Vertical winds and 3-4 day momentum flux in the MLT inferred from meteor radar measurements.

Fábio Egito, Universidade Federal do Oeste da Bahia-UFOB
Paulo P. Batista, Barclay R. Clemesha, Instituto Nacional de Pesquisas Espaciais.
Ricardo A. Buriti, Universidade Federal da Campina Grande-UFCG.

This paper was prepared for presentation during the 14th International Congress of the Brazilian Geophysical Society held in Rio de Janeiro, Brazil, August 3-6, 2015.

Abstract

Planetary scale waves in equatorial region transport a significant amount of energy and momentum through atmosphere. Quantifying the momentum transported by these waves and its effects toward the mean flow is rather important. Direct estimative of the momentum flux transported by these waves requires horizontal and vertical wind measurements. Ground-based meteor radars have provided continuous and reliable measurements of the horizontal wind components in the MLT region. On the other hand, vertical wind component does not present the same reliability. However, an approach presented by Babu et al. (2012), made possible to calculate tridimensional daily winds by using only near zenith echoes detected around their maximum counting rate, i.e., during early morning hours. From daily tridimensional winds, momentum fluxes due to planetary scale waves can be estimated. Following this approach, we have used measurements performed by a meteor radar installed at São João do Cariri (7.4ºS; 36.5ºW) in order to measure vertical winds and after determine the momentum flux transported by these waves. Vertical wind presents magnitudes of a few meters per second and occasionally reaches magnitudes higher than 10 m/s. Below 92 km vertical wind is upward during the whole year and above exhibits a semi-annual oscillation with downward phase during the equinoxes. Variations associated to planetary scale waves in the vertical wind are also observed and some of them appear simultaneously in the zonal and meridional wind. Vertical transport of zonal momentum fluxes of 3-4 day component is found to be maximum near autumn equinox, when its value reaches almost 20 m^2s^{-2}, while minimum momentum fluxes were observed before winter solstice.

Introduction

Vertical winds play an important role in the dynamics of the middle atmosphere since they are responsible for vertical distribution of minor constituents and temperature. It is believed, for instance, that they contribute significantly to variations observed in the MLT airglow. Regarding atmospheric dynamic, considerable efforts have been done concerning the calculation of momentum fluxes transported by atmospheric waves, such as tides, gravity and planetary waves, which play an important role in forcing long period oscillations in the atmosphere such as Quasi-Biennial Oscillation (QBO), Semiannual Oscillation (SAO) and Intraseasonal Oscillation (ISO) (Andrews, 1987; Miyoshi and Fujiwara, 2006). Measurements of momentum fluxes require information about vertical wind component, in additional to the horizontal (zonal and meridional) ones. One successful technique to measure neutral winds in the MLT is that employed by meteor radars, in which winds are retrieved from backscatter of radio signals by meteor trails between 80 and 100 km height. This technique has provided continuous and reliable zonal and meridional winds, which have been used to study tides, gravity and planetary waves. In this case, winds are usually calculated in time/height bins of 1-2h/2-3km. However, vertical winds retrieved of this way do not present the same reliability as zonal and meridional ones and are neglected. Nevertheless, recently, Babu et al. (2012) presented an approach that made possible to retrieve daily vertical winds from meteor radar measurements. Then, they used retrieved three-dimensional wind to calculate the momentum flux transported by equatorial planetary scale waves and their effects toward the mean flow in the MLT.

In this paper we will present and discuss the procedures followed to calculate vertical winds from the meteor radar installed in the Brazilian equatorial region at São João do Cariri (7.4ºS, 36.5ºW) and also the characteristics of the retrieved vertical wind, as well the signatures of equatorial planetary scale waves. Finally, we will present and discuss the estimates of the vertical transport of zonal momentum flux due to 3-4 day wave component.

Method

Neutral wind components are derived by using measurements performed by the meteor radar installed at São João do Cariri (7.4ºS, 36.5ºW). The radar operates at 35.24MHz frequency and consists of one transmitter antenna and an array of five receiving ones. The radar transmits pulses of 12kw power peak. Many investigations of MLT dynamics involving gravity waves, tides and planetary waves have been conducted by means of data provided by this radar. Most of them have used horizontal (zonal e meridional) wind components. Meteor radar provides positional information, i.e., altitude, zenith (θ) and (ϕ) azimuth angles, along with radial velocity (V_r) of each meteor. In terms of the zonal (u), meridional (v) and vertical (w) velocities and angle positions, the radial velocity can be expressed as follow:

$$V_r = u\sin\theta\cos\phi + v\sin\theta\sin\phi + w\cos\theta \quad (1)$$

By grouping the echoes detected by the radar in time/height bins three-dimensional wind (*u, v, w*) can be retrieved by inverting the equation 1. For most of the studies involving horizontal wind, echoes are usually grouped in 1-2h/2-3km bins. In this case, about 10 meteors are sufficient to retrieve the horizontal winds with reasonable accuracy. In this case, the vertical wind is normally neglected. However, if one wants to improve reliability in the retrieved vertical wind it is necessary to increase the number of meteors used to calculate the wind components. Following the method proposed by Babu et al. (2012), to increase the confidence in the retrieved vertical wind restrictions in the position and the time of acquisition of the meteors are imposed. Meteor detection presents a diurnal variation in their count rate, i.e., during certain periods of the day the number of meteors is maximum. Usually, meteor counting peaks during early morning hours. Then, to estimate daily three-dimensional wind we use only meteors detected between 04:00 and 11:00 UT (around the counting peak) and between 10º and 35º zenith angles. Meteors are binned in five vertical layers centered at 82, 86, 90, 94 and 98 km height with thickness of 4 km and overlapped (below and above) by 1 km. Winds have been calculated only when a minimum of 30 meteors for each time/height bin were detected by the radar. Standard deviations involved in the vertical wind determination do not exceed 10% of the calculated value.

Results

Vertical wind has been calculated as described in the previous section at 82, 86, 90, 94 and 98 km during 2005 year and the results are shown in Figure 1. It is possible to observe that vertical wind presents magnitudes of a few meters per second and varies near zero wind line especially at 86 and 90 km. Occasionally, it reaches magnitudes around 10 m/s and are more variable at lower and higher altitudes. We also calculate yearly mean wind and its values are found to decrease with altitude from 3 m/s at 82 km to near zero at 98 km. Vertical wind variances tends to increase with altitude up to 94 km. At 82 km variance is found to be around 10 m^2s^{-2} and between 86 and 94 km stays approximately constant exhibiting values around 5 m^2s^{-2}. Above 94 km variance is maxima and reaches around 25 m^2s^{-2}. In the MLT reported of vertical wind magnitudes are quite variable. They range from a few centimeters (Fauliot et al., 1997) up to 30 meters per second (Bhattacharya and Gerrard, 2010), which result from individual measurements. From meteor radar measurements, Babu et al. (2012) reported vertical wind magnitudes ranging from 0.5 to 6 m/s in the equatorial MLT region. As one can see, our results about vertical wind are quite similar to those obtained by Babu et al. (2012) and it is worth to point out again that they were obtained employing a similar methodology as Babu et al. (2012), which helps to reinforce them.

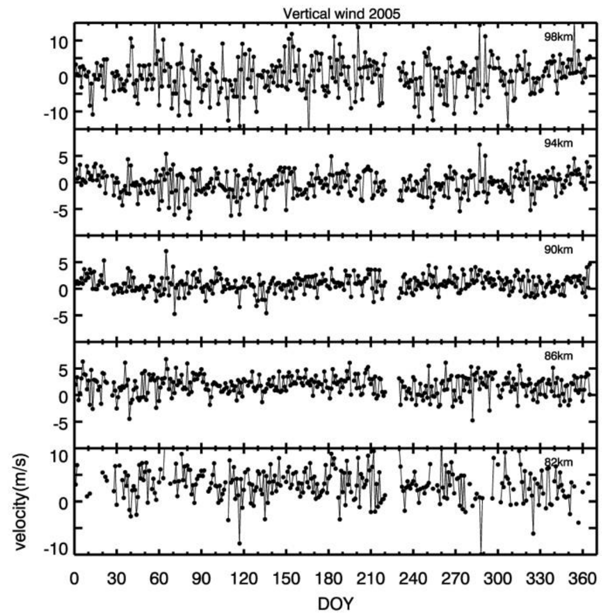

Figure 1 – Daily vertical wind at 82, 86, 90, 94 and 98 km from Cariri meteor radar in 2005.

Figure 2 shows the monthly mean vertical winds in a time-height frame. Monthly winds present small values (1 to 3 m/s) and also a consistent annual variation. Annual and semiannual components are dominant in all altitudes. Below ~90 km the winds for 2005 are positive (upward) and above this height there is a clear semiannual variation with maximum downward winds at the equinoxes and maximum upward winds in the solstices. From satellites measurements, Fauliot et al., (1997), found that in the equatorial region vertical winds are upward up to 105 km, which partially agrees with the results presented here, despite differences in the magnitudes.

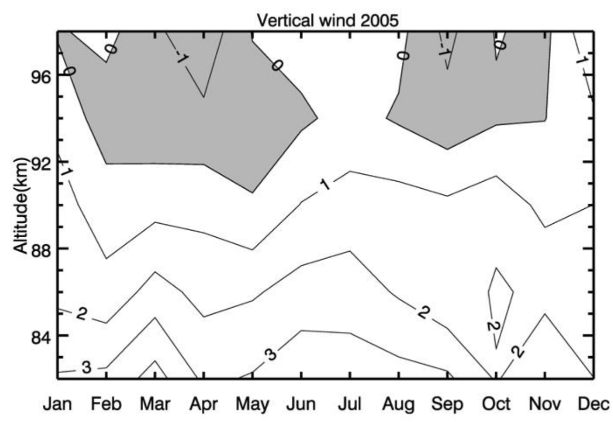

Figure 2 – Monthly mean vertical wind.

To reveal dominant periodicities in the wind components, we have performed spectral analysis using wavelet transform (Torrence and Compo, 1998). Figure 3 shows the wavelet spectra of the zonal and meridional wind at 90 km and of the vertical wind at 86, 90, 94 and 98 km. Wavelet spectral content exhibits clear signatures at planetary scale wave periods, especially around 3.5, 6.5, 10 and 16 days. At these periods, simultaneous signatures can be observed in the vertical and zonal wind components, as well in the vertical and meridional wind ones. Looking at zonal and meridional wind spectra, we can see that these signatures are similar to those observed by Lima et al., 2008, in which whole day and all sky Cariri meteor radar data were considered. This finding indicates that wind variations are not affected when they are derived from a limited region and time.

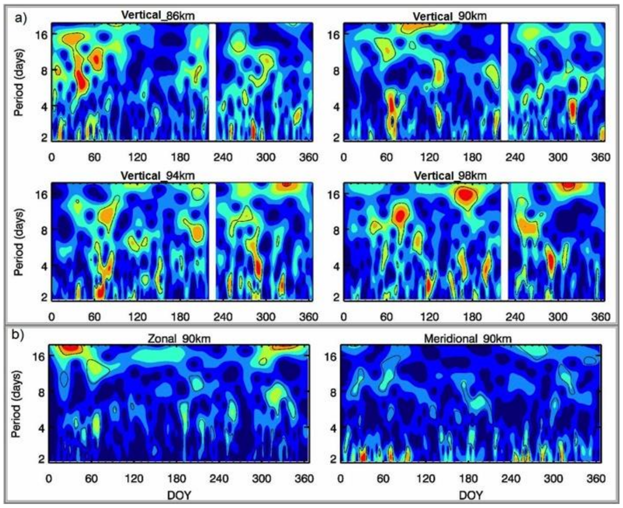

Figure 3 – Wavelet spectra of the vertical wind at 86, 90, 94 and 96 km. b) Zonal (left) and meridional (right) wavelet spectra at 90 km.

To illustrate the simultaneous presence of planetary scale wave signatures in the vertical and horizontal wind, Figure 4 shows an example of an variation around 4 days in the vertical (red line) and zonal wind (black line) during March 2005 at 90 km. As one can see, between days 64 and 71, vertical wind and zonal wind oscillate almost in phase. At the same site, previous reports (Takahashi et al., 2007; Lima et al., 2008) found that a 3.5-day ultra-fast Kelvin wave was present during this time. Planetary scale waves have extensively studied in the MLT by means of horizontal wind components, which are measured with good accuracy by meteor radar soundings. Given the difficulties to obtain reliable vertical wind measurements with meteor radars, simultaneous presence of planetary scale wave signatures in both vertical and horizontal (zonal and meridional) wind components can contribute to improve confidence in the derived vertical wind. If the uncertainties in the values can be subject of doubts, its time variability due to planetary scale waves seems to be feasible.

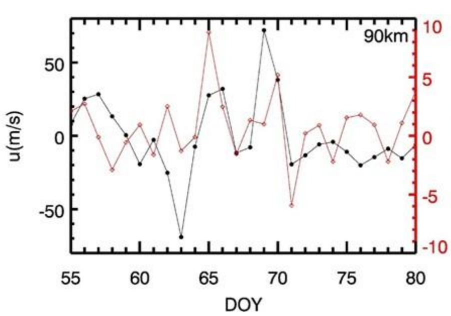

Figure 4 – Common 3-4 day variation in the zonal and vertical wind variation at 90 km during March 2005.

After identifying planetary wave signatures, perturbations in the wind components can be extracted out to estimate the momentum flux transported by the waves. Momentum flux can be estimated from the product between perturbations (*u', v', w'*) in zonal, meridional and vertical wind, respectively. Products *u'w', v'w'* and *u'v'* represent, respectively, vertical transport of zonal momentum, vertical transport of meridional momentum and horizontal transport of horizontal momentum. Here we present and discuss about the vertical flux of zonal momentum *u'w'* associated to 3-4 day component. This component is usually associated to ultra-fast Kelvin waves (Riggin et al., 1997; Yoshida et al., 1999; Kovalam et al., 1999; Younger and Mitchell, 2006; Lima et al., 2008; Davis et al., 2012; Takahashi et al., 2002; Buriti et al., 2005) and there are several investigations concerning the momentum flux transported by this wave. Time series of the perturbations u' and w' due to planetary scale waves are reconstructed by using wavelet transform. Figure 5 shows the height profiles of *u'w'* momentum fluxes in four distinct occasions when 3-4 day oscillations were observed simultaneously in the zonal and vertical wind. Numbers on the top represent the interval, in days of year, when oscillations were observed, which represent different seasons. A general examination of the Figure 5 shows that momentum flux exhibits eastward and westward transport, but most of time is eastward. Largest values of momentum flux are observed near autumn equinox (days 60-75), when it increases between 82 km and 90 km reaching almost 20 m^2s^{-2} and decrease above. During this time momentum flux is predominantly eastward. On the other hand, momentum flux transport is minimum just before winter solstice (days 140-155) when varies from around 4 m^2s^{-2} at 82 km to around -2 m^2s^{-2} at 98 km and, in this case, momentum flux transport changes its direction from eastward to westward. Height profiles and magnitudes of momentum fluxes are somewhat similar after winter solstice (days 206-221) and during spring (days 310-325), when momentum fluxes tend to increase with height and present similar magnitudes.

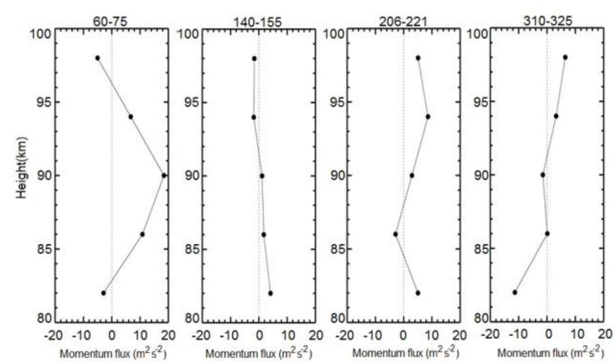

Figure 5 – Height profile of the vertical flux of zonal momentum flux in the band of 3-4 day in four distinct occasions.

Direct estimates of the momentum flux transported by planetary scale waves in the equatorial region are scarce. At our knowledge, Babu et al. (2012) paper is the first observational study to deal with this subject. Their results show that *u'w'* momentum flux in the band correspondent to 3-4 day component is found to increase with height during autumn equinox and reaches about 18 m^2s^{-2} at 98 km. During winter and vernal equinox $u'w'$ momentum flux magnitudes are less than 10 m^2s^{-2} and present similar height variations being most of time eastward.

As pointed out before, variations in atmospheric parameters such as zonal wind and airglow in the band of 3-4 day in the MLT have been associated to ultra-fast Kelvin waves. In several investigations, due to difficulties of measuring vertical winds, momentum fluxes are estimated by using dispersion and polarization relations for Kelvin waves, which allows one to recovery perturbation in the vertical wind (w') in terms of perturbation in the zonal wind (u') and atmospheric density, which can be obtained from models, such as MSIS-E-90 (Riggin et al., 1997; Kovalam et al., 1999; Davis et al., 2012). In this case, momentum fluxes are expressed in units of $kgm^{-1}s^{-2}$. In spite of being estimated in different units, comparison with this sort of measurement can be valuable. Davis et al. (2012) applied this method to the meteor radar data from Ascension Island (8ºS, 14ºW), which is located almost at almost the same latitude as Cariri, and determined monthly momentum fluxes of the 3-4 day component in a composite year sense with data from 2005 to 2010. Their findings show that 3-4 day momentum flux exhibits a clear seasonal variation maximizing February, July and November and decrease with height. As one can see much of the features of $u'w'$ 3-4 day momentum fluxes we presented here are in reasonable agreement with what has been previously published and discussed as much for direct measurements momentum flux component as for indirect ones. In the case of Babu et al. (2012) study, besides qualitative features related to seasonal variation of 3-4 day $u'w'$ momentum flux, magnitudes are also similar, which suggests the consistence of our results. As a next step, we intend to calculate the effects of such waves toward mean flow.

Conclusions

In this paper, we presented the estimates of the vertical wind retrieved from a meteor radar installed in the Brazilian equatorial region based in a recent published methodology and the signatures of planetary scale waves on it. In additional, vertical transport of zonal momentum flux $u'w'$ of 3-4 day component has been calculated. Vertical wind usually presents magnitudes of a few meters per second and occasionally reaches magnitudes higher than 10 m/s. Monthly mean vertical wind is upward most of the time and exhibits distinct behavior with height. Below 92 km the wind is upward during the whole year and above this level presents a semi-annual oscillation with downward phase during the equinoxes. The vertical wind presents periodic variations associated with equatorial planetary scale waves and some of them are simultaneously observed in the zonal and meridional wind components. Vertical transport of 3-4 day zonal momentum flux are as much eastward as westward, but eastward transport is predominant. Largest values of momentum flux are observed near autumn equinox and minima before winter solstice. After winter solstice and during spring, momentum fluxes exhibits similar behavior. In general, our results are consistent with those previously published as much for vertical wind as for momentum fluxes.

Acknowledgments

We are thankful to Fundação de Amparo à Pesquisa do Estado de São Paulo – Fapesp (processes nº 2013/00166-6) for support our research and to Universidade Federal do Oeste da Bahia (UFOB) for supporting our attendance at this congress.

References

ANDREWS, D. G., HOLTON, J. R. and LEOVY, C. B. **Middle Atmosphere Dynamics**. Academic Press, 1987.

BABU, V. S.; RAMKUMAR, G.; JOHN, S. R. Seasonal variation of planetary wave momentum flux and the forcing towards mean flow acceleration in the MLT region. **Journal of Atmospheric and Solar-Terrestrial Physics**. v.78-79,n.p. 53-61, 2012.

BHATTACHARYA, Y.; GERRARD, A.J. Winter time mesopause region vertical winds from Resolute Bay. **Journal of Geophysical Research.** Vol. 115, D00N07, 12 pp., 2010.

BURITI, R. A.; TAKAHASHI, H.; LIMA, L. M.; MEDEIROS, A. F. Equatorial planetary waves in the mesosphere observed by airglow periodic oscillations. **Advanced in Spaces Research**. vol. 35, p.2031-2036, 2005.

DAVIS, R. N.; CHEN, Y. W.; MIYAHARA, S.; MITCHELL, N. J. The climatology, propagation and excitation of ultra-fast Kelvin waves as observed by meteor radar, Aura MLS, TRMM and the Kyushu-GCM. **Atmos. Chem. Phys**. Vol. 12, p. 1865-1879, 2012.

FAULIOT, V.; THUILLIER, G.; VIAL, F. Mean vertical wind in the mesosphere-lower thermosphere region (80-120 km) deduced from the WINDII observations on board UARS. **Ann. Geophysicae**. Vol. 15, p. 1221-1231, 1997.

KOVALAM, S.; VINCENT, R.A.; REID, I.M.; TSUDA, T.; NAKAMURA, T.; OHNISHI, K.; NURYANTO, A.; WIRYOSUMARTO, H. Longitudinal variations in planetary wave activity in the equatorial mesosphere. **Earth Planets and Space.** vol. 51, n. 7-8, 665–674, 1999.

LIMA, L. M.; ALVES, E. O.; MEDEIROS, A. F.; BURITI, R. A.; BATISTA, P. P.; CLEMESHA, B. R. AND TAKAHASHI, H**.** 3-4 day Kelvin waves observed in the MLT region at 7.4º S, Brazil. **Geofísica Internacional.** Vol. 47 (3), p.153-160, 2008.

MIYOSHI, Y. and FUJIWARA, H. Excitation mechanism of intraseasonal oscillation in the equatorial mesosphere and lower thermosphere. **Journal of Geophysical Research-Atmospheres**. v.111,n.D14, p. 2006.

RIGGIN, D.M.; FRITTS, D.C.; TSUDA, T.; NAKAMURA, T.; VINCENT, R.A. Radar observations of a 3-day Kelvin wave in the equatorial mesosphere. **Journal of Geophysical. Research**. 102 (D22), 26141–26157, 1997.

TAKAHASHI, H., WRASSE, C. M., FECHINE, J., PANCHEVA, D., ABDU, M. A., BATISTA, I. S., LIMA, L. M., BATISTA, P. P., CLEMESHA, B. R., SCHUCH, N. J., SHIOKAWA, K., GOBBI, D., MLYNCZAK, M. G. and RUSSELL, J. M. Signatures of ultra fast Kelvin waves in the equatorial middle atmosphere and ionosphere. **Geophysical Research Letters**. v.34, 11, 2007.

TAKAHASHI, H.; BURITI, R A; GOBBI, D; BATISTA, P. P. Equatorial planetary wave signatures observed in mesospheric airglow emissions. **Journal of Atmospheric and Solar-Terrestrial Physics**, vol. 64, p. 1263-1272, 2002.

TORRENCE, C. and COMPO, G. P. A practical guide to wavelet analysis. **Bulletin of the American Meteorological Society**. v.79,n.1, p. 61-78, 1998.

YOSHIDA, S.; et al. Seasonal variations of 3.0~3.8-day ultra-fast Kelvin waves observed with a meteor wind radar and radiosonde in Indonesia. **Earth Planets Space**, v. 51, n. 7-8, p. 675-684,1999.

YOUNGER, P. T.; MITCHELL, N.J. Waves with period near 3 days in the equatorial mesosphere and lower thermosphere over Ascension Island. **Journal of Atmospheric and Solar-Terrestrial Physics**, v. 68, n. 3-5, p. 369-378, 2006.