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# Correlation between the Earth's Outer Radiation Belt Dynamics and Solar Wind Parameters at the Solar Minimum According to EMP Instrument Data onboard the CORONAS-Photon Satellite

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**Abstract**—The study of variations in the electron flux in the outer Earth radiation belt (ERB) and their correlations with solar processes is one of the important problems in the experiment with the Electron-M-Peska instrument onboard the CORONAS-Photon solar observatory. Data on relativistic and subrelativistic electron fluxes obtained by the Electron-M-Peska in 2009 have been used to study the outer ERB dynamics at the solar minimum. Increases in outer ERB relativistic electron fluxes, observed at an height of 550 km after weak magnetic disturbances induced by high-velocity solar wind arriving to the Earth, have been analyzed. The geomagnetic disturbances induced by the high-velocity solar wind and that resulted in electron flux variations were insignificant: there were no considerable storms and substorms during that period; however, several polar ground-based stations observed an increase in wave activity. An assumption has been made that the wave activity caused the variations in relativistic electron fluxes.

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## INTRODUCTION

Data on variations in the relativistic electron fluxes in the outer ERB, significantly determining the radiation conditions in the near-Earth space (NES), are required at periods of solar minimum for both fundamental scientific researches and application problems. There have been and still are many space satellites (SS) providing data on charged particles fluxes and spectra in the NES (such as GOES, POES, SAMPEX); however, the problem of tracing the dynamics of relativistic electrons at low altitudes remains urgent, because of the still unsolved problem of electron acceleration to relativistic energies in the Earth's magnetosphere (Friedel et al., 2002; Reeves et al., 2003; and references therein) and the need to analyze the dependence of the space instrument failure frequency on geomagnetic disturbances during intense increases in relativistic electron fluxes (Romanov et al., 2005).

One of the main scientific problems of the experiment, carried out by researchers of Institute of Nuclear Physics, Moscow State University (INP MSU) with the use of the Electron-M-Peska instrument onboard the CORONAS-Photon space satellite (SS)—the third CORONAS SS—is the study of the dynamics of relativistic electron fluxes in the Earth's magnetosphere. The CORONAS-Photon SS operated during the solar minimum; therefore, the above problem became the main one, since monitoring of solar cosmic rays (SCRs) and the study of variations in the boundaries of the region of SCR penetration into the Earth's magnetosphere were irrelevant due to the total absence of solar flares.

## EXPERIMENT

The Electron-M-Peska instrument, designed at INP MSU and mounted onboard the CORONAS-Photon SS, was designed to record electron, proton, alpha particle, and CNO nucleus fluxes [4]. The measurement data provide information on the dynamics of SCR and ERB particles and allow continuous monitoring of NES radiation conditions from onboard the CORONAS-Photon solar observatory. CORONAS-Photon's low polar orbit (550 km, inclination of 82.5°) allowed electrons in the outer ERB to be recorded four times per one circuit of about 1.5 h in duration.

The instrument consists of two modules: the Electron-M-Peska detector module and the Electron-M-Peska electronic module. The Electron-M-Peska instrument is a four-element semiconductor telescope designed to recordi electrons, protons, alpha particles, and CNO nuclei in NES using the path–energy release technique. The instrument includes two parallel telescopes consisting of detectors about 6 cm$^2$ in area, a working part thickness of 0.375 mm, and a padding thickness of 0.6 mm. The first detector is protected by an aluminum filter 0.1 mm in thickness. The second detector is mounted directly above the first. Aluminum filter 4.5 mm in thickness is mounted between the second and third detectors. A brass filter 7 mm in thickness is mounted between the third and fourth detectors.

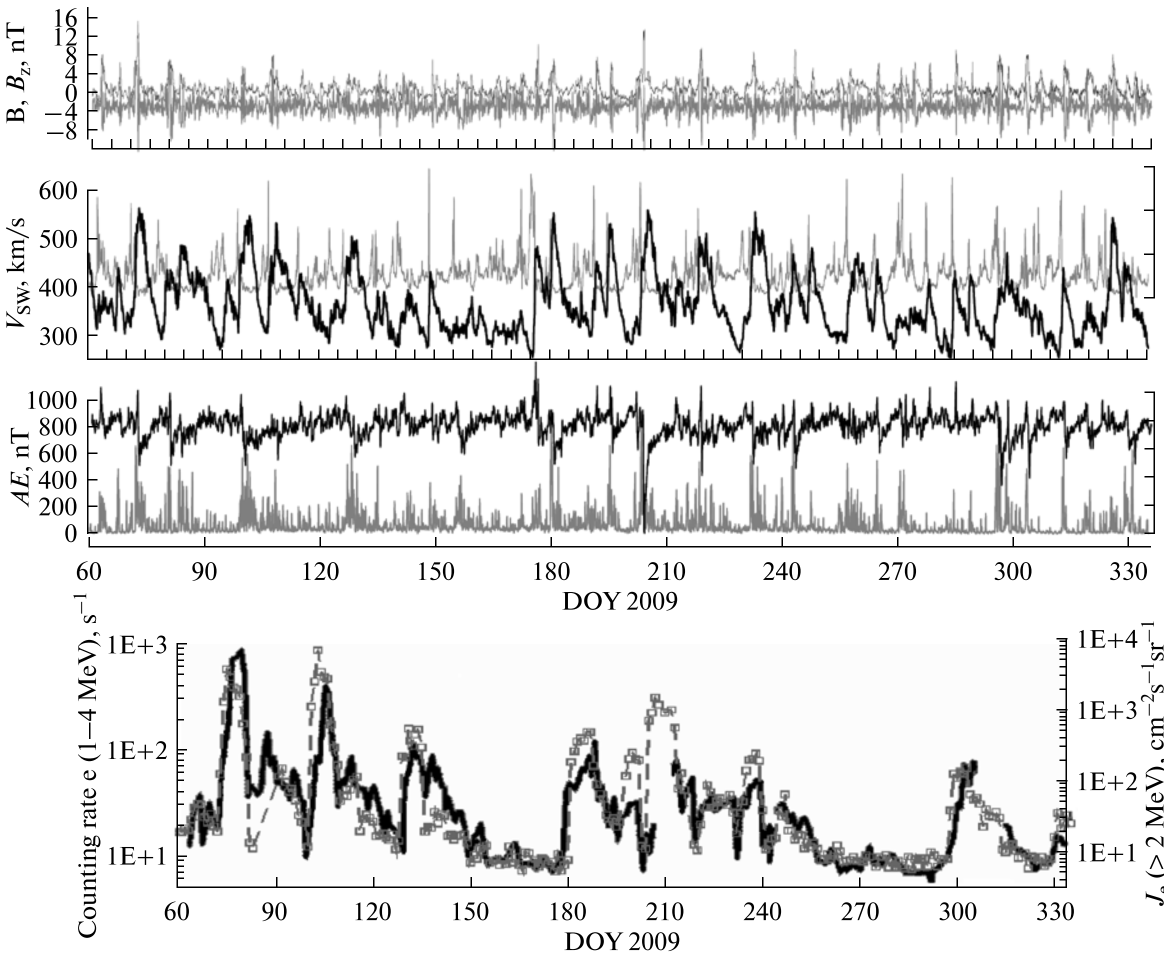


**Fig. 1.** Variations in relativistic electron fluxes in the outer ERB at an altitude of 550 km and a geostationary orbit (bottom part, black solid curve), as well as in the IMF and SW parameters and geomagnetic indices from March to November 2009 (for designations see text).

Electrons are recorded by the first three detectors within an energy release range of 0.1–0.8 MeV against protons with energies higher than 80 MeV.

## DATA ANALYSIS AND DISCUSSION

Variations in the relativistic electron fluxes in the outer ERB were studied at an altitude of 550 km in the period from March to November 2009 based on the Electron-M-Peska data (lower part of Fig. 1, solid black curve). The data are presented for the daily maximum flux measured in the outer ERB in the Southern Hemisphere.

The parameters of the interplanetary magnetic field (IMF)—IMF modulus B (black curve) and its component $B_z$ (gray curve, the upper part of Fig. 1) and of the solar wind (SW)—the SW velocity (black curve) and density (gray curve, Fig. 1, second part from top), as well as $D_{st}$ (black curve) and $AE$ (gray curve, Fig. 1, second part from bottom) geomagnetic indices are given according to Goddard Space Flight Center data (http://cdaweb.gsfc.nasa.gov/).

In addition to the data on electron fluxes at an altitude of 550 km (CORONAS-Photon), data on variations in electrons with energies higher than 2 MeV at a geostationary orbit are presented in the bottom part of Fig. 1 according to GOES-11 data (http://cdaweb.gsfc.nasa.gov/; gray dashed curve with empty squares).

As is seen from Fig. 1, the average relativistic electron flux in the outer ERB decreased both at geostationary orbits and at a low altitude (550 km) from March to November 2009; it was lower than the instrument sensitivity in June and in mid-September 2009. In comparing the variations in the electron flux and SW parameters, note that the mean SW velocity was lower in these periods than in other time.

It is clear from Fig. 1 that the relativistic electron fluxes increased many times by more than two orders of magnitude at a geostationary orbit (GOES-11 data) and by more than an order of magnitude at an altitude

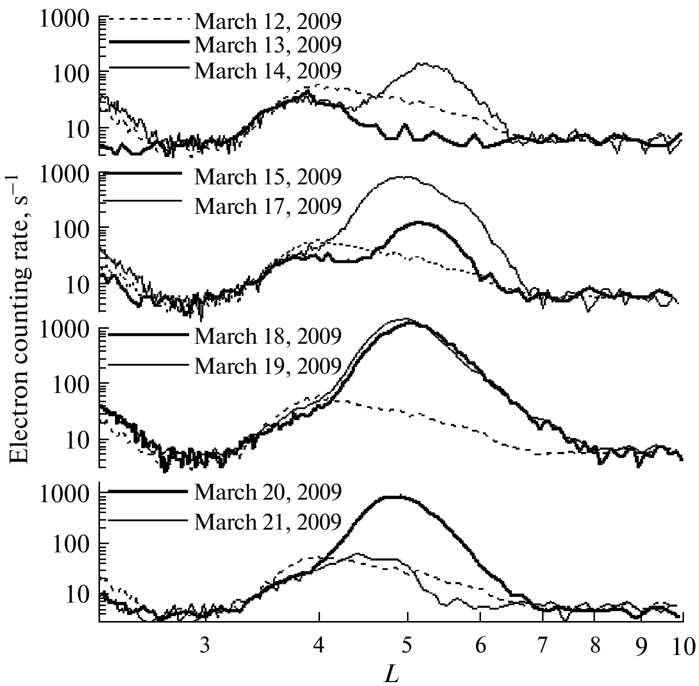


**Fig. 2.** Counting rates of electrons with energies of 1–4 MeV as functions of the number of the *L* shell for nine passes of CORONAS-Photon through the outer ERB, obtained during March 12–21, 2009.

of 550 km during the period from Match to November 2009 under comparatively weak geomagnetic perturbations. In this case, the increase in the flux of electrons with energies higher than 2 MeV at a geostationary orbit usually began several days earlier than that of electrons with energies o f 1–4 MeV at an altitude of 550 km. We relate the increases in the relativistic electron fluxes in the outer ERB in the period under study with the arrival of high-velocity SW streams, which is confirmed by comparing the variations in the electron flux and SW velocity and does not contradict other experimental results, e.g., in (Li et al., 2005).

It is clear from Fig. 1 that 20 high-velocity SW streams reached the Earth's orbit in the period under study; however, not all of them produced a weak geomagnetic disturbance and thus induced an increase in the electron flux in the outer ERB at a geostationary orbit and at small altitudes. In this case, the presence or absence of increases in the relativistic electron flux for each of the high-velocity SW streams were related neither to SW density nor the modulus of the magnetic field *B*, nor the maximum value of $B_z$. Some high-velocity SW streams that reachsed the Earth in the second half of November 2009 could serve as examples of non-increase-inducing SW streams. These streams did not cause strong variations at geostationary orbits or at small altitudes. In this case, SW velocity amplitudes, variations in $D_{st}$, and values of the *AE* index in the second half of November 2009 differed insignificantly from the values observed in the end of October.

Variations in the parameters of IMF and SW and geomagnetic indices in the night of October 12/13, 2009 were considered in detail in (Myagkov et al., 2010); in this period, a weak ($D_{st} = -28$ nT and $K_p = 5$) magnetic disturbance was observed caused by a high-velocity SW stream that arrived to the Earth (the maximum plasma velocity $V_{SW}$ = 550 km/s) and induced an intense increase (by two orders of magnitude) in the counting rate of relativistic electrons in the outer ERB (CORONAS-Photon data). The auroral activity was relatively low in the considered period. According to the data of the Kyoto World Data Center (swdcwww.kugi.kyoto-u.ac.jp), the *AE* index reached its maximum of 800 nT only at about 07:00 on March 13 (at the maximum of the main phase of the geomagnetic disturbance) and about the afternoon on March 21. Increasing wave activity was recorded at several polar stations, such as Sodankyla and Narsarsuaq, in the period from March 15 to 20, 2009. Figure 2 in (Myagkov et al., 2010) shows the profiles of the counting rate of electrons with energies of 1–4 MeV depending on the *L* shell (McIlwaine *L* coordinate) for nine passes of the CORONAS-Photon SS through the outer ERB at the same geographic coordinates and magnetic local time before, during, and after the geomagnetic disturbance of March 12–13. Dashed curves in all four parts of the figure show the background electron counting rates obtained before the disturbance in the early morning of March 12. A weak decrease in the counting rate of recorded electrons on

March 13 during the main phase of the storm is seen in Fig. 2 (thick curve in the upper part). This does not contradict the results obtained from the previous CORONAS SS, CORONAS-F, i.e., a sharp decrease in the intensity of relativistic electrons in the outer ERB down to its almost complete depopulation during strong geomagnetic storms (Kuznetsov et al., 2007). Then, on March 14 (thin curve in the upper part), the electron flux remained invariable near the prestorm maximum at $L = 4$, while an additional peak appeared at higher $L$ with the maximum at $L = 5.2$. On March 17 (thin curve in the second-from-the-top part), the new maximum shifted a little closer to the Earth (approximately $L = 5$), and its intensity increased by about an order of magnitude. The intensity of electron fluxes in the outer ERB continued to increase during March 18 and 19. The counting rate of relativistic electrons maximum for this event was recorded on May 19. The maximum fluxes at $L = 5–6$ were recorded one day earlier than at $L = 4–5$ and four days after the instant of the disturbance caused by a high-velocity SW stream. The time lag assessments coincide with the data of (Li et al., 2005), assessed on the basis of SAMPEX data.

A correlation between fluxes of relativistic electrons (with energies higher 1 MeV) at a geostationary orbit (LANL) and the SW velocity was noted earlier in, e.g., (Williams et al., 1968) and, like in our case, near the solar maximum (1995). It was suggested in that work that relativistic electron fluxes can vary due to the radial diffusion or "heating" by VLF waves; however, their parts were not ascertained.

Variations in the relativistic electron fluxes in the outer ERB have been studied experimentally both in Russia and abroad by different scientific teams since the discovery of ERBs, e.g., (Williams et al., 1968; Vakulov et al., 1975; Bezrodnykh et al., 1987; Baker et al., 1997; Li et al., 1997; Friedel et al., 2002; Li et al., 2001; Reeves et al., 2003) and references therin. A correlation between variations in in relativistic electron fluxes and SW parameters, in particular, the SW velocity, was shown in many of these works.

It should be noted that 2009 was characterized by extremely quiet geomagnetic conditions, when the arrival of high-velocity SW streams did not cause the development of significant geomagnetic storms in the Earth's magnetosphere. Thus, the above-considered geomagnetic disturbance of March 12–13, 2009, that caused the described variations in the relativistic electron fluxes was not strong; moreover, it cannot be considered a magnetic storm in the commonly accepted meaning of the word. No significant substorms were observed in the period under study; however, some polar stations recorded increased wave activity, which could cause the observed increase in the relativistic electron fluxes.

## CONCLUSIONS

The experiments with the Electron-M-Peska instrument onboard the CORONAS-Photon solar observatory has shown that significant (by more than an order of magnitude) increases in relativistic electron fluxes were observed in the outer ERB at small (500–550 km) altitudes during the period of the deep solar minimum in 2009, caused by the arrival of high-velocity SW streams correlating with increases in relativistic electron fluxes at a geostationary orbit. The mentioned increases were observed in March, April, and the beginning of May, as well as in June, August, and the at end of October 2009.

Comparison of variations in the relativistic electron fluxes at a circular polar orbit of 550 km in altitude (CORONAS-Photon) and at the GOES-11 geostationary orbit has shown that increases in relativistic electron fluxes begin almost simultaneously at a geostationary orbit and an altitude of 550 km (within one day) but are much slower and reach a maximum several days later. The geomagnetic disturbances caused by high-velocity SW streams and that resulted in variations in electron fluxes were weak; i.e., no significant storms and substorms occurred in the period under study, but several polar ground-based stations recorded increased wave activity; therefore, we assume that just the wave activity was the reason of variations in the relativistic electron fluxes.

The results show that even weak geomagnetic disturbances in combination with wave activity can significantly affect the dynamic of outer ERB in a period of solar minimum.

## REFERENCES

Baker, D.N., Li, X., Turner, N., et al., Recurrent Geomagnetic Storms and Relativistic Electron Enhancements in the Outer Magnetosphere: ISTP Coordinated Measurements, *J. Geophys. Res.*, 1997, vol. 102, no. A7, pp. 14141–14148.

Bezrodnykh, I.P., Morozova, E.I., and Shafer, Yu.G., Influence of Large-Scale Solar Wind Disturbances on the Dynamics of Relativistic Electrons of the Outer Radiation Belt, *Kosm. Issl.,* 1987, vol. 25, no. 1, pp. 64–73.

Friedel, R.H.W., Reeves, G.D., and Ohara, T., Relativistic Electron Dynamic in the Inner Magnetosphere: A Review, *J. Atmos. Sol.-Terr. Phys.*, 2002, vol. 64, no. 2, pp. 265–282.

Kuznetsov, S.N., Myagkova, I.N., Yushkov, B.Yu., Denisov, Yu.I., Myrav'eva, E.A., and Kudela, K, Dynamics of the Earth Radiation Belts During Strong Magnetic Storms Based on CORONAS-F Data, *Sol. Sys. Res.*, 2007, vol. 41, no. 4, pp. 338–347.

Li, X., Baker, D.N., Temerin, M.A., et al., Multisatellite Observations of the Outer Zone Electron Variation during the November 3–4, 1993, Magnetic Stroms, *J. Geophys. Res.*, 1997, vol. 102A, p. 140.

Li, X. and Temeric, M.A., The Electron Radiation Belt, *Space Sci. Rev.*, 2001, vol. 95, pp. 569–580.

Li, X., Baker, D.N., Temerin, M., et al., Energetic Electrons, 50 KeV–6 MeV, at Geosynchronous Orbit: Their Responses to Solar Wind Variations, *Space Weather*, 2005, vol. 3, p. 04001.

Myagkova, I.N., Panasyuk, M.I., Denisov, Yu.I., et al., *Pervye Etapy Letnykh Ispytanii i Vypolnenie Programmy Nauchnykh Issledovanii* (First Stages of Flight Tests and Execution of the Scientific Research Program), Moscow: IKI RAN, 2010. Ser. Mekhanika, Upravleniye i Informatika, pp. 196—205.

Reeves, G.D., McAdams, K.L., Friedel R.H.W., et al., Acceleration and Loss of Relativistic Electrons During Geomagnetic Storms, *Geophys. Rev. Lett.*, 2003, vol. 30, no. 10, pp. 1529–1541.

Romanova, N.V., Pilipenko, V.A., Yagova, N.V., and Belov, A.V., Statistical Correlation of the Rate of Failures on Geosynchronous Satellites with Fluxes of Energetic Electrons and Protons, *Cosm. Res.,* 2005, vol. 43, no. 3, pp. 179–185.

Vakulov, P.V., Kovrygina, L.M., Mineev, Yu.V., et al., Dynamics of the Outer Belt of Energetic Electrons during Moderate Electromagnetic Storms, *Geomagn. Aeron.*, 1975, vol. 15, no. 6, pp. 1028–1032.

Williams, D.J., Arens, J.F., and Lanzerotti, L.J., Observations of Trapped Electrons at Low and High Altitudes, *J. Geophys. Res.*, 1968, vol. 73, pp. 5673–5696.