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Gravity wave amplitudes and momentum fluxes inferred from OH airglow intensities and meteor radar winds during SpreadFEx

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Abstract. We show in this report the momentum flux content input in the mesosphere due to relatively fast and small scale gravity waves (GWs) observed through OH airglow images. The acquisition of OH NIR images was carried out in Brazil at Brasilia (14.8° S, 47.6° W) and Cariri (7.4° S, 36.5° W) from September 2005 to November 2005 during the SpreadFEx Campaign. Horizontal wind information from meteor radar was available in Cariri only. Our findings showed strong wave activity in both sites, mainly in Cariri. High wave directionality was also observed in both sites during SpreadFEx, which have been observed by other investigators using different analysis' techniques and different types of data during the campaign. We discuss also the possibility of plasma bubble seeding by gravity waves presenting spatial and temporal scales estimated with our novel analysis technique during the SpreadFEx campaign.

Keywords. Atmospheric composition and structure (Airglow and aurora) – Meteorology and atmospheric dynamics (Middle atmosphere dynamics; Waves and tides)

1 Introduction

Atmospheric gravity waves have a great significance in the global circulation at mesosphere and lower thermosphere (MLT) region. In this sense, there is considerable interest in measuring momentum fluxes carried by those waves (Holton, 1982; Gardner et al., 1999). Co-located optical imagers and radar wind instruments (mean horizontal wind information) at the same observation site are combined to provide intrinsic wave parameters (frequency, horizontal wavelength, direction of propagation), determined directly from the airglow images. Intrinsic wave parameters permit to estimate the momentum fluxes, which are used as indicators of wave activities at the mesosphere region (e.g., Swenson and Liu, 1998). The vertical wavelength is calculated from the theory of the gravity wave propagation as usual by using the dispersion relation. The gravity wave amplitude is another essential parameter required to infer wave fluxes.

The task of determining wave amplitudes by way of airglow variations is not simple, mainly for two reasons: first, the altitude variation of the minor constituent perturbations are not the same of that the background gas, i.e. the airglow chemistry generally is important; second, the wave amplitude is related to the vertical extension of the airglow emission layer (~8 km), which filters out short vertical wavelength gravity waves. Swenson and Liu (1998) and Vargas et al. (2007) have developed a method of representing analytically perturbations of the airglow emission radiance (ratio between the radiance I and temperature T variances) as a means of estimating wave momentum fluxes from all-sky airglow image data. Specifically for the OH emission, the ratio $(I'/I)/(T'/T)$, called the "Cancellation Factor", CF, is approximated by the exponential fitting (Vargas et al., 2007)

$$\mathrm{CF} = 3.68 - 3.41 \exp[-0.0053(\lambda_z - 6)^2] \quad (1)$$

where the vertical wavelength λ_z is given in km (CF can be neglected if $\lambda_z < 6$ km). Virtually the equation is not valid for vertical wavelengths smaller than 12 km because the error associated with CF is very large in this range.

In this study, the momentum flux per mass unit is defined as the covariance between the horizontal (u', v') and vertical (w') wind fluctuations, averaged over one wave cycle. Here u' is the fluctuation on the zonal wind and v' is the fluctuation on the meridional wind. Zonal and meridional components of wave fluxes are calculated by using the acoustic-gravity wave polarization relations in terms of the temperature amplitudes (Fritts and Alexander, 2003) and CF model (Eq. 1),

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that are combined to give a set of equations for zonal and meridional momentum flux, that is:

$$F_{\mathrm{Zon}}/\bar{\rho} = \langle u'w' \rangle = -\frac{1}{2}\frac{km\omega^2}{k^2+l^2}\frac{g^2}{N^4}\left(\frac{I'/\bar{I}}{\mathrm{CF}}\right)^2$$

$$F_{\mathrm{Mer}}/\bar{\rho} = \langle v'w' \rangle = -\frac{1}{2}\frac{lm\omega^2}{k^2+l^2}\frac{g^2}{N^4}\left(\frac{I'/\bar{I}}{\mathrm{CF}}\right)^2 \qquad (2)$$

where $\bar{\rho}$ is the mean mass density of the atmosphere, k and l are the zonal and meridional wavenumbers, m is the vertical wavenumber, ω is the intrinsic frequency, g is the gravity acceleration and N the buoyancy frequency.

Image data obtained during the SpreadFEx campaign at two sites, Brasilia (14.8° S, 47.6° W) and Cariri (7.4° S, 36.5° W) with optical imagers of OH NIR airglow are used for gravity wave studies. Particularly for Cariri, these measures are combined with radar wind observations to infer intrinsic wave parameters. General characteristics of gravity wave parameters obtained and momentum fluxes estimations were investigated in this paper. A short discussion in terms of momentum fluxes is presented for two nights with evidence of strong correlation between wave motion followed by ionospheric plasma depletion, which are compared to the results obtained by Takahashi et al. (2009).

2 Observations and data analysis

The database used in this report has been taken at two sites in Brazil during the SpreadFEx Campaign by using two all-sky airglow imagers. Both of them use a backilluminated CCD sensor of 1024×1024 pixels. The exposition time was 15 s for recording OH images, while the sampling rate between images was about 2 min. An all-sky CCD image covers a large horizontal extension of the nocturnal sky, but here it was used an area of 512×512 km centered at the zenith in order to avoid lens distortion at the edges of the images. For a complete description of the all-sky CCD imagers used in this work see Takahashi et al. (2009) or Medeiros et al. (2004).

We selected for analysis 15 nights of OH images in Brasilia and 21 nights of data in Cariri. Time intervals of clear nocturnal sky of each night were selected by using keogram analysis. Keograms are built from the images acquired during the night by taking the central row (or column) of each one and placing them side by side in a new image. Keograms permit to check rapidly the luminosity of the central portion of the sky during the observation period and also permit to define quickly the best time interval for analysis during one specific night.

During the campaign in Cariri, horizontal wind data obtained with meteor radar were available, but not in Brasília. Horizontal wind estimation over Brasilia for one single night (from 24 October to 25 October) was provided by S. Vadas (private communication). S. Vadas used meteor radar wind data (averaged) from 80–100 km linearly interpolated to the TIME-GCM (thermosphere – ionosphere – mesosphere – electrodynamics general circulation model) to estimate horizontal wind magnitudes over Brasilia. We used those wind profiles ahead in this paper for pointing out differences observed on the estimated wave parameters under the influence of the horizontal atmospheric flow.

Gravity waves present in airglow images were analyzed with a modified version of the method described by Tang et al. (2005). Their analysis method was designed for obtaining wave parameters (frequency, horizontal and vertical wavelength, phase velocity, propagation direction, relative wave amplitude I'/I) and associated energy and momentum fluxes of GWs disturbing the OH layer only. We have extended the method by including O_2 and OI5577 emissions. We will give here only general aspects of the extended version of Tang's method. A complete description of it will be given in a separate paper.

The field of view considered in our procedure has an extension of 512×512 km. It was defined a box of 150×150 km of field of view for analysis and GW parameter estimation. We can avoid spectral contamination of the Milky Way if it is appearing on the images by changing the position of the analysis box by placing it at the southeast portion of the image. The analysis box is positioned at the zenith of the image when it is not the case.

The algorithm performs first typical corrections on the images, including flat fielding, unwarping and star removal operations. If horizontal wind information is available, it is used for Doppler shift correction of each image (Fig. 1a). The images acquired during one specific night are then subtracted from one to another to obtain time difference (TD) images (Fig. 1b). The time difference operation benefits the detection of small period waves (high frequency), working as a bandpass filter of large wave periods. Also, TD images show a better contrast, which benefits visual inspection of waves on the field of view. The amount of images recorded in one night depends on the observational conditions during that period. Typically more than 200 images of the OH emission are recorded during one observation night.

The method processes a set of three sequential images which result in two TD images and automatically calculates wave parameters of prominent events in the field of view (Fig. 1b). At this point, the cross spectra is computed by using two remaining TD images. The amplitude periodogram is a result of the cross spectra operation (Fig. 1c) and is used for estimating the relative amplitude I'/I of dominant waves (prominent peaks), their direction of propagation and their horizontal wavelength. Basically, the direction of propagation is given by the position of the peak in the plot in terms of wavelength (cartesian relation between the x-component of the position and the y-component). The relative amplitude I'/I is given by the integrated area surrounding a prominent peak. The horizontal wavelength is the distance from the origin of periodogram to that given peak. The phase velocity and the period of dominant waves are obtained from the