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GLOBAL DISTRIBUTION OF AURORAL LUMINOSITY INFERRED FROM THE AURORAL PRECIPITATION MODEL

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Abstract. The Auroral Precipitation Model (http://apm.pgia.ru/) was used to calculate the global distribution of the auroral luminosity in visible and UVI spectral ranges. Integral intensities of N_2 LBH bands near 170.0 nm, 1NG N_2^+ at 391.4 nm, (OI) 557.7 nm, and the 1PG N_2 band near 669.0 nm have been calculated. To calculate (OI) 557.7 nm intensity the production of O(^{1}S) in the electron energy transfer process $N_2(A^3\Sigma_u^+)$ + O(^{3}P), the dissociative recombination, auroral electron impact and the production of electronically excited N_2 by auroral electron impact were taken into account. A good agreement was revealed by comparison of the LBH global distribution observed by spacecraft UV imagers and calculated from the model.

Introduction

Empirical models of global distribution of precipitating particles are very convenient to use for studying (monitoring and the forecast) characteristics of auroral luminosity in different spectral region during magnetospheric disturbances. The first attempt to create a planetary model of auroral luminosity has been undertaken by *Ivanov et al.* [1993]. These authors used the model by *Spiro et al*. [1982] in which the electron precipitation pattern was developed from AE-C and AE-D spacecraft observations for four magnetic activity intervals. In this model (and in later models also) Kp and one hour averaged AE indexes were used as a level of magnetic activity. However, the time of the spacecraft pass through the auroral zone is only a few minutes that is why such models can provide only a rough estimation of the planetary distribution of auroral precipitation characteristics.

In the present work to calculate the planetary distribution of auroral luminosity we used the Auroral Precipitation Model (APM) which is available on the PGI website *http://apm.pgia.ru/* [*Vorobjev and Yagodkina*, 2005, 2007]. APM was developed on the base of statistical treatment of DMSP F6 and F7 spacecraft observations. This model at a specified level of magnetic activity allows us to receive a global distribution of the average electron energy and the energy flux in different precipitating zones. The APM precipitation pattern is a function of Dst and 5-min averaged AL indexes.

Modelling of emission intensities

The model of the electronic kinetics of molecular nitrogen in auroral upper atmosphere in this work is similar to the models of *Kirillov* [2008, 2010, 2011a]. We consider five triplet $A^3\Sigma_u^+$, $B^3\Pi_g$, $W^3\Delta_u$, $B'^3\Sigma_u^-$, $C^3\Pi_u$ and three singlet $a'^1\Sigma_u^-$, $a^1\Pi_g$, $w^1\Delta_u$ electronically excited states of N_2. A main difference in the model consists in a neglecting of molecular collisions for the $B^3\Pi_g$, $W^3\Delta_u$, $B'^3\Sigma_u^-$ and $a'^1\Sigma_u^-$, $a^1\Pi_g$, $w^1\Delta_u$ states. Here we have included the following processes of the excitation and quenching of electronically excited N_2 molecules:

1. The electronic excitation by auroral primary and secondary electron impact. The method of "excitation energy costs" was suggested by *Gordiets and Konovalov* [1991], *Sergienko and Ivanov* [1993] where rates of the processes can be calculated using the value of the energy dissipated by auroral electrons in 1 cm^3 [*Kirillov et al.*, 1984].

2. The spontaneous radiative transitions with the emissions of bands of first positive group (1PG), Wu-Benesch system (WB), afterglow system (AG), second positive group (2PG), Vegard-Kaplan system (VK) for triplet states and with the emissions of McFarland (MF), Ogawa-Tanaka-Wilkinson-Mulliken (OTWM) and Lyman-Birge-Hopfield (LBH) bands. Einstein coefficients for radiational spontaneous transitions are taken according to *Gilmore et al.* [1992] and *Kirillov* [2011a].

3. The quenching of the $A^3\Sigma_u^+(v=0–6)$, $W^3\Delta_u(v=0)$, $a'^1\Sigma_u^-(v=0,1)$, $a^1\Pi_g(v=0)$ states in collisions with N_2, O_2, O atmospheric components. We neglect the quenching for another vibrational levels of the $W^3\Delta_u$, $a'^1\Sigma_u^-$, $a^1\Pi_g$ states and for all vibrational levels of the $B^3\Pi_g$, $B'^3\Sigma_u^-$, $C^3\Pi_u$, $w^1\Delta_u$ states because of high spontaneous radiative rates in comparison with collisional ones at the altitudes of upper atmosphere. The quenching rate coefficients by N_2 and O_2 molecules are taken according to quantum-chemical calculations by *Kirillov* [2008, 2011b,c]. The quenching rate coefficients by atomic oxygen are taken according to [*Thomas and Kaufman*, 1985] for the $A^3\Sigma_u^+$ state and [*Gudipati et al.*, 2002; *Khachatrian et al.*, 2003] for the $a'^1\Sigma_u^-$ and $a^1\Pi_g$ states. It is supposed that the quenching rate of the $W^3\Delta_u,v=0$ level by O is the same as for the $A^3\Sigma_u^+,v=0$ level.

The solving of corresponding equations allows us to calculate vibrational populations N_v^Y of triplet states. The emission of 669.0 nm band of 1PG is related with spontaneous radiative transition with $B^3\Pi_g,v=5$ and $A^3\Sigma_u^+,v'=2$. So the intensity of the band 669.0 nm can be calculated by the equation

$$I_{669.0} = A_{669.0}\cdot[N_2(B^3\Pi_g,v=5)] \quad (1)$$

where $A_{669.0} = 5.93\times10^4$ s^{-1} is Einstein probability for the transition [*Gilmore et al.*, 1992].

The solving of corresponding equations allows us to calculate also vibrational populations N_v^Y of singlet states. Applying Einstein probabilities for radiative transitions we can calculate intensities of LBH bands (transitions $a^1\Pi_g,v \to X^1\Sigma_g^+,v'$). Here we take into account 21 bands of LBH system in the interval 160–180 nm: $v'=v+3$, $v+4$, $v+5$ for v=0–3 and $v'=v+2$, $v+3$, $v+4$ for v=4–6. The function *f* of the contribution of every band is as follow:

$$f(\lambda) = \exp[-(\lambda-170)^2/23], \tag{2}$$

where λ is the wavelength (in nm), 170 nm is the centre of the interval.

The emissions of first negative group (1NG) of molecular nitrogen ion are related with radiative transitions:

$$N_2^+(B^2\Sigma_u^+,v) \to N_2^+(X^2\Sigma_g^+,v') + h\nu_{1NG}\,. \tag{3}$$

To calculate the intensity of 391.4 nm band of 1NG ($v=v'=0$) we apply the equation:

$$I_{391.4} = Q^*\cdot q_v^*\cdot A_{391.4}/A_{tot}, \tag{4}$$

where Q^* is the production rate of the $B^2\Sigma_u^+$ state of N_2^+ by auroral primary and secondary electrons [*Gordiets and Konovalov*, 1991; *Sergienko and Ivanov*, 1993], q_v^*=0.883 is the Franck-Condon factor for the transition $X^1\Sigma_g^+,v=0 \to B^2\Sigma_u^+,v=0$, $A_{391.4}=1.14\times10^7$ s^{-1} is the spontaneous transition probability for the transition $B^2\Sigma_u^+,v=0 \to X^2\Sigma_g^+,v'=0$, $A_{tot}=1.60\times10^7$ s^{-1} is the total spontaneous transition probability for the transitions $B^2\Sigma_u^+,v=0 \to X^2\Sigma_g^+,v'\geq0$ (Gilmore et al., 1992).

The emission of green line 557.7 nm of atomic oxygen is related with the radiative transition:

$$O(^1S) \to O(^1D) + h\nu_{557.7}\,. \tag{5}$$

The main production mechanisms of $O(^1S)$ in auroral upper atmosphere are (Sharp et al., 1979): (*a*) the energy transfer from metastable molecular nitrogen, (*b*) the electronic excitation by auroral primary and secondary electron impact, (*c*) processes of dissociative recombination of thermal ionospheric electrons with O_2^+ ions. Therefore, to calculate the intensity $I_{557.7}$ of 557.7 nm line of atomic oxygen we apply the equation:

$$I_{557.7} = \frac{A_{557.7}\left(\sum_v k^*(v)N_v^A[O] + Q_{^1S} + 0.06\alpha N_e[O_2^+]\right)}{A_{557.7} + A_{297.2} + k_{O_2}^*[O_2] + k_O^*[O]}, \tag{6}$$

where $A_{557.7}$ = 1.215 s^{-1} and $A_{297.2}$ = 0.076 s^{-1} [*Bates,* 1992] are the spontaneous transition probabilities for the transitions $^1S\to^1D$ and $^1S\to^3P$, respectively, $k_{O_2}^*$, k_O^* are the rate coefficients for the quenching of $O(^1S)$ in collisions with O_2 and $O(^3P)$, respectively, $k^*(v)$ are the rate coefficients for the processes (*a*) for v=0–6, $Q_{^1S}$ is the rate of the process (*b*) [*Gordiets and Konovalov,* 1991; *Sergienko and Ivanov,* 1993], α is the rate coefficient of dissociative recombination (*c*) of ionospheric electrons (with concentration N_e) and molecular oxygen ions O_2^+, 0.06 is the quantum yield of $O(^1S)$ in the process (*c*) [*Petrignani et al.,* 2005]. The coefficients $k_{O_2}^*$, k_O^* are taken according to (Bates, 1992), the coefficients $k^*(v)$ are taken according to [*Kirillov and Aladjev*, 1998].

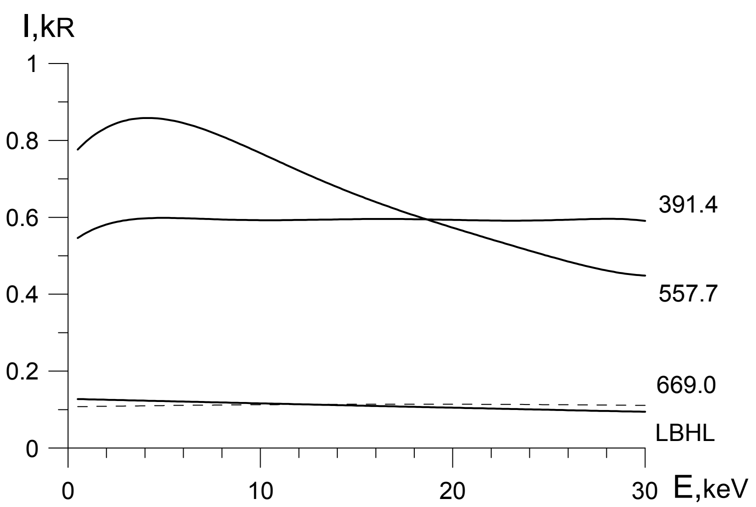

Fig. 1

The brightness of auroral emissions associated with the energy flux of 1 erg·cm^{-2}·c^{-1} versus of precipitating electron energy is shown in Fig. 1. The isotropy pitch-angle and Maxwell energy flux distributions of electrons were assumed to calculate these relations. An albedo for isotropic incident flux was calculated according to results by *Sergienko and Ivanov* [1993]. Concentrations of N_2, O_2, O(^{3}P) components and temperature profile at the altitudes from 90 to 200 km were taken from *Morrill and Benesch* [1996].

391.4 nm 557.7 nm 669.0 nm LBH(L)

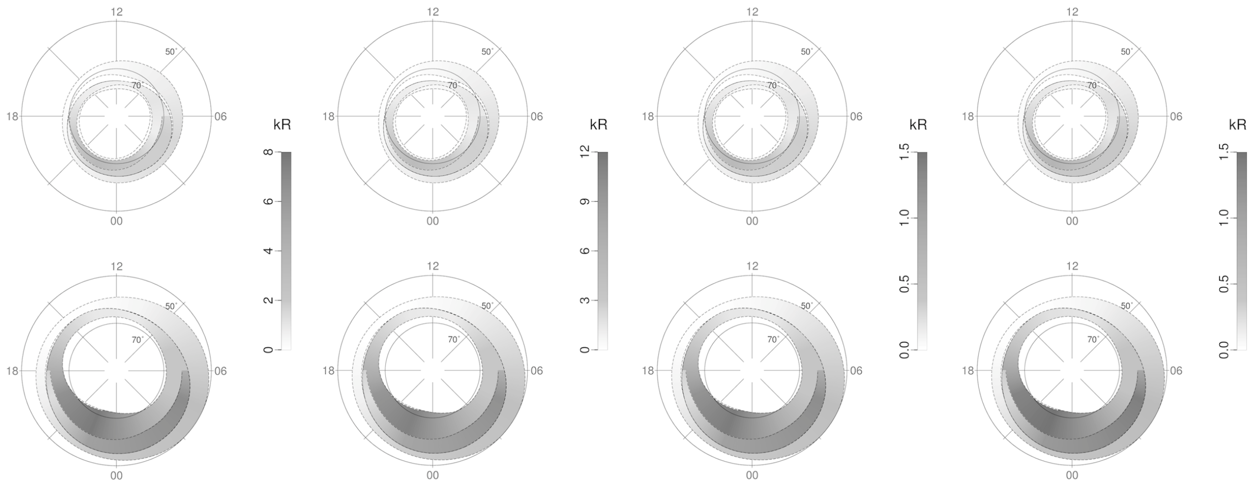

Fig. 2

These relations and characteristics of precipitating electrons inferred from APM are used to get the global patterns of auroral luminosity under different magnetic activity conditions. As an example, Fig. 2 demonstrates the global distribution of four auroral emissions for the low (top panel, AL= -200 nT, Dst= -5 nT) and disturbed (bottom panel, AL= -1000 nT, Dst= -100 nT) magnetic activity. 1200 MLT is at the top of each panel and 0600MLT on the right side. The vertical color scale indicates the luminosity brightness in kiloRelights (kR). Maxima intensity on the colour scales in Fig. 2 are 8, 12, 1.6, 1.6 kR from 391.4 nm to LBH, respectively.

POLAR APM

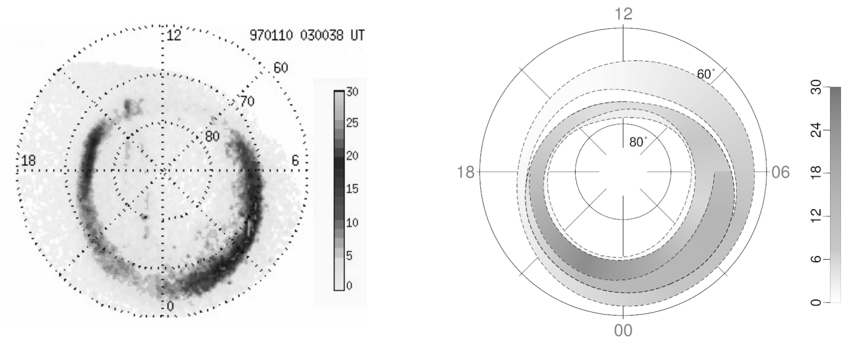

Fig. 3

The function *f* (equation 2), which represents the contribution of LBH bands in the interval 160–180 nm, is similar to the resultant LBH(L) filter utilized in POLAR spacecraft ultraviolet imager (UVI) [*Torr et al., 1995*]. The POLAR UV image obtained on Jan. 10, 1997 at 0300:38 UT and corresponding APM pattern constructed for the same magnetic activity level (AL= -224 nT; Dst=8 nT) are shown in Fig 3. The brightness of UV luminosity in units of POLAR imager (photon·cm^{-2}·s^{-1}) is indicated by vertical black-white and color scales in the right-hand side of patterns. The maximum of brightness on these scales is 30 photon·cm^{-2}·s^{-1}. The comparison of two patterns gives an evidence of similarity both in disposition and distribution of oval luminosity. However, the dayside diffuse luminosity equatorward of the oval is noticeable only in the APM pattern. It could be because of the low sensitivity of POLAR UVI. *Torr et al.* [1995] reported that only 250 R (~8 photon·cm^{-2}·s^{-1}) are measured by UVI with a signal to noise ratio of 5. That is why the luminosity in the ~0830-1230 MLT sector of the auroral oval is very poorly expressed. The same are observed in a number others events compared by us under low and moderate magnetic activity.

Conclusion

Algorithm for the calculation of the integral auroral intensity in the 557.7 nm emission and N_2 LBH at 170.0 nm, 1NG N_2^+ at 391.4 nm, 1PG N_2 at 669.0 nm bands is presented. This algorithm is used for the Auroral Precipitation Model to construct the global patterns of auroral luminosity at different level of geomagnetic activity expressed by AL and Dst. Comparison of APM patterns and POLAR images in the LBH(L) luminosity was carried out and showed a good agreement between each other.

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