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A superposed epoch study of the effects of solar wind stream interface events on the upper mesospheric and lower thermospheric temperature

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Abstract

The response of mesosphere and lower thermosphere (MLT) temperature to energetic particle precipitation over the Earth's polar regions is not uniform due to complex phenomena within the MLT environment. Nevertheless, the modification of MLT temperatures may require an event-based study to be better observed. This work examines the influence of precipitation, triggered by solar wind stream interfaces (SI) event from 2002 to 2007, on polar MLT temperature. We first test the relationship between the ionospheric absorption measured by the SANAE IV (South African National Antarctic Expedition IV) riometer and the layer of energetic particle precipitation from POES (Polar Orbiting Environmental Satellites). The combined particle measurements from POES 15, 16, 17 and 18 were obtained close in time to the pass of the SABER (Sounding of the Atmosphere using Broadband Emission Radiometry) temperature retrieval. Here, a superposed epoch technique is described and implemented to obtain average temperature profiles during SI-triggered particle precipitation. The superposed epoch average shows no significant temperature decrease below 100 km prior to the onset of SI-triggered precipitation, whereas a clear superposed average temperature decrease is observed at 95 km after the SI impact. A case study of SI event also yields similar observations. Results indicate that cooling effects due to the production of mesospheric odd hydrogen might be major contributors to temperature decrease under compressed solar wind stream.

Keywords: Solar wind stream interface region; Polar MLT temperature; Magnetospheric convection; Superposed epoch analysis

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1. Introduction

The MLT (mesosphere (50–100 km) and lower thermosphere (100–180 km)) regions are not fully understood when considering the dynamics of the Earth's upper atmosphere. The complication in understanding the energy and thermal balance ranges from a great number of parameters determining the heating processes to those cooling it (Offermann, 1985). Plasma flow from the sun, energetic particle precipitation, heat conduction, neutral winds, gravity waves breaking and infrared cooling are among the important parameters. These parameters play significant roles in the heating and cooling processes depending on the effective geophysical conditions (Roble, 1995). The level of geophysical activities generally increases during magnetospheric storms. The magnetospheric storms can be fueled by the solar wind streams and consequently drive particles into the Earth's upper atmosphere; this function defines the term geomagnetic storms. During geomagnetic storms, the atmosphere experiences influx of precipitating energetic particles (Rees, 1989). The rate of precipitation

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also depends on the solar wind stream structure that triggers the geomagnetic storm. For instance, the bimodal structure of the solar wind streams provides the mechanism for the stream interface (SI) occurrence (Burlaga, 1974).

The slow-speed solar wind streams (SSWS) from the vicinity of streamer belt are constantly at the leading edge of the trailing high-speed solar wind streams (HSSWS) which originate from coronal holes. Due to the Earth's magnetic field, however, both streams cannot mingle. The region that separates these dense, slow-moving plasma from fast, less dense plasma is the SI (Burlaga, 1974; Gosling et al., 1978). SI is a type of storm-driven event (Friedel et al., 2002; Dal Lago et al., 2002) and can trigger precipitation, which might cause significant compositional changes if it interacts with the upper atmospheric constituents. Intuitively, particle precipitation is anticipated to enhance upper atmospheric temperature. Nonetheless, some previous works (for example, Banks, 1977; Offermann, 1985; Jackman et al., 2007; von Savigny et al., 2007; Pancheva et al., 2007) have shown a potential heating effect, an apparent cooling effect or no measurable temperature response to precipitating particles. The apparent inconsistency is probably due to some differences in the solar wind–magnetosphere coupling processes. Here, we focused on just the SI-triggered precipitation effects on the MLT temperature within the period of 2002–2007, the details of which will be presented in Section 2. It should be noted that SI is associated with the corotating interaction region (CIR) and thus recurs (Heber et al., 1999; Borovsky and Denton, 2008, 2009; Morley et al., 2010b). Due to this recurrence nature, according to Borovsky and Denton (2009), SI is amenable to superposed epoch analysis (SEA).

In this study, we have performed SEA on the selected 27 SI-driven storms that occurred from 2002 to 2007. We have investigated the ultimate implications of these events by studying the associated geophysical properties, solar wind conditions and absorption of the precipitating particle. We also examined the MLT temperature changes in response to (or caused by) SI-triggered precipitation over SANAE IV (71.7°S, 2.9°W, $L = 4.32$). Finally, we validated our technique with temperature measurement above 100 km and also with a nightside SI event that occurred on 7 May 2007.

2. Data description and event selection

2.1. TIMED/SABER data

The TIMED (Thermosphere Ionosphere Mesosphere Energetic and Dynamics) satellite was launched on 7 December 2001 into a 625-km circular orbit, with 74.1° inclination. The satellite's orbit period is 102 min. The SABER (Sounding of the Atmosphere using Broadband Emission Radiometry), which is one of the four instruments on-board the TIMED satellite, measures the CO_2 15-μm limb emission, which is useful for estimating the neutral temperatures up to approximately 130 km. In order to maintain the instrument at a certain temperature, SABER obtains temperature profiles from 83°S to 52°N during its south-looking mode for 60 days and then switches to an analogous north-looking mode. Here, we obtain the temperature measurements during SABER's south-looking mode.

TIMED/SABER has been found to be useful and contributes to the validation of assimilative atmospheric models such as the International Reference Ionosphere (IRI, Bilitza et al., 2014). An empirical model of neutral (CIRA-86) temperature published on the IRI-2007 website http://omniweb.gsfc.nasa.gov/vitmo/iri_vitmo.html is employed in this study.

2.2. NOAA/POES data

The NOAA/POES (National Oceanic and Atmospheric Administration/Polar Orbiting Environmental Satellites) is a polar-orbiting, Sun-synchronous, low-altitude (850 km) satellite with a period of approximately 100 min. The satellite has on-board the Medium Energy Proton and Electron Detector (MEPED) and Total Energy Detector (TED), which monitor the intensities of precipitating energetic particles (Rodger et al., 2010). These detectors have up to 30° field of view. POES (15–18) orbit the Earth in such a way that they pass over the poles within the period under study. The MEPED on each satellite provides directional (0° telescopes for precipitating and 90° for trapped) measurements of protons and energetic electrons. At high latitudes, the vertical detector measures the particles in the drift loss cone. During geomagnetic disturbances, trapped energetic particles can enter drift shells located above the upper ionosphere via a loss mechanism. Since the vertical detectors look approximately along the field line, it will only detect precipitating particles.

In this study, data from 0° telescope were selected only when it measures protons and electrons within the loss cone. With POES satellites, our statistical work is organised across all local time such that at any given time, one of the POES satellites provides measurements.

2.3. Riometer data

Remote sensing of electromagnetic waves of cosmic origin is a technique useful in studying the state and the structure of the ionosphere (Hargreaves, 1979). Riometers respond to both the integrated absorption of cosmic ray noise through the ionosphere and electron density at heights where there is a high collision (see, Clilverd et al., 2010). The riometers are mostly widebeam, typically 30 MHz, and sensitive to any incident particle population capable of reaching the altitude range of 70–100 km. In order to identify extraordinary ionospheric absorption from remote measurements, a reference Quiet Day Curve (QDC) value is an important parameter to be considered (Ogunjobi et al., 2014). Any deviations from this expected