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Short Communication

Solar flare impact on FUV based thermospheric O/N_2 estimation

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ABSTRACT

During/after intense solar flares, FUV based thermospheric O/N_2 ratio decreases and recovers instantly, indicating that the decrease is not physical. Simulations with an increased solar X-ray (0–10 nm) flux and a fixed O and N_2 profiles show a significant 135.6 nm/LBHS decrease that is sufficient to explain the O/N_2 decrease. The false O/N_2 decrease is mostly due to increased differences in O_2 absorption at 135.6 nm and LBHS caused by low-altitude emissions associated with enhanced X-rays. However, the heating from solar flares may cause a weak depletion in O/N_2.

1. Introduction

Solar flares are the sudden enhancements in solar radiation across a wide wavelength range, especially in the EUV and X-ray bands that impact the thermosphere and ionosphere significantly. A number of studies revealed that the thermospheric density, temperature and ionospheric density increases during solar flares (Sutton et al., 2006; Liu et al., 2007; Pawlowski and Ridley, 2008, 2011; Qian et al., 2011; Le et al., 2012; Zhu and Ridley, 2014). The two intense X17 flares on October 28 and November 4, 2003 attracted lots of attention. Using the CHAMP and GRACE neutral density measurements at altitude ~400 and 490 km, Sutton et al. (2006) found the thermospheric density increased by 50–60% at low and mid-latitudes associated with the October 28 flare. The enhanced density took about 12 h to return to pre-flare values. The flare on November 4, 2003 led to a density increase of ~35 to 45% with a similar recovery time. The density enhancements indicate an exosphere temperature increase of about 125–175 K and 100–125 K, respectively. The neutral density from the CHAMP satellite also showed a rapid (in a few minutes) response to the October 28, 2003 flare and a 20% increase almost homogeneously at all latitudes below 50°N/S (Liu et al., 2007). Using the Global Ionosphere and Thermosphere (GITM) model, Pawlowski and Ridley (2008) found that the modeled neutral density increased rapidly (up to ~15%) at 400 km within 2 h of the October 28 and November 4, 2003 flares. The GITM output also revealed the creation of gravity waves after the flares. Furthermore, GITM simulations show divergent horizontal wind around the sub-solar point and convergent wind on the nightside. Qian et al. (2011) did simulations for weaker flares (X6.2 and X5.4) and they found that the neutral density at CHAMP altitude was enhanced by ~15 to 20% and ~5%, respectively. A statistical analysis of the solar flares between 2001 and 2006 indicates that the neutral density at the CHAMP altitudes increased 10–13% on average for X5 and stronger flares (Le et al., 2012).

These earlier studies (and references therein) significantly advanced our understanding of the thermospheric response to solar flares. However, these studies focused on neutral density and temperature around the 400–500 km where in situ satellite measurements are available. What is the response of lower thermosphere (100–200 km)? TIMED/GUVI based O/N_2 shows significant decrease during intense solar flares. Is the O/N_2 decrease real? In this paper, we report the impact of solar flares in estimating the O/N_2 ratios.

2. TIMED/SEE solar flux data

The Solar EUV Experiment (SEE) instrument on the NASA TIMED satellite measures the solar spectral irradiances from 0.1 to 194 nm in 1 nm intervals (Woods et al., 2005). Fig. 1 shows the total flux in the wavelengths between 0 and 105 nm. The solar flux data are obtained from the NASA space physics database at http://cdaweb.gsfc.nasa.gov/. Most contribution to the total flux comes from irradiance between 0 and 7 nm. Three major flares are marked by black arrows with date and UT. There are two or more minor flares during the period. The Dst index is also plotted (red line) in Fig. 1. It is clear that the major flares occurred before a major geomagnetic storm, after recovery from the storm, and during a recovery from a minor geomagnetic storm, respectively. These intense flares provide an opportunity to examine the

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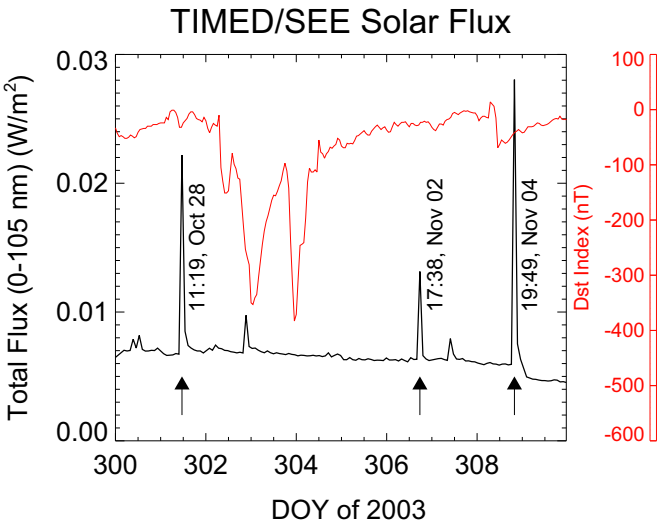

Fig. 1. Total flux (black line) of solar EUV and X-ray (0–105 nm) from TIMED/SEE between DOY 300 (October 27) and 309 (November 5), 2003. There are three major flares marked by black arrows. The red line is for Dst index. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

thermospheric O/N_2 response without contamination from the storm-time O/N_2 changes or depletions (Zhang et al., 2004).

3. TIMED/GUVI O/N_2 data

The Global Ultraviolet Imager (GUVI) on NASA TIMED satellite provides cross-track scanned images of the Earth's airglow and auroral emission in the far ultraviolet (FUV) at wavelengths ~110.0 to 185.0 nm (Paxton and Meng, 1999; Christensen et al., 2003; Paxton et al., 2004). Major emission features include HI (Lyman α, 121.6 nm), OI (130.4 nm), and OI (135.6 nm) lines; and N_2 LBHS (140.0–150.0 nm) and N_2 LBHL (165.0–180.0 nm) bands. The dayglow data in the 135.6 nm and LBHS bands (135.6 nm/LBHS intensity ratios) have been used to estimate the thermospheric O/N_2 column density ratios (Zhang et al., 2004). Fig. 2a, the GUVI O/N_2 map on October 28, 2003, shows typical geomagnetic quiet time O/N_2 distributions: relatively smooth O/N_2 and a south–north gradient due to the seasonal effect (low O/N_2 in summer hemisphere) and localized O/N_2 depletion in the northern high latitude and the southern region around Australia (due to a large shift of the southern geomagnetic pole from the southern geographic pole). However, there is a narrow longitude region in the Indian Ocean sector where the O/N_2 shows an anomaly: latitude independent depletion (marked by a red arrow). The O/N_2 over a wide latitude region (~ −50° to 50°) is significantly lower than the values over Asia or Africa sectors. Note that the O/N_2 map consists of GUVI data over 14 orbits for a given day at roughly a fixed local time (~16:00LT). This means that the O/N_2 pixels in the map have different UT. The UT and local time (LT) of the pixels with smallest solar zenith angle (SZA) for one of every two orbits are marked at the bottom of the O/N_2 map. The UT increases from right to left as Earth rotates under the TIMED orbit at a roughly fixed LT over a few days. The O/N_2 anomaly (depletion) was observed over a single orbit. The undisturbed O/N_2 in the Asia and Africa sectors was observed before and after the O/N_2 anomaly (roughly 3 h difference as TIMED orbit period is ~1.5 h). The O/N_2 anomaly occurred during geomagnetic quiet time. This is different from the geomagnetic storm-time O/N_2 depletion that extends form high to mid and low latitudes (Zhang et al., 2004, 2014). The storm-time O/N_2 depletion does not penetrate through the equatorial region

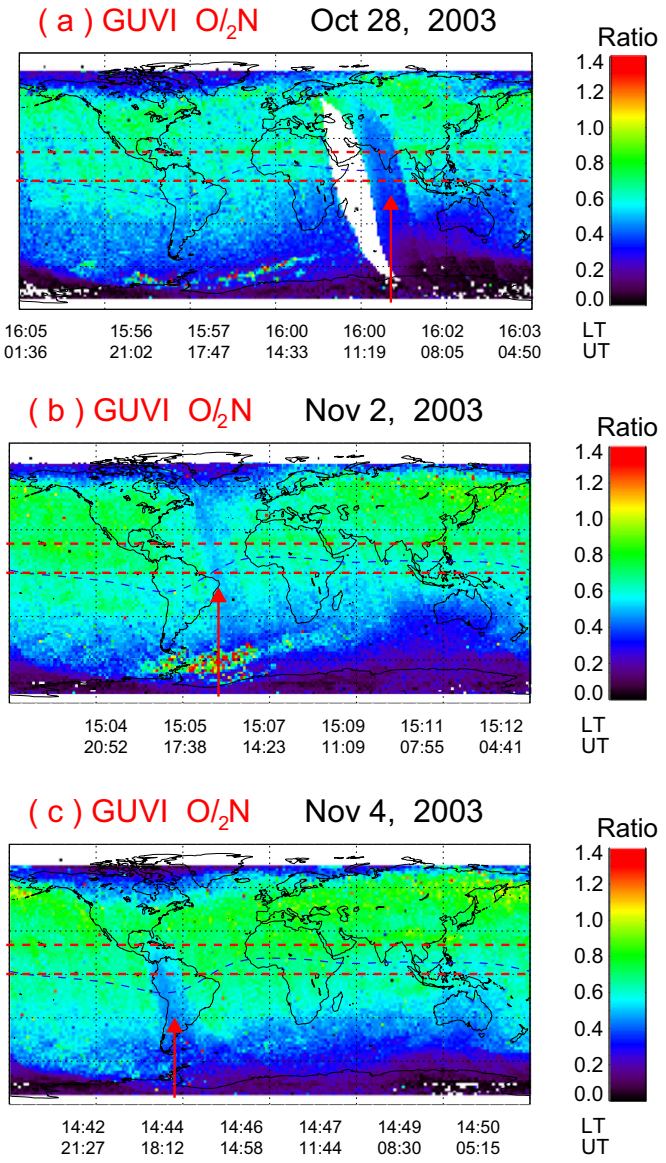

Fig. 2. TIMED/GUVI O/N_2 maps on October 28, November 2 and November 4, 2003. The red arrows indicate the time when the O/N_2 depletion anomalies were observed. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

with a depletion tunnel connecting O/N_2 depletion regions in both hemispheres. What causes this O/N_2 depletion anomaly under geomagnetic quiet conditions? Similar O/N_2 anomalies were also obtained on November 2 and 4, 2003 (see Fig. 2b,c as marked by red arrows).

The above three O/N_2 anomalies (Fig. 2) were associated with intense solar flares seen in Fig. 1. To examine the details, the GUVI O/N_2 values between latitudes 0° and 20° are averaged for each GUVI orbit to get mean O/N_2. Statistical deviations (or errors) from the means are calculated. The mean UT of the O/N_2 pixels is also obtained. Fig. 3a is similar to Fig. 1 but for a shorter period of time (DOY 300-303) with the mean O/N_2 and deviations/errors (blue color) plotted. The statistical errors are about 10% of the mean O/N_2 and represent the background uncertainties. The black arrow in Fig. 3a indicates the time (11:19 UT, October 28, 2003) when the flare peaked. Interestingly, the mean O/N_2 (blue diamond) shows a clear drop of ~27% (from ~0.60 to ~0.44). The 27% drop is bigger than the statistical error or background variation (~10%) so it is significant. The associated peak solar flux is 0.022 W/m^2.