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Application of the Signal Correlation for the Construction of Age Models of Lake Baikal Sedimentary Records

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Summary

A new magnetic susceptibility stack from Lake Baikal drilled cores (BDP-96-1, BDP-96-2 and BDP-98) was built for the last 1.1 Myrs. A new timescale for the drilled sedimentary sequences was established based on the correlation of two signals i.e. experimental magnetic susceptibility and theoretical solar irradiation. The automatic orbital tuning algorithm was applied to maximize the correlation between the input signals. Our results are subsequently tested using spectral and wavelet analysis. The obtained timescale is in agreement with the published theoretical models. Moreover the calculated age model shows much improvement when compared with timescales produced by other authors. Our spectral and wavelet analysis proves the presence of Milankovitch cycles, especially at the precession and obliquity frequencies. This reveals the difference in spectra between continental and oceanic sedimentary records where eccentricity has stronger spectral power. The stack that was developed in the study can be used to assist correlation between data from different boreholes.

Introduction

Many studies in recent years showed that some properties of sediments are influences by insolation . The amount of solar irradiation that reaches Earth is associated with Milankovitch periodicities. This knowledge can be used in so-called orbital tuning to construct timescales for sediments from drilled boreholes. In the present study we first create an initial timescale based on available well known ages from beryllium dating (Sapota et al. 2004), magnetostratigraphy (Kravchinsky et al. 2003, Rohraff et al. 2011) and by visual correlation of the most profound extrema between magnetic susceptibility and insolation. The initial age model is subsequently improved with an automatic tuning technique of Yu and Ding (1998). The definite advantage of this method is simplicity and short CPU time required to compute a high resolution timescale.

Tuning Method

In the study we employ the tuning method of Yu and Ding (1998) that compares insolation with a paleoclimatic record. To calculate theoretical insolation we utilize the program of Paillard et al. (1996) that applies the newest solution of Laskar et al. (2004). As a paleoclimatic record we use the magnetic susceptibility data sets that were obtained from the measurements of the Lake Baikal BDP-96-1, BDP-96-2 and BDP-98 drilling cores (Kravchinsky et al. 2003). In the tuning technique the susceptibility record is stretched and squeezed until the best matching between both data sets is obtained. The best matching is found by shifting the points between their neighbours until the maximal correlation is found (Dynamic Optimization method of Råde and Westergren 1995). The correlation ***R*** is represented by the standard formula

$$R = \frac{\sum_{j=1}^{M}(A(t_j) - \langle A(t_j)\rangle)(B[t_j(x)] - \langle B[t_j(x)]\rangle)}{\sqrt{\sum_{j=1}^{M}(A(t_j) - \langle A(t_j)\rangle)^2 (B[t_j(x)] - \langle B[t_j(x)]\rangle)^2}}, \qquad (1)$$

where ***A*** and ***B*** are the data series that depend on time ***t*** and depth ***x***, respectively and ***M*** is the number of points in the series.

Results and Discussion

The tuning algorithm was applied to all BDP cores. An example of the calculated timescale is shown in Fig. 1. Our age model in an improvement of the one constructed by Ochiai and Kashiwaya (2005). This is because our timescale additionally utilizes absolute ages from beryllium chronology and magnetostratigraphy.

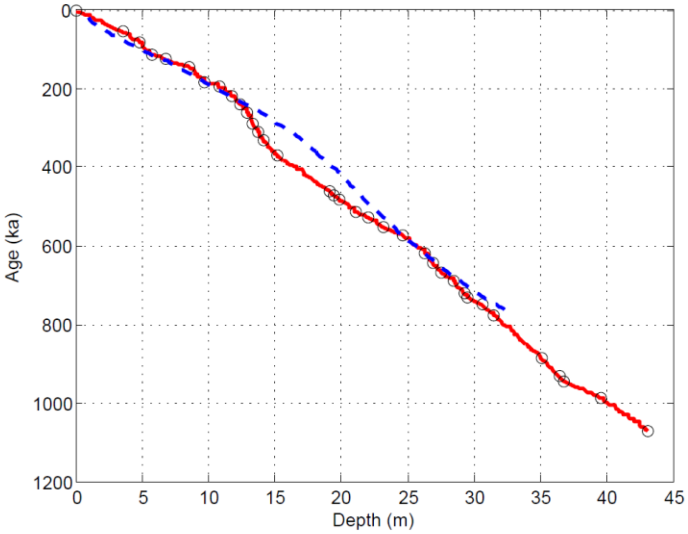

Figure 1: Circles denote the initial timescale. Tuned high resolution age model for the BDP-98 core is represented by the red line. The blue line is the model for the same core obtained by Ochiai and Kashiwaya (2005).

After tuning, all of BDP records were stacked and the result is given in Fig. 2. The blue area corresponds to the standard deviation. To check the quality of the stack two methods were applied. First, we chose to use

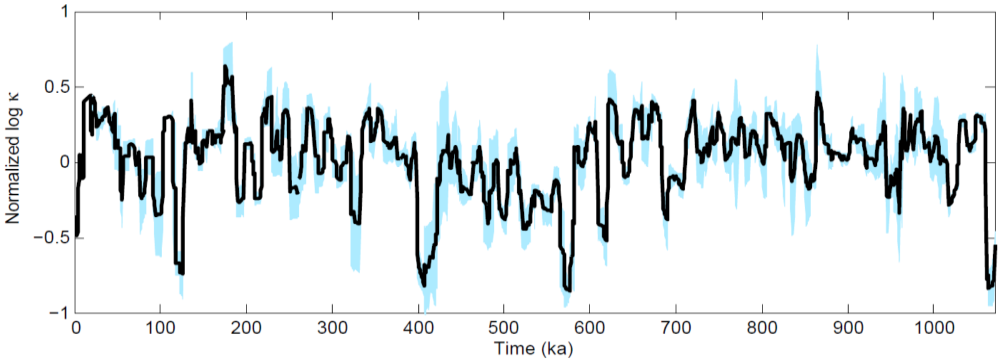

Figure 2: Normalized stack of the magnetic susceptibility data from the BDP-96-1, BDP-96-2 and BDP-98 cores. Standard deviation is denoted by the blue area.

the method of MacDonald (1989), as it allows the possibility of investigation of irregularly spaced data resulting from a nonlinear process. The age profile of sedimentary sequences is always unequally sampled and interpolation can introduce errors in the spectrum by enhancing low frequency components. Additionally signals that are recorded in sediments are caused by climatic nonlinear behaviour (Rial and Anaclerio 2000). The method of MacDonald (1989) also allows the estimation of the spectral noise under the assumption of normal distribution of the series. The results are given in Fig. 3. One can notice that the Milankovitch cycles are clearly resolved. Our results agree with the theoretical modeling of Short et al. (1989), who showed that the climatic response to insolation in the north central Eurasia is most profound for the precession periodicities. Also, our continental spectra are different from oceanic, where the largest power is found for the eccentricity cycle (Rohraff et al. 2011).

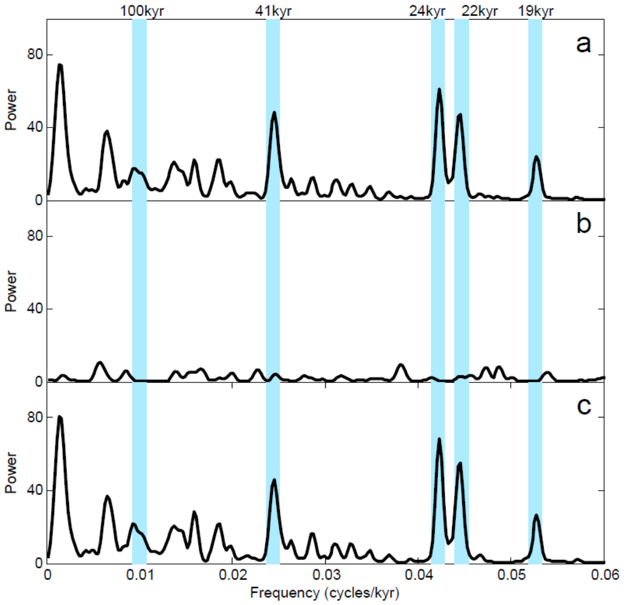

Figure 3: Smoothed periodograms of the stacked magnetic susceptibility data set (a), the estimated noise (b), and true signal after noise was removed (c) based on the procedure from MacDonald (1989). Vertical blue lines represent known Milankovitch cycles.

In the further investigation of the quality of the stack we applied the software of Grinsted et al. (2004). This method was chosen since it allows not only examining common powers but also phases. In this way we can gain the confidence that the common peaks are in fact related and are not the result of a chance. Fig. 4 gives

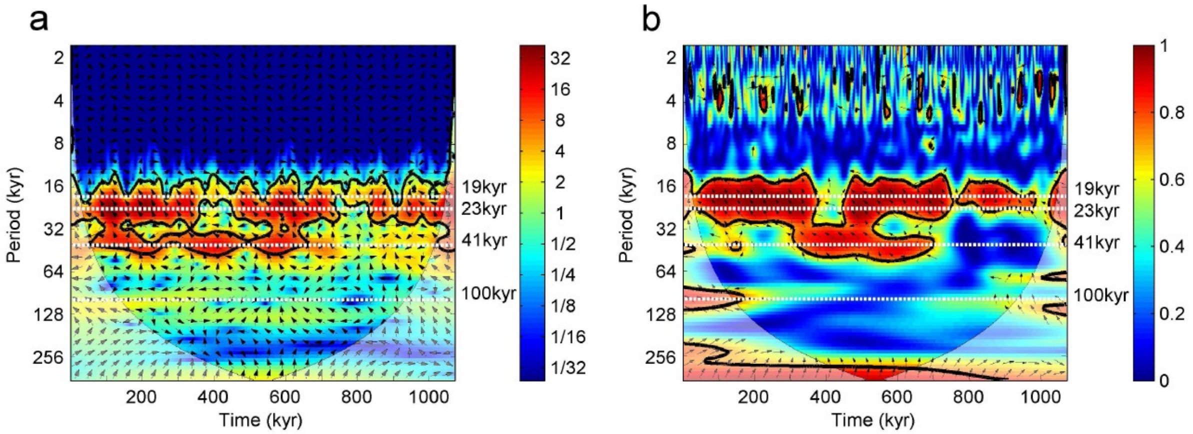

Figure 4: (a) Cross wavelet transform and (b) squared wavelet coherence of the tuned magnetic susceptibility and insolation time series. Arrows denote the phase relationship of the two data sets, the thick black contour represents 5 % significance level, the thin black line yields the cone of influence, and the horizontal white dashed lines show Milankovitch cycles.

the results after applying the wavelet analysis of Grinsted et al. (2004). Both figures show common powers and coherence associated with the Milankovitch cycles. The correlation is also confirmed by almost constant phases represented by the direction of arrows in the region of the desired significance level.

Conclusions

In the present study new age models were created for the Lake Baikal drilling cores. The magnetic susceptibility stack for all three cores was also produced. The developed stack can be potentially applied in establishing timescales of sedimentary records from the continental interior.

Our sedimentary sequences with the newly built age model clearly show the presence of Milankovitch cycles. Precession periods are dominant when compared with other orbital periodicities. This is in agreement with the previously published theoretical results that showed the importance of precession cycles in the continental interior. Our findings also prove that the spectra of the sedimentary sequences in the continent are different than in the ocean where the eccentricity peak dominates.

The procedure and program developed in the present study can be utilized in many fields of geology and geophysics, for instance, it can serve as a tool to match the well-log parameters between various boreholes.

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