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PRECIPITATION OF PROTONS RELATED TO EMIC WAVES ON THE DAYSIDE

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Abstract. In our previous works we found that some EMIC waves (geomagnetic pulsations Pc1 and IPDP) relate to localized precipitation of energetic protons (LPEP) equatorward of the isotropic boundary. Typically, LPEP map onto the equatorial plane at r<7 R_E. At the same time, observations of EMIC waves in the magnetosphere showed that most of EMIC wave events are observed well beyond the geosynchronous orbit on the dayside. In this report we describe another type of proton precipitation that can be produced by interaction of EMIC waves and magnetospheric protons. In contrast to LPEP, this precipitation occupies a wide latitudinal range and is observed at relatively high latitudes (but still, like LPEP, equatorward of the isotropy boundary). The relationship between such precipitation of energetic protons and EMIC waves is confirmed on the basis of the case and statistical comparisons.

1. Introduction

Several recent studies were devoted to investigation of global characteristics of EMIC waves in the equatorial magnetosphere. *Usanova et al.* (2012) and *Min et al.* (2012) used data from the *THEMIS* mission. In agreement with earlier study by *Anderson et al.* (1992), they found that probability to observe EMIC waves is generally small within the geosynchronous orbit (< 3%) and increases beyond it. *Usanova et al.* found the maximal occurrence (some 10%) of waves at noon-dusk sector at L=9 (note that radial coverage in that study was L =3-10). *Usanova et al.* did not distinguish between H and He bands of EMIC waves. In contrast, *Min et al*., considered these bands separately. For the H band they found the maximal occurrence (some 20%) at L=10-12 and MLT=5-8 with secondary maximum (10%) at noon-dusk. The maximal occurrence of the He band waves was found in the afternoon (20%) at L=8-12 and the minor maximum (10%) was found at the dawn sector. *Keika et al.* (2013) used data from the *AMPTE/CCE* spacecraft at L=3-9, and also examined the occurrence rate for He and H bands separately. They found the maximal occurrence of EMIC waves in the afternoon (25% and <10% for the H and He bands, respectively). All above-mentioned authors (see, also *Fraser and Nguyen*, 2001) noted a reduced occurrence of EMIC waves in the night sector in comparison with dayside.

Since EMIC waves scatter resonant ions into the loss cone, the fact that EMIC waves are mostly occur on the dayside should be manifested in the ion precipitation. Using data from the *NOAA-12* satellite, *Yahnina et al*. (2003) selected a specific pattern of proton precipitation related to the EMIC waves seen on the ground as quasi-monochromatic geomagnetic pulsations Pc1 and intervals of pulsations of diminishing periods (IPDP). This is localized (≤1° in latitude) precipitation of energetic protons (LPEP) within anisotropy zone equatorward of the isotropic proton precipitation region. The localized nature of the precipitation is, likely, related to the fact that wave-particle interaction responsible for Pc1 and IPDP and LPEP occurs at gradients of the cold plasma density in the equatorial magnetosphere (*Yahnin et al*., 2007, 2009, 2013; *Morley et al.,* 2010; *Yuan et al*., 2012; *Liu et al*., 2013). The maximal occurrence rate of the LPEP was found to be equal to ~1% and ~2% at dawn and dusk, respectively (*Yahnina et al*., 2003). However, due to peculiarities of the orbit, *NOAA-12* observations did not cover the 10 < MLT <15 sector. Also, LPEP are typically observed at L<7 (*Yahnina et al*., 2000; 2003). Thus, LPEP events can hardly be associated with a major part of EMIC waves on the dayside in the outer magnetosphere.

The aim of this paper is to find and describe a proton precipitation pattern that might be associated with the bulk of the EMIC wave events on the dayside. To solve this problem we use the data from low-orbiting satellites of the *NOAA POES* series. The satellites are equipped with the MEPED instrument, which measures charged particles with the energy *E*> 30 keV, both within the loss cone and trapped at the satellite altitude (~800 km).

In section 2 an example of particle measurements conjugated with a dayside EMIC wave event is shown. Some characteristics of the revealed proton precipitation pattern including the occurrence distribution in MLT-CGLat coordinates are described in section 3. Section 4 presents the discussion and conclusion.

2. Low-orbit observations of the proton precipitation conjugated with dayside EMIC waves in space

In the paper by *Min et al.* (2012), the example of wave observations in the day sector of the outer magnetosphere was presented (their Fig. 1). The waves in frequency range 0.2-0.4 Hz were observed at 01- 04 UT of 31 August 2007 in the distance range of 6-10 R_E. Below 7.4 R_E these waves were identified as EMIC waves in the He band, and further from the Earth as EMIC waves in the H band. In projection onto the ionosphere the waves were observed within a wide range of CGLat (67°-72°). Fig. 1 shows the trace of the *THEMIS A* spacecraft for the time of the wave observations mapped onto the northern ionosphere in Corrected Geomagnetic coordinates along with traces of two *NOAA* satellites traversed the conjugated region. Black dots on the *THEMIS A* trace indicate 30-minute intervals, and circles on the *NOAA-18* and *Metop-02* traces indicate minutes. Both *NOAA* satellites registered a wide region of proton precipitation at latitudes 67° to 71.5° CGLat shown in Fig. 1 by thick bars.

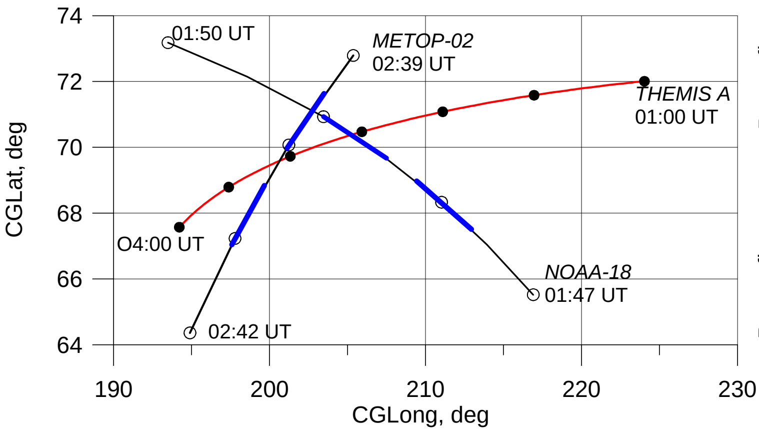

Fig. 1

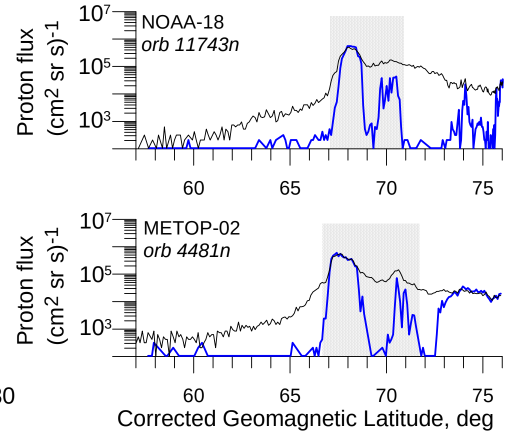

Fig. 2

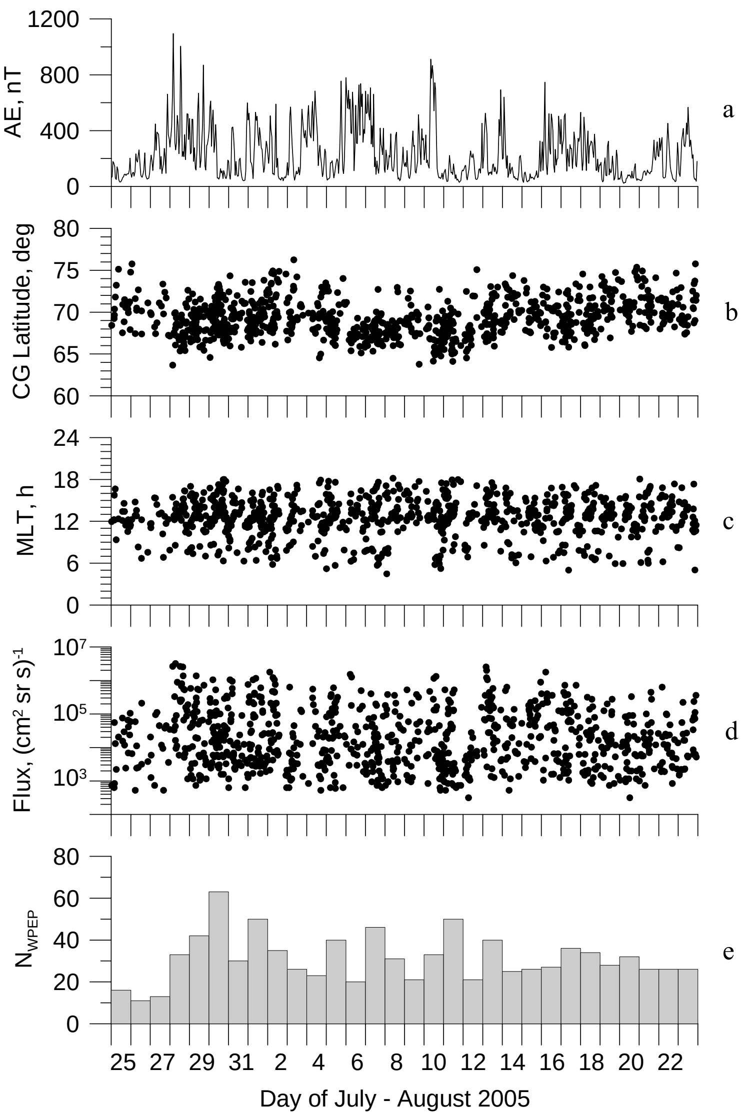

Fig. 3

Data from the two satellites before and after 01-04 UT do not show any significant precipitating flux in this region. The conjunction of the precipitation region with the region of the wave activity suggests their close relationship. The trapped and precipitating proton fluxes for the two NOAA orbits are shown in Fig. 2. It is clear that the precipitation is inside the anizotropic zone and is well separated from isotropic fluxes at higher latitudes. The precipitation pattern shown in Fig. 2 has a wide latitudinal size and, therefore, differs from LPEP, which are narrow spikes of precipitating flux with latitudinal dimension typically less than 1°.

3. Occurrence of the dayside proton precipitation within the anisotropic zone

A search through *NOAA* satellite particle data showed that such structures of proton precipitation (below we call them as WPEP - wide precipitation of energetic protons) are rather common on the dayside. To illustrate this fact, let us consider a relatively prolonged interval of 25 July – 23 August 2005. This interval was characterized by the variable geomagnetic activity (see, Fig. 3a). Invariant latitude and MLT of each of proton precipitation events observed during this interval are plotted in the Fig. 3b,c (actually, coordinates of middle points of precipitation events are plotted).

In particular, the precipitation is observed in the range of 64°-76° CGLat. Median value is 69.13° and first and third quartiles are ~68° and 71°, respectively. Fig. 3d presents intensity of the proton fluxes in WPEP. Finally, Fig. 3e shows the number of orbits of *NOAA* satellites with registration of WPEP for every day during the whole interval under study. The data presented in Fig. 3 demonstrate that the large-size precipitation of protons within the anisotropy zone is, indeed, a typical dayside phenomenon. The occurrence rate, which is defined as the ratio of the number of satellite orbits with registration of WPEP to the number of all orbits crossing the dayside, is about 25%.

A spatial distribution of the WPEP occurrence in coordinates MLT-CGLat is shown in Fig. 4. The occurrence in percent is presented in bins with resolution of 1 h in MLT and 1° in latitude. The occurrence is defined as the ratio of the number of orbits with WPEP registration within the bin to the number of all orbits crossing the bin. The occurrence is maximal (7-9%) in the afternoon sector at CGLat=68°-70° and decreases to both dawn and dusk. In general, this WPEP occurrence distribution is consistent with the results of statistical studies of EMIC waves. The occurrence distribution in Fig. 4 mapped onto the equatorial plane resembles that found, for example, by *Usanova et al.* (2012). Similar to the EMIC wave statistics, the probability to observe WPEP maximizes outside the geosynchronous orbit and is small in the near Earth magnetosphere.

MLT / CGLat	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18
74-75	0	0	0	0.27	1.56	1.38	0.54	0.66	0	0	0	0
73-74	0	0.61	0	2.63	2.02	1.79	1.63	0.5	0	0	0	0
72-73	0.29	1.8	2.12	0.59	2.03	2.95	2	2.67	1.49	1.04	0	0
71-72	1.25	4.27	0.4	0	3.24	3.41	2.86	3.32	2.51	1.84	1.19	0
70-71	0.74	1.27	2.88	1.82	4.22	2.98	5.3	5.72	6.33	4.64	0.76	0
69-70	1.81	3.17	3.45	0	2.12	5.47	6.24	6.72	7.86	4.66	2.52	1.39
68-69	0.7	3.89	1.36	1.72	2.6	3.12	8.53	5.87	6.72	7.17	5.48	0.99
67-68	2.39	3.17	2.07	3.28	2.02	2.76	6.87	5.86	5.33	7.17	3.64	2.23
66-67	1.25	2.21	1.95	3.18	0.98	0	3.23	1.93	1.97	5.93	1.23	2.6
65-66	0.94	1.22	0	1.52	0	0.27	0.54	1.64	0.38	1.25	1.52	0.8

Fig. 4

4. Discussion and conclusion

Using the *THEMIS* data, *Wang et al.* (2013) studied spatial distributions of the ion pitch-angle anisotropy at different energies (from 0.05 to 600 keV). For ions with the energy of a few tens of keV, they found well-defined transverse anisotropy ($T_\perp > T_{||}$) in the outer magnetosphere (at r > 5 R_E) on the dayside. The most convenient mechanisms of the transverse anisotropy of energetic ions on the dayside are the drift shell splitting (*Roederer*, 1967) and drift orbit bifurcation (*Shabansky*, 1971). Both mechanisms are the result of the interaction of the magnetosphere with the permanently flowing solar wind producing day-night asymmetry of the magnetospheric magnetic field, which is compressed on the dayside and stretched on the night side. The stronger compression the larger dayside anisotropy resulting from the two mentioned mechanisms (*McCollough et al.*, 2012). This anisotropy should permanently exist on the dayside. The transverse anisotropy of ions is a favorable condition for growth of EMIC waves and related scattering of ions into the loss cone. Thus, on the dayside there exists a permanent source of precipitation of protons. The solar wind-magnetosphere interaction and magnetospheric processes producing the energetic protons in the day sector rule spatial scale and structure of the source region as well as intensity of the precipitation. Note, that characteristics of EMIC waves on the dayside demonstrate clear dependence on both solar wind dynamic pressure and geomagnetic activity (e.g. *Usanova et al.*, 2012).

The dependence of WPEP on solar wind and geomagnetic activity are not discussed here (this will be a subject of future investigations). Nevertheless, the case study illustrated by Figs. 1, 2 and occurrence statistics (Fig. 4) show that WPEP events within the region of anisotropic fluxes of energetic protons are the particle counterpart of EMIC waves in the outer magnetosphere on the dayside.

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