**Supplementary Material**

**Early Cretaceous Terrestrial Milankovitch Cycles in the Luanping Basin, North China and Time Constraints on Early Stage Jehol Biota Evolution**

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**S1. R command sequence for ASM objective testing**

Below, the R commands are in blue text; the output is in black text. Comment line starts with #. The input data file is “dbgmsnew2.csv”.

**# Open R-studio, point directory to desired folder**

library(astrochron)

**## PART 1: READ IN “new” AND ANALYZE WITH EHA**

**# Read “dbgmsnew2.csv” into “new”**

new=read()

---- READ STRATIGRAPHIC SERIES FROM DATA FILE ----- The following options are selected:

\* What type of column delimiter are you using?: Comma

\* Does your file have column titles/headers?: auto detect

<PLEASE CHOOSE YOUR FILE>

\* No column titles/headers detected

\* Number of stratigraphic samples (rows)= 5892

\* Number of variables (columns)= 1 (excluding depth/height/time)

\* Sorting data into increasing depth/height/time order. Will remove empty entries (from either column).

\* Number of samples (rows) post-sorting= 5892

\* Mean sampling interval= 0.02

\* Median sampling interval= 0.02

\* Maximum sampling interval= 0.02

\* Minimum sampling interval= 0.02

\* First 3 lines of data file: V1 V2

1 0.00 -4.24e-08

2 0.02 -3.69e-08

3 0.04 -3.70e-08

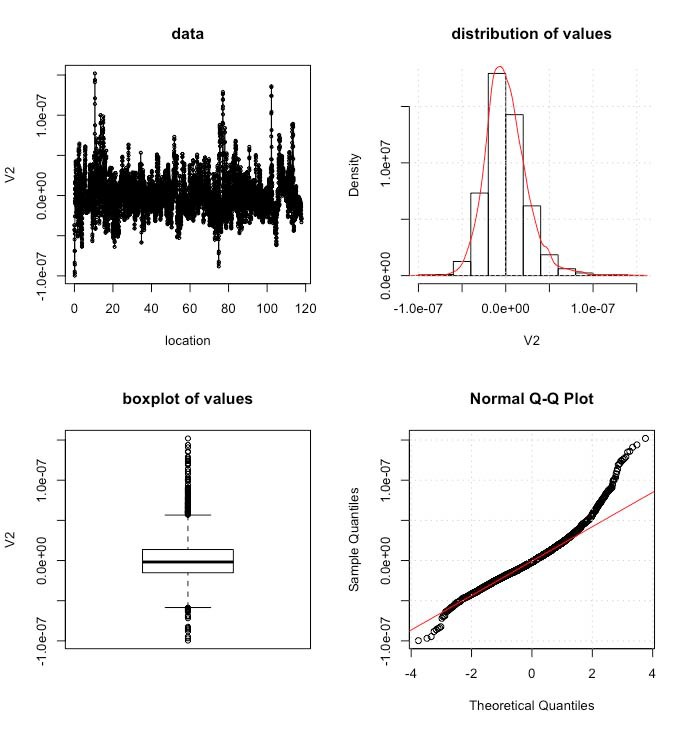


Figure S1. Top left: the plot of the Magnetic Suceptibility (MS) of Dabeigou Formation (DBG). Top right: the normal distribution of the DBG MS. Bottom left: the boxplot of all MS values. Bottom right: the normal Q-Q plot of the DBG MS.

strats(new)

---- DETERMINING SUMMARY STATISTICS FOR STRATIGRAPHIC SERIES -----

\* Number of data points= 5892

\* New number of data points= 5892

\* Duration of stratigraphic series= 117.82

Minimum= 0

Maximum= 117.82

\* SAMPLING INTERVAL / EQUIVALENT NYQUIST FREQUENCY: Mean= 0.02 / 25

Median= 0.02 / 25

Maximum= 0.02 / 25

Minimum= 0.02 / 25

\* Variance of sampling interval= 2.219973e-29

\* Mean data value= 6.19767e-10

\* Median data value= -1.795e-09

\* Minimum data value= -9.97e-08

\* Maximum data value= 1.52e-07

\* Variance of data values= 5.994319e-16

**# Run single EHA on “new” (set window to duration of “new”)**

EHAnew=eha(new,tbw=2, win=117.82, demean=T, detrend=T, sigID=T, siglevel=0.85, output=5, fmin=0., fmax=1.5, xlab="Frequency (cycles/m)",ylab="Height (m)")

----- PERFORMING EVOLUTIVE HARMONIC ANALYSIS -----

\* Number of data points in stratigraphic series: 5892

\* Stratigraphic series length (space or time): 117.82

\* Sampling interval (space or time): 0.02

\* Number of data points per window: 5891

\* Moving window size (space or time): 117.8

\* Window step points: 10

\* Window step (space or time): 0.2

\* Number of windows: 1

\* Mean value for each window will be subtracted

\* Linear trend for each window will be subtracted

\* Nyquist frequency: 25

\* Rayleigh frequency: 0.008487523

\* MTM Power spectrum bandwidth resolution (halfwidth): 0.01697505

\* Will use 3 DPSS tapers

\* Padded to 16384 points

\* Searching for significant Harmonic F-test peaks

that achive 85 % confidence level:

\* Number of significant F-test peaks identified = 42

ID / Frequency / Period / Harmonic\_CL

1 0.006103516 163.84 99.09266

2 0.0579834 17.24632 87.45255

3 0.07629395 13.1072 91.51055

4 0.1220703 8.192 94.95378

5 0.1403809 7.123478 94.21246

6 0.1586914 6.301538 90.45943

7 0.1831055 5.461333 95.23335

8 0.2197266 4.551111 97.15396

9 0.2380371 4.201026 92.45728

10 0.2929688 3.413333 91.82689

11 0.3204346 3.120762 92.79432

12 0.3875732 2.580157 90.44452

13 0.4180908 2.391825 97.82735

14 0.4425049 2.259862 89.11312

15 0.4638672 2.155789 96.05995

16 0.5615234 1.78087 92.46273

17 0.579834 1.724632 99.85114

18 0.5981445 1.671837 99.72052

19 0.6439209 1.552986 87.81228

20 0.6561279 1.524093 85.99387

21 0.7141113 1.400342 95.30654

22 0.7995605 1.250687 96.19337

23 0.8209229 1.218141 98.81714

24 0.8422852 1.187246 95.66488

25 0.869751 1.149754 98.32827

26 0.8911133 1.122192 94.09365

27 0.9185791 1.088638 91.90227

28 0.9552002 1.046901 91.67351

29 1.013184 0.986988 86.45853

30 1.05896 0.9443228 96.78334

31 1.107788 0.9026997 96.80415

32 1.126099 0.8880217 95.17657

33 1.16272 0.8600525 86.86812

34 1.202393 0.8316751 96.49064

35 1.254272 0.7972749 85.91012

36 1.281738 0.7801905 93.74081

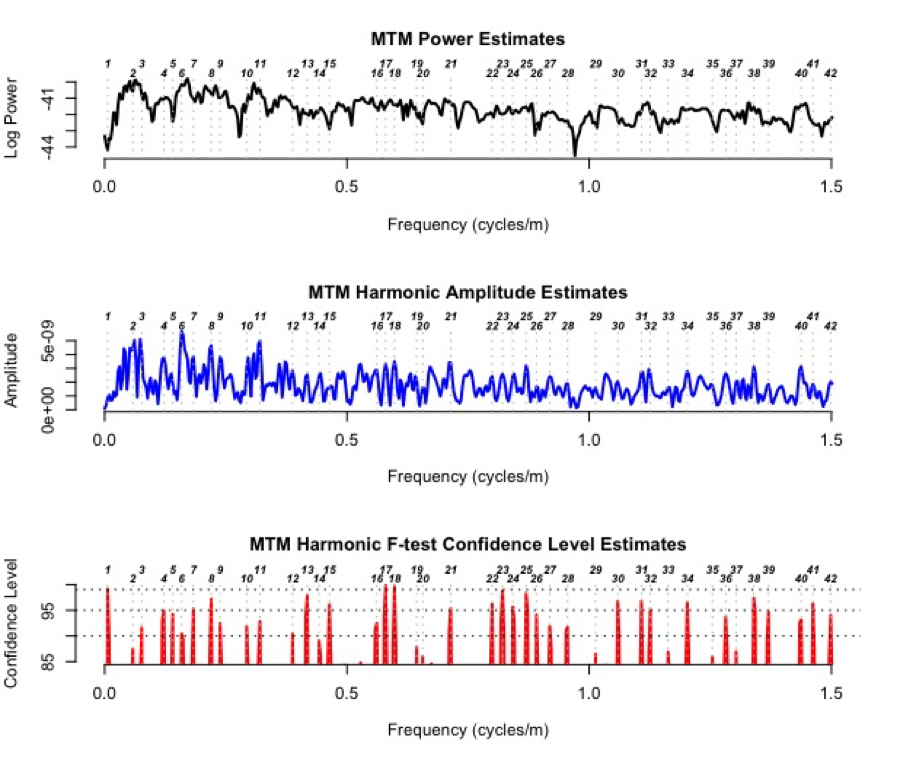
37 1.303101 0.7674005 86.90999

38 1.339722 0.7464237 97.35264

39 1.370239 0.7297996 94.65716

40 1.437378 0.6957113 93.09663

41 1.461792 0.6840919 96.27012

42 1.498413 0.6673727 94.04433

**Figure S2.** Harmonic analysis of dbg stratigraphic series

**## PART 2: ANALYZE “new” with ASM**

**# ASM target in cycles/kyr, from La2004 ETP Spectral Analysis (130 – 135 Ma) (see Table 1)**

**# Apply ASM to “dbgmsnew2” with 10 astronomical terms**

targetla=c(1/409.6, 1/132.129, 1/124.1212, 1/99.9024, 1/94.1609, 1/36.6, 1/22.14, 1/20.95, 1/18.08, 1/17.9256)

**# Set up input parameters:**

freq <- data.frame(EHAnew)

rayleigh <- 0.008487523

nyquist <- 1.0

**# Run ASM:**

asm(freq=freq,target=targetla,rayleigh=rayleigh,nyquist=nyquist,sedmin=1,sedmax=10,numsed=400,linLog=1,iter=10000,output=FALSE)

----- PERFORMING AVERAGE SPECTRAL MISFIT ANALYSIS -----

\*\*\*\* WARNING: No uncertainty assigned to astronomical target frequencies.

\* Analysis complete:

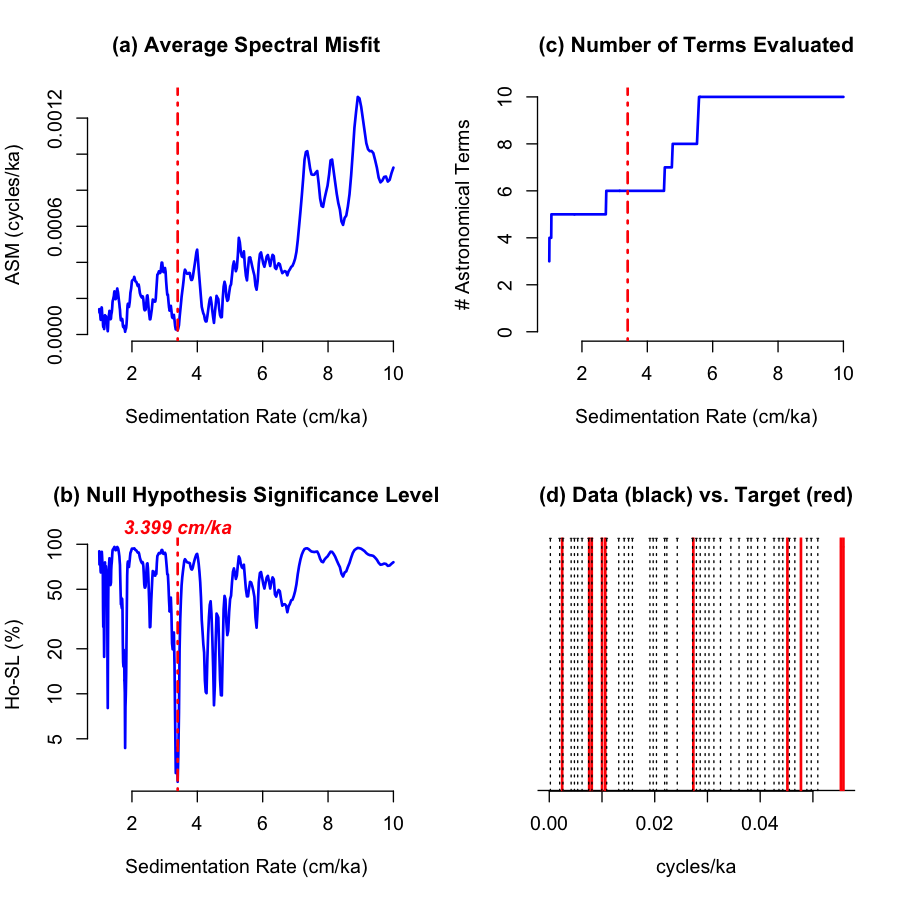
Optimal Sedimentation Rate (cm/ka) at = 3.398821

Ho-SL (%) = 2.58

or p-value = 0.0258

ASM (cycles/ka) = 2.277076e-05

Number of Astronomical Terms Fit = 6

****

**Figure S3.** ASM results for “new” with 10 astronomical terms

**# Apply ASM to “new” with 8 astronomical terms**

targetla=c(1/409.6, 1/132.129, 1/95.25, 1/36.6, 1/22.14, 1/20.95, 1/18.08, 1/17.9256)

**# Set up input parameters:**

freq <- data.frame(EHAnew)

rayleigh <- 0.008487523

nyquist <- 1.0

**# Run ASM:**

asm(freq=freq,target=targetla,rayleigh=rayleigh,nyquist=nyquist,sedmin=1,sedmax=10,numsed=400,linLog=1,iter=10000,output=FALSE)

----- PERFORMING AVERAGE SPECTRAL MISFIT ANALYSIS -----

\*\*\*\* WARNING: No uncertainty assigned to astronomical target frequencies.

\* Analysis complete:

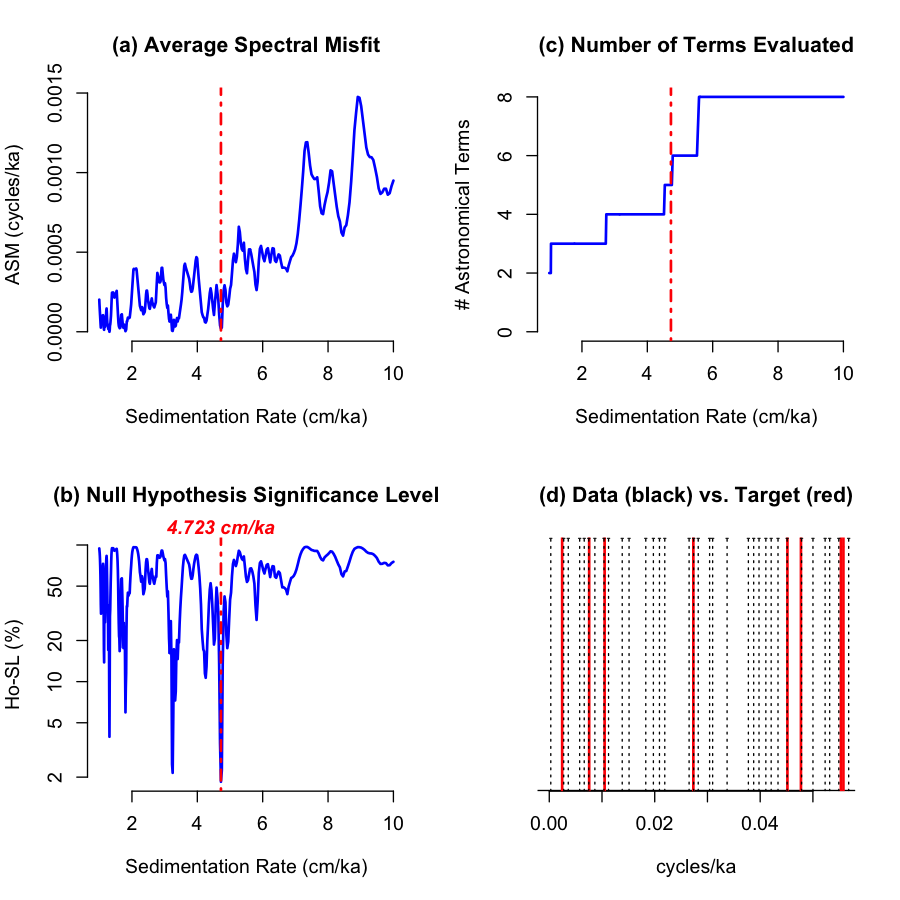
Optimal Sedimentation Rate (cm/ka) at = 4.722647

Ho-SL (%) = 1.9

or p-value = 0.019

ASM (cycles/ka) = 1.93054e-05

Number of Astronomical Terms Fit = 5



**Figure S4.** ASM results for “new” with 8 astronomical terms

**S2. TimeOpt and TimeOptSim objective testing in Acycle 2.1.1**

**## ANALYZE “new” with TimeOpt and TimeOptSim**

**# Download Acycle 2.1.1 (Matlab compatible) and unzip the zipped file**

**# Open Matlab, point directory to acycle-2.1.1 folder**

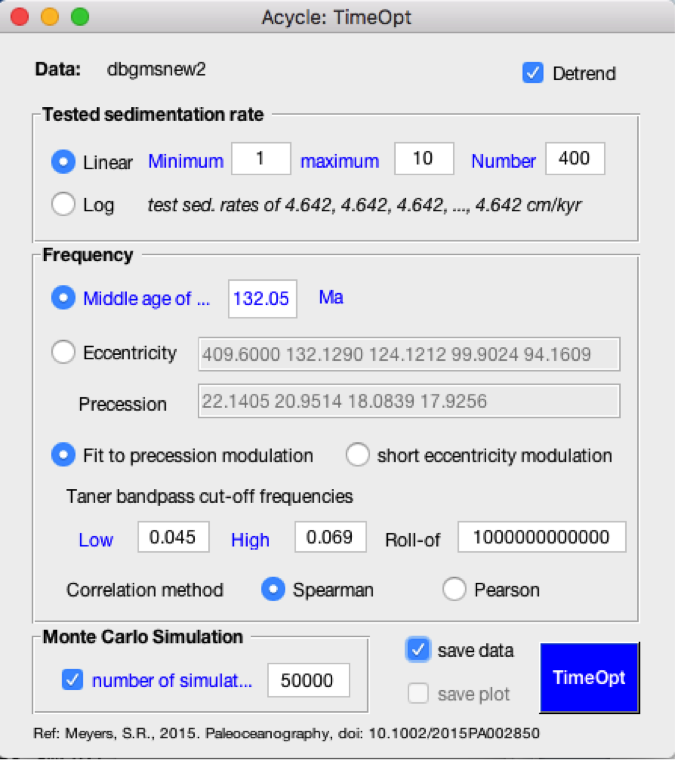
**# Open Acycle**

ac.m

**# Copy “new.txt” file into the acycle-2.1.1 – data – Examples folder**

**# Select “new.txt” file and then press Timeseries – TimeOpt.**

**# All parameters setting are shown in Figure S4 as follow:**

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**Figure S5** TimeOpt testing parameters settings

**# Press the bottom right button “TimeOpt”**

14-Mar-2020 19:43:00

new-timeOpt-log.txt

minimum tested sedimentation rate: 1

maximum tested sedimentation rate: 10

number of tested sedimentation rate: 400

Scaling for sedimentation rate grid spacing: Linear

Test for (1) precession amplitude modulation

Low frequency cut-off for Taner bandpass: 0.045

High frequency cut-off for Taner bandpass: 0.069

Taner filter roll-off rate, in dB/octave: 1000000000000

A vector of eccentricity periods to evaluate (in kyr):

[409.6 132.129 124.1212 99.9024 94.1609]

A vector of precession periods to evaluate (in kyr):

[22.1405 20.9514 18.0839 17.9256]

Remove linear trend from data series?: Yes

correlation method: Spearman

RESULTS:

Maximum spectral power r^2 = 0.08538

at sedimentation rate of: 6.3388 cm/kyr

Maximum envelope r^2 = 0.38323

at sedimentation rate of: 9.2239 cm/kyr

Maximum (envelope r^2) x (spectral power r^2) = 0.014757

at sedimentation rate of: 4.6416 cm/kyr

Number of Monte Carlo simulations: 50000

At sedimentation rate of 4.6416 cm/kyr

Envelope r^2 p-value = 0.05348

Spectral power r^2 p-value = 0.05348

Envelope r^2 p-value = 0.47128

(Envelope r^2) x (spectral power r^2) p-value = 0.11902

- - - - - - - - - - - - - - End - - - - - - - - - - - -

**# TimeOpt and TimeOptSim outputs for “new” plots are shown in Figure 6.**

**S3. COCO and eCOCO objective testing in Acycle 2.1.1**

**## ANALYZE “new” with COCO**

**# Download Acycle 2.1.1 (Matlab compatible) and unzip the zipped file**

**# Open Matlab, point directory to acycle-2.1.1 folder**

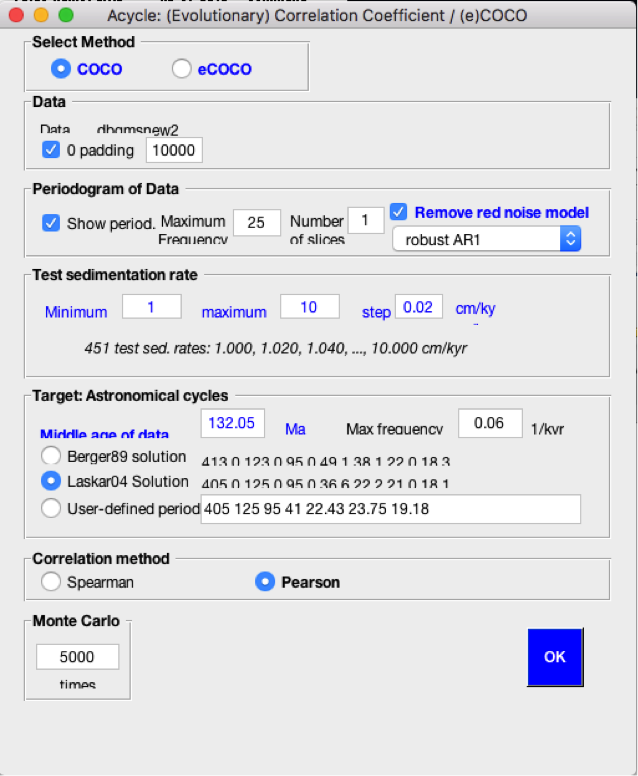
**# Open Acycle**

ac.m

**# Copy “new.txt” file into the acycle-2.1.1 – data – Examples folder**

**# Select “new.txt” file and then press “Timeseries - Correlation Coefficient (COCO/eCOCO)”**

**# All parameters setting are shown in Figure S5 as follow:**



**Figure S6** COCO testing parameters settings

**# Press the bottom right button “OK”**

- - - - - - - - - - - - - Summary - - - - - - - - - - -

15-Mar-2020 16:10:11

new-5000sim-1slice-COCO-log-1.txt

Data: 0 to 117.82m. Sampling rate: 0.02. Number of data points: 5892

Data: Number of slices is 1. Number of simulations is 5000

Data: Remove red noise model: robust AR1 removed (F - Fred). Correlation method: Pearson

Zero padding for the data is 10000

Tested sedimentation rate step is 0.02 cm/kyr from 1 to 10 cm/kyr

Target age is 132050 ka. Zero padding is 10000. Freq. is 0-0.06 cycles/kyr

Astronomical solution: Laskar04

Seven astronomical cycles are: 405, 125, 95, 36.6159, 22.1522, 21.0039, 18.1368

- - - - - - - - - - - - - - End - - - - - - - - - - - -

**# COCO outputs for “new” plots are shown in Figure 7.**

**## ANALYZE “new” with eCOCO**

**# All parameters setting are shown in Figure S6 as follow:**

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**Figure S7 e**COCO testing parameters settings

**# Press the bottom right button “OK”**

- - - - - - - - - - - - - Summary - - - - - - - - - - -

15-Mar-2020 18:56:41

new-50000sim-1slice-38win-ECOCO-log.txt

Data: -19 to 136.82m. Sampling rate: 0.02. Number of data points: 5892

Data: Number of slices is 1. Number of simulations is 50000

Data: Remove red noise model: robust AR1 removed (F - Fred). Correlation method: Pearson

Zero padding for each window is 5000; Zero padding for the edge of data: zero

Tested sedimentation rate step is 0.02 cm/kyr from 1 to 10 cm/kyr

Target age is 132050 ka. Zero padding is 5000. Freq. is 0-0.06 cycles/kyr

Astronomical solution: Laskar04

Seven astronomical cycles are: 405, 125, 95, 36.6159, 22.1522, 21.0039, 18.1368

- - - - - - - - - - - - - - End - - - - - - - - - - - -

**# eCOCO outputs for “new” plots are shown in Figure 7.**