Atmospheric planetary waves inferred from airglow and meteor wind measurements

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Abstract

Measurements of the OH(6-2), OI(5577) and O_2 (0,1) emissions by airglow photometer at São João do Cariri (7° S, 36° W), Brazil, and horizontal winds carried out by meteor radar at Cachoeira Paulista (22.7° S, 45° W), Brazil, and Jakarta (6.4° S, 106.7° E), Indonesia, are used to study atmospheric planetary oscillations of these parameters in the upper mesosphere and low thermosphere (MLT) region. Spectral analysis shows a distinct power spectrum with peaks associated with diurnal and semidiurnal tides as well as low-frequency oscillations, ranging from 2 to 16-day periods. Along the year 1999, quasi-two-day variations were simultaneously observed in airglow and winds data, and the present results suggest that this airglow intensity variability should have the same origin as the wind oscillation. Some differences between the oscillation modes seen at equatorial and low-latitude sites are also discussed.

Introduction

The terrestrial atmosphere is a dynamical system in which periodic oscillations such as internal gravity, tidal and planetary waves, are present. Planetary waves are global-scale oscillations in the atmosphere with periods longer than 1-day.

The fact that planetary waves play a significant role in the dynamics of the upper mesosphere and low thermosphere (MLT) region is already well known, and these waves have been studied either theoretically or observationally for many years. From radar wind observations in the MLT region, oscillations with period ranging from 2-16 days have been studied (Manson et al., 1987; Williams and Avery, 1992) and satellite data have allowed the global investigation of some atmospheric waves (Wu et al., 1993, 1994; Meek et al., 1996).

The vertical structure and some propagation characteristics of the planetary-scale waves such as quasi-two-day and ultra-fast Kelvin (UFK) waves have been studied in the equatorial wind data obtained by atmospheric radar (Riggin et al., 1997; Harris and Vincent, 1993). Although the quasi-two-day and UFK waves are already well known, mainly the former, some characteristics still need to be understood.

Oscillatory effects caused by atmospheric waves in the intensity and temperature of the airglow emissions have been studied, mainly those due to gravity waves and atmospheric tides (Zhang et al., 1993; Takahashi et al., 1998). The fluctuations in the green line airglow intensity due to planetary waves, with a quasi-two-day period, have been evidenced by Teitelbaum et al. (1981) using simultaneous photometer and radar wind measurements and by Ward et al. (1997) through WINDII observations.

The present study was motivated by early analysis of airglow emissions data obtained in the equatorial region by airglow photometer during 1998 by Takahashi et al. (2002). In their analysis they showed the presence of distinct 2- and 3.5-day oscillations in the emission rates. Lichstein et al. (2002) demonstrated through simulation that the quasi-3-day oscillations in the equatorial airglow observed by Takahashi et al. (2002) are consistent with their interpretation as UFK waves.

This study is an extension to the investigation of equatorial planetary waves observed in airglow carried out by Takahashi et al. (2002). In our study the presence of airglow variations with periods of the order of those of planetary waves will be compared with wind data obtained in the equatorial region and at lower latitudes sites, since global-scale events can be observed quasi simultaneously at differentes sites.

Observations

a. Airglow Data

Measurements of the airglow OH(6-2), OI(5577) and O_2(0,1) emissions have been recorded at São João do Cariri (7° S, 36° W), Brazil, since January 1998 by a multi-channel airglow photometer, the MULTI-3 instrument, designed and constructed at INPE. The instrument characteristics and the data analysis method have been described elsewhere (Takahashi et al., 1989). During all the period of data acquisition the photometer was pointed to the zenith.

The airglow database used in the present work was obtained during the time interval from April to August 1999. In order to study the day-to-day variation, 5 sequences containing at least 11 nights (61 nights in total) were used.

b. Meteor Wind Data

The meteor wind data analyzed here were obtained at Cachoeira Paulista (22.7^o S, 45^o W), Brazil, and at Jakarta (6.4^o S, 106.7^o E), Indonesia. The Cachoeira Paulista horizontal winds were acquired by a SKiYMET meteor radar, which uses an antenna that transmits pulses at 35.24 MHz and five receiver antennae, whilst the Jakarta winds were measured by radar, which operated at a central frequency of 31.57 MHz. Both radars are pulse-modulated monostatic systems.

In order to study planetary-scale periodic oscillations in the wind field, the zonal and meridional wind components over Cachoeira Paulista, were estimated in 3-hour time bins and in 7 atmospheric layers of 3-km thickness centered at 81, 84, 87, 90, 93, 96 and 99 km, during the time interval from April to August 1999. The horizontal wind velocities for Jakarta were inferred every 4 hours for 7 layers of 4-km thickness ranging from 78 to 102 km, during the time interval from April to August-10 1999. The missing data were filled in using linear interpolation.

In Figure 1, we show the observation periods for photometer and meteor radars used in this study.

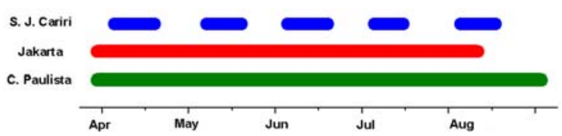

Figure 1 – Observation intervals for the photometer at S. João do Cariri and the meteor radars at Jakarta and at C. Paulista during 1999.

Data analysis: examples

To determine the periodicity of the oscillations present in the airglow parameters, the Lomb-Scargle spectral method was applied to each data sequence obtained during the time intervals from April to August 1999. The Lomb-Scargle method is based on the least squares fitting technique (Lomb, 1976; Scargle, 1982) and can be applied to unevenly time spaced data or data with gaps like those in our airglow observation. The results indicated probable periodic oscillations in all analyzed sequences, mainly for tidal periods and peaks in the 1.5-4 days period range. Peaks near 2-day period were revealed in airglow parameters in the months of April, June, July and August. Peaks between 3-4 days, above 95% confidence level, were registered for OH parameters in July and for all airglow parameters only in the August series. Examples of Lomb-Scargle periodograms obtained for OI5577, O_2 (0,1) and OH (6,2) band intensities, and for OH rotational temperature for the time sequence of July 05-16, 1999, are illustrated in Figure 2. In this figure, the horizontal line represents 95% the confidence level.

In order to evaluate the wave energy in the horizontal winds at Cachoeira Paulista and Jakarta, the data were multiplied by a Welch window and the power spectra were estimated using a discrete Fourier transform for data time segments of 30 days. To help in our decisions, the Jakarta wind data containing gaps were also submitted to the Lomb-Scargle spectral method and the results were compared with those of the FFT. Meteor winds spectral analysis, for both sites, shows a distinct power spectrum with peaks associated with diurnal and semidiurnal tides as well as low-frequency oscillations ranging from 2 to 16-day periods.

At Jakarta, peaks near the 2-day period appeared in April, May, June and July in the meridional wind. During July the wind components showed peaks near 6-8 days. The results for the power spectrum analysis at Cachoeira Paulista showed weak peaks associated with quasi-two-day oscillations in the meridional wind component during April, July and August. The wind components showed power near 4 days in the time sequences of June and July. Peaks near 6 days occurred during June and in the 7-8 days range in July (only the zonal wind). The quasi-10-day period oscillations appeared during May (weak) and June (strong) in both wind components.

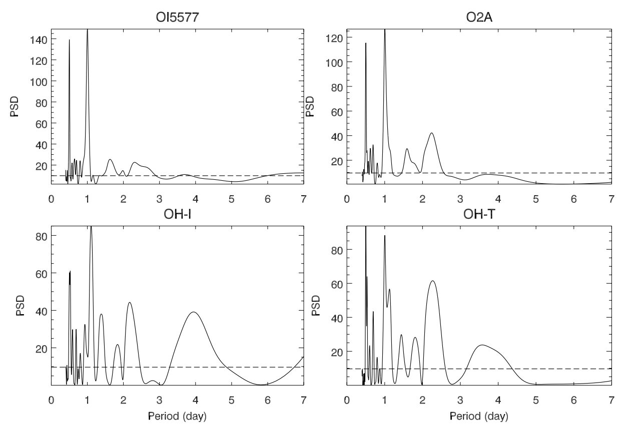

Figure 2 – Lomb-Scargle periodogram for OI5577, O_2 (0,1) and OH (6,2) band intensities, and for OH rotational temperature obtained over São João do Cariri, Brazil, for time sequence July 05-16, 1999. Horizontal line represents 95% confidence level.

Among the large-scale events which appeared either in the airglow emission or in wind field observations, we focused on those that occured quasi-simultaneously, which limits our analysis to the ~2-day oscillation events. Thus, we will give attention to the already known quasi-two-day oscillation, where we found one concurrent event in the airglow and in the winds along all the observed period, at all sites.

Results

In order to compare the quasi-two-day oscillation events between airglow and wind data, we have applied a filter with a pass band of 42-54 hours to the time series of the zonal and meridional winds for all 7 levels at Jakarta and Cachoeira Paulista. The results indicate that quasi-two-day oscillation amplitudes in meridional winds were more intense than in the zonal wind components. In Figure 3 are shown the results for the meridional wind amplitudes at three heights for time series from April to August-10 1999 at Jakarta (centered on 86 km, 90 km and 94 km – black lines) and at Cachoeira Paulista (centered on 87 km, 90 km and 93 km – blue lines). The shaded intervals denote the periods observed by photometer at São João do Cariri.

Bearing in mind this figure, and considering the discrete Fourier transform and Lomb-Scargle analyses results, the periods when the quasi-two-day oscillation occurs in both parameters at Jakarta and São João do Cariri are the 156-170 day and 186-197 day intervals, or, during June 05-19 and July 05-16. In the interval from 97 to 111 day (April 07-21) the airglow PSD shows significant power near 2-days, however the meridional wind amplitude at Jakarta decreases during this time interval. Yet, in the interval from 128 to 140 days (May 08-20) the spectral analysis for meridional winds and airglow parameters does not reveal peaks near two days.

The weaker meridional filtered amplitudes for Cachoeira Paulista were more intense in April, July and August when weak peaks for ~2 days are presents in the power spectra. Note also in Figure 3 that the amplitudes suggest that the July occurrence of the quasi-two-day oscillation started soon after the related equatorial event.

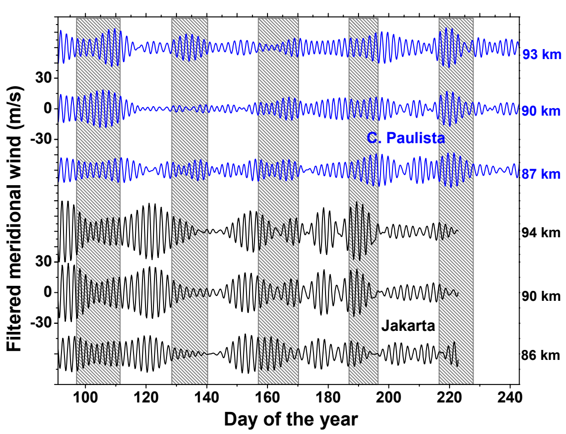

Figure 3 – Filtered time series for the meridional component of the wind at 3 altitude levels over Jakarta (86, 90 and 96 km - black) and over Cachoeira Paulista (87, 90 and 93 km – blue). The data were filtered by a band-pass filter with periods of 42-54 hours for the time span from April to August-10 1999. The shaded intervals denote the periods observed by photometer at São João do Cariri.

The characteristics of the quasi-two-day variations in the wind and airglow series were determined by use of harmonic analysis. The amplitude and phase were fitted in a least-mean-square sense to:

$$A(t) = DC + \sum [A_i \cos(2pi/T_i - fi_i)]_{i=1 \text{ to } 3} \qquad (1)$$

where DC, A_i and fi_i are the coefficients of the fitting process and represent the DC level, the amplitude and phase of the i th harmonic component with a period of quasi-two-days, 1-day and 0.5-days for i = 1, 2 and 3, respectively. The periods used to determine the amplitudes of the quasi-two-day variations in the airglow parameters (1.8, 2.0 and 2.2) were chosen on the basis of the Lomb-Scargle periodogram. The wind amplitudes and phases were estimated for 2-day periods.

The harmonic analysis results showed that airglow quasi-two-day amplitudes during May were smaller than those for other months, with July presenting more intense amplitudes, in agreement with the power spectral density (PSD) obtained by the Lomb-Scargle method, as can be seen in Figure 4. In this Figure, the plot represents the quasi-two-day peaks of the PSD for airglow parameters in each month obtained by the Lomb-Scargle analysis for parameters observed at São João do Cariri from April to August 1999.

The meridional wind amplitudes for quasi-two-day oscillations were obtained for sliding 4-day intervals stepped by 1 day. Considering the same airglow observation intervals, the results for mean amplitudes at Jakarta show behavior to that observed for airglow parameters. Maximum amplitudes (up to 22 m/s) were registered during July, and the vertical phase structures showed descending phase for April, June and July, indicating upward energy propagation. The vertical wavelengths were estimated to be mostly around 50, 60 and 70 km for April, June and July, respectively, but reaching values of around 150 km during July. The vertical phase structures during May were uncertain and indicate some ascending phase events.

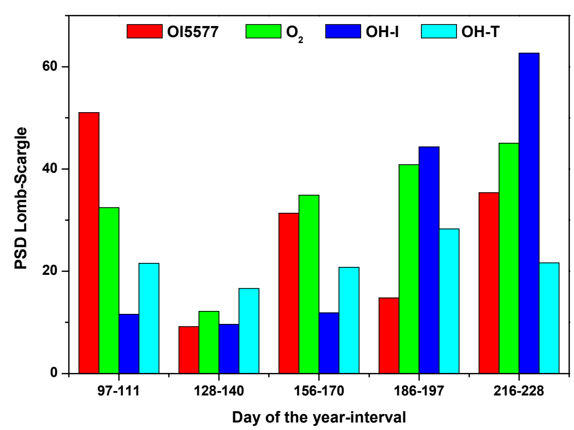

Figure 4 – PSD representative of the quasi-two-day peaks for airglow parameters in each month obtained by Lomb-Scargle analysis. The parameters were observed at São João do Cariri from April to August 1999.

Mean amplitudes for quasi-two-day oscillations at Cachoeira Paulista were larger than those for Jakarta only during April. However, maximum amplitudes (about 20 m/s) were reached during August. The vertical phase structures indicated a downward propagation in July and August and the vertical wavelengths were estimated to be mostly around 50 km for both months, reaching values around 70 km during July. The vertical phase structures estimated for April, May and June were uncertain and also indicate some ascending phase events.

Table 1 sumarizes the typical amplitudes of the quasi-2-day variations seen in airglow parameters for each month as determined by harmonic analysis, and in Table 2 are shown the mean amplitudes (A) and vertical wavelengths (L_v) for ~2-day oscillations seen in meridional winds as obtained from vertical phase structures.

Table 1 – Amplitude of the quasi-2-day wave seen in airglow parameters

	Amplitudes (%)			
Month	OI5577	O_2	OH-I	OH-T
Apr	10	18	10	1
May	12	5	4	2
Jun	26	35	15	1
Jul	21	25	22	1.5
Aug	27	33	20	0.7

Table 2 – Mean amplitudes and vertical wavelengths of the quasi-2-day oscillations seen in Meridional winds at Jakarta and Cachoeira Paulista

	Jakarta		Cachoeira Paulista	
Month	A (m/s)	L_v (km)	A (m/s)	L_v (km)
Apr	7.8	50	8.7	-
May	5.5	-	4.0	-
Jun	7.7	60	5.9	-
Jul	8.3	70	7.0	50
Aug	-	-	8.5	50

In their study, Takahashi et al. (2002) interpreted peaks ranging between 3-4 days, present in São João do Cariri airglow data for 1998, as being due to UKF waves. During April-August 1999, peaks with 3-4 day periods were obtained from airglow data at São João do Cariri for OH parameters in the July series and for all airglow parameters only in the August series. However, the spectral analysis of the zonal wind data obtained at Jakarta during the same time intervals did not show sufficient power to prove the presence of UFK waves in the wind during the period studied.

Summary and Conclusions

We have investigated the presence of atmospheric planetary wave activity in airglow and wind data at equatorial and low latitudes in the Southern Hemisphere. The data were obtained at São João do Cariri and Cachoeira Paulista, Brazil, and Jakarta, Indonesia during 1999.

Spectral and harmonic analysis showed simultaneous quasi-two-day oscillation events in equatorial airglow and wind data during April, June and July 1999, however during April the meridional wind amplitudes at Jakarta were decreasing. In the May interval the spectral analysis for meridional winds and airglow parameters did not reveal peaks near to the 2-day period. Quasi-two-day oscillation was also registered at Cachoeira Paulista during April, July and August. The characteristics of the ~2-day wave events in meridional winds over Jakarta are in accordance with those reported in the literature as well as the July and August events over Cachoeira Paulista (Harris and Vincent, 1993).

Early observations from equatorial latitudes at Christmas Island (2^o N, 157^o W) and from low latitudes at Kauai (22^o N, 160^o W), in the Northern Hemisphere, displayed significant amplitudes during both solstices in both wind components (Harris and Vincent, 1993; Fritts and Isler, 1994). Observations carried out at Townsville (19^o S, 147^o E) showed activity of the quasi-two-day wave at both solstices (Craig et al., 1983). Significant amplitudes for ~2-day oscillations during winter solstices are predicted theoretically as being due to leakage of the 2-day wave across the equator from the summer hemisphere. In our analysis we observed that the July event began soon after the equatorial event suggesting the possible leakage of the quasi-two-day wave from the Summer Hemisphere during this event.

Assuming emission peak heights to be 97 km for OI5577, 94 km for O_2 (0,1) and 87 km for OH (6,2) on the basis of rocket observations (Takahashi et al., 1996), and considering the results of the spectral and harmonic analysis for airglow and winds data, which suggest that the quasi-two-day oscillations occurred on a planetary scale, the present study suggests that the quasi-two-day variability observed in the airglow intensities should have the same origin as that of the wind oscillation in the equatorial region, which is the quasi-two-day planetary wave.

The airglow data revealed peaks between 3 and 4 days for OH parameters in July and for all airglow parameters in August, a fact which can be attributed to the ultra fast Kelvin wave. However, spectral analysis of the zonal wind data obtained during these periods did not show the presence of UFK waves.

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