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IPDP geomagnetic pulsations and their relation to coronal holes and high speed solar wind streams

S. Bravo and J.A.L. Cruz-Abeyro
Instituto de Geofísica, UNAM
México D.F., México

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RESUMEN

La frecuencia de ocurrencia de intervalos de pulsaciones de periodo decreciente (IPDP) muestra una correlación inversa con el número de manchas solares, contrariamente a lo que ocurre con la actividad geomagnética en general. En este trabajo tomamos la frecuencia anual de ocurrencia de IPDPs en la estación de Sodankyla para los años 1974-1985 (un ciclo solar) y encontramos que los IPDP tienen una correlación positiva con el área de los hoyos coronales solares, con un coeficiente de correlación de 0.77. Esto sugiere una correlación física entre este tipo de pulsaciones y las corrientes de viento solar rápido (HSSs) que se originan en los hoyos coronales. Comparamos la ocurrencia anual de IPDPs en el periodo 1974-1982 con el número anual de HSSs asociados a hoyos coronales, con velocidades mayores o iguales que 550 km/s en esos años y encontramos una buena correlación alrededor del máximo y en la parte descendente del ciclo. Sin embargo, durante el mínimo y la fase ascendente del ciclo, los IPDPs fueron más frecuentes que los HSSs. Concluimos que la ocurrencia de los IPDPs parece estar relacionada con ciertas propiedades del viento solar de alta velocidad y discutimos una posible causa de las diferencias cerca del mínimo.

PALABRAS CLAVE: Actividad geomagnética, pulsaciones magnéticas, interacción viento solar-magnetosfera.

ABSTRACT

The frequency of occurrence of intervals of pulsations of diminishing periods (IPDP) has shown a very surprising inverse relation to the sunspot number. In this paper we take the annual frequency of occurrence of IPDPs at Sodankyla station for the period 1974 to 1985 and find that they correlate positively with coronal hole area with a correlation coefficient of 0.77. This suggests a physical relationship between this kind of pulsations and the high speed streams (HSSs) in the solar wind coming from the holes. We compare the annual rate of IPDPs to the annual number of coronal-hole associated HSSs having a velocity equal to or higher than 550 km/s for the period from 1974 to 1982. We find a good agreement during the descending part of the solar cycle and around the maximum, but during the minimum and the first years of the ascending phase IPDPs were more frequent than HSSs. We conclude that IPDPs are related to some solar wind characteristics in HSSs and we discuss a possible reason for the differences during the minimum.

KEY WORDS: Geomagnetic activity, magnetic pulsations, solar wind-magnetosphere interaction.

INTRODUCTION

Hydromagnetic emissions in the Pc1 period range of 0.2-5 seconds are divided in several categories one of which includes the so-called intervals of pulsations of diminishing periods (IPDP). IPDP magnetic pulsations observed on the ground are characterized by a decreasing period, typically from 5-10 to 1-2 seconds in 0.5-2 hours which is the duration of the event. It is generally accepted that these pulsations are due to ion-cyclotron waves (ICW) generated in the magnetospheric plasma. Favorable conditions for IPDP generation seem to exist especially in the plasmaspheric bulge region in the evening sector of the magnetosphere where the protons injected during a substorm meet the increasing cold plasma density of the plasmasphere. IPDP type events are indeed intimately associated with the magnetospheric substorm activity and are most often observed at evening and night (Heacock, 1971; Cruz-Abeyro, 1982; Pikkarainen *et al.*, 1983).

The long-term variation of IPDP magnetic pulsations has been studied by Cruz-Abeyro (1982), Kawamura *et al.* (1983), and Maltseva *et al.* (1988). They conclude that there is an inverse relation between the frequency of occurrence of IPDP events and sunspot cycle. As magnetic activity is high during sunspot maximum years and IPDP are directly associated with magnetic disturbances, this inverse relation was unexpected, but Hayashi *et al.* (1984) reported also that, surprisingly, during high solar activity, many substorms were not accompanied by IPDP pulsations.

On the other hand, Maltseva *et al.* (1988) found that IPDP are more frequent during recurrent magnetic storms typically in the period of low solar activity. Recurrent geomagnetic storms are associated with recurrent high-speed solar wind streams, whose sources are large and long-lived solar coronal holes (see for instance Krieger *et al.* 1973; Sheeley *et al.* 1977). The stability and size of coronal holes have an inverse relation to the sunspot number: the holes are much larger and more stable around sunspot minimum and smaller and short-lived at times of high solar activity.

Bravo and Otaola (1989) found a very good correlation between the size of polar coronal holes and the sunspot number about half a solar cycle later. Thus, as IPDP pulsations are inversely correlated with the sunspot number, we would expect to find a positive correlation between the frequency of occurrenc of IPDP pulsations and the size of polar coronal holes, and probably a direct association of this type of pulsations with the Earth crossing the high speed solar wind streams generated in these holes.

IPDPs AND CORONAL HOLE LONG-TERM VARIATION

IPDPs are very frequent during the years of low solar activity and they are rare during a solar maximum. As a representative sample of the long-term variation of IPDP pulsations, we took the observations at Sodankyla station, in Finland (L = 5.1) (Maltseva *et al.*, 1988). A histogram showing the annual rate of IPDP pulsations observed at this station during 1974-1985 (about solar cycle 21) is shown in Figure 1. Annual means of polar coronal holes size for the same period, from Wang and Sheeley (1990), are also shown as dots joined by a continuous line. The IPDP annual rate shows a positive relation to coronal hole size. Figure 2 shows a scatter plot of IPDP annual rate versus polar coronal hole size. The regression analysis yields a correlation coefficient $r = 0.77$, and the linear least square fit to these data yields the equation

$$F = 4.56 + 2.09\,S$$

where F is the IPDP annual rate and S is the polar coronal hole size.

IPDPs AND HIGH-SPEED STREAMS

The positive relation between IPDPs and coronal holes suggests a physical relationship between the arrival at Earth of the high speeds streams (HSSs) originating from the holes and the generation of IPDP pulsations in the magnetosphere. We used the catalogues of HSSs by Lindblad and Lundstedt (1981, 1983), and Lindblad, Lundstedt, and Larsson (1989) to compute the annual frequency of HSSs observed at Earth from 1974, the first year of IPDP data, to 1982, the last year in the HSS catalogues. These authors defined a HSS as an observed velocity increase between two consecutive days of at least 100 km/s. Figure 3 shows the annual rate of all HSSs in the catalogue and the annual frequency of IPDP pulsations observed at Sodankyla. Annual means for sunspot number are also plotted as a reference. Annual frequency of HSS shows no dependence on the solar activity cycle although higher peaks of HSS frequency occur during the sunspot maximum. In relation to IPDPs, the IPDP frequency is comparable to the HSS frequency in 1974, 1975, and 1978. IPDPs are more frequent than HSSs in 1976 and 1977, and in 1979-1982 HSSs are much more frequent than IPDPs. Thus IPDPs tend to be more frequent than HSSs in the vicinity of solar minimum and the reverse appears to hold in the vicinity of solar maximum. This is mainly the effect of the lack of sensitivity of HSS frequency to solar activity.

As to coronal holes, we should compare IPDP frequency with the frequency of those HSSs in the catalogue

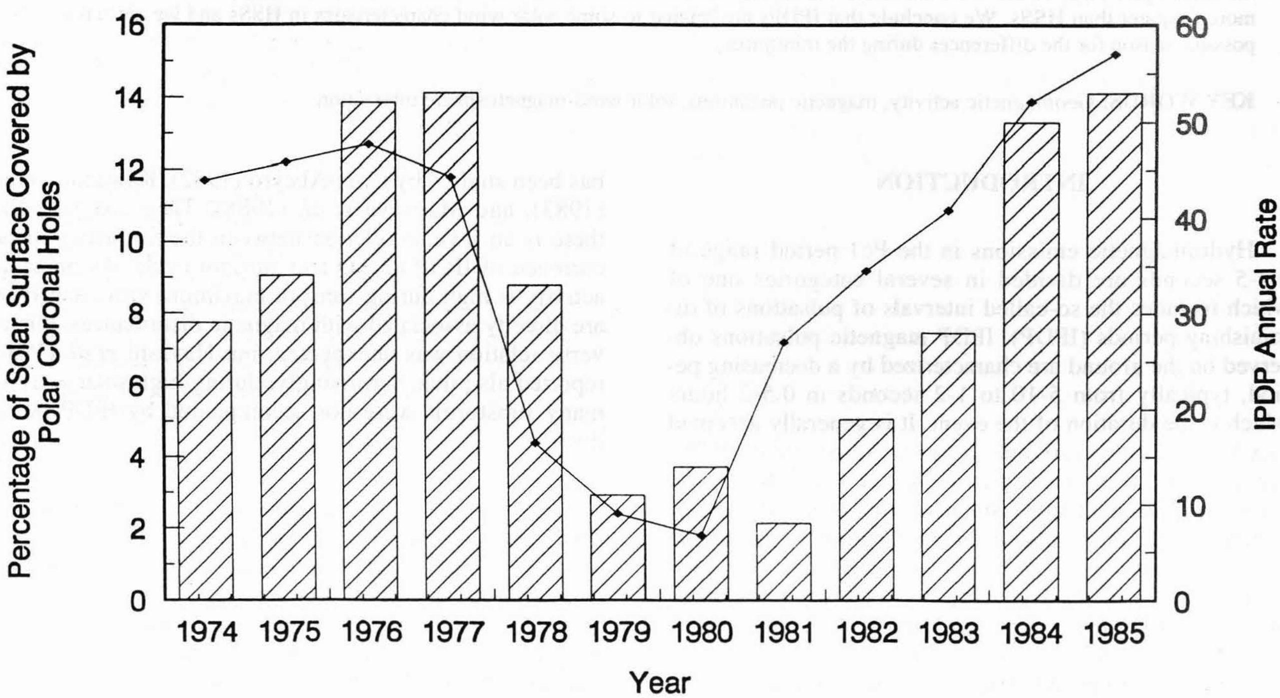

Fig. 1. Annual rate of occurrence of IPDPs in Sodankyla (histogram) and mean annual size of coronal holes (dots joined by a continuous line) from 1974 to 1985.

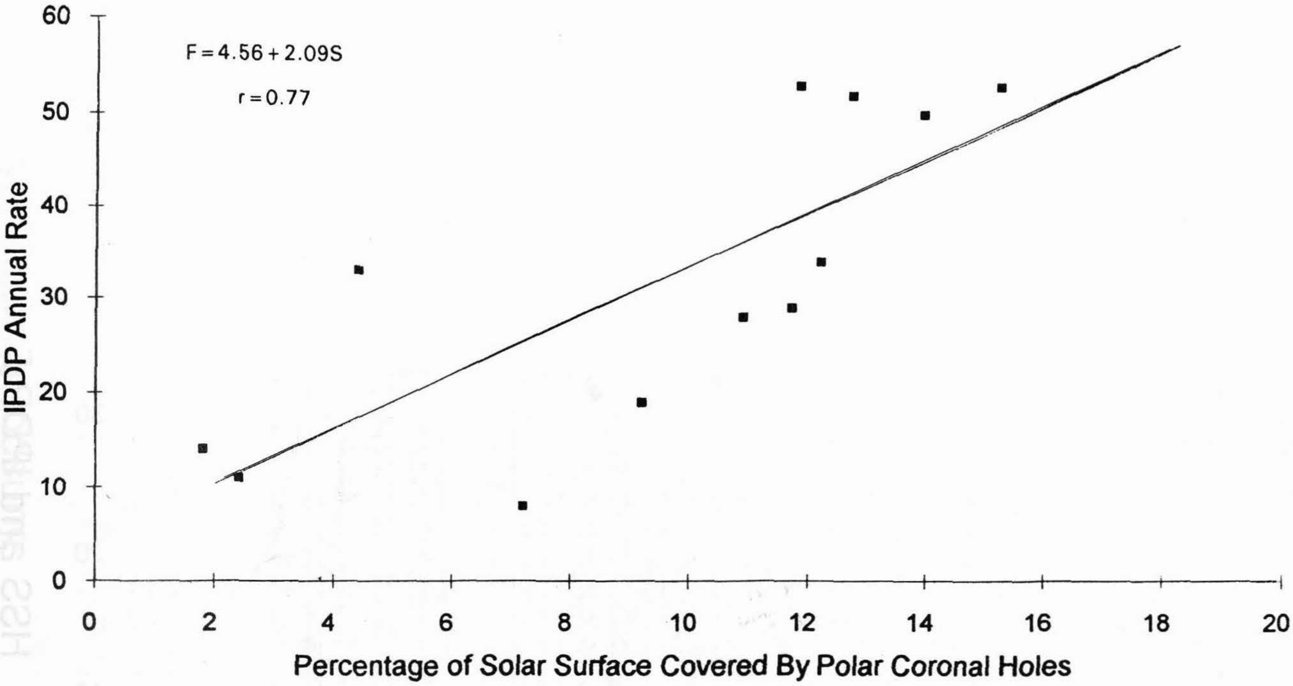

Fig. 2. Linear regression plot of IPDP annual rate (F) versus polar coronal hole size (S). The best fit straight line and the correlation coefficient are indicated.

that are not related to solar flares and which have a high mean velocity. The annual rate of such coronal-hole associated HSSs, considering a minimum speed of 550 km/s, is compared in Figure 4 with the annual frequency of IPDP pulsations observed at Sodankyla. The annual means for sunspot numbers are also indicated as a reference. We included the annual frequency of the coronal-hole associated HSSs in 1973 to show the oscillating character of these events during the solar cycle, in contrast with the behaviour of the complete set of HSSs.

The good agreement between IPDP events and HSSs during the descending part of the cycle is preserved, but we now have much better agreement around solar maximum. The much lower frequency of HSSs during the periods of high solar activity is due to the fact that we excluded the flare-related cases which are very frequent in these periods. For 1976 and 1977 (the minimum and the initial period of the ascending phase) the number of IPDPs was much greater than the number of HSSs. This is not unexpected because the overabundance of IPDPs in this period is already present in Figure 3 and with our criterion we have an even lower HSSs frequency. Finally in Figure 5 the IPDP and flare-related HSS frequencies suggest no correlation between these two phenomena.

DISCUSSION AND CONCLUSIONS

Our results suggest a correlation between IPDPs and the Earth crossing of coronal-hole associated HSSs on the basis of the annual frequencies of occurrence of both events. A one-to-one analysis should be done, but unfortunately this is not possible because IPDP individual data are not available. However, the possibility of such a relation is highly suggestive as coronal-hole associated HSSs have interesting properties which distinguish them from other kinds of high-speed solar wind and may be related to the generation of IPDPs in the magnetosphere.

Neugebauer (1992) discussed the properties of the wind coming from different solar sources. High-speed streams with velocities above 550 km/sec coming from coronal holes (quasi-stationary flows) are very different from those of explosive origin (transient flows). Quasi-stationary, high-speed flows from coronal holes (CHHS flows) have proton temperatures 2 to 3 times higher than the proton temperatures of the transient high-speed (THS) flows, while the electron temperature in CHHS flows is always lower than in the THS flows. CHHS flows are associated with much lower magnetic fields than THS flows. The β parameter in CHHS flows is about one, against less than one in THS flows. Cross helicity (degree of Alfvenicity of the fluctuations) has high and positive values (corresponding to outward propagating waves) in CHHS flows, and low and negative values in THS flows. Besides, CHHS flows have about ten times more rotational than tangential discontinuities, while the ratio is much lower in THS flows, and the ratio of alpha particles to protons in CHHS is systematically lower (about 4-5 times) than in THS flows.

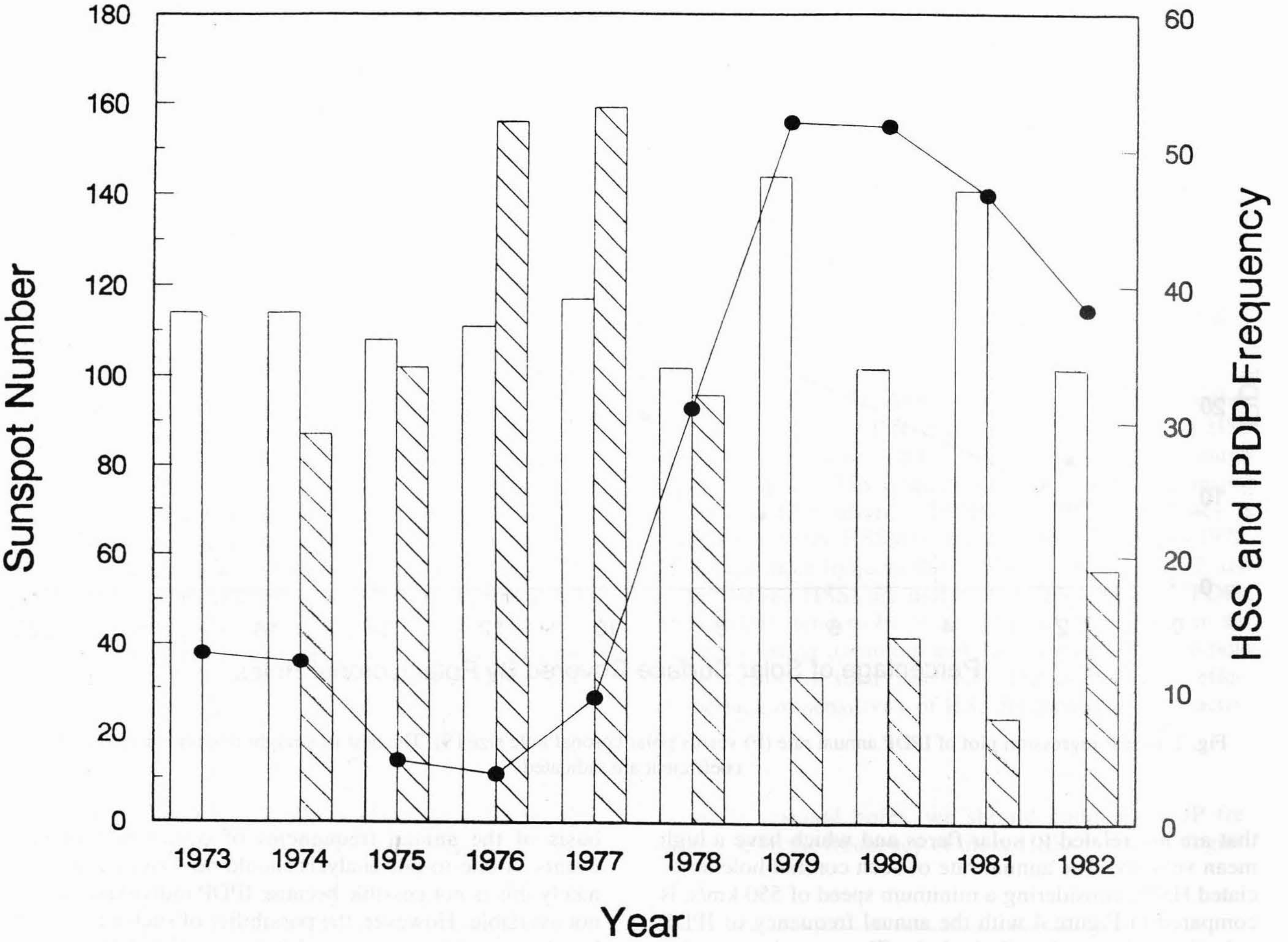

Fig. 3. Histograms showing the annual rate of IPDPs in Sodankyla (hatched) and the annual frequency of HSSs in the catalogues (blank) from 1974 to 1982; the HSS frequency value for 1982 includes only up to October. The annual frequency of HSSs in 1973 is also shown to stress the insensitivity of these events to the solar activity. The annual mean sunspot number is indicated with dots joined by a line.

Another interesting difference (e.g., Feldman *et al.*, 1976) is that the anisotropy of the peaks of proton distribution in CHHS flows is such that $T_\perp$ is always greater than $T_\parallel$ ($T_\perp/T_\parallel = 2.4$ on the average), while in THS flows $T_\parallel > T_\perp$. Also, in CHHS flows the alpha particle bulk velocity is higher than the proton bulk velocity, up to 20-30 km/s and more, and that the temperature ratio T_α/T_p is commonly around 4 (Asbridge *et al.*, 1976; Bosqued *et al.*, 1977; Neugebauer and Feldman, 1979). Finally quasi-steady flows associated with coronal holes often constitute corotating streams (especially around the minimum of solar activity). According to Burlaga and King (1979), the existence of a stream interface appears to be necessary and sufficient for the identification of a corotating stream at 1 AU. In such interfaces the magnetic field increases suddenly by a factor of about 4; it remains high in the interface and suddenly recovers its previous value after the interface crossing. The velocity and temperature of the wind increase across the interface and remain high after it, while the density decreases and remains low.

Transient (flare associated) HSSs do not correlate with IPDP occurrence. Thus the high velocity of the flow seems not to be the important parameter in relation to these waves, but rather some feature that CHHS flows do not have in common with THS flows.

It is widely accepted that IPDPs are generated by injection of plasma from the tail in the initial phase of a substorm. During high solar activity, however, many substorms are not accompanied by IPDP pulsations. The results of our study suggest that this has to do with the properties of the high speed streams from coronal holes.

Yet the number of HSS in the catalogs is not sufficient to account for the large number of PDPs observed during the minimum and the first part of the ascending phase of the solar sunspot cycle. A number of CHHS flows may be missing in the Lindblad and Lundstedt HSSs catalogues because of the criteria used by these authors. During solar minimum, some of the typical properties of CHHS flows

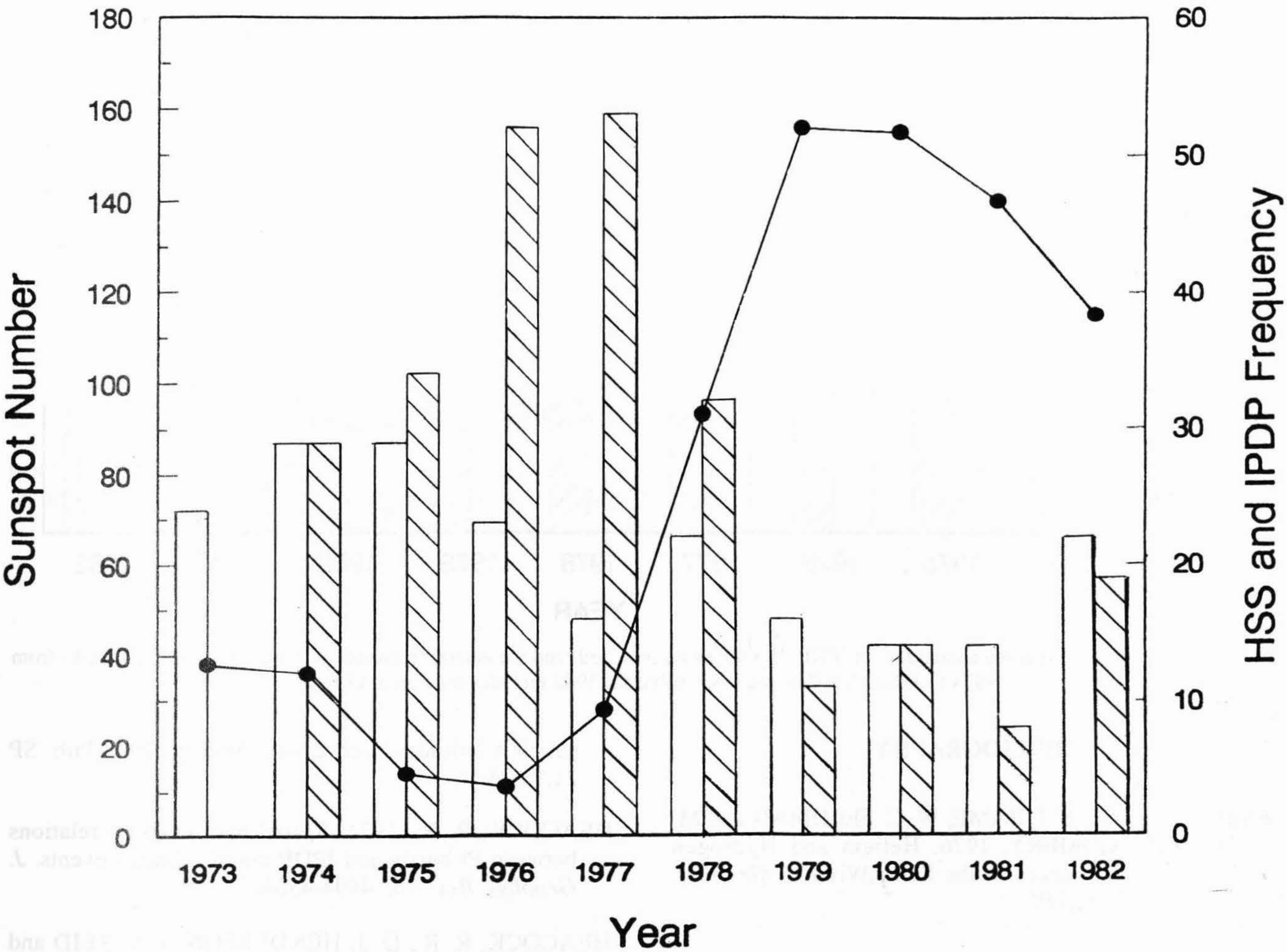

Fig. 4. Histograms showing the annual rate of IPDPs in Sodankyla (hatched) and the annual frequency of non-flare related HSSs with velocity equal to or higher than 550 km/s (blank) from 1974 to 1982; the HSS frequency value for 1982 includes only up to October. The annual frequency of these HSSs in 1973 is also drawn to show the oscillatory character of these events. Annual mean sunspot number is indicated with dots joined by a line.

may also be present in solar wind flows which do not have a very high velocity. A detailed study of the solar wind during IPDP pulsations will be necessary in order to understand the driving mechanism and the observed correlation between the IPDP frequency and the size of polar coronal holes. Some of the considerations in relation to IPDP pulsations may apply also to other kinds of ICWs which show a similar solar cycle dependence.

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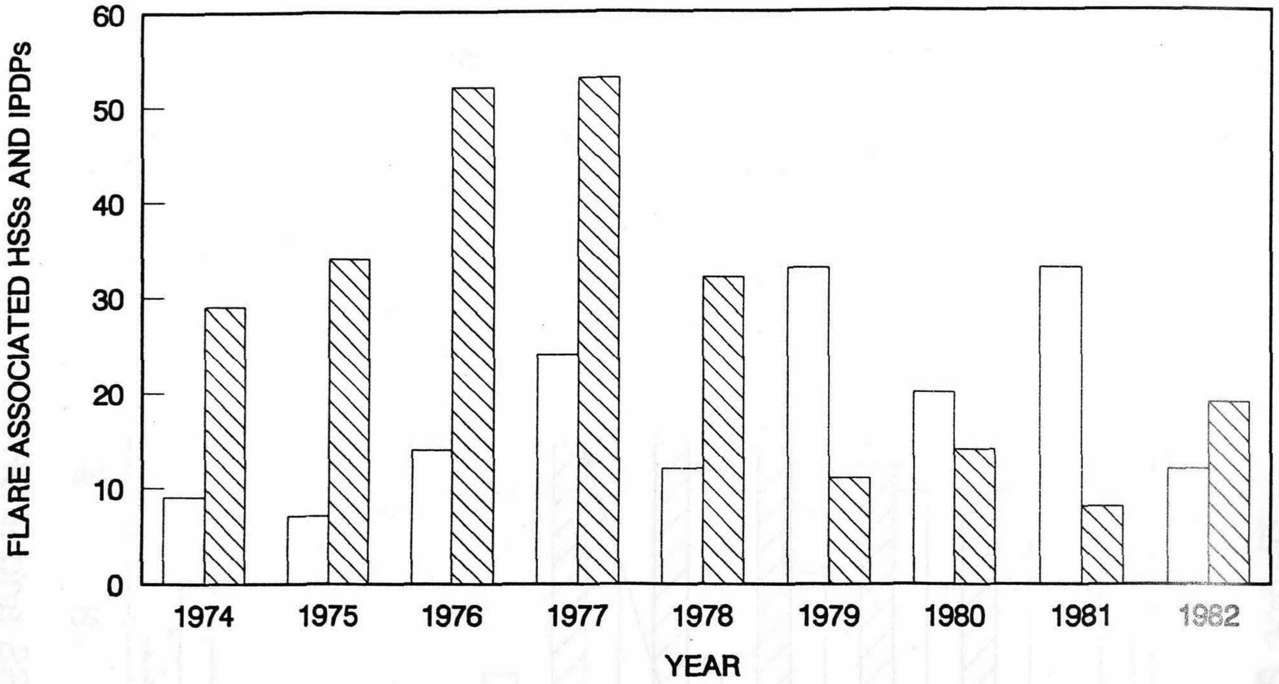

Fig. 5. Histograms showing the annual rate of IPDPs in Sodankyla (hatched) and the annual frequency of flare-related HSSs (blank) from 1974 to 1982; the HSS frequency value for 1982 includes only up to October.

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S. Bravo and J.A.L. Cruz-Abeyro
Instituto de Geofísica, UNAM
04510 México, D.F., México.