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ENERGETIC ELECTRON PRECIPITATION MEASURED BY CORONAS-F SATELLITE AND POLAR MAGNETIC DISTURBANCES: CASE STUDY OF DECEMBER 13, 2003

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Abstract. The energetic (0.3-1.5 MeV) electron precipitation at polar latitudes of the northern hemisphere on December 13, 2003 are analyzed on the base of CORONAS-F satellite measurements. The comparison of the moment of electron precipitation registration and the ground-based observations of geomagnetic disturbances and optical auroras from the stations located near footprint of the satellite pass is carried out. It is found that the energetic electron precipitation in the night sector at comparatively high polar latitudes are accompanied by the simultaneous development of bay-like magnetic disturbances, by appearance of the riometer absorption bursts, Pi3 geomagnetic pulsations and visual auroras.

1. Introduction

The precipitation of electrons with the energies from tens to hundreds keV in the polar region has been previously observed in different experiments [Fritz, 1970; Imhof et al, 1992; Kuznetsov et al, 2000; ets.]. Using the data of the low orbiting CORONAS-I satellite, Kuznetsov et al. [2004] showed that the precipitations of the energetic (E > 0.5 MeV) electrons, accompanied by riometer absorption enhancement, can occur at the night side of the polar cap immediately after a substorm, observed at the aural zone. However, the precise localization of the regions of these precipitations and their relationship with ULF waves was not examined.

The purpose of this work is the comprehensive analysis of the fluxes of the energetic electrons measured on the low orbiting CORONAS-F satellite and the simultaneous ground-based observations of the magnetic field variations, ULF pulsations, riometer absorption and visual aurora recorded near the footprint of the satellite pass in the polar region for the event on December 13, 2003.

2. Instrumentation

The fluxes of electrons with energies of 300-600 keV and 0.6-1.5 MeV have been detected by the semiconductor telescope on the board of CORONAS-F low-altitude satellite (altitude ~500 km, inclination ~82.5°) [Kuznetsov et al., 2002]. We used the ground-based observations of magnetometer data from the global networks such as INTERMAGNET, the Greenland array and the Scandinavian IMAGE profile to study the magnetic disturbances and geomagnetic pulsations. The Finnish riometers data (30 MHz, ftp://sgodata.sgo.fi/pub_rio/) and the optical aurora observation by the all-sky cameras (ASC) of the system MIRACLE (Magnetometers – Ionospheric Radars – All-sky-cameras Large Experiment, http://www.space.fmi.fi/MIRACLE/ASC/ASC_keograms/) have been analyzed in this study. The comparison of the data of observations with the auroral oval position was based on the OVATION (Oval Variation, Assessment, Tracking, Intensity, and Online Nowcasting, http://sd-www.jhuapl.edu/Aurora/T) model.

3. Results of the observations

We study in details the energetic (0.3-1.5 MeV) electron precipitations in northern polar region for the event on December 13, 2003. The cases of the electron flux enhancement at L > 8 (where L is the MacIlwain parameter) with the maximum exceeding three standard deviations from a background electron flux of these energies have been analyzed. The CORONAS-F satellite crossed the northern polar region 15 times during this day, but only in 6 cases the sporadic electron precipitations at L > 8, which were not detected neither on previous, nor on the subsequent orbit, are observed. It is necessary to mention that the enhancements of the solar flare electron fluxes are not observed in the interplanetary space during this day.

Figure 1 shows the variations of the parameters of the solar wind (SW) and the interplanetary magnetic field (IMF) for the period of 03-14 December 2003. One can see that after the small magnetic storm (Dst_{min} = -66 nT on 05 December), the Dst-index was not restored to the pre-storm level during the 10 following days. It can be a result of the high-speed solar wind stream (SW velocity reached ~800 km/s) arriving to the Earth on 08 December. The considered event (13 December) was observed during the extremely long late recovery phase of the 5 December magnetic storm. In the analyzed time interval, the SW velocity was 750-850 km/s, the SW density was ~2 cm^{-3}, IMF By and Bz varied from -5 to +6 nT, and IMF Bx was small and negative.

It is well known that a recovery phase of a "classical" magnetic storm, which is typically developed under positive IMF Bz values, is characterized by the cessation of night geomagnetic disturbances and the excitation of the Pc5 geomagnetic pulsation in the morning and day-side sectors of the magnetosphere. However, in the discussed event, the substorm activity continued even in the storm recovery phase during several days (from December 5 to 14, 2003) as it is seen in the AE- index variations (Fig. 1b). On December 13, the AE values increased up to 1500 nT. Such geomagnetic activity associated with high speed solar wind streams has been called high-intensity long-duration continuous AE activity (HILDCAA) events [Tsurutani and Gonzalez, 1987].

On December 13, 2003, the most intensive 300-600 keV electrons precipitations are recorded on two satellite passes: at 17.34 - 17.43 UT and at 22.13 - 22.23 UT. Figure 2 demonstrates the orbit positions of the CORONAS-F satellite in the geographical coordinates and the location of the auroral oval in accordance with OVATION model. One can see that the ground-based stations (NAL, LYR and HOR) at Spitsbergen archipelago are located near the mapping of the intense bursts of the electron precipitations at the polar latitudes.

Figure 3 shows the X component of the magnetic field at the high-latitude observatories of Finnish network IMAGE (the lower plot) and the aurora keograms from obs. NAL and LYR (the upper plot).

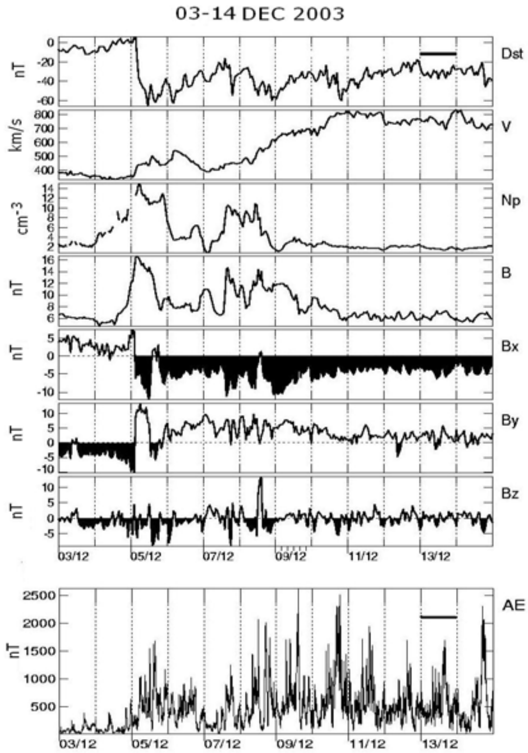

Fig. 1. Variations of the Dst-index, solar win velocity (V), density (Np) and IMF (B, Bx, By, Bz components (the upper plot) and AE-index (the lowe plot) during December 03-14, 2003.

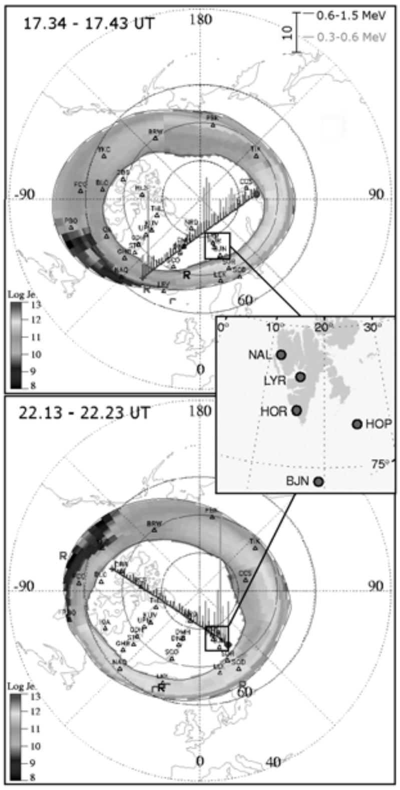

Fig. 2. The satellite passes at 17.34-17.43 (the upper plot) and 22.13-22.23 UT (the lower plot) in geographic coordinates, 0.3-0.6 MeV and 0.6-1.5 MeV electron precipitation intensity and the auroral oval location based on OVATION model.

The middle plot of Fig. 3 presents the riometer data at obs. HOR. The grey vertical lines mark the moments of the satellite passes. The visual auroras are observed at obs. NAL and LYR during both cases, being the most intense at the lower-latitudes (obs. LYR, $\Phi = 75°$).

Figures 2 and 3 show that the electrons precipitation is localized at the higher latitudes in the first pass than in the second one. According to the OVATION model this region maps into the polar cap, however, the ASC data from obs. NAL and LYR showed that the aurora developed near the polar border of the auroral oval.

During the first CORONAS-F pass (17.34 - 17.43 UT), the magnetic polar bay-like disturbances (polar substorms) are observed at obs. NAL, LYR and HOR (Fig. 3), located in the evening (~20 MLT) sector of the magnetosphere, whereas in the auroral latitudes there were no magnetic disturbances.

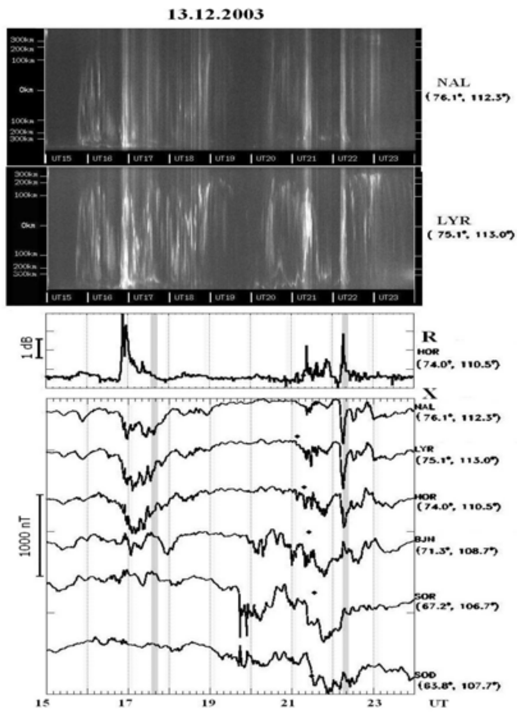

Fig. 3. The keograms of polar cap visual auroras a NAL and LYR (the upper plot), riometer data a HOR (the middle plot), and X component o geomagnetic field at high latitude observatories o IMAGE network (the lower plot).

In the second satellite pass (22.13 - 22.23 UT), the bay-like magnetic disturbances at polar latitudes occurred immediately after the start of the magnetospheric substorm in the auroral zone (obs. SOD, SOR), resulted from the substorm polar expansion. The energetic electron precipitation was more intense than in the first satellite pass and was observed nearer to the poleward boundary of the auroral oval according to the OVATION model. It

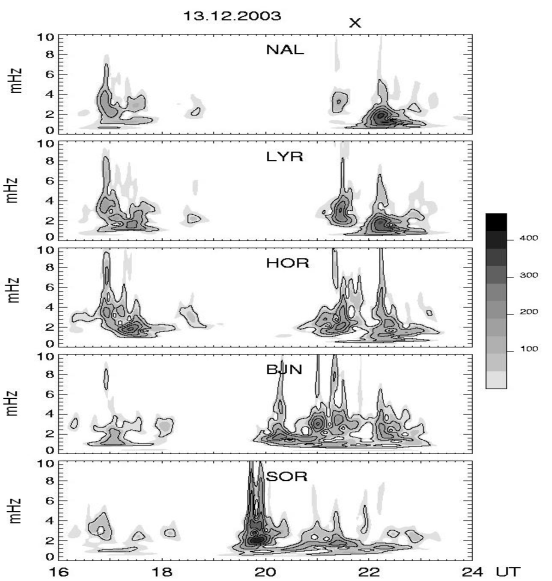

Fig. 4. The wavelet structure of the geomagnetic pulsations observed at high latitude observatories of IMAGE network.

should be mentioned that the strong precipitations of electrons with the energies not only of 300-600 keV, but also of 600-1500 keV were also observed in vicinity of the poleward boundary of the auroral oval during the pass at 11.25 - 11.33 UT (the data do not shown).

Figure 4 demonstrates the results of the wavelet analysis of the geomagnetic pulsation in the frequency band of 1-8 mHz, accompanied the bay-like magnetic disturbances and the energetic electron precipitations on the CORONAS-F satellite. Both the pulsations and the magnetic disturbances are observed only at the polar obs. HOR-NAL in the first event. However, in the second case, the geomagnetic pulsations are observed at auroral latitudes as well. The maximal intensity of the pulsations is registered in the frequency band of 1-2 mHz.

Figure 5 demonstrates the similarity of the wavelet structure of the magnetic and riometer pulsation at obs. HOR. We attributed these pulsations to the Pi3 type according to their burst-like structure and the frequency range.

4. Discussion

In this paper we studied the energetic (0.3-1.5 MeV) electron precipitations at high latitudes observed during the period of several days of high speed solar wind streams caused high-intensity long-duration continuous AE activity (HILDCAA). Tsurutani and Gonzalez [1987] argued that HILDCAAs can be the cause of the acceleration of the magnetospheric energetic electrons to high energies.

We found as a result of the detailed analysis of the satellite and ground based data obtained on December 13, 2003, that the intense precipitations of energetic electrons, detected on the CORONAS-F satellite orbits (17.34 – 17.43 UT and 22.13 – 22.23 UT), were observed simultaneously with the bay-like geomagnetic disturbances, riometer absorption enhancements, Pi3 geomagnetic pulsations, and polar auroras at the stations located near the satellite orbit mapping. Thus, the obtained experimental results can demonstrate the close connection of energetic electron acceleration processes with substorm activity and geomagnetic pulsations.

The polar boundary of the considered electron precipitations was found to be localized in the region, which is ordinarily identified as a polar cap (see the comparison with OVATION model). However, it is well known that during the substorm expansion phase the auroral bulge expands poleward to comparatively high latitudes [see, for example, Elphinstone et al., 1995]. It is confirmed by the results of our study of the ASC keograms and the ground-based high latitude riometer measurements.

The effect of the auroral bulge expansion to high latitudes is closely connected with the change of a magnetic configuration during the substorm expansion phase. Acceleration and injection of particles during the dipolization of the magnetic field lines leads to development of the eastward transverse current [Antonova et al, 1999; Akasofu, 2003]). As a result, a polerward shift of the fixed region of the high-latitude magnetosphere is observed [Antonova and Ganyshkina, 1999]. Thus, the magnetic field at the geostationary orbit can exceed the value of the dipole one. It leads to the “hiperdipolization” [DeForest and McIlwain, 1971; Kuznetsov et al., 2000; 2004].

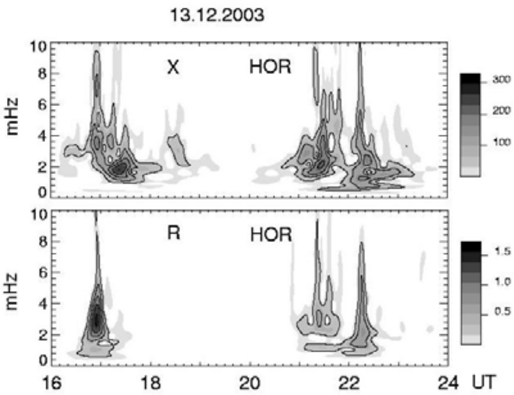

Fig. 5. The wavelet structure of the geomagnetic and riometer pulsations at HOR.

Coincidence of the area of the energetic electron precipitations with the region of the intense riometer absorption manifests the possibility of the localization of the observed electron events in the quasi-trapping region, in spite of a rather high-latitude character of the observed phenomena. This region is filled by auroral particles with energy of ~ tens and hundreds keV during magnetic disturbances [Lazutin, 2004]. The polar boundary of the quasi-trapping region is rather sharp for electrons and protons in a wide energy range [Lazutin, 2004]. It is usually considered that transverse currents in the region of quasi-trapping are a part of the magnetotail current system. However, it can be shown [Antonova, 2001; Antonova et al., 2009] that transverse currents in this region are localized inside the magnetosphere in the region of the high-latitude continuation of the ring current.

The considered events were observed in the late recovery phase of the small magnetic storm under very high values of the solar wind velocity up to 850 km/s that is typical for a substorm of the polar cap [Sergeev et al., 1979]. Despirak, et al., [2008] showed statistically that during the solar wind speed more than 500 km/s, the center of the westward electrojet can shift to the geomagnetic latitudes more than 75º. It should be noted also that the described electron precipitations are localized outside of the polar boundary of the outer radiation belt [Myagkova et al., 2008]. This finding can be very important for the analysis of the processes of the electron acceleration.

5. Summary

1. The precipitations of energetic (300-1500 keV) electrons are observed using the data of CORONAS-F satellite polar crosses in the night sector of the northern hemisphere in vicinity of the auroral oval boundary.
2. It is found that the electron precipitations are accompanied by simultaneous development of the bay-liked geomagnetic disturbances near the footprint of the satellite, riometer absorption enhancement, Pi3 geomagnetic pulsation and visible auroras.
3. The wavelet structure of the geomagnetic and riometer pulsations was similar in the frequency band of 1-10 mHz. Therefore, it can be caused by the same source. However, there is open question what phenomena are primary. Whether the modulation of the precipitated electrons with the energy of tens-hundreds keV by geomagnetic pulsation takes place or the increase of the flux of these electrons leads to excitation of the waves in the ionosphere, observed on the Earth’s surface as geomagnetic pulsations.

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