Chaos, Solitons and Fractals 84 (2016) 1–8

Contents lists available at ScienceDirect

Chaos, Solitons and Fractals

Nonlinear Science, and Nonequilibrium and Complex Phenomena

journal homepage: www.elsevier.com/locate/chaos

Temperature fluctuations superimposed on background temperature change

James Otto, J.A. Roberts*

Department of Physics, University of North Texas, Denton, TX 76203, United States

ARTICLE INFO

Article history:
Received 5 December 2015
Accepted 9 December 2015
Available online 11 January 2016

Keywords:
Climate impacts
Historical climate trends
Time series
Global temperature change periodic change
Quasi-periodic changes

ABSTRACT

Proxy data allows the temperature of the Earth to be mapped over long periods of time. In this work the temperature fluctuations for over 200 proxy data sets were examined and from this set 50 sets were analyzed to test for periodic and quasi-periodic fluctuations in the data sets. Temperature reconstructions over 4 different time scales were analyzed to see if patterns emerged. Data were put into four time intervals; 4,000 years, 14,000 years, 1,000,000 years, and 3,000,000 years and analyzed with a goal to understanding periodic and quasi-periodic patterns in global temperature change superimposed on a "background" average temperature change. Quasi-periodic signatures were identified that predate the Industrial Revolution, during much of which direct data on temperature are not available. These data indicate that Earth temperatures have undergone a number of periodic and quasi-periodic intervals that contain both global warming and global cooling cycles. The fluctuations are superimposed on a background of temperature change that has a declining slope during the two periods, pre-ice age and post ice age with a transition about 12,000 BCE. The data are divided into "events" that span the time periods 3,000,000 BCE to "0" CE, 1,000,000 BCE to "0" CE, 12,000 BCE to 2,000 CE and 2,000 BCE to 2,000 CE. An equation using a quasi-periodic (frequency modulated sine waves) patterns was developed to analyze the date sets for quasi-periodic patterns. "Periodicities" which show reasonable agreement with the predictions of Milankovitch and other investigators were found in the data sets.

1. Introduction

Direct temperature recording of Earth climate are available for only the past 150 years, which is not a sufficient period of time to analyze and get a meaningful picture of Earth's past temperature history. Instead, proxy data are used to go back in time. Multiple sets of proxy data were combined and averaged to get an average temperature reconstruction for the time period being studied. In this paper, four time periods; a 4000 year time period, a 10,000 year time period, one million year time period and a three million year time period were chosen for study. A diversity of methods used to obtain proxy data that were incorporated into this study to examine trends in temperature for various sources of proxy data and from a global distribution of data. Predictions have been made of cycles with periods of 11 years (Sun spot cycle), 100 years, 300 years, and 1450 years and some very long cycles due to astronomical patterns for the Earth as proposed by Milankovitch. [31]

2. Methods

The method used in this work was to gather the proxy data from the archives of data such as the National Oceanic and Atmospheric Administration (NOAA) and specific investigators. When expeditions collect data related to the NOAA, the natural temperature proxy data is available on its web site. These data sets were utilized to analyze select proxy data

* Corresponding author. Tel.: +940 565 3022.
E-mail address: roberts@unt.edu (J.A. Roberts).

http://dx.doi.org/10.1016/j.chaos.2015.12.005
0960-0779/

for periodic and quasi-periodic patterns over the course of hundreds to thousands of years.

The time periods investigated fall into four main categories. Initially the period of time chosen was the past four millennia. From this period the short-term trends in the data can be reviewed. Significant amounts of data are available for select proxies for this limited time period. A second step in the work was to analyze the temperature patterns for fourteen millennia. For this time interval analysis of the temperature reconstruction allows any patterns of temperature change since the last ice age to be examined. Another phase of the work was to review and analyze the temperature patterns in the hundreds of millennia. For this interval of time we chose to examine the past one million years and three million years of time to be examined in order to detect temperate changes that occur about every 100,000 years. Periodicities of 100,000 ± 5000 year time periods were found in the long term temperature data. Milankovitch has proposed a 100,000 year cycle in the temperature. [31]

The proxy temperature reconstructions were divided into the four separate groups and each group tested separately. The averages of the temperatures of each data set were made. Each average was then subtracted from each data set. This allowed the different temperature sets to be evaluated relative to a baseline of zero, with temperatures that were higher than the average being positive, and temperatures smaller than the average being negative. The data were then linearly interpolated to fill in some gaps between data points in the data sets. Then, data with measurements every 10 years were collected and averaged together to obtain an overall picture of how the temperature fluctuated over the time period being studied.

3. Results

A large number of temperature reconstructions were reviewed for trends over the past 4000 years to search for periodicity. The average of the data sets is plotted in Fig. 1. The sources for the data sets used to produce Fig. 1 are listed in Appendix A with more complete information provided in the reference section of this work.

The data for temperature show trends tending toward periodicity. In that the periods were not following simple sine or cosine patterns, it was proposed that modulated sine waves may fit the data sets. A frequency modulated (FM) pattern was assumed and a function f(ωt) was adopted for analysis of the data.

The equation chosen to compare the patterns in temperature fluctuations is given by:

$$f(x) = \sum_{n=1}^{N} a_n * \mathrm{Cos}\left[b_n + c_n * \mathrm{Cos}\left[d_n + e_n * \frac{x}{t_n}\right]\right] \quad (1)$$

where a_n are amplitudes, b_n are phase angles c_n are the amplitudes of the modulation, d_n are the phase angles of the modulation, e_n are equivalent to ωt, with x the time and t_n is the "period" of each frequency component. The number N is the number of components selected for each fitting activity. Those components that had large amplitudes were selected after analysis was made for each data set.

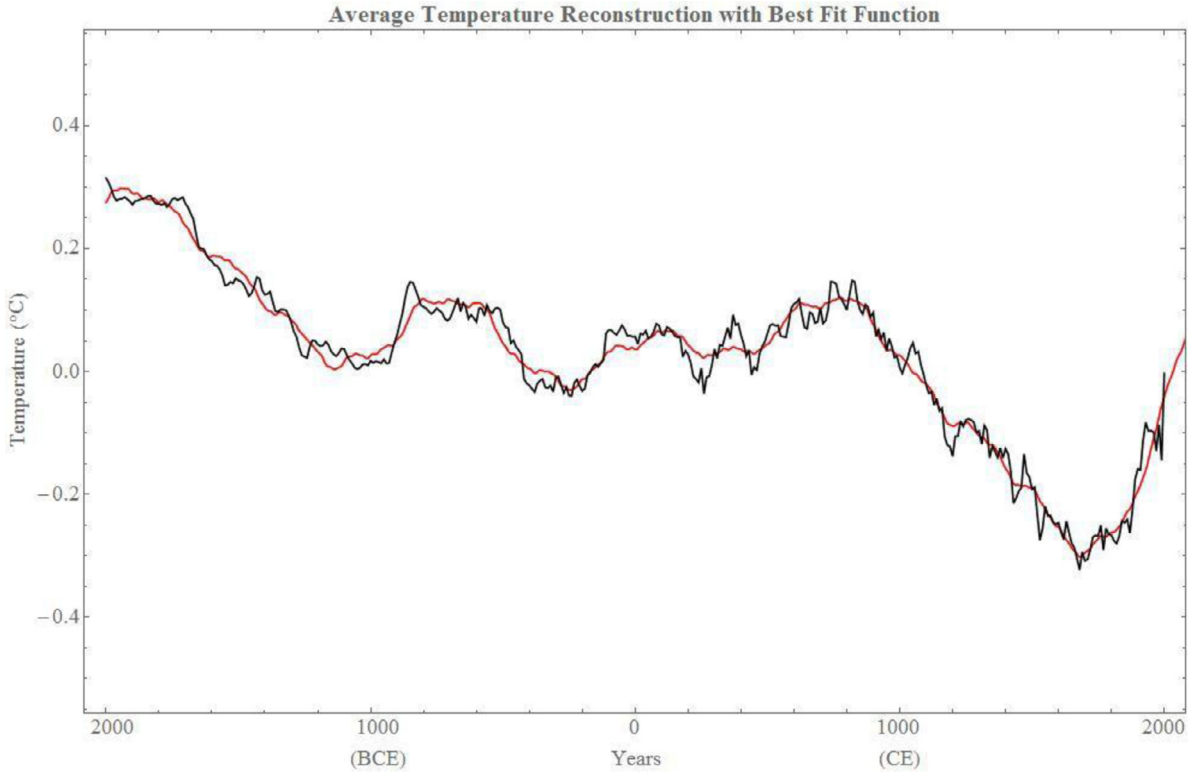

Fig. 1. A summary plot of 4,000 years of temperature reconstruction using the data sets referenced in Appendix A. The smoother curve is the plot obtained using Eq. (1).