Non-Seasonal Annual Variation in the Period of Pc 5 Observed at Syowa Station

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昭和基地における Pc 5 型磁気脈動周期の非季節年変化

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要旨: 昭和基地において磁気テープレコーダーに録音された ULF 波動を，speed-up ratio 2×10^4 で再生し，HISSA (high-speed spectrum analyzer) で解析した．その結果，1973 年 6 月の Pc 5 周期は 1973 年 12 月の Pc 5 周期より短かかったことが見出された．さらに，昭和基地で 1974 年から 1977 年までの間得られた correlation chart の記録から，毎年 6 月および 12 月の期間中の Pc 5 周期を読取ったが，やはり 6 月の Pc 5 周期は 12 月の Pc 5 周期より短かくなるような年変化をしていることが確かめられた．

Byrd での Pc 5 周期，Fredericksburg の Pc 4 周期そして Stanford での whistler dispersion などが，局所的な季節に関係せず，昭和基地における年変化とまったく同様な年変化を示すことから，これらの年変化は non-seasonal annual variation と呼ばれるべきである．これらの観測結果と，sun-earth distance model, conjugate point wandering model そして Φ-ϕ model の 3 つの model が比較検討された．

Abstract: ULF signals registered at Syowa Station are reproduced by an FM tape recorder with a speed-up ratio of 2×10^4 and are analyzed with a high-speed spectrum analyzer called HISSA. The Pc 5 periods in June, 1973, are revealed to be shorter than those in December, 1973. An eye-reading analysis of Pc 5's on the correlation chart obtained at Syowa Station from 1974 to 1977 shows also such annual variation in which the June periods are shorter than the December periods. These annual variations arc regarded to be non-seasonal, since all Pc 5 period at Byrd, Pc 4 period at Fredericksburg, and whistler dispersion at Stanford exhibited the same annual variation as that at Syowa Station independent on the local seasons of these stations. These observed results are examined by three models, sun-earth distance model, conjugate point wandering model, and Φ-ϕ model.

1. Introduction

Magnetic pulsation Pc 5 is considered to be due to the standing Alfvén wave along the polar magnetic field lines. Nevertheless, the period of Pc 5, $T_{Pc\,5}$, at Byrd Station

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(together with the Pc 4 period, $T_{Pc\,4}$, at Fredericksburg and whistler dispersion, D, at Stanford) was found to show peculiar annual variations. These variations have a common maximum in $T_{Pc\,5}$, $T_{Pc\,4}$, and D around June and a common minimum around December, irrespective as to whether the station is in the northern hemisphere or in the southern hemisphere (SAITO and MATSUSHITA, 1967). So, these were called the non-seasonal annual variation (SAITO, 1964; KATO and SAITO, 1964). They pointed out that some common plasma density variations in the magnetosphere and in the ionosphere are governing the observed non-seasonal variations in $T_{Pc\,4}$, $T_{Pc\,5}$, D, satellite drag (NEWTON *et al.*, 1965; JACCHIA, 1966), f_0F2 (YONEZAWA, 1959; YONEZAWA and YASUHARA, 1959) and f_0E (APPLETON *et al.*, 1963; SHIMAZAKI, 1963).

The purpose of the present paper is to confirm the previous result by analyzing Pc 5 observed at Syowa Station by using a high-speed spectrum analyzer (HISSA) and by examining three possible models.

2. HISSA Analysis

The HISSA method is shown with a block diagram in Fig. 1, while Fig. 2 shows the HISSA system (SAITO, 1976). The ULF signals registered on MT at Syowa Station with a tape transport speed V_{R1} are reproduced by the data recorder in Fig. 2 with

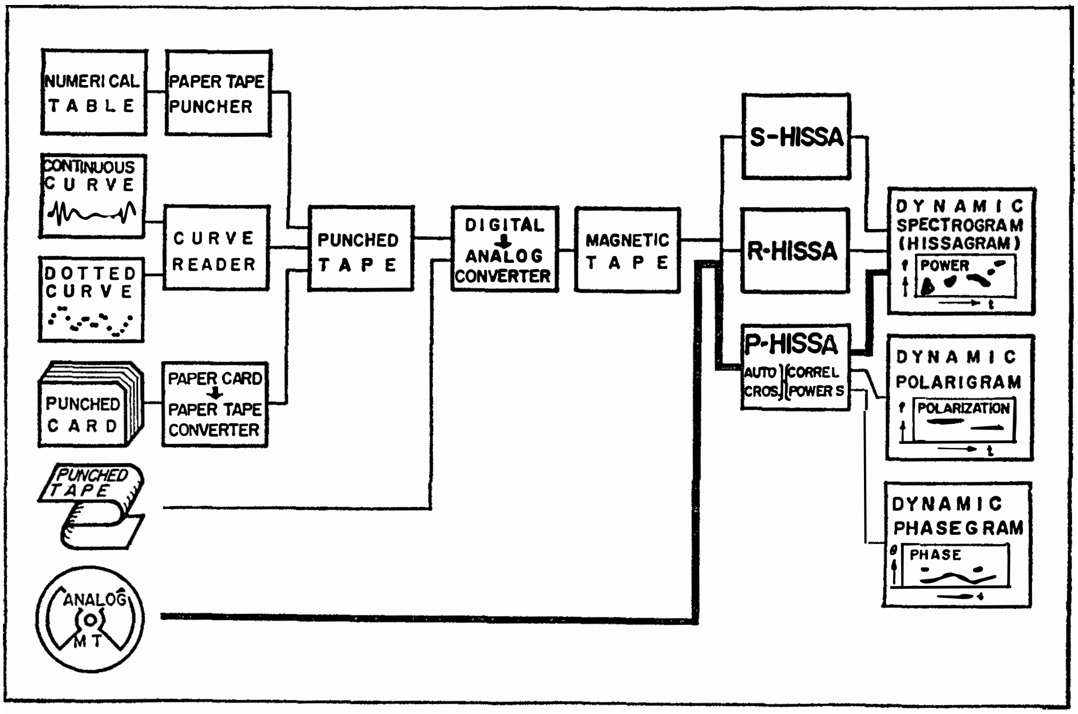

Fig. 1. Block diagram of the HISSA method. The thick lines indicate the analysis method applied in the present study

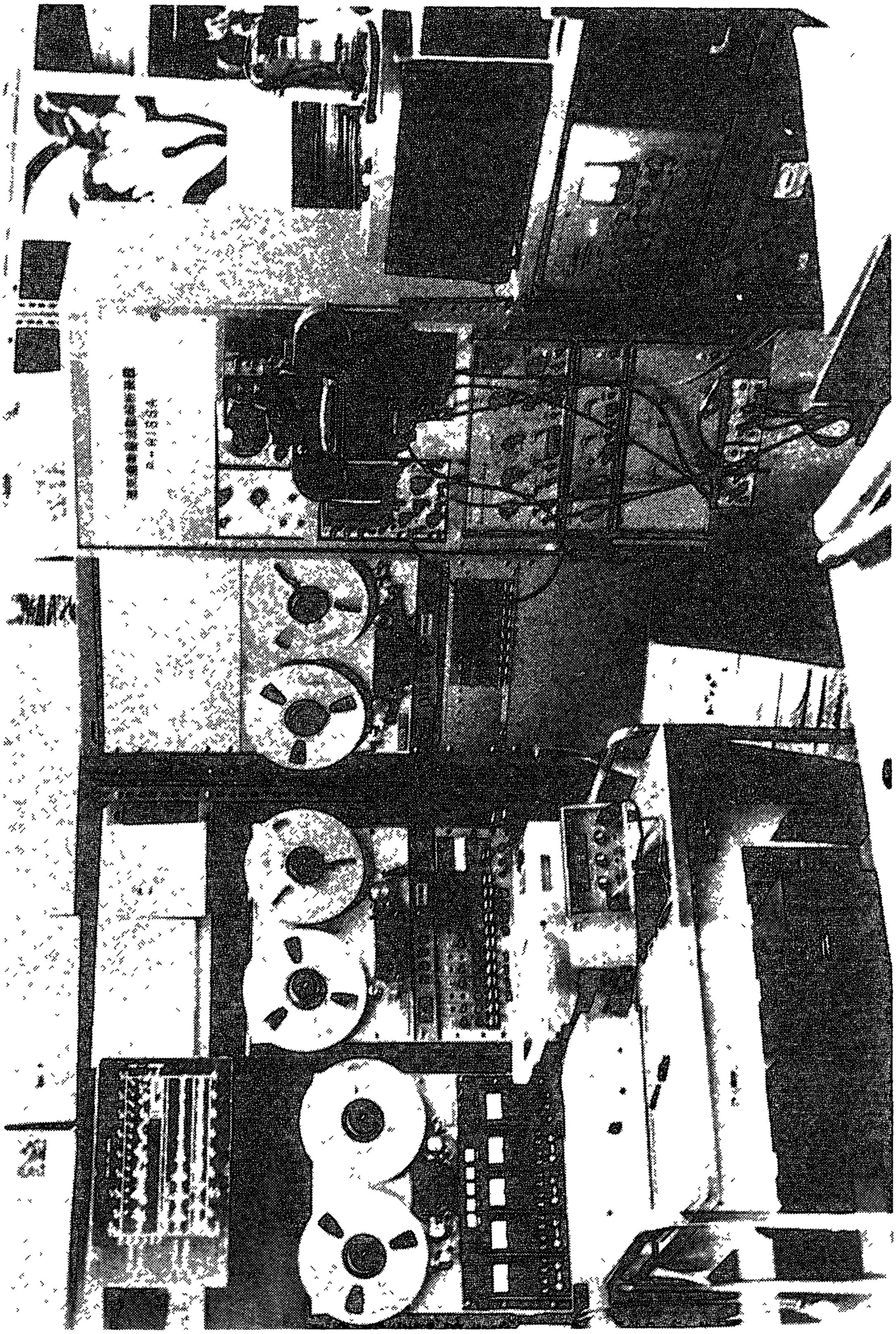

Fig 2 HISSA system used in the present study

the following speed-up ratio R (SAITO, 1960);

$$R=\frac{V_{P1}}{V_{R1}}\cdot\frac{V_{P2}}{V_{R2}}=10^4\ ,$$

where $V_{R1}=3$ mm/s, $V_{P1}=375$ mm/s, $V_{R2}=1\frac{7}{8}$ inch/s, and $V_{P2}=30$ inch/s.

The reproduced signals are promptly analyzed by HISSA and the calculated results are simultaneously pictured by the long-recording camera in Fig. 2.

Typical hissagrams for June 1–30 and December 1–31, 1973 are displayed in Figs. 3 and 4, respectively. The time required for both calculation and picturing of one month data is only 260 seconds. The vertical structures in Figs. 3 and 4 indicate Pi-

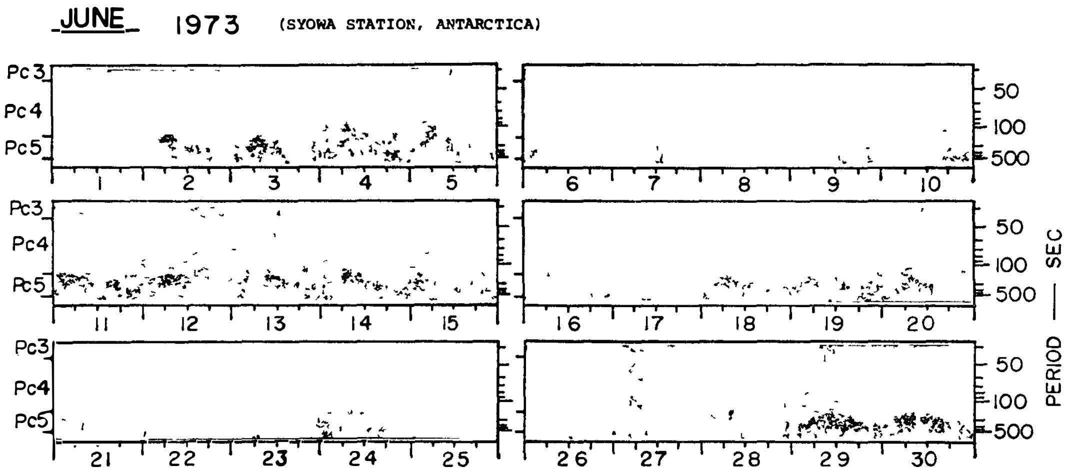

Fig 3. Hissagrams of ULF waves observed at Syowa Station during 1–30 June, 1973.

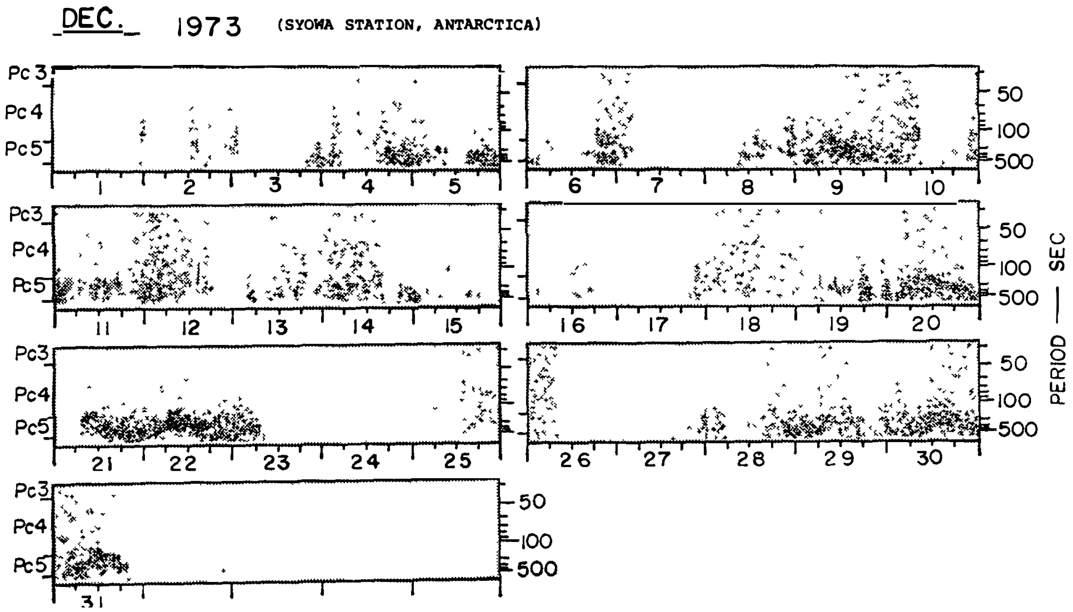

Fig 4. Hissagrams of ULF waves observed at Syowa Station during 1–31 December, 1973

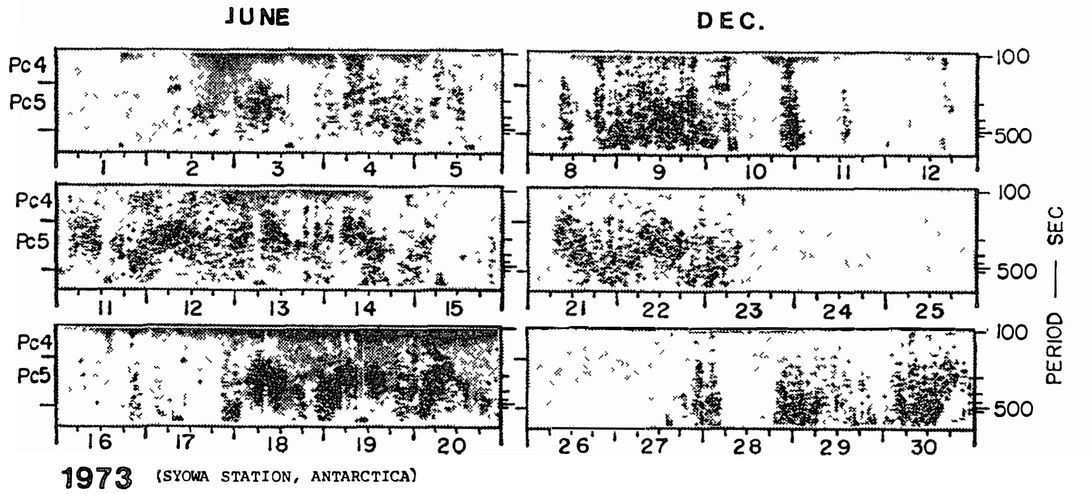

Fig. 5. Hissagrams of ULF waves observed at Syowa Station in 1973. Note that the Pc 5 period in June is shorter than in December.

type pulsations associated with substorms. It is striking that the Pc 5 period exhibits repeatedly a clear U-type diurnal variation, namely, the period is shorter in the daytime than in the nighttime (SAITO, 1969). In order to obtain the Pc 5 period correctly, the speed-up ratio of 2×10^4 is further applied and the June hissagrams are compared with the December hissagrams in Fig. 5. As shown in the figure, the Pc 5 period is shorter in June than in December as was expected in Introduction, provided the diurnal variation is eliminated.

3. Preliminary Analysis for the Data in 1974–1977

Although the HISSA analysis is so rapid and easy, most of time is spent not in the HISSA analysis but in compiling MT with V_{P1} and V_{R2}; as a matter of fact it takes as long as two months or more to compile a one-year data. So we read the representative Pc 5 periods from the correlation charts of only June and December from 1974 to 1977 and plotted them as shown in Fig. 6. The number of cases is much smaller in this eye-reading case than the case of the HISSA analysis, because of the low sensitivity of the magnetogram in the correlation chart. Nevertheless, such a non-seasonal annual variation as was expected in Introduction can be seen clearly in the figure. It is noteworthy that the variation of the Pc 5 period at Syowa Station in Fig. 6 is quite similar to that of Pc 5 period at Byrd in Fig. 7, that of Pc 4 period at Fredericksburg in Fig. 8, and whistler dispersion at Stanford (PARK *et al.*, 1978) in Fig. 9.

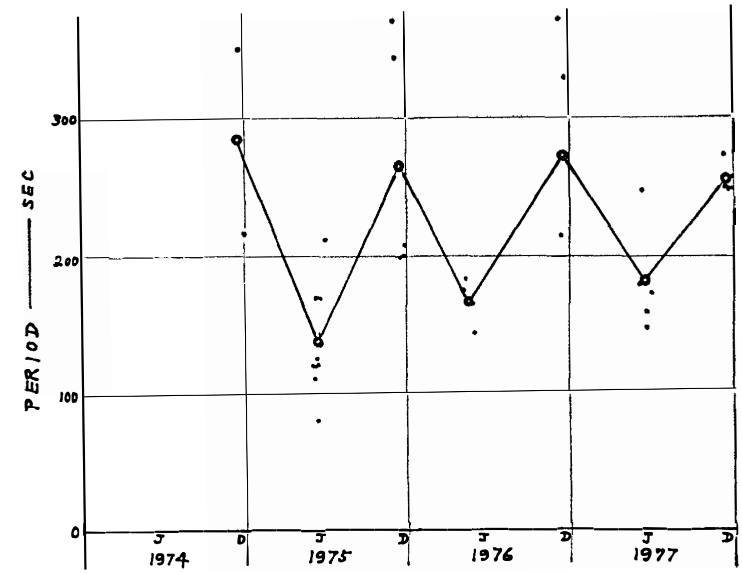

Fig. 6. Annual variation of the Pc 5 periods observed at Syowa Station from 1974 to 1977

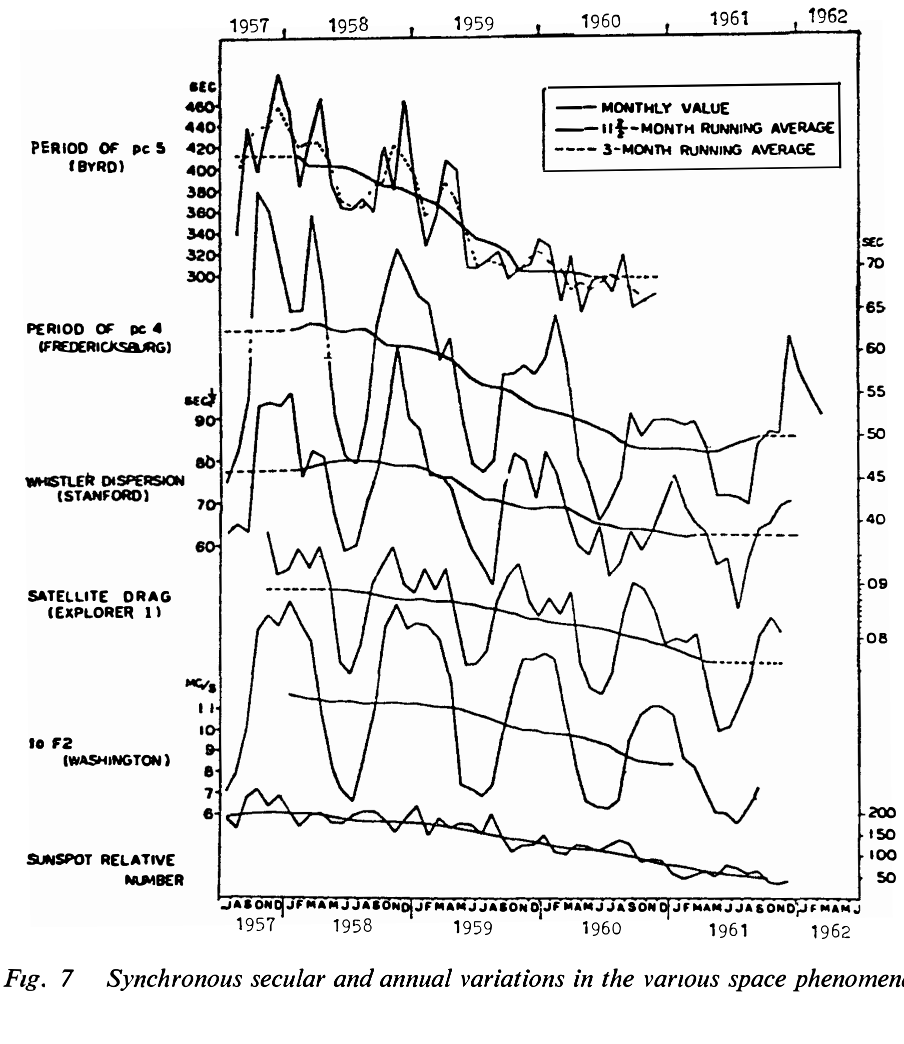

Fig. 7 Synchronous secular and annual variations in the various space phenomena.

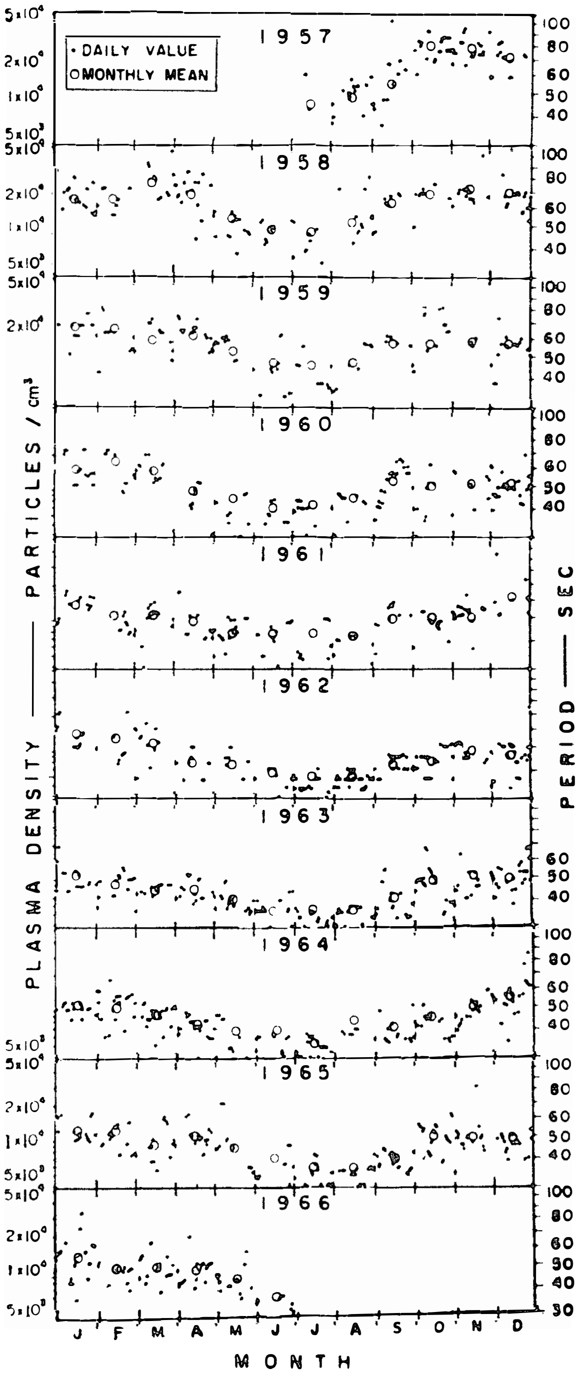

Fig. 8. Clear non-seasonal annual variation in Pc 4 periods observed at Fredericksburg from 1957 to 1966

4. Mechanism of the Non-Seasonal Annual Variation

4.1. Sun-earth distance model

The period of Pc 5 or Pc 4 is expressed by

$$T=4\pi^{1/2}\int_{s} H^{-1}\cdot N^{1/2}ds\ ,$$

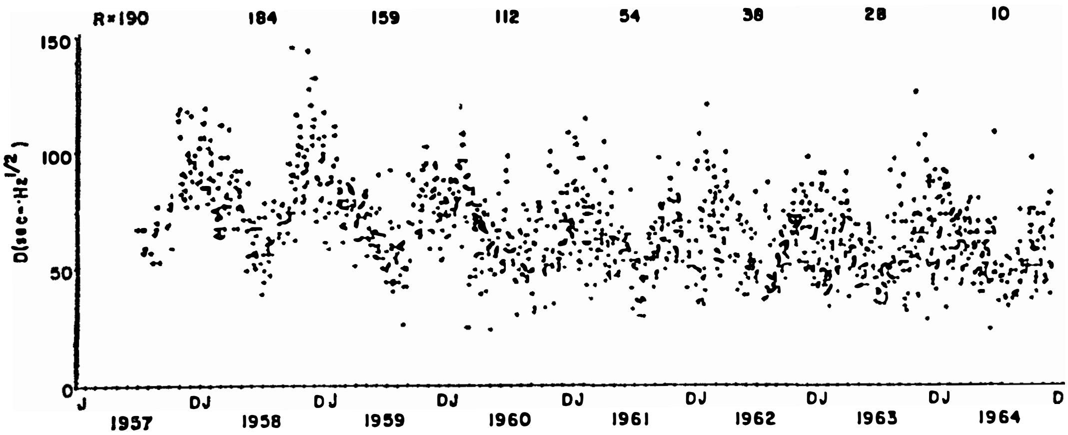

Fig. 9. Daily average values of whistler dispersion $tf^{1/2}$ measured at 5 kHz from mid-1957 through 1964. The whistlers were recorded at Stanford, California Yearly average sunspot numbers are shown at top (PARK et al, 1978)

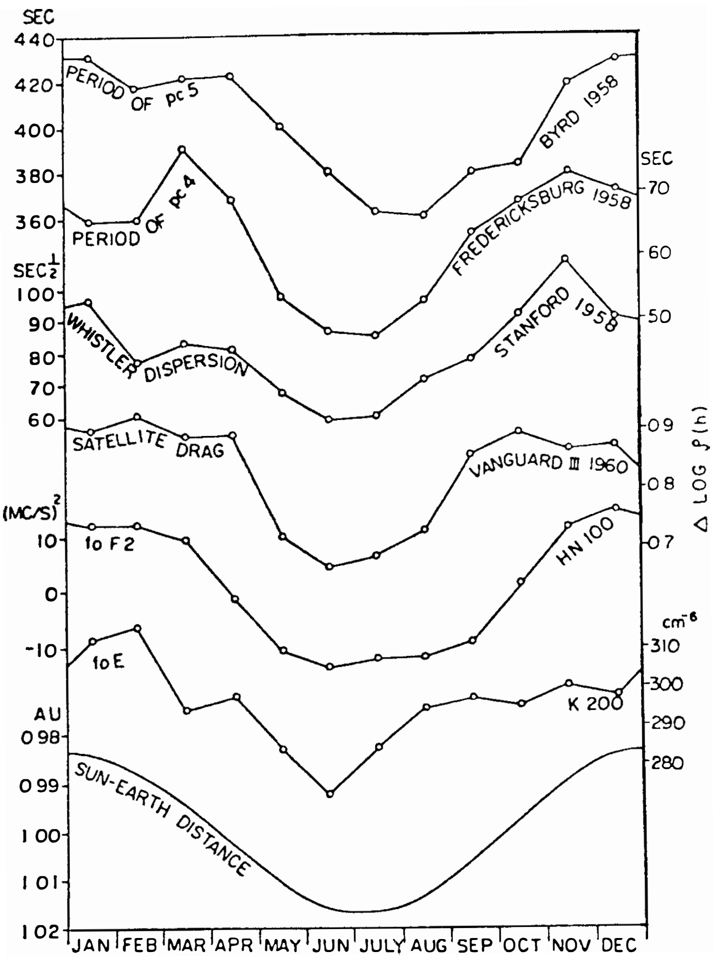

Fig. 10. Non-seasonal annual variation commonly observed in the various magnetospheric and ionospheric phenomena. The data of whistler, satellite drag, ionospheric F 2 and E are after CARPENTER (1962), PAETZOLD (1962), YONEZAWA (1959) and SHIMAZAKI (1963), respectively.

while the whistler dispersion D is expressed by

$$D=\frac{2.67}{c}\int_S H^{-1/2}n^{1/2}ds\ .$$

Hence the observed non-seasonal annual variation in T and D must be attributed to the non-seasonal annual variation in S, H or n (SAITO, 1964).

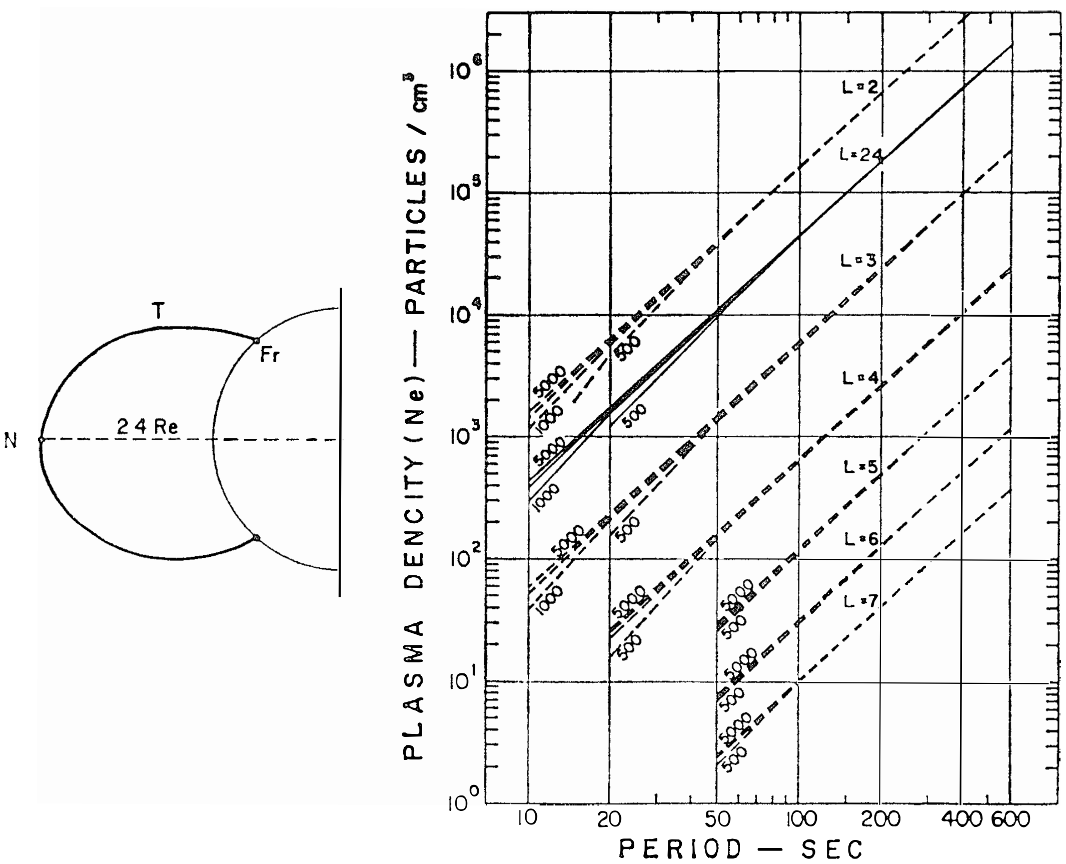

Fig 11 Relation between the plasma density N and period T of the odd mode torsional oscillation of field line for various L-values

One of the possible causes of the variation can be attributed to the variation in n due to the variation in the sun-earth distance The phase of the variation in the sun-earth distance seems appropriate to explain the observed phase as shown in Fig. 10. However, this sun-earth distance model seems to be not so possible, since the variation in the distance is only 4% of the distance itself, while the variation in n (KITAMURA and JACOBS, 1967) expected from the observed T (between 80 and 50; for example) is as much as 300% (between 3×10^4 and $1\times10^4/\mathrm{cm}^3$) as shown in Fig 11.

4.2. Conjugate-point wandering model

Since magnetic latitude of the dayside cusps makes a seasonal variation (FUKU-

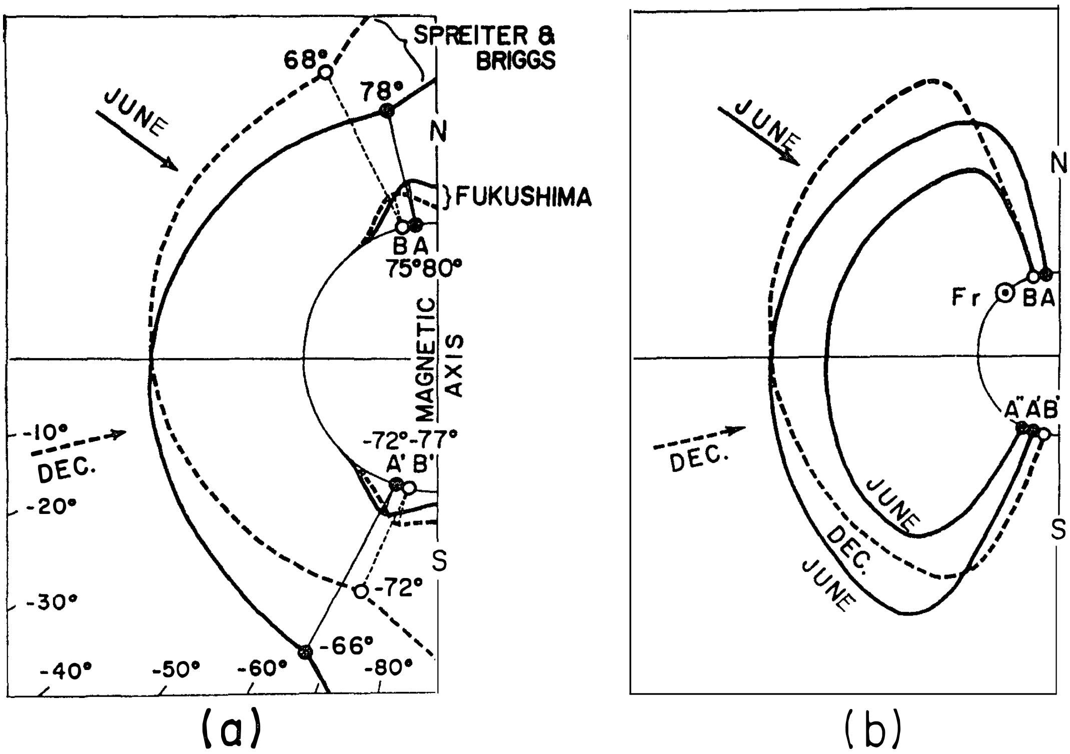

Fig. 12 (a) Annual variation in the latitude of the dayside cusps in the Fredericksburg meridian (b) Wandering of the conjugate point of B from A'' in June to B' in December.

SHIMA, 1962, 1965; SPREITER and BRIGGS, 1962; see Fig. 12a), the magnetic latitude of the conjugate point of a high-latitude station must exhibit a seasonal variation (see Fig. 12b), which causes seasonal variations in S, H, and n. This wandering effect of conjugate point must not be ignored in the observed $T_{Pc\,4}$ and D, since the phase of the seasonal variation expected from the model coincides with the observed phase. In the case of the Pc 5 period at both Syowa and Byrd Stations, however, we must consider a model other than this, since the seasonal phase at a station in the southern hemisphere expected from this model is opposite to the observed phase.

4.3. $\Phi-\phi$ model

Magnetospheric plasmas can be supplied from the sunlit ionosphere in high latitudes. If geomagnetic and geographic latitudes are denoted by Φ and ϕ, respectively, $T_{Pc\,4}$, $T_{Pc\,5}$, and D observed at a station in the hemisphere where $\Phi>\phi$ must exhibit such an annual variation as observed. So, this Φ-ϕ model seems to be possible for the observed annual variation, since all the stations, Syowa, Byrd, Fredericksburg, and Stanford are in this $\Phi>\phi$ hemisphere. However, it should be noticed that an annual variation in the Pc 3 period observed in Japan has the same phase, namely, $(T_{Pc\,3})_{DEC}>(T_{Pc\,3})_{JUN}$ (KAWAMURA *et al.*, 1979), even though Japan is in the $\Phi<\phi$ hemisphere.

5. Discussion and Conclusion

The present preliminary study provided more evidences to confirm the reality of the peculiar non-seasonal annual variation in the Pc 5 period. We examined the three models; sun-earth distance model, conjugate-point wandering model, and Φ–ϕ model. We have to continue this study to obtain the quantitative variation by using HISSA. Also we have to obtain a T_{Pc5} variation in the $\Phi<\phi$ hemisphere.

The dip latitude of the plasma trough in the Northern Hemisphere was reported to be generally lower in northern summer than in winter (Fig. 1 of THOMAS and RYCROFT, 1970) The L-value of the southern curtain of irregularities as observed by backscatter measurements at Lindau, W. Germany, was reported to be generally lower in May-July than in November-January (Fig. 20 of MÖLLER, 1974). Based on the data of scintillation boundary of satellite signals in the subauroral ionosphere, a non-seasonal annual variation in the size of the plasmasphere was suggested, namely, the size is smaller in June solstice than in December solstice (*eg*. OKSMAN, 1971; Fig. 7 of OKSMAN and TAURIAINEN, 1971, Fig. 6 of OKSMAN, 1979). All these results could be closely related with our results on the non-seasonal annual variation in the periods of Pc 5 observed at Syowa Station and of Pc 4 at Fredericksburg

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