"Physics of Auroral Phenomena", Proc. XXVII Annual Seminar, Apatity, pp. 141-145 , 2004

Polar Geophysical Institute

RELATIVISTIC ELECTRON EVENTS IN RELATION TO SOME ATMOSPHERE PARAMETERS AND GROUND MAGNETIC VARIATIONS

M. Yu. Goncharova *(Polar Geophysical Institute, Apatity)*
M.D. Looper *(Dept. Of Space Sciences, Aerospace corp., Los Angeles, USA)*

Abstract. Relativistic particle data of 1.5-6 MeV (ELO) and 2.5-14 MeV (EHI) with daily resolution for 2000 and 2001 years from SAMPEX and ground data from sub-auroral Vernadsky observatory (-65°S, 65°W) are compared. Cross correlation between precipitating relativistic electrons and stratosphere ozone, ground pressure, temperature and magnetic field near Vernadsky is examined; the correlation is found as real, possible, missing and doubtful respectively.

Introduction. Relativistic electrons (e.g., with energies exceeding ~1 MeV) are often registered onboard low-altitude and geosynchronous satellites while crossing the outer radiation belts a few days after the storm maximum [Roth et al., 1999], though during main storm phase the relativistic electron enhancements are also possible [Lorentzen et al., 2001]. Storms follow the magnetic cloud arrivals, but not every magnetic cloud give rise to relativistic electron injections into 5-7 L-shells [Baker et al., 1998]. For decades these electrons have been considered as trapped since, in quiet conditions [Selesnick et al., 1997a], their loss rates due to the pitch-angle diffusion are small. For disturbed conditions [Selesnick et al., 1997b] the phase space density variations with L-shell, with the Dst-like adiabatic variation in the electron flux intensity within the outer radiation belt, have been found and interpreted in frames of yes/no external source. Report of Tverskaya [1998] on satellite observations of ring current relativistic (>500 keV) electrons suddenly filling and unfilling the slot region between the two radiation belts on the nightside during severe storm conditions suggests the relativistic electrons might be effectively escaped from their common location by precipitations. Gotselyuk et al. [2000] report on the relativistic electron precipitations during substorm recovery phase. Meanwhile, most of evidences for the 'precipitating relativistic electrons' are indirect. Amongst them are variations in phase of arrival of the super-long radiowaves, often observed in quiet magnetic conditions [Brunelli and Lyatsky, 1988]. Relativistic electrons, indeed, should not disturb the conducting ionosphere layers, but the quiet geomagnetic conditions are unfavorable for elevating their loss rates. However, no other satisfactory hypothesis could explain such a phase anomaly. Usually the relativistic electrons are observed together with less energetic particles. Lorentzen et al. [2001] inferred a fraction of the satellite-observed relativistic electron precipitations based on purely statistical criterion. Besides, the problem of trust to the experimental results encounters with a distinguishing between relativistic electrons and protons observed together, especially in high latitudes (Valentin Roldugin, private communication). Kalisher et al. [1985] emphasized that by satellite motion towards higher latitudes (L-shells higher than ~ 5) the relativistic protons enhance while relativistic electrons weaken, and vice versa by backward motion. The same (but extended) region the observations by Baker et al. [1998] refer to. There are more indirect evidences that the relativistic electrons have to or could be precipitated; but, to our knowledge, still no one has clearly seen relativistic electrons to precipitate. Here we present first SAMPEX direct observations of relativistic electron precipitations in southern high latitudes, cleaned up of relativistic proton background. We show that they appear to occur just during (not after then) storm conditions, and are related to some atmosphere phenomena, as well as to weak high-latitude ground magnetic variations due to their association with less energetic precipitations.

Technical notes

Technical characteristics of SAMPEX (Solar Anomalous and Magnetosphere Particle EXplorer) are described in detail in Lorentzen et al. [2001], and in references therein. SAMPEX is a low-altitude satellite, with perigee and apogee being at 520 and 650 km respectively, with the near-polar orbit with inclination of 82°. Description of its instrumentation is given at http://surya.umd.edu/www/sampex.html, see [Cook et al., 2000]. The PET (Proton/Electron Telescope for studies of magnetospheric, solar, and galactic particles) instrument, being the source for the data analyzed here, is an all solid-state system designed to detect differential energy spectra of electrons from ~0.4 to ~30 MeV and H and He nuclei from ~20 to ~300 MeV/nuc. The particles are detected in a wide range of angles of arrival counted off the line-of-site (the centerline) of the camera. Most of time the centerline is oriented to local zenith. The angle α between this direction and the magnetic field line is accepted roughly as a pitch angle of the entering particles. By this pitch angle the particles were divided into the ones trapped (mean α

≈90°±(30..40)°) and those precipitated (mean α°≈140°±(30..40)°). The geometric acceptance "cone" of the PET instrument for electrons is rather broad, several tens of degrees in opening angle. Thus the pitch angle information is very approximate, but, due to absence of the best, can be used for distinguishing between 'trapped' and 'precipitating' electrons if the mean centerline directions differ more than by these several tens of degrees. When the camera looks nearly along the magnetic field line, in high latitudes the precipitated particles should be amongst all the entering particles anyway. In the raw data from SAMPEX a striking likelihood between relativistic SAMPEX electrons and GOES protons in auroral zone in the same longitude sector has been observed. Using an impulse height as a removal criterion, the precipitating relativistic protons have been picked out. After this procedure somewhat 10% of precipitating relativistic electrons remained. No similar procedure was applied to the response parameters.

Data comparison technique

According to preliminary cross-correlation examination, the response effect is near the error level. Therefore, to reveal the extent of independence between the time series of relativistic electron count rates (at ionosphere heights) and ground data at Vernadsky, preliminary the following three simple statistic criteria have been applied: cross-correlation function, mathematical expectation ratio and dispersion ratio for centered variables. Time series of the response variable was multiplied by shift from –10 to +10 points, i.e., days.

The cross-correlation criterion used here is a ratio of a covariation moment to standard deviation product, taken for the time series with various time shifts. Both the mathematical expectation criterion and the dispersion criterion employ respective theorems on products of independent and centered independent variables. Mathematical expectation of product of the independent variables equals to their mathematical expectation products. That is, their ratio is the further distanced from 1 the lesser independent the variables are. Dispersion of product of the independent variables, centered to their mathematical expectations each, equals to a product of their dispersions. Thus, their ratio for dependent variables has to deviate from 1 significantly.

Before plotting the criteria values versus time shift, the technique was checked for effeciency. First, all three criteria were applied to random X and Y. For over 31 realizations of this random processes the error intervals have been determined: ~25% for cross-correlation function, ~30% for dispersion criterion, and ~2% for mathematical expectation criterion. However, the mathematical independence is not equivalent to physical independence, and the criterion effectiveness is different for the random processes and false dependencies. If the two variables are random together, this might be rather in favor of their relationship. Here we shall consider two variables as physically unrelated if one of them possesses autocorrelation, whereas the other one (the response variable) is fully random. In this case, the error percentage remains approximately the same for the cross-correlation function, ~ 30%, but grows strongly for other two criteria, up to 100% and more. Based on this observation, the last two criteria have been removed from consideration.

The scattering in each concrete realization leads to the false maxima forming, especially undesirable by small criterion values. Situation is complicated also by strong and fanciful seasonal course, for example, that of the total ozone content and ground temperature. 'To center' these variables means 'to remove their seasonal courses', due to which their mathematical expectations glide gradually between maximum and minimum values. The polynomial spline (I) and averaging for two years (II) provided similar results. With respect to the relativistic electron data some signatures of the seasonal course could be identified in lower energies. Therefore, the lower energy relativistic electrons also have been cleaned up from suggested seasonal course. The higher energy relativistic electrons did not manifest a visible seasonal dependence and they were centered to a simple average.

To fix false maxima effect, the rest cross-correlation criterion have been applied first to a true dependence between the ELO electron series and 21 series of time-shifted total ozone content from the same year, then to a false dependence between the ELO electrons and ozone from different year. It appeared that the criteria variations with time shift for the true and false dependencies are closer when they are based on the same year agent variable than on the same year response variable. Thus a possibility occurred to distinguish between false and true deviations of criteria from their control value, 0. The searched effect is thus counted out not from the control value, but from the false dependence curve.

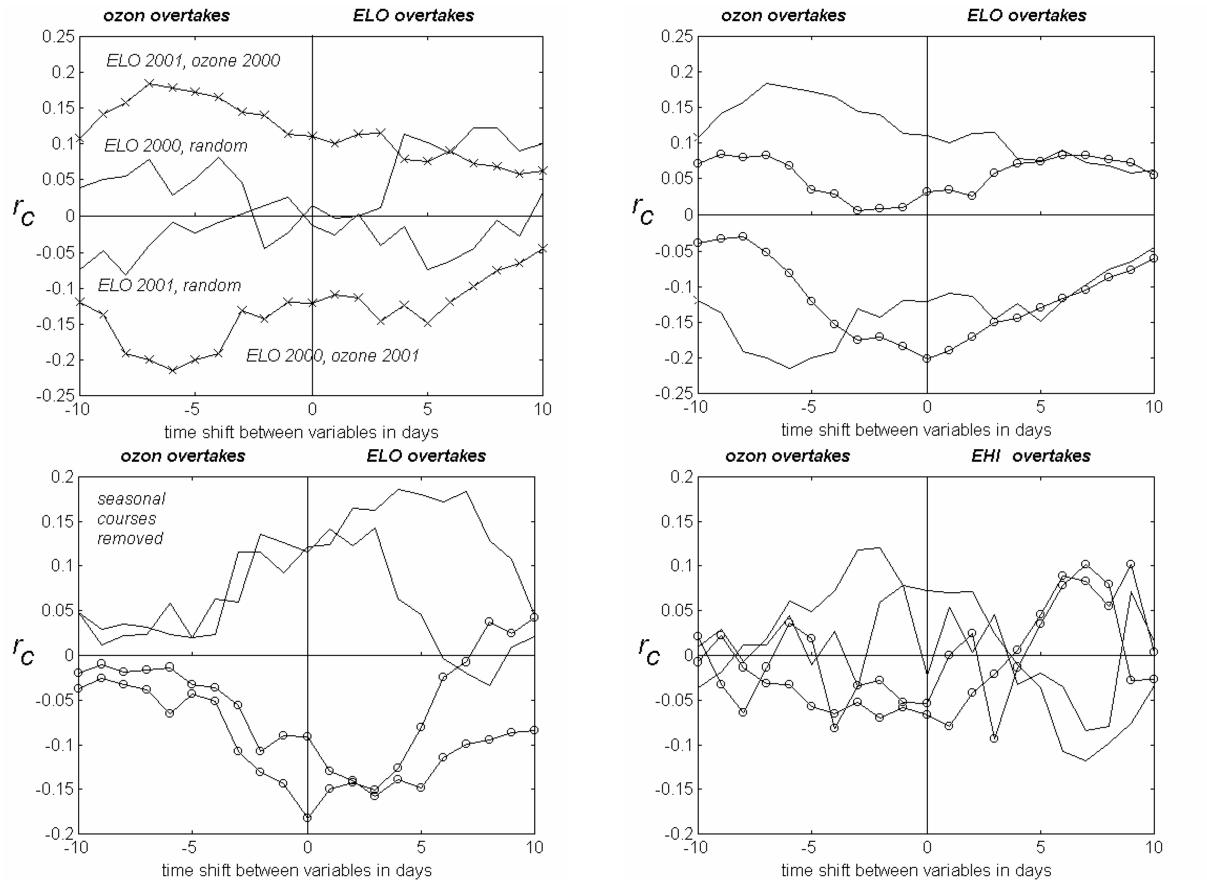

Fig. 1. Cross-correlation criterion application to the relationship finding between: ELO and 250+random fluctuations time series (top left panel, solid curve), ELO and ozone from wrong year (top left, solid marked); ELO and ozone from wrong (top right, solid) and right year (top right, solid marked with circles), with seasonal courses left. Bottom panel: ELO (left) or EHI (right panel) and ozone from wrong (solid curve) and right year (solid marked with circles), with seasonal courses removed.

Relationship to the total ozone content

In Fig. 1 the process of finding the low- and high-energy (ELO and EHI respectively) relativistic electrons – total ozone content relationship is represented. Top panel shows verification of the cross-correlation criterion applied to random functions and false year dependencies. False dependence curves are marked with 'x' symbols. The correlation curves further deviate from zero control value if one of the compared functions is the real data time series. In the present case, the maximum false deviation for the cross-correlation criterion is of ~ 25%.

Time shift was applied to the response variables. The response variable in Fig. 1 is the total ozone content, for that 21 time series were created shifted respectively by from –10 to +10 days. Negative time shifts correspond to the 'ozone overtakes' and positive time shifts correspond to the 'ELO (or EHI) overtakes' situation.

Seasonal courses left, a meaningful deviation of the correct dependence from false one is absent (top right panel). Seasonal courses removed, a distinct and systematic deviation from control value as well as between the correct and false dependencies occurs (bottom panel). For ELO electrons and ozone the maximum in negative correlation falls to +3 days, with cross-correlation coefficient r_c=-0.15, for EHI electrons cross-correlation as though as absent.

Stratosphere ozone undergoes annual migrations due to seasonal system of winds, as well as due to the local variability of the odd nytrogen number density. Some annual variation rising from interplanetary condition change and satellite orbit precession (being not precisely annual but of the same order) also presents in the precipitated relativistic electron fluxes given by rates of their counting. This was accounted for by the seasonal course removal (calculated as the mean of the two annual variations obtained by running average technique, with 5 days averaging interval). However, the orbit precession leads to the mixture of local times of observation at the same ground region, and this factor is very difficult to remove without significantly reducing the data set. But, since the mixture of local times can hardly be much different for different years, this factor would cause only minor corrections.

Smallness of the cross-correlation coefficient between the relativistic electron precipitations and stratosphere ozone perturbations may be due to the unaccounted factor effects. First, the temperature regimes are rather different for different years; that is, the atmosphere state might be strong perturbing factor; second, the relativistic protons were picked out but their possible effect left ignored.

Relativistic electron precipitation relationship to the ground pressure and temperature at Vernadsky

The relationship to ground magnetic pressure was examined immediately after receiving the data. With cross-correlation technique, a definite response of the ground pressure to ELO electron precipitations has been found. Between the EHI precipitating electrons and ground pressure the correlation was absent.

In Fig. 2 the relationship of trapped and precipitating ELO count rates to ground pressure at sub-auroral Antarctic Vernadsky (-65° S, 65° W) observatory is shown. Scatter plots show that the trapped electrons diminish in count rate, whereas the precipitating ones grow, giving evidence for the precipitations. Cross-correlation between ground pressure and precipitating ELO electrons shows a 5 day-delayed maximum of ~0.36, that is above the 25% error threshold. Unfortunately, the pressure file has been damaged soon after obtaining this result. The cross-correlation between ELO electrons and ground pressure for year 2001 held immediately then showed no any correlation throughout the cross-correlation interval (Fig. 3). Thus, the question about ground pressure reaction remains open.

.

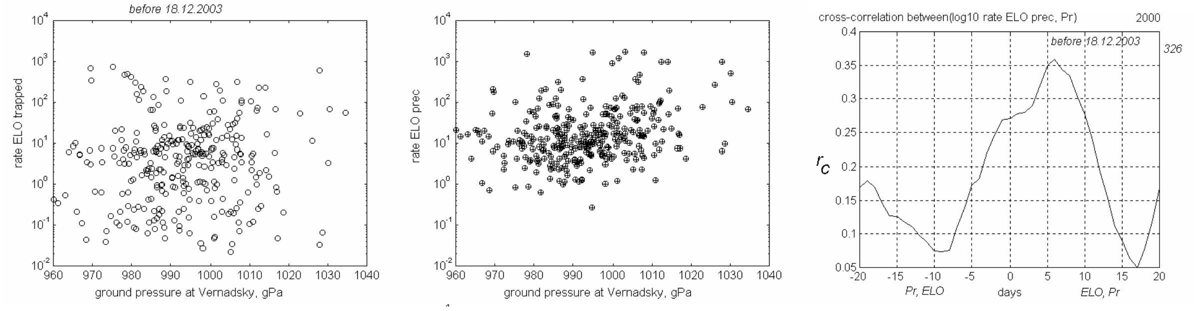

Fig. 2. Scatter plots of the ELO electron count rate, trapped (left panel) and precipitating (middle panel) versus ground pressure at Vernadsky observatory, as well as cross-correlation between logarithm of the precipitating ELO electron count rate and ground pressure.

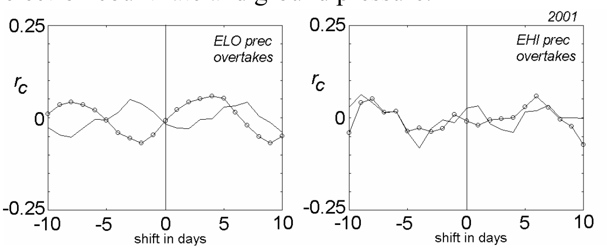

Fig. 3. Cross-correlation between ground temperature at Vernadsky and ELO (left), EHI (right) electron precipitations in 2001 Seasonal course is removed.

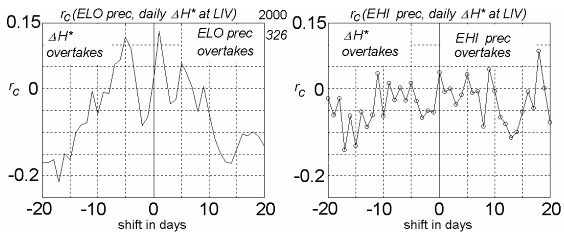

Fig.4. Cross-correlation between ELO (top) and EHI (bottom) panel and full horizontal magnetic field at LIV

Relationship of the relativistic electron precipitations to ground magnetic variations

The nearest to Vernadsky observatory measuring the ground magnetic field is LIV, Livingston Island (-63°S, 61°W; -55° GMLat, 8° GMLong). Analysis of the data is very preliminary. The solar quiet variation was not removed from the considered *H component data full horizontal component) data. Fig. 4 shows a cross-correlation between precipitating ELO and EHI relativistic electrons and daily variation amplitude of *H. The correlation coefficient varies well inside the error interval, though undergoing a positive excursion during the relativistic electron precipitation events. For EHI electrons the absence of magnetic field response is manifested better.

Conclusions

Having obtained a cross-correlation between relativistic electron precipitations of low (1.5-6 MeV) and high (2.5-14 MeV) energies, cleaned up of proton component, with the total ozone content, ground pressure, ground temperature and horizontal magnetic field measured at sub-auroral Antarctic zone, the following has been found.

The response in stratosphere ozone content is found as real, being weak negative, by 1-3 day delayed with respect to the precipitation event; in ground pressure is found as possible and positive, with a ~5 day delay; in horizontal magnetic field the response is doubtful, and in ground temperature is absent. The response to low-energy relativistic precipitating electrons, those having much more powerful fluxes than the high-energy electrons, is everywhere stronger. The cross-correlation has been testified by false dependence method.

Acknowledgments. To Dr. V. Roldugin for help.

References.

Brunelli, B. E., W.B. Lyatsky, Physics of auroral phenomena, L., "Nauka", 1988, volume 260 p.

Cook, R.W., A. C. Cummings, J. R. Cummings, T. L. **Garrard, B. Kecman, R. A. Mewaldt, R. S. Selesnick and E. C. Stone; D. N. Baker and T. T. von Rosenvinge; B. Blake; L. B. Callis, PET:** A Proton/Electron Telescope for Studies of Magnetospheric, Solar, and Galactic Particles, WWW, 2000

Gotselyuk Yu.V., Yu.I. Denisov, S.N. Kuznetsov, Observations of relativistic electron fluxes at the boundary of the outer radiation belt under high substorm activity, in proceedings of the 5th International Conference on Substorms, St.-Petersburg, 16-20 May 2000, 435-438.

Kalisher, A. L., Mineev Yu.V., Spir'kova E.S., Troitskaya V.A., Glukhov G.A., Pulsations of the geomagnetic field and charged particles during severe magnetic storm, Geomagn. And Aeron., 25, No.6, 981-985, 1985.

Lorentzen K.R., M.D. Looper, and J.B. Blake, Relativistic electron microbursts during GEM storms, *Geophys. Res. Lett., 28*, 2573-2576, 1997.

Selesnick, R.S., J.B. Blake, W.A. Kolasinski, A quiescent state of 3 to 8 MeV radiation belt electrons, *Geophys. Res. Lett., 24*, 1343-1346, 1997.

Selesnick, R.S., and J.B. Blake, Dynamics of the outer radiation belt, *Geophys. Res. Lett., 24*, 1347-1350, 1997.

Tverskaya, L. V., The magnetosphere processes diagnostics based on the radiation belt relativistic electron data, Geomagn. And Aeron., 38, No 5, 22-32, 1998.