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DYNAMICS OF LOCALIZED PRECIPITATION OF ENERGETIC PROTONS DURING GEOMAGNETIC STORMS

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Abstract. Localized precipitation of energetic protons (LPEP) observed by low-orbiting satellites has been found to be a counterpart of magnetospheric EMIC waves observed on the ground as pulsations of the Pc1 frequency range (Yahnina et al., 2003). In this paper the LPEP dynamics during geomagnetic storms is described. The MLT and latitudinal locations of LPEPs and their dynamics during both main and recovery phases of the geomagnetic storms are considered and compared with known properties of EMIC waves registered in space and on the ground. The LPEP behavior during storms is found to be similar to that of the EMIC waves in space and on the ground. This confirms the close relationship between LPEP and EMIC waves and suggests that low-altitude LPEP observations can be used to monitor the dynamics of the ion-cyclotron interaction in the equatorial plane during geomagnetic storms.

Introduction

The ion-cyclotron (IC) interaction is an important process influencing on the dynamics of the near Earth magnetosphere. The role of the IC interaction in the development of the geomagnetic storm has been studied theoretically (e.g. Bespalov et al., 1994; Kozyra et al., 1997), but for verification of the theoretical predictions a comprehensive knowledge of the morphology of this process is necessary. The morphology can be investigated using observations of the electromagnetic ion-cyclotron waves, which are the result of the IC interaction. Unfortunately, the satellite EMIC wave observations covering the storm intervals are scanty. Bräysy et al. (1998) used EMIC observations from low-orbiting Freja satellite to investigate the wave dynamics during a storm of April 1993. Erlandson and Ukhorsky (2001) used data from DE-1 to study statistically the EMIC waves near the equatorial plane during storm intervals. The data from both Freja and DE-1 satellites showed that during the main phase of the storm the wave amplitudes are enhanced by one-two orders of magnitude and the waves are observed mainly in the evening MLT sector. In the later recovery phase the most persistent wave activity is in the day-morning sector. The latitude of EMIC waves decreases during the main phase and increases during the recovery phase (Bräysy et al., 1998). As to the ground signature of the EMIC waves, that is, Pc1 pulsations, they are, mainly, observed in 2-7 days from the beginning of the storm recovery phase (Wentworth, 1964; Heacock and Kivinen, 1972; Heacock and Akasofu, 1973; Kerttula et al., 2001). This delay relatively to the storm onset was interpreted as the result of the improved ionospheric conditions for wave amplification and ducting during recovery phase (Kerttula et al., 2001). During the storm main phase the ground Pc1s, even rare, occur in the evening-night hours, and later, during the recovery, they shift to the morning sector in agreement with space-born observations.

Another consequence of the IC interaction in the near-Earth magnetosphere is the localized precipitation of energetic protons (LPEP) equatorward of the isotropy boundary. The close relationship of the precipitation with EMIC waves has been shown on the basis of statistical comparison with ground Pc1 pulsations (Yahnina et al., 2000; 2003) and on the basis of direct observations in space near the equatorial plane (Yahnin et al., 2002). Thus, the LPEP observations can provide an additional opportunity to investigate the dynamics of the IC interaction in the inner magnetosphere. In particular, LPEP can be observed by the low-orbiting satellites, such as NOAA POES (Evans and Greer, 2000). The advantage of these observations is in the fact that several NOAA satellites are permanently in orbit in different MLT sectors. Hence, the storm-time statistics of the observations related to the IC interaction can be significantly increased. Below we present some first results of the analysis, which is based on the NOAA data, of the LPEP behavior during several geomagnetic storms.

Observations and results

For the study, six magnetic storms occurred in 2003-2005 were selected using a criterion of "classical" variation of Dst-index representing fast decrease (the main phase) and slow increase (the recovery phase).

Table 1

№	Date	UT, h	Dst, nT
1	20.11.2003	19	-472
2	15.05.2005	08	-263
3	24.08.2005	11	-216
4	30.08.2004	22	-126
5	11.02.2004	17	-109
6	17.07.2004	02	-80

The selected storms are listed in Table 1, where the date and time of the Dst minimum are indicated for each event as well as the Dst minimal values. Figure 1 shows Dst variations for these storms in the same scale. (The numbers of events as they appear in Table 1 are shown on the right side of the Fig. 1) The Dst minimum values vary from -472 nT to -80 nT. In Fig. 1 the day 0 corresponds to the 24-hour interval before the minimum of Dst; the successive 24-hour intervals of the recovery phase are called as day 1, day 2, etc.

The recovery phase comes to the end in day 5, or day 7, or day 9. The last day is defined by approaching the preceding storm Dst value or by the onset of a new storm.

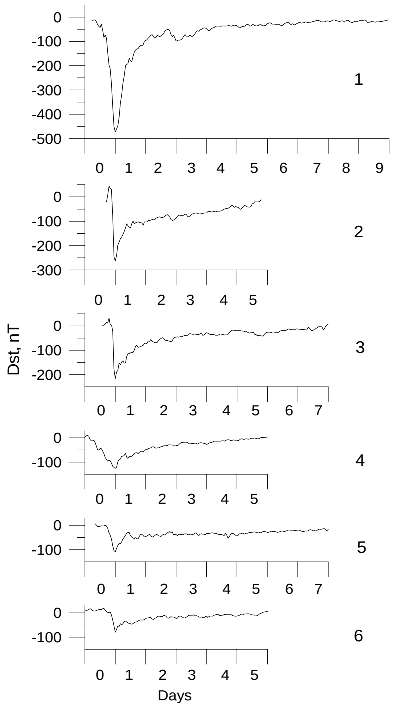

Fig. 1

Observations of LPEP during these storms were performed with three-to-four NOAA satellites, which permanently were in orbit providing good MLT coverage. The daily averaged intensity of the proton precipitating fluxes, daily averaged geomagnetic latitude of LPEP events, and the amount of LPEP events observed during every day are displayed,

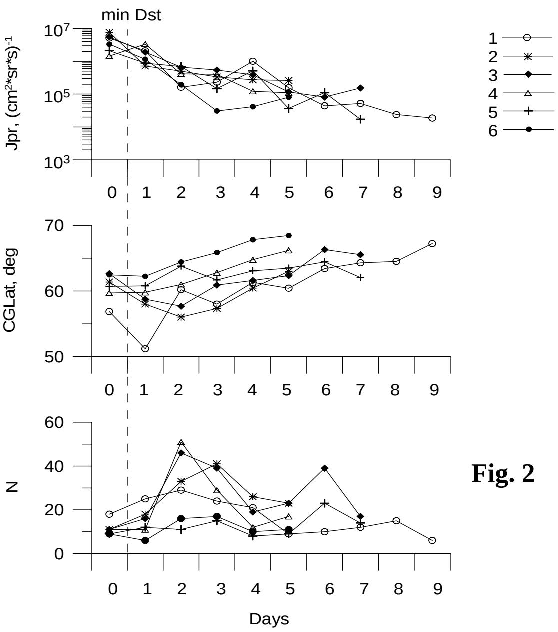

Fig. 2

respectively, in the top, middle, and bottom panels of Fig. 2. Lines with different symbols are numbered in the legend in accordance with corresponding storm numbers.

As one can see, the maximal LPEP intensity is observed in day 0 (the main phase) and the intensity decreases in the course of the storm. It is interesting that the decrement of the LPEP intensity is similar for weak and intense storms. At the main phase of the storms under study the average LPEP latitude was 57-63°. The latitude of LPEP decreases during the first 1-2 days of the recovery phase and then increases up to 62-68°. During intense storms the latitude of LPEP is lower. The amount of LPEP events is maximal in 2-3 days after minimum of Dst.

Note, that the NOAA satellites are three-axis stabilized and flying at altitude of about 800 km. The energetic protons are measured by two detectors, one of which is directed along the Earth-satellite radial vector. At L>3 this detector is within the loss-cone and observes the precipitating flux. At L<3 this detector is out the loss cone, and the information on precipitating particles is not available. The second detector views perpendicularly to the Earth-satellite vector and registers particles that are magnetically mirrored above the atmosphere. During the main phase of intense storms (like that №1) all precipitating boundaries are, in fact, shifted toward very low latitudes. Thus, some localized bursts of the proton flux seen by the detector viewing along the Earth-satellite vector are not real precipitation, but the flux enhancement outside the loss cone. Such bursts, nevertheless, mean the enhanced pitch-angle scattering of energetic protons, and the intensity of the flux can be considered as a proxy for the precipitating one.

Yahnina et al. (2003) divided the LPEP events into two types according, respectively, to the absence (type 1) or presence (type 2) of the low energy component in the proton precipitation (examples are shown in Fig. 3). The LPEP events of type 1 are associated with Pc1 pulsations, while the LPEP events of type 2 are

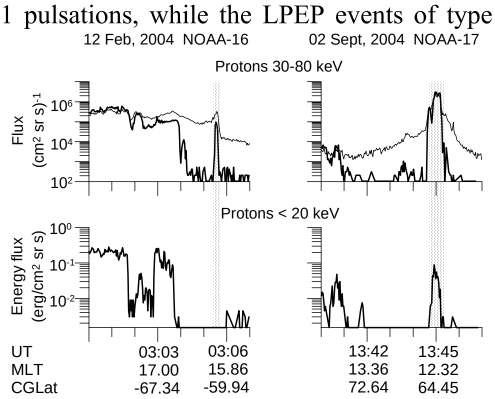

Fig. 3. Two types of LPEP (according to Yahnina et al., 2003). Time interval of LPEP is marked by shading.

mainly associated with IPDP.

In Fig. 4 the intensity of both types of LPEP is shown as function of MLT for two storms (№3 and №6). Proton fluxes (both trapped and precipitating) of type 1 and type 2 are marked by different symbols. Storm №3 is more intense (-216 nT) in comparison with storm №6 (-80 nT), however the MLT dynamics of LPEP are rather similar. During the main phase the LPEP events of type 2 prevail, and they are concentrated in the evening-night MLT sector. During the late recovery the LPEP activity shifts to the day-morning sector. Such behavior is also typical for other storms under study.

2. The latitude of LPEP decreases during the main and early recovery phase and increases during the recovery phase of geomagnetic storms.
3. The maximal amount of the LPEP events falls on the storm recovery phase. This is due to the LPEP events of type 1, since the LPEP events of type 2 mainly fall on the main phase.

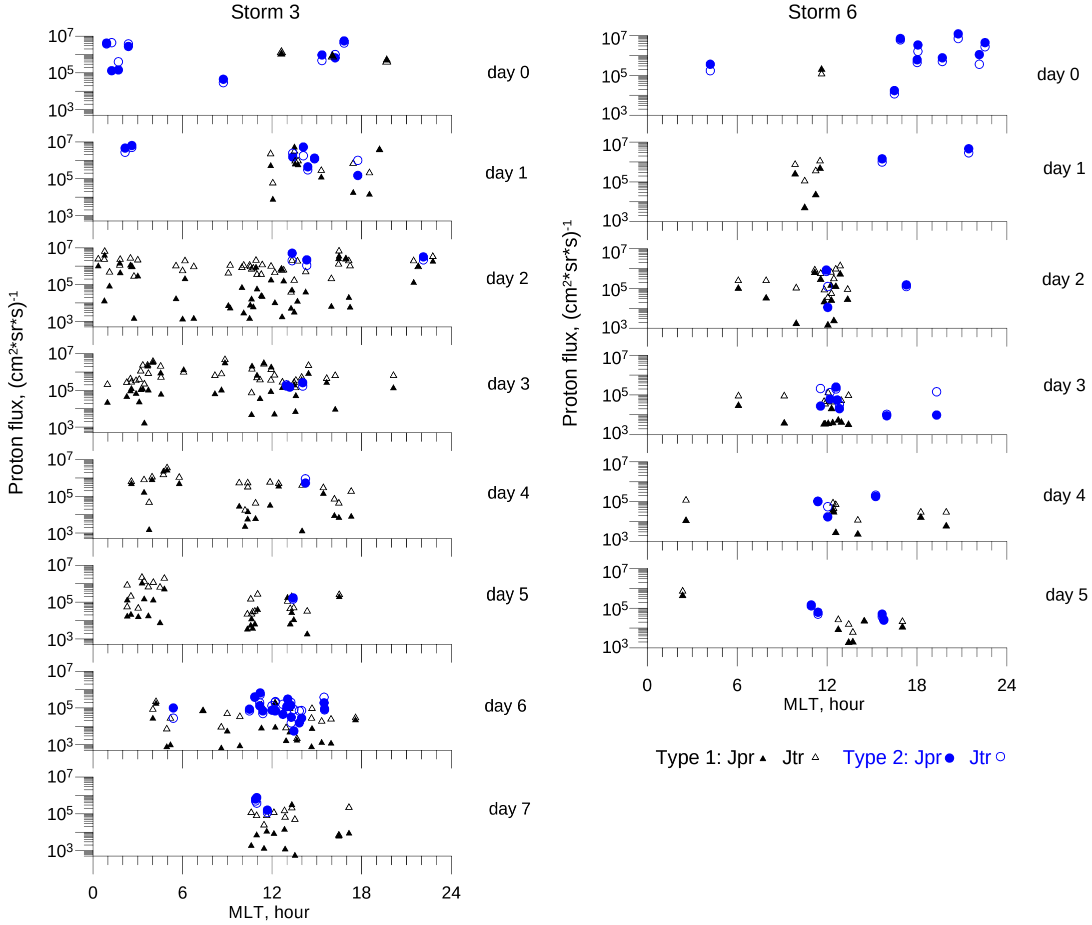

Fig. 4. The MLT distribution of the LPEP events of type 1 (triangles) and type 2 (circles) during every day of the storms №3 and №6. The intensities of both precipitating flux (filled symbols) and locally trapped flux (open symbols) are shown.

The upper panel of Fig 5 shows the sum over all storms of amounts of the LPEP events for each of days 0-5. Next two lower panels show the total amounts of LPEP of type 1 and type 2. The total amount of LPEP of type 1 reaches its maximum in second day of the recovery phase, while the occurrence of LPEP of type 2 is maximal in day 0 (the main phase).

Summary and Discussion

The above analysis of the LPEP dynamics during six magnetic storms has revealed the following properties:
1. The strongest LPEP intensity is observed during the main and early recovery phase of the geomagnetic storms, while as LPEP concentrate in the evening-night MLT sector. Later in the recovery phase the intensity of LPEP gradually decreases, and LPEP concentrate in the day-morning sector. The decrement of the LPEP intensity is similar for weak and intense storms.

To our knowledge the temporal behavior of the EMIC waves during geomagnetic storm has been considered only in one paper by Bräysy et al. (1998) on the basis of Freya satellite data. The findings of these authors are in very good agreement with properties of the LPEP storm behavior mentioned above in points 1 and 2. Erlanson and Ukhorsky (2001) dealt with much larger statistics (45 storms), although they did not considered the temporal variations. Their conclusions that the more intense EMIC events concentrate in the evening MLT sector and relate to stronger Dst disturbances also agree with the LPEP properties. Besides, Erlandson and Ukhorsky (2001) noted that larger amount of the EMIC wave events was observed at the recovery phase, in agreement with LPEP observations (see, point 3 in the above summary of the LPEP properties).
In the comprehensive study of the ground Pc1 pulsations performed by Kerttula et al. (2001) the similar spatial-temporal behavior was revealed as

well. Their conclusions on major wave occurrence during the recovery phase as well as on the shift of the Pc1 activity from evening to morning MLTs in the course of the storm agree with both EMIC and LPEP observations in space. However, Kerttula et al. used a sudden storm commencement as the reference time, thus their timing of the Pc1 behavior differs from the timing of LPEP in our study. To compare the temporal behavior of Pc1 with the LPEP statistics, we have repeated this part of the Kerttula et al. study using the observations of Pc1 in Lovozero (67.97° N, 35.02° E; MLT=UT+3) during the storms listed in Table 1 and using minimum of Dst as the reference. The result is shown in Fig 5. The occurrence of Pc1 is characterized by the Pc1 total duration (in hours). The maximal occurrence of Pc1 is found during third day of the recovery phase (Fig. 5 fourth panel). This slightly differs from the maximal occurrence of the LPEP events of Type 1, which relate to Pc1 (Yahnina et al., 2003). The difference can be explained by different ways to determine the occurrence of the phenomena. In particular, the longer duration of the Pc1 events in later stage of the recovery phase can be the reason of the difference. The number of the IPDP events on the ground station registered during the storms under study is shown in the bottom of Fig. 5. The maximum falls on day 0 in agreement with occurrence of the LPEP events of type 2.

As follows from the above consideration, the properties of the LPEP dynamics revealed from this study agree with known properties of the Pc1/EMIC waves during geomagnetic storms. This once more confirms that LPEP and EMIC waves are related phenomena being the consequence of the interaction of the ring current particles with the cyclotron waves. Thus, the LPEP observations can be used for monitoring the ion-cyclotron instability in the magnetosphere. It would be interesting to use the statistical characteristics of LPEP for quantitative estimate of the ring current losses in the course of the geomagnetic storm. This will be the aim of the future work.

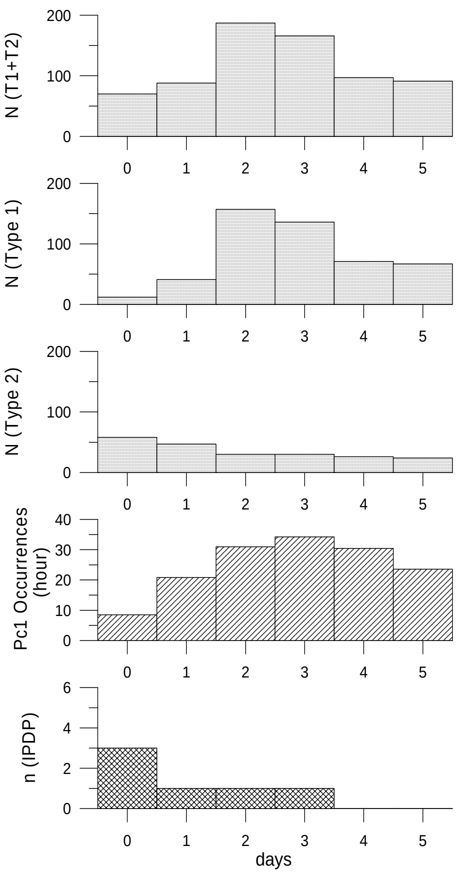

Fig. 5

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