THE SOLAR CYCLE BEHAVIOUR OF THE PERIOD OF STRUCTURED AND UNSTRUCTURED Pc1 PULSATIONS

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Abstract

We have studied the solar cycle behaviour of the period and occurrence rate of Pc1 micropulsations at the high-latitude station of Sodankylä, Finland (L=5.2). This analysis covers the two spring equinox months (March and April) in two sunspot minimum years, 1975-76, and in two maximum years, 1979-80. Pc1 events were classified into structured and unstructured pulsations. A strong depletion of both types of Pc1 pulsations during sunspot maximum years is observed with the relative amount of structured pulsations being slightly more depleted than the unstructured pulsations. We find out that the average period of all pulsations remains nearly constant over the solar cycle. However, the average periods of the structured and unstructured pulsations seem to change in opposite directions, the former increasing, the latter decreasing with increasing sunspot activity. These results support the idea that changes in the propagation conditions of the ionospheric waveguide are the main factor responsible for the depletion of Pc1 pulsations detected by ground-based observers during high sunspot activity years. Furthermore, the plasmapause position may also have an effect on the observed amount of structured Pc1s.

1. Introduction

The solar cycle variation of the occurrence of Pc1 micropulsations has been studied both at low and mid-latitudes [Benioff, 1960; Fraser-Smith, 1970 and 1981; Matveyeva et al., 1972; Strestik, 1981; Fujita and Owada, 1986; Matveyeva, 1987] and at high latitudes [Kawamura et al., 1983; Mursula et al., 1991]. The main result from these studies, roughly valid for all latitudes, is that the dominant feature in the long-term behaviour of the Pc1 activity is the solar activity cycle, and that more Pc1 pulsations occur during the sunspot minimum years than during the maximum years. Even in a more detailed analysis [Mursula et al., 1991], the long-term Pc1 activity curves at low and high latitudes were shown to have interesting similarities, following the changes in the annual sunspot activity from one solar cycle to another.

Some differences may also exist in the long-term Pc1 behaviour between low and high latitudes. Matveyeva [1987] has reported that the mid-latitude Pc1 events have their maximum in occurrence number and average frequency during the declining phase of odd solar cycles rather than during the minimum. If verified, this behaviour would notably differ from the strong negative correlation observed between annual sunspot numbers and the low-frequency Pc1s at high latitudes [Mursula et al., 1991]. However, these observations may be reconciled when the differences between the structured and unstructured pulsations and their source regions are taken into account.

While structured pulsations (also called periodic emissions) are the dominant Pc1 pulsation type at mid- and low-latitude stations [Fraser-Smith, 1970; Kawamura, 1970; Kuwashima et al., 1981], the majority of Pc1 pulsations at high latitudes are unstructured pulsations, particularly of the type of hydromagnetic chorus [Nagata et al., 1980; Fukunishi et al., 1981]. Many properties, e.g. diurnal distributions and average frequencies, are known to be different between structured and unstructured pulsations [Kuwashima et al., 1981]. It has also been found that the structured pulsations are intimately related to the evolution of magnetic storms [Wentworth, 1964; Plyasova-Bakunina and Matveyeva, 1968; Kuwashima et al., 1981], but the unstructured pulsations do not show such a dependence [Kuwashima et al., 1981]. These and other differences have led to the present view that, while the source region of structured pulsations is close to the plasmapause, the unstructured pulsations originate at much higher latitudes.

In view of these dramatic differences between the dominant forms of Pc1 pulsations at high and low latitudes, it is a remarkable and highly non-trivial fact that the Pc1 pulsations at both high-, mid- and low-latitudes have a roughly similar solar cycle behaviour, underlining the need for a general explanation. The long-term variation may, at least in principle, be due either to the changes in the intensity or position of the two source regions, or in the wave propagation conditions. Three physical mechanisms have been considered, including changes in either of both of these two cathegories: plasmapause position, magnetospheric heavy ions and ionospheric waveguide.

The change in the average position of plasmapause is a mechanism which, due to the connection mentioned above, is expected to affect the structured pulsations. However, it can not explain the long-term behaviour of unstructured pulsations. On the other hand, the observed increase of heavy ions in the magnetosphere [Young et al., 1981, 1982] may affect both the intensity of the source(s) and the wave propagation conditions in the magnetosphere. Due to the formation of stop bands, the amount of wave activity observed on ground may decrease and shift to lower frequencies. Thirdly, the amount ionization in the ionosphere increases in high sunspot number times and changes the properties of the ionospheric waveguide. This is already known to be a significant factor for Pc1 activity since, e.g., the diurnal distribution at low and mid-latitudes prefers post-midnight hours [see e.g. Kuwashima et al., 1981; Strestik, 1981], closely following the minimum ionization time of the ionosphere.

In the present paper we study the solar cycle behaviour of the occurrence and 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 waveguide. Therefore we suggest this as the main factor responsible for the solar cycle behaviour of Pc1s observed on ground. In the next section we will introduce the equipment used and the data collected for this analysis. Then, in sections 3 and 4, we will present our results for the solar cycle behaviour of the Pc1 occurrence and period, respectively. The results are discussed in section 5. Section 6 concludes the paper.

2. Equipment and data

In this study we have used data from a magnetometer situated at the high-latitude station of the Sodankylä Geophysical Observatory (geographic coordinates 67.4 Lat, 26.6 Long, corrected geomagnetic coordinates 63.9 Lat, 109 Long, L=5.2), Finland. The equipment is an amplitude modulated pulsation 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 with an analogue sonagraph (type number 7029A, Kay Elemetrics Corp.). For each true Pc1 event we then registered the start and stop times and the average frequency of the event, as well as the possible change of the mid-frequency during the event. For occasional multi-band Pc1 events we counted each band as a separate event.

When studying the period of magnetic pulsations one should correct the data of each event with the frequency response of the magnetometer. (The frequency response has a broad maximum at around 1 Hz). However, because the Pc1 pulsation bands have quite a narrow frequency range of about 0.2 Hz on an average, the mid-frequency of a Pc1 band, which was the main property registered in this study, remains almost constant in this correction. Therefore we can safely neglect the gargantuous amount of work which would be needed for a complete correction of all Pc1 events. We would also like to note that if the data were corrected, the mid-frequency of pulsations larger (smaller) than 1 Hz would slightly increase (decrease). Thus, since the average frequency of structured pulsations is larger than that of unstructured pulsations, the correction would make the differences between the average frequencies of structured and unstructured pulsations even larger than obtained now without correction. This would further strengthen the main observation presented in this work.

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. For that purpose, we concentrate 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 pulsation events and, in particular, to avoid the influence of possible seasonal variations without having to cover full years. As already mentioned, Pc1 pulsations were divided into two broad groups: structured pulsations (or periodic emissions) which show clear pearl-type intensity variations, and unstructured pulsations mainly consisting of hydromagnetic chorus and Pc1-2 band-type events.

3. Solar cycle change of Pc1 occurrence

We observed altogether 640 Pc1 events 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 times and the average event durations for the two pulsation types and the two study periods with minimum and maximum sunspot activity are given in the Table.

One can see from 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 Pc1s appear up to about 30 Pc1 activity during maximum years is almost one order of magnitude lower. This is in accordance with the previous results showing a strong negative correlation between Pc1 activity at high latitudes and sunspot activity (see e.g. Mursula et al., 1991, and references therein). We would also like to note that the Pc1 events during maximum years were found to be consistently much less intensive than during the minimum years. Secondly, we can now also verify that this reduction in the occurrence of Pc1 pulsations during high sunspot number years is separately true for both structured and unstructured pulsations. (The separation of the two different event types was not possible in the resonance method used by Mursula et al., 1991).

	Number of events	Total time (min)	Average duration (min)	Average frequency (Hz)
1975–76				
Structured	224	21974	98.1	0.75
Unstructured	296	30630	103.5	0.52
All	520	52604	101.2	0.62
1979–80				
Structured	17	1702	100.1	0.70
Unstructured	103	4061	39.4	0.61
All	120	5763	48.0	0.64
1975–80				
Structured	241	23676	98.2	0.75
Unstructured	399	34691	87.0	0.53
All	640	58367	91.2	0.62

Table. The properties of structured, unstructured and all pulsations for sunspot minimum years (1975-76), maximum years (1979-80) and the two periods added.

Thirdly, the Table also shows interesting differences in the solar cycle behaviour of structured and unstructured Pc1 pulsations. We find that the ratio in total active time between unstructured and structured pulsations seems to increase from about 1.4 for minimum sunspot years to 2.4 for maximum years. Accordingly, structured Pc1 pulsations seem to be relatively less abundant at high latitudes during high sunspot years than low sunspot years.

Furthermore, we wish to note from the Table 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.

Accordingly, it seems that sunspot activity affects, in addition to the common and dominant decreasing trend, slightly differently on the structured and unstructured pulsations observed at high latitudes. The structured pulsations are relatively more decreased in activity during the sunspot maximum years than the unstructured pulsations, but retain their other properties the same. However, the unstructured pulsation activity is slightly less suppressed by solar activity, but seems to get more patchy during high sunspot number years.

4. Solar cycle behaviour of Pc1 period

In order to study the solar cycle behaviour of the period of Pc1 pulsations we have calculated the average (mid-)frequency of structured and unstructured Pc1 events for minimum and maximum sunspot years. These results are also presented in the Table. (Since, as discussed above, Pc1 activity is much stronger during minimum than maximum years, the as the depletion of Pc1 activity of both types with increasing sunspot number would simply be due to the contraction of the propagation oval, whence both types of pulsations observed at Sodankylä in sunspot maximum years would originate at field lines closer to Sodankylä than in minimum years. Accordingly, the average frequency of the structured (unstructured) pulsations, coming, on an average, from the south (north) would be lower (higher) in maximum years. Such a contraction of the propagation oval would, of course, be due to the deteriorated Pc1 propagation conditions during high sunspot activity compared to low activity.

This interpretation is further supported by the fact that the average frequency of all pulsations remains almost constant over the solar cycle. The small increase of the total average frequency from 0.62 Hz to 0.64 Hz reflects the fact that the increase of the average frequency of unstructured pulsations, which are also more in number, is slightly larger than the corresponding decrease of the structured pulsations. This difference between the two pulsation types may possibly be due to the average position of the plasmapause (source of structured pulsations) being closer to Sodankylä than the average source of the unstructured pulsations. The smaller relative amount of structured pulsations during maximum years may, on the other hand, reflect the change of the plasmapause to lower latitudes in maximum years.

The observed decrease of the average duration of the unstructured pulsations during sunspot maximum years (patchyness) is the only fact which can not be naturally understood in terms of the above interpretation of an contracting propagation oval. This might be due to the natural intensity variations, which may remain unobserved for the stronger pulsation events of the minimum years and become observable for the more feeble pulsations of the maximum years. As a new finding, this subject needs to be verified by additional observations. However, if verified, it may reflect some real physical changes in the source of the unstructured pulsations.

Let us now compare the propagation oval explanation with other possible mechanisms. If the solar cycle changes were due to the change in the properties of the magnetospheric sources of Pc1 pulsations alone (leaving the ionospheric propagation conditions unchanged), then the source of structured pulsations would have to decrease its average frequency while that of the unstructured pulsations would have to behave in the opposite way. It is practically impossible to find one single mechanism which would affect the two sources in such a contrived way.

Therefore one needs different explanations for the structured and unstructured pulsations. As such, this would not be a serious limitation because of the many differences known to exist between the two pulsations types. However, when considering the two other physical mechanisms mentioned above, the observed changes in the average frequencies of structured and unstructured pulsations are opposite to those expected from these mechanisms. More specifically, one would, first of all, expect that the average frequency of structured pulsations would increase rather than decrease with the shrinking of the plasmapause in maximum years. Secondly, the increase in the amount of magnetospheric heavy ions during sunspot maximum times is expected to decrease rather than increase the average pulsation frequency and, thus, could not explain the increase of the average frequency of unstructured pulsations.

In summary, we think that the results presented in this study on the solar cycle change of the average frequency of structured and unstructured pulsations give strong evidence for the view that the change in the conditions of the ionospheric waveguide is the dominant mechanism responsible for the depletion of Pc1 pulsations observed on ground during high solar activity. However, we would like to note that this result does not deny the possibility average frequencies for the whole data period are almost the same as for the minimum years).

One can see, first of all, that the average frequency of all Pc1 pulsations remains nearly the same, increasing only slightly from 0.62 Hz in sunspot minimum years to 0.64 Hz in sunspot maximum years. This approximate constancy of the average Pc1 frequency over the opposite phases of the solar cycle is very interesting e.g. from the point of view of our long-term analysis [Mursula et al., 1991], where Pc1 pulsations were detected at the sharp eigenfrequencies of a resonant quick-run magnetometer. In that analysis, a strong negative correlation between annual Pc1 activity and annual sunspot number was found to persist over several solar cycles. However, since the eigenfrequencies were restricted between 0.3 Hz and 0.5 Hz, the observation of a negative correlation by this method could, in principle, be due to the rise of the average Pc1 frequency with increasing sunspot number, and not due to the actual depletion of Pc1 activity. With the present analysis we can further confirm the confidence in the results obtained by the resonance method and note that the observed depletion of Pc1 pulsations at high latitudes during high sunspot number years is not due to the rise of the average frequency.

Secondly, the Table shows that, again, there are notable differences between the two pulsation types. The average frequency of structured pulsations is seen to be consistently higher than that of unstructured pulsations. During sunspot minimum years the difference in the average frequencies of the two types is as large as 0.23 Hz. However, it is interesting to note that during maximum years this difference has decreased down to 0.09 Hz. This is due to the fact that, although the total average frequency remains almost constant, the average frequencies of the two pulsation types do in fact change, but in opposite directions. The average frequency of the structured pulsations decreases with sunspot number while that of the unstructured pulsations increases.

5. Discussion

Sodankylä is situated at an interesting latitude where, as seen in the Table, a sizable amount of both structured and unstructured Pc1 pulsations are observed. Pulsations can propagate via the ionospheric waveguide and may have their source at a sizable distance from Sodankylä. The latitude of Sodankylä is high enough to register the unstructured pulsations whose source is located at still higher latitudes, and low enough to register the structured pulsations connected with the position of 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 ionospheric footpoints cover quite a large range of latitudes. We call the region from where the bulk of the Pc1 pulsations are propagating to Sodankylä the propagation oval around Sodankylä. (Note that its value is also dependent on the magnetometer used, not only the position of the station). The higher (lower) the frequency of the observed pulsation event is, the lower (higher) latitude it, on an average, comes from. (The fact that the average frequency of structured pulsations is consistently higher than that of structured pulsations is another manifestation of this rule). The structured pulsations come mainly from the southern part of the propagation oval and unstructured pulsations from the northern part.

It is very natural to interpret the observed solar cycle changes in Pc1 occurrence and period in terms of the change of the size of the propagation oval. The decrease (increase, respectively) of the average frequency of structured (unstructured) pulsations, as well of long-term changes of the magnetospheric sources of Pc1 pulsations, but makes it very difficult for ground-based observers, for which the ionospheric changes seem to be more crucial, to study them. Therefore it would be highly desirable to make analogous long-term observations using satellite instruments.

6. Conclusions

In this analysis we have studied the solar cycle changes in the amount and average frequency of Pc1 pulsations observed at the high-latitude station of Sodankylä, Finland. We find out that the strong negative correlation between solar activity and Pc1 pulsation activity is separately valid for both structured and unstructured Pc1 pulsations. The average frequency of structured Pc1 pulsations is seen to be consistently higher than that of unstructured pulsations, in accordance with the view that the two pulsation types have different source mechanisms.

The average frequency of all Pc1 pulsations was found to remain almost constant over the solar cycle. However, the average frequency of structured (unstructured, respectively) pulsations was observed to decrease (increase) with sunspot number. These results give strong evidence for the view that the main factor responsible for the depletion of Pc1 activity in sunspot maximum years, as observed on ground, is the deterioration of the ionospheric propagation conditions. Accordingly, the ionospheric changes are dominant for observations made by ground-based observers, and make the observation of any other changes very difficult for these observers.

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