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ScienceDirect
Advances in Space Research 43 (2009) 1325–1336
ADVANCES IN SPACE RESEARCH (a COSPAR publication)
www.elsevier.com/locate/asr

Influence of solar-geomagnetic disturbances on SABER measurements of 4.3 μm emission and the retrieval of kinetic temperature and carbon dioxide

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Received 17 July 2008; received in revised form 21 October 2008; accepted 24 October 2008

Abstract

Thermospheric infrared radiance at 4.3 μm is susceptible to the influence of solar-geomagnetic disturbances. Ionization processes followed by ion-neutral chemical reactions lead to vibrationally excited NO^+ (i.e., $NO^+(v)$) and subsequent 4.3 μm emission in the ionospheric E-region. Large enhancements of nighttime 4.3 μm emission were observed by the TIMED/SABER instrument during the April 2002 and October–November 2003 solar storms. Global measurements of infrared 4.3 μm emission provide an excellent proxy to observe the nighttime E-region response to auroral dosing and to conduct a detailed study of E-region ion-neutral chemistry and energy transfer mechanisms. Furthermore, we find that photoionization processes followed by ion-neutral reactions during quiescent, daytime conditions increase the NO^+ concentration enough to introduce biases in the TIMED/SABER operational processing of kinetic temperature and CO_2 data, with the largest effect at summer solstice. In this paper, we discuss solar storm enhancements of 4.3 μm emission observed from SABER and assess the impact of $NO^+(v)$ 4.3 μm emission on quiescent, daytime retrievals of Tk/CO_2 from the SABER instrument.
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Keywords: SABER; Temperature; Carbon Dioxide (CO_2); Infrared remote sensing; Non-LTE; Radiation Transfer; Ionosphere E-Region; Magnetic Storms; E-Region Ion-Neutral Chemistry

1. Introduction

The Thermosphere–Ionosphere–Mesosphere Energetics and Dynamics (TIMED) satellite was launched in December 2001. The primary objective of TIMED is to investigate and understand the energetics of the mesosphere, lower thermosphere and ionosphere (MLTI) region. Precipitating

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0273-1177/$36.00 Published by Elsevier Ltd. on behalf of COSPAR.
doi:10.1016/j.asr.2008.10.029

energetic particles induced by solar-geomagnetic disturbances rapidly and dramatically changes the chemistry and thermal energy balance of the MLTI region. Several major solar eruptive events have occurred during TIMED mission operations. The two events considered in this paper are the April 2002 and the Halloween (October–November) 2003 solar storms. TIMED provides a suite of observations uniquely suited for investigating the response of the MLTI region to solar-geomagnetic disturbances. For example, data from the TIMED Global Ultraviolet Imager (GUVI) instrument have been used to analyze the total energy flux and characteristic energy of auroral electrons during the April 2002 storm (Christensen et al., 2003) and to investigate the causal mechanisms responsible for nighttime detached auroras during the Halloween 2003 storm (Zhang et al., 2005).

The Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument is an infrared limb sounder on the TIMED satellite (Russell et al., 1999). SABER provides global measurements of broadband infrared limb emission, which are analyzed to derive vertical profiles of kinetic temperature and key chemical species needed to quantify the radiative and chemical energy balance of the MLTI region. Large enhancements of thermospheric infrared emission were observed by several of the SABER radiometer channels during the April 2002 and Halloween 2003 solar storm events. Radiance enhancements observed in the 5.3 μm channel are due to emission from the vibration–rotation bands of nitric oxide (NO). The NO 5.3 μm emission is indicative of the conversion of solar energy to infrared radiation and represents a “natural thermostat” by which heat and energy are efficiently lost from the thermosphere to space and to the lower atmosphere. SABER 5.3 μm emission observations during the April 2002 storm and their subsequent interpretation in terms of energy loss were reported by Mlynczak et al. (2003, 2005).

Another thermospheric infrared spectral region subject to solar-geomagnetic influences is the 4.3 μm region, due to the vibration–rotation bands of NO^+ (Picard et al., 1987; Espy et al., 1988). During solar-geomagnetic storms, electron precipitation increases the ionization of the neutral atmosphere producing primarily N_2^+, O_2^+, O^+ and N^+ (e.g., Banks et al., 1974; Strickland et al., 1976). In the ionospheric E-region, these ions react with neutral species to produce NO^+ (Torr et al., 1990; Fox and Sung, 2001). Some of the ion-neutral reactions are exothermic enough to produce vibrationally excited NO^+, i.e., NO^+(v) (Winick et al., 1987). The exothermic reactions are relatively fast. Above ~110 km quenching of NO^+(v) becomes less important and prompt emission of NO^+(v) at 4.3 μm is a direct indication of auroral dosing in the E-region. The NO^+(v) fundamental band (2344 cm^{-1}) is nearly coincident with the strong major isotopic $CO_2(\nu_3)$ band at 2349 cm^{-1}. Infrared emission at 4.3 μm during strong nighttime aurora can be enhanced by several orders of magnitude by NO^+(v) compared to the background $CO_2(\nu_3)$ radiative emission. The E-region is largely inaccessible to in situ observations and the SABER 4.3 μm measurements provide an excellent dataset to investigate the E-region response to solar-geomagnetic storms.

Infrared NO^+(v) emission has important implications for the operational processing of SABER routine data products at high-latitudes near summer solstice, even for quiescent conditions. During daytime, kinetic temperature (Tk) and carbon dioxide (CO_2) volume mixing ratio (vmr) are simultaneously retrieved in version 1.06 data processing from SABER measurements of 15 μm and 4.3 μm limb emission, respectively (Mertens et al., 2002). Nighttime Tk is retrieved from 15 μm measurements using CO_2 data from the TIME-GCM climatology (Mertens et al., 2001, 2004). Solar EUV photons ionize the neutral atmosphere during the daytime, eventually leading to NO^+(v) and emission at 4.3 μm through the exothermic ion-neutral reactions mentioned above. These processes are not included in the SABER operational Tk/CO_2 retrieval algorithm. Quiescent daytime thermospheric NO^+(v) 4.3 μm emission is a small percentage of the background $CO_2(\nu_3)$ emission. However, 4.3 μm radiation transfer is strongly non-linear along the limb line-of-sight at mesospheric tangent heights, with non-negligible contributions coming from the lower thermosphere. Consequently, weak atmospheric emission from NO^+(v) not accounted for in the Tk/CO_2 retrieval algorithm can have a rather significant effect on retrieved CO_2 throughout the MLTI region, which subsequently introduces a bias in retrieved Tk. Most of the SABER data products require temperature as input into their respective retrieval algorithms. Thus, a bias in Tk introduces biases in nearly all of the SABER data products. We have evidence, from a combination the SABER CO_2 data and model simulations, that strongly suggests that quiescent 4.3 μm emission by NO^+(v) is introducing errors in retrieved Tk/CO_2 at high latitudes, with the largest effect at summer solstice.

The focus of this paper is on NO^+(v) 4.3 μm emission during both quiescent and geomagnetically disturbed conditions. We present SABER observations of nighttime auroral enhancements of 4.3 μm emission during the April 2002 and Halloween 2003 storms. We conduct a preliminary assessment of the impact of quiescent daytime NO^+(v) 4.3 μm emission on high-latitude SABER Tk/CO_2 retrievals.

2. Solar storm enhancements of 4.3 μm emission

Nighttime enhancements of 4.3 μm emission can be several orders of magnitude during strong aurora. Fig. 1 shows representative radiance profiles measured by the SABER (channel 7) 4.3 μm radiometer channel during the April 2002 and Halloween 2003 solar storms. The vertical, dashed line in the figure is the channel 7 noise equivalent radiance (NER), which is 7.35×10^{-7} W/m^2/sr. Prior to the onset of the storm periods, the radiance decreases with increasing altitude reaching the detector noise level