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Annales Geophysicae Discussions

# *Interactive comment on* "Variability of the lunar semidiurnal tidal amplitudes in the ionosphere over Brazil" *by* Ana Roberta Paulino et al.

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REVIEWER:**"The authors examined seasonal and intraseasonal variability of the semidiurnal lunar tide in TEC over Brazil. The main finding is that the amplitude of the semidiurnal lunar tide in TEC often shows 7-11 day variations. The authors speculate that these variations are associated with the quasi-10-day wave in the middle atmosphere."**

AUTHORS: We appreciate the revision and the contributions from the Reviewer # 2. We have done our best to address all of the concerns from the reviewer.

REVIEWER:**"Although the results are interesting, I am not totally convinced that**



**the authors were able to extract 7-11 day variations of the semidiurnal lunar tide. The authors used the technique of Paulino et al. (2017) to derive the amplitude of the semidiurnal lunar tide. This technique involves a 27 day window, which enables to distinguish between the semidiurnal lunar tide (12.42h) and semidiurnal solar tide (12.00h). The technique should largely eliminate variations with periods less than 27 days, even though the amplitude is calculated for each day. Thus, it is unclear whether the presented short- period variations are meaningful."**

AUTHORS: We thank the reviewer for this important comment. The TEC in the tropical region is mainly produced by the absorption of the EUV and X-rays solar radiations. Thus the diurnal cycle is faraway dominant and should be removed. The determination of the lunar semidiurnal tides in TEC maps were done according to the Pedatella and Forbes (2010) methodology and only quiet days were considered ($K_p < 3$) in the analysis. Figure 1 (upper panel) shows a 29.5 days window of TEC from 27 July 2011 to 25 August 2011 measured at ($15^o$S, $39^o$W).

After the elimination of geomagnetic influences, a Fourier analysis was performed to extract the subharmonics of the solar day (diurnal, semidiurnal and terdiurnal oscillations). Effects of the solar rotation was removed using a 27-day window moving it forward one day at time to calculate the mean solar day centered in the window as can be seen in Figure 1 (middle panel). In addition, residual TEC was determined subtract the original TEC from the recovered one. Figure 1 (bottom panel) shows the residual TEC for this example, where the power of the diurnal cycle is reduced and other oscillations can be observed. In the relative residual data (residual TEC divided by the mean TEC), a least square analysis in a window of 29-day was applied using the following equation:

$$y(\tau) = \sum_{n=0}^{2} A_n \cos(n\tau + \phi_n) \quad (1)$$

where $\tau$ if the lunar time given by $\tau = t - \nu$, $\nu$ in the age of the Moon, which is set to be $0$ at the New Moon. The solar time is represented by $t$, the amplitudes and phases of the lunar tide components are represented by $A_n$ and $\phi_n$, respectively.

We have included this explanation in the manuscript in order to clarify the methodology. It was requested by Reviewer #1 as well. Furthermore, the scope of the present work was investigate the day-to-day variability of the amplitude of the lunar semidiurnal tide, which was calculated for each day and change as well as shown in Pedatella and Forbes (2010) and Paulino et al. (2017). Additionally, the determination of the short-period oscillations were statistically significant as in the LS periodogram as in the wavelet analysis (the significance level were included in all plots).

REVIEWER:**" The authors are advised to check the spectrum of the original TEC data (instead of the spectrum of the semidiurnal lunar tide) to confirm that a spectral peak exists at the semidiurnal lunar tide (12.42h) as well as the sideband frequency corresponding to the quasi-10-day wave modulation of the semidiurnal lunar tide."**

AUTHORS: We thank to the reviewer for this comments. Regarding to the presence of the lunar tide in the TEC, Figure 1 of Paulino et al. (2017) shows very clear evidences in different periods.

On the other hand, we have followed the suggestion from Reviewer #2 to show the presence of the Q8D wave in the TEC. Figure 2(a) shows the data of the quiet day TEC maps for November 2013 (when the Q8D wave was strong in the amplitude of the semidiurnal lunar tide) at $8^o$S, $35^o$W (where there are confident GNSS receivers and the



amplitude of the amplitude of the Q8D was strong). One can see that there is a strong day-to-day variability in the TEC. Figure 1(b) shows the Lomb-Scargle periodogram calculated using the data from Figure 1 (a). The diurnal cycle is very pronounced compared to the other oscillation. Figure 1(c) shows the same results of Figure 1(b) but ranged from 0 to 50 PSD units. One can see that the Q8D wave peak is above of the confidence level and it demonstrates what was suggested by the reviewer.

REVIEWER:**"1. Equation (1) - This needs more explanations. What is "filter" on the left-hand side? How is it applied to the data?"**

AUTHORS: Thank you for the comment. We have included a citation about the application of the filter as suggested by the Reviewer #1. To apply the filter, first we apply the FFT transform, then we multiply the "filter" by the FFT signal. Finally we apply the inverse FFT to recover the filtered signal.

REVIEWER:**"Lomb-Scargle periodogram - Since the authors show wavelet spectra in Figures 3 and 5-8, Lomb-Scargle periodograms in Figures 2 and 4 do not seem necessary. I suggest to remove them."**

AUTHORS: The reviewer is right! Most of the aspects showed in Figure 2 and 4 can be seen in the wavelet charts. However, LS periodograms can give us a general idea about the periodicities using the whole period of analysis and comparisons between the latitudes are easily matched. Even so, if the reviewer thinks better to remove them, we can do it for the revised version.

REVIEWER:**"Figure 9 - The antisymmetric mode such as the quasi-10-day wave has the phase structure that is antisymmetric about the equator, but not the amplitude structure. That is, when there is a strong quasi-10-day wave, we should**

**expect the amplitude of the wave to be large in both northern and southern hemispheres but with the opposite phase. What is shown in Figure 9 is the anti-correlation of the amplitude between the northern and southern hemispheres, which does not necessarily support the involvement of the quasi-10-day wave.**"

AUTHORS: The reviewer is right! Figure 9 does not necessarily support the anti-symmetry. Thank you for the comment. Besides, we are not sure about how is the symmetry of planetary waves regarding the magnetic coordinates. Therefore, we decide to remove these analysis. Thank you for this contribution.

Please also note the supplement to this comment:
https://angeo.copernicus.org/preprints/angeo-2020-34/angeo-2020-34-AC2-supplement.pdf

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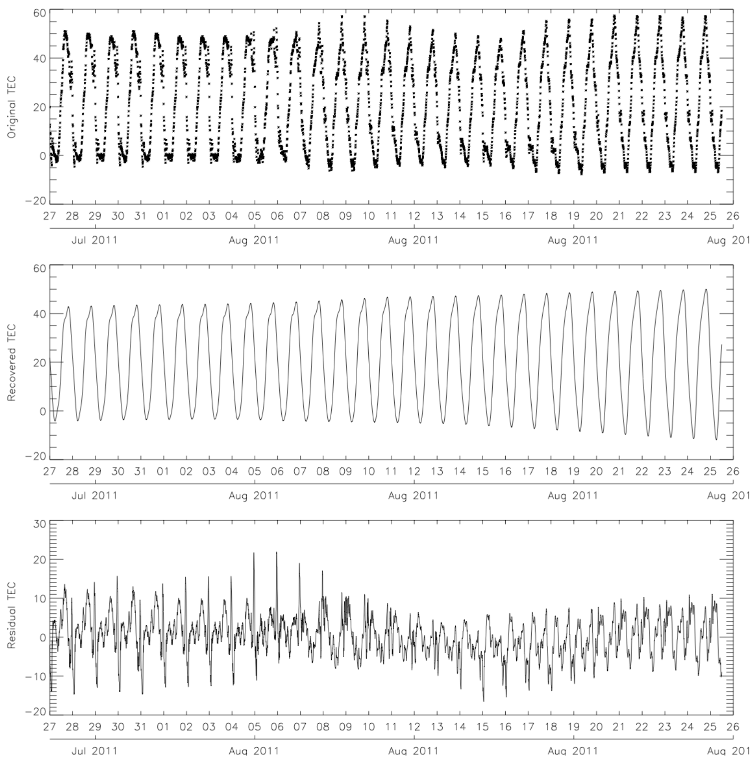

**Fig. 1.** Original TEC from 27 July 2011 calculated at (15o S, 39o W). (Middle panel) recovered signal using sub-hamornics of the solar day within a 27 days window. (Bottom panel) Residual TEC.

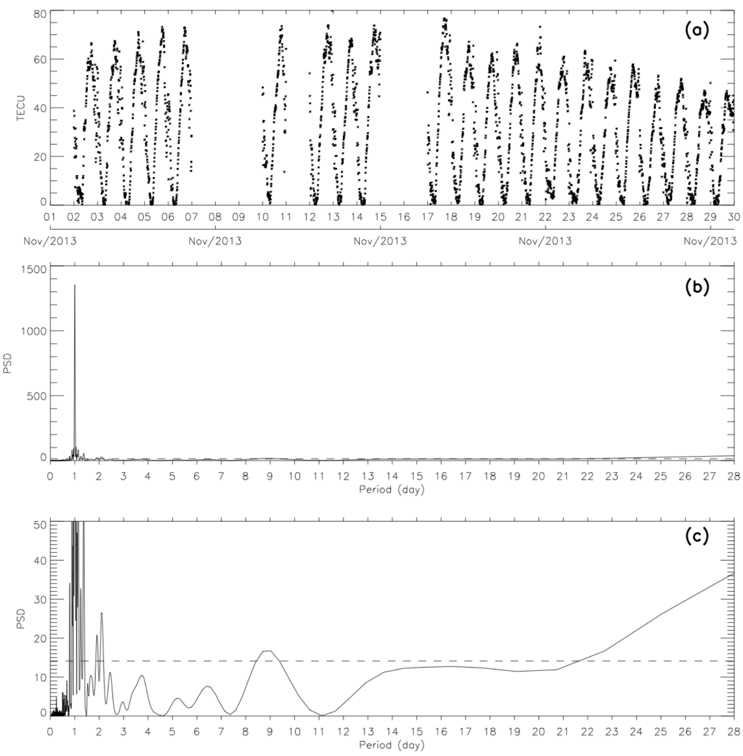


**Fig. 2.** (a) TEC data calculated to November 2013 at (8o S, 35o W) (b). Lomb-Scargle periodgram for the data TEC data shown in panel (a). (c) Same as Figure (b), but for zoomed to the y-range from 0 to