Evidence of the lunar tide in the ionosphere

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Abstract

Using data collected by a Digisonde DPS-04 located at Cachoeira Paulista – SP, it was possible to identify the lunar tide in the ionosphere. We have used two parameters (fof2 and hmf2) during 2001 in order to study the semidiurnal and diurnal lunar tide. The amplitude and phase of these oscillations were calculated using least square analysis. The diurnal tide presented a maximum amplitude of 0.25 MHz in Fof2 and 6 km in Hmf2. The phase was ranged between -1 and 1 rad. Both parameters presented a seasonal variation in phase and amplitude. For the Semidiunal lunar tide the maximum amplitude was 0.25 MHz in August for fof2, and 4.5 km for hmF2 in June. A semiannual variation was observed as well.

Introduction

Waves and tides are always presented in the neutral atmosphere and ionosphere. The atmospheric tides are excited either thermally by solar radiation or gravitationally by the lunar and solar gravitational fields. Lunar tides are mainly generated by the gravitational attraction between Earth and Moon, but also due to vertical motion of the Earth and oceans in the lower atmosphere. The lunar tides are responsible to produce modifications in atmospheric pressure, magnetic and electric fields, electron density and ionosphere currents [Chapman and Bartels, 1940; Chapman and Lindzen, 1970; Matsushita, 1967]. These modifications affect considerable the dynamics of the atmosphere.

The major difficulty to study the lunar tide is the low amplitude compared to the solar tone. Other oscillations can overlap the lunar tide such as gravity waves, planetary waves and semidiurnal solar tide, which has a period of 12 solar hours, practically the same of the semidiurnal lunar tide that has a period of 12,424 solar hours.

Several works have been published studding the lunar tide in the mesosphere and lower thermosphere and ionosphere [Silva, 2010; Stening and Fejer, 2001; Sandmford and Mitchell, 2007; Sandmford et al, 2007; Stening et al, 2003; Stening and Rastogi,2002; Stening et al 1997; Stening et al, 1994; Stening and Vicent, 1989; Stening, 1989; Stening and Winch,1979; Stening et al, 1987].

In this paper we used ionospheric parameters collected by a digisonde located at Cachoeira Paulista – SP (22º S; 45º W) to observe the lunar tide in 2011. The main aim is contributed to understand how the lunar tide can affect the atmospheric coupling and dynamics.

Instrumentation and Data Analysis

The data were collected by digisonde DPS-04 located in Cachoeira Paulista during 2001. The Digisonde is a radar system that works in radio frequency from 1 up to 20-30 MHz. This system is composed by transmitting and receiving, antenna and computer which control the whole system. A pulse is generated by the transmitter with a known frequency and when it finds a region in the ionospheric plasma with the same critical frequency, there is a reflection which is collected by the receiver system. A spectrum is obtained of the height as a function of the frequency which known as Ionogram. The height is computed from the time delay of the electromagnetic pulse wave between the transmitter and receiver process. From the Ionogram, few F layer parameters can have extracted. In this paper, we used the critical frequency of the F2 layer and the height of the F layer (hmF2). To see the dominant oscillations in our data, a Lomb Scargle analysis was applied in September 2001. Fig 1 presents the Lomb-scargle periodgram for FoF2. Figure 1 shows the presence of oscillation with period of 1, 1/2 and 1/3 days. These peaks are related to the diurnal, semidiurnal and Terdiurnal solar tides.

To determine the lunar tides it was necessary to remove the solar influences in the data. The solar tides are determined performing a least squares fit according to the equation 1

$$P = A_1 cos\left(\frac{2\pi}{1}t + \varphi\right) + A_2 \cos\left(\frac{2\pi}{0.5}t + \varphi\right)$$
$$+A_3 \cos\left(\frac{2\pi}{0.333}t + \varphi\right) + A_4 \cos\left(\frac{2\pi}{0.25}t + \varphi\right) + P_0$$

Where P is the parameter under study, Po is the mean of the parameter and t is the time in solar hours.

A 27 day window was used to eliminate any solar rotation effects. The 27 day window was moved forward day-to-day to determine the mean solar daily variation for the day which is centered in the window. Thus, for each day of the year we obtain the amplitude and phase. Figure 2 shows the FoF2 and HmF2 and the computed fit overplotted. Residuals from the solar tides are used to determine the lunar tide.

After the residual data had been obtained, it is possible to observe evidence of the lunar tide, with a period of 14.5 days, showing in Figures 3a and 3b. The solid line represents the least square fit for this data set. Figure 3a shows the residual of Fof2 in August 2001 (stars) and Figure 3b shows the residual of HmF2 in March 2001.

Then, the solar time was converted to the lunar time in order to observe the lunar tide components in the ionospheric parameters. Figures 4a e 4b show the diurnal and semidiurnal lunar tide in the residual data for Fof2 and Hmf2 respectively. The solid line represents a least square fit for March with a period of 24 and 12 lunar hours (Fof2) and in June (HmF2).

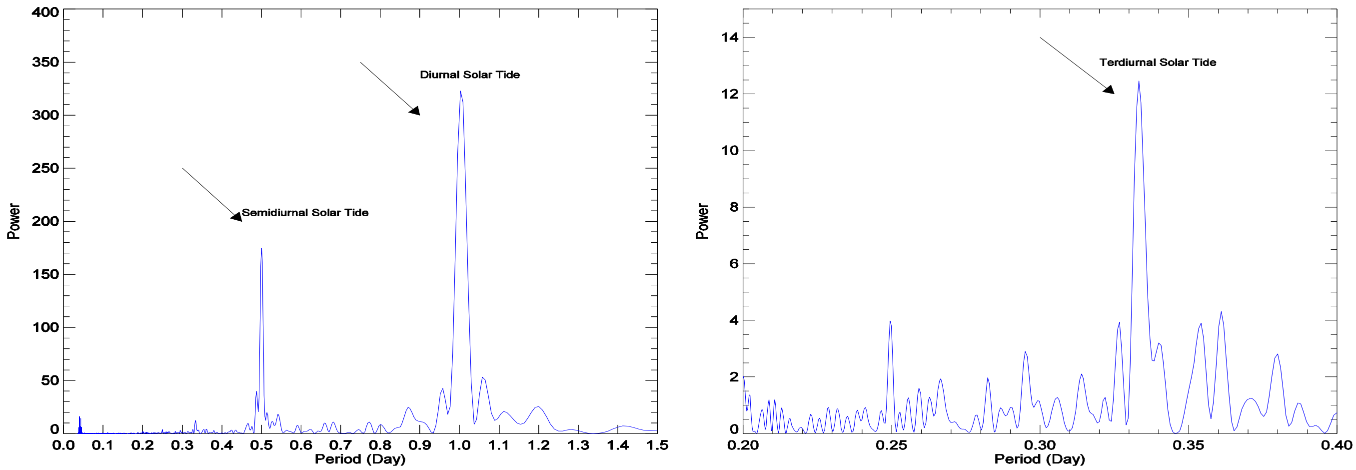

Figure 1 - Lomb-Scargle analysis of FoF2 on September,2001. The right side is an enlargement of the figure in the right

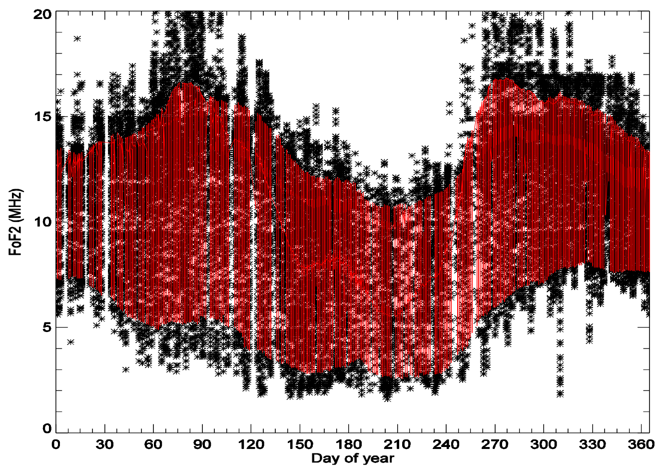

Figure 2a - FoF2 (Black) overlap by the fit (Red) during 2001.

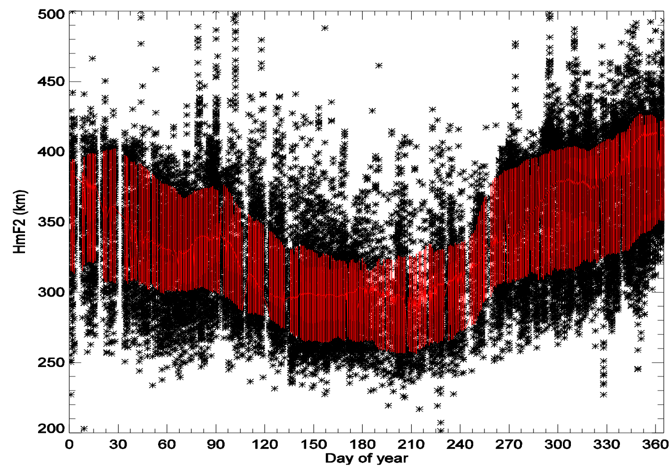

Figure 2b - HmF2 (Black) overlap by the fit (Red) during 2001.

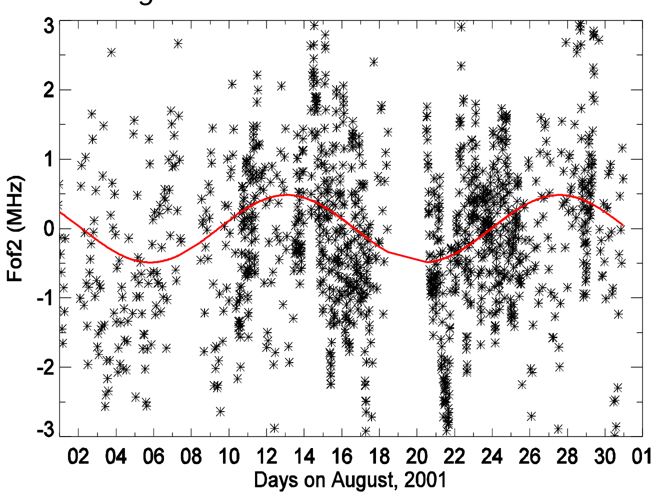

Figure 3a - Evidence of the semimonthly oscillation in Fof2 in August, 2001.

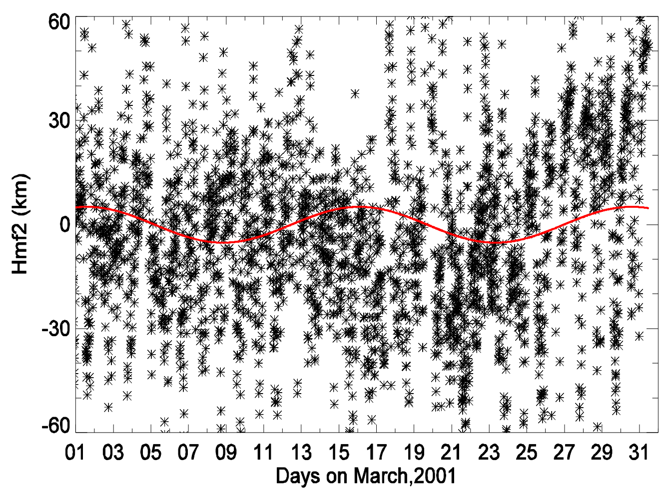

Figure 3b - Evidence of the semimonthly oscillation in Hmf2 in March, 2001.

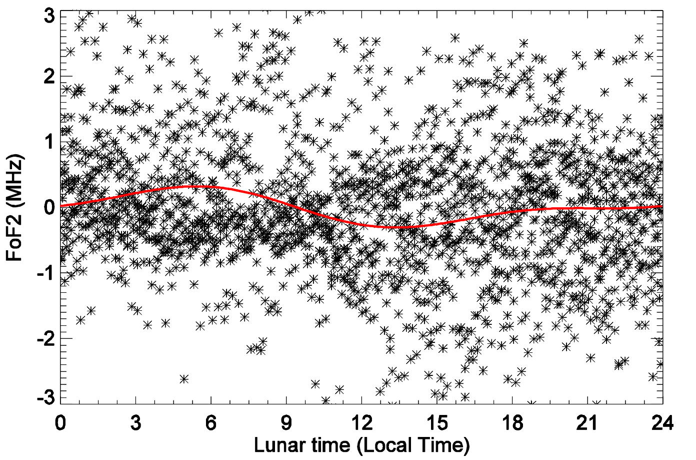

Figure 4a – Evidence of the diurnal and semidiurnal lunar tide in Fof2 on March,2001. The solid line represents the least square fit.

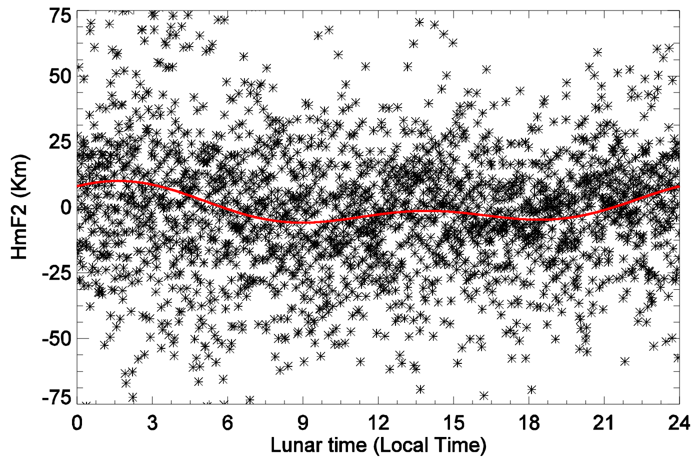

Figure 4b – Evidence of the diurnal and semidiurnal lunar tide in Hmf2 on June,2001. The solid line represents the least square fit.

Results and Discussions

The annual variability of the diurnal lunar tide is shown in Figure 5 and Figure 6. The results of Figure 5a represent the amplitude for the foF2 in 2001. Figure 5b represents the amplitude for hmF2 in 2001. One can see strong variability in foF2. The largest peaks were observed in February, May, July and September for the critical frequency and in February, May, September and November for hmF2. The smallest amplitudes were observed in April, June, August and December for FoF2 and in March, August and October for HmF2. Furthermore, it was possible realize a small variability in the amplitudes of hmF2. For the Fof2, 50% of the amplitude was greater than 0.15 MHz (and 33% of the months had amplitude greater than 5 km in hmF2. Figures 6a and 6b show the phase for both parameters in 2001. There were no defined cycles in Hmf2 and Fof2 along the year.

For the phase in Fof2, there were peaks in March, June and August. For the HmF2, there were peaks in January, April, June and August. The phase for both parameters were maximum close to 1 and minimum close to -1.

Padatela and Forbes. (2010) found a seasonal variability studding the diurnal lunar tide in the ionospheric TEC. This variation is predicted in the classical theory and have been observed in surface pressure, lower atmospheric winds, geomagnetic observation and ionospheric F-layer at high latitudes [Geller and Schoeberl, 1973; Jones and Jones, 1950; Tarpley, 1971].

Figures 7 and 8 represents the annual behavior of the Semidiurnal Lunar Tide. It is clear, in both figures and parameters a semiannual variability. The amplitude for both parameters are shown in Figure 7a and 7b. One can see that the lunar tide had greatest amplitude in August for Fof2 and in June for HmF2. In August the amplitude of the lunar tide in Fof2 reached ~0.3 MHz. In June in the amplitude in hmF2, almost reached 5 km. Other peaks in Figure 7a were observed in February, June, October and December. Figure 7b shows peaks in February and October.

Figure 8 shows the phase for semidiurnal lunar tide in fof2 and hmf2. It was possible realize that the phase had a month variability. The values had maximum close 1 and minimum close -1 in both parameters. In figure 8a the lunar tide had peaks in January, April, October and December. In Figure 8b one can see peaks in Mach, June, August and November.

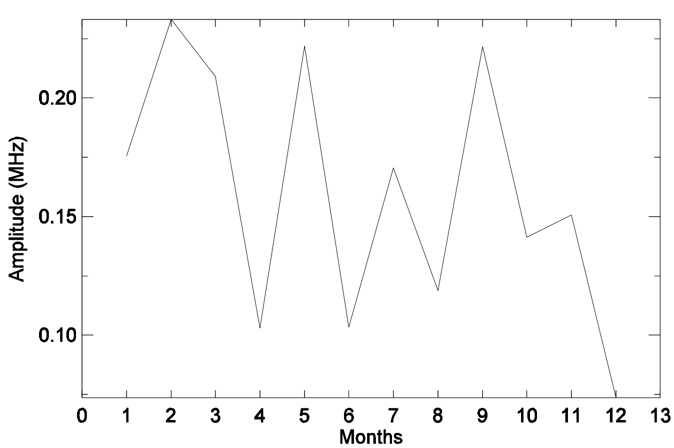

Figure 5a – Amplitude of the diurnal lunar tide as function of the month during 2001 in Fof2

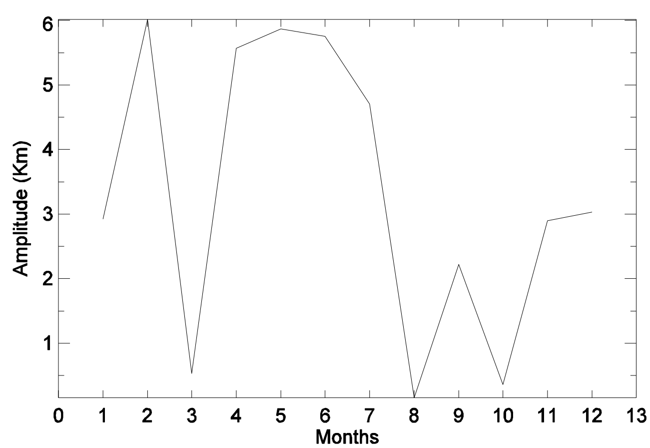

Figure 5a – Amplitude of the diurnal lunar tide as function of the month during 2001 in Fof2

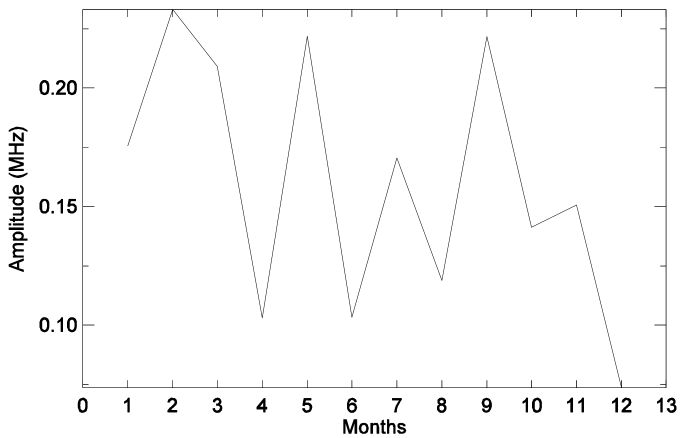

Figure 6a – Phase of the diurnal lunar tide as function of the month during 2001 in Fof2

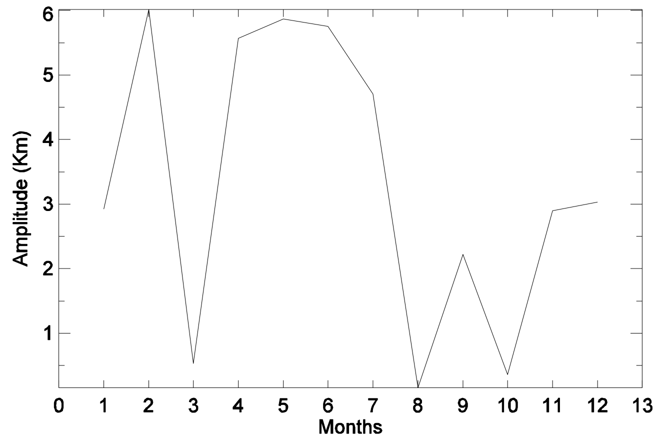

Figure 6b – Phase of the diurnal lunar tide as function of the month during 2001 in Hmmf2

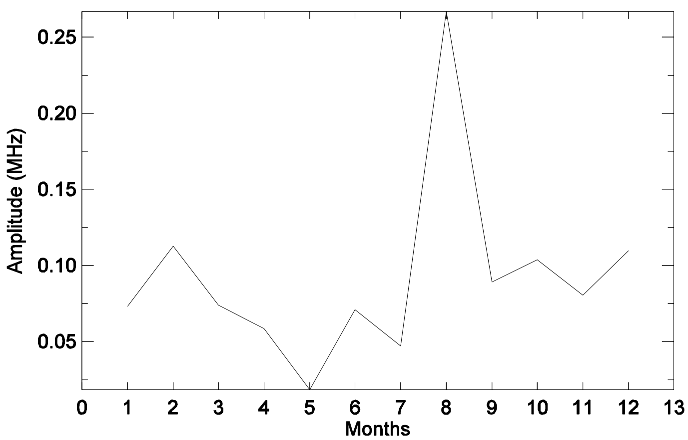

Figure 7a – Amplitude of the semidiurnal lunar tide as function of the month during 2001 in Fof2

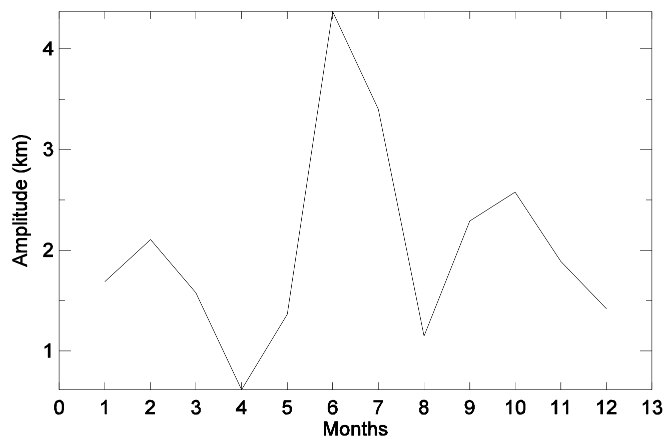

Figure 7b – Amplitude of the semidiurnal lunar tide as function of the month during 2001 in Hmf2

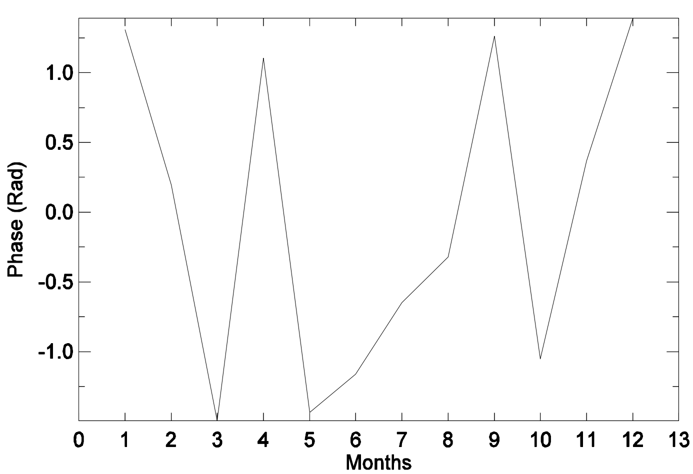

Figure 8a – Phase of the semidiurnal lunar tide as function of the month during 2001 in Fof2

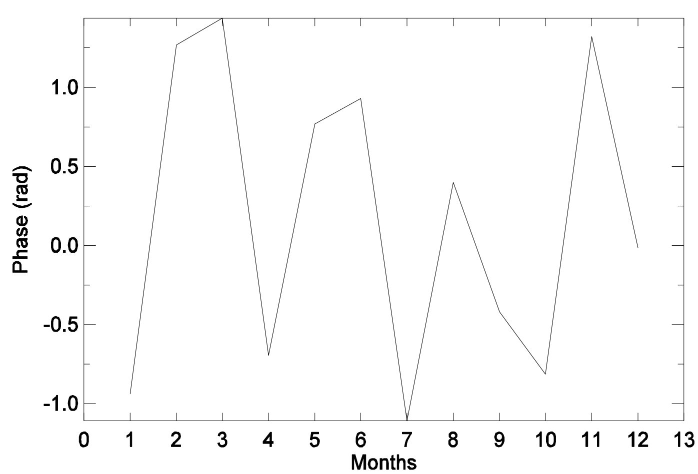

Figure 8b – Phase of the semidiurnal lunar tide as function of the month during 2001 in Hmf2

Stening and Vicent (1989) and Samford (2007) also observed a semiannual variability for the amplitude and phase for the semidiurnal lunar tide. They demonstrated through the vertical wavelength that is directly related by the tidal phase. The semidiurnal lunar tide also was studied by Paulino et al. (2012) who showed the effect of the sudden stratospheric warming (SSW) to explain some structures in the MLT region using wind data during 2006 at the same location used in this paper.

Conclusions

The present study used two ionospheric parameters of F-Layer, collected by a digisonde located in Cachoeira Paulista during 2001, in order to investigate the lunar tidal effects in these parameters.

After remove the solar daily variation was possible to obtain the Diurnal and semidiurnal lunar tide components

The results are summarized as following:

- The amplitude of the diurnal lunar tide in Fof2 ranged from 0.1 MHz to 0.24 MHz. The phase was ranged from -1.2 to 1.5 radians.
- The amplitude of the diurnal lunar tide in hmf2 was between 0.7 and 6 km. The phase was between -1.5 and 1.5 radians.
- The amplitude of the semidiurnal lunar tide in Fof2 ranged from 0.05 MHz to 0.26 MHz with maximum in August. The phase ranged from-1.3to 1.3 radians.
- The amplitude of the diurnal lunar tide in hmf2 ranged from 0.7 to 4.6 km with maximum in June. The phase ranged from -1 to1.5 radians.
- The semidiurnal components presented a semiannual variation in both parameters.

Acknowledgments

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