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ScienceDirect

Advances in Space Research 57 (2016) 1118–1126

ADVANCES IN SPACE RESEARCH
(a COSPAR publication)

www.elsevier.com/locate/asr

Palaeoclimate and solar activity cyclicity 100–150 million years ago

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Received 21 July 2015; received in revised form 8 December 2015; accepted 11 December 2015
Available online 18 December 2015

Abstract

Variations in the annual radial growth of fossil trees (a palaeoclimatic indicator of the environment) that grew in the Gobi Desert (Mongolia) about 100–150 million years ago are considered. By using the method of combined spectral periodogriams of variations in the ring widths of fossil samples, quasi-harmonic components with the periods similar to basic solar activity cycles of our days have been revealed. This suggests that the Earth's climate is influenced by the solar activity over large time scales.

Keywords: Climate change; Solar activity; Tree rings

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1. Introduction

The research into the solar activity cyclicity in the past is of vital importance because direct (instrumental) observations of solar activity cover only the last ~400 years, while the Sun has been affecting the Earth's climate from the moment of the primitive atmosphere formation and the origin of life, i.e., approximately over four billion years.

The abrupt climate change of recent decades also stimulates the search for the physical mechanisms responsible for the influence of solar activity on weather and climate which is impossible without analysis of the solar activity variations in the past and at present.

Information on the environmental and climate change in the past can be obtained from numerous natural archives, such as ring widths of fossil trees, lake and marine varves, aerosol concentrations in the Greenland ice and the Antarctic ice sheets, because the annual radial tree growth, varve thickness, etc. are determined by such characteristics of the environment as temperature, humidity, and illumination.

In particular, analysis of variations in the ring widths of fossil trees the age of which is tens and hundreds of millions of years has shown that the palaeoclimatic data exhibit the periodicities characteristic of the modern solar activity (Dergachev, 2006; Dergachev et al., 2007; Raspopov et al., 2010, 2011, 2013a,b). The studies of variations in the cosmic ray fluxes modulated by the solar activity have demonstrated that the changes in the level of the Earth's atmosphere ionization caused by these fluxes affect such atmospheric processes as cloud formation, thunderstorms, and tropical storms, i.e., weather and climate conditions (Sloan, 2013; Gurevich et al., 2013; Makrantoni et al. 2013; Antonova and Kryukov, 2013; Kavlakov, 2012).

The goal of our study was to reveal quasi-periodic oscillations in the ring width variations of fossil trees having an age of 100–150 million years (the Late Jurassic – Early Cretaceous period). The tree samples were collected in the modern Gobi Desert (Mongolia) (Keller and Hendrix, 1997).

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http://dx.doi.org/10.1016/j.asr.2015.12.014
0273-1177/

2. Climate change in Mongolia ~150 million years ago

The tree growth is accompanied by a continuous record of environmental factors during the tree lifetime, and therefore the growth rings of fossil trees are a valuable tool for studies of the palaeoclimatic periodicity and solar activity.

The petrified forest of the Late Jurassic – Early Cretaceous period is located in the Gobi Desert in the south-eastern Mongolia at latitude 43°34′54″N and longitude 108°06′12″E (Tsagaan Tsav Formation, Suihent Petrified Forest) (Keller and Hendrix, 1997). Fossil trees crop out over an area approximately 100 m wide and 720 m long. 49 horizontal logs and 72 fossil trees in the initial upright position, all encased in a volcanic tuff, were found. The largest stump was 1.75 m in diameter and the longest trunk was 13 m in length. These fossil trees had a well preserved anatomic structure of the tree rings, which was extremely important for further numerical investigations of the ring widths.

To determine the age of the Tsagaan Tsav Formation, the tuff covering the fossil trees was dated by the argon method $^{40}Ar/^{39}Ar$. It was found that the forest grew 156 ± 0.76 million years ago. The stumps greater than 45 cm in diameter were used for the investigations (Keller and Hendrix, 1997).

The perfectly preserved cell structure of wood and fossil tree rings indicates that the climate was seasonal, possibly monsoonal, in southeastern Mongolia during the Late Jurassic period. The climate was warmer than that in the present-day Mongolia, which is shown by a wide distribution of evaporites up to latitudes 45 N and 45 S and corals to the latitude 60°N (Keller and Hendrix, 1997).

3. Method for analysis of palaeodata

The search for hidden quasi-harmonics in the time structure of initial data is carried out in the framework of the classical formulation of the problem of identifying the hidden periodicity (Serebrennikov and Pervozvansky, 1965), in which it is assumed that the initial signal consists of a polyharmonic and a noise components:

$$X(t) = A_0 + \sum_{k=1}^{v} A_k \cos\left(\frac{2\pi}{T_k} t\right) + B_k \sin\left(\frac{2\pi}{T_k} t\right) + n(t)$$

or

$$X(t) = A_0 + \sum_{k=1}^{v} R_k \cos\left(\frac{2\pi}{T_k} t - \varphi_k\right) + n(t),$$

where A_0 is a constant, $R_k = \sqrt{A_k^2 + B_k^2}, \varphi_k = arctg(B_k/A_k)$ and $n(t)$ typically implies a stationary random process, or, to be more exact, an interference in the form of "white" noise. In this case the goal of the study becomes to find the number $3v + 1$ of unknown parameters: A_0, A_k, B_k, T_k, where $k = 1, 2, 3, \ldots, v$;. The search is performed in two stages. At the first stage the number of quasiperiods v and their magnitudes T_k are determined by the method of combined spectral periodograms (CSP) (Dmitriev et al., 2009; Raspopov et al., 2013b). At the second stage, when v is known, amplitudes of A_k, B_k, and constant A_0 and their confidence intervals are estimated by solving the redundant system of conventional linear equations by the least squares method (Agekyan, 1972). To make the physical interpretation of the results more convenient, the parameters A_k, B_k and their standard deviations are recalculated by using the trigonometric formulas given above and the expression for 7 the transfer of errors to parameters R_k, φ_k and their standard deviations (Hamilton, 1964; Hudson, 1970; Agekyan, 1972).

The essence of the CSP method is as follows: a sample estimate of a normalized spectral density (Jenkins and Watts, 1969) for the initial time series is calculated as a function of a "sampling period" rather than as a function of frequency. Then the initial series is subjected to a high-frequency filtering (Alavi and Jenkins, 1965) with a specified cutoff frequency of the filter at half the signal power, which corresponds in the time domain to the value of the "separation" period T_f. Then the sample estimate of the normalized spectral density is calculated again as a function of period for each high-frequency component filtered with its specific parameter T_f.

In our case two sets of magnitudes of parameter T_f are used for the high-frequency filtering, depending on the data series length (number of experimental points of one sample). For the shortest time series (sample UK-3B), $T_f = 5, 7, 11, 13, 17, 19$ years, for all the other (longer) time series $T_f = 5, 7, 11, 13, 17, 19, 23$ years. All these estimates calculated for different T_f are superimposed on each other on the same graph field, and thus a CSP is obtained. The advantages and drawbacks of this method as compared with the classical power spectrum method are considered in detail in (Dmitriev et al., 2009). Here we only note that the CSP method allows one to investigate the stability of position of the period revealed in the periodogram by eliminating from the initial series the trend and more powerful low-frequency components which make the major contribution into the dispersion of the signal spectral density.

The confidence levels of the quasi-harmonic components revealed (i.e., the probability of their presence in the time structure of the initial data) is determined at the next stage of data processing from confidence estimates of their amplitudes. Since the number of harmonics v and values of their periods T_k, $k = 1, 2, 3, \ldots, v$, in the polyharmonic signal at this stage of processing is already known, the following system of conditional equations

$$X(t_i) = A_0 + \sum_{k=1}^{v} A_k \cos\left(\frac{2\pi}{T_k} t_i\right) + B_k \sin\left(\frac{2\pi}{T_k} t_i\right) + n(t_i), \quad \text{where} \quad i = 1, 2, 3, \ldots, N,$$