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Altitude distribution analysis of electron fluxes at $L = 1.2–1.8$

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Abstract

In this work, we present the investigation of experimental data of electron fluxes with energies $E_e = 30–480$ keV at $L = 1.2–1.8$ in wide altitude interval from 500 up to 1500 km. The data were obtained on ACTIVE satellite ("Intercosmos-24" in 1989–1990, altitudes from 500 up to 2500 km). Also, we analyze the distribution of electron fluxes with energies $E_e = 0.3–1.0$ MeV obtained onboard MIR station (SPRUT-VI experiment in 1999, altitudes from 350 up to 400 km). The comparison with results obtained onboard other satellites reveals that the borders of electron registration zones under the radiation belts of the Earth at middle latitudes coincide. The shape of these zones is stable in time and space. It can be explained by existence of unknown constantly working mechanism of particle precipitation. It is possible, that electron fluxes at $L = 1.6–1.8$ are caused by ground-based radiotransmitters (e.g., Nagata, K., Kohno, T., Murakami, H., et al. Electron (0.19–3.2 MeV) and proton (0.58–35 MeV) precipitations observed by OHZORA satellite at low zones $L = 1.6–1.8$. Planet. Space Sci. 36, 591, 1988).

1. Introduction

The investigation of trapped and quasi-trapped charged particles is essential part of space research near the Earth. The knowledge of spatial and temporal features of particle distribution allows us to predict the dozes of radiation and therefore to predict lifetime of space stations and satellites. The second reason to carry out such investigations is the possibility to clarify the different processes in magnetosphere of the Earth. The electron fluxes under the inner radiation belt observed in different experiments since 1980s. Previous experiments: (see Biryukov et al., 1996, 1999; Grachev et al., 2002a), SPRUT-VI (altitude $H \sim 400$ km, electron energies $E_e > 75$ keV, see Grachev et al., 2002b), CORONAS-I satellite (see Kuznetsov and Myagkova, 2002) (altitude $H \sim 500$ km, electron energies $E_e > 500$ keV) and OHZORA satellite (see Nagata et al., 1988) (altitude $H = 350–850$ km, electron energies $E_e = 190–3200$ keV) revealed the existence of electron fluxes at $L = 1.2–1.8$ (see Fig. 1, panels (A)–(C) correspondingly, shaded areas correspond to the flux level exceeding approximately 100 $(\text{cm}^2\ \text{s sr})^{-1}$). The comparison of these results shows that locations of electron precipitation zones observed in different experiments are similar. Moreover these zones have temporal and spatial stability. One of the main features of electron flux distribution at considered latitudes is strong longitude dependence.

Nowadays there is no quantitative model explaining all features of the described phenomenon. There are two hypotheses, which qualitatively explain the existence of electron precipitation zones at middle latitudes. One of them says that it is connected with the work of

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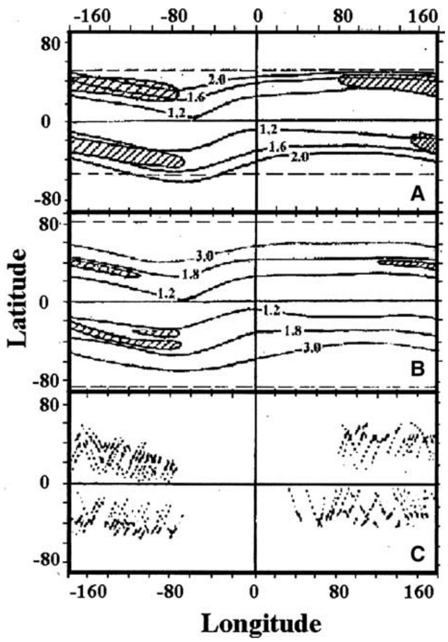

Fig. 1. The middle-latitude zones of electron precipitation: (A) MIR station; (B) CORONAS-I; (C) OHZORA experiments.

ground-based radiotransmitters (Nagata et al., 1988); the other says that the existence of these zones is connected with global thunderstorms activity (Kuznetsov and Myagkova, 2002).

In this paper, we investigate electron fluxes with energies $E_e = 30–480$ keV in wide altitude range ($H = 500–1500$ km) at $L = 1.2–1.8$, its longitudinal dependence, spectral characteristics, dependence on geomagnetic activity and on local time.

2. Experiment and discussion

The results, presented in this work, were being obtained on ACTIVE ("Intercosmos-24") satellite during 1989–1993 years. The parameters of ACTIVE satellite were: apogee 2500 km, perigee 500 km, inclination 82.6°.

The period of rotation around the Earth was 124 min. The cycle of the apogee's latitude was ~5.5 months and the cycle of the local time was ~3 months. The entire local time period near equator was covered within 115 days. The variation of attitude with respect to the magnetic field was smooth, and periodicities of the satellite axial variations (with respect to the nominal orientation) were 15–20 min. Since these periodicities were long, rapid particle flux variations, which were observed, were not caused by variations in the orientation (Kudela et al., 1992).

The analysis of experimental data bases on ~10,000 passes through the middle-latitudes region ($L = 1.2–1.8$) during the year 1990 (almost 3000 orbits). Electrons were registered with the use of single Si-surface barrier detectors. The diameter and width of each detector was 8 mm and 300 μm correspondingly. The geometrical factor of electron detectors was 0.03 cm^2 sr. All detectors were protected by Mylar foil to stop protons with energies $E_p < 500$ keV. Time of electron accumulation was 0.1 s. The period between electron flux measurements was 10 s. Three pairs of detectors measured fluxes at different angles. The axes of the detectors were 99°, 69° and 39° (for 1–3 detectors correspondingly) with respect to zenith axis of the satellite. Thus, electron fluxes were measured at three different pitch angles. We constructed the geographical maps of electron fluxes distribution using each detector's data independently. Comparison of the received distributions has shown that the basic features and longitudinal allocation of the observed zones are similar. Therefore, we present in this paper the results based on the first detector data. The whole energy range ($E_e = 30–480$ keV) was divided into seven energy channels. The comparatively wide altitude range, available during experiment, allowed exploring the electron fluxes in wider altitude range ($H = 500–1500$ km) than in previous investigation. Electron detectors had spectrometric properties so the information about electron energy spectra was available.

Large lifetime of satellite made it possible to estimate the dependence of electron fluxes on geomagnetic activity. Because of entire covering of all local time zones, the ACTIVE satellite permitted the investigation of low-energy electrons dependence at selected L-shells on magnetic local time (MLT).

2.1. Altitude dependence

Using the ACTIVE satellite data we constructed the geographical maps of electron fluxes distribution and located zones of registered electron fluxes at $L = 1.2–1.8$. The shaded areas on presented figures correspond to the flux level of more than 1500 $(cm^2\,s\,sr)^{-1}$ (we obtained similar distributions for the 600 $(cm^2\,s\,sr)^{-1}$ threshold value of electron fluxes registration). We do not consider particles at $L < 1.2$, at $L > 1.8$ and in the South Atlantic Anomaly zone. Fig. 2 shows the position of electron fluxes registration zones and the dependence of its shape on altitude. This figure was constructed using the value of electron fluxes averaged by all energy channels. The altitude H, marked at the top of every little picture, means $H \pm 50$ km.

The next conclusions follow from Fig. 2:

- zones of electron fluxes registration under the radiation belts at $L = 1.2–1.8$ exist constantly in an interval of altitudes from 350 up to 1500 km;
- electron fluxes are observed at $L = 1.2–1.8$ both in northern and in southern hemispheres;
- zones are located on longitudes from 90° up to 350° in northern hemisphere, and on longitudes from 90° up to 260° in a southern hemisphere;

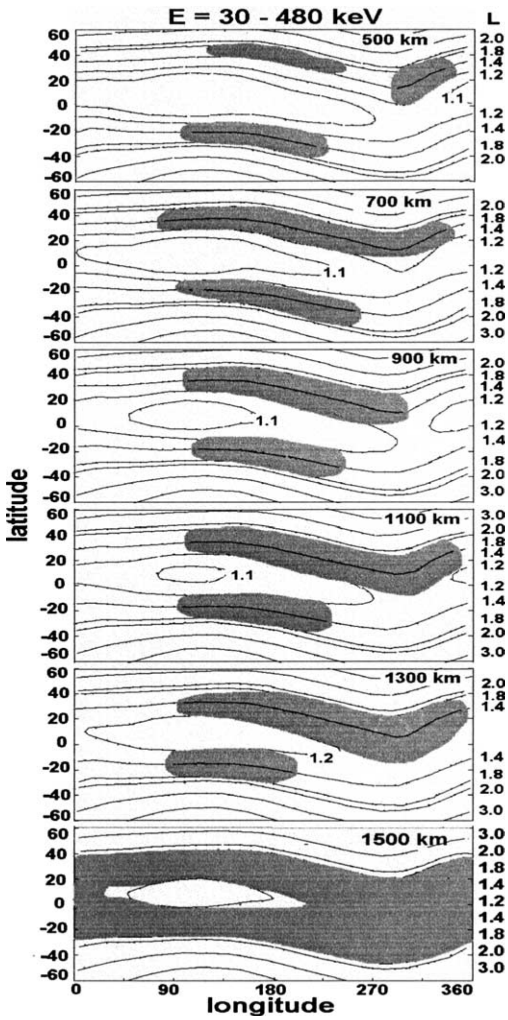

Fig. 2. The maps of electron fluxes (E_e = 30–480 keV, flux level > 1500 $(cm^2\ s\ sr)^{-1}$) at L = 1.2–1.8 at different altitudes ($H \pm 50$ km).

- the longitudinal sizes of zones practically do not depend on altitude up to 1300 km; at higher altitudes the electron fluxes become larger and it is difficult to locate them;
- the analysis of electron fluxes distribution dependence on energy shows, that the longitudinal width of these formations does not depend on energy up to 0.3 MeV. Zone's width decreases at higher energies. This result contradicts the result obtained by Nagata et al. (1988). We explain it by insufficient statistic volume for high-energy electrons due to the small geometrical factor of ACTIVE detectors (0.03 cm^2 sr). The CORONAS-I detectors' geometrical factor was 60 cm^2 sr, the OHZORA detectors' geometrical factor was 0.14 cm^2 sr;
- Table 1 shows that spectra in observed zones at L = 1.2–1.8 and in SAA are practically equal; spectra at L = 1.2–1.8 differ from the outer radiation belt spectrum in 500–1300 km range. So we can assume that some electrons do not die in the SAA region. These electrons can be reflected by the atmosphere and penetrate into conjugate to the SAA zone.

Table 1
The comparison of exponential energy spectra at region L = 1.2–1.8, in SAA, at L = 3.5–6.0

Atitude (km)	E_0 (keV) index of spectra approximation in region		
	L = 1.2–1.8	SAA	L = 3.5–6
500	114 ± 4	113 ± 5	76 ± 5
700	95 ± 7	106 ± 8	72 ± 4
900	105 ± 6	117 ± 6	73 ± 5
1100	99 ± 8	107 ± 7	76 ± 4
1300	116 ± 8	126 ± 6	77 ± 4

2.2. Geomagnetic activity dependence

Kuznetsov and Myagkova (2002) paper showed that electron precipitation under radiation belts did not correlate with the level of geomagnetic activity. To verify this fact we analysed the electron fluxes distributions at L = 1.2–1.8 as a function of activity at different altitudes. At -30 nT < D_{st} < 0 nT geomagnetic conditions considered as quiet and at $D_{st} < -30$ nT as disturbed.

Fig. 3 shows the distribution of electrons at H = 700 ± 50 km for quiet (upper panel) and disturbed conditions (bottom panel) at energies E_e = 44.2–69.9 keV and E_e = 111.0–277.0 keV.

The conclusion from Fig. 3:

- during the quiet periods of geomagnetic activity the zones of electron fluxes registration are localised at longitudes 120–300° in northern hemisphere, at 90–200° in southern hemisphere;
- during the disturbed periods of geomagnetic activity these zones shift to larger longitudes both in northern and in southern hemispheres, they are localised at longitudes 180–360° in northern hemisphere and at 170–270° in southern hemisphere.

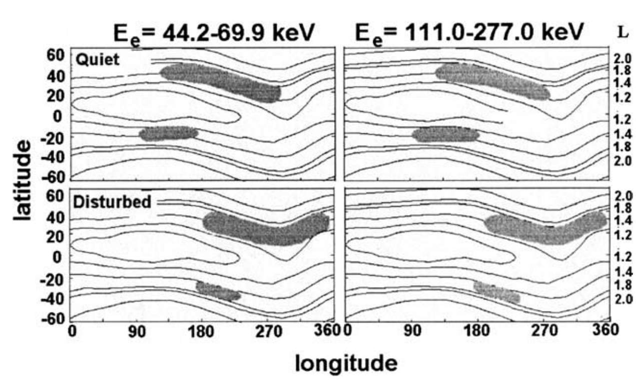

Fig. 3. The maps of electron fluxes at L = 1.2–1.8 at altitude H = 700 ± 50 km for different levels of geomagnetic activity; quiet: $-30 < D_{st} < 0$; disturbed: $D_{st} < -30$.

2.3. Energy spectra at L = 1.2–1.4 and in Anomaly

Electrons were registered in the conjugate to the South Atlantic Anomaly (SAA) zone during disturbances, so we assume that some electrons do not die (stop bounce motion) in the SAA region. These electrons can be reflected by the atmosphere and penetrate into conjugated to the SAA zone. Previous estimations (Leinbach and Willams, 1977; Spjeldvik, 1977) showed that reflected particle flux could be essential part of incident flux. It means that the particle distribution in the loss cone became non-exponential. To verify this assumption, we constructed the energy spectra of electrons in the northern zone of electron fluxes registration at $L = 1.2$–1.4 and in the SAA region using the ACTIVE satellite data.

Fig. 4 shows the analysis of electron spectra in these two regions. At the upper panel of the picture spectra were approximated by power-law ($j \sim E^{-\alpha}$), at the bottom panel spectra were approximated by exponential law ($j \sim \exp(E/E_0)$).

In Table 2, one can see the power (α) and exponential law (E_0) approximation indexes and the correlation coefficients (R) for selected type of approximation.

The comparison of two types of approximation shows that:

- the indexes of both approximations are similar for northern zone at $L = 1.2$–1.4 and for SAA in the ranges of errors;

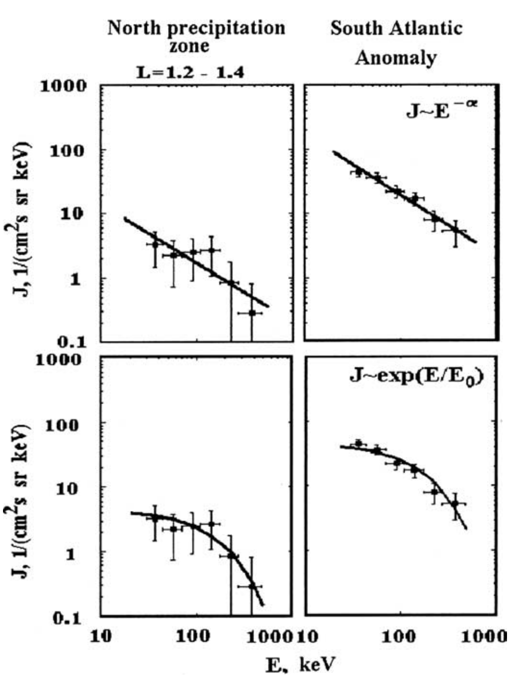

Fig. 4. The energy spectra (average flux as a function of energy) of electrons ($E_e = 28$–480 keV) in northern zone at $L = 1.2$–1.4 and in the SAA region at altitude $H = 700 \pm 50$. Power-law (upper panel) and exponential law (lower panel) approximate the spectra.

Table 2
The indexes of power-law α and of exponential E_0 approximation and correlation coefficients R of electron ($E_e = 28$–480 keV) energy spectra at altitude $H = 700 \pm 50$ km in northern zone ($L = 1.2$–1.4) and in the South Atlantic Anomaly (SAA)

	α	$R(\alpha)$	E_0 (keV)	$R(E_0)$
North $L = 1.2$–1.4	0.9 ± 0.3	0.86	140 ± 20	0.96
SAA	0.94 ± 0.07	0.99	160 ± 20	0.97

- the exponential approximation is better (the correlation coefficient is closer to 1) both for northern region and for the SAA.

2.4. Local time dependence

The previous experiments (see Kuznetsov and Myagkova, 2002) showed that there is no essential dependence of electron fluxes at $L = 1.2$–1.8 on geomagnetic local time (MLT), however, the analysis of ACTIVE satellite data reveals this dependence.

All the intervals of local time were divided to night (21^h–00^h–06^h MLT) and day (06^h–21^h MLT) hours. Fig. 5 shows the maps of electron distribution for energy $E_e = 44.2$–69.9 keV (left column) and $E_e = 111.0$–277.0 keV (right column) for night (top string) and for day hours (bottom string). We can see that:

- northern zone of electron fluxes registration exists mainly at night hours than at day hours;
- southern zone of electron fluxes registration shifts to larger longitudes at day hours and the latitudinal width of southern zone decreases at day hours.

Observed local time dependence of electron fluxes registration zones position at $L = 1.2$–1.8 can be an

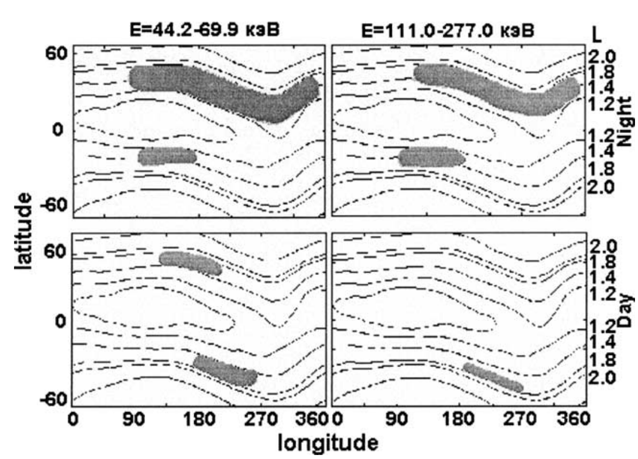

Fig. 5. The maps of electron fluxes at $L = 1.2$–1.8 at altitude $H = 700 \pm 50$ km as a function of MLT; night: MLT = 21^h–00^h–06^h; day: MLT = 06^h–21^h.

additional argue to confirm the hypothesis that these zones are connected with the work of ground-based radiotransmitters because the conditions of radio-waves in ionosphere are essentially better at night hours than at day hours.

3. Conclusions

These results follows from the observation:

- zones of electron fluxes registration under the radiation belts at $L = 1.2–1.8$ exist constantly at altitudes from 350 up to 1300 km;
- the electron fluxes have a longitude dependence;
- the electron distribution at $L = 1.2–1.8$ depends on geomagnetic activity;
- not all electrons die in SAA. Some electrons from the zone of SAA are reflected by the atmosphere into conjugate to the SAA region;
- the electron distribution at $L = 1.2–1.8$ depends on magnetic local time.

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References

Biryukov, A.S., Grigoryan, O.R., Kuznetsov, S.N., Ryaboshapka, A.V., Ryabukha, S.B. Low-energy charged particles at near equatorial latitudes according to "MIR" orbital station data. Adv. Space Res. 17 (10), (10)189–(10)192, 1996.

Biryukov, A.S., Grigoryan, O.R., Kuznetsov, S.N., Sinyakov, A.V., Tolstaya, E.D. Specific features of electron distributions at altitudes of 400 km. Adv. Space Res. 21 (12), 1665–1668, 1999.

Grachev, E., Grigoryan, O., Kudela, K., Petrov, A., Sheveleva, V. Altitude distribution of electron fluxes with energies more 40 keV at middle latitudes (Abstract), in: Proceedings of the Second Ukrainian Conference on Promising Space Research, Krim, September 2002, p. 35, 2002a (in Russian).

Grachev, E.A., Grigoryan, O.R., Novikov, L.S., Tchurilo, I.V. The role of proton and electron "abnormal" formations in radiation influence on construction elements of space apparatus (Abstract), in: Protection of Materials and Structures from Space Environment, PO-A-5, p. 29, 2002.

Kudela, K., Matisin, J., Shuiskaya, F.K., Akentieva, O.S., Romantsova, T.V., Venkatesan, D. Inner zone electron peaks observed by the "Active satellite". J. Geophys. Res. 97, 8681, 1992.

Kuznetsov, S.N., Myagkova, I.N. Quasi-trapped electron fluxes (>0.5 MeV) under the radiation belts: analysis of their connection with geomagnetic indices. J Atmos. Sol–Terr. Phys. 64, 409–414, 2002.

Leinbach, H., Willams, D.J. Evidence for very weak pitch angle diffusion of outer zone electrons. J. Geophys. Res. 82 (32), 5091–5098, 1977.

Nagata, K., Kohno, T., Murakami, H., et al. Electron (0.19–3.2 MeV) and proton (0.58–35 MeV) precipitations observed by OHZORA satellite at low zones $L = 1.6–1.8$. Planet. Space Sci. 36, 591, 1988.

Spjeldvik, W.N. Radiation belt electrons: structure of the loss cone. J. Geophys. Res. 82 (4), 709–713, 1977.