OUTER RADIATION BELT VARIATIONS DURING 1995

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ABSTRACT

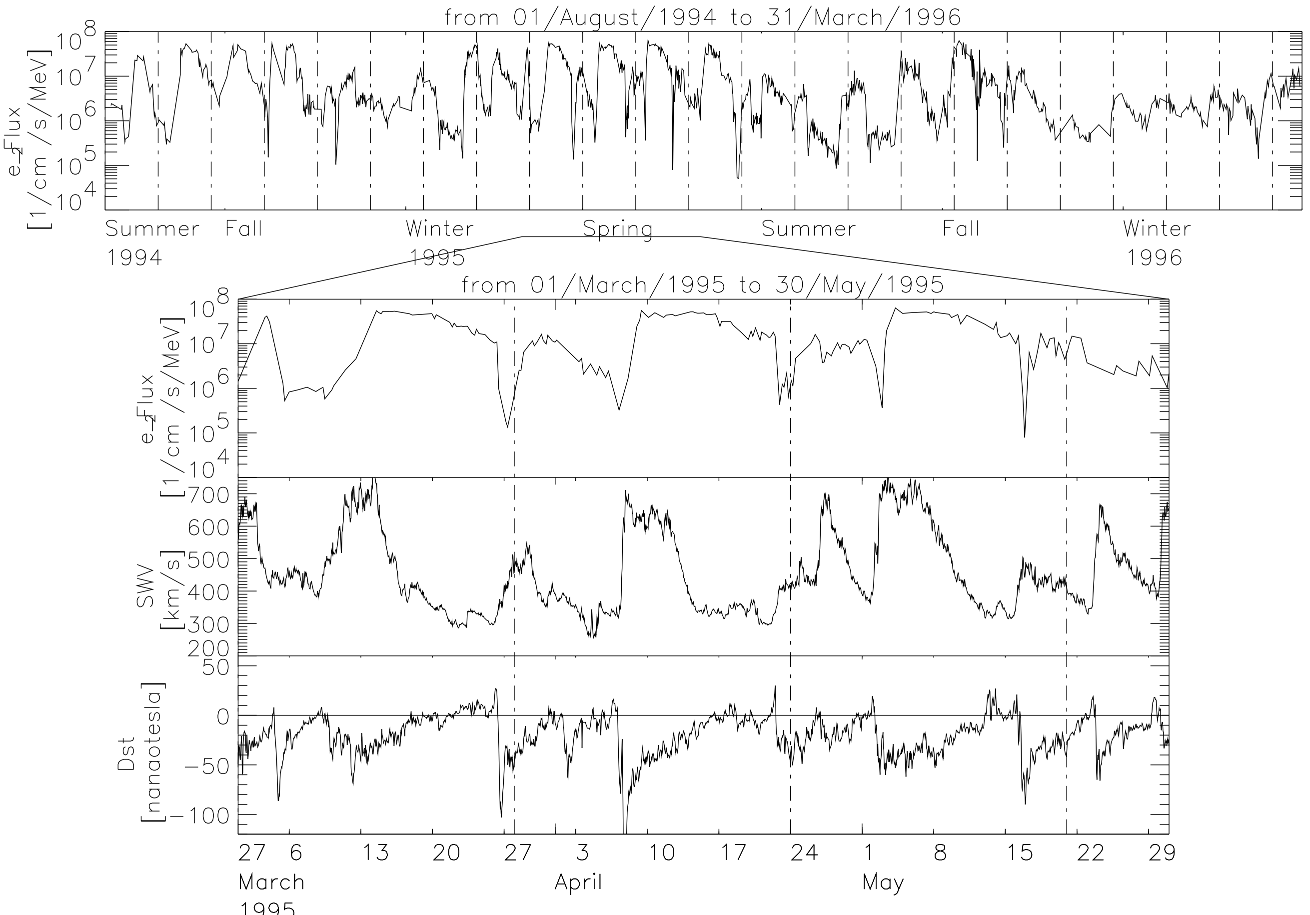
The dynamics of the relativistic electron flux in the earth's outer radiation belt measured by the Radiation Environment Monitor aboard the STRV–1B satellite is presented from August 1994 to end of April 1996. During this period the earth's magnetosphere has been driven by recurrent fast solar wind streams which have periodically compressed the magnetosphere and caused large variations of the trapped particle fluxes in the outer radiation belt. The periodic variations are characterized by a rapid depletion, strong and rapid increase and a more steady phase. The flux level reached depends on the velocity of the interacting solar wind stream. The effectiveness of the solar wind – magnetosphere interaction shows a semiannual modulation with a maximum around the equinoxes.

INTRODUCTION

The earth's outer radiation belt, confined between magnetic L–shell values 3 and 7, is populated by relativistic electrons. These parts of the magnetosphere are strongly influenced by the solar wind, which exerts a pressure on the earth magnetic field and is responsible for the long tailed shape of the earth's magnetosphere. Variations of the solar wind characteristics cause changes in the magnetosphere and of its constituents.
The population of relativistic electrons in the outer radiation belt have been observed with various satellites. Different characteristics of the temporal variations of these particles were described, like the 27–day periodicity during low solar activity (Paulikas *et al.*, 1979) or the increase and the decrease phase of the flux at geosynchronous latitude (Baker *et al.*, 1986). Attempts were made in forecasting the trapped particle fluxes at geosynchronous latitude and the importance of the solar wind velocity, SWV was studied (Nagai, 1988).
Different theories, like injection of jovian electrons (Chenette, 1988) or internal acceleration (Baker *et al.*, 1989), were proposed to explain the presence of such high energy particles in the outer belts but the question of their origin is still open. Loss of these particles have been explained by adiabatic deceleration of the particles during main phase of magnetic storm (McIlwain, 1966), and also with precipitation of the electrons into the atmosphere (Imhof *et al.*, 1991).
In this paper we present recent measurements of the relativistic electron population by the Radiation Environment Monitor, REM on the UK micro–satellite STRV–1B from August 1994 to March 1996.

INSTRUMENT AND OBSERVATIONS

The STRV–1B satellite was launched on June 17, 1994 into a nearly equatorial Geostationary Transfer Orbit, GTO with apogee of 300 km, perigee 36000 km, 7° inclination, and a period of approximately 10 hours (Wrenn, 1994). STRV–1B is spinning with a rate of approximately 6.5 revolutions per minute. GTO is a suitable orbit to study the outer belt dynamics, as the orbit passes every 10 h two times through the belt and spends roughly 8 hours per orbit in the outer belt region (at L–shell values larger than 3). Since August 1994, REM has been accumulating data during typically every second orbit and is still working.
The REM instrument consists of two silicon detectors with different shieldings, measuring energy loss spectra of charged particles (Bühler, 1995). The ΔE spectra are accumulated for a time t_{acc} and binned into 16–bin histograms. t_{acc} is a function of orbit position, 100 sec at L=3 to 1000 sec at L=6.
The main aperture of the detectors is defined by a aluminium cone with an opening angle of ±45°. Considering the large detector aperture and rotation of the STRV–1B satellite, REM is assumed to measure omnidirectional fluxes.



a)

b)

Figure 1: *a) REM 1.5 MeV electron flux at L=4.5, from August 1994 to March 1996. The temporal variations are characterized by series of peaks with a 27 day period and a semiannual modulation. b) Variation during May and June 1995 of (t.t.b.) REM electron flux (same flux as in a)), hourly solar wind velocity, and hourly Dst index.*

The energy response of the REM detectors has been determined by extensive calibrations and simulations. The resulting geometric factors are used to determine the incident particle fluxes from the measured histograms.

In this study we investigate REM fluxes together with solar wind parameters measured by the Solar Wind Experiment, SWE on the WIND spacecraft (Ogilvie *et al.* 1995), and with the geomagnetic Dst index. The L–shell parameter used throughout this paper has been calculated using IGRF 95 as internal magnetic field model and Tsyganenko 1989 (Tsyganenko, 1989) as external field model with Kp=0.

LONG–TERM VARIATIONS

Figure 1a) illustrates the long–term variations of the trapped electron flux in the outer radiation belt from August 1994 to end of March 1996. The REM 1.5 MeV electron flux is plotted versus time.

Two main features are noted: different series of peaks with a period of approximately 27 days and a semiannual modulation of the maximum fluxes reached.

The 27 day period structure is typical for epochs of low solar activity. It is correlated with the structure of the solar wind near the ecliptic plane: high speed corrotating solar wind streams which originate from solar coronal holes, interact with the earth's magnetosphere and reappear during several solar rotations (Baker *et al.*, 1986).

In Figure 1b) the period from beginning of March 1995 to end of May 1995 is shown in more detail. The REM electron flux (upper most panel) is plotted together with the solar wind speed and the Dst index (lower most panel) versus time. The periodic variation of the electron flux is characterized by three phases: rapid decrease, rapid increase and a more steady period. The rapid decrease takes place together with the arrival of a fast solar wind stream (increase of the SWV) and is associated with a rapid Dst decrease. The Dst

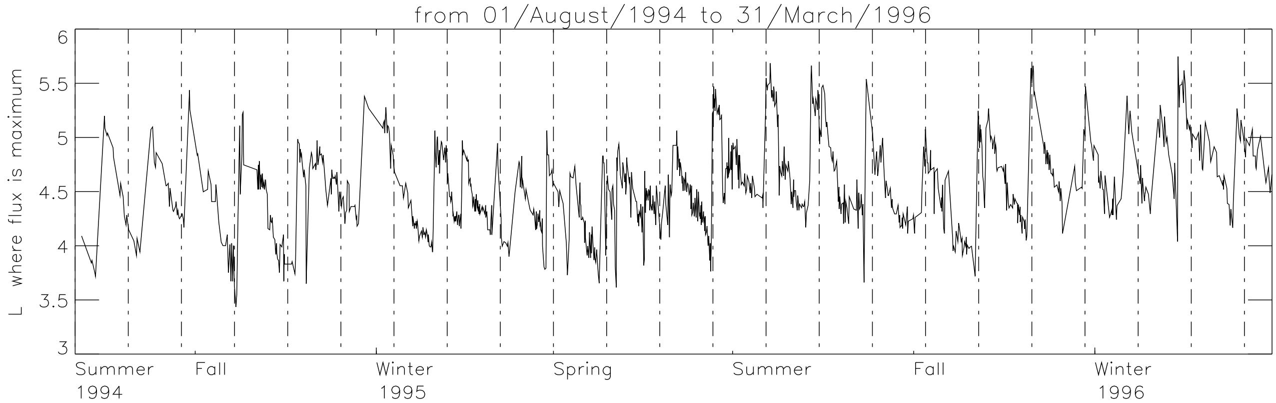


Figure 2: *L values at which the REM electron flux is maximum versus time. Electrons tend to appear first at large L values. During the slow decrease phase the maximum tends to move towards small L values.*

decrease represents the main phase of a magnetic storm caused by the interaction, of the interface between a rapid corrotating stream and the slower solar wind with the magnetosphere (Tsurutani *et al.*, 1995). In this phase the detected electron flux drops by up to a factor 100 in typically one day. The question is whether the electrons are decelerated below the lower threshold of the detector and are therefore not detected anymore or whether they are lost from stable trapping.

The decrease is normally followed by a strong increase. It takes place together with the beginning of the magnetic storm recovery phase. The flux level reached after the increase is not constant. It can vary from peak to peak but shows a tendency to be larger around the equinoxes (spring and fall) and lower around the solstices (winter and summer). As we will show in the following section the flux level reached depends on SWV structure. For example the higher flux peaks around 13 March, 10 April, and 6 May are associated with high and wide SWV peaks while the lower flux peaks around 27 March, 24 April, 22 May are correlated with lower SWV peaks.

The third phase is characterized by a slow decrease of the electron flux until the next wind stream arrives and the flux drops again in a short time. The decrease rate is a function of L (not shown here). It is more rapid at large L and slower at small L.

The shape of the measured electron distribution in L–space during the slow decay phase varies. This is shown in Figure 2 where the L value at which the flux is maximum is plotted versus time. Comparison of Figure 1 and 2 shows that during the phase when the flux rapidly increases, the L values at which the flux is maximum jumps from its actual value to a higher value and then slowly decreases again. This characterizes an injection or acceleration of electrons at higher L values followed by diffusion to lower L values during the quiet period. Also here we note a difference between equinox and solstice. Around the equinoxes, when the trapped electron flux is high the outer belt is centered at lower L values than around the solstices.

TRAPPED ELECTRON FLUX VERSUS SWV

In the precedent section we noted, that the relativistic electron flux in the outer radiation belt is correlated with the SWV but is also characterized by a semiannual variation which does not show up in the SWV. In this paragraph we quantify the correlation with the SWV and the importance of this semiannual variation, in function of L.

We therefore select cases of fast solar wind stream events from which 31 have been observed during 1995. For each event we determine the maximum electron flux $flux_{max}(L)$ at a series of L values (3.5, 4.0 ,4.5, 5.0 ,5.5, and 6.0) and the maximum solar wind speed V_{max}.

In Figure 3a) the correlation coefficient between $log(flux_{max}(L))$ and V_{max} is plotted as function of L (diamonds). The correlation is bad at low L but improves with increasing L. The result is significantly improved by including a semiannual modulation of the effectiveness of the solar wind–magnetosphere interaction (stars). We therefore consider the function $V_{max} \cdot (1 + A(L) \cdot cos^2(\pi \cdot (t - t_0(L))/T(L)))$, where parameter $A(L)$ is the amplitude of the modulation, $t_0(L)$ the phase and $T(L)$ the period. The parameter values are determined such that the correlation coefficient between electron flux maximum and corrected solar wind speed is maximized. The resulting correlation coefficients are between 0.75 and 0.95. Period T and phase t_0 are consistent with 0.5 year and 21 April. The importance of the semiannual modulation,

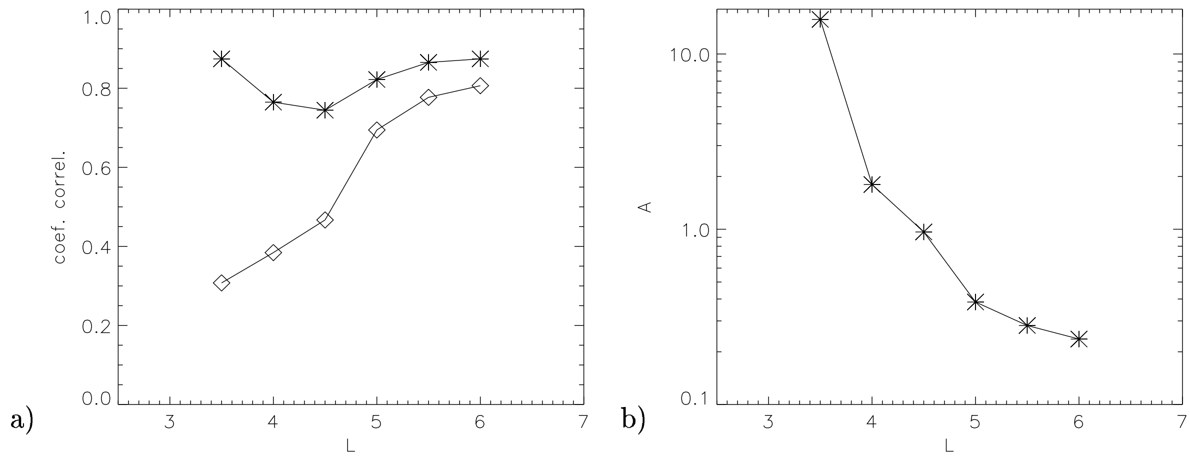


Figure 3: *a) Correlation coefficient between REM electron flux maxima and SWV without (diamonds) and with (stars) correction for semiannual modulation of effectiveness of solar wind–magnetosphere interaction. b) amplitude of the semiannual modulation versus L. The modulation is most important at low L values.*

quantified by parameter A, is a function of L (Figure 3b)). The amplitude is largest at small L and decreases with increasing L.

CONCLUSION

We have presented recent measurement of the relativistic electron population trapped in the outer radiation belt with the Radiation Environment Monitor aboard the UK micro satellite STRV–1B in a nearly equatorial GTO. The observations cover the time from August 1994 to April 1996, a period of low solar activity. The main characteristics of the variations of the electron fluxes in the outer radiation belt are the following

- several series of flux peaks with 27 day periodicity, correlated with the structure of the SWV
- 3 phases of the periodic flux variations: strong (up to a factor 100) and rapid (typically one day) decrease correlated with main phase of magnetic storm, strong increase where level reached depends on SWV, slowly decreasing period where decrease rate is more rapid at large L
- semiannual modulation of the effectiveness of the solar–wind magnetosphere interaction with maximum around equinoxes, modulation is most important at small L
- flux distribution in L space varies, after increase of particle flux the distribution peaks at large L and then moves towards lower L
- around the equinoxes the flux distribution tends to peak at lower L values than during the solstices

The presented work represents the baseline for further studies aiming to explain the observed characteristics with physical models.

ACKNOWLEDGEMENT

This study was supported by ESA/ESTEC/WMA Technology Research Contract 11108/94/NL/JG(SC). We aknowledge K.W. Ogilvie, A.J. Lazarus, and J.T. Steinberg of the WIND SWE instrument team for placing the WIND data to our disposal for publication.

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