# Energetic electron injections to the inner magnetosphere during magnetic storms and magnetospheric substorms

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**Abstract**

Radial injections of the energetic electron to the inner magnetosphere during magnetic storms are studied using data from the SERVIS-1 low altitude satellite. Fast radial injections with time scale less than 1-2 hours were found during the main storm phase in 0.3-3.4 MeV electron energy channels. Coincidence with an active phase of the magnetospheric substorms was found after inspection of the auroral zone magnetometer records. It seems that fast electron injection are the result of the electron radial injection caused by the induced electric field of the magnetic field dipolarization during substorm activations. As a «seed» particles freshly accelerated auroral electrons and «old» radiation belt electrons may be regarded.

## 1. Introduction

Electron radiation belt is extremely dynamic regions, especially during magnetic storms, when processes of the losses, transport, and acceleration of particles are working with complicated concurrency. Inward radial diffusion is regarded as one of the main energetic electron acceleration during magnetic storms and sometimes it took only several hours for the considerable intensity increase [Baker et al., 2004; Vassiliadis et al., 2005; Nagai et al., 2006]. Radial diffusion caused by the magnetic drift resonance with Pc5 magnetic pulsaions is a stochastic process demanding at least several hours for the gradual transport of the energetic particles. But there is also rapid particle injection by the single step, for example by SC induced impulse of the electric field. Such injection was registered during the March 24, 1991 super storm [Li et al., 1993]. Of cause SC-injection is a rare exotic effect, but there are impulsive induced eelctric fields which occur in numbers during magnetic storms, generated by magnetospheric substorms. Short-time induced electric field are important element of the magnetospheric substorms, more exactly substorm activations, responsible for the acceleration of the energetic auroral particles [see Lazutin, 1986 and reference therein]. Two cases of the fast electron flux increase in a slot region were described by [Nagai et al., 2006]. They did not analyzed substorm activity but suggested that substorms were responsible for the increases.

Present work is a part of the case study of energetic electron dynamics during several magnetic storms with comparison of the electron non-adiabatic acceleration with substorm activations.

## 2. OBSERVATIONS

Energetic electron and proton measurements were carried by low-altitude polar orbiter SERVIS-1, Japan, launched from Plesetsk Cosmodrome in Russia on October 30, 2003 on the Sun synchronous orbit in dawn-dusk plane, with altitude 1000 km and inclination 99.5°. Light Particle Detector was a charged particle spectrometer which consists on combined 0.5mm thick SSD and 24mm thick plastic scintillator. It has 60° field of view and oriented in anti solar direction. We will use data of electron channels 0.3-1.5 and 1.7-3.4 MeV from the database provided by Prof. N. Hasebe from Waseda University, Japan.

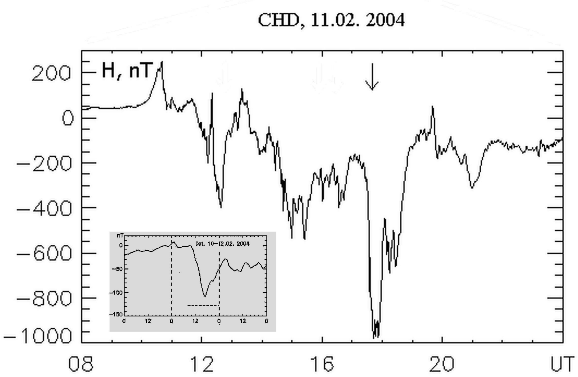


*Fig 1. Dst during February 10-12, 2004 (a) and H-component of the Chakhurdakh magnetometer records during magnetic storm. Time momens discussed in a text are inducated by the arrows.*

For the identification of the magnetospheric substorm will be used H-component of the magnetogramms of the Chokurdakh (64.7° and 212.1° GM latitude and longitude) and Tixie (65.6° 196.9°) auroral observatories

### 2.1 February 11, 2004 Magnetic Storm

Magnetic storm on February 11, 2004 starts at 10 UT and reached Dst minimum -120 nT at 16 UT. The main phase and beginning of the recovery phase were accompanied by substorm activity.

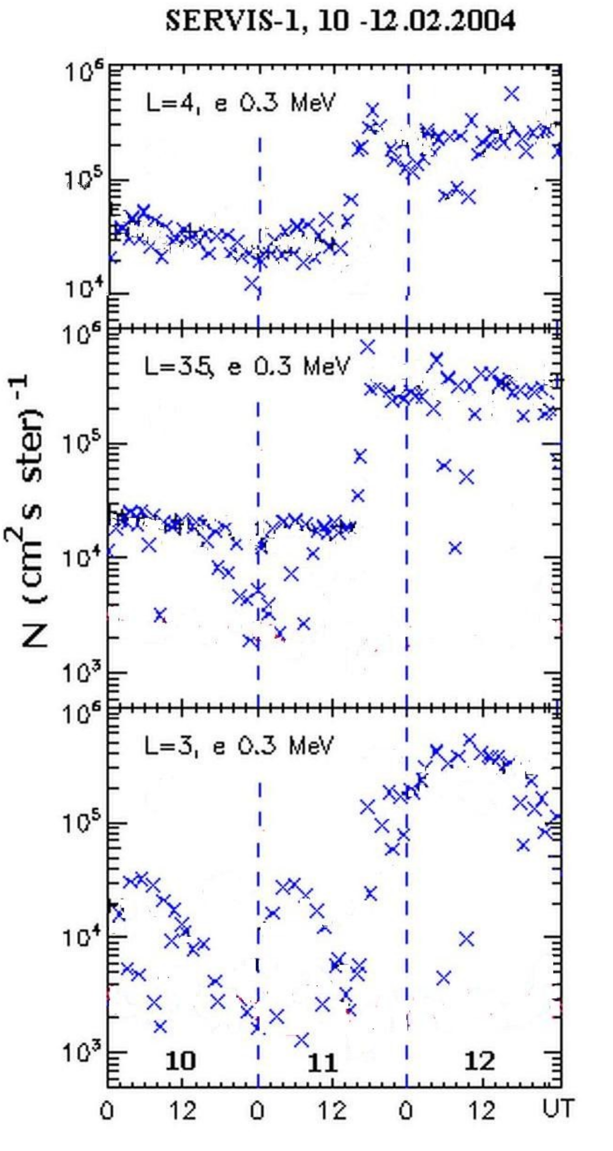


*Fig 2. Plots of the 0.3 MeV electron intensity at fixed L during February 11, 2004 magnetic storm, evening orbits.*

Figure 1 shows Dst-index and H-component of the magnetogramm of the Chokurdakh observatory which was at that time in a local night - early morning sector. Three activations can be identified at the magnetogramm, with the biggest one started at ~ 17.20 UT and reached magnetic bay minimum (-1000nT) at ~ 17.40 UT.

Figure 2 presents electron intensity temporal development measured at three L -levels from L=3 to L=4. Electron intensities were measured on down part of the satellite orbit. We are using here all data, two L-profiles per 90 minutes of each satellite orbit. During one day satellite pass several times over Brazilian (South Atlantic) Magnetic Anomaly (BMA) where satellite trajectory enters the radiation belt cusp.

During other orbits only precipitating particles can be measured at satellite altitude. Before the beginning of the magnetic storm difference between trapped particle

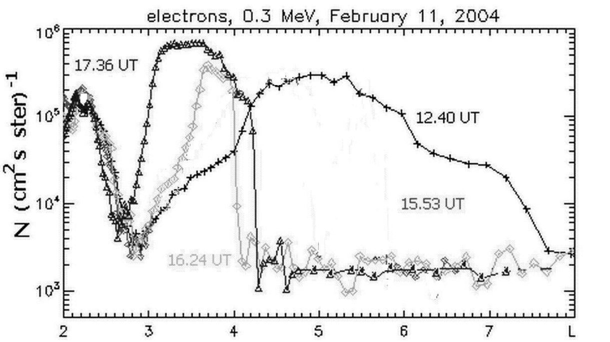


*Fig 3. Latitudinal profiles of the 0.3 MeV electrons during February 11, 2004 magnetic storm. Time of satellite crossings of L=4 are indicated.*

intensity measured over BMA and precipitating ones on other longitudes is clearly seen. For example on February 10 at the L=3 around 06 UT when satellite at the morning sector registered electron flux over BMA it exceeds by one order the precipitating flux near 18 UT. But this difference became smaller with increase of particle intensity, which allows to follow fast electron flux variations with time resolution less than one hour.

The most pronounced effect reflected by Figure 2 is a fast electron increase observed at the end of the storm main phase on L=3 to 4 at 17.36 UT, which coincides remarkably with substorm activation. It was not created by some impulsive intensification of the precipitating particle flux, but increase of the trapped particle flux as well, because an enhanced intensity level was observed until the end of the magnetic storm.

Examples of the latitudinal profiles (or L-profiles) are shown on Figure 3. Time marks near the plots indicate L=4 crossing. First profile was measured just at the beginning of the storm main phase, two other near the end of the main phase and all four during the substorm activity. One can see considerable variability of the L-profiles and effect of the erosion of the electron intensity at the end of the main phase at L > 4.2.

One of three substorms registered by magnetometer caused increase on L=4 and does not changed electron intensity on L=3.5 (Figure 3, profile 15.53 UT). Large earthward shift of the electron profile was registered at 17.36 UT and as it was said before exactly coincide with the sharp slope of the magnetic bay and, consequently with substorm activation. This shift creates intensity increase at the maximum of the radiation belt and more than tenfiold increase at L=3 and 3.5 level as seen on Figure 2 and 3.

In 1.7 MeV energy channel fast intensity increase was not observed.

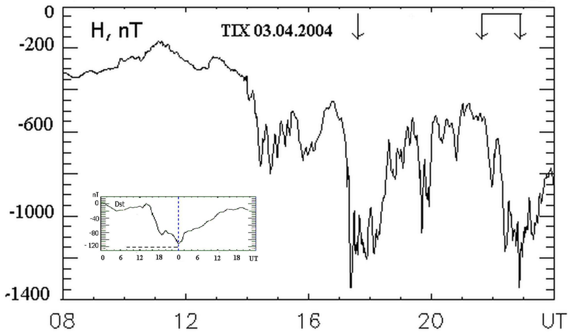


*Fig 4. H-component of Tixie magnetogramm of the April 3, 2004 auroral zone magnetic bays and Dst-index during April 3-4, 2004 magnetic storm.*

### 2.2 April 3-4, 2004 Magnetic Storm

Measurements of the 0.3 MeV electrons on April 3, 2004 give us an example of two-step fast intensity increase both during active phases of two substorms. Magnetic storm started at 04 UT April 3 and reached Dst minimum -110 nT at 24 UT. During all the main phase substorm activity was recorded. Figure 4 presents Dst index and H-component of the Tixie magnetogramm.

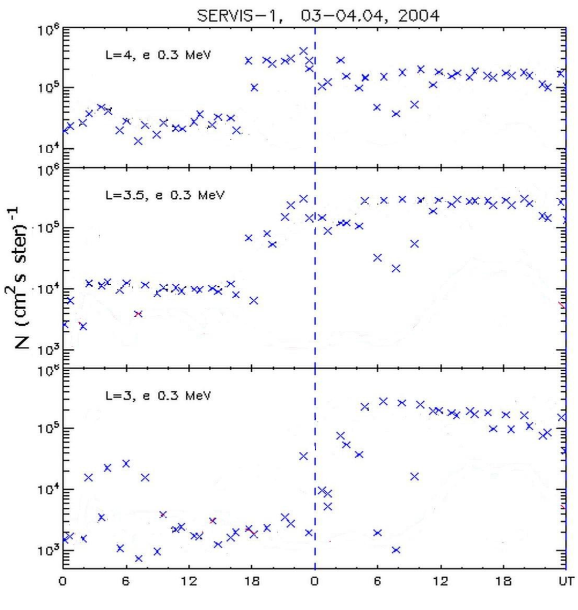


*Fig 5. April 3, 2004 magnetic storm. The same as on Figure 2 .*

Figures 5 shows temporal 0.3 MeV electron fluxvariations on three latitude levels in the same manner as in a previous case study. First fast 0.3 MeV intensity increase at L=3.5 and 4 was registered before the end of the main phase during substorm activation on 17.40 UT. On Figure 4 first arrow indicates that it happens during strong magnetic bay. It is not easy to indicate exact time of the inward injection during the second increase which involved also L=3 level. It occurs between 2140 and 2256 UT. Intensity increase was registered this time also in 1.7 MeV channel at L=3 (not shown).

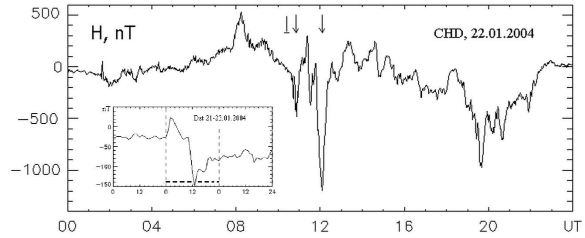


*Fig 6. Dst-index and H-component of the Chakhurdakh magnetometer records during January 22, 2004 magnetic storm.*

### 2.3. January 22, 2004.

Strong magnetic storm (-150 nT) was recorded on January 22, 2004. The main phase was very short, less than three hours and was accompanied by substorm activity.

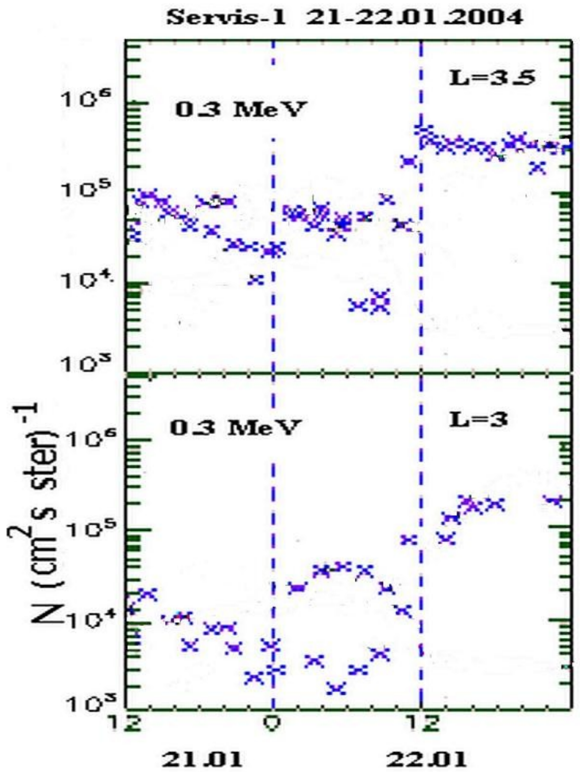


*Fig 7. The same as on Figure 2 during January 22, 2004 magnetic storm.*

Ring current development and CHD magnetogramm are shown on Figure 6. 0.3 MeV electron intensity measured on L= 3, and 3.5 are presented by Figure 7. On L=4 and 5 adiabatic effects with magnetic field line stretching results in electron intensity decrease, therefore particle injection effect was recorded only at lower L-shells. Two steps of the electron intensity increase were registered on L=3.5. On Figure 6 three time marks are indicated: at 10.21 UT when normal electron flux (4 .104 (cm2.s.ster)-1 was measured and two moments with increased flux half of minute later at 10.55 UT (2 105 (cm2.s.ster)-1) and at 12.07 UT (5 105 (cm2.s.ster)-1). Both intensity increases coincides remarkably with sharp magnetic bays. At L=3 there are sign of the first steplike increase, but later, after 12 UT to 20 UT electron intensity increased gradually, indicating on the radial diffusion process. Similar effect of the moderate radial diffusion was registered on 1.7 MeV electron channel.

## 3. DISCUSSION

An enhancement of the relativistic electron flux in the inner magnetosphere including the slot region (L = 2 –3), was frequently observed at the beginning of storms [e.g., Baker et al., 1994, 2004; Li et al., 1997; Kanekal et al., 2001]. The flux increase is observed by low-altitude spacecraft are not caused simply by an enhanced precipitation rate because it was registered near the equatorial plane as well [Baker et al., 1994]. Time scale of the flux increase ws too short for the acceleration by radial diffusion caused by the resonance with ULF-Pc5 magnetic pulsations . This type of the acceleration is widely discussed [see review by Spritz et al., 2008]. Fast injection by SC also must by excluded from the discussion, therefore substorm associated injections remains as a best candidate. From the substorm case studies it is known that ExB radial injection during local magnetic field dipolarization is the main source of the energetic auroral electron acceleration up to 300 keV measured by balloons bremstrahlung auroral X-ray bursts [Lazutin, 1986 and references therein].

During one year of the SERVIS-1 observations we found 6 cases of the fast electron flux increases coinciding with substorm activations. That is the main finding of the present study: close relation of the fast electron injections with auroral activations. In all cases fast increases were observed in a channel 0.3-1.7 MeV and in three case less intensive increases were registered in a channel >1.7 MeV. That outlines the upper energy limit of the fast radial injection effect approximetely near or less than 1 MeV. Time scale of the intensity increase was between 0.5 and 1.5 hours.

There may be two possible scenario how auroral activation creates observed fast electron increases. It can be direct injection of the auroral electrons during the process of the substorm acceleration. It is known that during magnetic storm auroral activity region is shifted toward lower latitudes following the radial displacement of the radiation belt. Another model may be proposed when "old" radiation belt electrons are accelerated by the pulses propagated inward from the substorm activation region. The mechanism is similar to the fast injection by SC pulse and can transport electrons down to the slot region.

**Acknowlegements**

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