COMPARATIVE STUDY OF MAGNETIC Pc 1 PULSATIONS OBSERVED AT LOW AND HIGH LATITUDES: LONG-TERM VARIATION OF OCCURRENCE FREQUENCY OF THE PULSATIONS

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***Abstract*:** Main purposes of this study are to clarify source region and generation mechanism of periodic emissions by means of comparison of characteristics of the emissions observed at high and low latitudes. In the present paper, long-term variations of the occurrence at Syowa Station and Memambetsu during five years from 1976 to 1980 are investigated statistically.

It is an important result obtained from the investigation that the variation has a clear reverse relation to that of the relative sunspot number, that is, the occurrence decreases with increase of the solar activity. More intense attenuation of the emissions in the ionospheric duct in such active years will be regarded as the main cause of the decrease. Because of inward shift of the plasmapause, the wave-particle interaction caused by ring-current protons will also hardly occur statistically in the active years. In other words, the long-term variation can also be explained well by the mechanisms of generation and propagation of the emissions proposed already by the same authors.

As an only event in 1980, periodic emissions with unusual low frequency were observed successively at Memambetsu throughout the day of December 20. As the frequency seems to be fairly lower than the cutoff frequency of the ionospheric duct, the emissions will be unable to propagate through the duct. Therefore, the source latitudes will be located near Memambetsu. The generation may be related to another exciting mechanism such as helium cyclotron resonance.

1. Introduction

Pc 1-range pulsations observed at Memambetsu, Kakioka, Kanoya and Chichi-jima are examined regularly. These four observatories constitute a network of surface stations at low latitudes. Particularly, the observations at Memambetsu and Kanoya are carried out continuously since the IQSY period (April 1964). Then, we have available data ranging over about 18 years. While, similar observations at Japanese Antarctic Stations, Syowa and Mizuho, are also carried out as a main project by the National

Institute of Polar Research.

Since the 1960's, the characteristics of pc 1-range pulsations have been analyzed with various types of dynamic spectral analyzers by many research workers (SAITO, 1960; HEACOCK and HESSLER, 1962; KATO and SAITO, 1964; TROITSKAYA, 1967; KAWAMURA, 1970; KOKUBUN, 1970; SAKURAI, 1975; FRASER, 1975; TOYA *et al.*, 1979; KUWASHIMA *et al.*, 1981; KAWAMURA *et al.*, 1981, 1982; FUKUNISHI *et al.*, 1981; HAYASHI *et al.*, 1981). Meanwhile, the theoretical studies of the pulsations have also been done by many workers. The generation mechanism in the magnetosphere has been examined by CORNWALL (1965), JACOBS and WATANABE (1966) and GENDRIN (1970). TEPLEY and LANDSHOFF (1966), MANCHESTER (1966) and GREIFINGER and GREIFINGER (1968, 1973) have introduced the ionospheric duct propagation theory. In spite of the many research works mentioned above, several important problems remain unresolved.

So far, there was considerable confusion in the research work on characteristics of pc 1. As is pointed out in the previous papers (FUKUNISHI *et al.*, 1981; KUWASHIMA *et al.*, 1981), pc 1-range pulsations observed at auroral latitudes can be classified into three groups, HM chorus, periodic emissions and others (such as IPDP, morning IPDP, dot and so on) and about half of them are HM chorus at least in two year period, 1977–1978. While, at low latitudes only periodic emissions are observed. Various differences in the characteristics of occurrence of pc 1 between auroral latitudes and low latitudes may be ascribed to the above facts.

As for the exciting mechanism of the periodic emissions, a model of proton cyclotron instability was proposed by CORNWALL (1965) and by JACOBS and WATANABE (1966). In the cases where the beam velocity of trapped protons exceeds the local Alfvén velocity, hydromagnetic waves at a frequency corresponding to the cyclotron resonance are emitted. It has been suggested that the particle energy of the storm-time ring current protons is transferred to the hydromagnetic wave energy through the instability. Significant relations between generation of the emissions and geomagnetic activity have been reported in our previous papers (TOYA *et al.*, 1979; KUWASHIMA *et al.*, 1981; KAWAMURA *et al.*, 1981, 1982).

Another important factor is the ionospheric effect on propagation of the waves from the source latitudes to lower and higher ones. According to the investigations by CAMPBELL and THORNBERRY (1972) and FRASER (1975), there is a remarkable westward propagation of the waves in the ionospheric duct. While, the observations by ALTHOUSE and DAVIS (1978) show that the propagation direction of the waves tends to coincide approximately with the geomagnetic meridian. Such an apparent contradiction in results should be clarified. In a previous paper (KAWAMURA *et al.*, 1981) the authors pointed out that the waves observed at low latitudes will propagate from the plasmapause latitudes to lower ones through the ionospheric duct along the magnetic meridian.

Long-term variation of occurrence of the pc 1 pulsations has been also investigated by some authors. FRASER-SMITH (1970) pointed out an approximate inverse relation between the occurrence rate of hydromagnetic emissions at California stations and the solar activity. MATVEYEVA *et al.* (1972) tried long-term prediction of the occurrence of the pc 1 by extrapolating the observational data in the present into the future. LEE and FRASER-SMITH (1975) investigated the periodicity of occurrence of pc 1 from the monthly occurrence obtained at the California stations during the 18.5 year period, January 1955 to June 1973, and also predicted the occurrence rate of the pulsations in the following several years. Recently, FRASER-SMITH (1981) compared the monthly occurrence of the pc 1-active days in California during the interval, 1970–1976, with the prediction curve and confirmed that the prediction was successful for the following years. In a previous paper, the authors pointed out that geomagnetic activity (*Dst*) was higher in 1978 than in 1977 but the occurrence of periodic emissions was fairly infrequent in 1978 than in 1977.

In the present paper, the long-term variation of pc 1-range pulsations is examined statistically based on the data obtained at Syowa Station and Memambetsu for the five-year period, 1976–1980. An approximate inverse relation between the pc 1 occurrence and the solar activity will be also discussed based on the above observational facts.

2. Long-term Variation of Occurrence of Periodic Emissions

In a previous paper (KAWAMURA *et al.*, 1982), the authors pointed out that, at both auroral and low latitudes, hydromagnetic emissions are observed usually during the recovery phase of an intense magnetic storm and that a peak of the occurrence at low latitudes appears on the second or third day after the maximum of *Dst* but the peak at auroral latitudes occurs about two days later than that at low latitudes. Daily occurrences of the emissions observed at Syowa (−66.7°, 72.4°) and Memambetsu

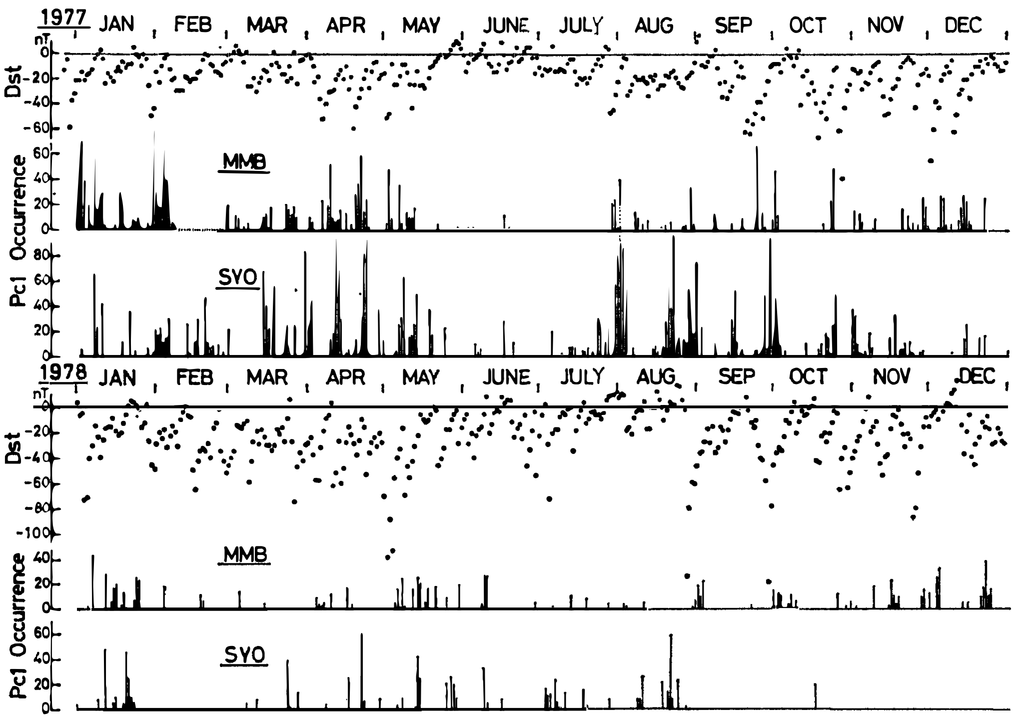

Fig. 1. Daily occurrences of periodic emissions observed at Syowa (SYO) and Memambetsu (MMB) and development of equatorial ring current (daily mean of Dst), in both 1977 (upper frame) and 1978 (lower frame).

(34.3°, 209.7°) are illustrated in Fig. 1 in comparison with daily means of equatorial *Dst*. The above-mentioned facts are clearly seen in the figure. In spite of such a close correlation between the occurrence and the geomagnetic activity (*Dst*), the occurrence frequency is rather lower in a more active year, 1978, than in 1977. It can be suggested from the fact that, although the periodic emissions are surely generated near the plasmapause by an ion-cyclotron resonance caused by ring-current protons, some other causes affecting considerably the occurrences at auroral and low latitudes must exist. Based on a spectral analysis of the data obtained at California stations over the 18.5 year period from January 1955 to June 1973, LEE and FRASER-SMITH (1975) have predicted the pc 1 occurrence for the following several years. Superimposed on a prediction

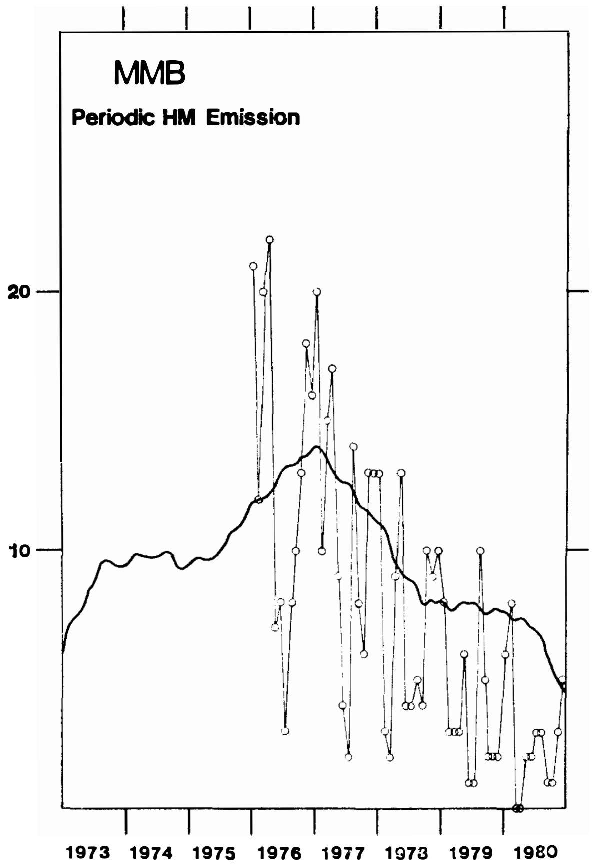

Fig. 2. Monthly occurrence of periodic emissions observed at MMB during five years, 1976–1980. The occurrence is superimposed on a prediction curve proposed by LEE and FRASER-SMITH.

curve of the occurrence proposed by them, monthly occurrence of the periodic emissions observed at Memambetsu during five years from 1976 is plotted in Fig. 2. The occurrence shows an well-known large fluctuation related to the seasonal variation and the *Dst* dependence, though the general trend in the five years is fairly consistent with their prediction. The authors have an intense interest in such a long-term variation in occurrence of pc 1-range pulsations, because the occurrence frequency seems to provide some essential information on plasmas in the magnetosphere.

3. Long-term Variation of Pc 1 Occurrence at Syowa Station

As pointed out in the preceding section, it will be important whether such a long-term variation of the occurrence is observed not only in periodic emissions but also in the other pc 1-range pulsations or not.

In the previous papers (FUKUNISHI *et al.*, 1981; KUWASHIMA *et al.*, 1981), the authors divided pc 1-range pulsations observed at Syowa Station into four characteristic groups and/or twelve subgroups. Long-term variation in occurrence of each sub-

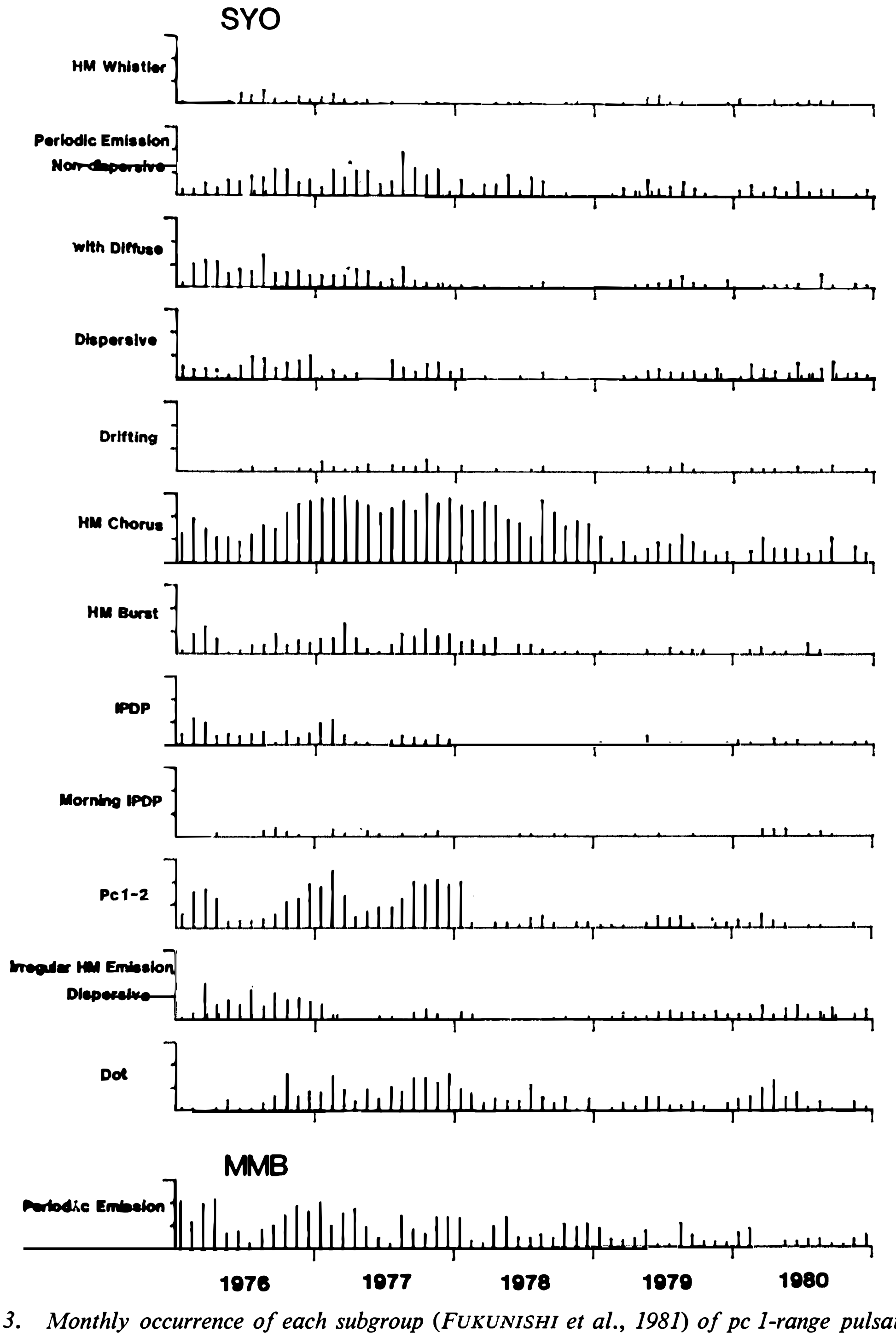

*Fig. 3. Monthly occurrence of each subgroup (*FUKUNISHI *et al., 1981) of pc 1-range pulsations observed at SYO during five years, 1976–1980. These long-term variations are compared with that of periodic emissions at MMB.*

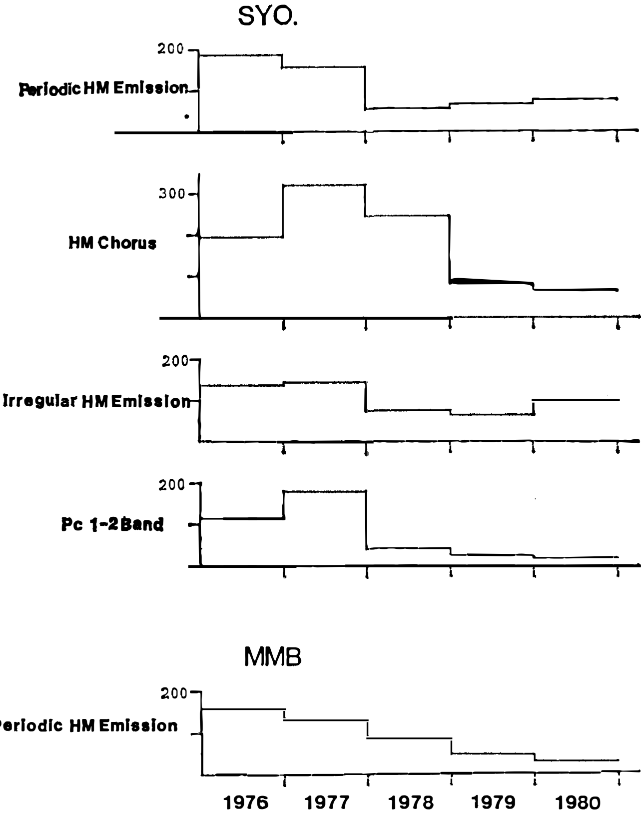

Fig. 4. Annual occurrences of four main groups (periodic HM emission, HM chorus, irregular HM emission and Pc 1–2 band) of pc 1-range pulsations observed at SYO during five years, 1976–1980. That of periodic HM emission at MMB is shown at the bottom of the figure.

group is investigated in detail in the present paper. The results are shown in Fig. 3 together with the occurrence of periodic emissions at Memambetsu. In the figure, each bar gives monthly occurrence of each subgroup. All subgroups but periodic emissions have clear maxima of the occurrence in 1977 and then the occurrences decrease sharply. Only the periodic emissions show the occurrence peaks in 1976. Yearly occurrence of the four groups, periodic hydromagnetic emission, hydromagnetic chorus, irregular hydromagnetic emission and pc 1–2 band, are summarized in Fig. 4. The above-described characteristics of the long-term variations pointed out in Fig. 3 are shown more clearly. Particularly, the occurrence ratio of the hydromagnetic chorus to all kind of the pc 1 pulsations decreased distinctly from 50% or more in 1977 to about a quarter in 1980. It should be noted that, although the generation mechanisms of these subgroups will differ from each other, the subgroups show similar long-term variation. The fact will give us an important information for interpretation of the plasma state and the dynamics in the magnetosphere.

LEE and FRASER-SMITH (1975) calculated the periodicity of the long-term variation of occurrence of the pc 1 by means of a frequency analysis from the data obtained at their California stations and showed 13.9 years as the most predominant period. In Fig. 5 the monthly occurrence of pc 1 at Syowa Station is superimposed on a smoothed prediction curve proposed by LEE and FRASER-SMITH (1975), together with the monthly occurrence of pc 1-active days obtained at Stanford, California, by FRASER-SMITH

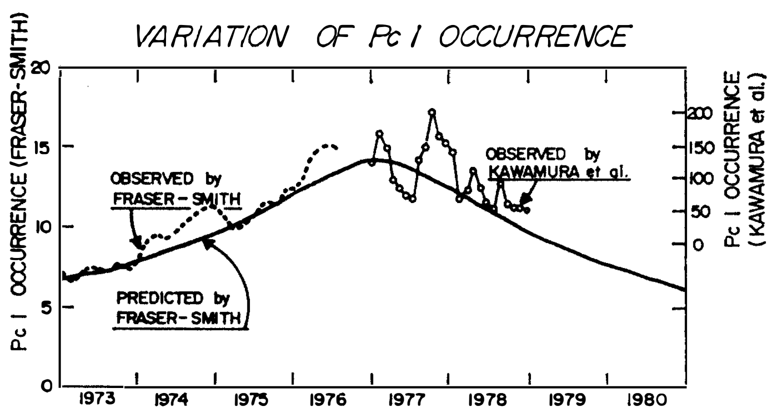

Fig. 5. Monthly number of pc 1-active days at Stanford during about four years, 1973–1976, and monthly occurrence of pc 1 pulsations at SYO during the following two years, 1977–1978. These are superimposed on a smoothed prediction curve by LEE *and* FRASER-SMITH.

(1981). It should be noticed in the figure that the scale of the ordinate is different between the results at Stanford and those at Syowa Station. For the FRASER-SMITH's observation, the ordinate shows a monthly number of days in which any periodic emission was observed. The prediction curve is also given with the same scale. While, the monthly occurrence at Syowa Station means a monthly number of 20-minutes intervals in which pc 1 pulsations but periodic emissions were observed. In spite of such clear differences of the scale and the pulsation type, the trend for the above different-type pc 1 pulsations also agrees well with the prediction. The fact gives an evidence that not only periodic emissions but also the other pc 1-range pulsations observed mainly at auroral latitudes show the same long-term trend.

In the lower frame of Fig. 6, the annual occurrence of the periodic emissions observed at Memambetsu is normalyzed in the same scale and connected to the monthly occurrence of the emissions at Stanford. Thus the long-term variation is compared with that of the annual-mean relative sunspot number in the same 22-year period (upper frame in the figure). The relative sunspot number is illustrated in the opposite sense.

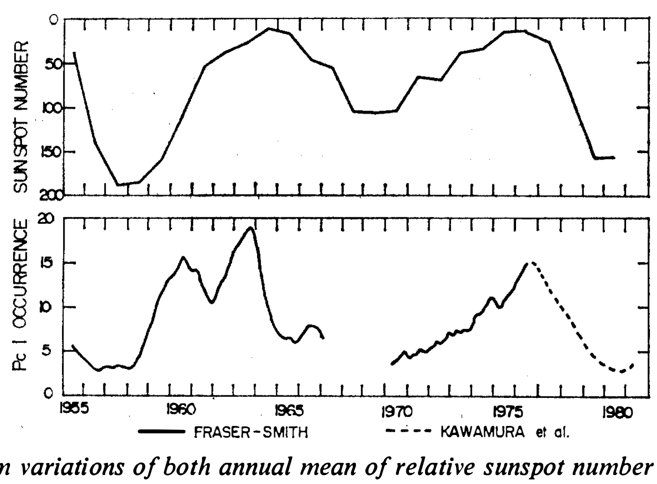

Fig. 6. Long-term variations of both annual mean of relative sunspot number (upper frame) and occurrence of pc 1 at low latitude stations (lower frame) during the period over two sunspot cycles.

It will be seen in the figure that the occurrence of the periodic emissions corresponds well to the solar activity and the occurrence peaks appear around sunspot minimum years. It should be noted that, in spite of the clear correlation of the occurrence of periodic emissions to the geomagnetic activity (*Dst*), the emissions are observed more frequently around the sunspot minimum year. As is well-known, the plasmapause shifts inwards with increase of the *Kp* activity. In relation to high *Kp* activity, in solar active years, the source region, plasmapause, of the periodic emissions will shift usually deeper inwards. In a previous paper (KAWAMURA *et al.*, 1982), the authors pointed out that the wave-particle interaction caused by ring-current protons are hard to occur in the initial and main phases of an intense magnetic storm. Therefore, it seems that the inverse correlation between the occurrence of the periodic emissions and the solar activity can be also explained by the same cause.

4. Periodic Emissions with Unusual Low Frequency

Examples of dynamic spectrum of the periodic emissions observed at Memambetsu are illustrated in the upper and lower frames of Fig. 7. The spectra in the upper frame were obtained on January 14, 1976, during the recovery phase of an ssc magnetic storm. Mid-frequency of the emissions is 1 Hz or more and shows an well-known characteristic diurnal variation which suggests the dawn-dusk asymmetry of the plasmasphere. While, it is seen clearly from the dynamic spectra in the lower frame that the emissions observed successively on December 20–21, 1980, in the recovery phase of an intense sc storm, have unusual low frequencies. The frequencies were at most 0.3 Hz. Particularly, one of the emissions observed at about 05 UT had a very low frequency of about 0.1 Hz. As already described, in 1980 only a few periodic emissions are observed at Memambetsu. And most of the emissions occurred on the above December 20–21. It is very interesting that only the emissions with such an unusual low frequency are observed at Memambetsu in solar active year, 1980.

In Fig. 8, the dynamic spectra at Memambetsu during about two days, December

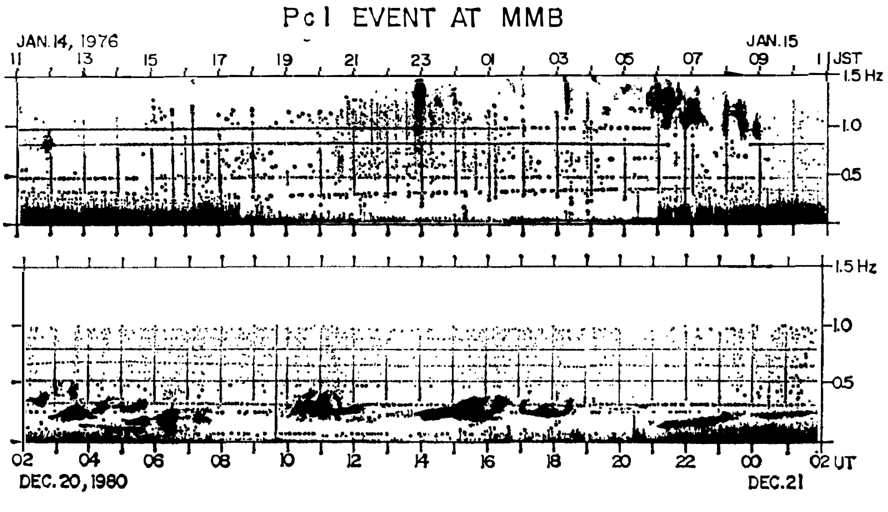

Fig. 7. Comparison of dynamic spectra of periodic emissions observed at MMB between sunspot minimum year, 1976 (upper frame), and the active year, 1980 (lower frame).

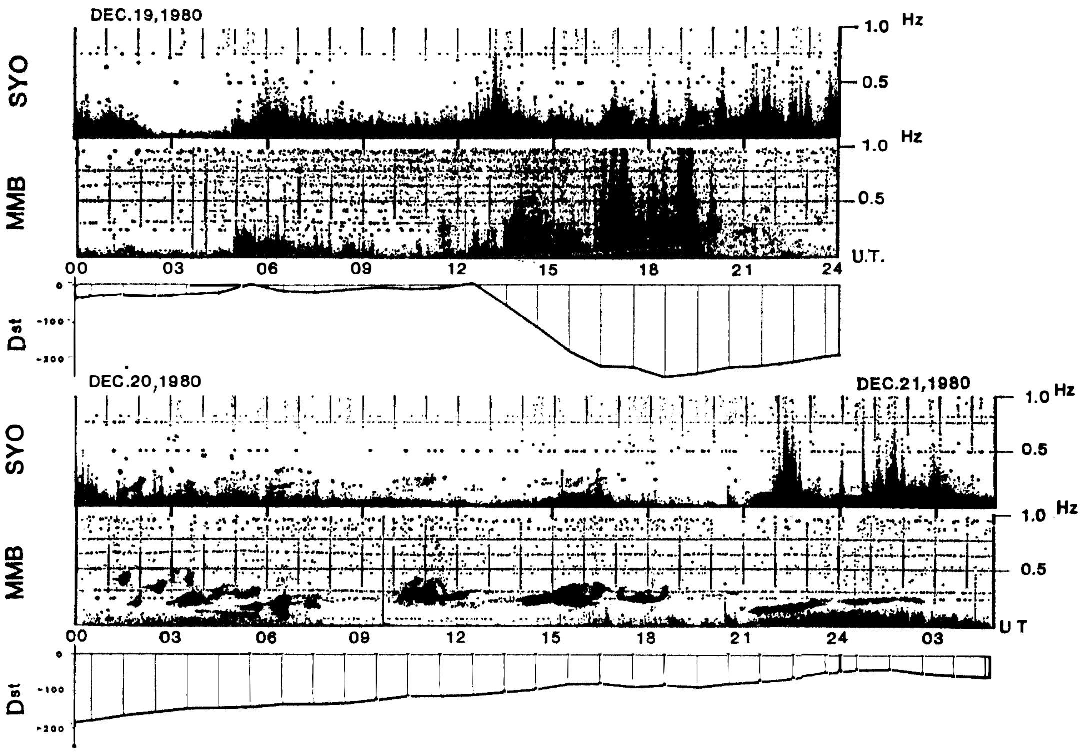

Fig. 8. Dynamic spectra of periodic emissions with an unusual low frequency observed successively at MMB in solar active year, December 1980.

19–20, are compared with those at Syowa Station on the corresponding days. The upper and lower frames show the spectra observed on December 19 and on December 20, respectively. Corresponding hourly *Dst* values are also given at the bottom of each frame. At Memambetsu, distinct periodic emissions with an unusually low frequency are observed successively throughout the day, December 20, which was in the recovery phase of an intense magnetic storm. While, at Syowa no periodic emission but weak traces is observed on that day and the following days. It is already pointed out in the previous papers (KAWAMURA *et al.*, 1981, 1982) that the well-known diurnal variation of occurrence of the waves, periodic emissions, at low latitudes can be explained by an attenuation in the propagation path, ionospheric duct. In other words, at a low latitude station, Memambetsu, periodic emissions should be observed usually in night hours. Nevertheless, the emissions on December 20 were observed all day long. It will be suggested from the fact that source latitudes of the periodic emissions are near Memambetsu. Moreover, the mid-frequency of the emissions is perhaps fairly lower than the cutoff frequency of the duct. Therefore, the emissions can not propagate through the duct. The fact will also lead to the same conclusion. However, there is an important question. The lower the source latitudes are, the higher the resonance frequency becomes usually. Nevertheless, the mid-frequency in this case was very low. Therefore, it may be speculated that the helium ions take part in the resonance. The question remains to be resolved.

5. Summary and Discussion

In the present paper, an essential long-term trend of occurrence of pc 1 pulsations, in particular hydromagnetic emissions, is examined statistically based upon the data obtained at Syowa Station in Antarctica and at Memambetsu in Japan. This trend shows a negative correlation to the solar and geomagnetic activities. The results are summarized as follows:

(1) Occurrence of the hydromagnetic emissions has a clear maximum around the sunspot minimum year at both auroral and low latitudes. The occurrence seems to be correlated negatively to the relative sunspot number.

(2) Occurrence of the other pc 1-range pulsations observed at auroral latitudes also shows similar long-term trend.

(3) Such a clear long-term trend of the occurrence of pc 1 pulsations observed at both Syowa Station and Memambetsu during the period from 1976 to 1980 can be connected smoothly to that observed at California stations during the preceding 20 years and also, on the whole, fits a curve predicted by LEE and FRASER-SMITH (1975).

(4) The long-term trend of the occurrence of the pc 1 pulsations seems to be interpreted as a sunspot cycle variation.

(5) At a low latitude station, Memambetsu, hydromagnetic emissions with an unusual low frequency are at times observed in solar active years.

It is already pointed out from the *Dst* dependence of the occurrence that the hydromagnetic emissions will be generated by an ion-cyclotron resonance in the recovery phase of an intense magnetic storm near the plasmapause and the time lag of the occurrence peaks between low and auroral latitudes will suggest an outward shift of the source region, plasmapause (KAWAMURA *et al.*, 1982). Nevertheless, long-term variation of the occurrence shows an inverse relation to those of geomagnetic and solar activities. In the active years, electron density of the ionosphere becomes higher and then the emissions will be subjected to more intense attenuation, compared with the cases in the quiet years. Therefore, the emissions in the active years may be difficult to propagate over such a long-range as that from the source latitudes to low or auroral latitudes through the ionospheric duct. Moreover, in the active years, the plasmapause will shift inwards statistically compared with that in the quiet years. In other words, plasmapause latitudes in the active years will be usually lower than those in the quiet years. Therefore, the wave-particle interaction caused by high energy beams (ring current protons) will hardly occur statistically in the active years, as though in initial and main phases of an intense magnetic storm. Because the plasmasphere will be compressed severely related to the higher *Kp* activity (KAWAMURA *et al.*, 1981, 1982). Moreover, it will be deduced from the lower shift of the plasmapause latitudes that a distinct decrease of the occurrence should be seen specially at auroral latitudes. These are perhaps the main reasons why such a clear solar cycle variation of the occurrence of the emissions is observed at both low and auroral latitudes. The above-described relation is also illustrated in Fig. 9.

It is also a well-known fact that the lower the plasmapause latitudes are, the higher the resonance frequency of the emissions becomes. Nevertheless, no periodic emission with such a higher frequency was observed at Memambetsu in the most active year,

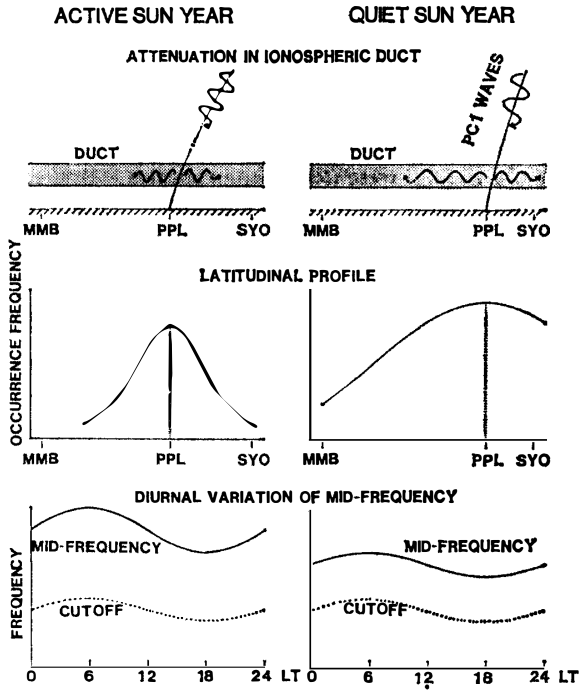

Fig. 9. A schematic model for long-term variation of occurrence of the periodic emissions at both auroral and low latitudes.

1980, of the present analysis. On the contrary, the emissions with an unusual low frequency were seen continuously throughout the day on December 20–21. Namely, the frequency was at most 0.3 Hz. On the other hand, as the lower limit of frequency of the periodic emissions observed at Memambetsu is 0.3–0.4 Hz usually, it may be regarded as a lower cutoff frequency in the ionospheric duct. Therefore, it can be deduced from the above-mentioned facts that the source latitudes of the emissions will be located near Memambetsu, because the emissions can not propagate in the ionospheric duct. Moreover, it will be suggested that cyclotron resonance by helium ions should be taken into consideration as a possible generation mechanism of periodic emissions with such an unusual low frequency.

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