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Feasibility of developing an ionospheric E-region electron density storm model using TIMED/SABER measurements

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Abstract

We present a new technique for improving ionospheric models of nighttime E-region electron densities under geomagnetic storm conditions using TIMED/SABER measurements of broadband 4.3 μm limb radiance. The response of E-region electron densities to geomagnetic activity is characterized by SABER-derived $NO^+(v)$ 4.3 μm Volume Emission Rates (VER). A storm-time E-region electron density correction factor is defined as the ratio of storm-enhanced $NO^+(v)$ VER to a quiet-time climatological average $NO^+(v)$ VER, which will be fit to a geomagnetic activity index in a future work. The purpose of this paper is to demonstrate the feasibility of our technique in two ways. One, we compare storm-to-quiet ratios of SABER-derived $NO^+(v)$ VER with storm-to-quiet ratios of electron densities measured by Incoherent Scatter Radar. Two, we demonstrate that $NO^+(v)$ VER can be parameterized by widely available geomagnetic activity indices. The storm-time correction derived from $NO^+(v)$ VER is applicable at high-latitudes.
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Keywords: Infrared remote sensing; Ionosphere; E-region; Magnetic storm; SABER

1. Introduction

The Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument is a multi-channel radiometer onboard the Thermosphere–Ionosphere–Mesosphere-Energetics and Dynamics (TIMED) satellite (Russell et al., 1999). TIMED was launched in December, 2001. Continuous SABER measurements began in January 2002. SABER scans the Earth's limb line-of-sight and radiance measurements are made by 10 broadband radiometer channels from 1.27 to 17 μm. Depending on the specific data product, geophysical parameters are derived at tangent altitudes ranging from the tropopause to over 180 km. Daytime and nighttime measurements are made over a latitude range that alternates hemispheres in a 60-day yaw period, extending in latitude from 83° in one hemisphere to 52° in the opposite hemisphere. After approximately 60 days, the TIMED satellite performs a yaw maneuver and the hemispheric coverage is reversed, as depicted in Fig. 1. Dashed lines in Fig. 1 indicate dates of the yaw maneuvers for the year 2003. Similar yaw dates are performed every year. The SABER quiet-time climatological averages discussed in Section 2 are multi-year (2002–2006), quasi-seasonal averages based on the SABER yaw cycles shown in Fig. 1. Hemispheric symmetry is also assumed in the data analysis.

Radiance measurements at 4.3 μm are significantly increased during geomagnetic disturbances, such as during the Halloween 2003 superstorm reported by Mertens et al. (2007a). These enhancements are due to vibrationally excited NO^+ emissions produced by precipitating auroral electrons that increase the ionization of the neutral atmosphere. At E-region altitudes, these ions react with neutral

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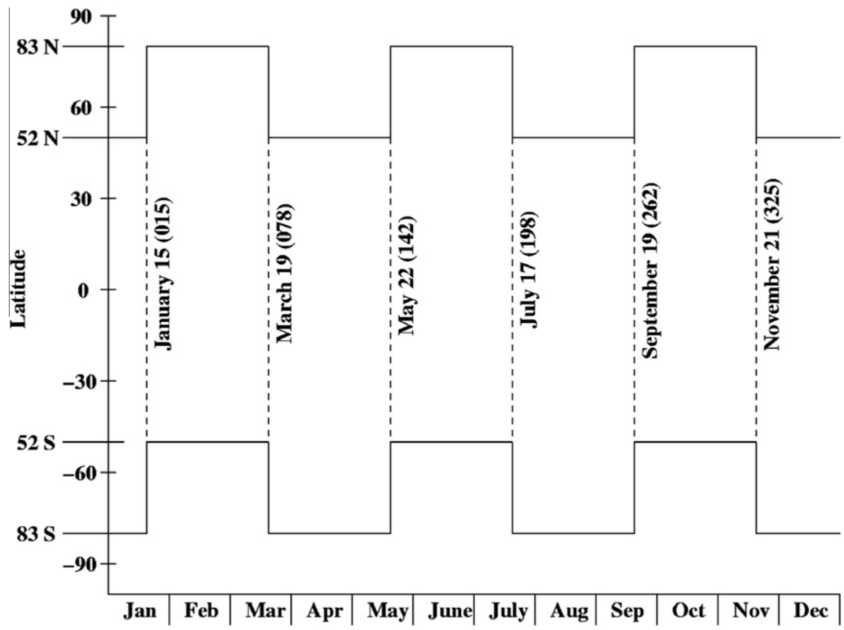

Fig. 1. TIMED/SABER latitude coverage during 2003. Dashed line indicates the yaw maneuvers.

species to produce NO^+ (Torr et al., 1990; Fox and Sung, 2001). Moreover, some of these reactions are exothermic enough to produce $NO^+(v)$, which emits at 4.3 μm. In order to isolate the $NO^+(v)$ emissions, a new $NO^+(v)$ Volume Emission Rate (VER) data product was produced by simulating the $CO_2(\nu_3)$ contribution and subtracting it from the measured radiance values using non-local thermodynamic equilibrium (non-LTE) algorithms, and performing a standard Abel inversion on the residual radiance. This procedure is applied to nighttime 4.3 μm measurements since $CO_2(\nu_3)$ contributions are dominant during daytime. The error in modeling the $CO_2(\nu_3)$ contribution is on the order of 20%. During modest geomagnetic storms, the $NO^+(v)$ emission contributes 60–80% of the 4.3 μm limb radiance measured by SABER. Thus, the SABER-derived storm-time $NO^+(v)$ VER modeling error is expected to be on the order of 4–8% for moderate geomagnetic storms with decreasing errors for stronger storms (Mertens et al., 2007a).

There are other sources of uncertainty associated with deriving the $NO^+(v)$ VER from a 1D Abel inversion. The uncertainties are due to affects of non-tangent layer emission and non-homogeneous, horizontal spatial structure in NO^+ along the limb line-of-sight. These influences are difficult to assess and can induce biases and non-physical vertical structure in the derived single-profile VER. However, it is reasonable to expect that these errors will be partially filtered out in developing the storm-time correction model by computing altitude averages (see Section 2) and by binning the $NO^+(v)$ VER in latitude bands and according to geomagnetic activity indices (Mertens et al., 2009b). The most reliable assessment of errors in the approach is to conduct numerous comparisons with independent measurements such as presented in Section 4 and by Mertens et al. (2009b).

Fig. 2 shows an example of both radiance and SABER-derived $NO^+(v)$ VER at 60N and 227E for two measurement scans: before (blue line) and during (red line) the Halloween 2003 magnetic storm. Note that at quiet times, radiances values reach the 4.3 μm channel detector noise limit, denoted by the Noise Equivalent Radiance (NER), at about 135 km. During the geomagnetically disturbed periods, the 4.3 μm limb radiance measurements do not reach the noise limit until above 180 km. Storm-enhanced radiances are increased by several orders of magnitude compared to quiescent values. VER values are also enhanced as shown in the right panel.

$NO^+(v)$ VER enhancements can be used as a proxy to characterize the electron density during geomagnetic storms at high-latitudes since the $NO^+(v)$ VER enhancements are mainly due to auroral particle precipitation (Mertens et al., 2007a,b). The global $NO^+(v)$ VER distribution, near the altitude of the E-region electron density peak, correlates very well with patterns of auroral particle precipitation measured by the NOAA/POES satellites (Mertens et al., 2009a, 2007b). This led to the idea of using a storm-to-quiet time ratio (SQR) to generate a correction factor for the International Reference Ionosphere (IRI) model. The IRI model is an empirical model widely used in the ionospheric community to obtain climatological mean values for the electron density, electron and ion temperatures, among other parameters (Bilitza, 2001). However, parameterizations in IRI for geomagnetic storm activity remain largely incomplete, and there is currently no storm-time correction to IRI parameters in the E-region. In this work, we demonstrate the feasibility of using the SABER $NO^+(v)$ VER SQR to develop a storm-time E-region electron density correction factor by comparing with Incoherent Scatter Radar (ISR) measurements for several geomagnetic storm events.