Testing the Milankovitch-Croll hypothesis using δ^{18}O foram data

The Milankovitch-Croll hypothesis suggests that changes in the Earth's orbit around the Sun leads to changes in the Earth's planetary climate through fluctuations in solar insolation [1]. We can access and view this change of climate through analysing proxy data. By using deep ocean sediment cores and Earth orbital data, we can explore the hypothesis through performing various data analysis techniques and we hope to uncover whether if the theory has any validity.

The importance of sediment cores arises from the fact that they contain a good trace for measuring the δ^{18}O ratio across periods of Earth's history [2]. The change in this ratio can provide us with an indication of how the global temperature has been fluctuating, this could then be linked to other changes on the Earth such as whether global ice volume was increasing or decreasing.

Defined from laboratory experiments, for a $\sim$ 5°C temperature increase there is a $\sim$ 1‰ decrease in the δ^{18}O ratio of the foram shell. Looking at Figure 1 we can see two example periods from Earth's history, a more recent and an older period. We find that in the more recent age the amplitude of the δ^{18}O varies more considerably than from 4 Myr to 5 Myr, this suggests that in more recent times there have been longer periods of cooling and a more dramatic shift in temperature. Comparatively, the older δ^{18}O data still has the sinusoidal-trend, suggesting that the glacial-interglacial events are a normal part of Earth's planetary climate cycle.

We could suggest that due to the periodic nature of the foram data, there must be a connection to the cyclical Earth-Sun orbital relationship. Through the analysis of such data we can investigate if a connection exists. We can begin by split up the phenomena into three separate but interlinked features, namely eccentricity, obliquity, and precession.

The eccentricity describes how elliptical the orbit of the Earth is around the Sun [3]. From an initial wavelet analysis using the software PAST3 [4] we find that there are three wavelengths of interest. In Figure 2(a) and from Table I we see that the dominant signal throughout the dataset is 401.7 ka, with 89.1 ka and 100.4 ka as two other signals present. However, the influence of eccentricity on insolation is not independent as eccentricity ε depends on the angle between the solstices and the perihelion/aphelion ω on the orbit. This can be summed up to be $\chi = \varepsilon \sin \omega$, where χ is the precessional index. Performing a similar wavelet analysis we can see in Figure 2(b) that there is only one main wavelength prevalent at 21.1 ka. Finally obliquity is the third orbital feature to consider, this value represents the tilt of the Earth's axis, with Figure 2(c) we can find a wavelength of 39.4 ka.

Comparison with the "true" wavelengths, from Table I

References

[1] William F. Ruddiman. Earth's Climate: Past and Future. W. H. Freeman and Company, 2nd edition, 2008.

[2] Henning A. Bauch and Helmut Erlenkeuser. Interpreting glacial-interglacial changes in ice volume and climate from subarctic deep water foraminiferal δ^{18}o. In André W. Droxler, Richard Z. Poore, and Burckle Lloyd H, editors, Earth's Climate and Orbital Eccentricity: The Marine Isotope Stage 11 Question, volume 137, pages 87 – 102. American Geophysical Union, 2013.

[3] Bradley W. Carroll and Dale A. Ostlie. An Introduction to Modern Astrophysics. Pearson, 2nd edition, 2007.

[4] Ø. Hammer, D. A. T. Harper, and P. D. Ryan. Past: Paleontological statistics software package for education and data analysis. Palaeontologia Electronica, 4(1):9, 2001.

[5] Christopher J. Campisano. Milankovitch cycles, paleoclimatic change, and hominin evolution. Nature, 4(3):5, 2012.

Appendices

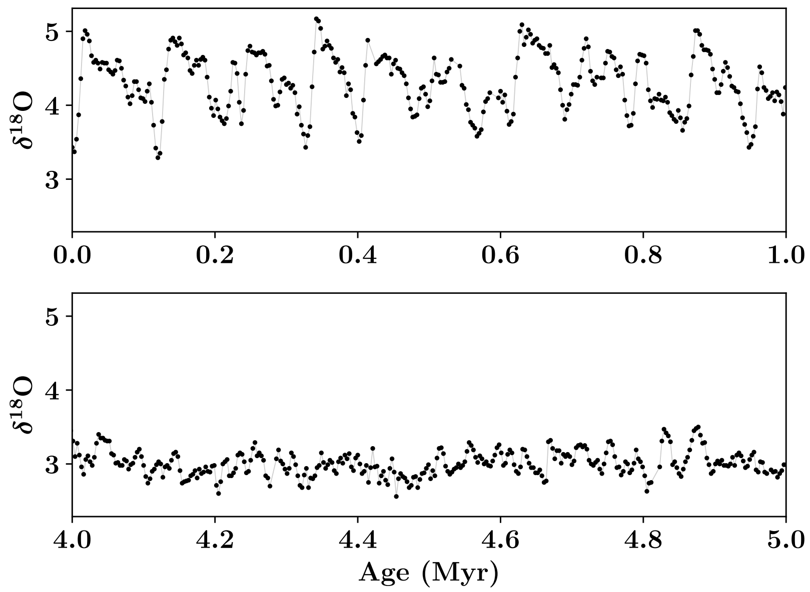

FIG. 1: Plots of the marine benthic foram δ^{18}O data against age since the present day (the holocene). Both data sets have been taken out of a larger set which spans from 0 Myr to 6 Myr. We see that as we move closer towards the present day, the periodicity and amplitude is larger which implies that there is a more extreme temperature variation.

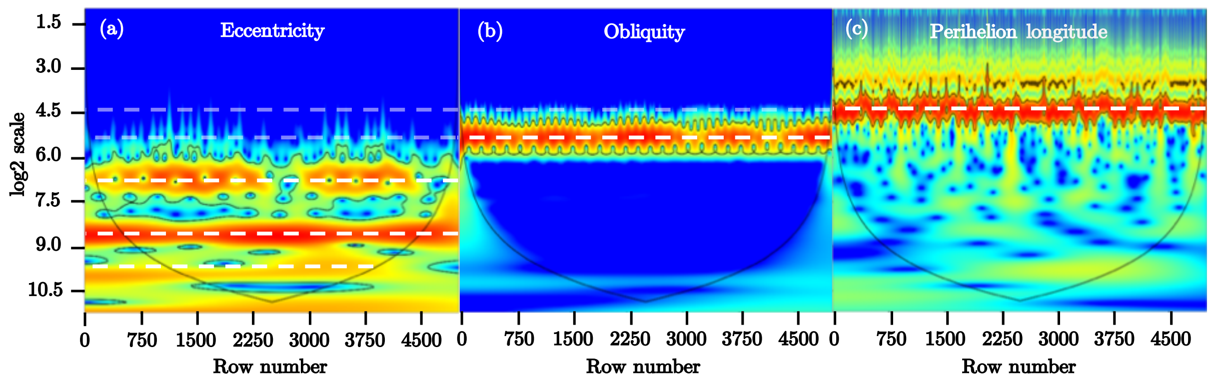

FIG. 2: The eccentricity, obliquity and perihelion longitude orbital data processed with the wavelet analysis tool in PAST3. The periodicities from the data can be obtained by considering the "hottest" areas of each of the heat maps. In Table I we summarise the wavelengths which can be obtained from the dashed lines.

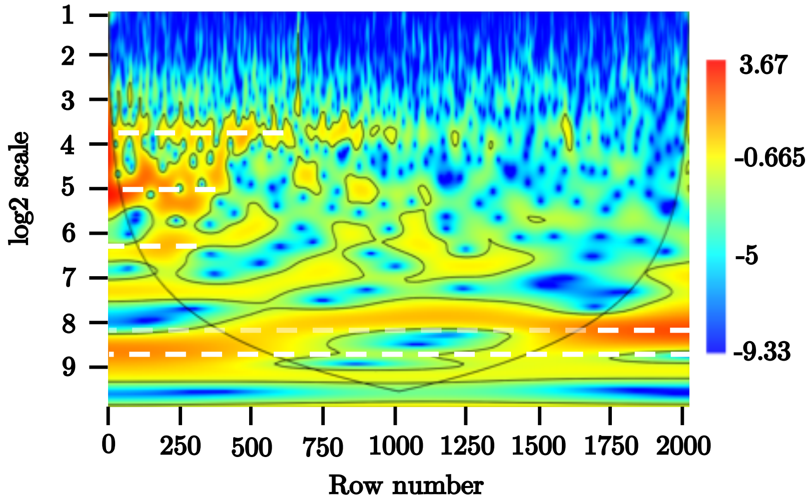

FIG. 3: Applying the PAST3 wavelet analysis tool to the δ^{18}O benthic foram data we can use this as one of the possible ways to verify if the Milankovitch-Croll hypothesis is valid.

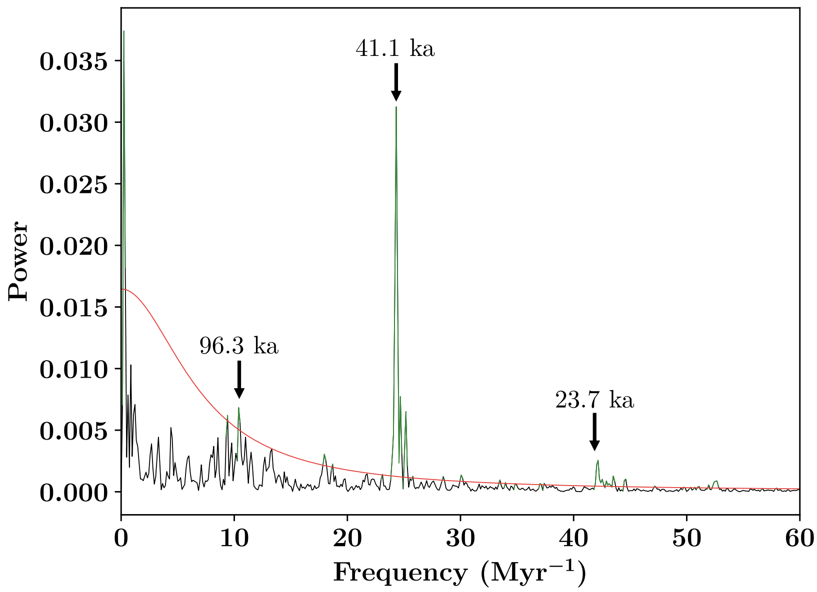

FIG. 4: The benthic foram δ^{18}O data analysed using the REDFIT spectral analysis tool in PAST3.

	"True" (ka)	**REDFIT (ka)**	**WA (ka)**
Eccentricity	100, 413	95.2, 128.2, 416.7	89.1, 100.4, 401.7
Perihelion Longitude	23, 100	23.8, 22.2	21.1
Obliquity	41	41.7	39.4
δ^{18}O		23.7, 41.1, 96.3	38.9, 96.0, 271.5, 945.5, 1247.6

TABLE I: Table showing three columns of wavelength data: the approximate correct wavelengths for the periodicity of the orbital features [5], and the results of the REDFIT analysis and Wavelet Analysis (WA) on the orbital and benthic foram data.