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Validating astronomically tuned age models

Christian Zeeden (1,2), Stephen R. Meyers (3), Lucas L. Lourens (1), and Frederik J. Hilgen (1)

(1) Faculty of Geosciences, University of Utrecht, Utrecht, Netherlands, (2) RWTH Aachen University, Chair of Physical Geography and Geoecology, Aachen, Germany (c.zeeden@geo.rwth-aachen.de), (3) Department of Geoscience, University of Wisconsin-Madison, Madison, Wisconsin, USA

Astronomical age models supply the most precise ages for most of the Cenozoic sedimentary record, and are widely used in combination with other dating techniques to obtain well-understood chronologies for proxy data interpretation. Astrochronology is fundamental to many paleoclimate studies, but a standard statistical test has yet to be established for validating stand-alone astronomically-tuned time scales (those lacking detailed independent time control) against their astronomical-insolation tuning curves. Shackleton et al. [1995] proposed that the modulation of precession's amplitude by eccentricity can be used as an independent test for the successful tuning of paleoclimate data. Subsequent studies have demonstrated that eccentricity-like modulations can be artificially generated in random data by tuning. Here, we introduce a new statistical approach that circumvents the problem of introducing frequency modulations during tuning and data processing, thereby allowing the use of amplitude modulations for astronomical time scale evaluation. The method is based upon the use of the Hilbert Transform to calculate instantaneous amplitude following application of a wide-band precession filter, and subsequent lowpass filtering of the instantaneous amplitude to extract potential eccentricity modulations. Statistical significance of the result is evaluated using phase-randomized surrogates that preserve the power spectrum structure of the data, but have randomized amplitude modulations. Application of the new validation algorithm to two astronomically tuned data sets demonstrates the efficacy of the technique and confirms the presence of astronomical signals. Additionally it can be demonstrated that a minimal tuning approach using (at maximum) one precession cycle per $\sim$100 kyr eccentricity cycle does not introduce systematic frequency modulations, even when a narrow bandpass filter is applied, allowing direct comparison of data amplitudes and orbital eccentricity.