HOLOCENE SECULAR VARIATION FROM LAKE SEDIMENTS REASSESSED

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ABSTRACT

Time variations in the magnetic record of lake sediments are reexamined in this paper by applying a new method for spectral analysis of time series irregularly sampled. The method produces a combination of all the spectra by means of a modified version of the Lomb-Scargle periodogram. This combination of information approach is a stacking-like procedure reducing noise and highlighting features that may be not sufficiently clear in individual spectrum. We investigated the magnetic declination and inclination records from 17 lakes from Argentina, Australia, North America and Greece limited to the first 10,000 years. The combination of the periodograms from the investigated lakes showed some high correlation maxima in the range ~1400-1700 yr. for declinations and ~2100-2800 yr. for inclinations, although individually the subsets by country may display slight different intervals. The velocities of virtual geomagnetic pole displacement were investigated by the same method and gave spectral features in the same range (1500-2600 yr.), consistent with the directional data. These results were already reported in literature. However, the method turned out efficient in bringing common features from individual spectra supposed to express the same phenomena, as the operations perform the combination of uncertainties in the means.

Keywords: Secular variation, Bayesian combined periodograms, Holocene

RESUMO

Variações temporais nos registros magnéticos de sedimentos lacustres foram reexaminadas neste trabalho aplicando-se um novo método de análise espectral de séries irregularmente espaçadas. O método produz uma combinação de todo os espectros baseados numa versão modificada do periodograma de Lomb-Scargle. Esta abordagem de combinação de informação é um procedimento do tipo 'stacking' que reduz ruído e ressalta feições que podem não estar suficientemente claras em espectros individuais. Foram investigados os registros de declinação e inclinação de 17 lagos da Argentina, Austrália, América do Norte e Grécia, limitados aos primeiros 10,000 anos. A combinação de periodogramas dos lagos investigados mostrou alguma correlação máxima no intervalo ~1400-1700 anos para declinação e ~2100-2800 anos para inclinação, embora os subconjuntos de dados por país podem exibir intervalos um pouco diferentes. As velocidades de deslocamento dos polos geomagnéticos virtuais também foram investigadas e mostraram feições espectrais no mesmo intervalo (1500-2600 anos), consistentes com os dados direcionais. Esses resultados já foram relatados na literatura. Entretanto, o método revelou-se eficiente em trazer feições comuns de espectros individuais que se supõe expressem o mesmo fenômeno, uma vez que as operações realizam a combinação das incertezas nas médias.

Palavras Chave: Variação secular, Periodogramas combinados Bayesianos, Holoceno

Introduction

Fluctuations in the geomagnetic field have been the subject of investigation for some decades, because they represent important characteristics to constrain the geodynamo behavior. Directional data obtained

from Holocene lake sediments are believed to display time variations with periodicities of hundreds to thousands of years. However, even for close sites, the spectral content on declination or inclination time series may vary considerably, and reasons for those differences may be attributed to local variations in the field or to processes involved in the acquisition of magnetizations or recorded information retrieving as well as to the accuracy in calibrating ages.

Panovska *et al*. (2013) revised the global database of recent sediments aiming to reevaluate the periodicities in the magnetic record by means of three types of signal analysis: multitaper spectral estimation, wavelet analysis and empirical mode decomposition. Their results pointed to a continuous spectrum of time variations in the range 300 - 4000 yr., rather than to discrete periods recognizable widely. However, time variations of 1100, 1700 and 2400 yr. were generally seen on the European spectra (Fig. 1a), although the period of 1700 yr. seems to be more widely recognized.

Methodology and results

In this paper we reexamined these time variations in the magnetic records of lake sediments by applying a new method for spectral analysis of multiple series with irregularly sampling intervals (Caminha-Maciel and Ernesto, 2013). If any of those periods represent worldwide time variations of the global

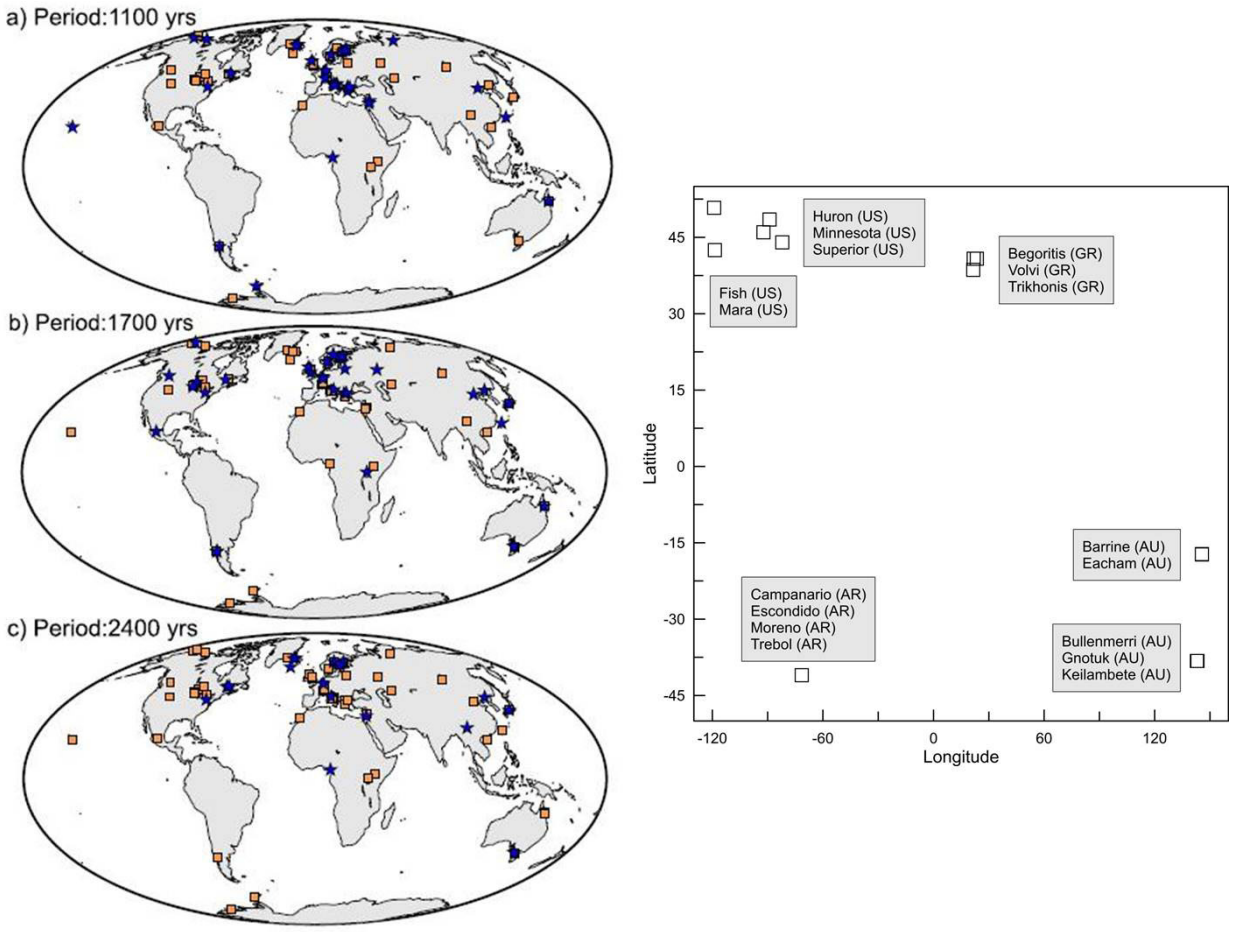

Figure 1. a) Distribution of Holocene sediment magnetic records (Fig, 6 from Panovska *et al*., 2013) indicating those where periods of 1100, 1700 and 2400 years were found (dark stars), and those where the periods were not found (orange squares); b) location of the lakes investigated in this paper.

geomagnetic field, they should emerge in all investigated sites. Limitations can arise from the short length of the series and irregular sampling, producing spectral misleading features as aliasing, scalloping losses and spectral leakage errors. These features have the effect of distort spectral analysis results, causing divergence between results from original dynamical forcing periods and those measured from a particular time series. Also, general dynamical systems usually exhibit quasi-periodical states much more frequently than purely periodic frequencies. Thus, real frequencies from the dynamical system could a) not be shown at all (shadowed by noise, by side lobes or by aliases), b) appear on a deviated frequency, c) appear divided for two neighboring frequencies (scalloping error) and, d) appear on the right frequency; all of this contributing for a lack of resolution on overall analysis. Then the spectral analysis method of Caminha-Maciel and Ernesto (2013) appropriately produces a combination of all the spectra by means of a modified version of the Lomb-Scargle (LS) periodogram (Lomb, 1976; Scargle, 1982). This combination of information approach is a stacking-like procedure reducing noise and highlighting features that may be not sufficiently clear in individual spectrum. The combinations are done in two different modes – correspond to the 'OR' and 'AND' operations over all states of information (function describing the different estimates for each frequency) - resembling the union and intersection of sets (Tarantola and Mosegaard, 2000). Mathematically, these operations can be related to sum (OR) and product (AND) of these states of information, after normalization by total bandwidth.

We investigated the magnetic declination and inclination records from 17 lakes from Argentina, Australia, North America and Greece (Fig. 1b) limited to the first 10,000 years. The data were downloaded from the NOOA website, except for the Argentinean data which correspond to a more recent publication (Gogorza *et al.*, 2000). We examined the AND spectrum for declination and inclination separately, for possible periods of 500-3000 years. We first analyzed the data by country to avoid interferences inherent to distant geographical locations, and concluded that even very close sites produce different individual spectra. However, as already pointed out by Panovska *et al.* (2013), there is more consistency amongst nearby records of inclinations than of declinations. This was particularly true for the Argentinean lakes, as can be seen by comparison of Figs. 2 and 3.

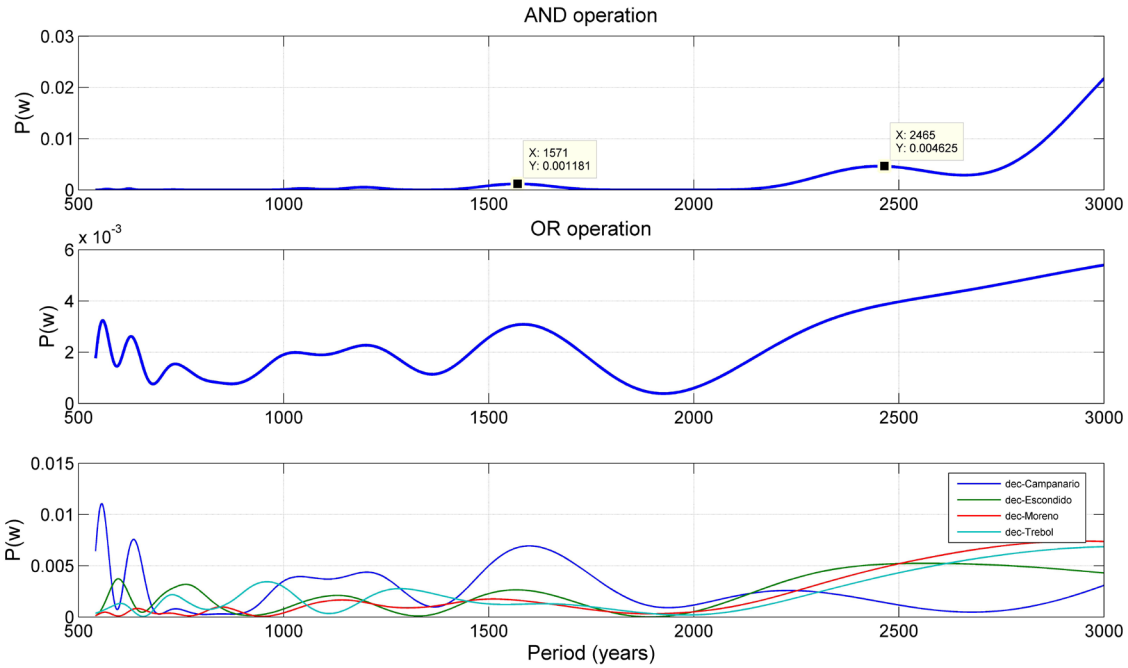

Figure 2. LS spectra for the declination sequences of the Argentinean lakes. Combination of all curves are expressed by the 'OR' and 'AND' spectra. P(w) in arbitrary units.

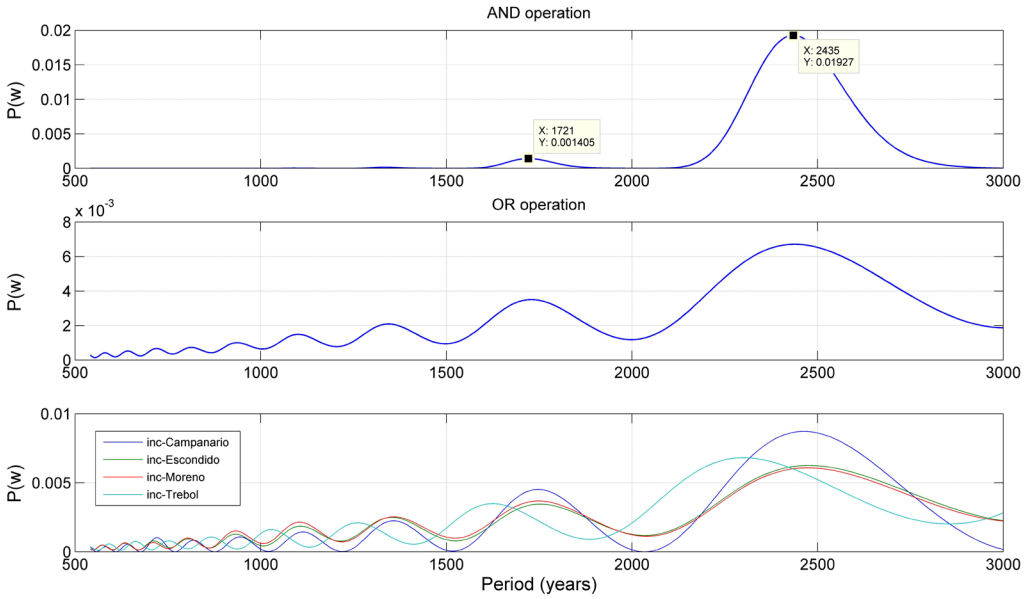

Figure 3. LS spectra for the inclination sequences of the Argentinean lakes. Combination of all curves are expressed by the 'OR' and 'AND' spectra. P(w) in arbitrary units.

The AND combination of the periodograms from the 17 investigated lakes (Fig. 4) showed some high correlation maxima in the range ~1400-1700 yr. for declinations and ~2100-2800 yr. for inclinations, although individually the subsets by country may display slight different intervals. These intervals are compatible with the findings of the other authors, although our analysis is restricted to fewer areas, and more limited number of records. However, we do not interpret these results as indication of periodical behavior of the data, as this would imply in purely sinusoidal (plus uncorrelated noise) pattern for the variables. Actually, the two angles (declinations and inclination) are inseparable parts of a process that generates periodical patterns – the movements of the magnetic poles.

We also investigated the movements of the virtual geomagnetic poles (VGPs) by means of studying the spectral behavior of their velocities as a function of time. The VGP velocities were calculated by considering the arc described between two consecutive VGPs, and dividing it by the corresponding time interval. For the investigated cases we found the same results as for the directional data, sometimes showing more resolved peaks. As an example the velocity spectrum for the Argentinean lakes (Fig. 4) resulted in a more complete AND spectra with all the major periods (~1100, 1700 and 2400 yr.) reported before. The combination of all velocity spectra (AND spectrum) showed periods in the range 1500-2600 yr. which are consistent with the directional data results.

The above results did not reveal any still unknown spectral feature of those times series that contributes to the understanding of the secular variation behavior. However, our method turned out efficient in bringing common features from individual spectra supposed to express the same phenomena, as the operations perform the combination of uncertainties in the means. We therefore presented a new approach in the investigation of the long-scale geomagnetic variations, through the combination of information of time series, which is not simply the application of the Lomb-Scargle periodograms, but a complete inverse procedure on spectral estimation from multiple (incomplete - irregularly sampled) time series.

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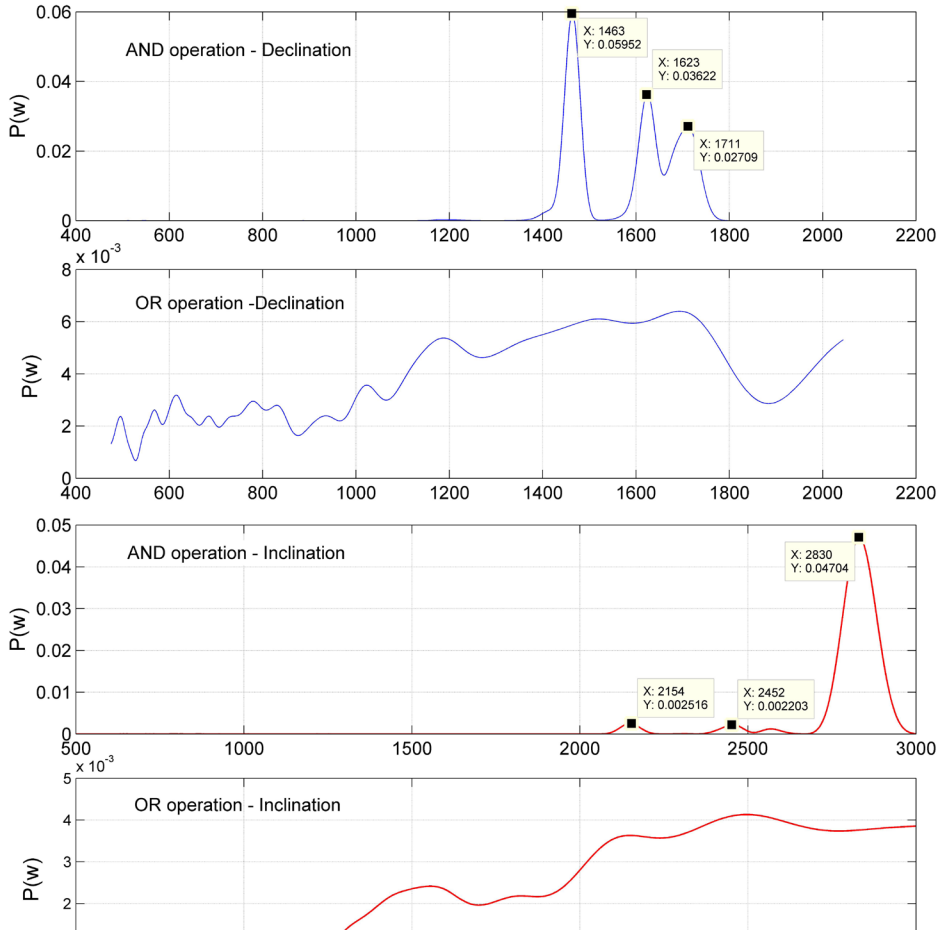

Figure 4. Combined 'OR' and 'AND' spectra for the 17 declinations (above) and inclinations (bottom) time series investigated in this paper. P(w) in arbitrary units.

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