Journal of Atmospheric and Solar–Terrestrial Physics 149 (2016) 59–68

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar–Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

Preliminary observations and simulation of nocturnal variations of airglow temperature and emission rates at Pune (18.5°N), India

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ARTICLE INFO

Keywords:
Spectral airglow
Mesosphere
Temperature
Whole Atmosphere Community Climate Model (WACCM)

ABSTRACT

Preliminary observations of the nocturnal variations of the OH(6-2) and O2b(0-1) nighttime airglow in the mesosphere and lower thermosphere are investigated in the context of tidal influence for the tropical latitude station Pune (18.5°N, 73.85°E). This is the only tropical Spectral Airglow Temperature Imager (SATI) station where the tidal variations of mesosphere and lower thermosphere (MLT) temperature have been determined from ground based SATI observations. The SATI observations obtained since October 2012 reveal the influence of the migrating semidiurnal tides during solstice at this tropical station. There is variability in amplitude and phase obtained from SATI observations. In this paper, SATI observations on 10 Dec 2012 and 3 March 2013 are compared with Whole Atmosphere Community Climate Model (WACCM) simulations. The amplitude of semidiurnal tides is ~25 K/30 K on 10 Dec 2012 during solstice for OH/O_2 temperature. During equinox SATI data indicates existence of semidiurnal tide also. The airglow observations are compared with simulations from the WACCM. The model underestimates the amplitude of the semi diurnal tide during equinox (1.6 K/2.7 K at 87 km/96 km) and solstice (~3.8 K/4.8 K at 87 km/96 km) for these days. The reason may be related to dampening of tides in the model due to the effect of strong latitudinal shear in zonal wind. The diurnal variation of airglow emission – which the model simulates well – is related to the vertical advection associated with the tides and downward mixing of atomic oxygen.

1. Introduction

It has been known for the last few decades that the most prominent motions in the mesosphere and lower thermosphere (MLT) are atmospheric tides which dominate the meridional wind field at low latitudes (Hays et al., 1994; Lieberman et al., 2007). The variability in the diurnal tide in the mesosphere and lower thermosphere is discussed by Hagan et al. (1997). A brief description of tides is given below.

Atmospheric tides are an integral part of the general circulation and play an important role in coupling between the lower and upper atmosphere (e.g. Hagan, 2000; Zeng et al., 2008). Tides that propagate into the MLT affect the large-scale dynamics, chemistry, and energetics of this region. They may transport momentum and energy upward from the source regions (the troposphere and stratosphere), modulate the fluxes of gravity waves (Manson et al., 1998), and dissipate in the MLT region (e.g. Forbes et al., 1993; Miyahara et al., 1993).

Tides also play a major role in the diurnal cycle of chemical species and transport in the MLT region (Ward et al., 1999; Marsh and Russell, 2000; Zhang et al., 2001) and therefore influence chemical heating/cooling (Smith et al., 2003). Airglow observations also show strong seasonal variation in the amplitude of diurnal and semidiurnal tides (López-González et al., 2005). The tidal variability is so dominant that the seasonal cycle in the nighttime emission depends very strongly on the local time of the analysis (Marsh et al., 2013).

Ground-based measurements have helped to delineate the characteristic tidal motions of the middle atmospheric temperature and winds (e.g. Shepherd et al., 1998; Zhou et al., 2000; Akmaev, 2001; Yuan et al., 2008a, 2008b; Gurubaran et al., 2009; Jaya Prakash Raju et al., 2010; Hibbins et al., 2011). Studies pertaining to tropical regions are based on satellite observations (McLandress et al., 1996; McLandress, 2002; Lieberman et al., 2007; Zeng et al., 2008; Liu et al., 2008), radar/lidar observations (Manson et al., 2003; Gurubaran et al., 2005, 2009; Pant et al., 2004, 2007) and airglow rotational temperatures (e.g. Taori et al., 2005, 2007, 2010, 2012; Taori and

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http://dx.doi.org/10.1016/j.jastp.2016.10.002
Received 4 January 2016; Received in revised form 30 September 2016; Accepted 3 October 2016

Taylor, 2006; Guharay et al., 2009; Ghodpage et al., 2015; Kishore Kumar et al., 2008, 2014).

The main advantage of ground-based observations at a specific geographical location is that they provide continuous long-term measurements at very high temporal resolution and at all local times on a given night, but optical measurements such as lidar or airglow provide data only during nighttime hours, insufficient to separate the diurnal and semidiurnal tides. In contrast, satellite measurements can provide a near-global picture over 24 h of local time, but their measurements at a given latitude on a single day are for just two local times, one for the daytime side of the orbit and one for the night time; which changes from day to day.

Tidal influences on the diurnal emission rate of $O(^1S)$ were the first strong indication that dynamics are responsible for variations in the emission rate (Shepherd et al., 1995, 2012). Details of their diurnal and seasonal variation are still under investigation (McLandress, 2002; López-González et al., 2004, 2007; Liu et al., 2008). These observations also exhibit a strong diurnal tide at the equator. The meridional and zonal wind components attain their maximum values at equinox, while the solstitial minima are smaller by nearly a factor of 2 around 20°N and 20°S. Vertical advection of atomic oxygen associated with the tides has been proposed to be the primary mechanism for the diurnal variation of the $O(^1S)$ airglow at the equator (Angelats i Coll and Forbes, 1998; Ward, 1999) but confirmation with a ground-based instrument in the tropics has so far been lacking. Atomic oxygen plays an important role in the production of the OH and O_2 bands (McDade, and Llewellyn, 1986). TIME-GCM simulations also suggest that the advection of the mean circulation is responsible for the transport of atomic oxygen (Liu and Roble, 2004).

Temperature variations in the migrating tides have been less well studied. Mukhtarov et al. (2009) employed satellite data provided by the Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument on the Thermosphere Ionosphere Mesosphere Energetics and Dynamics (TIMED) satellite to present the global characteristics of the diurnal migrating tide. This study showed strong diurnal tides from 15°S to 15°N latitude, showing a seasonal cycle with maxima at equinoxes. Somewhat weaker amplitudes, with a semiannual variation, were observed poleward of about 25° in latitude. In between the equatorial and mid-latitudes there was a narrow “slot” in which the diurnal temperature amplitudes are very small.

The Spectral Airglow Temperature Imager (SATI), described by Sargoytchev et al. (2004) is able to determine the airglow emission rate and rotational temperatures from the OH Meinel (6,2) and O_2 Atm (0,1) bands. The performance at a higher latitude station has been well demonstrated by López-González et al. (2005, 2007). In this paper, preliminary observations of airglow measurements at the tropical station Pune (18.5°N, 73.8°E) from ground-based SATI observations are reported for the first time. The new Pune results are compared against simulations from a 3D Chemistry Climate Model (CCM), the Whole Atmosphere Community Climate Model (WACCM) (Chang et al., 2012; Feng et al., 2015). There are only a few ground-based studies of the variation of airglow intensity over the Indian region (Gogawale and Tillu, 1983; Ranade et al., 1988; Ghodpage et al., 2012), and they did not report temperature measurements.

The paper is structured as follows: section two describes the airglow measurements and WACCM model run. Section three gives details of the observed diurnal variations of temperature and emission rates during equinox and solstice. The influence of diurnal tides as observed in airglow temperature and emission rate, and WACCM results on the MLT temperature, are presented in Section 3. Model and observed tidal characteristics are given in Section 4. Key results including the correlation between airglow temperature and emission rates as well as vertical advection associated with tides and downward mixing of atomic oxygen are discussed in Section 5 and conclusion are made in Section 6.

2. Airglow data and WACCM experimental setup

2.1. The Spectral Airglow Temperature Imager (SATI)

The Spectral Airglow Temperature Imager (SATI) is a spatial and spectral scanning Fabry-Perot spectrometer, comprising a conical mirror, Fresnel lens, a CCD detector and narrow-band interference filters centered at (1) 867.6 nm (O_2 atmospheric (0-1) band) and (2) 836.8 mn (OH Meinel (6-2) band) (López-González et al., 2004). Its field of view is an annulus of 30° average radius and 7.1° angular width centered on the zenith. It measures the column emission rate for several rotational lines and the rotational temperature is inferred from their ratios (Sargoytchev et al. 2004). The images obtained correspond to a ring of observation on the sky observed. The radial distribution of the image provides information on the spectral distribution while the azimuthal sectors correspond to different azimuths on the sky. In this study the images are analyzed as a whole (obtained from whole sky ring) to obtain an average of the rotational temperature and emission rate of the airglow. The exposure time is 120 s and time resolution is 4 min for the OH and O_2 airglow layers. The instrument error for both the OH and O_2 relative temperature is ~1.7 K, and ~2% for emission rates. Further details of the SATI instrument and image reduction method are documented by López-González al. (2005) and Sargoytchev et al. (2004). The SATI was built by CRESS (the Centre for Research in Earth and Space Science at York University, Toronto). The SATI Airglow observations at Pune used in this study is for 14 individual nights during the period October 2012–December 2014, eight nights of data for equinox conditions and six nights of data for solstice conditions.

In this paper, the influence of the sun-synchronous and migrating diurnal tides at the tropical station Pune (18.5°N, 73.8°E) from ground-based SATI observed temperature and OH and O_2 airglow intensity, are reported for the first time. The results are compared against simulations from a 3D Chemistry Climate Model (CCM), the Whole Atmosphere Community Climate Model (WACCM) (details are given in the next Section 2.2). The model simulations are used to study the dynamical changes in temperature, airglow intensity, and the atomic oxygen flux. Western Ghats around Pune is a gateway for monsoon convection. This hilly region may be a source of strong gravity/mountain waves and may impact mesospheric waves. In the past, the High Resolution Dynamics Limb Sounder (HIRDLS) on the Aura satellite which measured temperature profiles of the atmosphere, has shown propagation of mountain waves into the mesosphere (Joan, 2008). Due to the lack of a longer time series, this study is focused on the equinox and solstice periods.

2.2. Whole Atmosphere Community Climate model (WACCM) experimental setup

We employ WACCM (version 4) (Marsh et al., 2013), a “high-top” coupled chemistry-climate model with an upper boundary at 6.0×10^{-6} hPa (~140 km) to understand dynamical processes in the mesosphere and lower thermosphere (MLT) region. WACCM reproduces diurnal and semidiurnal tide in the MLT (Chang et al., 2012, Feng et al., 2015). We have used the specified dynamics version nudged (forced) with the Goddard Earth Observing System 5 (GEOS-5) meteorological data set (Feng et al., 2013; Plane et al., 2014). A nudging coefficient value (0.01) was used when assimilating the GEOS-5 analysis into WACCM, so that 1% of the meteorological conditions were combined with WACCM fields below 60 km at every model dynamics time step. Above 60 km the model was free running with a horizontal resolution of 1.9° ×2.5° and ~3.5 km vertical resolution in the MLT. The Prandtl number is set to 4. We sampled the model output every 30 min from January 2012 until the end of December 2013.

The OH and O_2 volume emission rates were estimated by integrating the product of $k_{H+O3}[H][O_3]$, and $k_{O+O}[O]^2[M]$ (Chamberlain,