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Study of atomic oxygen greenline dayglow emission in thermosphere during geomagnetic storm conditions

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Abstract

The influence of geomagnetic storms on the atomic oxygen greenline (557.7 nm) dayglow emission in thermosphere is studied during solar active and solar quiet conditions. This study is primarily based on the photochemical model with inputs obtained from experimental observations and empirical models. The updated rate coefficients, quantum yields and related cross-sections have been used from experimental results and theoretical studies. This study is presented for a low latitude station Tirunelveli (8.7°N, 77.8°E), India. The volume emission rate (VER) has been calculated using densities and temperatures from the empirical models. The modeled VER shows a positive correlation with the Dst index. The VER also shows a negative correlation with the number densities of O, O_2, and N_2. The VER, calculated at peak emission altitude, exhibits depletion during the main phase of the storm. The altitude of peak emission rate is unaffected by the geomagnetic storm activity. The study also reveals that the peak emission altitude depends on the F10.7 solar index. The peak emission altitude moves upward as the value of F10.7 solar index increases.

Keywords: Airglow & aurora; Thermosphere: composition and chemistry; Solar radiation; Geomagnetic storms

1. Introduction

The interaction between solar wind and Earth's magnetosphere leads to the formation of geomagnetic storm (Gonzalez et al., 1994; Buonsanto, 1999; Daglis, 2001). The strength of the storm is determined by the Dst index. The geomagnetic storm deposits huge amount of energy and particles in Earth's atmosphere. It has adverse effects on the communication, space technology and also on human life (Buonsanto, 1999; Jansen and Pirjola, 2004; Balan et al., 2014). The ionosphere/thermosphere reacts abruptly to the high amount of energy input in a short duration. Consequently, the severity of storm depends on the rate of energy input and not on the total amount of energy deposited (Balan et al., 2013). The ionosphere/thermosphere reacts differently to a particular geomagnetic storm. This response of ionosphere/thermosphere to a geomagnetic storm depends on the electric field, thermospheric meridional wind surge, particle precipitation (Fuller-Rowell et al., 1994; Prolss, 1993; Buonsanto, 1999; Danilov, 2001), local time, season, and latitude (Vijaya Lekshmi et al., 2011; Mansilla and Zossi, 2012). Depending on the response of ionosphere/thermosphere, the storms are classified into positive storm and negative storm. The increase in the ionospheric electron density is referred as positive storm. Similarly, the decrease in the ionospheric electron density is called as negative storm. The positive storm is caused by electric field, mechanical effect of the equatorward neutral winds, and traveling atmospheric disturbances (Prolss and Jung, 1978; Fuller-Rowell et al., 1994; Forster et al., 1999; Fuller-Rowell et al., 2002; Kelley et al., 2004; Lin et al., 2005). Whereas, the negative

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storm is due to equatorward propagation of neutral wind during storm period (Rishbeth, 1991; Prolss, 1993; Fuller-Rowell et al., 1994).

The Joule heating and the particle heating in the polar region dictate the atmospheric variation in the low latitudes. This Joule heating and particle heating move the air along the pressure surface. It results in the enhancement of molecular density and depletion of atomic oxygen density (Crowley et al., 1989). This air, with enhanced N_2 and depleted atomic density, propagates to mid and low latitudes due to the equatorward meridional wind. It changes the circulation pattern of neutral wind in the low latitude.

In the low latitude sectors, the prompt penetration of electric field (PPEF) (Jaggi and Wolf, 1973) and disturbance dynamo (Blanc and Richmond, 1980; Fejer and Scherliess, 1995) play significant roles in the variation of structure, chemistry, composition, and dynamics of atmosphere. The PPEF depends on the solar wind, magnetospheric mechanisms and global variation of ionospheric conductance (Fejer and Scherliess, 1997; Fejer and Emmert, 2003; Kelley et al., 2004). Whereas, the disturbance dynamo electric field depends on the energy input on the polar region (Blanc and Richmond, 1980). The variation in the composition has significant influence on the airglow emissions (Deutsch and Hernandez, 2003; Mukherjee, 2006; Das and Sinha, 2008; Leonovich et al., 2011, 2012; Shepherd et al., 2013; Bag et al., 2014; Sakai et al., 2014). The airglow emission provides strong information about the composition, dynamics and chemical state of atmosphere. The atomic oxygen greenline airglow emission at 557.7 nm has been given particular attention over years due to the fact that it is one of the brightest emissions. The atomic oxygen greenline airglow emission peaks in the two regions of atmosphere, the upper mesosphere and lower thermosphere. The neutral and charged species vary dramatically during geomagnetic storm period. The variation in these densities would have clear signature in the volume emission rate (VER). The variation of volume emission rate (VER) of atomic oxygen greenline dayglow emission in upper mesosphere, under the influence of geomagnetic storm, has been reported by Bag et al. (2014). Here, we report the influence of geomagnetic storms on atomic oxygen greenline dayglow emission during solar active and solar quiet conditions in thermosphere. This study is primarily based on the photochemical model developed by Sunil Krishna and Singh (2009). The modeled results have been validated with the VER profiles measured by WINDII. This close agreement between modeled and WINDII measured VER suggests that this model can be used for any geographic conditions.

2. Model

The atomic oxygen greenline dayglow emission results due to the following transition.

$$O(^1S) \rightarrow O(^1D) + 557.7\ \text{nm} \tag{1}$$

It has two peaks, one in upper mesosphere and another in lower thermosphere. The sources for the production of O(^{1}S) in both regions are different. The reaction mechanisms populating O(^{1}S) in lower thermosphere are given below.

- Photoelectron impact on atomic oxygen.

$$O(^3P) + e_{ph} \rightarrow O(^1S) + e_{ph} \tag{2}$$

The production rate of O(^{1}S) due to photoelectron impact on atomic oxygen can be written as,

$$R_{PE}[O(^1S)] = [O]\int_{E_{th}}^{\infty} \Phi(E_s, z, \alpha)\sigma_{O(^1S)}(E_s)dE_s \tag{3}$$

where [O] is the atomic oxygen number density, $\Phi(E_s, z, \alpha)$ is the photoelectron flux as a function of photoelectron energy (E_s), altitude (z) and solar zenith angle (α), $\sigma_{O(^1S)}(E_s)$ is the photoelectron excitation cross section and E_{th} is the excitation threshold of O(^1S). The photoelectron fluxes are obtained from the model of Richards and Torr (1983) with the updates to the electron impact cross sections of O and O_2. The total O_2 excitation and ionization cross sections are used from Kanik et al. (1993). The photoelectron excitation cross sections have been used from Laher and Gilmore (1990).

- Dissociative recombination of O_2^+.

$$O_2^+ + e_{th} \xrightarrow{k_4} O(^1S) + O \tag{4}$$

The corresponding production rate of O(^1S) can be written as,

$$R_{DR}[O(^1S)] = \beta_4 k_4 [O_2^+][e] \tag{5}$$

Here, $[O_2^+]$ is the number density of O_2^+, $[e]$ is number density of electron, β_4 is the quantum yield (Bates, 1990) and k_4 is the reaction rate coefficient.

- Collisional deactivation of $N_2(A\Sigma_u^+)$ with atomic oxygen. $N_2(A\Sigma_u^+)$ is produced due to the photoelectron impact on N_2.

$$N_2 + e_{ph} \rightarrow N_2(A\Sigma_u^+) + e_{ph} \tag{6}$$

The production rate of $N_2(A\Sigma_u^+)$ due to the photoelectron impact on N_2 can be written as,

$$R[N_2(A\Sigma_u^+)] = [N_2]\int_{E_{th}}^{\infty} \Phi(E_s, z, \alpha)\sigma_{N_2A}(E_s)dE_s$$

where $[N_2]$ is the number density of molecular nitrogen, E_{th} is the excitation threshold of $N_2(A\Sigma_u^+)$ and $\sigma_{N_2A}(E_s)$ is the photoelectron impact excitation cross section of $N_2(A\Sigma_u^+)$. In the present study, the photoelectron impact excitation cross sections have been used from Trajmar et al. (1983).The loss processes of $N_2(A\Sigma_u^+)$ are given as,

$$N_2(A\Sigma_u^+) + O(^3P) \xrightarrow{k_7} N_2\left(X^1\Sigma_g^+\right) + O(^1S) \tag{7}$$

$$N_2(A\Sigma_u^+) + O_2 \xrightarrow{k_8} N_2(X^1\Sigma_s^+) + O_2 \tag{8}$$