Searching for Tropospheric Sources of Gravity Waves Observed in Airglow Emissions

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Abstract

Atmospheric gravity waves have been largely observed through the mesospheric airglow layers using all-sky CCD imager. This technique provides useful information about the gravity waves horizontal structure, phase velocity and period. An all-sky CCD imager for the airglow OH emission was installed and operated at São João do Cariri (PB) (7°S, 36°W), between September 2000 and September 2001. Dominant gravity waves were extracted form this images, which showed horizontal wavelength typically between 5 to 80 km, period of 5 – 36 minutes and horizontal phase speed of 5 to 95 m/s. In order to find possible source of the gravity waves, the ray tracing technique was used using the CIRA86 wind and temperature models, including the GSWM tidal wind model. The locations of the tropospheric sources were related with the cloud convection activity observed in the infrared images taken by GOES satellite.

Introduction

Gravity waves in the middle atmosphere are known to transport momentum and energy form the lower atmosphere to the upper atmosphere. The transference of momentum is given when the gravity waves are broken or damped at mesospheric heights due the rapid change in the background wind and temperature profiles (e.g. Lindzen, 1981; Fritts, 1982, 1984).

The recent development of highly sensitive cooled CCD (Charge Coupled Device) camera has made it possible to measure two-dimensional structure through out the airglow layers (Taylor et al., 1995). These observations made it possible to investigate the horizontal structure more directly and clearly, and has been applied to observe the characteristics of gravity waves with short periods (< 1 hour) and small horizontal wavelengths (5~100 km) at various locations. However, only the waves with long vertical wavelength are observed due the thickness of the airglow layers (~10 km) (Nakamura et al. 1999).

The source of these waves was thought to be in the troposphere from which the wave propagates upward in the middle atmosphere (Taylor and Hapgood, 1988). Several mechanisms susceptible of generating gravity waves have been identified. The most common one is the emission of waves by a flow over orography (Nastrom and Fritts, 1992), shear instability (Fritts and Nastrom, 1992), convection (Lu et al, 1984; Pfisler et al, 1986), frontal acceleration and geostrophic adjustments (Ford et al, 2000). However, in-situ excitation at airglow altitudes or ducting in the upper middle atmosphere has also been suggested by observations and numerical modelings (Ilser et al., 1997).

The ray tracing technique has been used to investigate the effect of background wind and temperature variation on the gravity wave propagation. Zhong et al. (1995) used the ray tracing technique to investigate the propagation of gravity waves through the middle atmosphere characterized by a vertically wind and temperature models, plus a tidal wind model that has a temporal and vertical variation. The reversal ray tracing has also been used to locate the source of the gravity wave disturbances (e.g. Bertin et al. 1978, Hertzog et. al., 2001). This technique is useful when the gravity wave signatures are located in the upper mesosphere and lower thermosphere (MLT) region and to find out the source region in the lower heights.

In this present work, we use airglow image data observed at São João do Cariri (7°S, 36°W), Brazil, to investigate the wave sources using the reversal ray tracing method. The COSPAR International Reference Atmosphere, CIRA-1986, (Fleming et al., 1988) wind and temperature models and the Global Scale Wind Model, GSWM-2002 (Hagan and Forbes, 2002) tidal model, were used in the analysis.

Observations and Gravity Waves Characteristics

The observations were carried out at São João do Cariri (7°S, 36), hereafter Cariri, using an all-sky CCD imager to measure the OH airglow emissions. The measurements were taken between September 2000 to September 2001 and a total of 327 gravity waves events were observed. The CCD imager is composed by a fish-eye lens with a 180° field of view, a telecentric lens system, a broadband pass band filter for the near-infrared OH emission (715-930 nm), a narrow band filter for the OI(557.7 nm), O2, and OI(630.0 nm) emissions and a CCD chip with a large area (6.45 cm^2) and high resolution, 1024x1024 back-illuminated array with a pixel size of 14 bits. The exposure time for each airglow layers was set as 15 s for the OH airglow layer and 90 s for the OI(557.5nm), O2 OI(630 nm) airglow layers. The image acquired was binned on-chip down to 512×512 resolution to enhance the signal-to-noise ratio. Medeiros et al. 2001, 2003 reported the details of the equipment, data acquisition and methodology used in the data analysis.

The horizontal wavelength of gravity waves is mainly distributed between 10-25 km and the observed period is distributed between 4-10 min, which are similar to the gravity waves observed at Cachoeira Paulista (22.7°S) using a similar CCD imager. However, the horizontal phase speed is distributed between 10-100 m/s which is a bit larger compared whit Cachoeira Paulista, mainly distributed 10-40 m/s. The propagation direction is mainly in eastward/northward direction during summer/winter.

Figure 1 shows an example of a gravity wave event observed in OH airglow emission around 8:20 Local Time (LT) on October 1st, 2000. The top and the left side of each image represent north and west directions respectively. The gravity wave was a band type wave with horizontal wavelength of 27.7 km, period of 5.4 min. and speed of 19.8 m/s propagating to northeast direction (55.7°).

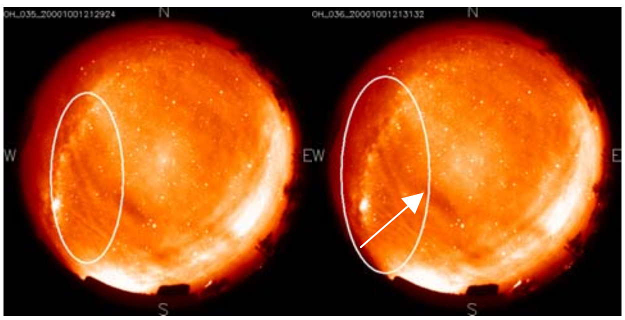

Figure 1 – Gravity wave event observed at São João do Cariri on October 1th,2000 at 20:25 LT. Note that the white ellipses show the region in the image where the wave was observed and the arrow indicates the propagation direction.

Ray Tracing Results

A simple ray tracing model for gravity waves was used for computing the back trajectory of the observed wave packet to its source region. Our model uses the base ray tracing equations described by Marks and Eckermann (1995) to trace backwards the trajectory of the gravity waves observed in the mesopause region in order to estimate source region of them. The effects of background and tidal wind fields in the ray tracing technique are also tested for the wave propagation condition. The ray tracing technique require some initial parameters to find out the region source of wave, like the background wind velocity and temperature, Brunt-Väisälä frequency and the observed parameters such as horizontal wavelength, horizontal phase speed and propagation direction. However, the observational data corresponding to the wind velocity and temperature near the observation site were not available.

Thus, in this work CIRA-86 model was used to get zonal wind and temperature data. These data were linearly interpolated to get a 2.5° resolution in zonal and meridional directions and height interval of 1 km. The GSWM-02 tidal wind model, was also computed in the ray tracing, provides the diurnal atmospheric tide parameters such as the amplitude and phase of zonal and meridional wind components. The data has a spatial resolution of 3° in meridional direction and was interpolated in height to get a resolution of 1 km.

The background meridional wind component was assumed to be zero, since the CIRA-86 model does not contain it, while the tidal component of the meridional wind was considered. The absence of meridional wind would not introduce a significant error in the estimated gravity wave source, considering that the mean meridional wind, around ±10 m/s, is relatively smaller compared to the zonal wind, which is around ± 50 m/s.

In building a ray tracing model, is necessary a careful choice of an appropriate time increment, δt, for the integrations. A small δt ensures accurate ray paths but requires large amount of computing time. However, too large a choice for δt leads to small errors at each time step, which accumulate into large errors in wave parameters and trajectories over longer times (Marks and Eckermann, 1995). In this model we integrate the ray tracing using a time step of 100m/Cgz and height resolution of 100 m. To assure that the WKB approximation remain valid for the ray parameters, the integration is stopped under either of the following conditions: 1) where the value of m^2 (vertical wavenumber) becomes negative, the wave cannot propagate vertically under that condition; 2) when m^2 becomes more than 1×10^6 (cyc^2/m^2), in this condition vertical wavelength becomes less than 1 km and it is close to a critical level; 3) when the intrinsic frequency, $\hat{\omega} \to 0$ or $\hat{\omega} < 0$, result a $|m| \to \infty$, which means that the wave is approaching to a critical level and the wave packet is likely to break. The points to which the ray is traced backwards in time will be referred to as 'final point' of the wave hereafter.

Figure 2 shows the result of ray tracing technique, applied to the wave event observed in Figure 1. The plot of longitude-latitude map is shown, together with altitude-latitude and longitude-altitude cross-sections. The solid line represents the ray path of the wave using the CIRA-86 +GSWM-02 wind models.

The characteristics of the gravity wave in Figure 1 were first determined from the image analysis of the OH airglow emission (located at around 87 km of altitude). After applying the ray tracing, the source region was estimated to be around 9.8° S 39.8° W. The ray tracing stopped near the ground and this position is to be considered as the source region of the wave. The horizontal distance between the observation site and source location was estimated around 600 km.

The ray tracing model also determines the wave parameter along the ray path. Figure 3 shows these parameters for the gravity wave in Figure 1. In the longitude and latitude panels could be observed a large drift of the wave packed between 55 and 70 km. This is due the increase of the zonal wind with the altitude until reach the maximum value ~ 60 km, which leads to a maximum value of zonal group velocity in this altitude. In the same way, the meridional component of the tide wind also increases with the altitude (maximum ~ 70 km) and increases the meridional group velocity. However, at these altitudes the Brunt-Väisälä frequency became smaller affecting the intrinsic frequency and vertical group velocity, resulting in a decrease of the vertical wavelength around 65 km to ~ 3 km. These variations on the basic parameters of the atmosphere could explain the occurrence of drifts observed in the gravity waves ray paths (e.g. Figure 2, bottom and left panels). Some changes are also noted between 1-40 km where the zonal wind tilts from westward to eastward direction and the ray parameters shown a small variation in this range compared to the mesospheric heights.

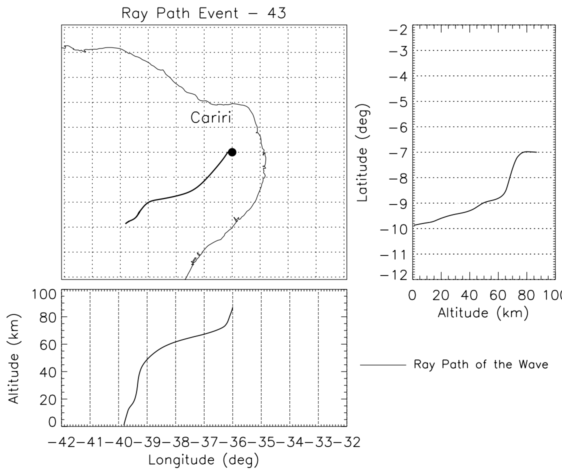

Figure 2 – Ray tracing technique applied to a gravity wave event showed in Figure 1. The center, right and bottom panels show the plot of longitude-latitude, altitude-latitude and longitude altitude cross-sections.

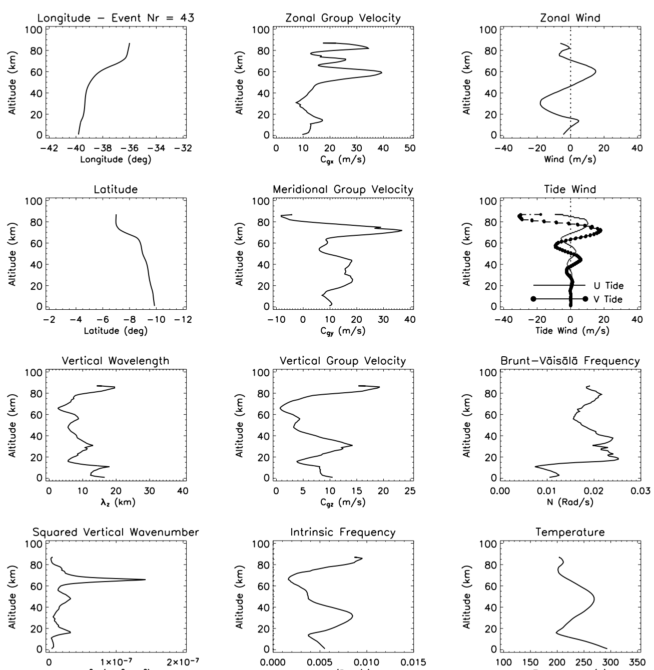

Figure 3 – Plots of the estimated parameters for the gravity wave event shown in Figure 1.

Discussions

One of the factors to characterize propagation direction of the gravity waves is distribution of the wave source around the observation site. In low latitudes, convective cloud activity is considered to be an important source of gravity waves (Nakamura et al., 2003). Therefore, we investigate the cloud distribution using infrared images obtained by GOES 8 (Geosynchronos Operational Enviromental Satellites) satellite.

Figure 4 shows the cloud distribution between 12:00 and 00:00 LT in north and northeast site of Brazil on October 1st, 2000. At 12:00 LT the satellite image shows a cloud cover in west and southwest site of Cariri. The panels from 15:00 LT to 00:00 LT shown the ray path of the gravity wave seen in Figure 1 plotted (red line) over satellite image. Using the ray tracing model, the launched time of gravity wave was estimated ~ 14:30 LT and 1 km of altitude. The satellite images show that the clouds moves toward the observation site region during this period. In fact, some clouds were observed in the OH images late afternoon and earlier in the morning of October 2nd,2000. Such convective clouds are associated with heat transfer from the earth surface and the latent heat released to the air during condensation, both of which make these clouds dynamics (Salby, 1996). This mechanism could be responsible in generating the gravity wave observed in the middle atmosphere.

Since the gravity wave showed in Figure 1 propagates in northeast direction, the cloud distribution is consistent whit the propagation direction and this result supports the scenario that the observed propagation direction is highly correlated with the cloud distribution in the troposphere.

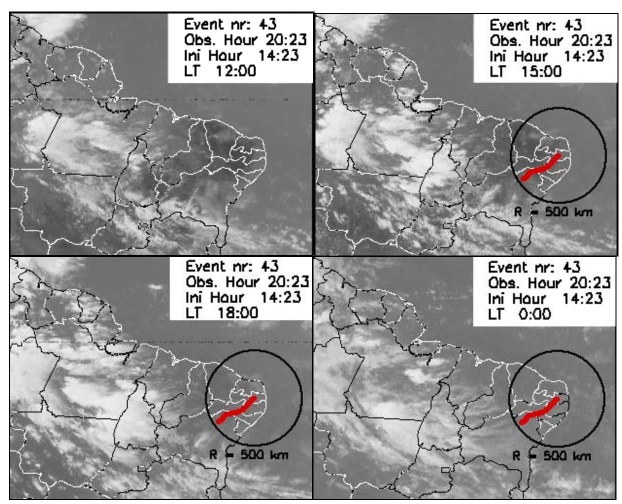

Figure 4 – Infrared images taken from GOES 8 satellite showing the cloud distributions from 12:00 to 00:00 LT during October 1st ,2000. The red line represents the ray path of the gravity showed in Figure 1 and the circle represents a distance of 500 km form the observation site.

Figure 5 displays the distribution of all the tropospheric sources of gravity waves events observed at Cariri during one year. The symbols represent the estimated source at each season. The major part of sources is located in the western site of the observatory around 250 km away from it. However, some sources can also be seen farther than 500 km of the observation site.

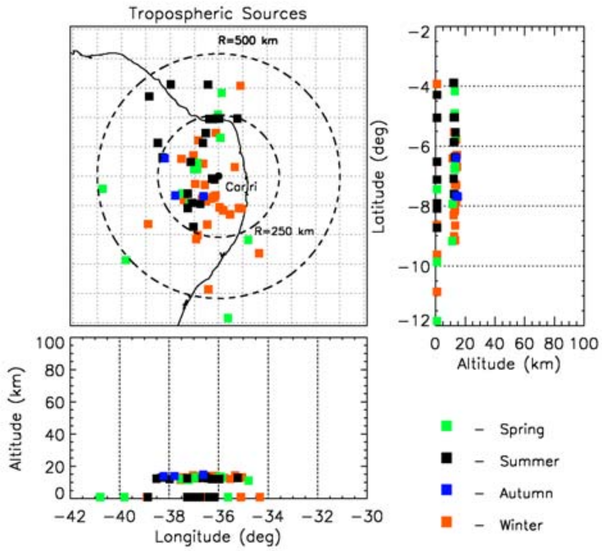

Figure 5 - Distribution of tropospheric sources for the gravity wave events observed at Cariri (7° S, 36° W). The different simbols represents a gravity wave sources at each season.

In order to investigate the cloud activity with the gravity wave occurrence, each gravity wave that has tropospheric sources was analyzed using the cloud distribution from satellite images. The results show that in all events the final point of the back traced ray paths was near to a region with high concentration of clouds, showing good agreement with such generation mechanism. Thus, the gravity waves sources observed at Cariri could be related to the convection activity observed mainly in westward direction of the observation site.

Conclusions

Gravity waves observations was caried out at São João do Cariri (7° S, 36° W) between September 2000 and September 2001. A ray tracing model was used to find out the region source of the observed gravity waves and the results show that more than 70% of the tropospheric sources where distributed around 250 km from the observation site. These gravity wave sources were compared with the cloud distribution images obtained by GOES 8 satellite that show a great correlation between the wave activities and the final position of the ray paths. Thus, it can be suggested that the cloud activities could be the sources of the gravity waves seen at São João do Cariri.

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