IONOSPHERIC CONTROL OF THE LONG-TERM OCCURRENCE OF Pc1 PULSATIONS OBSERVED ON GROUND

K. Mursula, T. Rinne, J. Kangas and T. Pikkarainen

Physics Department, University of Oulu, SF-90570 Oulu, Finland

ABSTRACT

The approximate inverse correlation between the annual sunspot number and the annual amount of Pc1 pulsations observed on ground was recently verified using very long series of high- and mid-latitude observations extending over several complete solar cycles. We have now studied the solar cycle behaviour of the average frequency of Pc1 pulsations at high latitudes, classifying the events into structured and unstructured Pc1's. We find that the average frequency of structured Pc1's decreases with solar activity, but that of unstructured increases. These results support the idea that changes in the propagation conditions of the ionospheric wave guide over the solar cycle are the main factor responsible for the long-term occurrence rate of Pc1 pulsations detected by ground-based observers.

Keywords: Pc1 pulsations, Solar cycle changes, Ionospheric wave guide

1. INTRODUCTION

The Earth's ionosphere and magnetosphere are strongly influenced by solar activity and respond to its 11-year cycle. For example, the annual amount of Pc1 pulsations observed at low latitudes was already 30 years ago found to be in approximate inverse correlation with the annual sunspot number (Refs. 1-3). More recently, a similar anti-correlative relation was verified to be persistently valid for both mid- (Ref. 4) and high latitudes (Ref. 5) by using very long series of Pc1 observations extending over several complete solar cycles.

Pc1 pulsations can roughly be divided into structured and unstructured Pc1's (Ref. 6) according to their spectral characteristics (see Figure). Structured pulsations, also called periodic emissions, are by far the dominant Pc1 type at low and mid-latitudes (Refs. 2, 7). On the other hand, the majority of Pc1 pulsations at high latitudes are unstructured pulsations (Refs. 6, 8). The source region of structured Pc1's is close to the plasmapause (Ref. 9), but unstructured Pc1's originate at much higher latitudes (Refs. 10). In view of the differences between these two forms of Pc1 pulsations and their sources, it is an interesting and highly non-trivial fact that the Pc1 pulsations at both high, mid- and low latitudes have a roughly similar solar cycle behaviour. This underlines the need for a common explanation.

Three different mechanisms have been suggested to explain the observed anti-correlation: plasmapause position, magnetospheric heavy ions and ionospheric wave guide. The change of the average position of the plasmapause over the solar cycle is, due to the above mentioned connection (Ref. 9), expected to affect the amount of structured pulsations. However, it can hardly explain the long-term behaviour of unstructured pulsations. Secondly, magnetospheric heavy ions whose density increases sizably over the solar cycle (Refs. 11, 12) may affect the sources and the propagation conditions of ion cyclotron waves in the magnetosphere e.g. by forming stop bands, thus decreasing the amount of waves observed on ground. Thirdly, changes in the ionosphere over the solar cycle (e.g. increased amount of ionization and perturbations) decrease the wave propagation conditions in the ionospheric wave guide. Accordingly, waves can propagate in the wave guide further away from the magnetospheric footpoint during low solar activity, thus leading to an effectively larger amount of Pc1

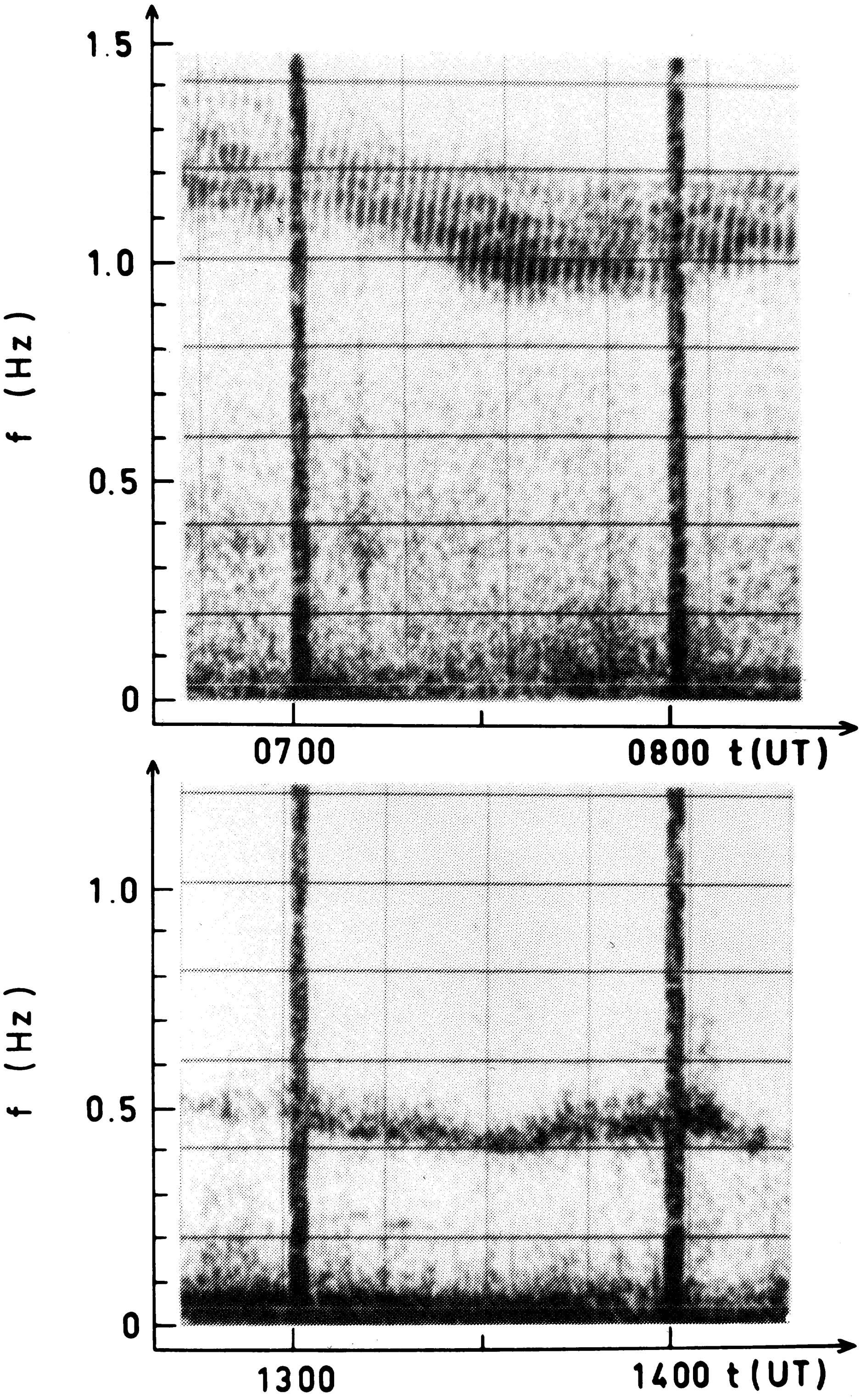

Figure. Dynamic spectra for typical structured (top) and unstructured (bottom) Pc1 pulsations registered at Sodankylä in the morning of March 27, 1975, and in the afternoon of March 6, 1976, respectively. Structured Pc1's are characterized by a series of separate successive intensity maxima which often are dispersive. No such structure is seen for unstructured pulsations. The average frequency of structured Pc1's is higher than that of unstructured Pc1's. Dynamic spectra were produced by a sonagraph using analogue magnetic registrations by a search-coil magnetometer.
The dark vertical lines are hour signals.

events observed by ground-based observers in sunspot minimum years.

In the present paper we study the solar cycle behaviour of the occurrence and, in particular, the average period of both structured and unstructured Pc1 pulsations. As we will discuss later, our results can naturally be understood in terms of the changes in the propagation conditions of the ionospheric wave guide. Therefore we suggest this mechanism as the main factor responsible for the solar cycle behaviour of Pc1's observed on ground.

2. EQUIPMENT AND DATA ANALYSIS

In this study we used data from a magnetometer situated at the high-latitude station (L=5.2) of the Sodankylä Geophysical Observatory, Finland. The equipment is an amplitude modulated search-coil magnetometer using analogue registration of data on 6"/h magnetic tapes. The magnetic registrations were first analyzed aurally and, after detecting pulsation activity, a sonagram was made using an analogue sonagraph (type number 7029A, Kay Elemetrics Corp.). For each verified Pc1 event we registered the start and stop times, as well as the mid-frequency at the start and its possible change during the event. Events were classified into the two above mentioned groups of structured and unstructured Pc1's on the basis of their sonagram signature. For occasional multi-band Pc1 events we counted each band as a separate event.

Since the main aim of this study is to examine the differences in the properties of Pc1 pulsations during the opposite phases of the solar cycle, we concentrated on two equinox months, March and April, of two sunspot number minimum years 1975-76 (with average annual sunspot numbers of 15.5 and 12.6, respectively) and two maximum years 1979-80 (155.4 and 154.6). By the choice of equinox months we try to maximize the number of Pc1 events and, in particular, to avoid the influence of possible seasonal variations without having to cover full years.

3. SOLAR CYCLE CHANGE OF Pc1 OCCURRENCE

Altogether 640 Pc1 events were observed during the 8 months analyzed with a total Pc1 active time of more than 40.5 days. The average length of all Pc1 events was about 91 minutes. The number of events, the total Pc1 active time and the average Pc1 frequencies for the two pulsation types and the two study periods with minimum and maximum sunspot activity are given in the Table.

Table: Properties of structured and unstructured Pc1 pulsations in sunspot minimum years (1975-76) and maximum years (1979-80). The number of events, their total time (in minutes) and the average frequency (in Hz) is given for both types of pulsations separately, as well as all pulsations together.

	Number of events	Total time (min)	Average frequency (Hz)
1975-76			
Struct.	224	21974	0.75
Unstruct.	296	30630	0.51
All	520	52604	0.61
1979-80			
Struct.	17	1702	0.69
Unstruct.	103	4061	0.62
All	120	5762	0.64

One can see in the Table that, first of all, there is a strong reduction in total Pc1 activity from the low sunspot years 1975-76 to high activity years 1979-80. While Pc1's appear up to about 30 % of the time during minimum years, Pc1 activity during maximum years is almost one order of magnitude lower. This is in accordance with the previous results showing a strong anticorrelation between Pc1 activity and sunspot activity (see e.g. Ref. 5 and references therein). Secondly, we can now verify this anticorrelation separately for both structured and unstructured pulsations. (The separation of the two Pc1 types was not possible in the resonance method used in Ref. 5). Thirdly, the Table shows interesting differences in the solar cycle behaviour of structured and unstructured Pc1 pulsations. Structured pulsations seem to be slightly more suppressed by high solar activity as their relative portion decreases from about 0.4 in minimum years to 0.3 in maximum years.

Furthermore, we wish to note that the average durations of structured and unstructured Pc1 pulsations are approximately the same (about one and a half hours) during sunspot minimum years but seem to deviate from each other during maximum years. While the average duration of structured pulsations in maximum years remains approximately the same as in minimum years, the duration of the unstructured pulsations in maximum years is decreased to about forty minutes, i.e. to less than one half of the value during minimum years.

4. SOLAR CYCLE CHANGE OF Pc1 PERIOD

The average frequency of all Pc1 pulsations as well as of structured and unstructured Pc1 events separately are given in the Table for both minimum and maximum sunspot years. One can see that the average frequency of all Pc1 pulsations remains nearly the same, increasing only slightly from 0.61 Hz in sunspot minimum years to 0.64 Hz in sunspot maximum years. More interestingly, notable differences between the two pulsation types are observed. The average frequency of structured pulsations is always higher than that of unstructured pulsations. This is consistent with the fact that the source of structured Pc1's is at lower latitudes than that of unstructured pulsations.

However, while the difference between the average frequencies of the two types is as large as 0.24 Hz in sunspot minimum years, in maximum years it is only 0.07 Hz. This is due to the fact that the average frequencies of the two pulsation types change in opposite directions. The average frequency of the structured pulsations decreases from 0.75 Hz to 0.69 Hz over the solar cycle while that of the unstructured pulsations increases from 0.51 Hz to 0.62 Hz.

5. DISCUSSION

Sodankylä is situated at a very suitable latitude where, as seen in the Table, a sizable amount of both structured and unstructured Pc1 pulsations is observed. As is well known, pulsations can propagate in the ionospheric wave guide, and some of these pulsations may have their footpoint at a sizable distance from Sodankylä. The latitude of Sodankylä is high enough to register unstructured pulsations whose source is located at still higher latitudes, and low enough to register the structured pulsations connected with the plasmapause. Plasmapause is above the latitude of Sodankylä only during the most quiet geomagnetic conditions. Therefore, most of the time the plasmapause is located at latitudes lower than Sodankylä, and most structured pulsations observed there have their origin to the south of Sodankylä.

Accordingly, the Sodankylä station registers pulsations whose footpoints, particularly in sunspot minimum years, cover quite a large range of latitudes. We call here the region from where the Pc1 pulsations propagate to Sodankylä the "propagation oval" around Sodankylä. Structured pulsations come, on an average, from the southern part of this oval and unstructured pulsations from its northern part. It is very interesting to note that all the observed features of the solar cycle behaviour of Pc1 pulsations can naturally be explained in terms of the contraction of the propagation oval. For example, if the effective radius of the propagation oval gets smaller by a factor of three in maximum years, the depletion of Pc1 activity by approximately one order of magnitude would follow (assuming constant activity of the source). Furthermore, both types of pulsations would originate in sunspot maximum years at field lines closer to Sodankylä than in minimum years. Therefore, the average frequency of structured (unstructured, respectively) pulsations would be lower (higher) in maximum years than in minimum years, in accordance with observations.

Such a contraction of the propagation oval is expected to occur due to the deterioration of the propagation conditions in the ionospheric wave guide during high sunspot activity. The importance of the ionospheric propagation conditions for Pc1 observations has previously been recognized e.g. by the fact that the diurnal variation of structured Pc1's at low and mid-latitudes prefers post-midnight to early morning hours (Ref. 10), following the minimum ionization of the ionosphere.

Let us now try to explain the observations presented in this paper in terms of other mechanisms. As a general comment one may first note that if the solar cycle changes observed on ground were only due to the modifications in the magnetospheric sources of Pc1 pulsations (leaving the ionospheric propagation conditions unchanged), then the sources of structured and unstructured pulsations would have to behave partly in the same way (decreasing pulsation activity with solar activity), partly in opposite ways (the former source decreasing the average pulsation frequency, the latter increasing). It may be hard to find a single physical mechanism which would affect the two magnetospheric sources in such a contrived way.

This note concerns most importantly one of the two alternative mechanisms, i.e. modifications caused by magnetospheric heavy ions. The increased number of heavy ions could, as mentioned above, cause the depletion of Pc1 activity via the formation of stop bands. However, it would be natural to expect that stop bands would decrease rather than increase the average pulsation frequency. Therefore, the observed notable increase in the frequency of unstructured pulsations would remain unexplained.

On the other hand, due to the connection with structured pulsations, changes in the plasmapause position can only affect structured pulsations. Therefore plasmapause can not explain the long-term development of unstructured pulsations. Even more generally, if the decrease (increase, respectively) of the average frequency of structured (unstructured) pulsations were due to the northward (southward) shift of its source, it would be difficult to understand why Pc1 activity decreases so dramatically although the source moves closer to Sodankylä. Accordingly, a shift in the average location of sources is not alone able to explain the observations.

6. CONCLUSIONS

In this paper we have studied the solar cycle changes in the amount and average frequency of structured and unstructured Pc1 pulsations observed at high latitudes. The strong anticorrelation between solar and Pc1 activity is observed to be valid for both Pc1 types separately.

The average frequency of all Pc1 pulsations is found to remain nearly constant over the solar cycle. However, the average frequency of structured (unstructured, respectively) pulsations decreases (increases) over the solar cycle. We note that all the long-term changes in Pc1 activity observed on ground can naturally be understood in terms of the deterioration of the propagation conditions of the ionospheric wave guide with high solar activity. Therefore we suggest that the ionospheric changes are dominant for the long-term Pc1 observations made by ground-based observers. However, this does not deny the possibility of long-term changes in the magnetospheric sources of Pc1 pulsations, but makes it difficult for ground-based observers to study them. Therefore analogous long-term observations of magnetospheric ion cyclotron waves using satellite instruments are highly desirable.

REFERENCES

1. Benioff, H. J. 1960, Observations of geomagnetic fluctuations in the period range 0.3 to 120 seconds, *J. Geophys. Res. 65*, 1413-1422.

2. Fraser-Smith, A. C. 1970, Some statistics on Pc1 geomagnetic micropulsation occurrence at middle latitudes: Inverse relation with sunspot cycle and semiannual period, *J. Geophys. Res. 75*, 4735-4745.

3. Matveyeva, E. T. & al. 1972, The long-term statistical forecast of geomagnetic pulsations of type Pc1 activity, *Planet. Space Sci. 20*, 637-638.

4. Matveyeva, E. T. 1987, Cyclic variation of the activity of Pc1 geomagnetic pulsations, *Geomagn. Aeron. 27*, 392-395.

5. Mursula, K., & al. 1991, Pc1 micropulsations at a high-latitude station: A study over nearly four solar cycles, *J. Geophys. Res. 96*, 17651-17661.

6. Fukunishi, H. & al. 1981, Classification of hydromagnetic emissions based on frequency-time spectra, *J. Geophys. Res. 86*, 9029-9039.

7. Kuwashima, M. & al. 1981, Comparative study of magnetic Pc1 pulsations between low latitudes and high latitudes: Statistical study, *Mem. Natl. Inst. Polar Res., Special Issue 18*, 101-117.

8. Nagata, T. & al. 1980, Classification of Pc1 and Pi1 waves observed in high latitudes, *Mem. Natl. Inst. Polar Res., Special Issue 16*, 56-71.

9. Fraser, B. J. & al. 1984, Pc1 pulsation source regions and their relationship to the plasmapause, *Eur. Space Agency Spec. Publ.*, ESA SP-217, 609-613.

10. Hayashi, K. et al. 1981, The extent of Pc1 source region in high latitudes, *Can. J. Phys. 59*, 1097-1105.

11. Young, D. T. 1983, Heavy ion plasmas in the outer magnetosphere, *J. Geophys. 52*, 167-175.

12. Stokholm, M. & al. 1989, Variations of the magnetospheric ion number densities near geostationary orbit with solar activity, *Ann. Geophys. 7*, 69-76.