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Rayleigh lidar observations of planetary waves in the middle atmosphere over Gadanki (13.5°N, 79.2°E)

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Abstract

Rayleigh lidar temperature data collected at Gadanki (13.5°N, 79.2°E) during two campaign periods in 1999 and 2000 have been analyzed to study the planetary wave activities in the stratosphere and lower mesosphere. Attention has been given to the Rossby-gravity (RG) wave, fast Kelvin wave, and slow Kelvin wave with remarkable periodicity of 3.6, 6.5, and 16 days, respectively. The well-known Lomb–Scargle periodogram (L–S) analysis was performed on the temperature profile to extract the wave characteristics. The analysis indicated the dominance of these waves in the stratosphere and mesosphere. The results obtained are consistent with other measurements based on radar, rocketsonde or satellite.

Keywords: Rayleigh lidar; Middle atmosphere; Planetary wave; Tropical meteorology

1. Introduction

Monitoring of the middle-atmospheric temperature has received much attention by the scientific community, due to the value of studies of the chemical reactions and the need to characterize wave dynamics (gravity waves, tides and planetary waves) and their interactions (Singh et al., 1996). There have been a number of techniques involving space-borne and ground-based instruments for middle atmospheric temperature measurements. Among those, the Rayleigh lidar, providing continuous measurements of temperature (or density) with high time and height resolutions over a height range of 30–80 km, has emerged as the most potent ground-based technique to study the structure and dynamics of the middle atmosphere (e.g., Hauchecorne and Chanin, 1980, 1982, 1983; Chanin and Hauchecorne, 1981, 1991; Chanin, 1989; Whiteway and Carswell, 1994; LeBlanc et al., 1998; Sivakumar et al., 2003). Atmospheric temperatures measured by lidars have been used to validate various satellite

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remote sensing instruments such as Microwave Limb Sounder (MLS), Cryogenic Limb Array Etalon Spectrometer (CLAES), and the HALogen Occultation Experiment (HALOE) onboard Upper Atmosphere Research Satellite (UARS) (Fishbein et al., 1996; Gille et al., 1996; Hervig et al., 1996; Remsberg et al., 2002b).

The characteristics of wave-like perturbations in the middle-atmospheric height region over a wide range of scales have been studied using both space-borne and ground-based instruments (e.g., Barnett and Corney, 1985; Mohankumar, 1989; Chanin, 1989; Chakravarthy et al., 1992). Studies have been carried out on atmospheric waves from the point of view of energy coupling from the middle atmosphere to the upper atmosphere (e.g., Sasi, 1980; Hocking, 1996; Sridharan, 1998). During the Indian Middle Atmosphere Programme (IMAP), several new results on the equatorial middle atmosphere have been reported based on a series of rocket campaigns (e.g., Sasi and Sen Gupta, 1986; Raghavarao et al., 1990; Chakravarthy et al., 1992; Sasi, 1994; Mohankumar, 1994). More recently, two unique campaigns of coordinated measurements have been conducted for studies on equatorial waves with emphasis on estimation of momentum fluxes. The first one involved 45 days of simultaneous measurements by co-located Rayleigh lidar and Indian MST radar (Krishna Murthy et al., 2000) and the second one employing lidar, MST radar and rockets (Krishna Murthy et al., 2002).

There are numerous studies of planetary waves (PW) and their modulation of other propagating waves (tides and GW) at mid and high-latitudes (e.g., Hauchecorne and Chanin, 1983; Bristow et al., 1996; Arnold and Robinson, 1998; Leblanc et al., 1998; Luo et al., 2000, 2002a, b), but not that many studies for low latitude stations. Arnold and Robinson (1998) developed a three-dimensional model to study PW propagation and the subsequent changes in the stratosphere circulation. They reported pronounced PW activity during winter. The model results show that high/low solar activity would promote/reduce the strong PW activity. Very recently, Sivakumar et al. (2004) reported both planetary wave breaking and a warming event in the stratosphere over Gadanki (13.5°N, 79.2°E). They provided evidence that the PW breaking can enhance the temperature by ~18 K at the stratopause height. Here, we use the above said two equatorial campaign data (1) from 18 January to 5 March 1999 and (2) 1 March to 10 April 2000, to explore the planetary wave characteristics over Gadanki.

2. Lidar system and data analysis

The lidar system is located at Gadanki (13.5°N, 79.2°E), India, and was installed jointly by the National Institute of Information and Communications Technology (NICT-Japan) and the National MST Radar Facility (NMRF-India). It is equipped with a Nd-YAG pulsed laser at 532 nm with pulse energy of about 550 mJ, operating at a pulse repetition frequency of 20 Hz and pulse width of 7 ns. The transmitting beam, with a divergence of 0.1 mrad, is directed vertically upwards by a flat mirror at 45° to the beam axis. The Rayleigh receiver employs a 75 cm Newtonian telescope for molecular density and temperature measurements over the height range of ~27–90 km. Details of the lidar system configuration and technical features are mentioned elsewhere (Sivakumar et al., 2003). The raw data are in the form of photon count profiles with a height resolution of 300 m and time resolution of 250 s (5000 laser shots were integrated for one profile). By assuming that the atmosphere is an ideal gas in hydrostatic equilibrium and free of aerosols, temperature profiles can then be computed with the help of COSPAR International Reference Atmosphere (CIRA 86) standard model of the atmosphere for the initialization at the top level (Hauchecorne and Chanin, 1980; Keckhut et al., 1993). The standard error involved in the 6 h average temperature profile is estimated to be ~3 K at 70 km which decreases with decreasing altitude and is ~1.5 K at 30 km.

The temperature data were collected continuously for a period of ~4–6 h on clear nights for two campaign periods from 18 January to 05 March 1999 and from 1 March to 10 April 2000. Figs. 1(a and b) show time sequences of 250 s integrated temperature profiles, for the nights of 27–28 January 1999 and 22–23 March 2000, respectively, for an altitude coverage of 30–70 km. The wave perturbations of gravity wave type with vertical wavelength of 5–15 km and downward phase progression are also seen in the lower height range of 30–45 km. It is found that there are low signal-to-noise ratios for altitudes above 70 km and for this reason we concentrate the altitude region of 30–70 km in the present study. All the 4–6 h of temperature profiles for each day is averaged to obtain the daily mean temperature profile. The daily