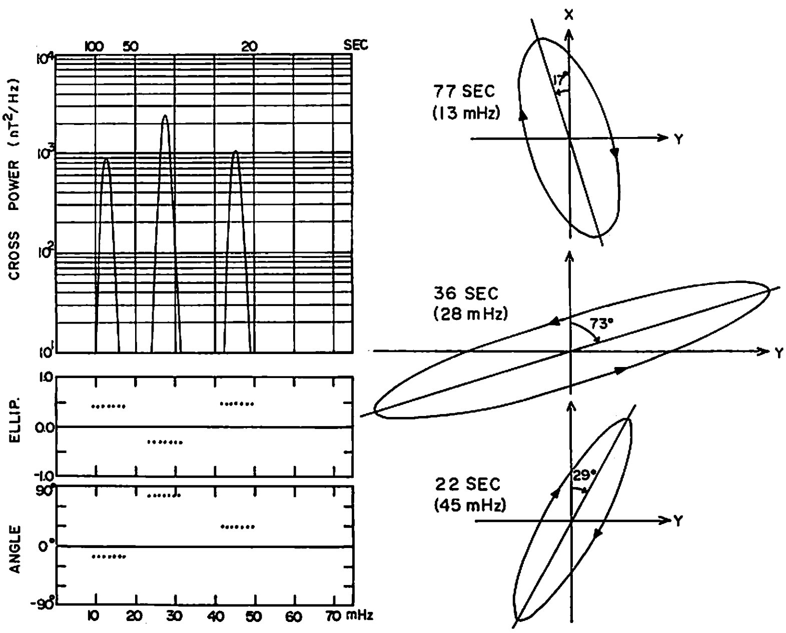


Fig. 23. Test signals for checking on our calculation program.

Fig. 24. Cross-power spectrum and polarization characteristics calculated from the test signals shown in Fig. 23.

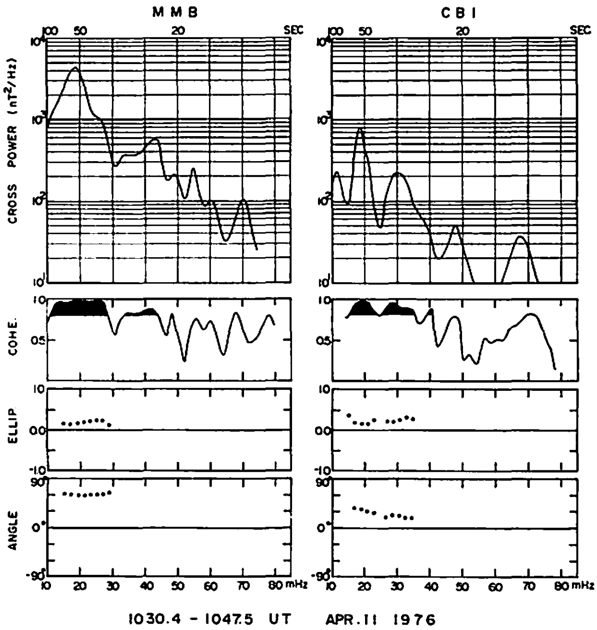


Fig. 25. An example of polarization analysis for pi-2 observed at Memambetsu and Chichijima. The top, second, third and bottom diagrams show cross-power spectrum, coherency, ellipticity and direction angle of the major axis, respectively.

figure give polarization characteristics of the pulsation at Memambetsu and Chichijima, respectively. The characteristics were computed only for the longer period side which corresponds to the blacked part having of higher values than 0.8 in the coherency diagram. It can be seen that both ellipticity and direction angle take some positive values at each observatory. In other words, this pi 2 observed in an evening hour has clockwise polarization and northeastward main direction. This result agrees well with those by many previous researchers (Kato et al., 1956; Saito and Matsushita, 1968; Sutcliffe, 1975 and others) who have pointed out that polarization vector of pi 2 in middle and low latitudes has clockwise rotational sense and northeastward main direction in premidnight hours and then changes into counter-clockwise and northwestward direction in postmidnight hours.

As already described, we investigated the dynamic polarization characteristics of continuous pc 3 in the daytime (60h-18h) on April 11, 1976. The characteristics were obtained successively for each 17 min interval. In the present paper, we illustrate the characteristics of each example in both morning and afternoon intervals. In Fig. 26 auto-power spectra of $X$ and $Y$ components in a morning interval (0824.8-0841.9 JST) at Memambetsu and Chichijima are given. A well-corresponding spectral

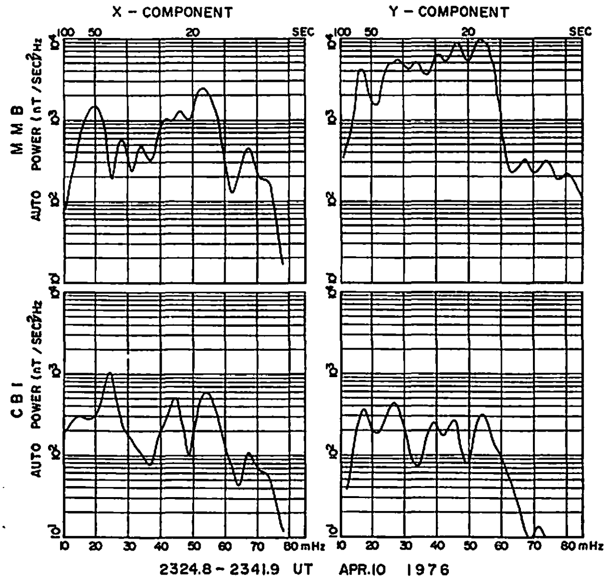


Fig. 26. An example of $X$- and $Y$- auto-power spectra for morning-side pc-3 at Memambetsu and Chichijima.

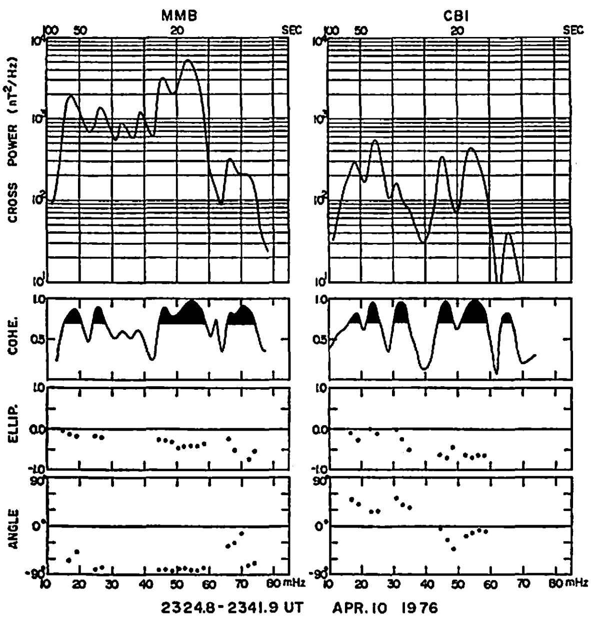


Fig. 27. Cross-power spectrum, coherency, ellipticity and direction angle of the major axis of the pulsation pc-3 shown in Fig. 26.

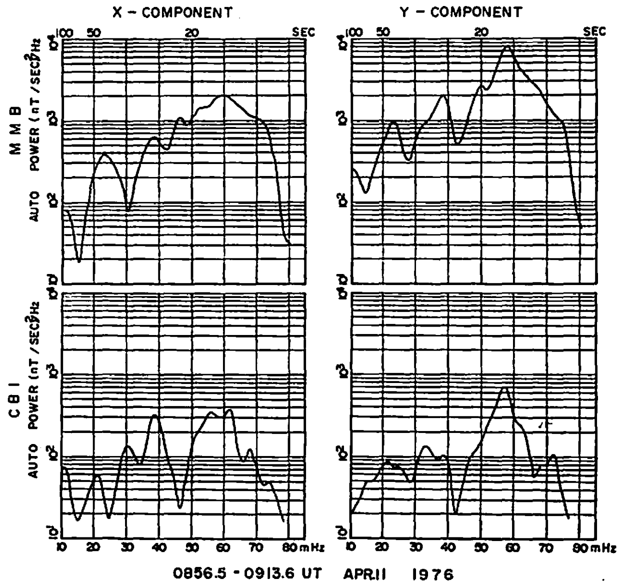


Fig. 28. An example of $X$- and $Y$- auto-power spectra for afternoon-side pc-3 at Memambetsu and Chichijima.

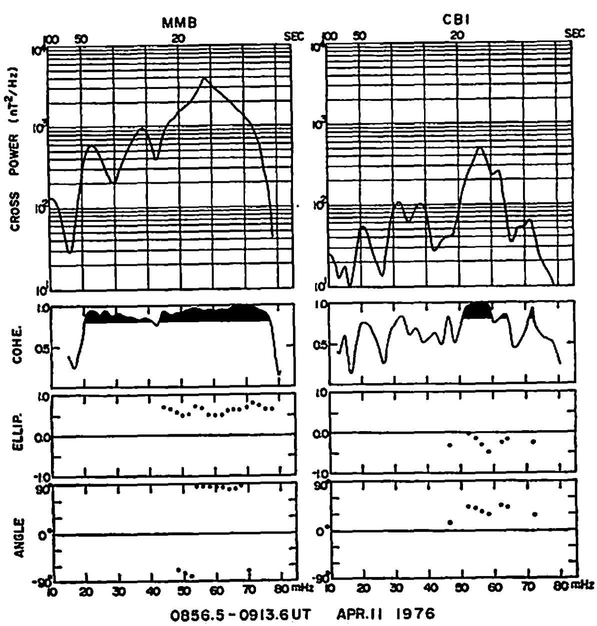


Fig. 29. Cross-power spectrum, coherency, ellipticity and direction angle of the major axis of the pulsation pc-3 shown in Fig. 28.

peak with a period of about 18 sec can be seen. Fig. 27 shows the cross-power spectrum, coherency, ellipticity and principal direction of the pc 3 in that interval. The ellipticity takes negative values throughout the range of 10-70 sec, so that it is deduced that the polarization of pc 3 range pulsation in morning hours is usually counter-clockwise in such the lower latitudes. The direction angle at Memambetsu has negative values in such lower latitudes. The direction angle at Memambetsu has negative values near $-90°$ throughout the period range but that at Chichijima is fairly dispersive around 0° and rather positive, particularly, in the shorter period range. This fact means betsu points east-to-west in the morning hours. Figs. 28 and 29 show the polarization characteristics in an afternoon interval (1756.5-1813.6 JST). These consist of quite similar figures as in Figs. 26 and 27, respectively. But a well-corresponding peak of this spectrum has a somewhat shorter period (about 16 sec), compared with that in the morning hours. At Memambetsu the ellipticity which was negative in the morning changed undoubtedly into positive in this afternoon interval but at Chichijima such a clear change in ellipticity was not observed. This fact means the polarization change from counter-clockwise in the morning hours into clockwise sense in the afternoon. The principal direction at Memambetsu was still east-to-west in this interval but that at Chichijima changed from northwest in the morning into northeast in the afternoon.

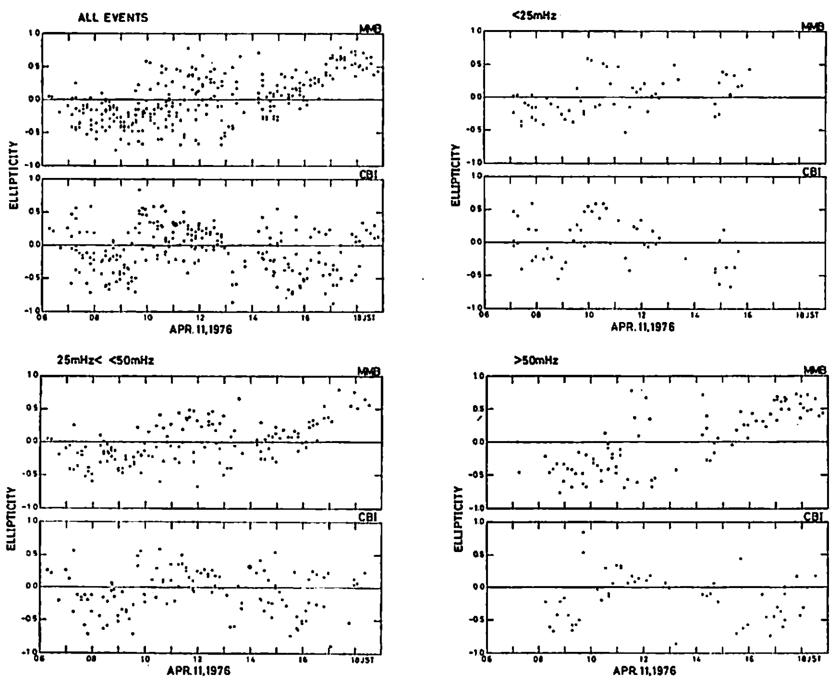


Fig. 30. Diurnal variations of ellipticity in full, less than 20 sec, 20–40 sec and more than 40 sec ranges, respectively. The upper and lower diagrams correspond to the variations at Memambetsu and Chichijima.

The above observational facts are summarized in Figs. 30 and 31. Fig. 30 shows the diurnal variation of the ellipticity of the horizontal polarization ellipse. Beginning with the top diagram, the variations in full, less than 20 sec, 20 to 40 sec and more than 40 sec ranges of the pulsation period are shown. In Fig. 31, similar diurnal variations of direction of the principal axis are shown in the same manner as in Fig. 30. It can be pointed out from these figures that the polarization sense at Memambetsu changes gradually from counter-clockwise in the early morning into clockwise in the evening but that at Chichijima is rather counter-clockwise or linear throughout the daytime and shows no such diurnal variations. At Memambetsu the principal axis of the polarization vector usually points northwest. Describing in more detail, the axis showing east-to-west direction in early morning or evening hours is likely to turn to north-to-south direction in only a few hours around noon. On the other hand, the direction at Chichijima changes from northeastward in morning hours into northwestward in evening hours and such a tendency is more remarkable in the longer period side of the pulsation. Although such a continuous pc 3 range pulsation was observed simultaneously at our four observatories in middle and low latitudes, there were some differences in the daily behavior of its polarization characteristics between Memambetsu and Chichijima. The locality of the direction angle of the major axis may be related partially to a difference of electric conductivity structure in the earth's interior. As the above results are based on only one example, we cannot make further discussion of the cause of such behavior.

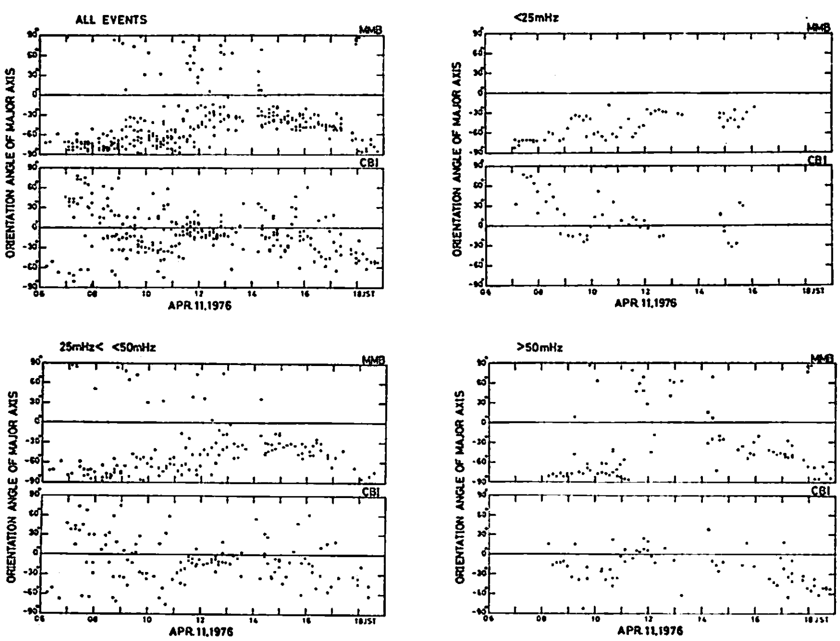


Fig. 31. Similar variations of direction angle of the same pulsation in the same four period ranges as in Fig. 30.

## 7. Concluding remarks

In the present paper, we investigated the characteristics of pc 3 range pulsations simultaneously observed in a Japanese station chain and obtained some interesting results. Those are summarized as follows:

1) There is a solar-cycle variation in the mean period of the pulsation. The variation can be connected closely with geomagnetic activity (Kp) rather than solar activity (e.g. Zürich sunspot number). This will be mainly due to changes in the geometry of the magnetospheric resonator, size of the plasmasphere, affected by geomagnetic activity (Saito, 1949; Fukunishi and Lanzerotti, 1974a). This result coincides with those by many previous researchers.

2) Diurnal variation of the pulsation period shows "Inverted U-type" only in summer in sunspot maximum years (1957-1961), but in the other seasons and in sunspot minimum years (1962-1967) the variation is not so clear or shows rather "U-type".

3) Occurrence frequency of the pulsation shows an apparent seasonal variation which has its maximum at equinox. However, it can be rather pointed out that this observational fact reflects the above-described Kp-dependence of pc 3 occurrence.

4) Maximum of occurrence frequency of the pulsation shifts to earlier hours of day as the geomagnetic activity becomes higher. This result coincides well with that by Nagata and Fukunishi (1969).

5) Power of the pulsation at Chichijima is usually less intense than that at Memambetsu; and the higher the frequency is, the smaller the ratio of the power at Chichijima to that at Memambetsu becomes. In other words, the power, particularly of the enhanced higher frequency part, of the pulsation is subjected to such an intense latitudinal effect.

6) Polarization of the pulsation shows some different daily behavior between Memambetsu and Chichijima. The polarization at Chichijima is counter-clockwise or linear throughout the daytime but that at Memambetsu changes from counter-clockwise in the morning hours to clockwise in the evening hours. Direction of the major axis at Chichijima changes from northeastward in the morning hours to northwestward in the evening hours but that at Memambetsu is usually east-to-west. The locality of the principal direction may be partially due to difference of conductivity structure in the earth's crust. Using more examples which contain those in various seasons, various geomagnetic activities and various phases of the sunspot cycle should be investigated, if possible, quantitatively.

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# Pc 型地磁気脈動（第三報）

## ――中低緯度 Pc 3 のスペクトル・偏波の特性――

桑 島 正 幸・佐 野 幸 三・河 村 譜

### 概　　要

日本の中緯度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ている。その資料からスペクトル解法により Pc 3 脈動のスペクトル・偏波などの諸特性が解析される。本文ではまず太陽・地磁気活動に関連する Pc 3 脈動の出現頻度と平均周期の11年周期変化，季節変化などが調べられた。また特にこの脈動の水平成分のパワーや偏波の中低緯度における緯度依存性がある一期間であるが詳しく調べられた。これらの結果について報告する。