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The Soft X-ray Emission of Nocturnal Atmosphere During the Descending Phase of the 23rd Solar Cycle

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Abstract. The spectrometer RPS-1 onboard the "CORONAS-F" satellite monitored solar X-rays in the energy range 3-31.5 keV using CdTe solid state detector with thermoelectric semiconductor micro cooler. At shadowed branches of the orbit the device registered X-ray emission of the upper atmosphere that mostly results from the bremsstrahlung radiation of magnetospheric electrons. Long-term observations with the device (July, 2001 to December, 2005) permitted the evaluation of the low energy 3-8 keV X-ray emission flux radiated by the upper nocturnal atmosphere and its dynamics during descending phase of 23 solar cycle

Keywords: X-ray emission, terrestrial atmosphere, solar activity phase, magnetospheric electrons

Introduction

The satellite of CORONAS-F mission was launched 31 July of 2001 on circular orbit with the altitude of about 500 km and with inclination of 820 and lasted in the orbit up to 06 December of 2005 that permitted to study the dynamics of terrestrial X-ray emission on the overall descending phase of 23 solar cycle.

It is well known that the Earth emits X rays. Chandra X-ray Observatory and XMM-Newton had observed auroral and low-latitude X-ray emissions from the Earth and other solar system planets. It became clear that the auroral X-rays in the Earth's atmosphere are generated by energetic electron bremsstrahlung. The spectrum of the emission is spread up to about 10 keV energy and its location is at latitudes higher than 60o. The non-auroral emission observed on the sunlit side of the Earth is mostly produced due to scattering of solar X-rays and its energy range is more or less below 2 keV. The low latitude X-ray background above 2 keV from the Earth is almost negligible except for brief periods during major solar flares (Bhardwaj, 2006). These X-ray fluxes are not very well studied until now, in particular on the nocturnal side of the Earth at > 2 keV energy range.

In this paper we present some results of global, overall latitude observations of 3-31.5 keV X-rays done with RPS-1 device at the shadowed branches of the Coronas-F orbit within 5 years.

Characteristics of RPS-1 spectrometer

The RPS-1 instrument performed detail spectrometry of X-rays in the 3 – 31.5 KeV energy range using a solid state CdTe detector with a semiconductor micro cooler (Pankov et al., 1989; 1996). The detector possesses high efficiency for X-ray detection and also high radiation stability needed for long-term space experiments. The basic characteristics of the detector are:

Energy range 3-31.5 keV;

The thickness of the entrance window 50 μm permits electrons to pass with energy > 100 keV and protons with energy > 3 MeV;

Sensitive surface of the detector 46 mm2;

Detector thickness 1.39 mm;

Working temperature from -35 to +50oC;

Energy resolution at rates ~103 s-1: Fe55 5.9 ± 0.74 keV ; Am241 13.87 ±0.88 keV;

Widths of the first 12 channels (3-9 keV) ≈0.5 KeV; the next 12 ones ≈ 1 keV ; the last 8 ones (21-31.5 keV) ≈ 1.3 keV;

The 32 channel data are accumulated every 16 sec;

RPS-1D dimensions 190×215×330 mm3;

Power consumption – 8.5 W. Mass 1.8 kg

Results: X-ray emission of the nocturnal atmosphere

Figure 1 shows the maps of the nocturnal atmosphere radiation in the energy ranges of 3-5 keV for the interval September 23, 2001 – March 3, 2005. The magnitude of X-ray flux is shown by color in relative units. It is the brightest in the northern hemisphere in winter and in the southern hemisphere in summer. Here "winter" and "summer" refer to the seasons in the northern hemisphere. In the northern hemisphere the brightest emission is observed during the winter of 2001-2002 when solar activity was greatest in the 23rd solar cycle. The seasonal effect on the 3-8 keV radiation is observed too, however it was veiled by the influence of solar activity.

The luminescence is seen both at high latitudes in the region of the outer earth radiation belt (ERB) and at lower latitudes down to the equator.

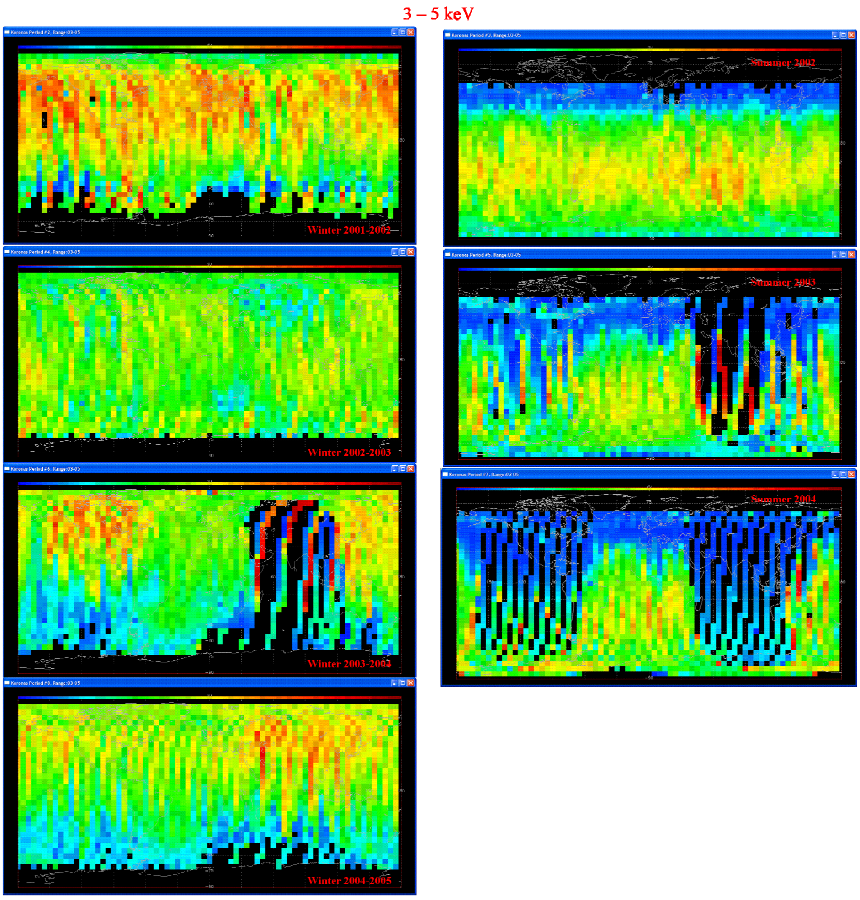

Figure 1. The 3- 5 keV nocturnal atmosphere emission for 2001– 2005 years.

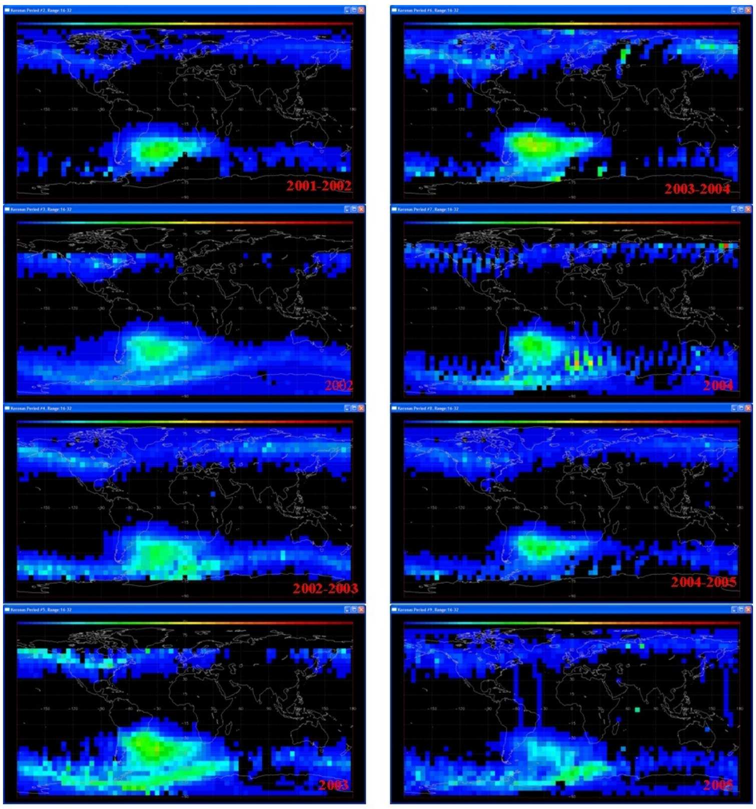

Figure 2. The 16- 32 keV nocturnal atmosphere emission for 2001– 2005 years

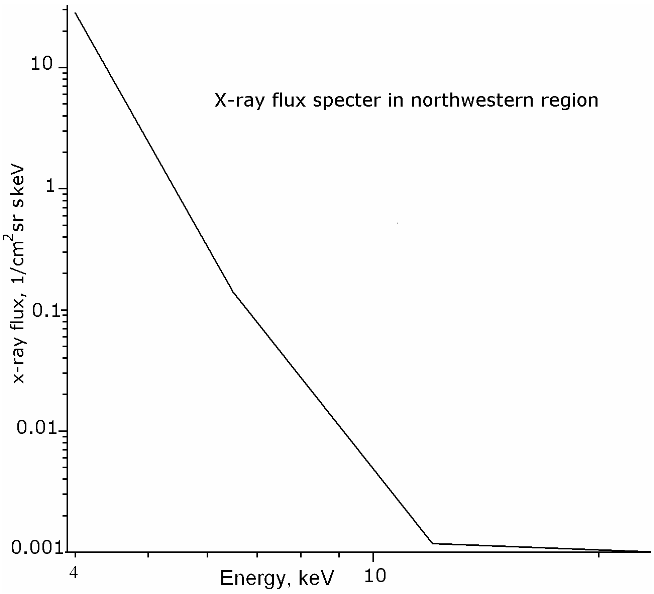

Figure 3. The spectrumof radiation in the northwestern part of the Earth's globe

On the maps of 5- 8 keV the emission still exists but it is almost negligible at > 8 keV and distinctly allocated only in the ERB zones and in the South Atlantic Anomaly (SAA). Figure 2 shows the maps of 16- 32 keV radiation for the same period. We conclude that the nocturnal atmosphere irradiates mostly in the energy range of 3- 8 keV. The spectrum of the emission observed in the northwestern part of the globe is soft and drastically dropped to 10 keV (Fig.3). It means that the radiation is probably caused by the bremsstrahlung radiation of the magnetospheric electrons.

Discussion

Coronas-F satellite passes in the inner magnetosphere in a low altitude orbit. There are well known AE8 min, max NASA's models describing the distribution and spectra of energetic electron fluxes confined in the inner magnetosphere at such orbits (Fig. 4). In Fig.4 one can see a map of space distribution of electrons with energy greater than 1 MeV at altitudes of 500 km. They are allocated in the ERB zones and in the SAA region and nowhere else. Outside these zones there are no trapped radiation electrons, at least electrons with energy greater than 40 keV: the models start with this electron energy. However the observations made in various space missions (POES, OHZORA, Active etc) revealed sporadic temporary tens keV electrons near the geomagnetic equator and at low and middle latitudes at altitudes of 300 – 1000 km (Fig. 5). These fluxes are precipitating from the inner radiation belt and slot region being influenced by electromagnetic disturbances of different origin (lightnings, earthquakes, geomagnetic storms, substorms, etc.). Such kind of precipitating electrons can be a source of X-rays under ERB zones. To penetrate directly into the detector and to be registered, the electrons need to possess energy above 100 keV. However the detector registers X-ray spectrum in the range of 3 – 8 keV (Fig. 3). All this testifies that the RPS-1 detector actually detects the bremsstrahlung of precipitating electrons (Figs. 1 and 2).

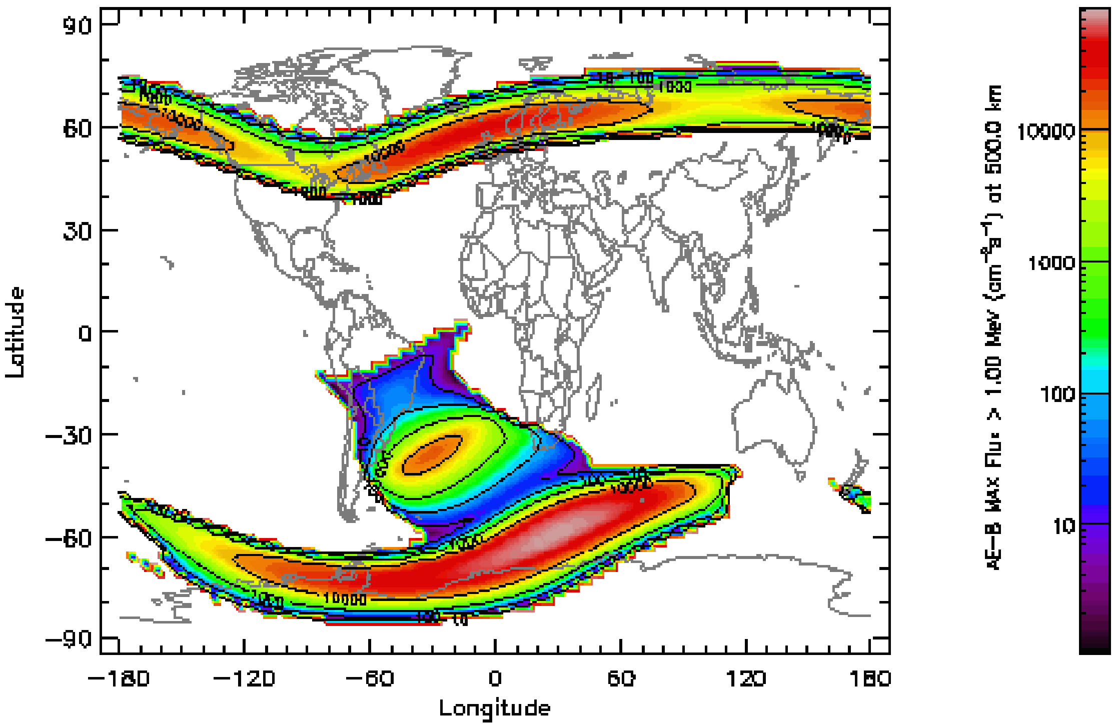

Figure 4. Space distribution of 1 MeV electron fluxes at the 500 km altitude by AE8 model

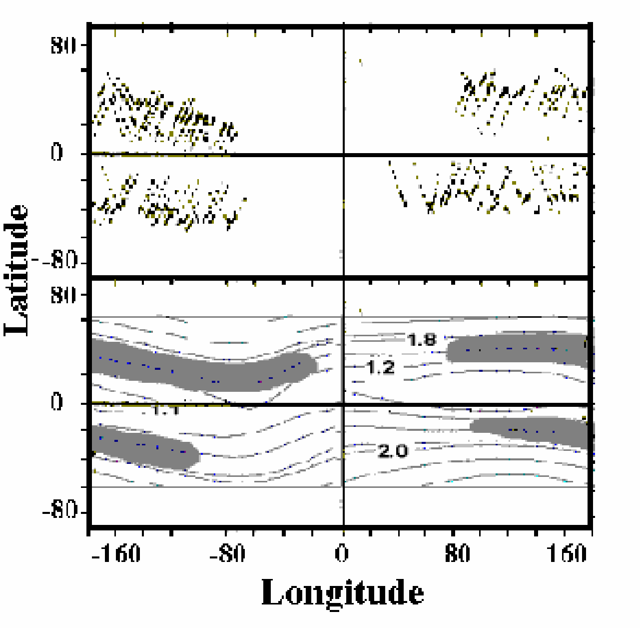

Figure 5. Space distribution of precipitating tens keV electron fluxes at the 500 km according to Active and Ohzora satellites (Grigorian, 2009).

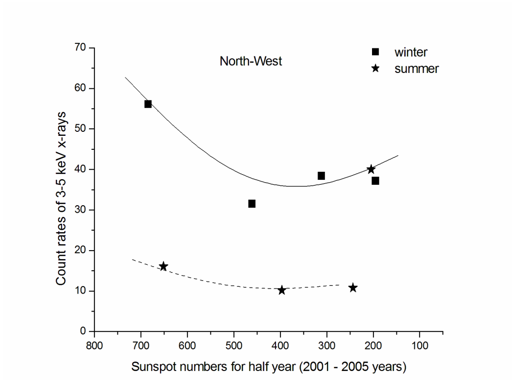

Figure 6 Dependence of North-West X-ray emission on solar activity in 2001–2005 years

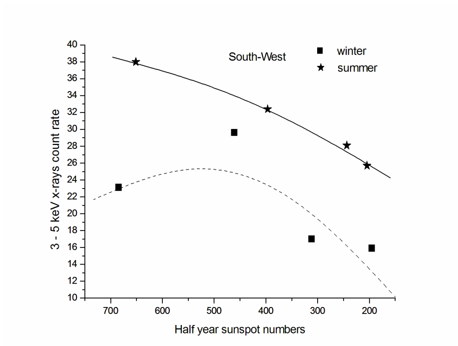

Figure 7. Dependence of South-West X-ray emission on solar activity in 2001–2005 years

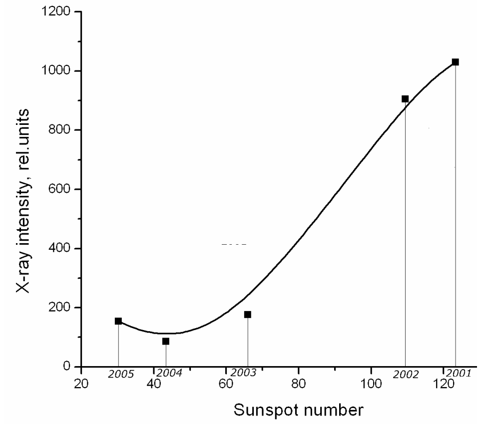

Figure 8. Dependence of X-ray emission on solar activity in equatorial region in 2001–2005 years

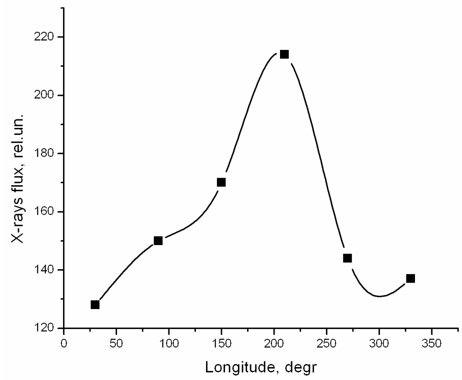

Figure 9. Longitudinal dependence of X-rays emission in equatorial region

To quantitatively evaluate how the X-ray emission changes with descending solar activity, we selected some large areas in the northwestern and southwestern parts of the hemisphere in the latitudinal intervals of ± (20°- 40°) and computed the mean emission level there (Figs. 6 and 7). In 2001 the 3- 8 keV X-ray flux reached the values of ~ 170 (cm2s sr)-1 in the northwestern region. This weak Roentgen intensity corresponds to brightness of about ~ 6000 MeV/m2. A preliminary rough estimate of luminosity of each square degree of the atmospheric surface at altitude of 500 km is equal to 10W and the luminosity of the brightest atmospheric spot on the Earth's globe on Fig.1 (about 2000 x 200) is equal to ~ 40 kW. For comparison the emitted power of auroral atmosphere is ~ 10- 30 MW (Bhardwaj, 2006).

The 3-8 keV emission generally decreases with the solar activity decrease (Figs.6 and 7).

For the equatorial region the X-ray flux values are averaged at ±20° latitudes and at all longitudes. Fig. 8 shows a drastic decrease of the emission: about 10 times from maximum to minimum solar activity. Fig.9 demonstrates the longitudinal dependence of the emission for the 2003 year data. By the way, the existence of longitudinal dependence in the distribution of precipitating electron fluxes was revealed at altitudes of 300- 1000 km too (see for example Fig. 5).

It should be taken into account that the satellite orbit lowered from 510 km to 380 km of altitude for the time interval from June 2001 to March 2005. The observed time dependence of the luminescence could be caused by the combination of two effects: solar activity changes and satellite orbit lowering too. However, firstly, the path length of a 3-5 keV quantum in the air is about 0.5 g/cm2 and this value is so big in km units at the orbital altitude, that it is practically the same X-rays flux which is observed at altitudes of the lowering orbit. And second, for neutral albedo X-rays emission flux mostly would be expected to increase with decreasing altitude, of course if the source is located at the atmospheric boundary.

Conclusion

The maps of the terrestrial nocturnal luminescence in 3-8 keV X-rays were obtained for northern summer and winter. Important regularities in the behavior of this emission are revealed: maximal energy of the emission does not surpass 8 keV; it has seasonal variations; the emission significantly depends on solar activity level; it demonstrates latitudinal – longitudinal dependence.

Acknowledgements

In memory of our colleagues Drs. V.Pankov and V. Prokhin who planned and performed this experiment.

References

Bhardwaj Anil: 2006, Advances in Geosciences, vol.3, 215-230.
Grigorian O.R.: 2009, Electron precipitations at low and middle latitudes, unpublished, Private communication.
Pankov, V.M., Prokhin, V.L., et al.: 1989, High energy space radiation, PhTI, Leningrad, 196, in Russian.
Pankov, V.M., Prokhin, V.L., Havenson, N. G.: 2006, Solar System Research, 40, No.4, 314.