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Evidence on 2–4 day oscillations of the equatorial ionosphere h′F and mesospheric airglow emissions

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[1] Equatorial ionospheric sounding has been carried out at São Luís (2.6°S, 44.2°W). The upper mesosphere-lower thermosphere (MLT) airglow OI5577, $O_2b(0,1)$ and OH(6,2) emissions and OH rotational temperature have been observed at Cariri airglow observatory (7.4°S, 36.5°W) within a distance of approximately 1000 km to the east of São Luís. Both observation sites are located in the equatorial region of South America. Spectral analyses of the ionospheric F-layer bottom height (h′F) and airglow emission intensity reveal that there are quasi 2- and 4-day period oscillations in their temporal variations. This might indicate that planetary scale oscillations, Rossby-gravity waves (or inertial-gravity waves) and Ultra Fast Kelvin waves, are present in the ionosphere. This is the first time that the planetary scale waves in the MLT region and in the ionosphere are discussed by airglow and ionospheric observations, respectively. **Citation:** Takahashi, H., L. M. Lima, C. M. Wrasse, M. A. Abdu, I. S. Batista, D. Gobbi, R. A. Buriti, and P. P. Batista (2005), Evidence on 2–4 day oscillations of the equatorial ionosphere h′F and mesospheric airglow emissions, *Geophys. Res. Lett.*, *32*, L12102, doi:10.1029/2004GL022318.

1. Introduction

[2] The Earth's ionosphere is strongly influenced by several physical processes from above (due to solar flux and magnetic activity variations) and by dynamical processes from the mesosphere-lower thermosphere (MLT) region. Attention has been called to the dynamical processes, known as "meteorological influence" after *Pancheva and Lysenko* [1988] reported existence of quasi-two-day oscillation of the F region maximum electron concentration and related it to the analogous oscillation of the meteor wind. *Chen* [1992] observed 2-day oscillation in amplitude of the equatorial ionization anomaly and suggested a presence of the planetary waves in the equatorial region. *Forbes et al.* [1997] also reported quasi 2-day oscillation in f_oF_2, which could be connected with the quasi 2-day oscillation in the MLT winds. A statistical survey on the periodic oscillation of the ionosphere was presented by *Forbes et al.* [2000]. They mentioned that under quiet geomagnetic conditions, the variability originated by MLT region dynamical processes is around 25–35% for the period of a few hours to 1–2 days and 15–20% for the periods of 2–30 days. *Rishbeth and Mendillo* [2001] further studied F_2-layer variability. *Pancheva et al.* [2002] studied the variation of the maximum height of the ionospheric F_2-layer, hmF_2, with 27-day, 16-day and quasi 2-day periods. They reported that the 16-day period must be related to a 16-day modulation of the semidiurnal tide in the MLT region, and the quasi 2-day oscillation activity increased during geomagnetic disturbances. The previous works demonstrate the presence of a long period (longer than 2 days) oscillation in the ionosphere. However the wave excitation and propagation mechanism, contribution of wave dynamics from the lower atmosphere and influence of magnetic disturbances, etc., are still open questions.

1.1. Periodic Oscillation of Ionospheric h′F

[3] Ionospheric F-layer base virtual height, h′F, is sensitive to the local electric field. Particularly in the magnetic equator region, where the magnetic field is horizontal, the **E** × **B** effect is mainly responsible for the vertical movement of h′F. There are several factors to be considered for the day to day variability of h′F during the evening period in the equatorial region. Electric field penetration from the polar ionosphere during magnetically disturbed conditions is one of them. Modulation of the global scale thermospheric wind system due to Joule heating in the polar region should be another one. These are, however, sporadic phenomena related to magnetic disturbances. Another factor to be considered should be the variation of the thermospheric wind system. It is well known that the thermospheric wind has a strong diurnal oscillation migrating with the sun. In addition to it, some planetary scale wave propagation is also present and modulates the tidal winds, resulting in variation of h′F.

1.2. Relation of h′F and Thermospheric Zonal Wind

[4] F-region dynamics in the magnetic equator region has a singular behavior. F-layer evening uplift is caused by the pre-reversal enhancement, resulting from the F-layer wind dynamo that dominates in the early evening [*Rishbeth*, 1971]. F-region vertical polarization electric field E_z can be represented by

$$E_z = U_y \times B_0\left[\sum\nolimits_F / \left(\sum\nolimits_F + \sum\nolimits_E\right)\right] \qquad (1)$$

where U_y is thermospheric zonal wind (at ~200 km) and B_0 is the earth magnetic field intensity, and $\sum_F$ and $\sum_E$ are the integrated conductivities of the E and F regions [*Abdu et al.*, 2003]. Due to a fast decay of the E-layer conductivity in the

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post sunset hours E_z tends to increase towards the nightside. The application of the curl-free condition to such an electric field variation could result in the enhanced evening zonal electric field, resulting upward drift of F-layer [*Eccles*, 1998]. Therefore it is reasonable to assume that the vertical drift velocity of h′F is proportional to the amplitude of thermospheric zonal winds. Since h′F at 17:00 LT is almost constant for any day, h′F at 20:00 or 21:00 LT should indicate an averaged vertical drift velocity at that evening. During magnetically quiet conditions, the F-region dynamo is mainly controlled by the thermospheric zonal wind. During magnetically disturbed conditions, however, the F-region dynamo is more complex. Penetration of auroral E-field into the equatorial region and modulation of the thermospheric wind system caused by Joule heating in the auroral region could induce the h′F variability. But a periodic oscillation should not be expected in this case.

[5] The purpose of the present work is to find out whether h′F in the equatorial region has any periodic oscillation. If such oscillations exist, is there any similarity with the other atmospheric parameters ? In order to investigate it, we chose two data sets, h′F and mesospheric airglow emissions observed in a same latitudinal zone, to find out common features between them. The MLT region winds observed at Cachoeira Paulista in the low-middle latitudes were also compared with the h′F variability.

2. Instrumentation

2.1. São Luís Ionosonde

[6] Ionospheric data are measured by a Digisonde DGS256 that works as a pulse radar system with a wideband 10 kW peak power transmitter and precise fast-switching frequency synthesis, covering the frequency range from 0.5 to 30 MHz. The operation frequency is one ionogram each 15 minutes. The ionospheric parameter used here is the minimum virtual height of the F layer (h′F).

2.2. Cariri Airglow Photometer

[7] A multi-channel filter photometer (MULTI-3) measures zenith intensity of the airglow emissions, OI 557.7 nm (hereafter OI5577), $O_2b(0,1)$ band at 865 nm (hereafter O2) and OH(6,2) band at 847 nm (hereafter OH). Airglow emission lines and the corresponding background continuum are measured by scanning the wavelength via filter tilting. One sequence of observation and the instrumental noise level check takes about 2.5 minutes. The OH rotational temperature (hereafter OHT) is calculated from the intensity ratio between the $P_1(4)$ and $P_1(2)$ lines. The photometer sensitivity was calibrated using a laboratory standard light source (ES-8315). Estimated error in the absolute intensity for OI5577 is approximately 5%, and for OH and O2 the errors are around 10%.

3. Observation and Results

[8] Airglow observation was started on a routine basis at São João do Cariri (7.4°S, 36.5°W) in January 1998. The observation site is located in a dry weather region in Brazil, permitting continuous observations. The Digisonde has been installed at São Luís (2.6°S, 44.2°W) in 1994, working on a continuous basis. The two sites are separated by approximately 1000 km. In the present analysis a data set of one year from March 1999 to February 2000 was used.

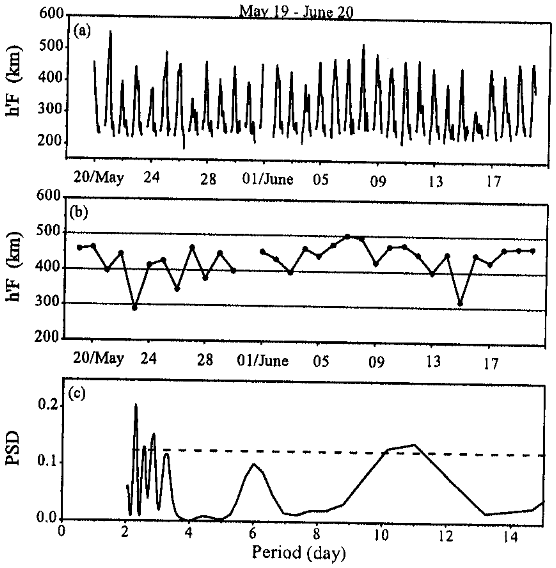

Figure 1. (a) Nighttime ionospheric h′F time series from May 19 to June 20, 1999, observed at São Luís (2.6°S, 44.2°W), (b) day to day variation of h′F at 21:00 Local Time, and (c) Lomb Scargle periodogram of the 21:00 LT time series. The dashed line is the 95% significance level.

3.1. São Luís Ionosonde Data Analysis

[9] Nocturnal and day to day variations of the ionospheric F-layer bottom height (h′F) are investigated. As an example, a time series of nocturnal variation from 17:00 to 08:00 LT, between May 19 and June 20, 1999 is shown in Figure 1a. At around 17:00 to 18:00 LT, h′F starts from a same height level at around 250 km. After that, it rises to 450 km at around 21:00 LT (pre-reversal enhancement), then comes down again to the height of around 250 km in the morning side. It can be seen that the height of the h′F maximum varies considerably from day to day, between 300 and 500 km. Local time of the maximum also changes from day to day, but not much. It can be seen from the figure that there are some periodic oscillation patterns.

[10] In order to see the day to day variability of h′F, we looked into the altitude at a fixed local time, as mentioned in the previous section. In Figure 1b we plot h′F at 21:00 LT as an example. From May 22 to 24, h′F varied from 450 km to 300 km, and from June 14 to 15 it decreased from 480 km to 310 km. In order to see any periodicity of the time series, we applied Lomb Scargle spectral analysis. The periodogram is shown in Figure 1c. Three periodic oscillations with a significance level above 95%, at 2, 3 and 10 days, can be identified. In the present analysis we focused on the periodic oscillation of less than 10 days in order to compare the results with the MLT airglow data.

[11] Looking into the h′F time series for the other months we found that there are frequent ~2- to 4-day oscillations among them. These oscillations seem to be intermittent, suddenly appear and disappear after a few periods of oscillation. This sort of oscillation (modulation) can be analyzed well by wavelet analysis which is suitable for

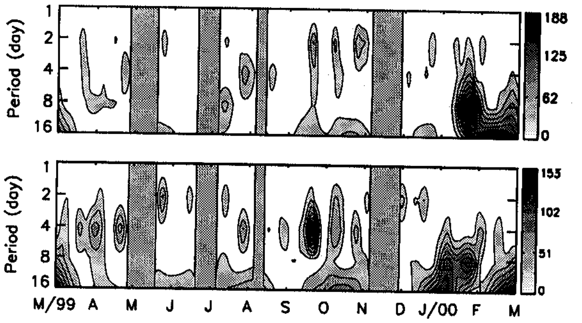

Figure 2. Wavelet power spectrum of the $h'F$ time series, for a fixed local time at (top) 20:00 LT and (bottom) 21:00 LT, from March 1, 1999 to February 28, 2000. Contour lines start at a significance level of 90%, and the gray scale shows spectral density. The rectangular gray areas indicate no data.

such localized variations. In Figure 2, the Morlet wavelet power spectrum is shown for the $h'F$ time series for 20:00 and 21:00 LT from March 1, 1999 to February 28, 2000. Only features with a significance level above 90% are shown. The spectrum for the 21:00 LT data shows the spectral signatures much clearer. The 2-day and 4-day oscillations are clearly identified, although the 4-day oscillation is rather wide band, between 3 to 5 days.

3.2. MLT Region Airglow Data

[12] For the airglow data time series, it is difficult to apply the wavelet analysis, because the series are not equally spaced but discrete. To find periodicities, we used Lomb Scargle (LS) spectral analysis for each monthly group. It should be remembered that the time series has a spacing of 10 minutes, with a duration of 8 to 10 hours of night time observation, and 12 to 15 days of observation during a new moon period. The length of the series is therefore different from month to month depending on the weather condition and the moon phase. In Figure 3, an example of the time series of the OI5577 and O2 band intensities from June 5 to 20, 1999 is shown. There is no data on the nights of June 10–11 and 17–18. It should be noted that there is a distinct two day intensity modulation from the night of June 11 to 16 for both the emissions. It is interesting to note that during the same period $h'F$ did show a strong two day modulation (Figure 1b). When the airglow intensity was in the maximum on the night of June 15, $h'F$ was in its minimum height. This oscillation feature can be clearly identified in the LS periodogram also shown in Figure 3. The OH intensity and the rotational temperature also showed a similar oscillation feature although the power spectrum was weaker compared to the oxygen emissions. The LS spectral analysis was applied for all the airglow time series grouped in each moon period from March 1999 to February 2000. Most of the months show some level of oscillation feature between the periods of 2 to 4 days. Among them a distinct periodic oscillation was seen during the month of March–April with ∼4-day period, June–July with 2-day period and September–October with ∼4-day period.

4. Discussion and Summary

[13] The similarity on periodicity between the ionospheric $h'F$ and mesospheric airglow parameters is worthwhile to be further investigated. In order to compare the two different time series, we tried to apply Morlet wavelet analysis for both of them. For this purpose nocturnal mean values are used. Data gaps are filled by interpolation to obtain equal-spaced time series for each month. Although the time series are limited, around 14 points, we expect to see periodic oscillations shorter than 7 days. The power spectra for the OI5577 and OHT nightly mean values are shown in Figures 4b and 4c for a period from March to October, 1999. Similar results were also obtained from the O2 and OH intensities. The power spectrum of $h'F$ is also shown for comparison in Figure 4a. It is interesting to note that $h'F$ and airglow have similar oscillation periodicities, ∼4-day period in March–April, ∼2-day period in June–July, and again ∼4-day period in September–October. We found the airglow and $h'F$ oscillations to be in phase in June 1999, but no consistent behavior at the other times. In order to further compare it with mesospheric wind components, meteor wind data observed at Cachoeira Paulista (22.7°S, 45.0°W) during the same period are analyzed and the result is shown in Figure 4d. Although Cachoeira Paulista is not in a same latitudinal zone, some similarity, distinct 4-day oscillation features in March and September can be seen. The similarity of the periodic patterns between the mesospheric and ionospheric parameters, therefore, suggests that there may be a dynamical link between them.

[14] The observed periodic oscillation, a quasi 2-day period, is well known in the MLT region [*Pancheva et al.*, 2004]. In the equatorial region, *Harris and Vincent* [1993] and *Gurubaran et al.* [2001] presented quasi-2 day

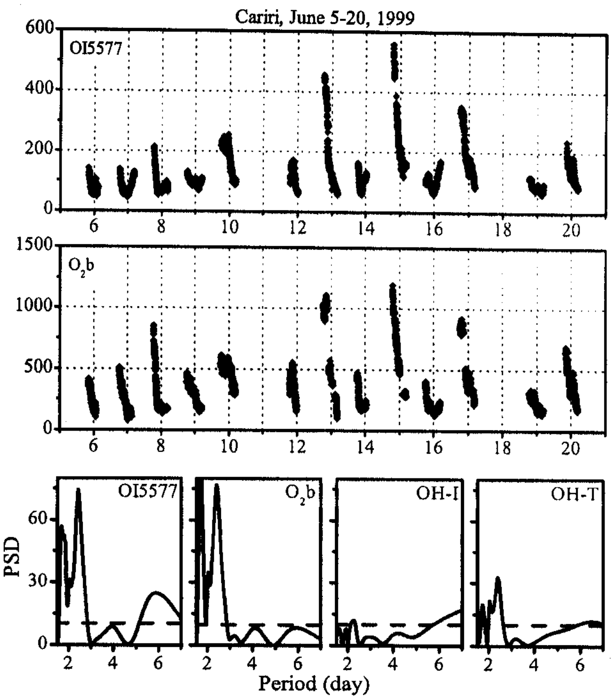

Figure 3. Mesospheric oxygen airglow emission time series, (top) OI 5577 and (middle) O_2 (0,1) band, and (bottom) Lomb Scargle periodogram of OI5577, O_2, OH, and OHT observed at Cariri (7.4°S, 36.5°W) from June 5 to 20, 1999.

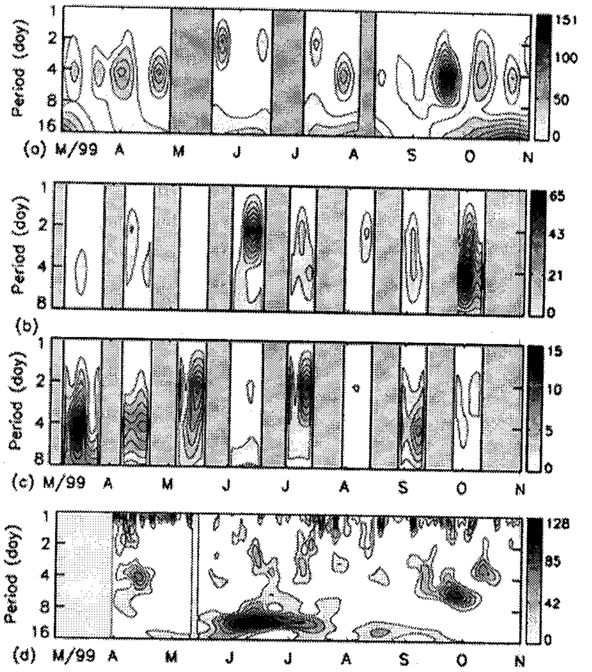

Figure 4. Morlet wavelet power spectra of (a) h'F, (b) OI5577, (c) OHT, and (d) zonal wind at 90 km altitude, from March to November 1999. The winds were observed at Cachoeira Paulista (22.7°S, 45.0°W).

oscillation of the mesospheric wind from the MF radar measurements. It is due to a Rossby–gravity wave propagating westwards and excited by baroclinic instability [*Norton and Thuburn*, 1996]. In the equatorial region, it is also possible to have inertial gravity waves with periods 2–3 days. In case of the quasi-2–day oscillation in the ionosphere, however, the excitation process is still not well known as mentioned before. *Pancheva et al.* [2002] suggested a close relation with geomagnetic activity in addition to the contribution of quasi 2-day oscillation from the MLT region. Our present results also show that there is a 2-day oscillation in the MLT region and ionosphere, occasionally.

[15] Concerning the periodic oscillation longer than 2 days in the equatorial MLT region, the Rossby (1,1) mode and Kelvin waves are to be considered. *Vincent* [1993] presented a 3–5 day oscillation in the mesospheric wind from MF radar observation and identified it as Ultra Fast Kelvin (UFK) wave, one of the eastward propagating equatorial waves. *Takahashi et al.* [2002] observed the UFK wave in their airglow intensity variability. Such equatorial waves are believed to have their origin in the lower atmosphere, most probably from tropospheric convection and released latent heat in the tropical region generating long scale waves. On the other hand, for the thermosphere-ionosphere region, little has been reported concerning the 3- to 5-day periodicities.

[16] In summary common periodic oscillation features between the airglow and ionospheric h'F day to day variability were observed in the equatorial region. Mesospheric wind observed at low-middle latitude in the southern hemisphere also showed similar oscillation during the equinox season. The results might suggest a common source of forcing in the equatorial region. It could be related to the dynamics in the MLT region, Rossby–gravity waves, inertial-gravity waves, and Ultra Fast Kelvin waves. Generation of the oscillation by the other sources such as geomagnetic activity pointed out by previous workers would also be possible and to be further investigated.

[17] **Acknowledgments.** São Luís ionosonde (Digisonde) is in operation under responsibility of INPE. The authors thank Goreti Aquino who reduced the ionogram and F. C. Bertoni for useful discussions. Airglow photometer (Multi-3) is in operation under collaboration with Federal University at Campina Grande.

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