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Climatology of GW-TIDs in the magnetic equatorial upper thermosphere over India

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ABSTRACT

An analysis of Gravity wave induced travelling ionospheric disturbances (GW-TIDs) in the thermosphere during high and low solar epochs is undertaken using ionosonde data at Trivandrum (8.5^0N, 77^0E). Wavelet analysis is performed on the temporal variations of foF_2 and the amplitudes of waves present in two period bands of (0.5–1.5) h and (2–4) h are extracted. The real height profiles are generated at 15 min internal for the whole day (for sample days) during high and low solar activity years. The study reveals that the GW-TID activity is significantly greater for solar minimum compared to solar maximum for the period 8.5–17.5 h. Diurnally the GW-TID activity in the (2–4) h period band peaks in the post sunset hours for both high and low solar epochs. For the 0.5–1.5 h period band, the diurnal maximum in GW-TID is occurring in the post sunset hours for high solar epoch while it occurs in the morning hours around 10 h LT for low solar epoch. Seasonally the day time GW-TID activity maximizes (minimizes) for winter (vernal equinox). The post sunset time GW-TID maximizes (minimizes) either for summer/winter (vernal equinox). The other interesting observation is the anti correlation of GW-TID in upper thermosphere with solar activity for day time and the correlation of the same with solar activity in the post sunset hours. The present results for daytime are in agreement with the equatorial daytime GW-TID behaviour reported from CHAMP satellite observations. The GW-TID activity during post sunset time for equatorial region upper thermosphere has not been reported so far.

1. Introduction

The vertical coupling between different regions of the atmosphere through waves is a topic of current interest since it plays a crucial role in modulating the different phenomena manifesting therein. Gravity waves originate in the troposphere, propagate spatially and in the process control the transfer of momentum and energy through different regions. A review on gravity waves of different periods and their transmission characteristics is given by Fritts and Alexander (2003).

In the ionosphere, atmospheric gravity waves (GWs) manifest as wave-like perturbations in the ionization density and temperature (Raitt and Clerk, 1973). The propagating disturbances in the ionospheric density, induced by the gravity wave are referred to as Gravity Wave Induced Travelling Ionospheric disturbances (GW-TIDs) in the work. Role of GWs as seeding perturbations for Equatorial Spread F (ESF) irregularities is discussed by Kelley et al. (1981). Secondary GWs produced from the wave breaking regions and their role in modulating the processes in the thermosphere is examined by Vadas and Fritts (2002). The importance of GW activity in the F region irregularity initiation and maintenance is discussed by several other authors also (Lin et al. (2005), Takahashi et al. (2009)). Singh et al. (1997) have reported that GWs cause the wave like ion density structures and provide the initial seeding effect. GWs having sufficiently large perturbation amplitudes are more favourable for the plasma instabilities at the bottom side F layer (Fritts et al., 2009). The airglow emission studies using 630 nm have revealed the presence of abundance of structures in the thermosphere (Garcia et al., 2000). Abdu et al. (2009) presented a case study which shows that days with discernible incidence of the GWs tend to be ESF days. Garcia et al. (2016) have studied the medium scale wave activity in the thermosphere and reported that the number of GWs observed as well as the GWs with shorter wavelengths are more in low solar activity years compared to high solar activity years. They have also shown that the GW activity is stronger in winter hemisphere than the summer hemisphere. The observation of the periodic waves in the lower thermosphere from the OI 630 nm airglow images has been studied and it is found that the occurrence rate of periodic waves follows the solar activity (Fukushima et al. (2012). High latitude Medium Scale Ionospheric Disturbance (MSTID) activity is reported to be maximum before the midnight (Shiokawa et al.

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(2013). Laskar et al. (2015) have carried out a study using multi wavelength day time oxygen airglow emission intensity and EEJ strength data and has shown that the occurrences of periodicities in the gravity wave regime are greater for high solar activity period compared to low solar activity period. Vadas (2007) has shown that the altitudinal extent that a GW can penetrate follows the solar activity. Manju et al. (2016) presented a method of establishing a threshold curve for the required GW amplitude at different heights, wherein all days with GW amplitude above the threshold curve are ESF days and those below are non-ESF days. Thus the role of GW activity in controlling the day to day variability of important phenomena like equatorial spread F in the upper thermosphere is increasingly becoming evident. In this context, it becomes imperative that one understands the diurnal, seasonal and solar cycle variations of GWs in the upper thermosphere. This will give an idea on the relative magnitude of the GW perturbations during varying geophysical conditions.

The temporal resolution of satellite data being sparse they are not very useful for GW studies although they do provide global coverage. Moreover, the wave activity is a predominantly local phenomenon which is controlled by the geographical distribution of the sources. Hence, long-term systematic observations using ground based instruments like ionosondes can be very useful for monitoring GW activity in view of the greater temporal resolution of such data.

Kumar et al. (2007) investigated the GW activity in the mesosphere lower thermosphere (MLT) region using meteor radar observations over Trivandrum (8.5^{0}N, 77^{0}E). They demonstrated the presence of upward propagating GWs with periods 1–2 and 4–5 h. For upper thermospheric altitudes there have been a few studies on global GW-TIDs climatology, which have not addressed the seasonal and longitudinal variations. A study focused mainly on high-latitudes wherein aurora-related strong atmospheric fluctuations occur, was presented by Hedin and Mayr (1987). Bruinsma and Forbes (2008) investigated dependences of GW climatology on geomagnetic/solar activity, local time, and latitude. Paulino et al. (2016) have observed the lower thermospheric waves reported that occurrence rate of these waves are higher (lower) in high (low) solar activity years, with predominant occurrence in the winter months. Using the Challenging Mini satellite Payload (CHAMP) mission data from 2001 to 2010, the seasonal/spatial GW climatology in the upper thermosphere at geomagnetically mid/low latitudes is investigated by Park et al. (2014). Kotake et al. (2006) investigated the climatology of medium scale travelling ionospheric disturbances in Japanese, European, Australian and American sectors, attributing the origin of these disturbances to GWs. The present study involves an analysis of the diurnal and seasonal variation of GW activity in two period ranges (0.5–1.5) h and (2–4) h during high and low solar epochs (2002 and 2005 respectively) using ionosonde data at Trivandrum Here, also we consider the ionospheric electron density perturbations to be caused by GWs.

2. Data and methodology

Ionosonde data from the geomagnetic equatorial location of Trivandrum for all seasons (Autumnal equinox, AE: August15- October 31, Vernal equinox, VE: February 15- April 30, Winter solstice, WS: November 11-December 31, SS, Summer solstice: May 15 - July 31) of low solar activity year 2005 and high solar activity year 2002 are used for the study. Only magnetically quiet days with Ap < 18 are considered. Considering this criteria as well as the availability of data, 241 days for 2002 and 268 days for 2005, are used in this analysis.

The frequency of the ionospheric F layer at an altitude of 350 km is scaled from the ionograms for the period 0600–2400 h (for non-ESF days) or the time just prior to ESF (for ESF days) where'h' stands for Indian Standard Time which is 5 h 30 min ahead of Universal Time.

2.1. Wavelet analysis

The GW-TID activity gets altered with time in the ionosphere thermosphere region and hence wavelet analysis is more suitable than conventional Fourier analysis (Kumar et al., 2007). In the light of this, we have used the wavelet analysis method to delineate the presence of GWs in this work.

The frequencies are scaled from ionograms with 15 minutes cadance. Wavelet analysis is performed on the data for each day to delineate the periodicities in the ranges of 0.5–1.5 h and 2–4 h as they likely represent the GW seed perturbations. 'Morlet' wavelet analysis (Torrence and Compo (1998)) is performed on the scaled data. Only data uncontaminated by ESF wherein the frequency can be scaled unambiguously are used in the analysis. The maximum period examined is limited to 4 h keeping in view the fact that data length can be less during days with ESF contamination.

The frequency resolution of ionosonde is the parameter which constraints the minimum amplitude of fluctuations that can be deciphered from the scaled data. In the case of the KEL ionosonde the frequency resolution is 0.039 MHz. It is seen that the amplitudes extracted in the present study are larger than 0.039 MHz and hence they are reliable.

3. Results

In the first part of this section, the GW origin of the fluctuations observed in the scaled data are investigated for 2 sample days in 2005 (low solar activity) and 2002 (high solar activity). The real height profiles are obtained from the scaled virtual height profiles for the period 08–16.5 h on 5 September 2005 while for 02 September 2002 the real height profiles for the period from 08–16.25 h are used.

In the second part, the diurnal, seasonal and solar cycle variations of GW-TID activity are presented.

3.1. GW origin of frequency fluctuations during 2 samples days in 2005 and 2002

From the real height vs. frequency variations obtained at 15 min interval on 5 September 2005 (low solar activity year sample day) and 5 September 2002 (high solar activity year sample day), the temporal variations of frequency can be obtained for specific altitudes. Here we examine the temporal variations of the scaled frequencies at the altitudes of 210 and 289 km for 2005 and 210 and 278 km for 2002. Data is available for both the altitudes in the interval 8–6.5 h for the year 2005 and 8–16.25 h for the year 2002. The daily mean value for each altitude is removed from the entire data to get the fluctuations. Fig. 1 shows the temporal variations of the mean removed fluctuations in the scaled frequency values at 210 and 289 km for 05 September 2005 and at 210 km and 278 km for 05 September 2002. The stronger level of fluctuations prevalent at the higher altitude is discernible in the figure.

In order to characterize and quantify the short period fluctuations (0.5–1.5) h, wavelet analysis is carried out on the time variations of the mean removed fluctuations for both the years. The wavelet spectra for the data at altitudes of 210 km (bottom panel) and 289 km (top panel) respectively of 05 September 2005 are shown in Fig. 2 and the wavelet spectra for the data at altitudes of 210 km (bottom panel) and 278 km (top panel) respectively of 05 September 2002 are shown in Fig. 3. The x axis represents time of day in hours, y axis depicts time period of the wave perturbations while the color bar represents the wave amplitude.

The increase in amplitude of the waves of different periodicities as the altitude increases is evident from figures (Figs. 2 and 3). Here two widely separated altitudes are used so that we are able to clearly decipher the phase propagation characteristics even if the waves are of large vertical wavelength.

Fig. 4(a) shows the wave amplitude of the (0.5–1.5) h wave for the altitudes of 289 km (top panel) and 210 km (bottom panel) and Fig. 4(b) the wave amplitude of the (0.5–1.5) h wave for the altitudes of 278 km (top panel) and 210 km (bottom panel). This range of periods is chosen so that sufficient number of cycles is available to check the phase propagation characteristics. From Fig. 4, it is clear that the amplitudes are