Correlations between solar semi-diameter and geomagnetic time series

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Abstract

We study the correlation between geomagnetic measurements at the Magnetic Observatory, Vassouras, RJ, and values of the solar semi-diameter obtained at the National Observatory, Rio de Janeiro, RJ. The study comprises the period from March 1998 to November 2003. Both series describe different phenomena and, consequently, before a correlation study, an individual analysis of each of data sets was necessary. One of the motivations of the present work is to further explore the correlation with lags found between the solar semi-diameter and some solar activity estimators, which supports the probabilistic forecasting of the solar activity, and hence of the solar driven geomagnetic variations.

Introduction

The possibility of predicting natural processes or phenomena has always been a challenging métier. Especially for those phenomena that threat the human life. During the last decades many research efforts of statistical physicists have been devoted to the study of this kind of problems that include, among many others, earthquakes (Sornette, 2004), magnetic storms (Papa et al., 2006, 2008) and geomagnetic reversals (Merrill et al., 1998; Dias et al., 2008). Magnetic storms are periods that last from one to three days during which the field suffers rapid variations. They are responsible for only around 1% of the amplitude of the total magnetic field that we can measure at the Earth's surface. However, they seriously affect many human activities. The magnetic field produced at the Sun's surface and Earth's atmosphere presents strong variations that, among other things, seriously affect telecommunications, and produce induction in transmission lines. Very recently, in November 2003, around 50000 Swedish people suffered an energy blackout during a short period of time caused by a strong magnetic storm. This was also the case during the year of 1989, but during more than nine hours, for Quebec, Canada. For some scientific and technical applications (for example, measurements of the crustal magnetic field for prospecting purposes, and directional drilling) the Earth's magnetic field is supposed to be known and used as a reference (Gleisner et al., 2006). Any variation or deviation from undisturbed values may be the source of unwanted errors. An intriguing fact, which possibility has been advanced by some scientist (Dimitrova, 2008; Stoilova et al., 2008), is the relation between the geomagnetic field activity and the human physiology (an increase in the number of heart attack in epochs of great geomagnetic activity, for example), but it will need deeper studies.
The possibility of a correlation between the occurrence of earthquakes and geomagnetic disturbances (and, as a consequence, of a potential earthquake forecasting based in geomagnetic measurements) has been advanced by several authors (Pulinets and Boyarchuk, 2004). However, its actual existence, as well as the eventual interconnection between geomagnetism and the human physiology, will need further studies.

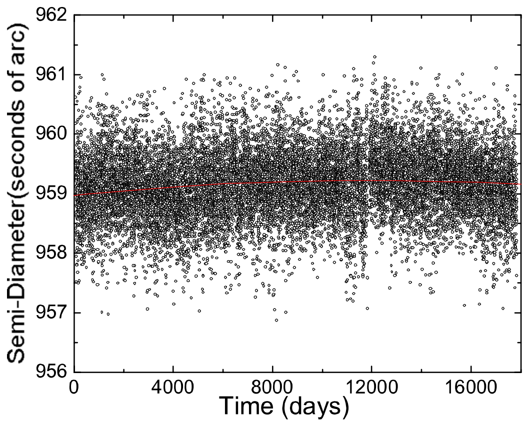

Figure 1.- Values of semi-diameter measured from March 1998 to November 2003 at the Observatório Nacional, Rio de Janeiro, after correcting for instrumental and local effects. Values adjust well around a given mean (see figure 2), though trends cannot be discarded (e.g., the significant 2nd degree polynomial adjusted by the red line).

There are prospecting methods (Magneto-telluric, for example) in which the occurrence of magnetic perturbations (far from detectors to accomplish the condition of plane wave front) is desired and useful. All the reasons mentioned above justify the search for methods to forecast magnetic storms at medium and long terms. However, for this case, as well as for other catastrophic events (earthquakes, for example), which threat man's life and activities there are no yet methods to accomplish this task in a reliable manner.

Magnetic storms are mainly caused by phenomena in the Sun that affect the Earth's atmosphere. In this work we address a study on the correlation between the solar semi-diameter and geomagnetic TIME series. The rest of the work is organized as follows, in the next section we expose the experimental details of data obtaining, and in the subsequent the results of our analysis. Finally, in the Conclusions section we present some final discussion and possible future approaches.

Experimental Details

Both series describe different phenomena and, consequently, before a correlation study, an individual analysis of each of data sets was necessary. An extensive use of FFT with filtering procedures in the solar semi-diameter set of data was done. In addition, the time distributions and densities of both data sets are different (a few measurements per diem for the semi-diameter series and a measurement each minute for the geomagnetic series).

The solar semi-diameter observations were obtained using a front prism of variable angle and a CCD camera with registrations containing both the direct and the reflected solar images. The arrangement allows observations between 26 and 56 degrees of zenith distance. There are a few measurements per diem.

Figure 1 shows the solar semi-diameter measurements after correcting for instrumental and local effects as measured at the National Observatory, Rio de Janeiro, Brazil, from March 1998 to November 2003. For details on the correction procedures see the work by Andrei et al. (Andrei et al., 2004) and references therein. In Figure 2 the distribution of values in Figure 1 is presented. It follows extremely well a Gaussian distribution, for a bin size of 0".2. The mean value of the gaussian distribution is d_0 = 959.165 seconds of arc. Notice that when the bin size is shortened to the level of 0".02 (the r^2 of the polynomial adjustment) and smaller, the fit to a gaussian progressively disrupts, as shown by the fall of the chi squared statistics. Such fact indicates that the semi-diameter series can be examined from the standpoint of the presence of signal.

The geomagnetic observations consisted in measuring the *H* (magnetic northward) component of magnetic field at our low latitude Vassouras Magnetic Observatory (latitude –22.41, longitude 316.31). The *H* component is essentially the same that the total field component, *F*, at that location. Data is recorded at 1 sample/min, providing more than 44,000 values for each month. The accuracy of the data is 1 nT and the relative error less than 10^{-4}. Geomagnetic measurements were performed using an Intermagnet system (3 component fluxgate and proton magnetometer) during the whole day.

In Figure 3 we see the dependence of the H component of the magnetic field as measured at the Vassouras Magnetic Observatory from 1998 to 2003. We can observe a trend to lower values while time increases. This trend is caused by change in the internal component of the magnetic field and was removed because it is not our study subject. The same was done with the direct component around 19400 nT because it is the mean value of the field produced at the Earth's interior (the amplitude of the more severe magnetic storms is around 400 nT). In a previous work (Papa et al., 2006) it was shown that after appropriated filtering procedures both the amplitude distribution of geomagnetic disturbances and the inter-event time distribution follow power laws.

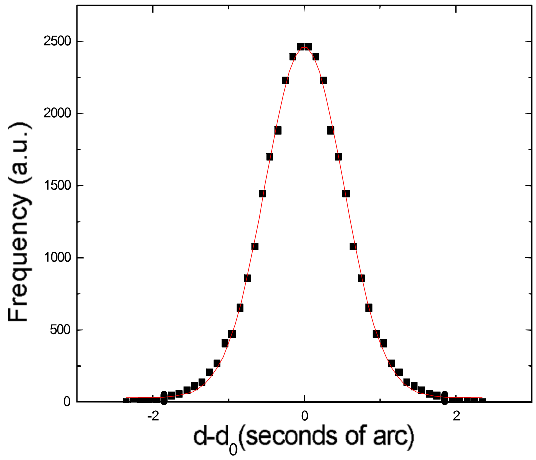

Figure 2.- Distribution of solar semi-diameter values after correcting for instrumental and local effects. For bin size commensurable to the standard deviation the experimental values closely follow a Gaussian distribution (red line). The mean value d_0 = 959.165´´. However the fit to a normal distribution disrupts when the bin size gets commensurable to r^2 of the polynomial adjustment.

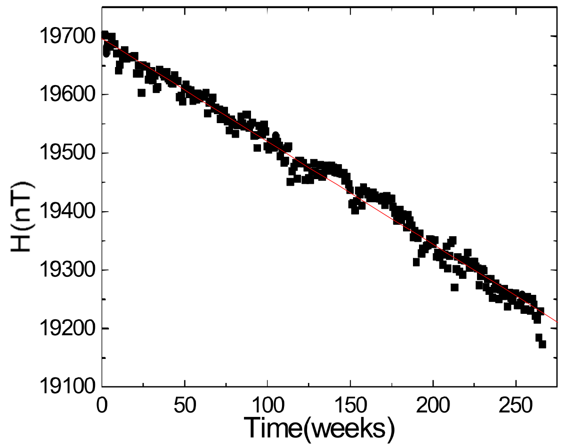

Figure 3.- Values of the magnetic field measured from March 1998 to November 2003 at the Magnetic Observatory of Vassouras, RJ. Values seem to decrease as time goes by, as known from previous works. This behavior has led some scientist to believe that the Earth's magnetic field is walking to a reversal (that might occur in a few thousands years).

Note that, in principle, there is no necessity of more sophisticated filtering procedures in the geomagnetic series in order to compare with solar semi-diameter series because, the period of the main disturbance for geomagnetic measurements (24 hours from the Earth's rotation) coincides very well with the nyquist frequency of the solar semi-diameter measurements.

The temporal density of both sets of data is not the same and, in order to allow the comparison of them (correlation) we have calculated the average values along the data sets in periods that range from 1 week to 12 months.

Results and Discussion

In Figure 4 it is shown the correlation between solar semi-diameter and geomagnetic time series. It was calculated over the average values corresponding to periods of 1 week and 1, 2, 4, 6 and 12 months. It is clearly observed an increase in the correlation as the interval used for the averages growths. The values for short periods of times (the periods we are interested in for prediction purposes) are very low.

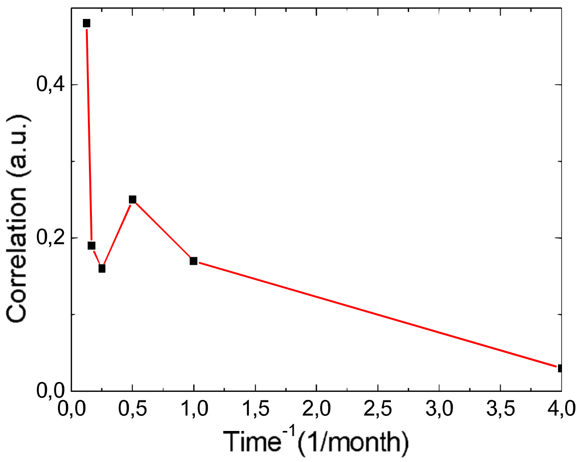

Figure 4.- Correlation between solar semi-diameter and geomagnetic measurements. The results are plotted for 1 week and 1, 2, 4, 6 and 12 months.

Figure 5 shows the correlation with lags between the solar semi-diameter and the geomagnetic measurements. It was used a 10 week interval for the averages and time displacements from –25 weeks to 25 weeks. There seems to be a pseudo-periodicity of period around 40-60 weeks. It is probably associated to some seasonal features. Note that there exist several local peaks and that the highest are near the extremes. However, the extremes are the less significant from the statistical point of view. They are represented by a few point while the central ones (near zero lag values) are represented by a larger data mass. To take this into account we have multiplied the correlation in Figure 5 by $(N)^{1/2}$, where N is the number of intervals entering each calculated correlation. The results are plotted in Figure 6.

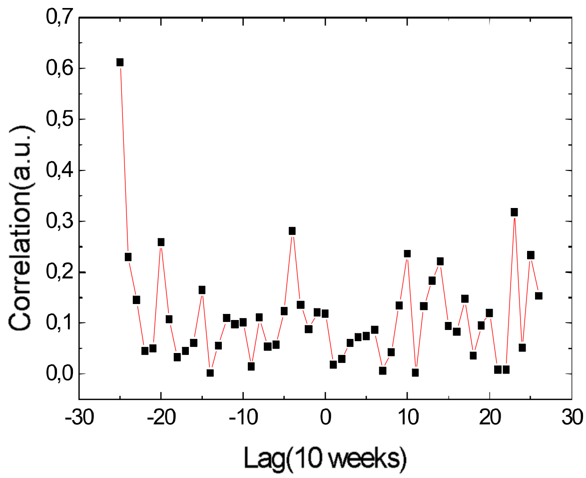

Figure 5.- Correlation with lags. All points were considered to have the same statistical weight (see Figure 6).

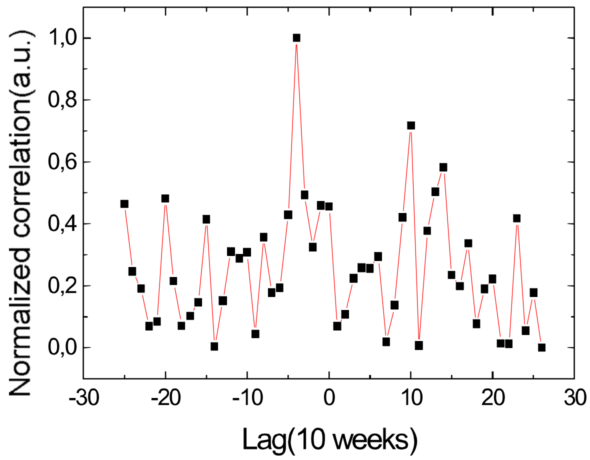

Figure 6.- Correlations with lags with statistical significance. There is a relative maximum near zero lag and the absolute maximum for a ~40 weeks lag (solar data preceding geomagnetic data).

Conclusions

We have performed a first approach to the study of correlations between the solar semi-diameter and geomagnetic measurements. It is clear that there exist some correlation that increases when longer periods are considered. However this is in the counter-hand of our primary objective: the possibility of predicting magnetic perturbations from solar semi-diameter measurements. When considering correlations with lags the results seem to be more promising. There is a local maximum near zero lag and an absolute maximum for lags (the solar semi-diameter series preceding the geomagnetic series) around 50 weeks (around 1 year). The local maximum near zero lag offers a way to be further explored. It suggests the same mechanism seen for the comparison between semi-diameter and solar irradiance variations (Andrei et al., 2008, this symposium), which show to maxima, one near zero phase and another towards one and a half year. The correlation close to zero phase regards the epochs of peak of solar activity. As such epochs are those prone to violent solar outbursts, the semi-diameter variations could than act as a precursor. The design and construction of a heliometer with improved characteristics (see the works by Reis Neto et al., 2008) in its capability of measurements in larger zenith distances and in precision will be of great help in the near future. Methods using mobile means (as well as wavelet analysis) will also help in future studies, they will allow us to follow both series in a more detailed fashion and, consequently, to establish correlations in shorter periods of time. Further studies are necessary and their results will be published elsewhere.

Acknowledgements

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