AGU PUBLICATIONS

Paleoceanography

Supporting Information for

The evaluation of eccentricity-related amplitude modulation and bundling in paleoclimate data: An inverse approach for astrochronologic testing and time scale optimization

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Additional Supporting Information (Files uploaded separately)

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Software S2. R-script for the analysis of ODP Site 926B oxygen isotope data

Introduction

This Supporting Information contains six figures illustrating TimeOpt analysis results for three models (Figures S1-S3), an alternative analysis of the benthic foraminifera $\delta^{18}O$ data from ODP Site 926B (Figure S5), and evolutive harmonic analysis results for the data from ODP Sites 1262 and 926B (Figures S4 and S6). In addition to these figures, two R-script files are presented that document the TimeOpt analyses of data from ODP Sites 1262 and 926B, including the reconstruction of Figures 3 and 5 from the main manuscript.

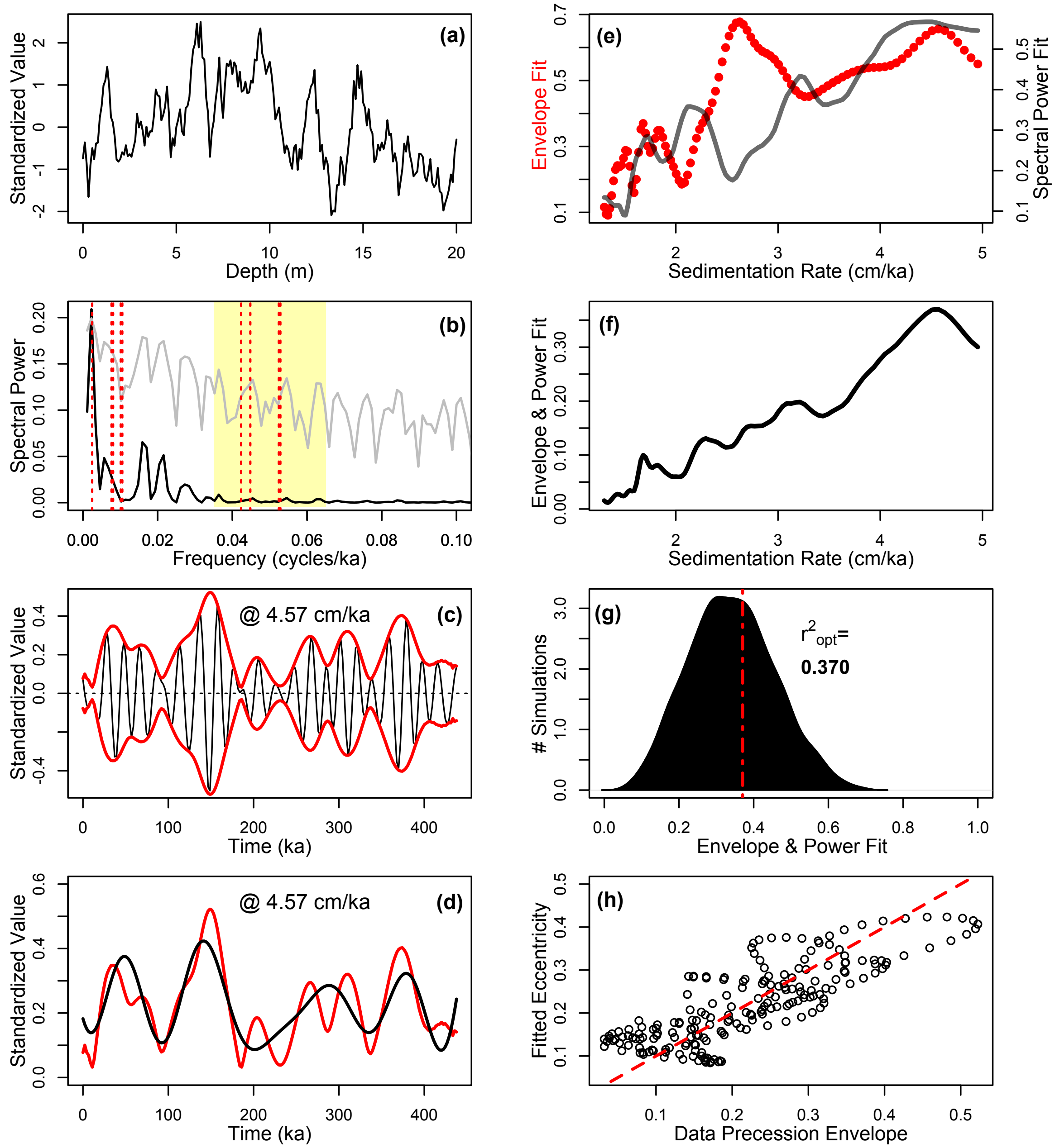

Figure S1. TimeOpt analysis of an AR1 stochastic noise model. The model spans 0-1000 ka (sampling interval of 5 ka), with a lag-1 autocorrelation of 0.9, and a sedimentation rate of 2.00 cm/ka. (a) The AR1 stratigraphic model. (b) Periodogram for the AR1 model, given the TimeOpt derived sedimentation rate of 4.57 cm/ka (black line=linear spectrum; gray line=log spectrum). Yellow shaded region indicates the portion of the spectrum bandpassed for evaluation of the precession amplitude envelope. (c) Comparison of the bandpassed precession signal (black), and the data amplitude envelope (red) determined via Hilbert transform. (d) Comparison of the data amplitude envelope (red) and the TimeOpt-reconstructed eccentricity model (black; derived using EQ. 1). (e) Squared Pearson correlation coefficient for the amplitude envelope fit ($r^2_{envelope}$; shown as red dots) and the spectral power fit ($r^2_{spectral}$; dark gray line) at each evaluated sedimentation rate. (f) Combined envelope and spectral power fit (r^2_{opt}) at each evaluated sedimentation rate. (g) Summary of 2000 Monte Carlo simulations with AR1 surrogates, used to evaluate the significance of the maximum observed r^2_{opt} of 0.370. The p-value is 0.398. (h) Cross plot of the data amplitude envelope and the TimeOpt-reconstructed eccentricity model in panel "d"; dashed red line is the 1:1 line.

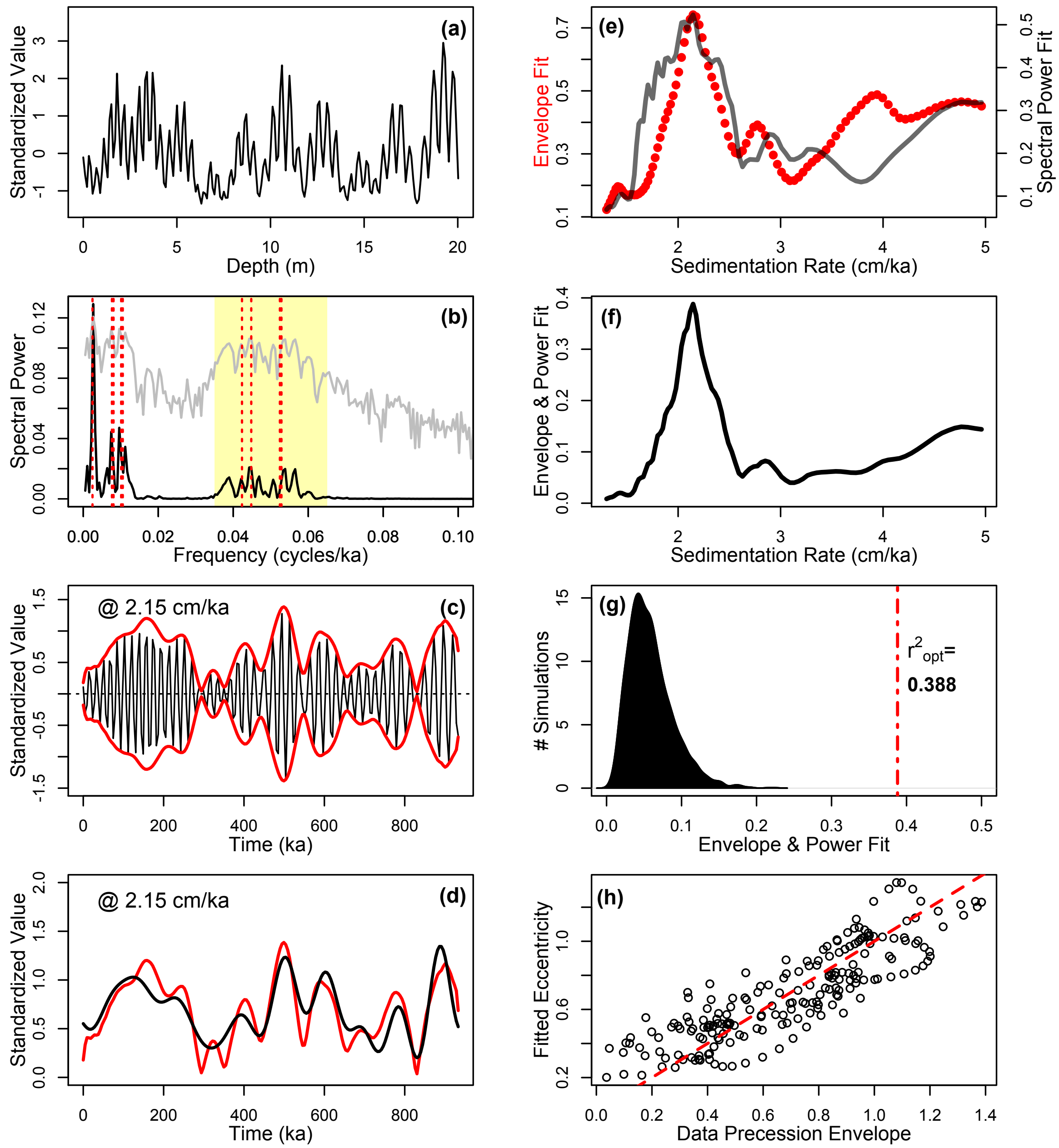

Figure S2. TimeOpt analysis of a standardized eccentricity + precession (EP) model that contains a linear sedimentation rate increase. The model spans 0-1000 ka (sampling interval of 5 ka), with a linear sedimentation rate increase from 1.5 to 2.5 cm/ka. The average sedimentation rate for this record is 2.00 cm/ka. (a) The EP stratigraphic model. (b) Periodogram for the EP model, given the TimeOpt derived sedimentation rate of 2.15 cm/ka (black line=linear spectrum; gray line=log spectrum). Yellow shaded region indicates the portion of the spectrum bandpassed for evaluation of the precession amplitude envelope. (c) Comparison of the bandpassed precession signal (black), and the data amplitude envelope (red) determined via Hilbert transform. (d) Comparison of the data amplitude envelope (red) and the TimeOpt-reconstructed eccentricity model (black; derived using EQ. 1). (e) Squared Pearson correlation coefficient for the amplitude envelope fit ($r^2_{envelope}$; shown as red dots) and the spectral power fit ($r^2_{spectral}$; dark gray line) at each evaluated sedimentation rate. (f) Combined envelope and spectral power fit (r^2_{opt}) at each evaluated sedimentation rate. (g) Summary of 2000 Monte Carlo simulations with AR1 surrogates (ρ_{AR1}=0.628), used to evaluate the significance of the maximum observed r^2_{opt} of 0.388. The p-value is 0.005. (h) Cross plot of the data amplitude envelope and the TimeOpt-reconstructed eccentricity model in panel "d"; dashed red line is the 1:1 line.

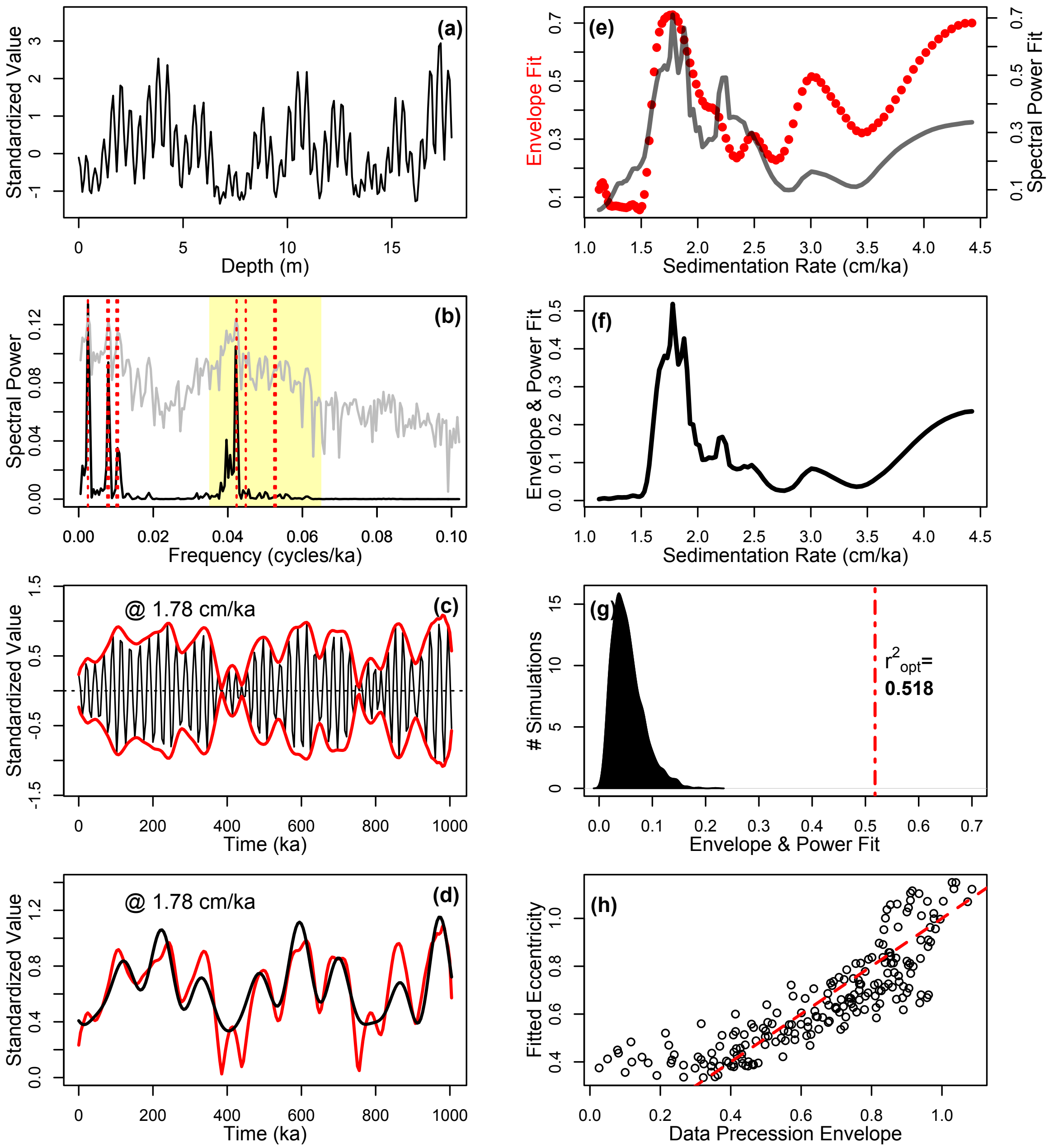

Figure S3. TimeOpt analysis of a standardized eccentricity + precession (EP) model that has undergone distortion by differential accumulation. The model spans 0-1000 ka (sampling interval of 5 ka), and the sedimentation rate is forced by the amplitude of the signal in panel "a", linearly scaled to range from 1.5 to 2.5 cm/ka. The average sedimentation rate for this record is 1.79 cm/ka. (a) The EP stratigraphic model. (b) Periodogram for the EP model, given the TimeOpt derived sedimentation rate of 1.78 cm/ka (black line=linear spectrum; gray line=log spectrum). Yellow shaded region indicates the portion of the spectrum bandpassed for evaluation of the precession amplitude envelope. (c) Comparison of the bandpassed precession signal (black), and the data amplitude envelope (red) determined via Hilbert transform. (d) Comparison of the data amplitude envelope (red) and the TimeOpt-reconstructed eccentricity model (black; derived using EQ. 1). (e) Squared Pearson correlation coefficient for the amplitude envelope fit ($r^2_{envelope}$; shown as red dots) and the spectral power fit ($r^2_{spectral}$; dark gray line) at each evaluated sedimentation rate. (f) Combined envelope and spectral power fit (r^2_{opt}) at each evaluated sedimentation rate. (g) Summary of 2000 Monte Carlo simulations with AR1 surrogates (ρ_{AR1}=0.676), used to evaluate the significance of the maximum observed r^2_{opt} of 0.518. The p-value is 0.005. (h) Cross plot of the data amplitude envelope and the TimeOpt-reconstructed eccentricity model in panel "d"; dashed red line is the 1:1 line.

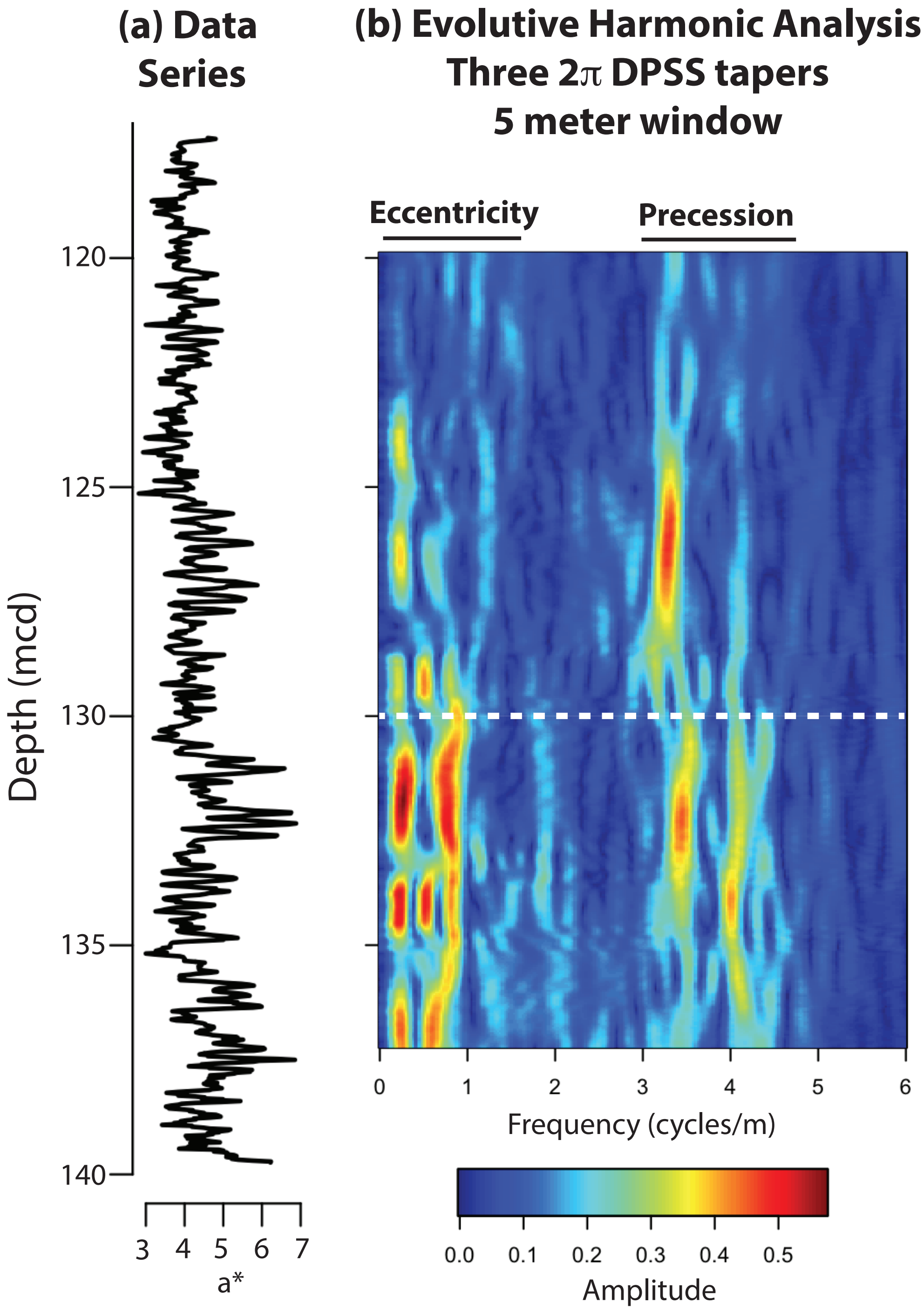

Figure S4. Evolutive harmonic analysis (EHA) of the Site 1262 a* data. (a) The a* (red/green ratio) color reflectance data from Site 1262. (b) EHA results for the Site 1262 a* data, using three 2π DPSS tapers and a 5 meter moving window (Meyers et al., 2001). A linear trend was removed from each 5 meter window before analysis. The dashed white line at 130 mcd identifies a stepwise spatial shift in the dominant precession frequency, indicative of a sedimentation rate change. Above this horizon, the strength of the eccentricity signal also gradually diminishes, consistent with the TimeOpt results in Figure 4 (main manuscript).

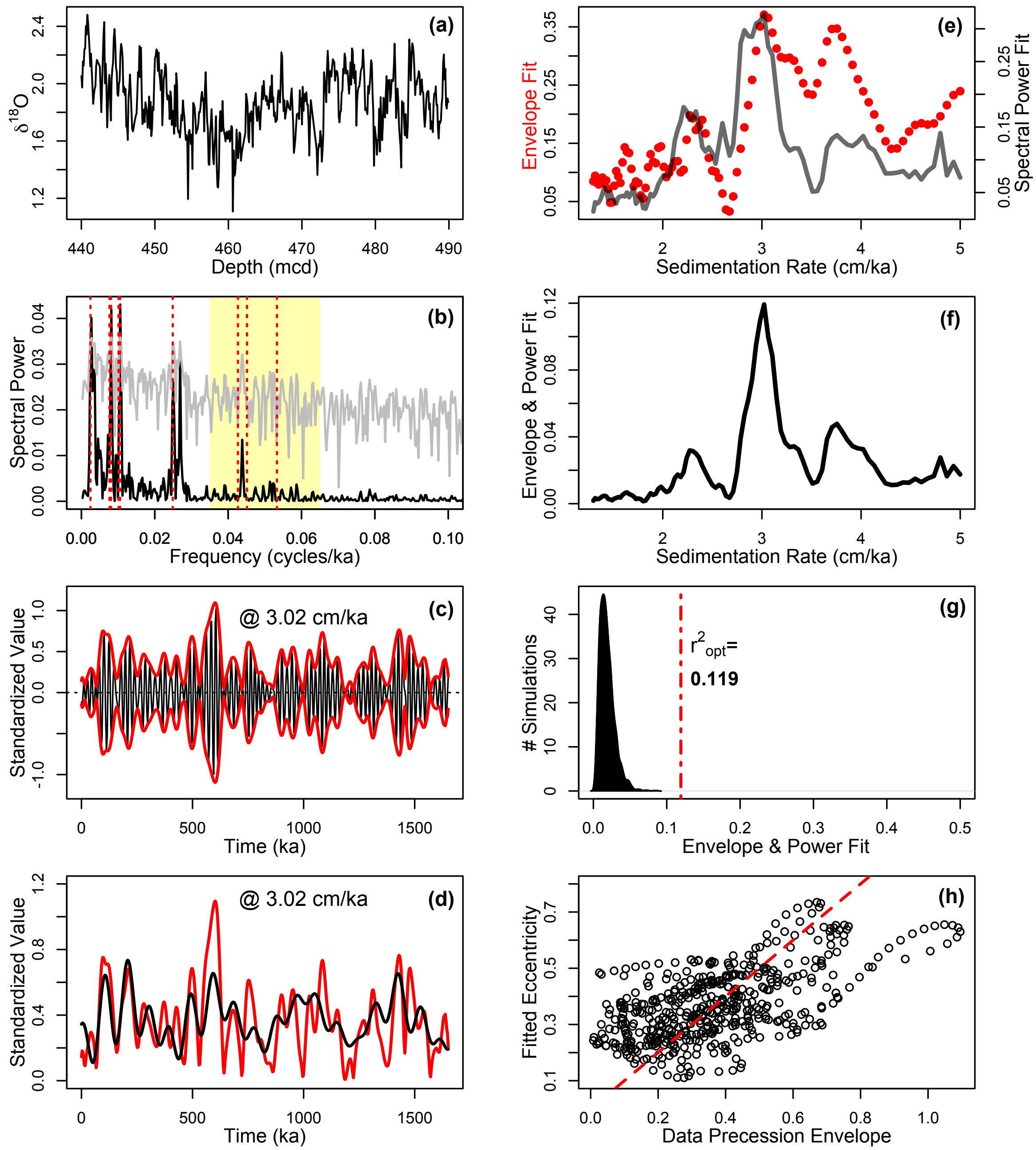

Figure S5. TimeOpt analysis of Miocene benthic foraminifera δ^{18}O data (440–490 m composite depth) from ODP Site 926B on the Ceara Rise, using a model that includes the dominant obliquity term (40.16 ka; Laskar et al., 2004). (a) Benthic foraminifera δ^{18}O data (permil VPDB), adjusted for seawater disequilibrium (Pälike et al., 2006a). (b) Periodogram for the 926B δ^{18}O data, given the TimeOpt derived sedimentation rate of 3.02 cm/ka (black line=linear spectrum; gray line=log spectrum). Yellow shaded region indicates the portion of the spectrum bandpassed for evaluation of the precession amplitude envelope. (c) Comparison of the bandpassed precession signal (black), and the data amplitude envelope (red) determined via Hilbert transform. (d) Comparison of the data amplitude envelope (red) and the TimeOpt-reconstructed eccentricity model (black; derived using EQ. 1). (e) Squared Pearson correlation coefficient for the amplitude envelope fit ($r^2_{envelope}$; shown as red dots) and the spectral power fit ($r^2_{spectral}$; dark gray line) at each evaluated sedimentation rate. (f) Combined envelope and spectral power fit (r^2_{opt}) at each evaluated sedimentation rate. (g) Summary of 2000 Monte Carlo simulations with AR1 surrogates (ρ_{AR1}=0.706), used to evaluate the significance of the maximum observed r^2_{opt} of 0.119. (h) Cross plot of the data amplitude envelope and the TimeOpt-reconstructed eccentricity model in panel "d"; dashed red line is the 1:1 line.

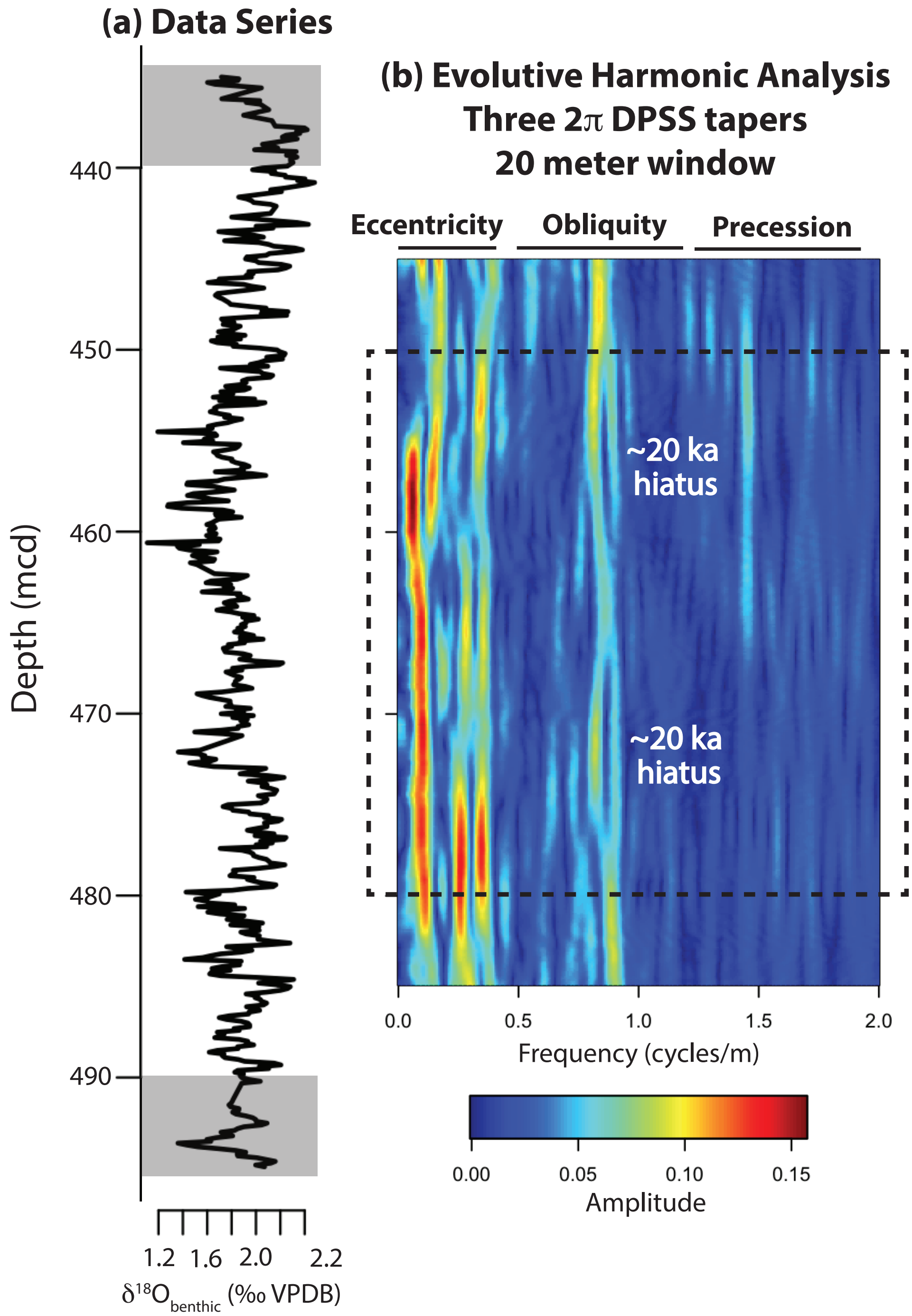

Figure S6. Evolutive harmonic analysis (EHA) of the Site 926B $\delta^{18}O$ data. (a) The $\delta^{18}O$ data from Site 926B. (b) EHA amplitude results for the Site 926B $\delta^{18}O$ data, using three 2π DPSS tapers and a 20 meter moving window (Meyers et al., 2001). A linear trend was removed from each 20 meter window before analysis. The presence of two hiatuses is suggested by the bifurcation of the obliquity signal centered on ~471 mcd and ~455 mcd; using the method of Meyers and Sageman (2004), each hiatus is estimated to have a duration of ~20 ka. Note that a larger interval of the Site 926B $\delta^{18}O$ data was analyzed here (gray boxes in panel "a" indicate additional data), to provide a better context for the observed obliquity bifurcations. The dashed box identifies the portion of the EHA plot containing results from the same interval analyzed using TimeOpt.

Software S1. R-script for the analysis of ODP Site 1262 a* data, Meyers_Software_S2_Site_1262.r.

Software S2. R-script for the analysis of ODP Site 926B oxygen isotope data, Meyers_Software_S2_Site_926B.r.