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COMPARISON OF CHARACTERISTICS OF THE LOCALISED PROTON PRECIPITATION AND PC1 PULSATIONS

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Abstract. By the analysis of one-year data from the low-altitude NOAA satellite and on the basis of comparison with observations of Pc1 pulsations at Sodankyla Geophysical Observatory, Finland, we have for the first time found and described a type of proton precipitation closely related to Pc1. Our findings lend support to the idea that Pc1 pulsations are the result of ion-cyclotron instability of energetic ring current protons.

Introduction

Pc1 pulsations observed on the ground and space are believed to be due to the interaction between energetic ions and cyclotron waves in the equatorial plane. One would expect that the pulsations should correlate with corresponding proton precipitation. But, to our knowledge, to date no explicit evidence has been presented of such correlation. There are observations, which show the correlation of Pc1 with aurora. *Mende et al*. [1980] suggested that the aurora was due to proton precipitation. But, this suggestion has been not proved yet. Some authors [e.g. *Arnoldy et al.,* 1979; *Pikkarainen et al*., 1986] have observed riometer absorption spikes produced by the electron precipitation, which were correlated with ULF emissions in the Pc1 range (IPDP). They, nevertheless, suggested that this precipitation was stimulated by parasitic interaction between ion-cyclotron waves and high energy electrons.

The aim of this paper is to present the ion precipitation pattern which exhibits the signatures of a close relation to the Pc1 type pulsation.

Data

For the present study the data from low-altitude (850 km) polar orbital NOAA satellites are used. Among others, these satellites are equipped with instruments for measurements of particles with energies <20 keV (instrument TED - Total Energy Detector) and > 30 keV (instrument MEPED - Medium Energy Proton and Electron Detector) [*Hill et al.,* 1985]. The TED instrument measures the total energy flux of precipitating electrons and protons. The electron detector of the MEPED instrument has three passbands: >30 keV, >100 keV, and >300 keV. The proton telescope is designed to select protons within energy ranges of 30-80 keV, 80-250 keV, 250-800 keV, etc. In fact, this instrument does not distinguish between protons and heavier ions. Nevertheless, we will suggest and label the particles registered by this instrument as protons. This is because we will consider the observations at rather high latitudes (L>4) where this species of the ring current is apparently dominant. Both electrons and protons are measured by the two detectors mounted to view outward along the Earth-satellite radial vector and along the direction just perpendicular to this vector, correspondingly. Thus, at high latitudes the detectors register the particles both inside and outside of the loss cone.

The data of geomagnetic pulsation observations at Sodankyla Geophysical Observatory (SGO, geographic coordinates 67° 22' N, 26° 38' E; L=5.2) have been used as well. The pulsations are measured by search coil magnetometer and digitised data are routinely used for preparation of the daily spectrogram in the frequency range of 0-4 Hz.

Example of the event

Below we describe a typical example of simultaneous particle and pulsation data, on which our analysis is based.

Fig.1 shows a daily spectrogram of electromagnetic emissions in the frequency range of 0-4 Hz measured at SGO on October 27, 1996. Arrow marks an approximate time of the NOAA-12 satellite pass (orbit 28220) over the southern polar region. At this time intense Pc1 pulsations were registered at SGO. A closer look at pulsation data showed that the signal was due to the so-called structured Pc1 or pearl pulsations.

The particle data from the NOAA-12 satellite are presented at the bottom of Fig.2. Typically the precipitation over polar region consists of two main zones: 1) isotropic precipitation zone, which is evidently due to the pitch-angle scattering in the region of small magnetic field in the equatorial plane [*Sergeev et al.*, 1983], and 2) anisotropic zone (equatorward of isotropy boundary) where the trapped population prevails. Sometimes, within the anisotropic zone a specific variation of proton fluxes is seen. They consist of short enhancements of the trapped flux ($J_{\perp}$) and, more seldom, of bursts of precipitating particles ($J_{||}$). In Fig.2 such spikes are seen approximately at 0302 UT, 04.31 MLT. The precipitation is more often observed in the 30-80 keV channel, but occasionally they are also detected at energies more than 80 keV. Sometimes, the proton precipitation bursts associate with energetic electron precipitation (as it is seen also at 0302 UT). There are no enhancements in the low-energy precipitation (data obtained from TED are shown in two panels in the bottom) correlated with the varying energetic particle fluxes described above.

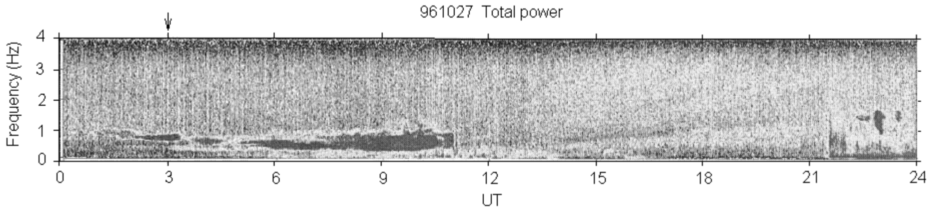

Fig. 1.

Similar particle features have been also observed on several other NOAA-12 passes on October 27, 1996 (approximately at 0355 UT, 0408 UT, 0901 UT, and 0912 UT). All of them occurred during the Pc1 interval. There were also passes when neither Pc1 pulsations nor proton events were registered. This gave us an idea that considered localised proton enhancements (LPE) might closely relate to the Pc1 waves. Below we will confirm the relationship statistically.

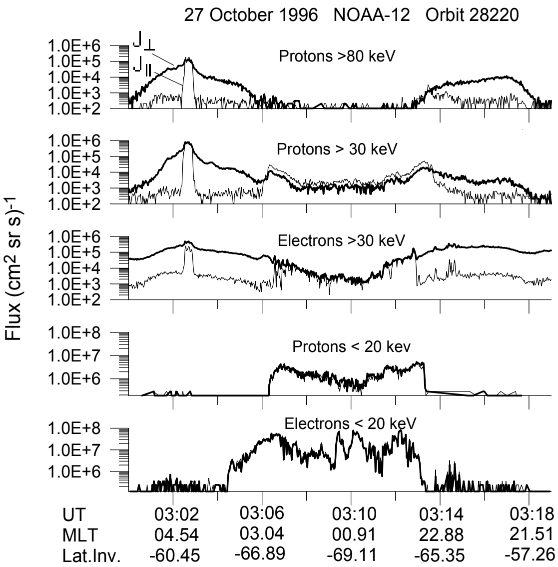

Fig. 2.

Comparison of characteristics of localised proton precipitation and ground Pc1

Some characteristics of the proton enhancements described above have been studied by *Yahnina et al.* [1998]. These authors analysed the NOAA-6 and TIROS satellite data for 20 days in August 1979. They found such phenomena during the recovery phases of geomagnetic storms. Typically only trapped flux variations were observed; the precipitation bursts were detected only in 7% of cases. Variations of the trapped flux are not temporal; they can be observed in the same MLT sector as long as several hours, and simultaneously at different MLTs. But precipitating protons are rarely seen on subsequent satellite passes.

Orbits of the two satellites NOAA-6 and TIROS cover a wide range of MLT. Fig.3a shows an amount of the polar region satellite passes at different local times. Good coverage (excluding the interval 10-12 MLT) enabled us to conclude that diurnal occurrence of the precipitating bursts (Fig.3b) exhibited a maximum on the day side.

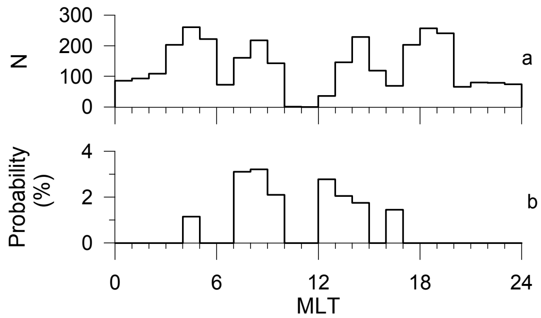

Fig. 3.

In this study, to enhance the statistical significance, we analyse observations obtained during the whole year 1996. Altogether 213 LPEs containing precipitation were registered in both hemispheres. Fig. 4 (upper panel) presents the number of the LPEs during every month of the year. At the middle of the Figure the total duration time of Pc1 observations (in hours per month) is shown. Both LPE and Pc1 exhibit similar annual variation that in turn correspond to the variation of geomagnetic activity as characterised by Dst-index shown in the bottom. More detailed consideration showed that in fact the phenomena under study appeared during the Dst-index recovery (data not shown).

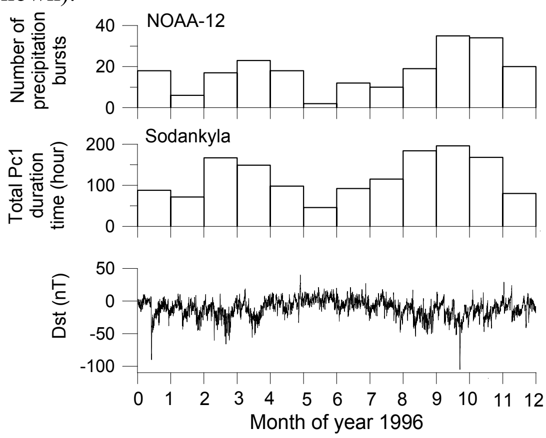

Fig. 4.

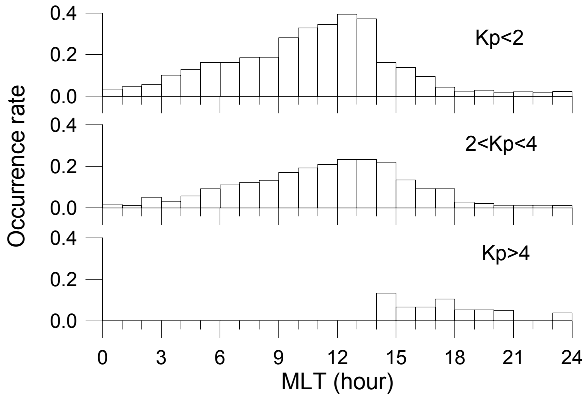

Fig. 5.

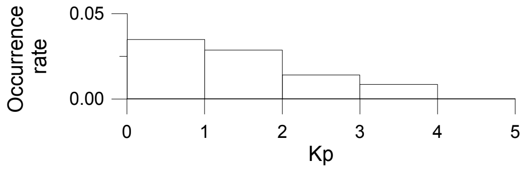

Fig. 6.

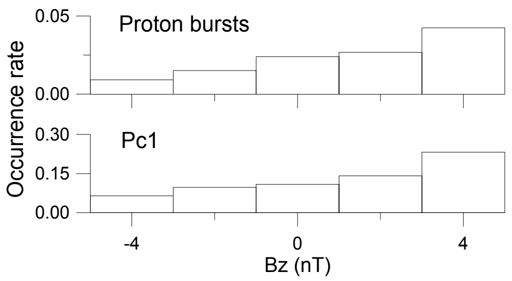

Fig. 7.

Fig.5 shows the diurnal occurrence rate of the Pc1 pulsations for different values of Kp. The occurence is higher as Kp is lower. Maximum of the pulsation occurrence is on the day side. The similar dependence on Kp is also found for the precipitation bursts (Fig.6). Fig. 7 illustrates how the occurrence rate of pulsations and bursts depend on the IMF Bz. The occurrence of both phenomena is higher when Bz is positive.

We checked if Pc1s were observed during every LPEs. The result is that 91 percents of the proton bursts were associated with Pc1 pulsations registered at SGO.

In the northern hemisphere 135 LPEs have been registered. Only 11 LPEs were not associated with Pc1s. The LPEs were divided into two groups accordingly to the intensity of simultaneous Pc1 pulsations. (The intensity in relative units was estimated from the colour scale of the spectrograms). In all, 64 events fell into the group associated with more intensive Pc1s. Fig.8 (top) shows how the occurrence rate of these intense Pc1s depends on the distance between observing station (SGO) and satellite footprint. As a measure for the distance we used the MLT difference. One can see that intense pulsations can be detected as far as 12 hours of MLT from the LPE location, but the occurrence rate increases significantly toward the satellite footprint. For the cases when Pc1 pulsations were not observed the dependence is opposite. Their occurrence rate increases as the MLT difference between the satellite and ground station increases (Fig.8, bottom). Such cases occur only when MLT difference exceeds the 4-hour range. The LPEs occupy a wide range of magnetic latitudes, but for every two-hour interval in Fig.8 the median value of the LPE latitude falls into the range of 64-65 degrees. Thus, there is no systematic increase of LPE latitude, relative to the latitude of SGO, with the increase of MLT difference. Correspondingly, the dependence shown in Fig 8 can not be explained by the latitudinal decay of the Pc1 waves.

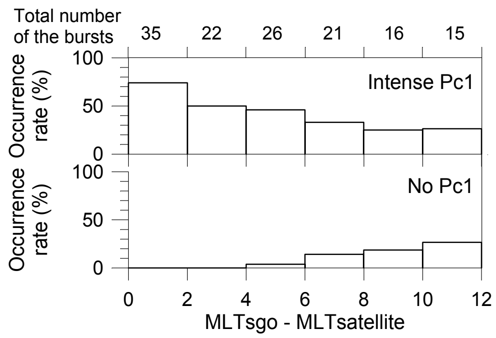

Fig. 8.

Also, we considered how often LPEs with precipitation were detected during the Pc1 events. For Pc1 observed when the NOAA satellite footprint was within 2 hours of MLT from the station, only 8% were associated with the precipitation bursts detected onboard the satellite. For intense Pc1 the probability to observe precipitating protons increases up to 14%.

We have studied how the proton precipitation latitude affects the pulsation frequency. Fig.9 shows this dependence. The plot has been constructed for precipitation bursts detected within 2-hour MLT distance from SGO and for those one-band Pc1s, for which both low and upper frequency cutoffs could be easily determined from the daily spectrogram plots. The Pc1 frequency shows a clear tendency to decrease as the latitude of the precipitation bursts increases.

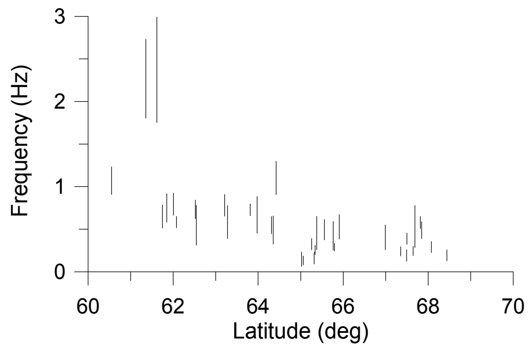

Fig. 9.

Discussion and conclusion

The main experimental findings of the present study can be summarised as follows:

-We selected a specific pattern of energetic proton flux - LPE, which is characterised by localised enhancement of quasi-trapped and precipitation flux within anisotropic zone.

-More than 90 percents of LPEs containing the precipitating flux are associated with the ground Pc1 observed in Sodankyla observatory.

-Occurrence rate of the intense Pc1 decreases when the distance between LPE and ground station increases; opposite dependence is found for cases when Pc1 pulsations were not observed during LPEs.

-The Pc1 frequency decreases as the latitude of LPE increases.

We consider these findings as an evidence of the close relationship between LPE and Pc1. Moreover, we consider LPE with precipitating flux as a signature of the field line of the Pc1 source. Indeed, an appearance of the flux variations in the ionosphere evidently means a transformation of the pitch-angle distribution in the magnetosphere. One can suggest that events with nearly isotropic precipitation bursts manifest moderate or even strong pitch-angle diffusion due to the operation of some scattering mechanism. The variations in the trapped flux can only be related either with very weak diffusion or with particle drift from the region of the localised source. The latter seems to be more possible because such phenomena are often seen at the close latitude at different MLTs.

The source of Pc1 is very much localised [*Fraser et al.,* 1989]. Keeping in mind this fact it is not surprising that the probability of detecting a precipitating burst within two-hour MLT range during the Pc1 observed in SGO is low. The fact that Pc1s can be observed far from the location of the proton burst is easily explained by signal propagation in the ionosphere wave guide.

The LPE and Pc1 have many similar features. Thus, the latitudinal width of the bursts is about 1° as well as that of Pc1 detected on satellites [e.g. *Erlandson and Anderson,* 1996]. Like LPEs, Pc1 pulsations appear mainly during intervals of undisturbed periods (Kp<2) (Figs. 6,7). Similar to Pc1 the diurnal distribution of the bursts exhibits the day-morning maximum (Fig.3).

The relationship between the LPE latitude and ground Pc1 frequency provides additional evidence that proton burst may mark the Pc1 source. This conclusion follows from the comparison of the dependence shown in Fig.9 with the results of some satellite observations of Pc1. In particular the dependence in Fig.9 amazingly coincides (within the latitudinal range of our observations) with that presented by *Erlandson et al.* [1990] in their Fig. 10. They plotted the Pc1 frequencies versus magnetic latitude for 21 cases observed onboard Viking satellite. *Anderson et al.* [1992] using the measurements of AMPTE/CCE in the equatorial magnetosphere found that the Pc1 frequency decreases as latitude of the source increases.

Rather often (in some 40% of events) the LPE described here are accompanied by energetic electron precipitation bursts. These electron precipitations would be an agent producing aurora which was detected in some previous studies [e.g. *Mende et al.,* 1980].

In conclusion, we would like to summarise that the comparison of characteristics of the LPE and Pc1 pulsations showed a close relationship of these phenomena. The findings described above support the ion cyclotron mechanism of Pc1 generation according to which both waves generation and particle scattering must occur in the source region.

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