Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research xxx (2018) xxx–xxx

ELSEVIER

Advances in Space Research
(a COSPAR publication)
www.elsevier.com/locate/asr

Study of wave signatures observed in thermospheric airglow imaging over the dip equatorial region

Sukanta Sau [a], V. Lakshmi Narayanan [b], S. Gurubaran [c,*], K. Emperumal [a]

[a] *Equatorial Geophysical Research Laboratory, Indian Institute of Geomagnetism, Tirunelveli 627011, India*
[b] *National Atmospheric Research Laboratory, Gadanki 517112, India*
[c] *Indian Institute of Geomagnetism, Navi Mumbai 410218, India*

Received 14 December 2017; received in revised form 25 June 2018; accepted 26 June 2018

Abstract

The observational data on OI 630 nm thermospheric nightglow from the Indian dip equatorial station, Tirunelveli (8.7°N, 77.8°E geographic, 1.6°N dip latitude) obtained between January 2013 and January 2015 using an All-Sky Airglow Imager (ASAI) are utilized in this work to examine the presence of gravity waves in the thermosphere. Two types of wave signatures were observed: (1) quasi-periodic waves consisting of alternating crests and troughs and (2) single bands of enhanced intensity (SBEI). The phase speed, wavelength and time period of the quasi-periodic waves were in the range of 70–160 m/s, 130–575 km and 25–75 min, respectively, while the phase speed and scale size of the SBEI features were found to be in the range of 150–250 m/s and 230–470 km, respectively. During equinoxes, quasi-periodic waves propagated towards north-northwest direction, while during winter they were observed to propagate towards northwest, south-southwest and southeast directions.

Keywords: MSTID; Thermospheric airglow; Thermospheric gravity waves; Low latitude ionosphere

---

1. Introduction

Travelling Ionospheric Disturbances (TIDs) are perturbations in the ionosphere that propagate over considerable horizontal distances and are typically observed at high to mid- and low-latitudes. TIDs have been investigated by the scientific community since late 1940s with the help of radio and optical instruments (e.g. Heisler, 1958; Hunsucker, 1982; Mendillo et al., 1997). TIDs are generally categorized into two types, namely, Large-Scale Travelling Ionospheric Disturbances (LSTIDs) and Medium-Scale Travelling Ionospheric Disturbances (MSTIDs).

LSTIDs are considered as signatures of large-scale gravity waves (GWs) in the ionosphere. These GWs often originate near auroral and subauroral regions during geomagnetic storms or substorms. The Joule heating, the Lorentz forcing and the collisional heating due to particle precipitation in the auroral electrojet region excite these GWs (Hunsucker, 1982; Hocke and Schlegel, 1996). The occurrence rate of the LSTIDs has been observed to be highly correlated with magnetic activity at high latitudes (Hajkowicz, 1991). The typical wavelength, time period and phase speed of LSTIDs were reported to be >1000 km, 30 min–3 h and 300–1000 m/s, respectively (Shiokawa et al., 2002; Ding et al., 2008; Idrus et al., 2013). LSTIDs usually propagate equatorward from high latitude regions, though poleward propagating LSTIDs have also been reported in the literature (Ding et al., 2013). While propagating equatorward, LSTIDs experience dissipative forces such as ion drag, molecular viscosity and thermal diffusivity. Relatively smaller scale LSTIDs

---

* Corresponding author.
E-mail address: gurubara@iigs.iigm.res.in (S. Gurubaran).

https://doi.org/10.1016/j.asr.2018.06.039
0273-1177/

Please cite this article in press as: Sau, S., et al. Study of wave signatures observed in thermospheric airglow imaging over the dip equatorial region. Adv. Space Res. (2018), https://doi.org/10.1016/j.asr.2018.06.039

thus get damped more effectively. On the other hand, larger scale and high speed LSTIDs prevail and are generally observed in the low latitude regions (Mayr et al., 1990; Ding et al., 2008). Another potential candidate for the excitation of LSTIDs in the ionosphere is the gravity waves generated by strong convective activity in the troposphere (Vadas and Crowley, 2010; Zhou et al., 2012).

MSTIDs that are commonly observed in the OI 630 nm all-sky images at mid-latitudes manifest as band structures elongated from northwest to southeast in the Northern Hemisphere (southwest to northeast in the Southern Hemisphere). They tend to propagate towards the southwest (northwest) in the Northern Hemisphere (Southern Hemisphere). These MSTIDs are identified to be of electrified type generated by Perkins instability (Perkins, 1973; Behnke, 1979; Otsuka et al., 2004; Narayanan et al., 2014a and references therein). The typical horizontal wavelength, time period and phase speed of these electrified MSTIDs are reported to be in the range of 50–500 km, 30–90 min and 50–170 m/s, respectively (Shiokawa et al., 2003). Another type of MSTIDs was reported from the Indonesian sector with their phase front aligned in the east-west direction. These MSTIDs propagated predominantly towards the south. The horizontal wavelength, time period and phase speed of these MSTIDs were estimated to be 790 ± 440 km, 42 ± 11 min and 320 ± 170 m/s, respectively (Shiokawa et al., 2006; Fukushima et al., 2012). Shiokawa et al. (2006) suggested that primary GWs generated in tropospheric deep convective regions or secondary GWs excited by the dissipation of primary GWs in the lower thermosphere can act as a source mechanism for these latter types of MSTIDs.

Signatures of GWs have been observed at ionospheric altitudes since decades through radio probing techniques (Röttger, 1977; Hocke and Tsuda, 2001; Vadas and Crowley, 2010). Several different sources are known to generate GWs in the troposphere, and among them deep convection is believed to be an important source in the tropical region (Piani et al., 2000). The spectrum of GWs excited by tropospheric deep convection is quite diverse, which encompasses horizontal wavelengths (λ_h) of ~1–300 km and phase speeds (c_o) in the range ~5–250 m/s (Medeiros et al., 2007; Yiğit and Medvedev,2010; Vincent et al., 2013, Vadas and Liu, 2013 and references therein). These GWs are termed as primary GWs. Due to the exponential decrease of the neutral gas densities with altitude, the primary GWs grow in amplitude as they propagate upwards. At certain heights in the mesosphere, some of them become saturated and break or reach critical levels when their phase speeds match the background wind (Fritts, 1984). In addition to the critical levels, reflections caused by oppositely directed background winds filter out a portion of small scale gravity waves with wavelengths less than few 10 s of km (Narayanan and Gurubaran, 2013). Some of the medium-scale GWs, however, do propagate to the thermosphere.

After reaching thermospheric altitudes, these GWs encounter damping due to thermal diffusivity and viscosity ultimately leading to their dissipation (Pitteway and Hines, 1963). There are now body forces whose spatio-temporal variation could excite a new set of GWs referred to as secondary GWs. From a numerical simulation of deep convection over Brazil, Vadas and Liu (2013) estimated the dissipation altitude of the primary GWs to be in the range 120–230 km. Besides, ray tracing of GWs carried out from Boa Vista (2.8°N, 60.7°S) revealed the altitude of dissipation to extend till ~140 km (Paulino et al., 2012). The horizontal wavelengths and phase speeds of the secondary GWs typically lie in the range of 100–6000 km and 100–700 m/s, respectively (Vadas and Crowley, 2010; Vadas and Liu, 2013).

In the present work we report all-sky imaging observations of wave signatures in the thermospheric OI 630 nm emission carried out from the Indian dip equatorial region from January 2013 to January 2015. We propose a mechanism to explain their presence over the dip equatorial region.

2. Instrumentation and data analysis

The nightglow images presented in this work were obtained using an All-Sky Airglow Imager (ASAI) operating from Tirunelveli. The front end optics of the ASAI consisted of a circular F/4 Mamiya achromatic fish eye lens and a pair of telecentric lenses. The fish eye lens enabled a field of view (FOV) of 180° but during the observation period the latter was restricted to ~140° in order to curb the effects of light noise emanating from the vehicular motions on the nearby road. The filter wheel of the ASAI was designed to accommodate six interference filters. During the chosen analysis period, filters tuned to image the oxygen emissions, namely, OI 630 nm and OI 557.7 nm, the OH Meinel band emission, the Na doublet, the O_2 band emission and the background emission (at 572.3 nm), were in operation. The images were recorded on a monochromatic, back-illuminated, CCD, having 512 × 512 pixels of 16 bits pixel depth. The camera system was cooled thermoelectrically to temperatures below −70° C during the data acquisition in order to reduce thermal noise (dark charge is 0.0023 electrons/pixel/s at −70 °C).

The images in the OI 630 nm emission were recorded at an exposure time of 180 s using a 3-in diameter interference filter of bandwidth of ~2 nm. Longer exposure times were chosen for the image acquisition, because the F layer over the dip equator rises considerably during post sunset hours accounting for the reduced airglow intensities around those hours. Some experimenters adopt a 2 × 2 binning of pixel area (typically of 1024 × 1024 pixels) to improve signal-to-noise ratio, though at the cost of spatial resolution. As the CCD used for the present experiment had a 512 × 512 pixel array, we did not take advantage of binning as that would have reduced the spatial resolution by half or

Please cite this article in press as: Sau, S., et al. Study of wave signatures observed in thermospheric airglow imaging over the dip equatorial region. Adv. Space Res. (2018), https://doi.org/10.1016/j.asr.2018.06.039