STUDIES ON ATMOSPHERIC GRAVITY WAVE ACTIVITY IN THE TROPOSPHERE AND LOWER STRATOSPHERE OVER A TROPICAL STATION AT GADANKI

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Abstract

Atmospheric Gravity waves plays a significant role in controlling middle and upper atmospheric dynamics. Till date, frontal systems, convection, wind shear and topography have been thought to be the sources of gravity wave activity in the troposphere. All these studies pointed out that, it is very essential to understand generation, propagation and climatology of gravity waves. In this regard, several campaigns using Indian MST Radar have been carried out to explore the gravity wave activity in the troposphere and the lower stratosphere. The signatures of the gravity waves in the wind fields have been studied in the troposphere and lower stratosphere. The wave activity during pre monsoon, monsoon, post-monsoon and winter seasons have been studied. The large wind fluctuations are more prominent above 10 km during pre monsoon and monsoon seasons. The dominant wave periods and their height profiles of amplitudes are studied. The vertical wavelength and the propagation direction of gravity waves are determined using hodograph analysis and the same are presented.

Introduction

The recent theoretical studies on gravity waves have shown the importance of excitation and vertical propagation of gravity waves and their forcing on the large scale circulation and structure of lower and middle atmosphere. In spite of its importance and significant advancements, very few studies are available in the tropical latitudes. VHF Radar is a promising tool to study such events and their dynamical effects because of its high temporal and spatial resolution capabilities. There have been few important observations on the generation of gravity waves due to convection process using VHF Radar [Fritts and Nastrom, 1992].

Most of the sources for the generation of the gravity waves lie in the troposphere [Fritts and Nastrom, 1992]. Some of the sources have been identified as topography [Nastrom and Fritts, 1992], convective and frontal activity [Fritts and Nastrom, 1992] and wind shear [Fritts, 1984]. Tsuda et al., [1994] also determined that in the equatorial region, gravity wave generation was typically associated with deep convection. Dhaka et al., [2001], [2002] showed the gravity waves activities associated with convection over a tropical region by using Indian MST Radar. The generation of gravity waves has also been attributed to various instability mechanisms occurring in the tropospheric region. Kelvin-Helmholtz instability is one such kind. These unstable wind shears are common sources of vertically propagating gravity waves in the atmosphere. Jet streams are identified as a source of gravity wave generation [Fritts and Luo, 1992]. These waves have typically wave periods of a few tens of minutes with a horizontal wavelength of a few tens to a few hundreds of kilometers. Near the jet stream maximum wind shears are very high providing conditions favoring the occurrences of shear instability and generation of gravity waves. Using radiosonde observations Tsuda et al., [1994] showed that gravity waves were mostly generated in the middle troposphere and that waves which reached stratosphere were propagating upward.

Data Base

In the present study the VHF Radar at Gadanki (13.48º N, 79.18º E), a tropical station is used to study the gravity wave activity in four typical months representing different seasons namely Pre Monsoon (March - May), Monsoon (June - September), Post Monsoon (October - November) and Winter (December-February) seasons. The observations were taken during 09-12 April 2001(Pre Monsoon), 19-22 July 1999, 16-19 July 2001 (Monsoon), 16-19 October 2000, 26-29 November 2001 (Post Monsoon), 22-25 January 2002 (Winter). Data is collected for three days in each season at 1000 -1600 LT, 2000 – 2030 LT, 0030 – 0100 LT, and 0500 – 0530 LT on each day. The Radar antenna beam was pointed towards 6 beam directions viz., East, West, North, South inclined at an angle of 10º from the Zenith and along two Vertical beams, one in E-W polarization and the other in the North-South polarization. For all the six beam directions, mean radial velocities observed in 3.6 min interval provided the original data. The received echo signals were sampled at height resolution of 150 m during 19-22 July 1999, 16-19 July 2001 and 22-25 January 2002 and 300 m height resolution during 16-19 October 2000 and 09-12 April 2001.

Results and Discussions

Figure 1 shows the background wind information in different seasons on a typical day. In pre monsoon season zonal winds are westward from 2 km to 6 km, eastward from 6-15 km and again westward above 14 km. During Monsoon season because of Jet streams the Zonal winds are maximum ~ -40 m/s around 17 km and these winds are easterlies above 9 km. During post monsoon season the zonal winds are almost westward with less magnitude compared to other seasons. In winter season the zonal winds are westward. In pre monsoon season meridional winds are northward up to 16 km and above that these winds are southward. In Monsoon season up to 6 km southward and above 6 km northward. During Post monsoon and winter seasons meridional winds are towards northward direction. In all the seasons vertical velocities are small with upward and downward oscillations.

Figure 2 represents the time series plot of Zonal velocity in different seasons for one typical day in the troposphere and lower stratosphere during the six-hour period of observation starting at 1000 hrs LT. Above 10 km the wind disturbances are more prominent and while going upward the magnitude of the disturbances are more, this will imply wave motions that are vertically propagating and it is evident from the figure that, wave like structure exists in the time series with a clear phase variation and different characteristic periods and also it is clear that the source mechanisms are originating in the lower atmosphere. In order to calculate the frequency spectra of gravity waves the zonal velocities were taken and they were subjected to the FFT analysis. Figure3 shows frequency spectra for zonal velocity on 18th July 2001 during 1000-1600 hrs observations. From this observations 5 harmonic components were determined and the corresponding time periods are 2 Hr 20 min, 55-46 min, 20-30 min, 20-15 min and 8 min. The maximum amplitude of these waves is 3 m/s. According to Tsuda et al., 1994, the periods ranging from 5 minutes to 2 hours are mainly due to the large wind shears, which are mainly observed during jet streams. The observed periods near the jet streams in the present study (around 16 –17 km) lie within the periods as reported by Tsuda et al., 1994. Previous studies revealed that gravity waves of such wave periods exist over this Radar site [Nagpal et al., 1994; Dutta et al., 1999]. During pre monsoon and monsoon season the wave activity is more dominant.

Figure 4 represents vertical wavelength and propagation direction of gravity waves are obtained using Hodograph analysis. On 18 Jul 2001 Zonal velocity has been taken on X –axis and Meridional velocity has been taken on Y-axis for hodograph analysis from 10.2 -20.1 km during

1100-1200 hours. From this plot 6.3 km vertical wavelength of waves are dominant with clockwise direction. If the rotation of the waves is in clockwise direction it represents that the waves are propagated upward. If it is anticlockwise direction, it represents that the waves are propagated downward. So this plot clearly shows the upward propagating waves means the source region is in the lower atmosphere. The downward zonal momentum flux shows higher values on 18th July 2001. Meridional momentum flux is southward from 7-13.5 km and northward from 13.5-17 km. Zonal and meridional variances are increasing with increasing height and reaching maximum values at higher heights.

Conclusion

The seasonal variation of gravity wave activity in the troposphere and lower stratosphere based on wind velocity observations made with the Indian MST Radar for about 3 days in a each season, continuously for six hours duration April 2001-2002 January have been analyzed. By taking this data we have examined the gravity wave activity in the troposphere and lower Stratosphere. Zonal, Meridional and vertical velocity fields exhibited motions with periods ranging from a few minutes to hours with propagating character.

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References

Dutta G, B.Bapiraju, P.Balasubramanyam, H.Aleem Basha, VHF Radar observations of gravity waves at a low latitude, Ann. Geophysicae., 17, 1012-1019. 1999

Dhaka, S. K, P.K.Devarajan, Y.Shibagaki, R.K.Choudhary, S.Fukao, Indian MST Radar observations of gravity wave activities associated with tropical convection, J. Atmos. Solar-Terr. Phy., 63, 1631-1642, 2001.

Dhaka, S. K, R. K.Choudhary, S. Malik, Y.Shibagaki, M. D. Yamanaka, S. Fukao, Observable signatures of a convectively generated wave field over the tropics using Indian MST radar at Gadanki (13.48º N, 79.18º E), Geophys. Res. Lett., Vol. 29, No.18, 2002.

Fritts, D.C., M.A. Geller, B.B.Balsley, M.L.Chanin, I.Hirota, J.R.Holton, S. Kato, R.S. Lindzen, M.R.Schoebert, R.A.Vincent and R.F.Woodman, Research Status and recommendations from the Alaska Workshop on gravity waves and turbulence in the middle atmosphere, Bull. Am. Meteorol. Soc., 65, 149-159, 1984.

Fritts, D. C., and Z.Luo. Gravity wave excitation by geostrophic adjustment of the jet stream. Part I: Two-dimensional; forcing, J. Atmos. Sci., 49, 861-697, 1992.

Fritts, D. C., and G. D. Nastrom, Sources of mesoscale variability of gravity waves, II, Frontal, Convective and Jet stream excitation, J. Atmos. Sci., 49, 111-127, 1992

Nagpal, O.P., D. Praveen Kumar and S.K. Dhaka., Characteristics of tropospheric gravity waves by the Indian MST Radar: ST mode operation, Indian J. of Radio and Space Physics, 23, 6-11, 1994.

Nastrom, G.D., and D.C.Fritts, Sources of mesoscale variability of gravity waves, I: Topographic excitation, J. Atmos. Sci., 49, 101-110, 1992.

Tsuda, T., Y.Murayama, H.Wiryosumarto, S.B.Harijiono, and S. Kato, Radiosonde observations of equatorial atmosphere dynamics over Indonesia, 2, Characteristics of gravity waves, J. Geophys. Res., 99, 10,507-10,516, 1994

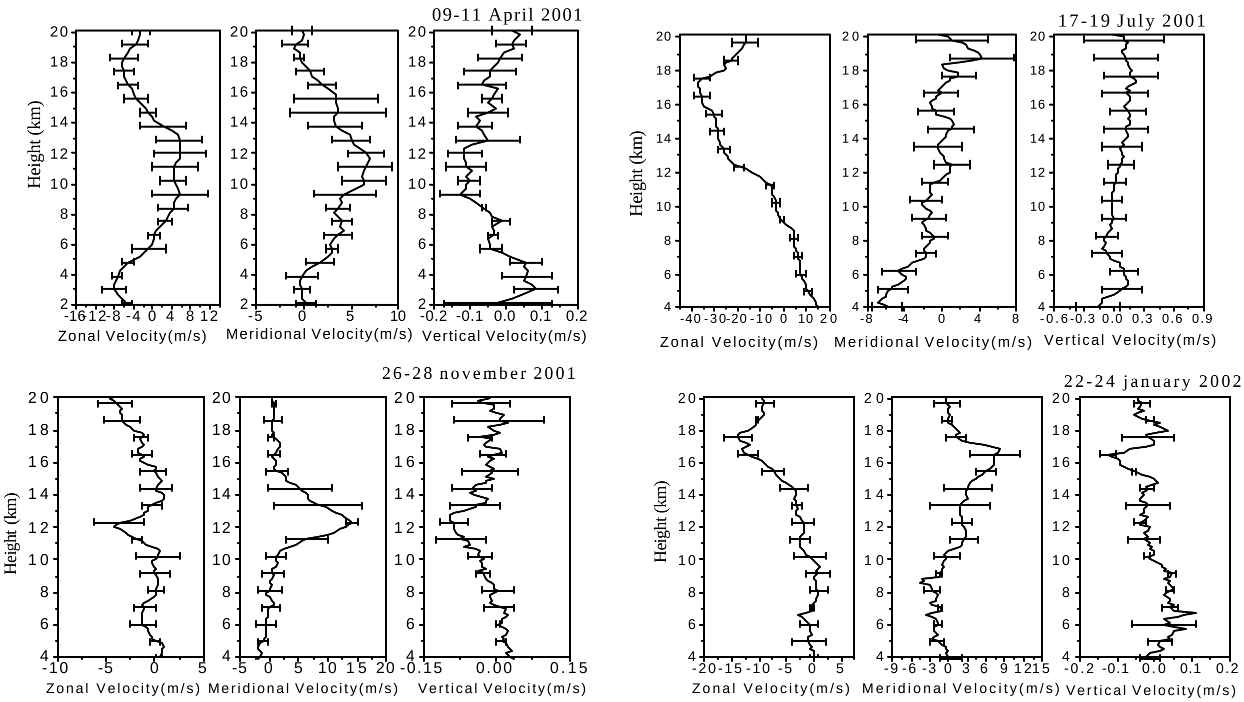

Figure 1. Mean vertical profiles of zonal, meridional and vertical velocities during (a)09-11 April 2001, (b)17-19 July 2001, (c)16-18 October 2001, (d)22-24 January 2002. Average for the entire 03 days time period of observation from 1000-1600 hours(LT) in each day has been taken.

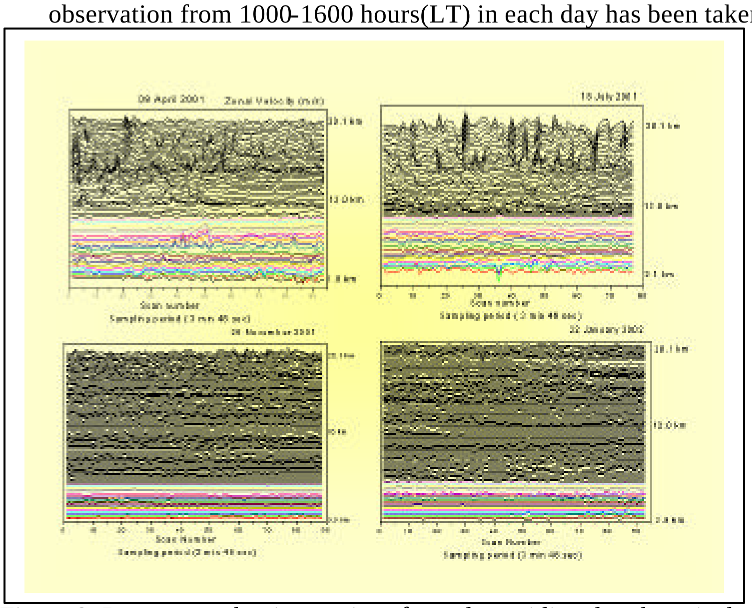

Figure 2. Represents the time series of zonal, meridional and vertical wind components during 06 hour period of observation on a typical day in different seasons starting at 1000-1600 LT (local time).

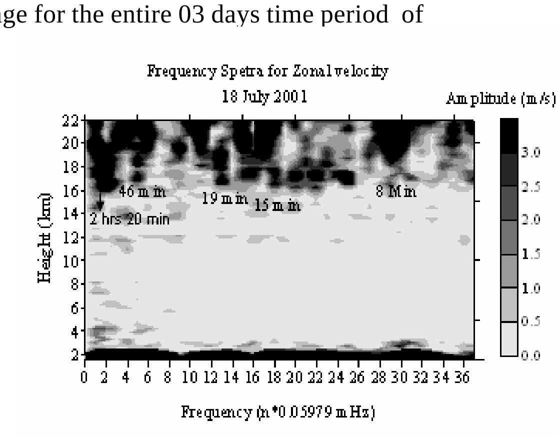

Figure 3. Frequency spectra for zonal velocity on typical day during 18[th] July 2001

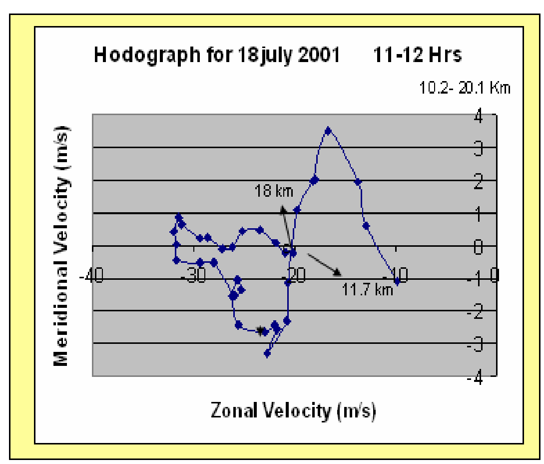

Figure 4. Hodograph for 18[th] July 2001 from 10.2 -20.1 km at 11-12 hours.

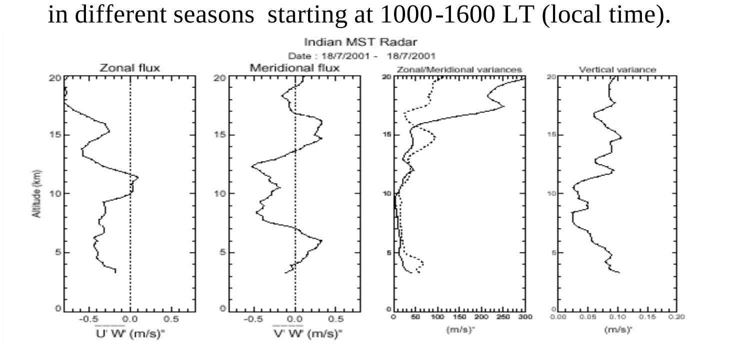

Figure 5. Momentum flux and variance of wind fluctuations determined from the MST radar data during 1000-1600 LT from 18[th] July 2001. For this total 06 hours of observations were averaged. Dotted line represents meridional variance and solid line represents zonal variance.