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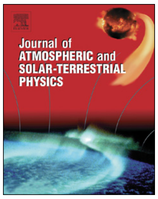

Short period gravity wave momentum fluxes observed in the tropical troposphere, stratosphere and mesosphere

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A B S T R A C T

Using long-term data (1998–2008) collected from mesosphere–stratosphere–troposphere (MST) radar and Rayleigh Lidar located at a tropical station, Gadanki (13.5°N, 79.2°E), India, vertical flux of the momentum from troposphere to mesosphere associated with the gravity waves of periods in the range 20 min to 2 h is investigated for the first time. The emphasis is on seasonal variability of mean zonal and meridional momentum fluxes in mesosphere and troposphere and vertical flux of horizontal momentum in the stratosphere. At tropospheric altitudes of 11–16 km large enhancement in flux is noticed during equinoxes. In the lower mesosphere in the altitude region 58–62 km the maximum values of flux (~2.8 m^2/s^2) observed are pragmatic in winter and spring. Interestingly, the vertical flux of horizontal momentum estimated from lidar is in the range of those estimated from radar data in the overlap altitude region, though the estimates are from two different techniques. In the mesosphere, large variations with altitude in zonal momentum flux are noticed with a magnitude ~0–4 m^2/s^2 in summer. In winter and summer the zonal wind direction is opposite to the momentum flux direction between 73 and 80 km and in equinoxes zonal wind follows the momentum flux. The meridional fluxes in the mesosphere are higher in equinoxes (~10–12 m^2/s^2).

1. Introduction

Numerous studies have addressed and widely recognized the important role of atmospheric gravity waves and their effects on both the large- and small-scale dynamics of the mesosphere and lower thermosphere (MLT) through their vertical transport of the wave energy and horizontal momentum (Lindzen, 1981; Fritts and Rastogi, 1985; Fritts and Alexander, 2003). Earlier studies on gravity wave generation and propagation (Fritts and Alexander, 2003) reported that most of the gravity waves will originate at tropical troposphere due to deep convection. Baldwin et al. (2001) reviewed their contribution in driving the quasi–biennial oscillation (QBO) through their interaction with background mean by transferring momentum flux. Most of the theoretical and modeling studies were primarily concentrated on the effect of gravity waves in the mesosphere, but later it has been found that these effects are also important in the troposphere and stratosphere. However, less is known about these wave effects in the mesosphere and in the lower atmosphere especially in the tropics.

Different methods are available to obtain the momentum flux (Gage, 1983; Worthington and Thomas, 1996) with their own limitations (Dutta et al., 2005). Vincent and Reid (1983) proposed a unique method (symmetric beam radar method) to measure the horizontal momentum flux using MST radar, in which two or more radar beams each offset from the zenith measure atmospheric motions by Doppler technique. The symmetric beam radar method has an advantage since it does not require vertical beam measurements to obtain momentum flux unlike other methods. In this method the momentum flux is obtained by assuming horizontal homogeneity between two beams over a suitable averaging interval in space and time. The technique has been applied to mesospheric (Vincent and Fritts, 1987; Tsuda et al., 1990), tropospheric and lower stratospheric altitudes (Fukao et al., 1988; Thomas et al., 1992). In recent years employing the dual beam method, gravity wave momentum fluxes in the MLT region have been estimated (Fritts and Vincent, 1987; Tsuda et al., 1990; Wang and Fritts, 1990; Hitchman et al., 1992; Nakamura et al., 1993; Gavrilov et al., 2000). At Arecibo observatory, Puerto Rico (18°N, 67°W) using UHF radar, Zhou and Morton (2006) and Janches et al. (2006) estimated

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gravity wave momentum fluxes and found that in the mesosphere region (65–85 km), the zonal momentum flux associated with the gravity waves with periods in the range 15 min to 2 h is ~10–40 m^2/s^2 and also reported that the zonal momentum flux changes sign at altitudes where dynamical instability occurs. Vertical flux of horizontal momentum in the troposphere and lower stratosphere has been studied by Prichard and Thomas (1993) and Worthington and Thomas (1996) using MST radar at Aberystwyth and found that momentum fluxes for long period waves show little changes in their magnitude, whereas for shorter periods enhanced substantially during active periods. Recently Zhang et al. (2012) provided altitudinal and seasonal variations of gravity wave momentum flux in the lower atmosphere using broad spectrum method for the radiosonde data at a mid-latitude station Miramar Nas (32.87°N, 117.15°W). They have reported evident annual cycle and altitude variation in the zonal and meridional momentum fluxes in the lower and upper stratosphere region.

Most of the above mentioned ground based studies are limited to mid and high latitudes and so far no information is available on gravity wave momentum flux in the low-latitude mesosphere. Though there are a few reports at tropical latitudes on gravity wave momentum flux at tropospheric altitudes (Sasi and Deepa, 2001; Nayar and Sreeletha, 2003; Dutta et al., 2005), and at stratospheric altitudes using Rayleigh lidar (Deepa et al., 2006; Antonita et al., 2007; Guharay and Sekar, 2011), no systematic study on these fluxes has been done covering entire middle atmosphere with long term data. For the first time we made an attempt to study the seasonal variation of gravity wave momentum fluxes from troposphere to mesosphere using long term data set from MST radar and Rayleigh Lidar at a tropical station, Gadanki (13.5°N, 79.2°E) and the results of this study are presented in this communication.

2. Database

2.1. MST radar data and analysis procedure

The MST Radar at Gadanki is high power VHF radar and operates at 53 MHz with a peak transmitter power 2.5 MW and with an average power–aperture product of 3×10^{10} Wm^2. The radar provides winds in troposphere, lower stratosphere, and mesosphere (~65–85 km) and operates in the Doppler Beam Swinging (DBS) mode. A detailed description of the radar has been given in Rao et al. (1995). The main experimental specifications and other important parameters used for the current study are given in Table 1. It is well known that VHF radar echoes from the mesosphere result from refractive index irregularities due to electron density fluctuations having scale size of half the radar wavelength (~3 m) (i.e., through Bragg scattering) and or from electron density gradient (i.e., through Fresnel reflection/scattering). Atmospheric scatterers are advected with the background air motions and the three dimensional velocity vectors can be directly deduced from the Doppler shifts of the radar echoes received in three independent beam directions. A detailed description of the data and signal detectability in mesosphere has been given in Kumar et al. (2007). For the present study the MST radar wind data in the altitude region 3.6 to 21 km and 65 to 85 km during 1998–2008 are used.

As mesospheric echoes from the MST radar are mainly due to fluctuations in electron density gradients and irregularities they are confined to daytime. The availability of data is restricted to ~1000 to 1600 h Indian Standard Time (IST) (IST=UT+0530 h). We have considered only data for days when continuous echoes were observed between 1000 and 1600 IST. The MST radar data used in the present study comprised of data from 20 days in winter, 13 days in spring equinox, 19 days in summer and 22 days in fall equinox during the period 1998–2008. The radial velocity profiles of individual days are carefully examined for interference, if any and the same is removed by a specially made algorithm. After removing the interference and also outliers in the data, percentage occurrence (PO) of echoes in each range bin is calculated using the relation PO=100 × ((number of samples with SNR > −12 dB)/(total number of samples)). Further, a minimum PO threshold criterion has been applied for the data. After trying out several threshold criteria to the data, it is found that reliable estimates of momentum flux can be obtained using a threshold of 20% for PO. Thus, the echoes in the range bins with PO less than 20% are omitted.

The background radial wind profile, which is not related to the mesoscale features of interest, has been removed from the data by subtracting the mean profile of the day. In order to know the dominant periodicities of gravity waves present, we performed the spectral analysis on time series of radial wind fluctuations and found that the dominant period is 20 min to 2 h. The time series of perturbation profiles have been filtered to retain oscillations between 20 min to 2 h using a fourth-order Butterworth filter. The filtered profiles of radial velocities have been used to derive momentum fluxes of horizontal winds using the following equations of the symmetric beam radar method of Vincent and Reid (1983).

$$\text{Momentum flux for the E–W beam}: \quad \overline{u'w'} = \frac{(\overline{v_E^2} - \overline{v_W^2})}{2\sin 2\theta} \tag{1}$$

$$\text{and for the N–S beam}: \quad \overline{v'w'} = \frac{(\overline{v_N^2} - \overline{v_S^2})}{2\sin 2\theta} \tag{2}$$

where $\overline{u'w'}$ is the zonal momentum flux, $\overline{v'w'}$ is the meridional momentum flux and $\overline{v_E^2}$, $\overline{v_W^2}$, $\overline{v_N^2}$, and $\overline{v_S^2}$ are square of radial wind

Table 1
Experimental specifications of MST radar and lidar used for the present study.

MST radar		**Lidar**	
Parameter	**Specification**	**Parameter**	**Specification**
Operating frequency	53 MHz	Laser source	Nd:YAG
Power aperture product (peak)	3×10^{10} W m^2	Operating wavelength	532 nm
Beam width	3°	Average energy per pulse	550 mJ
Pulse width	4/8/16 μs (uncoded)	Average output power	11 W
Inter pulse period	1000 μs	Pulse width	7 ns
No. of FFT points	128/256/512	Pulse repetition rate	20 Hz
No. of coherent integrations	32/64/128	Beam divergence	< 0.1 m rad
No. of incoherent integrations	1/2/4	Line width	1 cm^{-1}
Range resolution	1.2 km/2.4 km	Telescope	Newtonian
No. of beams	Five (E, W, Zenith Y, N and S)	Diameter and field of view	750 mm and 1.07 nm
		Maximum transmission	48%