Published in: *Geophysica*, Vol. 35, Pages 23-31, 1999

Solar cycle variation in the occurrence rate of Pc 1 and IPDP type magnetic pulsations at Sodankylä

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Abstract

The observations of short-period magnetic pulsations at Sodankylä in the years 1974-1995 confirm that there is a 11-year solar cycle in the occurrence rate of both Pc1 and IPDP type magnetic pulsations. Sodankylä Geophysical Observatory provides one of the longest records for the studies of short-period magnetic pulsations.

1. Introduction

Variations in the Earth's magnetic field observed on the ground in the period range between 0.2 and 600 s are called (geo)magnetic pulsations or micropulsations (see e.g. Jacobs, 1970). They have been further classified into several subgroups according to their period and spectral structure: Continuous, more regular pulsations are divided into five groups Pc 1-5 and irregular pulsations into three groups Pi 1-3. This classification scheme supported by IAGA is still useful and widely used. However, more is now known about the generation mechanisms of magnetic pulsations and new schemes based on genetical classifications are discussed (see the review by Samson, 1991).

Pc1 magnetic pulsations which are investigated in the present study occupy the frequency band 0.2-5.0 Hz. Fukunishi et al. (1981) have shown that it is useful to divide this band still into several subgroups. One basic classification is into three main gategories: periodic or structured Pc1, non-periodic or unstructured Pc1 and others including the so-called Intervals of Pulsations of Diminishing Periods (IPDP).

Sodankylä Geophysical Observatory has had an important role in the studies of Pc1 pulsations. Geomagnetic pulsations in the Pc 3-5 period range were identified in ground-based recordings already more than 100 years ago. Special quick-run magnetographs with suitable recorders to observe more rapid variations were available only since the Second International Polar Year, 1932-1933. First observations of Pc1 pulsations were published by Leiv Harang from the Auroral Observatory, Tromsoe, Norway and Eyvind Sucksdorff from the Geophysical Observatory, Sodankylä in the same issue of the Journal of Terrestrial Magnetism and Atmospheric Electricity (Harang, 1936, Sucksdorff, 1936). Short-period oscillations identified in quick-run recordings were called "micropulsations" or "pearl necklace" by Sucksdorff and "vibrations" by Harang. These first observations have been discussed in more details by Mursula et al. (1994a).

It is generally accepted that both Pc1 and IPDP pulsations observed on the ground are due to the ion-cyclotron waves generated in the magnetospheric plasma. It is also known that the most favourable conditions for wave amplification, especially for structured Pc1 occurs in the plasmasphere or in the plasmapause region. The source of unstructured pulsations is at higher latitudes (Fukunishi et al., 1981). Periodic Pc1 pulsations appear mostly during the recovery phase of the magnetic storm, whereas IPDP wave events are intimately associated with the magnetospheric substorm activity (as an extended review, see Kangas et al., 1998).

Both Pc1 and IPDP pulsations are signals of the changing plasma environment of the Earth. This environment is controlled by the solar and solar wind activities and one of the most prominent changing activity is associated with the 11- year cycle of sunspots. There are several studies of the long-term variation of the occurrence of Pc1 pulsations on the ground and the general conclusion is that there is the 11-year activity cycle also in both structured and unstructured Pc1pulsations and that more pulsations occur during the solar minimum years than during the maximum years (see Mursula et al., 1991, Mursula et al., 1994b and Kangas et al, 1998 and references therein). Less is known about the changes in the IPDP activity during the solar cycle but Pikkarainen (1987) and Maltseva et al. (1988) showed that the same negative correlation between the annual IPDP activity and the annual sunspot number seems to exist as between the Pc1 activity and sunspot number.

Much of the data used so far in the studies of the solar cycle effects on short-period magnetic pulsations has been recorded and collected by the Sodankylä Geophysical Observatory. The main aim of this study is to add the most recent observations made at Sodankylä to the data analysis of the long-term variation of Pc1 and IPDP pulsations at a high-latitude station. This complete data set confirms the earlier findings of the inverse relation with sunspot cycle for both Pc1 and IPDP pulsations.

2. Examples of Pc1 and IPDP pulsation events

The oldest data of Pc1 observations made at Sodankylä dates from the 30'ies when quick-run recordings of the La-Cour type magnetometer were made available as mentioned above. These recordings allow to detect Pc1 pulsations at a frequency close to the eigenfrequency of the magnetometer system. This data has been presented and discussed widely by Mursula et al. (1991).

In this paper we analyse the more recent observations made by the induction coil magnetometer at Sodankylä with a suitable magnetic tape recording system since the year 1974. This data makes it possible to study short-period magnetic pulsations by a more modern method over about two solar cycles. As the Sodankylä data system was changed in June, 1995 we include in our analysis the data only until that date in order to secure the homogeneity of data.

In Figs. 1 and 2 we show typical examples of the structured and unstructured Pc1 as well as IPDP pulsations, respectively recorded at Sodankylä. The structured Pc1 pulsation is characterized by a repetitive structure which often shows a dispersion of waves. This is traditionally interpreted in the framework of the bouncing wave packet model (as a review, see Kangas et al., 1998). This interpretation has been recently questioned by Mursula et al. (1997). Unstructured Pc1 pulsations do not show such a structure and their frequency is typically lower than that of structured Pc1 pulsations.

The most typical feature of IPDP type wave events is their frequency modulation as shown in Fig. 2. Within about half an hour the midfrequency increases from fractions of Hertz to about 1 Hz. Sometimes a series of IPDP events may occur as shown in Fig.2. Several mechanisms to explain the frequency rise have been suggested such as increase of the background magnetic field in the generation region, radial motion of the source region under the action of a large-scale electric field and azimuthal drift of generating protons in the magnetosphere (for details, see a review by Kangas et al., 1998).

3. Solar cycle variation in Pc1 and IPDP occurrence rate at Sodankylä

Sodankylä induction coil magnetometer data has been analysed by the spectrum analyzer to get the dynamic spectra of magnetic pulsations in the Pc1 frequency range. Both structured and unstructured Pc1 pulsations have been identified and their annual duration has been determined. The occurrrence rate of all Pc1 pulsations has been defined as the percentage of their duration with respect to the total annual observation time. The results for the years from 1974 to 1995 are shown in Fig. 3.

The Pc1 activity has been very high during the years 1974-77, 1984-87 and 1993-95, i.e. around the minimum epochs of the solar 11-year cycle. The occurrence rate has been quite low in the years 1979-82, 1989-91, i.e. around the maximum phase of the solar cycle.

The same analysis has been made to the IPDP wave events identified in Sodankylä recordings in 1974-1995. The variation in the annual number of events is illustrated by Fig.4. A remarkable similarity with Fig. 3 can be noted.

Fig. 5 shows the relationship between the pulsation activity at Sodankylä and sunspot number in detail. It illustrates the negative correlation with quite a high correlation coefficient -0,893 and -0,856 for Pc1 and IPDP pulsations, respectively.

4. Discussion

Our careful analysis of Pc1 and IPDP magnetic pulsations recorded at the Sodankylä Geophysical Observatory in 1974-95, i.e. over about two solar cycles confirms the earlier findings that there is an inverse relation with the solar activity measured by the sunspot number for both types of magnetic pulsations..

It is interesting that both types of short-period magnetic pulsations show the same behaviour. As was mentioned before IPDP pulsations have a more direct relationship to magnetic activity as they are associated with the substorm activity. They may appear at any phase of the magnetic storm as shown by Maltseva et al. (1988). The most active intervals of structured Pc1 occur during recovery phase of the magnetic storm, i.e. during relatively quiet magnetic conditions.

It was already mentioned and shown by Figs. 1 and 2 that there is a prominent difference between Pc1 and IPDP both in the character of their frequency modulation and in the bandwidth of wave excitation. There is also a great difference in the duration of events: structured Pc1 events last typically for hours whereas IPDP events are much shorter.

Mursula et al. (1994b) showed in their analysis of structured Pc1 pulsations that the average frequency of pulsations tends to decrease with solar activity. On the other hand Pikkarainen (1987) has reported that the highest end frequency in IPDP has been 0.8 Hz or smaller in solar active years whereas in quiet years it has been above 1.2 Hz.

Sometimes a periodic structure can be seen also in IPDP (see e.g. Kangas et al., 1998). But this is not the case in general and it is most probable due to the non-stationarity of the IPDP source. In spite of differences between Pc1 and IPDP it is most likely that they can be classified as a single group as discussed by Kangas et al. (1998).

There is no accepted theory to explain the observed inverse relation between Pc1 as well as IPDP occurrence and solar activity. Several mechanisms have been suggested: plasmapause position, heavy ions in the magnetospheric plasma and ionospheric wave guide (see e.g. Mursula et al., 1994b). It is most probable that all of them must be taken into account.

In the present analysis we have not made any difference between structured and unstructured Pc1 magnetic pulsations. As was already mentioned both types of pulsations observed on the ground follow the same long-term evolution with respect to the solar activity. It is most important that Mursula et al. (1996) have shown that the Pc1 activity in space observed by satellites seems to follow also the solar activity cycle. These pulsations were identified as unstructured Pc1 pulsations. Mursula et al. (1996) conclude that the long-term variation of high-latitude (unstructured) Pc1's may entirely be due to a change in wave generation. Mursula et al. (1996) conclude also that the two types of Pc1's remain separate over the solar cycle and it is not clear if the "external" interpretation suggested by Mursula et al. (1996) can also be applied on structured Pc1's.

The plasmapause seems to be an important source region of structured Pc 1 pulsations. It generates favourable conditions for both ion cyclotron instability and magnetospheric propagation of waves. On the other hand, it is known that the plasmasphere is more compressed during high solar activity. One conclusion might be that at middle latitudes the solar cycle effect on structured Pc1's should be small. However, a prominent effect has been observed (see eg. Matveyeva, 1987). Thus the "plasmapause" interpretation alone is not enough to explain the long-term variation of structured Pc1 occurrence.

Nevanlinna and Pulkkinen (1998) developed a substorm strength index using geomagnetic recordings from Sodankylä Geophysical Observatory. This index shows a correlation with the sunspot number with a multi-peak structure, one maximum being before the sunspot number maximum and another one during the the declining phase of the solar cycle. It is interesting that the peaks in our Fig. 4 in 1976-77 and 1985-87 correspond to low values of the substorm strength index whereas the IPDP maximum in 1993-95 coincides with the peak value of the substorm strength index. This comparison indicates that there is no straightforward relation between the generation of IPDP pulsation events and local substorm activity.

In conclusion, several physical parameters have been identified which control the long-term variation of both Pc1 and IPDP pulsation activity. However, the relative contribution of each of them is still unknown. It seems that the "magnetospheric" interpretation is quite appealing but more long-term measurements of the magnetospheric plasma environment are needed in order to clarify this issue.

Acknowledgements

We are grateful to the staff of the Sodankylä Geophysical Observatory for their long and dedicated care of the recordings of magnetic pulsations at Sodankylä.

References

Jacobs, J.A., 1970. Geomagnetic Micropulsations, Springer-Verlag, New York.

Fukunishi, H., Toya, T., Koike, K., Kuwashima, M. and Kawamura, M., 1981. Classification of hydromagnetic emissions based on frequency-time spectra, J. Geophys. Res., 86, 9029-9039.

Harang, L., 1936. Oscillations and vibrations in magnetic records at high-latitude station, Terrest. Magn. Atmospheric Electr., 41, 329-336.

Kangas, J., Guglielmi, A. and Pokhotelov, O., 1998. Morphology and physics of short-period magnetic pulsations (A review), Space. Sci. Rev., 83, 435-512.

Maltseva, N., Kangas, J., Pikkarainen, T. and Olson, J.V., 1988. Solar cycle effects in Intervals of Pulsations of Diminishing Periods pulsation activity, J. Geophys. Res., 93, 5937-5941.

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

Mursula, K., Kangas, J., Pikkarainen, T. and Kivinen, M., 1991. Pc1 micropulsations at a high-latitude station: A study over nearly four solar cycles, J. Geophys. Res., 96, 17651-17661.

Mursula, K., Kangas, J. and Kultima, J., 1994a. Looking back at the early years of Pc1 pulsation research, EOS, 75, 357.

Mursula, K., Kangas, J. and Pikkarainen, T., 1994b. Properties of structured and unstructured Pc1 pulsations at high latitudes: Variation over the 21st solar cycle, In: Solar Wind Sources of Magnetospheric Ultra-Low-Frequency Waves, AGU Geophysical Monograph, 81, 409-415.

Mursula, K., Anderson, B.J., Erlandsson, R.E. and Pikkarainen, T., 1996. Solar cycle change of Pc1 waves observed by an equatorial satellite and on the ground, Adv. Space Res., 17, (10)51-(10)55.

Mursula, K., Rasinkangas, R., Bosinger, T., Erlandson, R.E. and Lindqvist, P.-A., 1997. Nonbouncing Pc1 wave bursts, J. Geophys. Res., 102, 17611-17624.

Nevanlinna, H. and Pulkkinen, T., 1998. Solar cycle correlations of substorm and auroral occurrence frequency, Geophys. Res. Lett., 25, 3087-3090.

Pikkarainen, T., 1987. Statistical results of IPDP pulsations recorded in Finland during 1975-1979, Geophysica, 23, 1-19.

Samson, J.C., 1991. Geomagnetic pulsations and plasma waves in the Earth's magnetosphere, In: J.A. Jacobs (ed.), Geomagnetism, Academic Press, London, pp. 481-592.

Sucksdorff, E., 1936. Occurrences of rapid micropulsations at Sodankylä during 1932 to 1935, Terrest. Magn. Atmospheric. Electr., 41, 337-344.

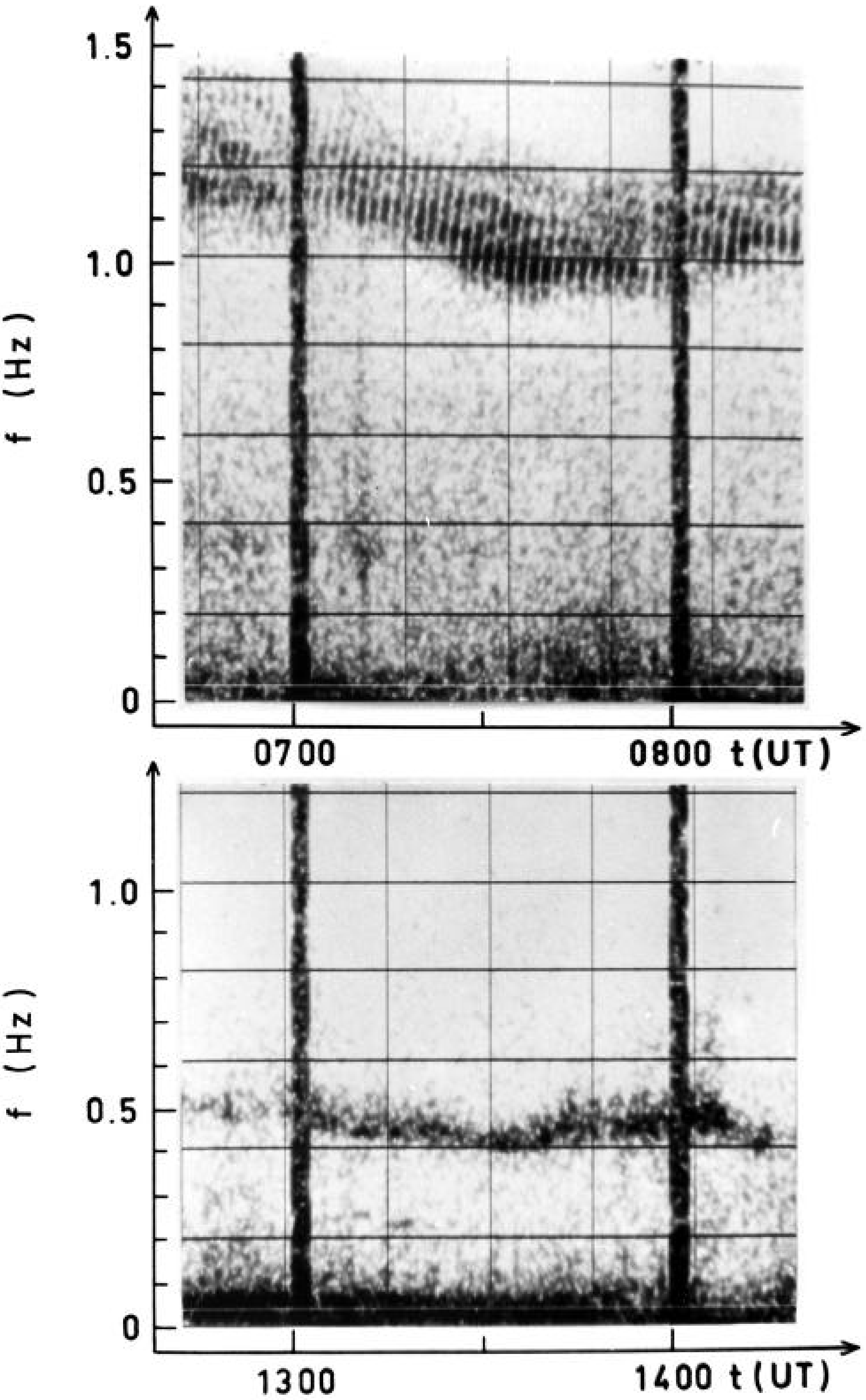

Fig.1

Dynamic spectra of structured (top) and unstructured (bottom) Pc1 pulsations registered at Sodankylä on March 27, 1975 and on March 6, 1976, respectively.

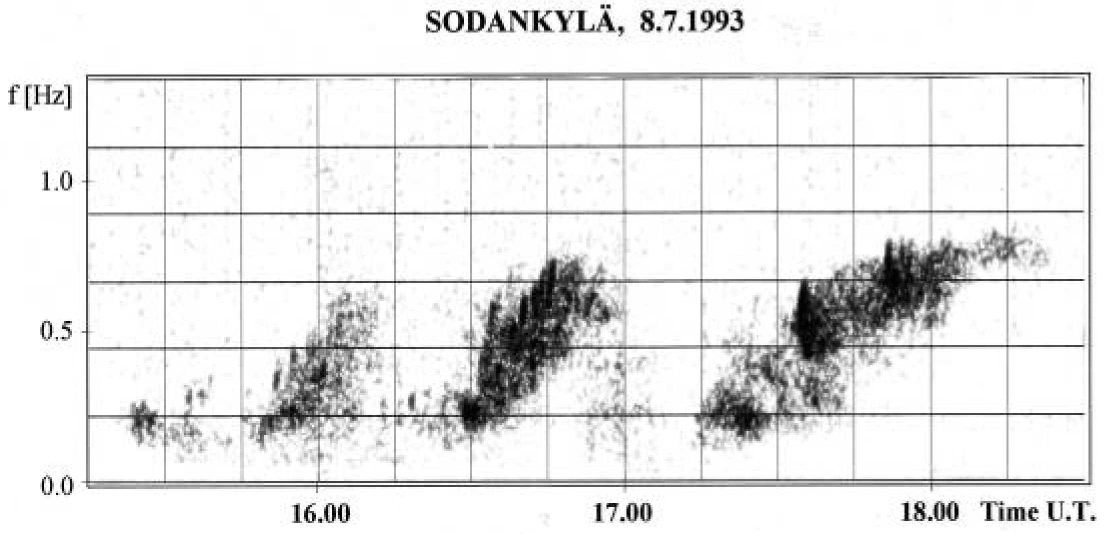

Fig. 2

IPDP type wave events recorded at Sodankylä on July 8, 1993

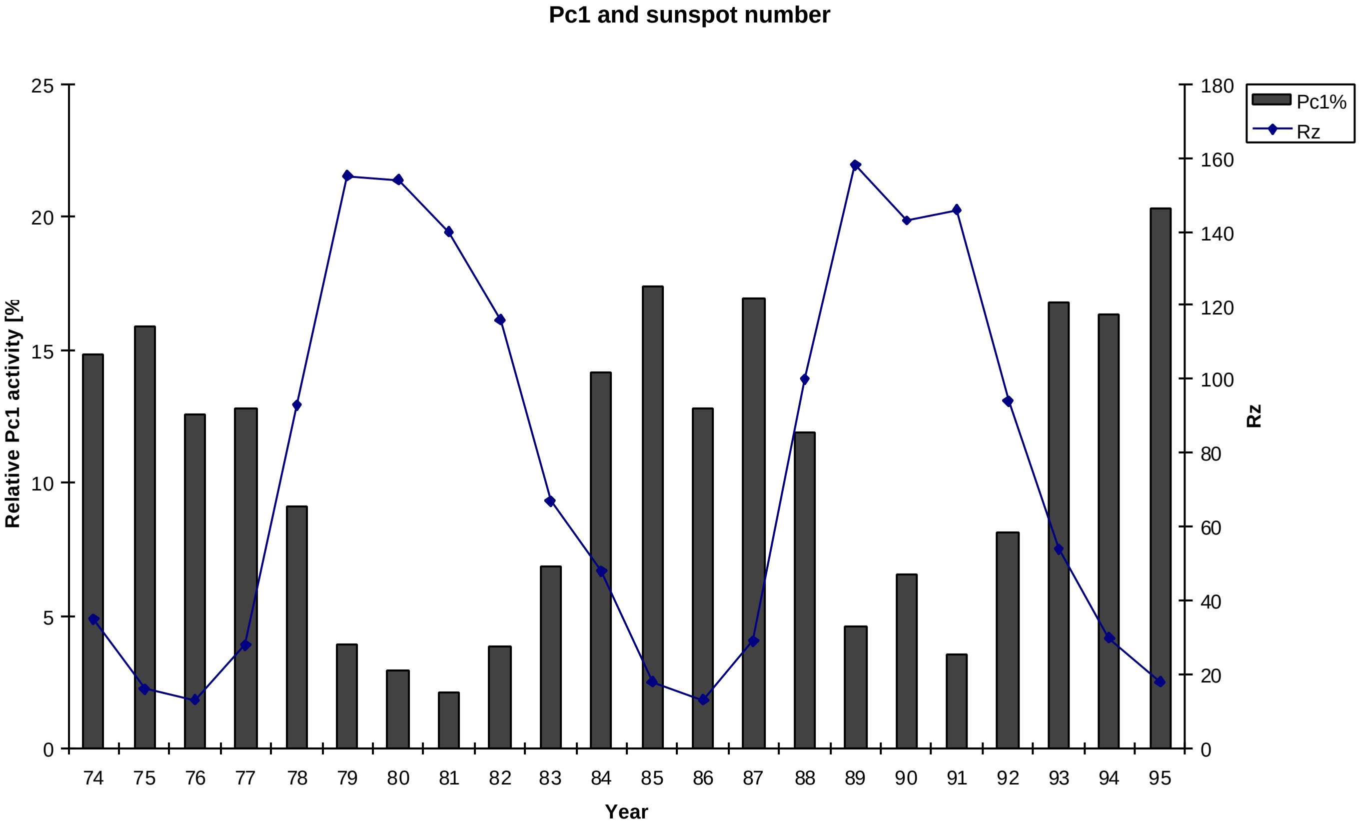

Fig. 3

Occurrence rate of Pc1 magnetic pulsations at Sodankylä in percentages in 1974-95. Annual mean of the sunspot number is given by the solid line. (Note: There have been breaks in Sodankylä recordings using the data system run since 1974 in March-August, 1994 and after May, 1995. For these periods complementary data from Oulu and Ivalo has been used.)

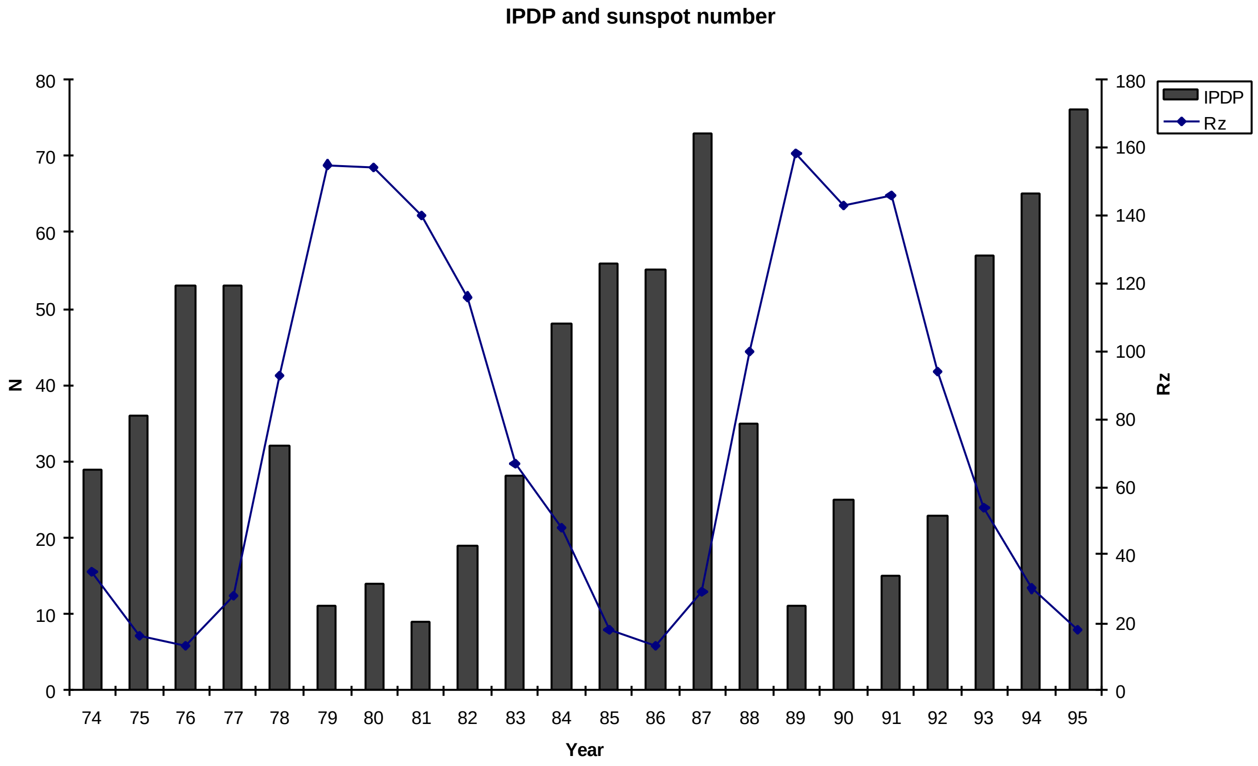

Fig. 4

Annual number of the IPDP events observed at Sodankylä in 1974-95. Annual mean of the sunspot number is given by the solid line. (See the notes in Fig. 3.)

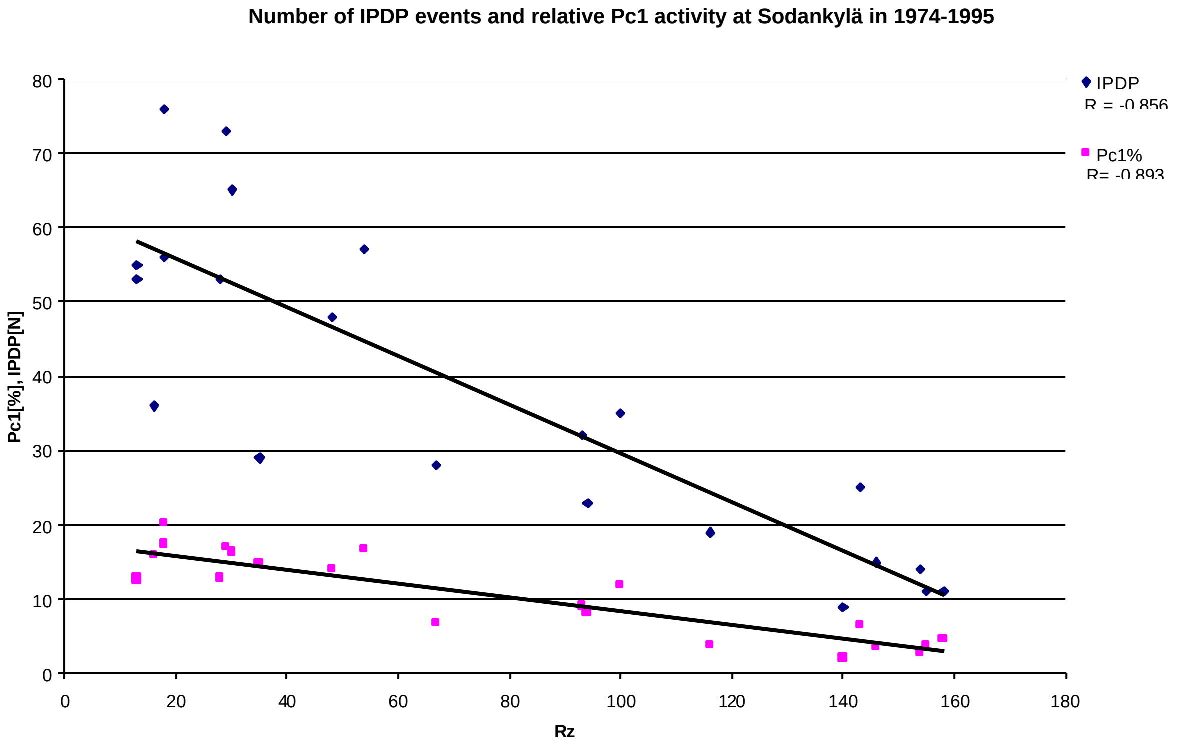

Fig. 5.

Annual relative Pc1 activity in percentages and number of IPDP events recorded at Sodankylä in 1974-1995 as a function of the annual mean of the sunspot number.