Planetary and Space Science 59 (2011) 733–740

Contents lists available at ScienceDirect

Planetary and Space Science

journal homepage: www.elsevier.com/locate/pss

Latitudinal profile of UV nightglow and electron precipitations

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ARTICLE INFO

Article history:
Received 9 November 2010
Received in revised form
4 February 2011
Accepted 21 February 2011
Available online 4 March 2011

Keywords:
Ionosphere
Mesosphere
Radiation belts
Particle precipitation

ABSTRACT

We studied experimental data on ultra-violet (UV) nightglow in the wavelength range 300–400 nm, and energetic electron fluxes measured by low-altitude polar satellite Universitetskii-Tatiana. From statistical analysis we have found three latitudinal regions of enhanced UV emission at low, middle and high latitudes. Modeling the electron precipitations to the atmosphere gave numerical estimation of the generated UV radiation. We found that the stable and quasi-stable fluxes of electrons precipitating at middle and low latitudes are too weak to explain the observed intensities of UV radiation. The high-latitude UV nightglow with intensity of several kiloRayleighs results from particle precipitation in the regions of aurora and outer radiation belt. The low-latitude UV enhancements of several hundreds Rayleighs can be related to the emission of mesospheric atomic oxygen whose concentration increases substantially at latitudes from 20° to 40°. A mechanism of the mid-latitude UV enhancements is still unknown and requires further investigations.

1. Introduction

The nighttime upper atmosphere and ionosphere emit abundant ultra-violet (UV) radiation, which is detected on the background of night atmospheric and ionospheric glow formed by scattered light coming from the Moon and stars (e.g. Kondrat'ev, 1969; Massey and Bates, 1982; Prolss, 2004). The UV nightglow is characterized by a complex of spatial and temporal variations related to various processes.

The brightest UV emission of thousands of Rayliegh (R) is observed in a wide range of wavelengths at high-latitude region of auroral particle precipitation (e.g. Østgaard et al., 2001; Christensen et al., 2003). The main source of precipitating electrons at high latitudes is the substorm activity. The UV spectrum of aurora is mainly represented by bright lines of exited and ionized nitrogen and oxygen with differential intensities of several hundreds R/Å (e.g. Shepherd, 2002). The ionization and excitation are produced at altitudes above 80 km by the energetic electrons (with energies of several keV), precipitating from the magnetosphere to the upper atmosphere, and by the low-energy secondary electrons (with energies of several eV) which are generated through ionizing collisions (e.g. Jones, 1974).

An intense background UV emission comes from mesosphere, altitudes of 90 to 110 km (e.g. Massey and Bates, 1982; Greer et al., 1986; Lopez-Gonzalez et al., 1992; Owens et al., 1993). Detail non-thermal spectra of the upper atmosphere airglow can be found in Shepherd (2002). In the mesosphere, the three-body recombination of atomic oxygen results in the formation of intermediate states of molecular oxygen, which radiate in Herzberg I, Chamberlain and Herzberg II bands. The UV nightglow is represented by bright lines of molecular and atomic oxygen with differential intensities of tens R/Å.

The mesospheric UV nightglow was measured in several ground-based, rocket and satellite experiments. At middle latitudes, the total integrated intensities in the Herzberg I and Chamberlain bands are estimated to be ~300–350 R and ~120–150 R, respectively (Greer et al., 1986; Johnston and Broadfoot, 1993). The low-latitude mesospheric nightglow spectral survey, reported by Owens et al. (1993), shows the integral intensities of several hundreds Rayleighs in the range ~260–390 nm (Herzberg I and Chamberlain bands).

Another source of the UV emission is located at low latitudes. Observations of ~135.6 nm emission in the nighttime ionosphere, performed by FUV/SI imager onboard the IMAGE satellite (e.g. Sagawa et al., 2003) and GUVI instrument onboard TIMED satellite (Christensen et al., 2003), reveal prominent low-latitude UV arcs corresponding to the equatorial ionization anomaly (EIA). That emission comes from radiative recombination mainly of the atomic oxygen ions. The brightness of the emission varies as the product of the electron density and the oxygen ion concentration,

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doi:10.1016/j.pss.2011.02.010

which peaks in the ionospheric *F*-layer at altitudes of ~300 km. Since in that region these quantities are approximately equal, the UV emission follows the square of the electron density. During geomagnetic quiet, the ~135.6 nm UV emission from the EIA is weak (~10 R) and peaks at geomagnetic latitudes of ~10–20°. At larger wavelengths, the UV nightglow from the EIA region is even weaker (e.g. Tinsley et al., 1994).

The intensity of UV nightglow changes with latitude (e.g. Meier, 1991). For the far UV (FUV) range of 110–190 nm the latitudinal profile of the nightglow is well investigated in satellite experiments. There are two regions of enhanced FUV emission: EIA with intensities of tens of Rayleighs and very wide and bright high-latitude region of aurora with intensities of hundreds to thousands of Rayleighs. The latitudinal profile of 300–400 nm UV in the Herzberg I and Chamberlain bands is still poorly investigated. Comparing data obtained in rocket experiments at low and middle latitudes (e.g. Lopez-Gonzalez et al., 1992), one can find that the UV intensity is weaker at lower latitudes.

It is well known that the region of latitudes from 20° to 60° is affected by energetic particle precipitating from the radiation belt (RB) and ring current during magnetic quiet and especially during storm-time conditions (Paulikas and Freden, 1964; Tinsley et al., 1986, 1994; Imhof et al., 1991; Selesnick et al., 2003; Bucik et al., 2005). This precipitation is considered as a powerful source of ionization in the upper atmosphere and ionosphere (Baker et al., 1987). Dmitriev and Yeh (2008) reported substantial enhancements of the mid-latitude ionosphere ionization related to intense precipitation from the inner RB during magnetic storms. It might be possible to observe an UV emission initiated by mid-latitude precipitations.

In the present paper we report the results of simultaneous observations of the integral UV nightglow in the range from 300 to 400 nm and energetic electron fluxes performed by low-altitude (950 km) polar satellite Universitetskii-Tatiana. We demonstrate enhancements of the UV emission at various latitudes and investigate a relationship of these enhancements with the electron precipitation.

2. Instrumentation

The satellite Universitetskii-Tatiana was launched on January 20, 2005 into polar circular orbit with altitude of ~950 km and inclination of 82°. The scientific equipment includes detectors of energetic electrons and UV radiation (Garipov et al., 2005a, b, 2006; Sadovnichy et al., 2007).

The fluxes of electrons are measured by a solid-state detector in energy ranges of >70 keV and 300–600 keV with the geometric factor of 9.7×10^{-2} (cm^2 sr), and 600–800 keV with the geometric factor of 2×10^{-2} (cm^2 sr). The electron detector has 50° conic field of view with the axis tilted by 15° from zenith direction. At low latitudes, the detector measures mostly electrons with pitch angles around ~90° (trapped and quasi-trapped) and at high latitudes, precipitating electrons with pitch angles around ~0° are detected.

The UV airglow in the range of 300–400 nm is measured by a detector of UV (DUV) in nadir direction with a field of view of 14°, which corresponds to 250 km diameter of the observed area in the atmosphere at 100 km. The DUV detector is based on a photoelectron multiplier tube, which anodic current is approximately constant, since the amplification is controlled by the intensity of UV radiation. That makes possible to measure the UV intensities in a wide dynamic range from minimal nighttime values of 2×10^7 photons/(cm^2 s sr) to maximal values of 10^{13} photons/(cm^2 s sr) on the dayside. Such a wide dynamic range on moonless nights allows measuring the intensity of UV airglow both in the auroral region and at low- and mid-latitudes, where the measuring fluxes are minimal.

The scheme of UV detector is shown in Fig. 1. The photomultiplier tube (PMT) of Hamamatsu type R1463 (13 mm tube diameter, multi-alkali cathode, UV glass window) was selected as a UV sensor. At the entrance window, a collimator limits the field of view of the detector of 14°. It also restricts the PMT's cathode area opening for the light to $S=0.4$ cm^2. The aperture of the detector is 0.02 cm^2 sr. The filter cuts the light with wavelength >400 nm. The quantum efficiency of the cathode is 20% in the range of wavelength 300–400 nm and goes down fast at smaller wavelengths. Hence, the effective wavelength range of the detector is 300–400 nm, limited by the filter at higher wavelengths and by the cathode quantum efficiency and absorption of light in the atmosphere at lower wavelengths, as shown in Fig. 2. The selected PMT has a high-energy resolution and a single photoelectron (p.e.) signal is well resolved. Before the detector operation, the 1 p.e. signal was measured as a function of the tube voltage and this characteristic is used for measuring the signals in p.e. number.

The second PMT is identical to the first one but covered by a black sheet. It is used for checking the "dark" noise from the charged cosmic particles producing light in the optical elements of the detectors (filter, PMT glass).

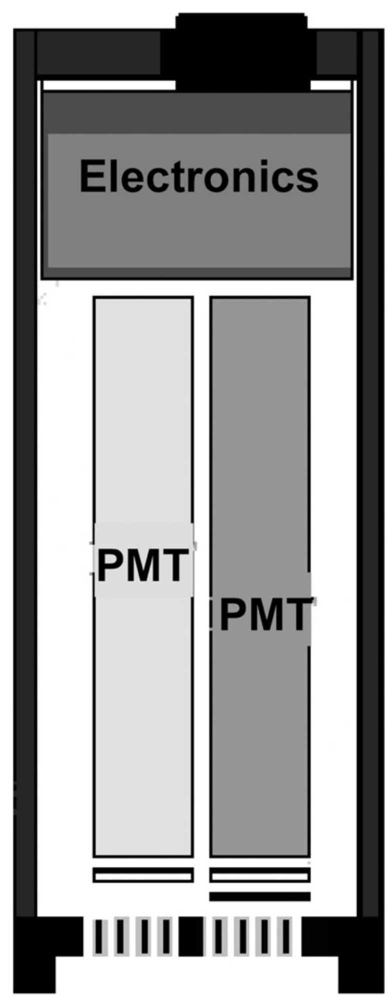

Fig. 1. Sketch of DUV instrument: two photo-multiplier tubes (PMT) observing atmosphere through filters and collimators, the right tube is a control one, covered by a screen.