ANALYSIS OF SOLAR TIDAL SIGNATURES IN IONOSPHERIC ELECTRIC CURRENTS OBSERVED BY MAGNETOMETERS

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Abstract

Wavelet analysis is used to derive solar tide on the Earth's magnetic field from magnetometer installed in the American sector. A latitudinal analysis over the whole American sector are shown and discussed. New results regarding the diurnal and semidiurnal are obtained and revealed a different domination of the atmospheric tidal modes with respect to previous published works. We have also obtained an evidence of a coupling process between the solar tide and the induced magnetic field at the ground level. In addition, we have find out and interesting dependence between the spectral density and the magnetic activity. Finally, the study of tides on the geomagnetic field revealed itself to be very important for a better understanding of the local space weather, since it plays a major role in the ionosphere electric fields during geomagnetic quiet days.

Introduction

The Earth's magnetic field can be basically represented by a geometric dipole not centered in the geographic axes. The main field, comprehending 99% of the total strength, is supposedly originated by electric currents in the liquid part of the Earth nucleus (Hargreaves, 1992). The remaining 1% is credited to external sources such as ionospheric and magnetospheric electric currents. It is not steady, having secular and spatial variations with amplitudes smaller than the portion generated in the nucleus. Some variations have been extensively studied like the secular (Allan and Bullard, 1966; Pais and Jault, 2008) and diurnal (solar or lunar) variations (Martyn, 1948; Forbes and Garret, 1976; Forbes and Wu, 2006). Secular variations are slow and continuous changes in the Earth's main magnetic field. Diurnal variations are caused mainly by current flows in the upper atmosphere, where the tidal wind movement in the atmosphere results in the dynamo action, generating fields and electric currents in the ionosphere (Rishbeth, 1997). Variations in the terrestrial magnetic field present dependence with the latitude, station, solar activity cycle (period of 11 years), and lunar transit. During low solar activity, diurnal variations of the geomagnetic field are named Solar Quiet variation (Sq). Sq variation presents magnetic field magnitudes around hundreds nanoTeslas of amplitude. Diurnal variations during high solar activity can be caused by compressions of the terrestrial magnetosphere due to the solar activity (Nair, 1970). The diurnal variations, which the present work concerns are caused by solar influence under quiet activity, called solar tide. The main tide periods are 24-hour (diurnal tide), 12 hours (semi-diurnal tide) and 8 hours (ter-diurnal tide). Recent studies (Almeida et al., 2007) have been carried out based on the spectral analysis of the magnetic dip angle (I) obtained from magnetometer installed at São Luís, Brazil, from 2002 to 2004. These studies revealed diurnal variations of the Earth's magnetic field with periods of solar and lunar tides. The solar tides were observed with following periods: diurnal tide ~24 h (23.15); semi-diurnal tide ~12 h (11.57); ter-diurnal tide ~8 h (7.93) and quadratic tide ~6 h (5.97). Still, the lunar tides were observed with periods of: diurnal tide ~24..84 h (24.79); semi-diurnal tide~12.42 h (12.39); ter-diurnal tide ~8.28 h (8.33) and quadratic diurnal tide ~6.20 h (6.12); all these in agreement with previous studies (Kelley, 1989). In the magnetic dip equator, the magnetic variations are closely related with the Equatorial Electrojet (EEJ). The EEJ is an electric current that flows in the ionospheric region, centered at approximately 105 km-height, around the magnetic equator. This current is basically caused by the electric field polarization in the solar terminators driven by the dynamo action and is subordinate to the ionospheric conductivity configuration. In this work extended our previous studies to analyze the signatures of the solar tides in the magnetic field variations on the ground level, as measured by a magnetometer network distributed in the American sector.

Methodology of data analysis

In order to investigate the magnetic signature of solar tides, magnetometric data from Kyoto network was chosen in a determined latitudinal band in the American sector (Fig. 1).

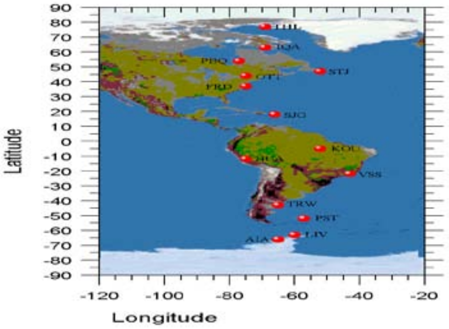

Fig.1 - Locations of the magnetic station selected for the study.

The chosen stations from where the data were analyzed are: Thule Qanaq (THL); Iqaluit (IQA); Poste De La Maleine (PBQ) St. Johns (STJ); Ottawa (OTT); Fredericksburg (FRD); San Juan (SJG); Kourou (KOU); Huancayo (HUA); Vassouras (VSS); Trelew (TRW); Port Stanley (PST); Livinston Land (LIV); Argentines Island (AIA). For each of these stations we obtained the horizontal component of the Earth's magnetic field (ΔH), which was the only component analyzed in this work. The period analysis covers from September 01 to December 31, 1998. This period was chosen due to the good availability of data of magnetometers available at the World Data Center for Geomagnetism. The Kp index variation were used to characterize the corresponding magnetic disturbance level. Data acquired during a geomagnetic quiet day, i. e., when Kp values were lower than 4, were selected only.

Wavelet Analysis

We used Wavelet Transform with the wavelet-mother form of Morlet to analyze the magnetometer data because it gives information about the temporal variation of the amplitude. Wavelet transform was chosen due to its ability to locate in time the oscillations, which allow us to check if their time of occurrence matches with the time of occurrence of solar tide. Indeed, the continuous wavelet transform (CWT) of a discrete sequence of samples (x_n) is defined as the convolution of the samples with a scaled and translated version of the wavelet-mother. Alternatively, it can be treated as the inverse Fourier transform of the product in the frequency domain, as proposed by (Torrence and Compo, 1998):

$$W_n(s) = (2\pi s/\delta t)\sum_{k=0}^{N-1}\hat{x}_k\hat{\psi}_0^*(s\omega_k)\exp[i\omega_k n\delta t] ,$$

because it is the appropriated type for searching periodicities on the data sets. The Heaviside step function H(ω) is equal to zero at for negative frequencies (ω) and equal to one otherwise. Finally, the space-scale energy density for a time series is defined as

$$E_n(s) = |W_n(s)|^2 / s \quad .$$

The different resolutions, the details of a signal, are generally characterized by different physical structures. In a coarser resolution, these details generally characterize the great structures that supply the context. Increasing the resolution, we get finer details (Bolzan, 2004).

Results and Discussion

The results of the spectral analysis of the ΔH are presented in Fig. 2. It shows the result of the wavelet power spectrum calculated for each magnetic station with time resolution of 1 hour. We would like to call the attention of the reader for data gap in Vassouras (VSS) and Kourou (Kou) in the period from September 1 to October 1, and from November 1 to December 20, respectively. Despite this limitation, we clearly see signatures of diurnal tidal, semidiurnal, in all the maps. Also, we can identify signature of ter-diurnal tide in some maps. Moreover, several characteristics can be observed and inferred through the analysis of this map. However, we focused in two of them only: a variation on the spectral range (stronger in high and low latitudes) with latitudes and dependence of spectral density with magnetic activity. With respect to the latitudinal variation, the inter-comparison between the stations shows that the influence of the tides varies in relation to latitude. The lower amplitudes are observed in middle latitudes while the higher amplitudes are detected in higher and lower latitudes. An explanation for higher amplitudes in these latitudinal bands lays on the influence of the electrojets in equatorial and high latitudes (Forbes and Garrett, 1979). In order to exemplify the influence of such jets on the amplitude of spectral component, let is take the variation of the equatorial electrojet.. The approximate effect of the induced magnetic field caused by the EEJ current on the H component of geomagnetic field can be investigated analyzing the diurnal variation of the component obtained by the magnetometer (ΔH). To eliminate the effects of the Sq current system and the ring current, we toke the difference of the ΔH from two magnetic observatories properly located. An observatory should be located in the region under the influence of the EEJ magnetic field, such as São Luís (ΔH_{SLZ}) and the other should be located in a magnetic latitude nearby the dip equator but outside the influence of the EEJ, as for example, Vassouras (ΔH_{VSS}). We named EEJ ground strength (ΔH_{EEJ}, given in nT) as the strength of the magnetic effect at the ground level caused by the EEJ current sheet, i. e., the difference between the ΔH from these two observatories.

This parameter can be used as a proxy of the daily behavior of the effect of the EEJ at ground, since this current is directly related to its magnetic field induced at ground (Fig. 3).

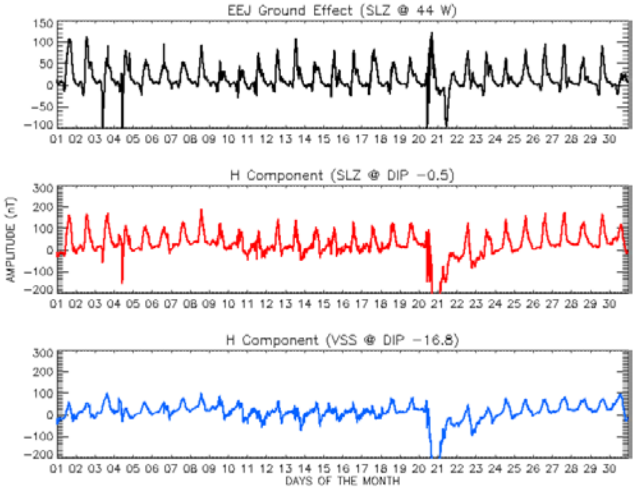

Fig. 3- Variation of *H* component for the stations of São Luís and Vassouras, for days on November 2003.

As described above, near the magnetic equator, ΔH is directly proportional to the east-west current of the EEJ. In addition, the variation of the vertical component ΔZ could be used to determine the gradient of the east-west current (Reddy, 1977). Thus, based on the magnetic component variations, it could be seen that the latitudinal structure of the EEJ owns about 6° magnetic latitude wide.

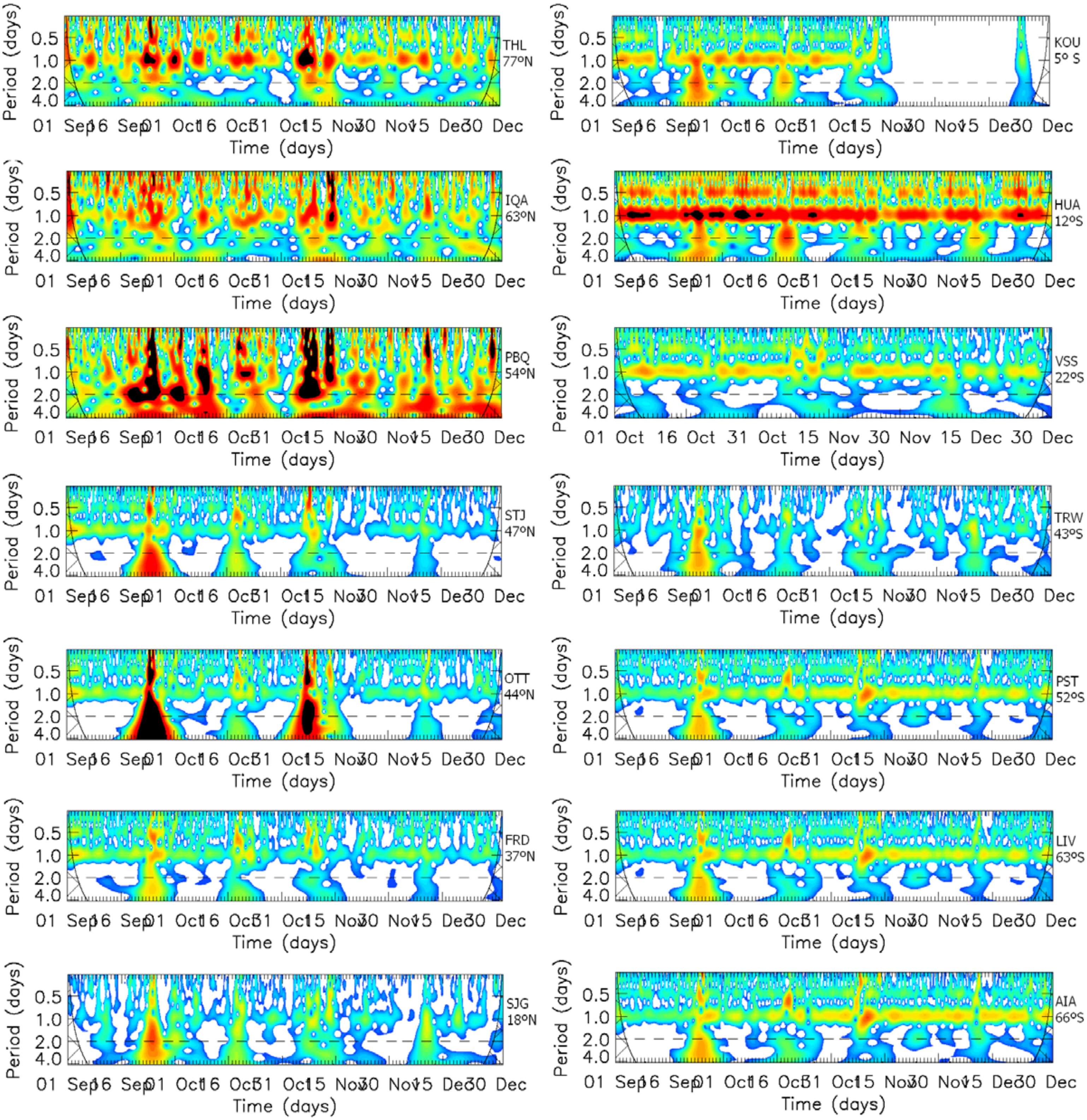

Fig. 2- Magnetometer data maps from the network of Kyoto.

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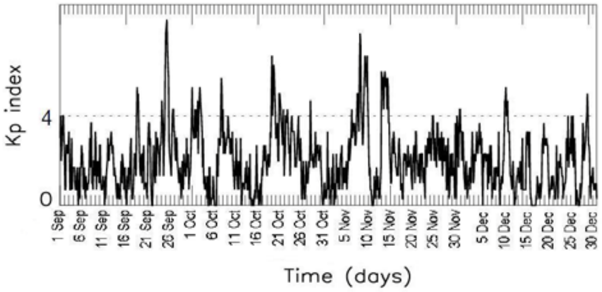

Fig.4 - Variation of Kp index for days on September 1 to October 31, 1998.

Conclusion

We were able to determine the presence of diurnal and semidiurnal tides by analyzing magnetometetric measurements. They were detected in all the maps present here. Ter-diurnal tides signatures were also observed but with lower amplitude. The inter-comparison among the maps revealed a latitudinal variation of the amplitudes of the solar tides. Higher and lower latitudes presented higher amplitudes. A possible explanation was suggested in terms of the influence of the ionospheric jets. Another conclusion is that the maximum spectral density seems to be subtle to the magnetic activity. Finally, it is important to mention that studies of variation in Earth's magnetic field and its influence by the Sun are of great importance for the understanding of the ionosphere-neutral atmosphere, and ionosphere-magnetic field system. This study may help understand the system of the magnetic field induced at the ground level. Therefore, we have a response about the variability of the ionospheric plasma, and indirectly, we can have a proxy of some influences on the magnetic field, electric field, and combination of both, due to the current imbibed in the plasma.

Acknowledgments

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