"Physics of Auroral Phenomena", Proc. XXXII Annual Seminar, Apatity, pp. 93 - 96, 2009

Polar Geophysical Institute

RELATIONSHIP BETWEEN SOLAR WIND PRESSURE PULSES, PROTON AURORA FLASHES, AND Pc1 BURSTS: A STATISTICAL STUDY

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Abstract. Simultaneous observations of proton aurora from the IMAGE spacecraft and ground magnetic pulsations during sudden solar wind pressure increases ($\Delta P > 1$ nPa) were used to investigate the relationship between dayside proton aurora flashes and bursts of pulsations in the Pc1 frequency range. The Pc1 bursts are always registered when the observing ground station is conjugated with the region occupied by the proton aurora flash. Outside the proton aurora flash region the Pc1 bursts are typically not observed. In addition, we noted a difference in responses of the proton aurora to the pressure pulses of different origin. About 100% of the pressure increases due to interplanetary shocks are associated with proton aurora flashes in events, while the pressure increases related to tangential discontinuities correlate with the proton flashes only in about 30% of the events.

Introduction

A lot of geophysical phenomena correlate with sharp increases of the solar wind dynamic pressure (e.g., sudden impulses, traveling convection vortices, precipitation of particles in the auroral oval, etc.). One of such phenomena is a short-lived burst of geomagnetic pulsations in the frequency range of Pc1 (from tenths to 1-2 Hz), called by Fukunishi et al. (1981), as "hydromagnetic emission bursts". These pulsations are typically observed on the dayside (e.g., Fukunishi et al., 1981; Kangas et al., 1986) and are indicator of electromagnetic ion-cyclotron (EMIC) waves (Anderson and Hamilton, 1993; Anderson et al., 1996). Recent observations from the IMAGE spacecraft revealed a new phenomenon related to the solar wind pressure pulses, namely, flashes of the proton aurora, which occur on the dayside equatorward of the proton aurora oval (Zhang et al., 2002; Hubert et al., 2002; Fusilier et al., 2004). The morphology of the proton flashes (such as duration and MLT distribution) is similar to that of the Pc1 bursts. Yahnina et al. (2008) and Zhang et al. (2008) showed that the proton flashes exhibit close temporal-spatial correlation with the Pc1 bursts (EMIC waves). Such correlation suggests that both proton precipitation responsible for proton flashes and geomagnetic pulsations are the result of cyclotron instability of the ring current protons that develops due to increase of the proton temperature anisotropy under magnetospheric compression. However, both Yahnina et al. and Zhang et al. papers dealt with case studies. The aim of our report is to confirm the relationship between proton flashes and Pc1 bursts statistically.

Data selection and results

To select necessary data for the study, the solar wind data (from OMNII data base) for 2001-2005 were searched to reveal dynamic pressure jump events. Strong enough pressure jumps (not less than 1 nPa), which duration did not exceed a few minutes, were selected. Then, those events were chosen, for which the data from the SI12 detector of the FUV instrument onboard the IMAGE spacecraft were available. This detector was designed to obtain global images of aurora, which is created solely by proton precipitation (Mende et al., 2000). Finally, 61 events were selected. Further, the data of the induction coil magnetometer in observatory Lovozero (CGMLat=64.2, MLT=UT+3) were investigated to determine the response of pulsations in the frequency range of 0.05-5 Hz to the selected solar wind pressure events. To characterize the magnetospheric compression the geomagnetic index SYM-H (e.g., Iemory and Rao, 1996) was applied.

The observed responses of the pulsations to the pressure jumps can be divided into following categories: 1) the Pc1 bursts, 2) the ULF noise (like PiC/PiB), 3) the quasi-monochromatic Pc1, and 4) no change in the pulsation regime. It is worth to note that the pulsations in the Pc1 frequency range often appeared together with the ULF noise, but not vice versa.

Figure 1 shows an example of the pressure jump and some associated phenomena, which took place around 0625 UT on 4 November 2003. Two upper panels represent, respectively, the interplanetary magnetic field magnitude and solar wind dynamic pressure. Third and forth panels show ground-based data: the SYM-H index and spectrogram of geomagnetic pulsation in Lovozero. On the bottom, three successive global images of the proton aurora obtained from the IMAGE spacecraft at 0625, 0627, and 0629 UT are presented. (The morning sector as well as some part of the night sector is not observed due to the camera orientation.) An arrow in the central image indicates the location conjugated with Lovozero. The magnetospheric compression in this case is confirmed by a strong increase of the index SYM-H at 0625-0627 UT. The pressure jump was associated with the proton aurora flash on the dayside. At the time of the flash (between 0625 and 0627 UT), the magnetometer in Lovozero, which was also situated on the dayside, registered the Pc1 burst simultaneously with the onset of the ULF noise. The Pc1 burst spectrum exhibits clear dispersion, like that discussed by Kangas et al. (2001), Safargaleev et al. (2002), Yahnina et al. (2008), Parkhomov et al. (2009).

In fact, not every sudden pressure increase was associated with the proton flash (actually, 41 flashes were observed during 61 pressure jump events) and with the Pc1 burst (20 of 61 events). A relatively low occurrence of the Pc1 bursts in response to the pressure increases has been noted by Olson and Lee (1983), Kangas et al. (1986), Safargaleev et al. (2002), Parkhomov et al. (2009).

To clarify reasons of such low occurrence, we divided the pressure jump events into two groups (see, Table 1). First group contains the pressure increases, which coincide in time with a sharp increase of magnitude of the interplanetary magnetic field. Such events represent interplanetary (IP) shocks. The events of the second group of the pressure increases associate with the decrease of the magnetic field magnitude and, likely, represent tangential discontinuities (TDs). The first group contains 37 events, and the second one – 24 events. During the IP shocks the proton flashes were observed in 34 cases, that is, in 92% of the events. Efficiency of the tangential discontinuities in the proton flash generation is only 29% (7 of 24 cases). Perhaps, this relates with the fact that magnetospheric compression is stronger during the IP shocks. Indeed, according to our data set, the mean SYM-H was 31 nT during the shocks and only 12 nT during TDs.

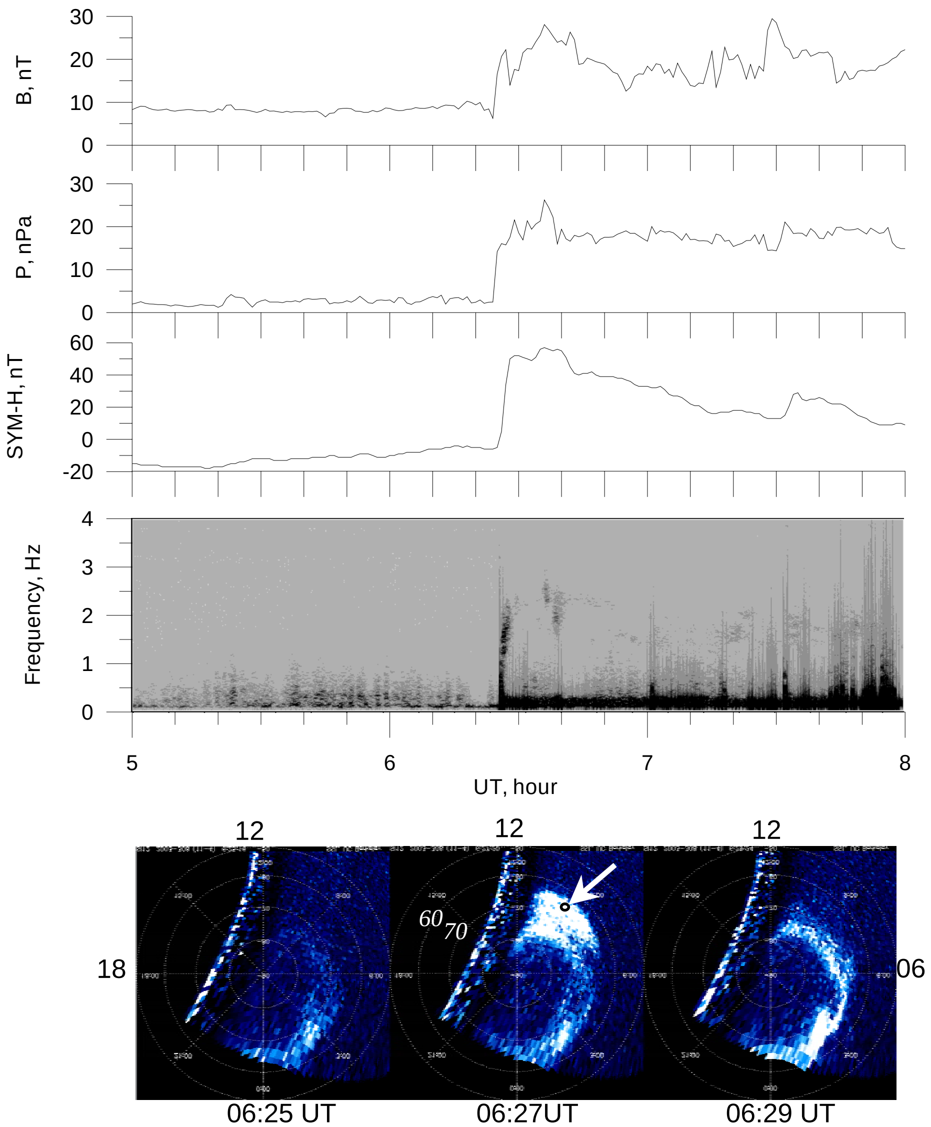

Figure 1

The observatory Lovozero got into the region conjugated with the proton flash in 19 cases (16 during IP shocks and 3 during TDs), and in 18 of them (15 during IP shocks and 3 during TDs) the Pc1 bursts were observed. Lovozero was not conjugated with the proton flashes in 22 cases (18 during IP shocks and 4 during TDs). During such events the Pc1 bursts were observed only in 2 cases, which occurred during IP shocks. Other 20 events were associated with the responses of the above-described categories 2, 3, and 4. Finally, 20 pressure jumps (3 related to IP shocks and 17 to TDs) did not produce the proton flashes. Only one Pc1 burst (related to IP shock) was registered during these 20 events.

Thus, the observation of the Pc1 bursts strongly depends on mutual location of the proton flash and the ground station observing the pulsations. When the observing station is in the region conjugated with proton flash, it observes the Pc1 bursts in almost 100% of events, and outside the proton flash region the Pc1 bursts are, practically, not observed. In turn, flashes appear more often in response to the pressure increases related to the IP shocks, but not the tangential discontinuities (see, also Parkhomov et al., 2009).

Table 1. Relationship between solar wind pressure pulses, proton flashes and Pc1 bursts

Solar wind structure associated with pressure pulse	IP shock	TD
Number of cases of the solar wind pressure pulses	37	24
Number of pulses associated with proton aurora flashes	34	7
Number of cases when Lovozero was conjugated with the proton flash (Number of cases when Pc1 bursts were observed)	16 (15)	3 (3)
Number of cases when Lovozero was not conjugated with the proton flash (Number of cases when Pc1 bursts were observed)	18 (2)	4 (0)
Number of pulses NOT associated with proton aurora flashes (Number of cases when Pc1 bursts were observed)	3 (1)	17 (0)
Mean of the SYM-H increase	32 nT	12 nT

Discussion

The almost 100% correlation of the proton flashes and Pc1 bursts (EMIC waves) statistically confirms the conclusion by Yahnina et al. (2008) and Zhang et al. (2008) that proton flashes are the result of the ion-cyclotron instability. The relationship between proton precipitation and Pc1 bursts has been found by Safargaleev et al. (2002) using the particle data from low-orbiting DMSP satellites and ground observations of the Pc1 bursts. However, they referred the precipitation to a spatial rather than temporal structure, and concluded that the proton precipitation did not seem to be due to the wave-particle interaction. Our data clearly show that the proton precipitation during the Pc1 bursts is a transient phenomenon (see, also papers by Yahnina et al. and Zhang et al.). The magnetospheric compression leads to the increase of the magnetic field and, consequently, to the increase of the energetic proton temperature anisotropy. This produces favorable conditions for the development of the IC instability, which generates both EMIC waves and scattering of the energetic protons into the loss cone. The later means the precipitation and, as result, the proton flash.

The appearance of the proton flashes mainly on the dayside confirms the conclusion by Olson and Lee (1983) that IC the instability related to the magnetosphere compression should develop preferably there.

The localization of the instability region on the dayside is a reason of the low probability of the Pc1 burst observations at a single ground station (e.g., Olson and Lee, 1983; Kangas et al., 1986; Safargaleev et al., 2002; Parkhomov et al., 2009). Another reason is that not every solar wind pressure jump associates with the development of the IC instability due to weakness of the compression (that is, insufficient increase of the anisotropy). It is not clear, however, why the pressure increases related to different solar wind structures produce different compressions.

Conclusion

On the basis of the five-year data set we statistically confirmed the close relationship between dayside proton flashes equatorward of the proton aurora oval and bursts of geomagnetic pulsations in the Pc1 frequency range. Both this phenomena are the result of the ion-cyclotron instability developing in response to magnetosphere compression due to sudden increases of the solar wind dynamic pressure. In addition we noted that compressions related the interplanetary shocks are more intense in comparison with those related to the tangential discontinuities.

Acknowledgements. The study of T.A.P., T.A.Y. and A.G.Y. was performed in frames of the basic research program 16/3 ‘‘Solar activity and space weather’’ of the Presidium of the Russian Academy of Sciences (RAS) and program VI.15 ‘‘Plasma processes in the solar system’’ of the Division of Physical Sciences of RAS. The work of H.U.F. was supported by NASA under the award NNG05GF24G.

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