STUDIES ON MOMENTUM FLUXES USING MST RADAR WINDS OBSERVED AT GADANKI (13.5°N, 79.2° E), INDIA

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ABSTRACT

VHF Doppler radars provide a unique database to estimate vertical flux of horizontal momentum in the troposphere and lower stratosphere. Estimation of the oblique momentum flux involves two methods: 1) using three beams – one vertical and two oblique, and 2) using four beams – two pairs of oblique beams systematically offset from the vertical. The rapid steerability of the Indian MST radar allows to make three – and four beam measurements simultaneously. The momentum fluxes measured by the two methods are almost the same for wind fluctuations in a fairly long period range (longer than 5 h). We choose frequency bands corresponding to periods of 30 min-2h, 2-8 h, 2-16h and 2-24 h. Vertical profiles of the zonal and Meridional flux in each frequency band were found to be consistent, in general, with the total flux. Zonal fluxes were small at lower levels and increasingly negative (westward) at higher heights. The dominant contributions to the Meridional flux occur in the lower-frequency band.

Introduction

The importance of gravity wave effects on various dynamical processes has been well documented in the upper and middle atmosphere. However, less is known about these waves in the the lower atmosphere especially in tropics. The upward propagating gravity waves transport energy and momentum in different regions of the atmosphere along with their propagation to produce effects at upper heights [Hines, 1972] indicated that the influence of such waves at upper heights might be significant. Most of the theoretical and modeling studies were primarily concentrated on the effect of gravity waves in the mesosphere and thermosphere, but later it has been found that these effects are also important in the troposphere and stratosphere. In early observations it is identified that for lower heights, the momentum divergence caused by mountain waves [Newton, 1971], and the importance of such divergence in the evolution of the general circulation was emphasized by Lilly [1972]. Furthermore, the lack of height coverage at a given time in aircraft flights is a limitation. Vincent and Reid (1983) presented a technique in which ground-based radars can be used to measure fluxes directly and this technique has been applied to both mesospheric heights [Vincent and Fritts, 1987; Tsuda et al., 1990] and tropospheric and lower stratospheric levels [Fritts et al., 1990; Thomas et al ., 1992]. Because of the continuous operation of multiple instruments, long term studies have been conducted to quantify the variability and latitudinal difference of gravity wave activity [e.g. Vincent and Fritts, 1987; Manson and Meek, 1993; Vincent, 1994]. It has been found that from theoretical and observational studies that the high frequency gravity waves with small horizontal scales are the majority carriers of momentum. ~70 % of the momentum and the associated zonal drag is due to gravity waves with observed periods less than one hour [Fritts and Vincent, 1987]. Chang et al., [1997] used ST radar data from Christmas Island to study tropospheric gravity waves and they found a broad range of frequency associated with gravity wave activity in the troposphere. A method of Vincent and Reid [1983] is used to estimate the vertical flux of zonal and meridional momentum fluxes from the radial velocities in two orthogonal beams measured by the Indian MST Radar at Gadanki (13.48º N, 79.18º E) is presented. These flux values are quite well with the values obtained from previous observations.

The purpose of this study is to examine Zonal and Meridional fluxes and their variation with both height and wave periods, and also to compare fluxes for three and four beam methods.

Data Base

In the present study a VHF Radar at Gadanki (13.48º N, 79.18º E) a tropical station is used to study the gravity wave momentum fluxes in different seasons namely Pre Monsoon (March - May), Monsoon (June - September), Post Monsoon (October - November) and Winter (December-February) seasons. Data is collected continuously for three days in a typical month representing as a season at 1000 -1600 LT, 2000 – 2030 LT, 0030 – 0100 LT, and 0500 – 0530 LT on each day. The observations are taken during 16-19 October 2000, 09-12 April 2001, 16-19 July 2001, 22-25 January 2002.

Results and Discussions

In Figure 1 upper panel shows mean zonal and meridional momentum flux and variance of wind fluctuations around the mean values during post monsoon season using MST Radar. The averaging is made for 3 days i.e.,16- 18 October 2000, for the entire observational period i.e., from 1000-1600 LT in each day. Lower panel is the same as above during 09-11 April 2001 represented as during pre monsoon season. All quantities except vertical wind variance are obtained by the four beam methods. The positive values of Zonal momentum fluxes indicate Eastward transport of momentum and negative values of Zonal momentum fluxes show westward transport of momentum. Zonal momentum flux was eastward from 5.5-12.5 km, westward from 12.5-15.5 km. eastward from 15.5 – 18 km and westward above 18 km. This represents that there is a systematic change in the zonal momentum flux. While going to higher altitudes the magnitude of the zonal momentum flux is increasing either eastward or westward, this represents that the waves are assumed to be generated in the lower part of the atmosphere and upward propagating waves are dominating and westward momentum fluxes are maximum ~ -0.6 m^2/s^2. The positive values of meridional momentum fluxes indicate northward transport of momentum and negative values show southward transport of momentum. During post monsoon season meridional momentum flux is northward from 5 km to 20 km altitude (+0.4 m^2/s^2). The zonal variance is more than the meridional variance in the altitude range of 12-17.5 km. The lower panel in figure 1 (during pre monsoon season) shows east ward momentum flux (+0.6 m^2/s^2) which is dominating rather than the westward momentum flux (-0.45 m^2/s^2). The meridional momentum flux is southward and its value is maximum (-6.5 m^2/s^2) around 11-12 km. In the lower heights up to 10 km the zonal and meridional variances are small and above 10 km the variances are large.

Figure 2 is similar as figure 1 but for monsoon season (upper panel) and winter season (lower panel). In upper panel zonal momentum flux is almost westward, indicating that the west ward fluctuations are more rather than the eastward. The meridional momentum flux is southward up to 7 km, 7- 8.5 km northward, 8.5 - 14.5 km southward and above 14.5 km it is northward. The zonal and meridional variances are small up to 12 km and above 12 km these variances are increasing with increasing height. Lower panel in figure 2 shows east ward momentum flux up to 7 km from 7-11.3 km westward and above 11.3 km it is eastward. The meridional momentum flux is northward up to 11 km, southward 11-13 km, northward from 13 – 17 km and southward from 17-19.5 km. Zonal and meridional variances are high above 13 km indicating that the wave activity is more prominent.

Figure 3 shows zonal and meridional momentum flux, calculated using four beam and three beam method during different seasons. Three and four beam method calculated zonal and meridional momentum fluxes agree within error bars both in magnitude and trend. During monsoon season some discrepancy has been observed above 16 km. This may lead to anisotropy of the backscatters in the atmosphere. During pre monsoon season some discrepancy has been observed below 10 km in meridional momentum flux.

Figure 4 shows vertical profiles of zonal and meridional momentum flux profiles determined by the four- beam method with different frequency bands in different seasons viz., pre-monsoon, monsoon, post monsoon and winter. The momentum flux for short - period motions during 16-18 October 2000 shows direction towards north for meridional momentum flux and east ward direction for zonal momentum flux. For longer-period motions meridional momentum flux is towards north and zonal momentum flux is towards east except in the altitude range of 11-15 km for all the frequency bands. Especially in the lower stratosphere, both long and short-period motions are towards north and east ward directions. During 09-11 April 2001 zonal momentum flux is towards westward in the troposphere and lower stratosphere except in the altitude range of ~ 15-16.5 km for both short and long-period motions (figure not shown). Meridional momentum flux is towards southward in the troposphere and lower stratosphere for both short and long-period motions. During 17-19 July 2001 zonal momentum flux of short and long-period motions is towards westward, meridional momentum flux is towards northward in the altitude range of ~13-16.7km for both short and long-period motions(figure not shown). During 22-24 January 2002 zonal momentum flux of short and long - period motions are towards east in the altitude range of 11-19 km, meridional momentum fluxes are towards south in the altitude range of ~11-19km for both short and long-period motions (figure not shown).

Conclusions

The excitation source of the short period gravity waves was suggested to be located near the peak of the mean zonal wind. The vertical flux of zonal momentum for waves with periods of 2-24 hours showed westward bias in the 14-17 km. while the zonal flux showed no significant seasonal cycle in the middle troposphere implying that the upward propagating gravity waves in the lower stratosphere mostly travelled westward relative to the background wind. The long period gravity waves which caused these wind fluctuations were generated in the lower troposphere, the observed results suggest that the horizontal propagation of gravity waves is azimuthally isotropic near the wave source and the eastward travelling waves seem to be filtered out during their upward propagation, which might result in the observed westward bias of momentum flux. The overall results suggest that, due to their persistent southward direction of propagation, long-period waves make a contribution to the momentum flux in the lower stratosphere which is comparable to that of short-period waves.

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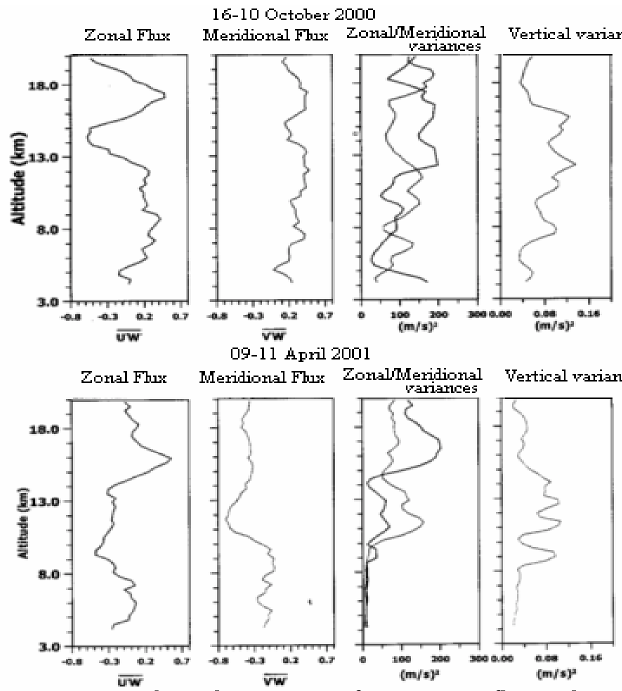

Figure1. Three-day average of momentum flux and variance of wind fluctuations determined from the MST radar data during 1000-1600 LT from 16-18 October 2000 (upper panel), 09-11 April 2001 (Lower panel). Thick and thin solid lines in third panel of both the lower and upper part shows the zonal and meridional variances respectively

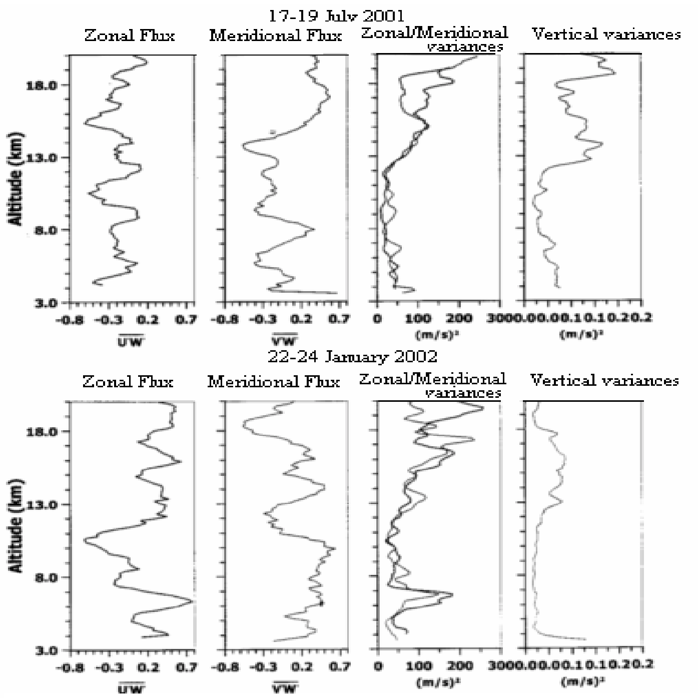

Figure 2. Same as figure 1 but for 17-19 July 2001 (Upper panel) and 22-24 January 2002 (Lower panel)

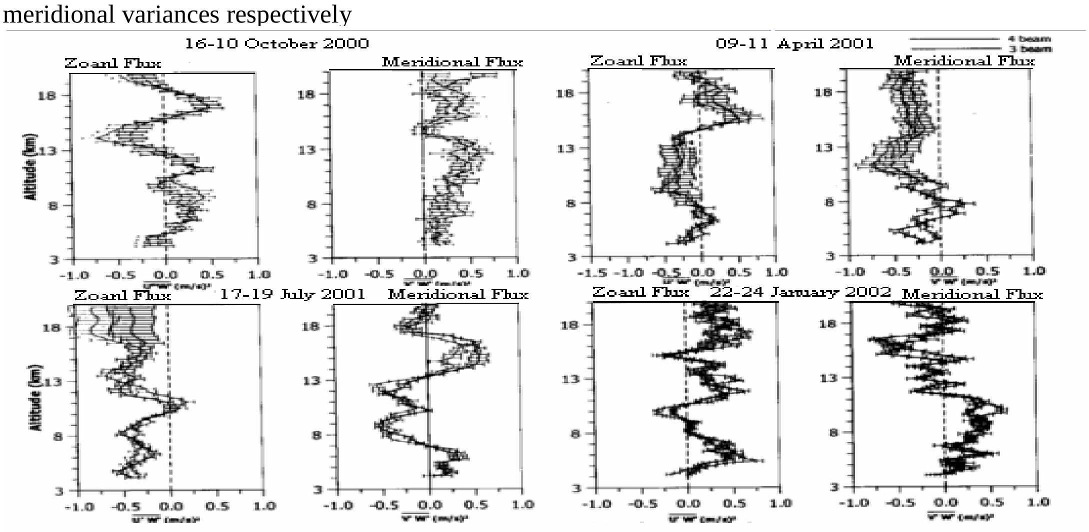

Figure 3. Momentum flux vertical profiles are determined by the four-beam and three-beam method using Indian MST radar winds

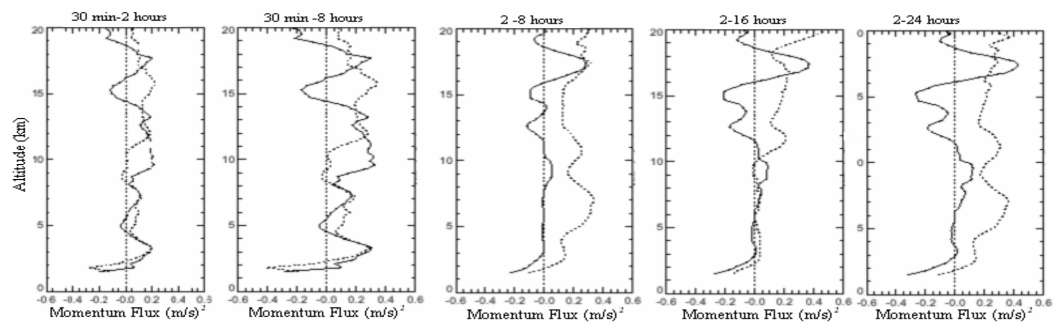

Figure 4. Vertical profiles of zonal and meridional momentum flux determined by the four beam method for different frequency bands during 16-19 October 2000. The solid line represents zonal momentum flux and dotted line represents meridional momentum flux