Geophysical Research Abstracts
Vol. 18, EGU2016-12979, 2016
EGU General Assembly 2016

Significance testing of orbital forcing in deep time

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The recognition of orbitally forced (Milankovitch) climate cycles in geological archives marked a paradigm shift in Earth science, revealing a heartbeat within the climate system of general importance and key utility. Resolving orbital cycles in stratigraphic data is, however, problematic owing to the imperfect stratigraphic preservation of climate signals, the masking effects of non-periodic variance, and uncertainties in the expected responses of proxy records to climate change. Power spectral analysis is the primary tool used to facilitate identification of orbital cycles in stratigraphic data, but commonly employed methods for testing the significance of relatively high narrow-band variance of potential orbital origin in spectra have been criticised for inadequately balancing the respective probabilities of type I (false positive) and type II (false negative) errors. This has led to suggestions that the importance of orbital forcing in deep time is overstated [1]. It can be readily demonstrated, however, that the imperfect nature of the stratigraphic record sets an upper limit on the attainable significance of orbital signals. Optimised significance testing is that which minimises the sum of type I and type II errors [2]. Numerical simulations of stratigraphically preserved orbital signals suggest that optimum significance levels at which to reject a null hypothesis of no orbital forcing cluster between 99% and 99.9%. This is lower than recently advocated [1], but higher than the 90-99% levels most commonly employed in the literature. Nevertheless, in consonance with the emergent view from other scientific disciplines, fixed-value null hypothesis significance testing of power spectra is likely ill suited to verifying orbital forcing. In part, this is because the experiments also indicate that the combined probability of making an error in the acceptance or rejection of an orbital hypothesis may be rather high for typical stratigraphic data, and hence the use of spectral analysis to validate orbital forcing remains a difficult and subjective endeavour in the absence of additional supporting evidence.

[1] Vaughan, S. et al., 2011. Detecting cycles in stratigraphic data: spectral analysis in the presence of red noise, Paleoceanography, PA4211, doi:10.1029/2011PA002195.
[2] Mudge, J.F. et al., 2012. Setting an optimal α that minimizes errors in null hypothesis significance tests, PLoS ONE, e32734, doi:10.1371/journal.pone.0032734.