



***Acycle*: Time-series analysis software for paleoclimate research and education**

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Sept. 6, 2019

OUTLINE

1. Introduction

2. Getting Started

3. *Acycle* Graphic User Interface (GUI)

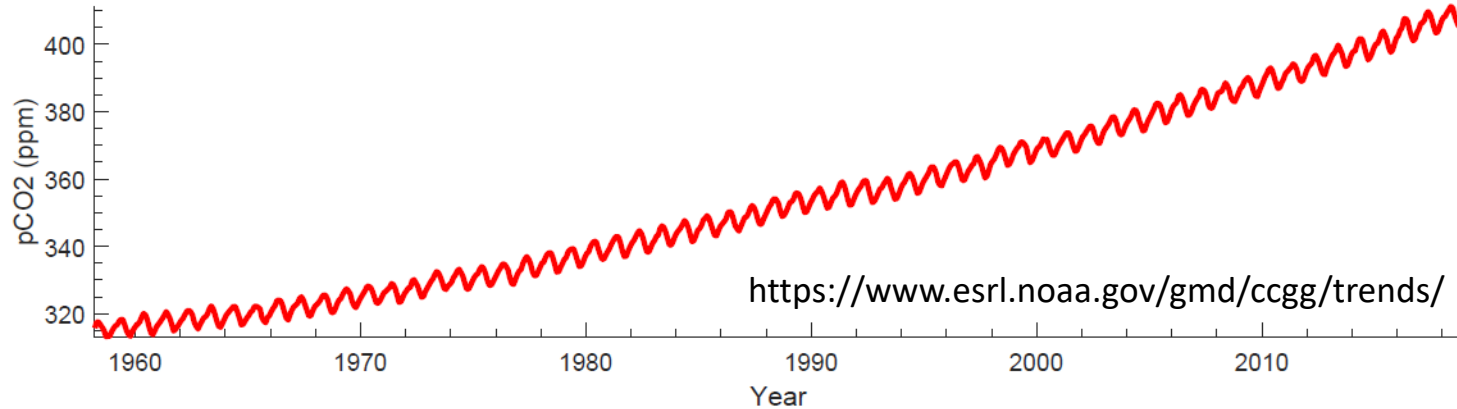
4. Case study: Carnian cyclostratigraphy

Time series analysis

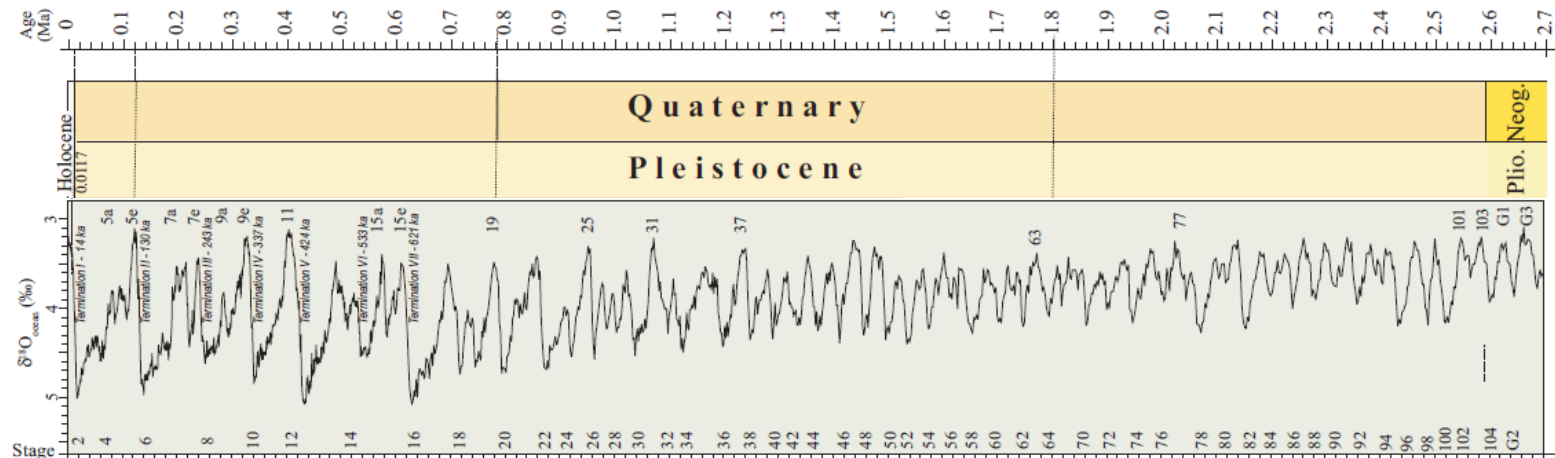
- a statistical technique that deals with time series data.
- accounts for the fact that data points taken over time may have an internal structure (such as trend or periodicity) that should be accounted for.
 - Economic Forecasting
 - Sales Forecasting
 - Population Forecasting
 - Stock Market Analysis
 - Yield Projections
 - STEM (Science, technology, engineering, and mathematics)
 - ...

Climate Time Series

Monthly average CO₂ at Mauna Loa Observatory, Hawaii



Global benthic marine $\delta^{18}\text{O}$ stack (global ice volume and temperature)



(Lisiecki & Raymo, 2005)

(Hinnov, 2013)

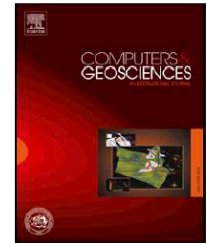


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Computers and Geosciences

journal homepage: www.elsevier.com/locate/cageo



Acycle: Time-series analysis software for paleoclimate research and education



Mingsong Li^{a,*}, Linda Hinnov^b, Lee Kump^a

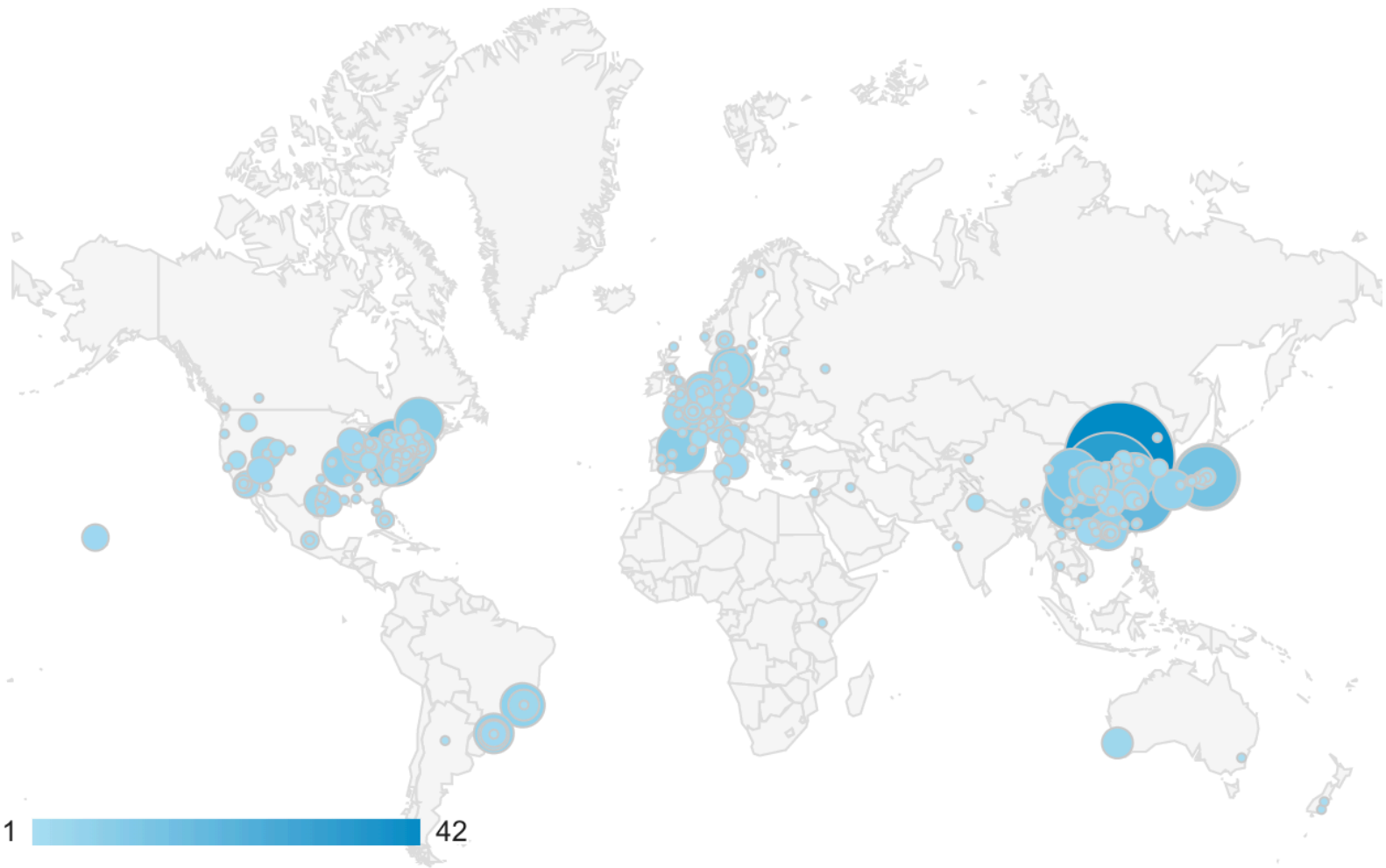
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[Download this paper](#)



Logo designed by Hewei Duan



Total: 1782 unique visitors

(Sept 2018 – Sept 2019)

<http://mingsongli.com/acycle>

Data source: <https://analytics.google.com>

What they say



"It is truly an amazing contribution to the geosciences community ... It opens up much needed access to these powerful tools for a wide audience in the sedimentary geology and paleoclimate community. ... A really marvellous job."

— **Dr. J. Fred Read** (Emeritus Professor, Virginia Tech)



"His **Acycle** software will become the standard tool for time-scale applications by all international workers."

— **Dr. James G. Ogg** (Professor, Purdue University)



"Not only is this software powerful and effective, it is also simple to use and therefore benefits researchers and at all levels within the paleoclimatology community, from novices to experts."

— **Dr. Paul E. Olsen** (Professor, Columbia University)

2. Getting Started

- * **Stand-alone versions of *Acycle* only needs Runtime, not MatLab**
- * **MatLab Runtime is not MATLAB!**
- * **MatLab Runtime is free!**

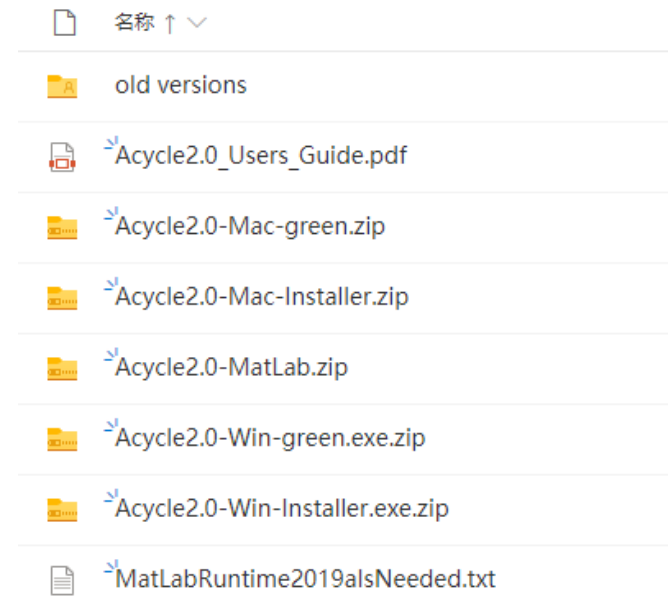
🔗 Download



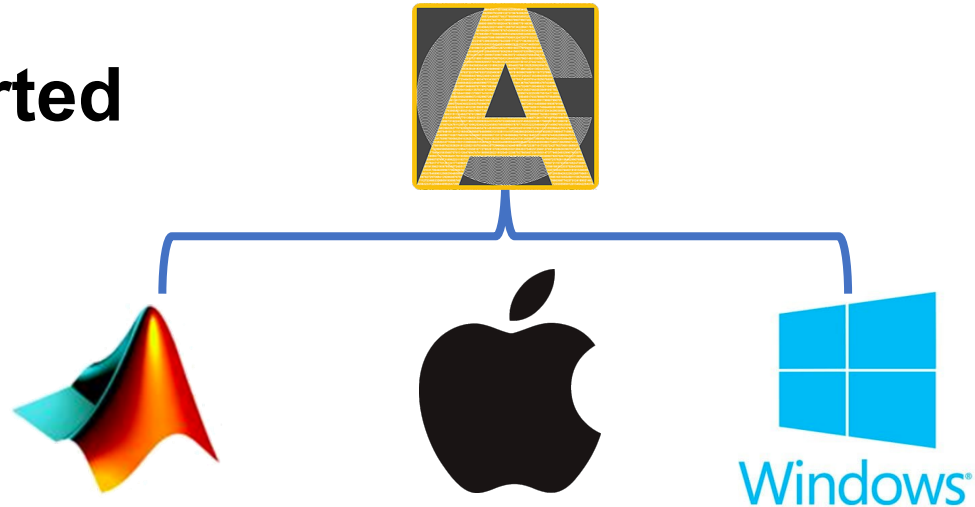
[Dropbox](#) | [OneDrive](#) | [BaiduCloud](#) | [GitHub](#)

Read more

- Wiki: <https://github.com/mingsongli/acycle/wiki>
- or: https://github.com/mingsongli/acycle/blob/master/doc/AC_Users_Guide.pdf
- or: *Acycle* "Help" menu - "Manual",
- or: /doc/AC_Users_Guide.pdf



2. Getting Started



Acycle for...	MatLab	Stand-alone **			
Platform	MatLab	Mac		Windows	
Requirement		MatLab Runtime 2019a (Free)			
<i>download</i>		Runtime for Mac		Runtime for Win	
Version		Installer	Green	Installer	Green
Size	63.5 MB	97 MB	91 MB	122 MB	121 MB
How to install	Acycle2.0_Users_Guide.pdf (Chapter 3)				

** Need to install the MatLab Runtime 2019a (!!!)

Fast installation:

1. Install MatLab Runtime 2019a (free)

You don't need to install MatLab (heavy and expensive)!

After the installation, you don't need to run runtime yourself

If you have installed **MatLab 2019a**, this step can be skipped

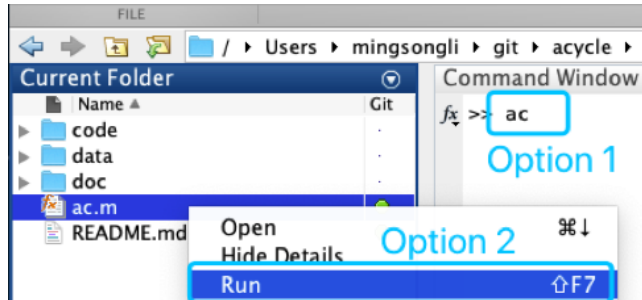
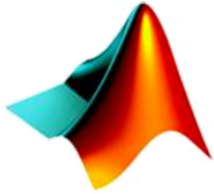
2. Download Acycle2.0 GREEN version

No installation is needed.

3. Follow the next slide to start up Acycle 2.0.

**** Need to install the MatLab Runtime 2019a (!!!)**

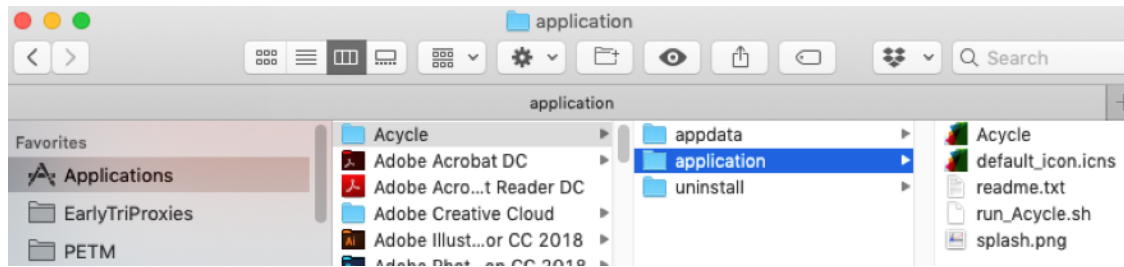
Startup



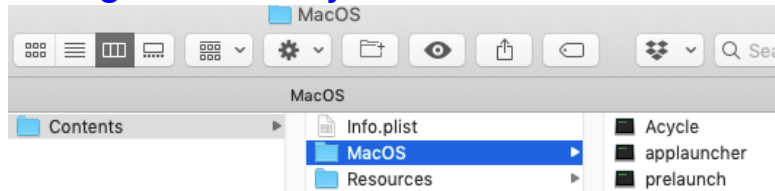
double-click



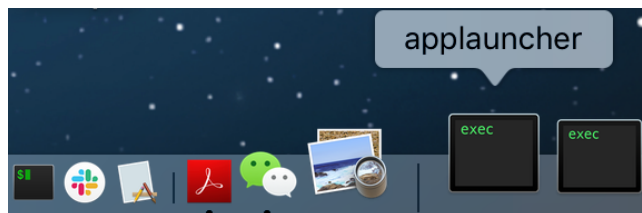
1. Go to the installation folder



2. Right click "Acycle" file, choose "Show Package Content"



3. Drag the applauncher file to the dock



Acycle Graphic User Interface (GUI)

The image shows the Acycle v2.0 GUI with several components annotated:

- Up one level**: Red, yellow, and green window control buttons.
- Open working folder**: Folder icon in the toolbar.
- Plot Pro**: Line graph icon in the toolbar.
- Refresh list box**: Refresh icon in the toolbar.
- Mini robot**: Robot icon in the toolbar.
- Software version**: "Acycle v2.0" text in the title bar.
- "unit" pop-up menu**: Dropdown menu showing "unit".
- Menu bar**: File, Edit, Plot, Basic Series, Math, Timeseries, Help.
- Change directory**: Address line showing "/Users/mingsongli/Dropbox/lectures/Acycle/demo".
- List box**: File list including ".DS_Store", "Example-Guandao2AnisianGR-sue.txt", "Example-Guandao2AnisianGR.txt", "Example-HiRISE-PSP_002733_1880_RED-controlpoints.txt", "Example-HiRISE-PSP_002733_1880_RED-profile.txt", "Example-HiRISE-PSP_002733_1880_RED.jpg", "Example-Insol-t-0-2000ka-day-80-lat-65-meandaily-La04.txt", "Example-LateTriassicNewarkDepthRank-rho1-median.txt", "Example-LateTriassicNewarkDepthRank-rho1-percentile-1C", "Example-LateTriassicNewarkDepthRank-rho1-percentile-1C", "Example-LateTriassicNewarkDepthRank-rho1-percentile-1C", "Example-LateTriassicNewarkDepthRank-rho1-percentile.txt", "Example-LateTriassicNewarkDepthRank.txt".
- Data files**: Label pointing to the list box.

A terminal window is open in the bottom right corner, showing the following text:

```
mingsongli — applauncher — Acycle — 80x24
Last login: Wed Aug 28 12:49:34 on ttys000
(base) Mingsongs-MacBook-Pro:~ mingsongli$ /Applications/Acycle/application/Acyc
le.app/Contents/MacOS/applauncher ; exit;
```

Don't close this window!

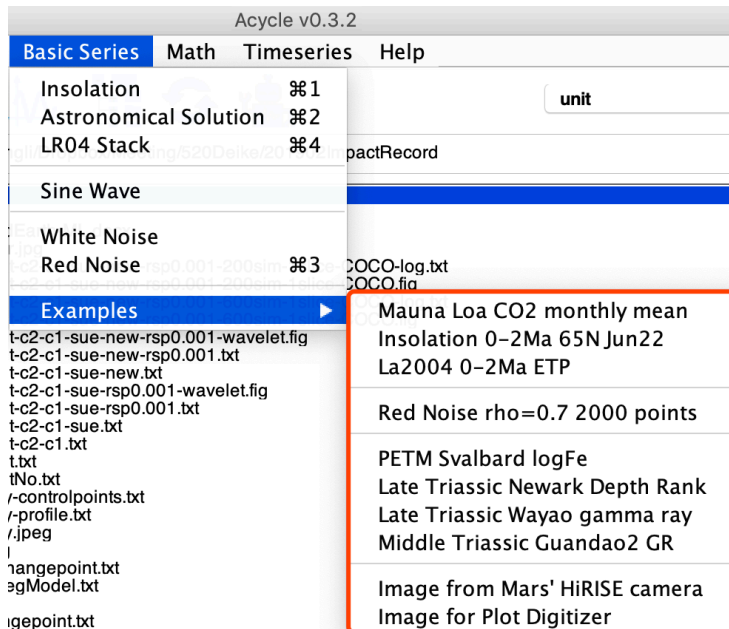
Press **CTRL + C** keys to kill *Acycle*

Data Requirement

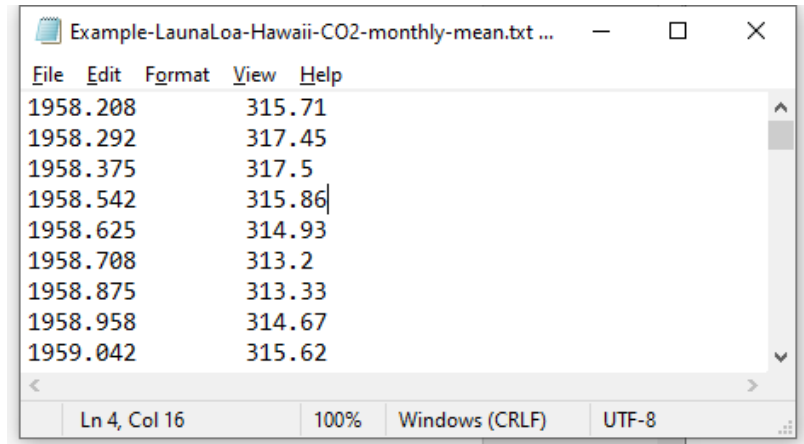
comma-, table- or space-delimited text (.txt)
comma-separated values files (.csv)

No header is permitted.

Most data files should contain two columns of series.



depth
or time value



File Edit Plot Basic Series Math Timeseries Help

File Edit Plot Basic Series

- New Folder
- New Text File ⌘N
- Save *.AC.fig
- Open Working Directory
- Extract Data

Edit Plot Basic

- Refresh ⌘R
- Rename
- Cut
- Copy
- Paste
- Delete

Basic Series Math Timeseries

- Insolation ⌘1
- Astronomical Solution ⌘2
- Signal/Noise Generator ⌘3
- LR04 Stack ⌘4
- Examples ▶

Help

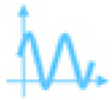
- Read Me
- Manual
- Find Updates
- Copyright
- Contact

Plot Basic Series Math

- Plot ⌘D
- Plot Pro ⌘P
- Plot Standardized
- Plot Standardized + 2
- Plot Swap Axis
- Stairs
- Sampling Rate
- Data Distribution
- Ecoco Plot

- Mauna Loa CO2 monthly mean
- Insolation 0-2Ma 65N Jun22
- La2004 0-2Ma ETP
- Red Noise rho=0.7 2000 points
- PETM Svalbard logFe
- Late Triassic Newark Depth Rank
- Late Triassic Wayao gamma ray
- Middle Triassic Guandao2 GR
- Image from Mars' HiRISE camera
- Image for Plot Digitizer

Plot Pro



Acycle: Advanced Plot

Data: Onoue2019rank-Digit-c2-c1-sue.txt

Plot Type: Line

Line: - 1.0 Color [black]

Marker: o 6.0 [Face] [none]

Axis: **X** -1.71976 -0.0137839 [Linear] [Normal] [--]

Click to set Y (or X) axis

click to modify

Plot

Figure 1: Acycle: Plot Pro

File Edit View Insert Tools Desktop Window Help

Example-WayaoCarnianGR0-rsp0.35341-35%lowess-2pil
Example-WayaoCarnianGR0-rsp0.35341-35%lowess.txt
Example-WayaoCarnianGR0-rsp0.35341.txt
fHalg.m

Acycle: Plot Pro

Data: Example-WayaoCarnianGR0.txt

Plot Type: Line

Line: - 0.2 Color [blue]

Marker: Square 6.0 [Face] [none]

Axis: **Y** 628.8 3355.2 [Log] [Normal] [Swap]

Plot

ac
clear;

Insolation

Acycle: Insolation

Insolation Type: Daily Mean

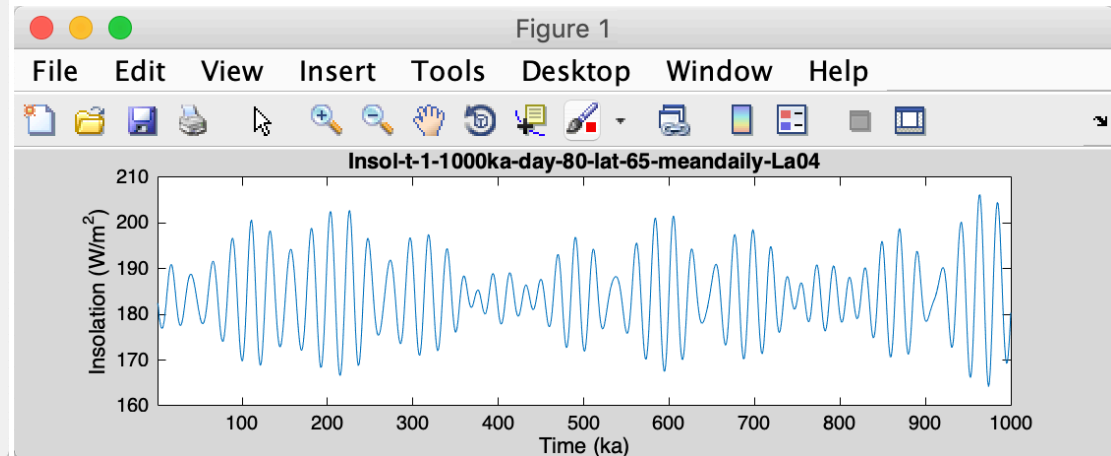
Astronomical Solution: Laskar et al. 2004

Time Scale: Choose the starting and final time:
from 1 step 1
to 1000 time unit kyr
The series will have 1001 points

Insolation parameters: Solar constant 1365 W/m² Mean daily Max daily
Starting day 80 or date March 21
Ending day 266 or date Septem... 23

Latitude: Single latitude from 65 degree (N>0, S<0) to 80 step 1
 Latitude range

OK



Based on the MatLab code **inso.m** by Jonathan Levine (2001), UC Berkeley.
modified by Peter Huybers (Harvard)
modified by Mingsong Li (Penn State, 2018)

Astronomical Solution

Acycle: Astronomical Solutions

Astronomical: La2004

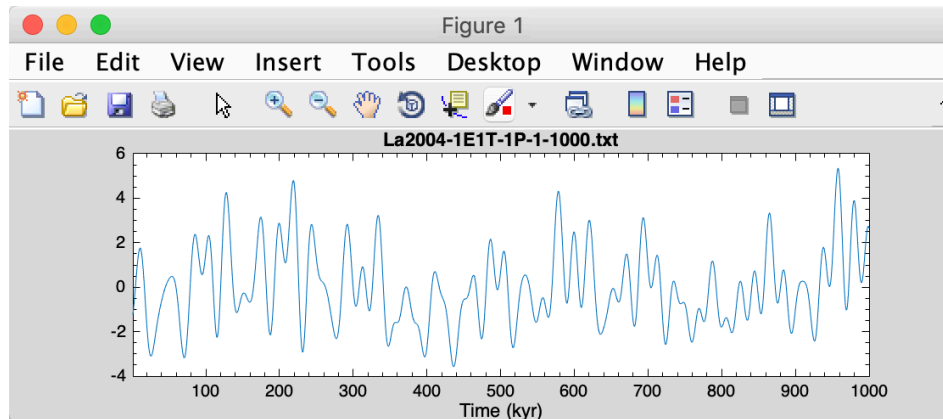
Time Interval: From 1 k.a. To t2 1000 k.a.

Astronomical: ETP

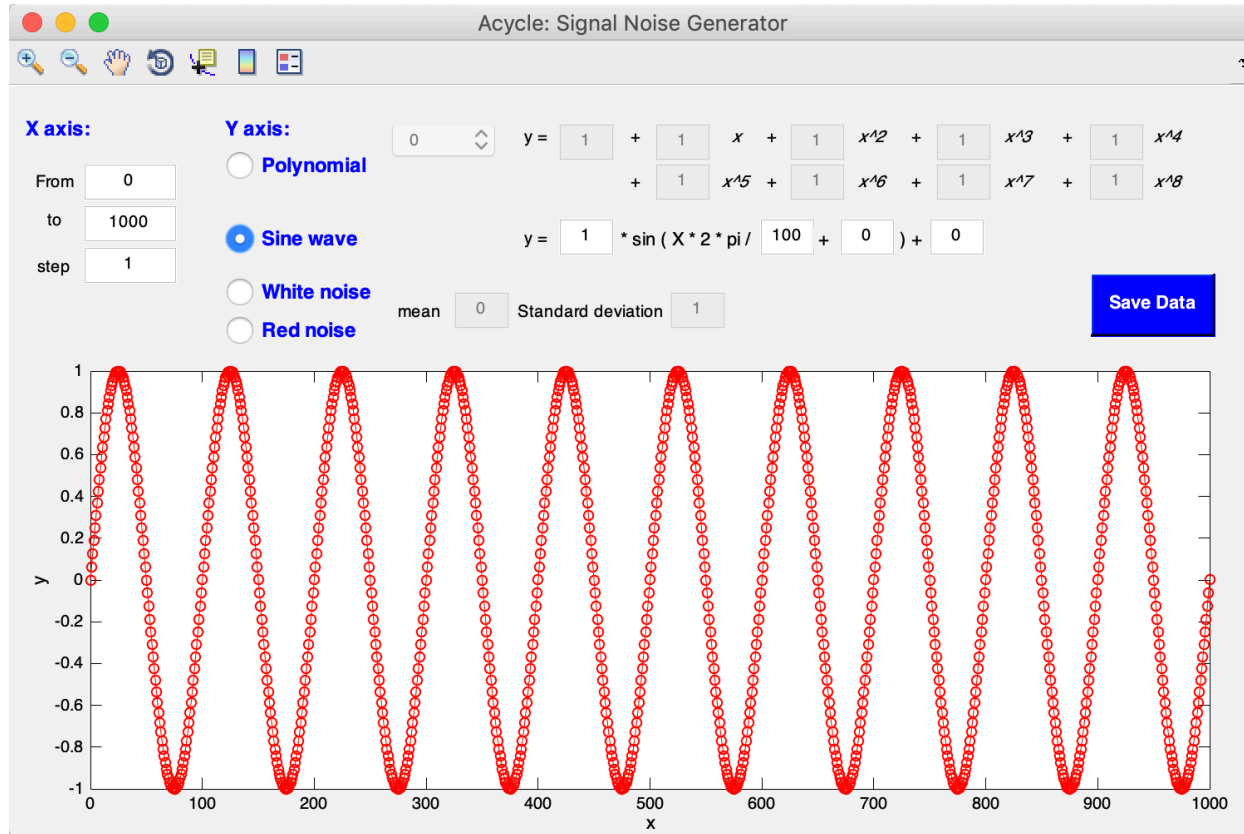
ETP weight: Eccentricit 1, Obliquity 1, Precession -1

OK

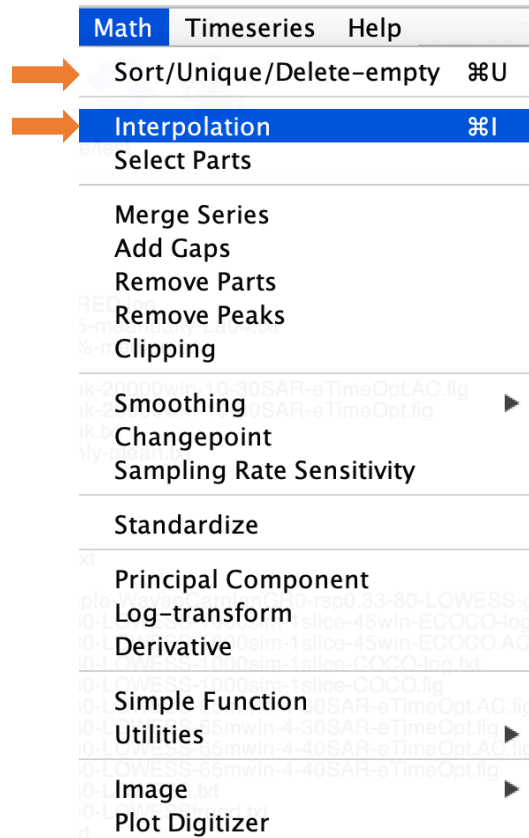
Laskar, J., Robutel, P., Joutel, F., Gastineau, M., Correia, A.C.M., Levrard, B., 2004. A long-term numerical solution for the insolation quantities of the Earth. *Astronomy & Astrophysics* 428, 261-285.



Signal/Noise Generator



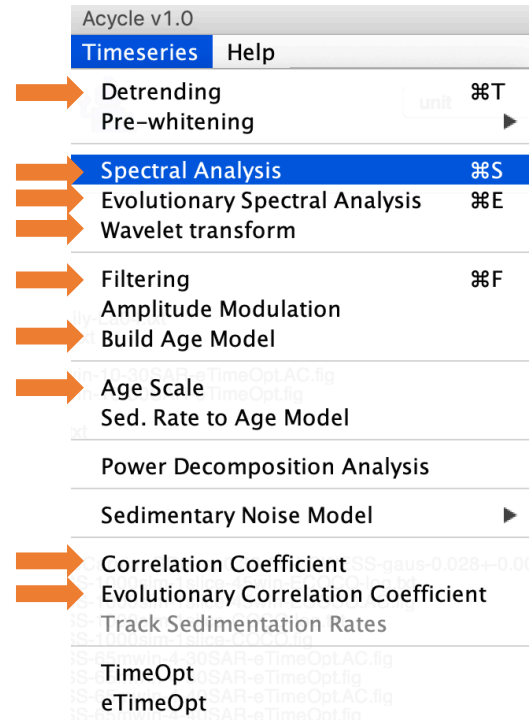
Math



Math Timeseries Help

- Sort/Unique/Delete-empty ⌘U
- Interpolation ⌘I**
- Select Parts
- Merge Series
- Add Gaps
- Remove Parts
- Remove Peaks
- Clipping
- Smoothing ▶
- Changepoint
- Sampling Rate Sensitivity
- Standardize
- Principal Component
- Log-transform
- Derivative
- Simple Function
- Utilities ▶
- Image ▶
- Plot Digitizer

Time series



Acycle v1.0

Timeseries Help

- Detrending unit ⌘T
- Pre-whitening ▶
- Spectral Analysis ⌘S**
- Evolutionary Spectral Analysis ⌘E
- Wavelet transform
- Filtering ⌘F
- Amplitude Modulation
- Build Age Model
- Age Scale
- Sed. Rate to Age Model
- Power Decomposition Analysis
- Sedimentary Noise Model ▶
- Correlation Coefficient
- Evolutionary Correlation Coefficient
- Track Sedimentation Rates
- TimeOpt
- eTimeOpt

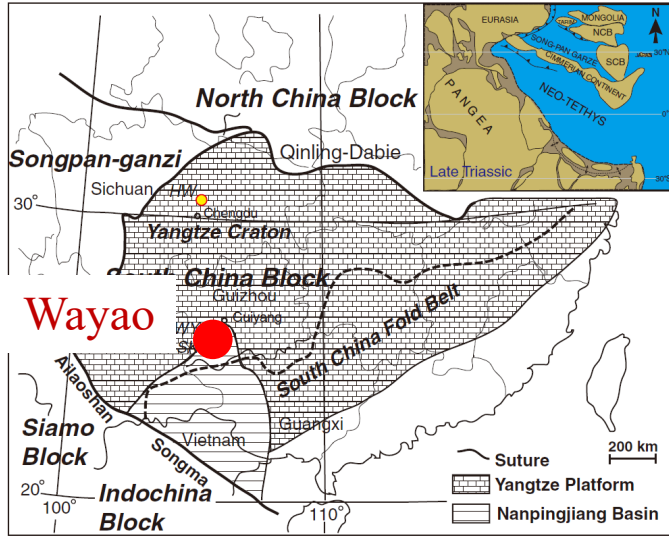
Case studies:

1. Insolation

2. Laskar 2004 astronomical solution

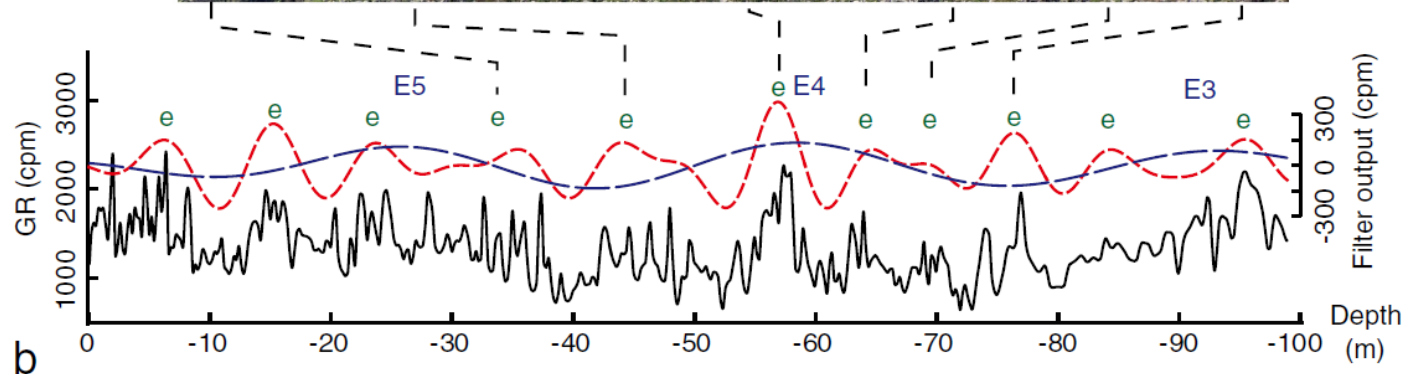
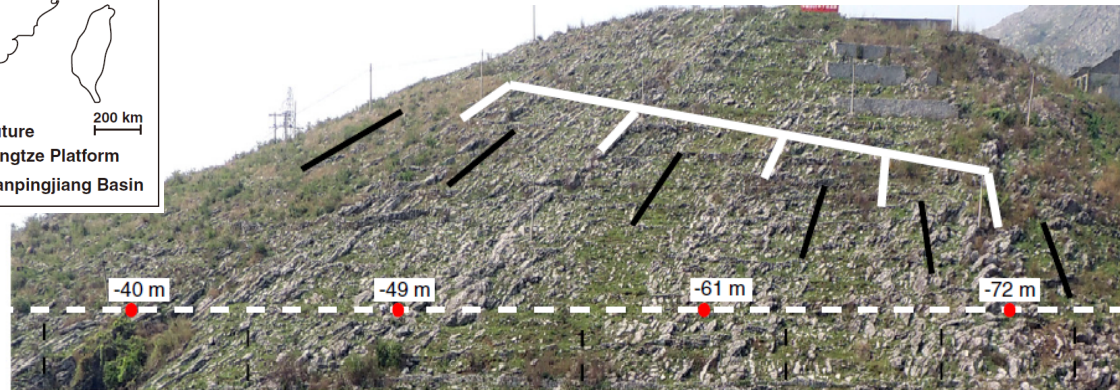
3. Carnian cyclostratigraphy (~235 Ma, Triassic)

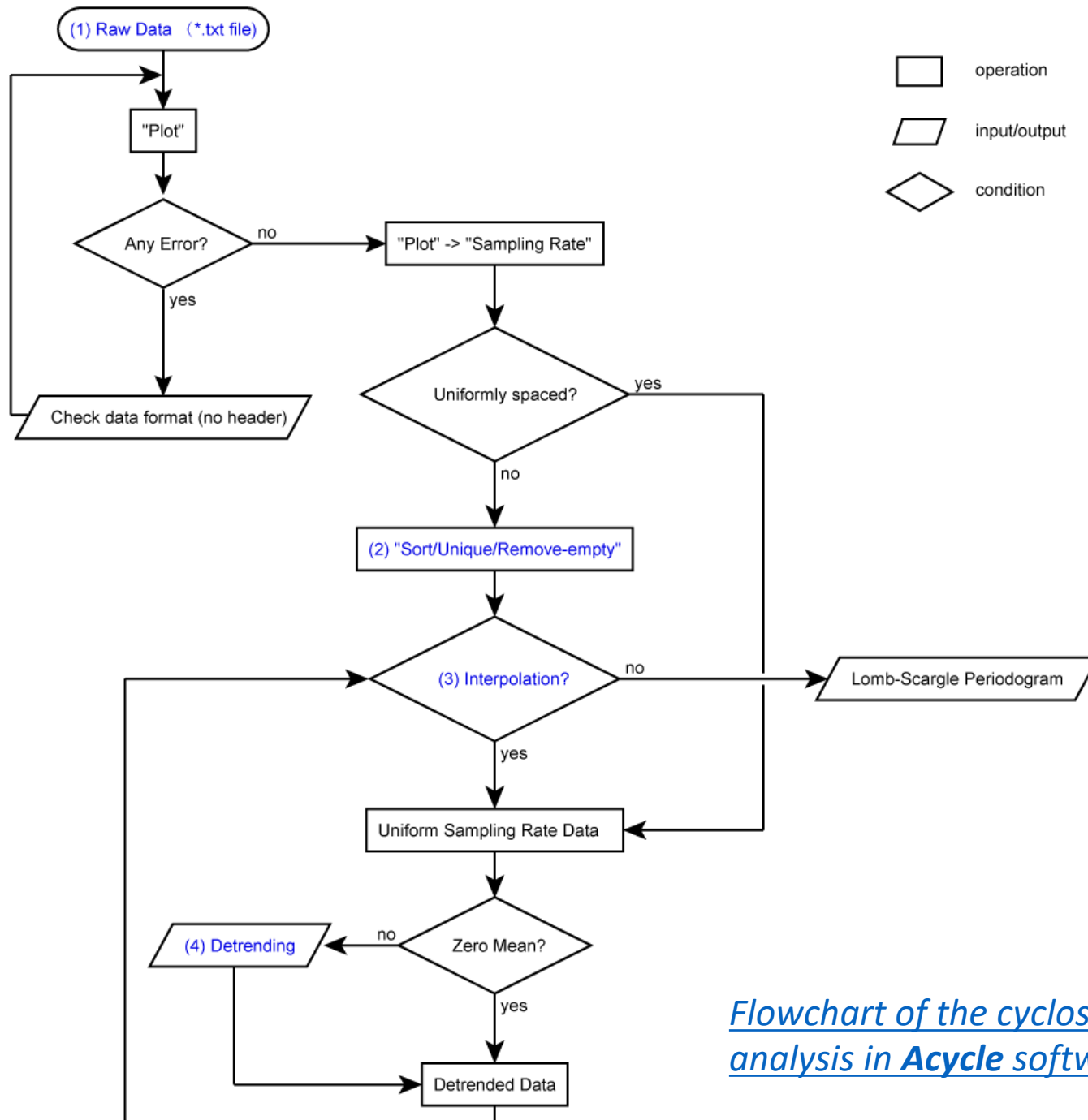
Carnian cyclostratigraphy (~235 Ma, Triassic)



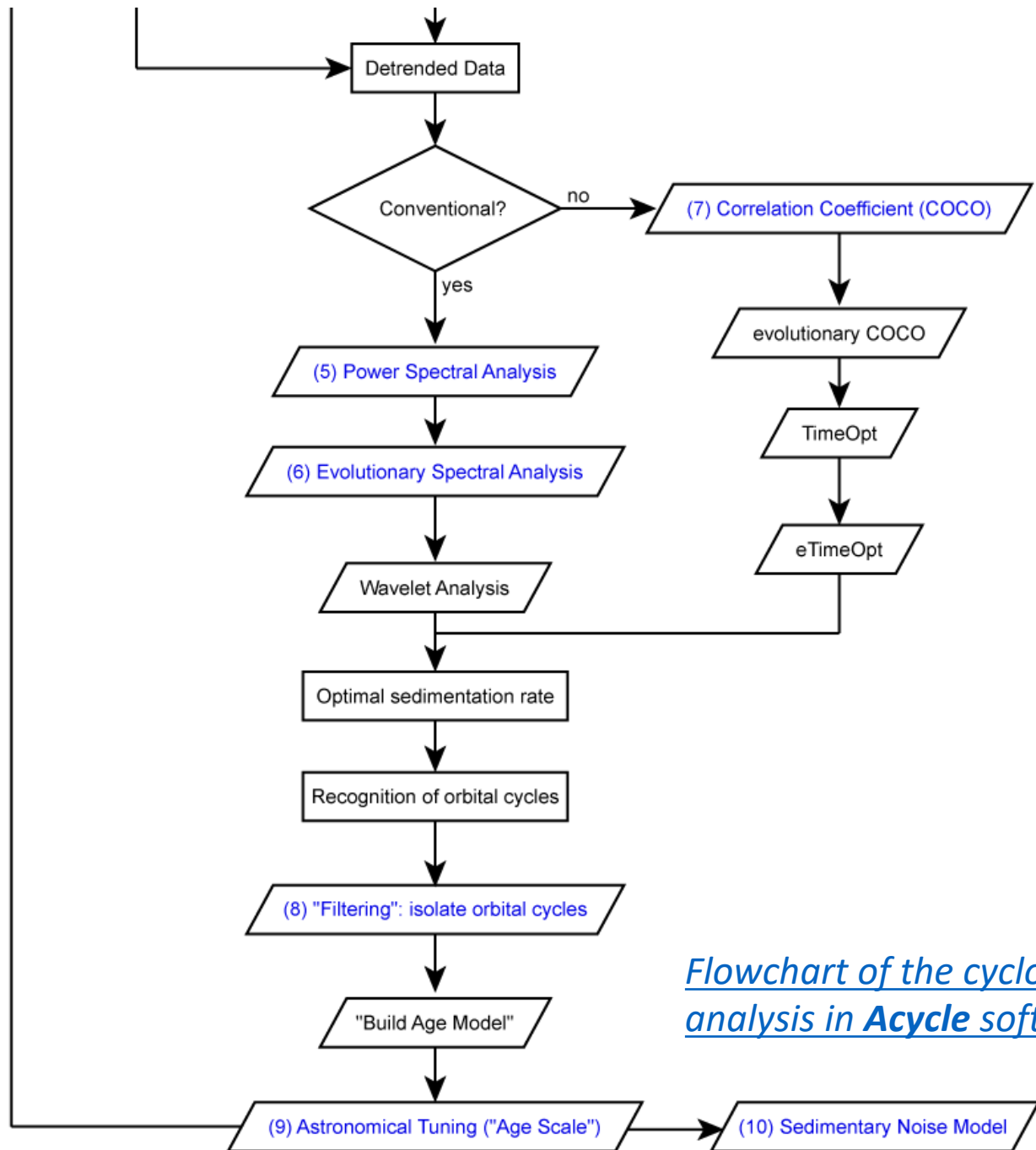
Proxy: gamma-ray with higher intensities indicating higher average clay contents

Target: learn typical data process steps



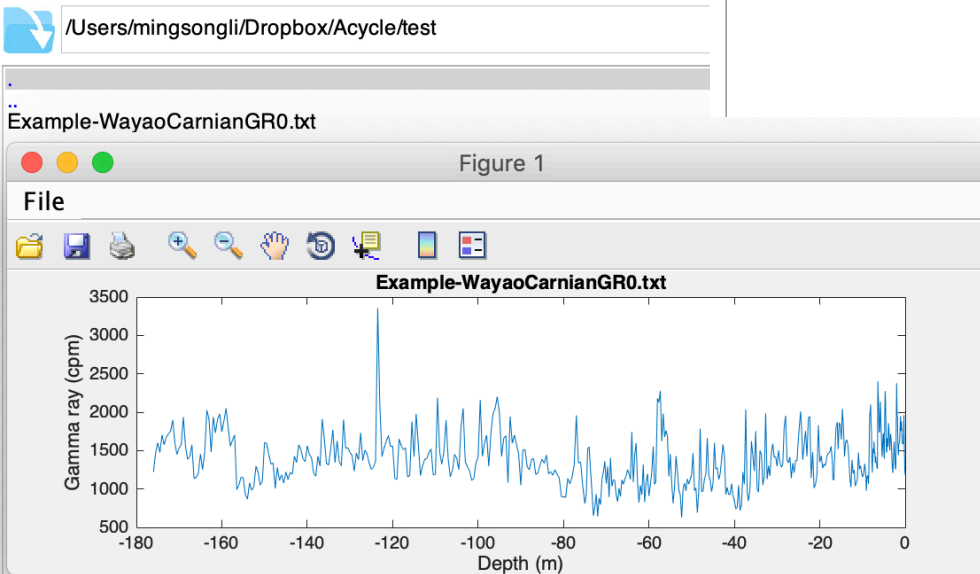
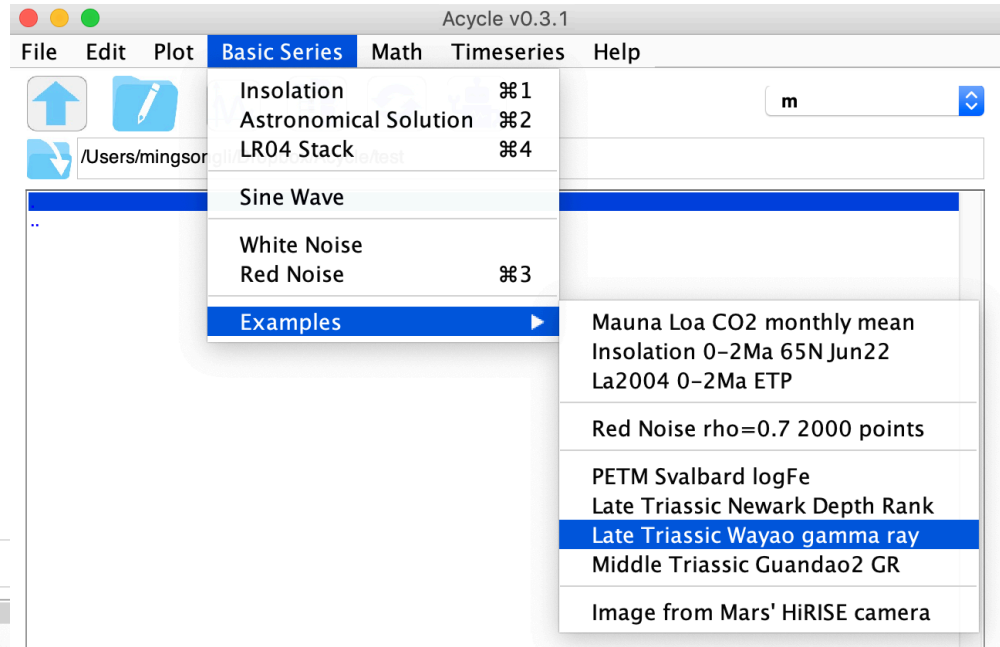


*Flowchart of the cyclostratigraphic analysis in **Acycle** software (1)*



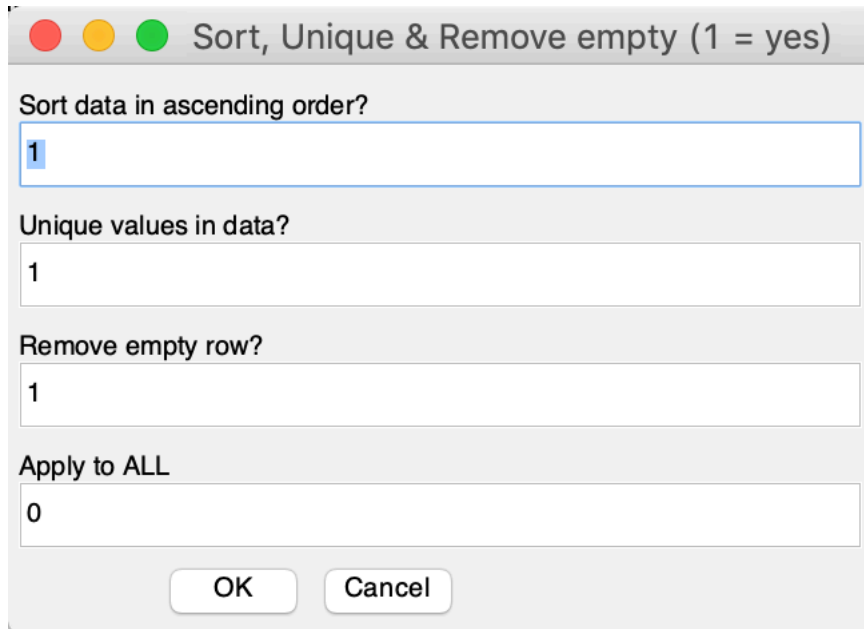
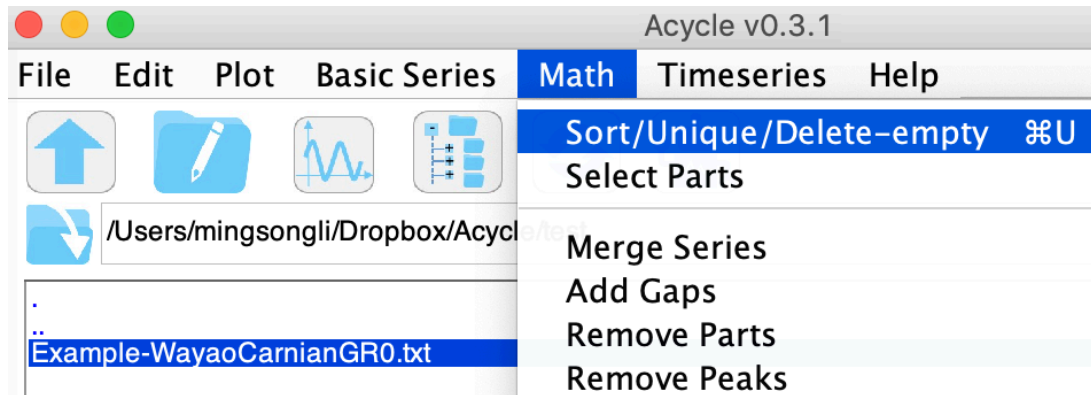
*Flowchart of the cyclostratigraphic analysis in **Acycle** software (2)*

Step 1. Load Data



The gamma ray data entitled “Example-WayaoCarnianGR0.txt” will be loaded and displayed in the *Acycle* main window.

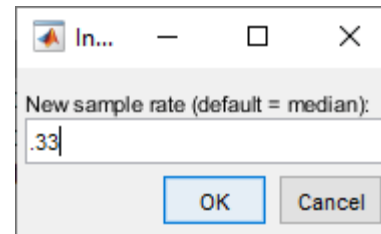
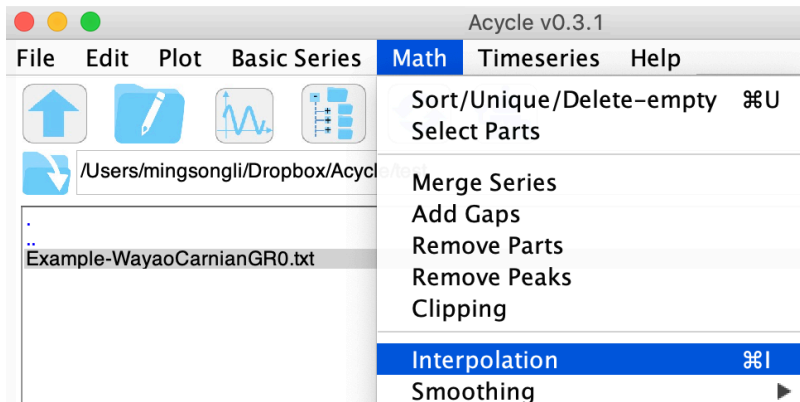
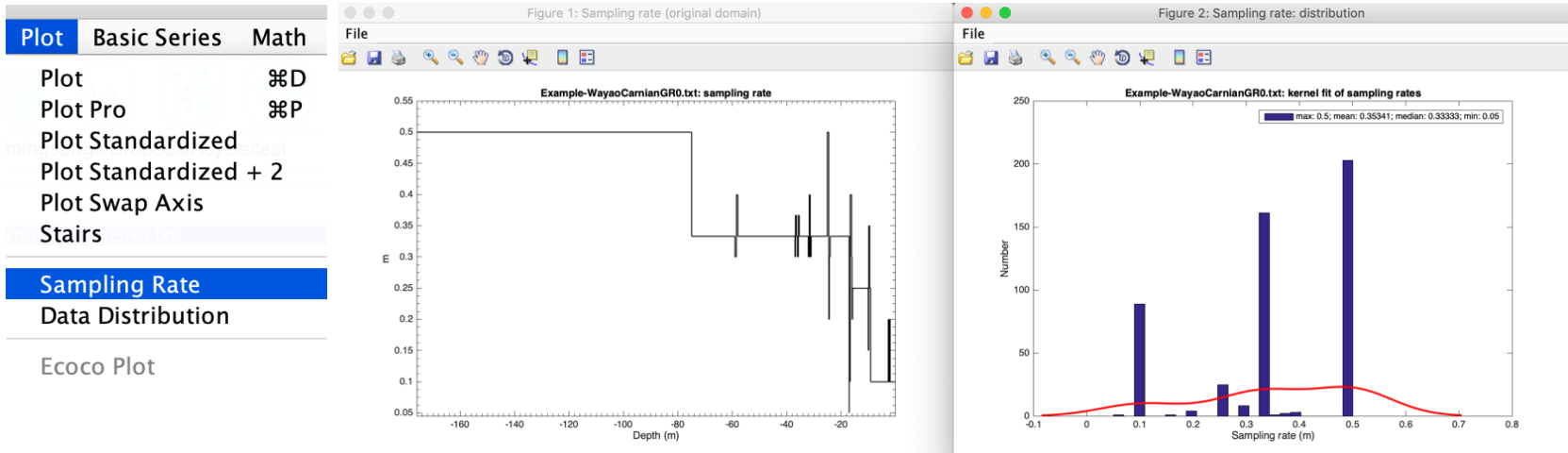
Step 2. Data Preparation (optional)



Users can sort data in ascending order. Two or more values for the same time (or depth) may be averaged with the "Unique" function.

Step 3. Interpolation

Stratigraphic depth or time series are typically irregularly spaced due to uncertain timescales or difficulty in data collection. This necessitates interpolation to generate uniformly spaced time (or depth) series.



“Example-WayaoCarnianGR0-rsp0.33.txt”.

Step 4. Detrending

Detrending is a critical step for power spectral analysis to ensure that data variability oscillates about a zero mean, and to avoid power leakage from very low-frequency components into higher frequencies of the spectrum.

The screenshot displays the Acycle v0.3.1 software interface. The main menu bar includes File, Edit, Plot, Basic Series, Math, Timeseries, and Help. The Timeseries menu is open, showing options: Detrending (marked with a red '2'), Pre-whitening, Spectral Analysis (marked with a red 'S'), Evolutionary Spectral Analysis (marked with a red 'E'), Wavelet transform, and Filtering (marked with a red 'F'). A file path is visible: /Users/mingsongli/Dropbox/Acycle/test. A file list below shows 'Example-WayaoCarnianGR0-rsp0.33.txt' (marked with a red '1') and 'Example-WayaoCarnianGR0.txt'.

The Detrending dialog box is open, showing a window size of 61.5615 OR 35 %. Under 'Polynomial fit', '1 order (Linear)' and '2 order' are selected. The 'Raw' model is chosen in the 'Select & Save detrending Model' section.

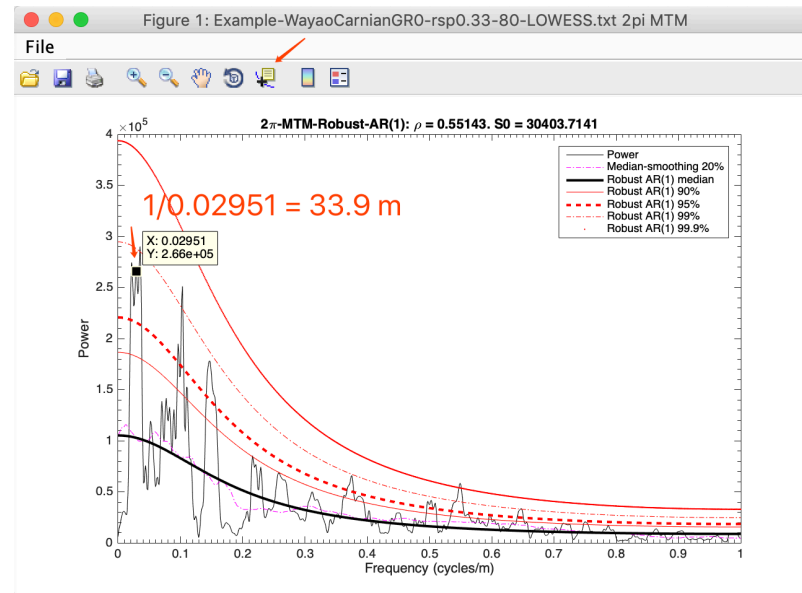
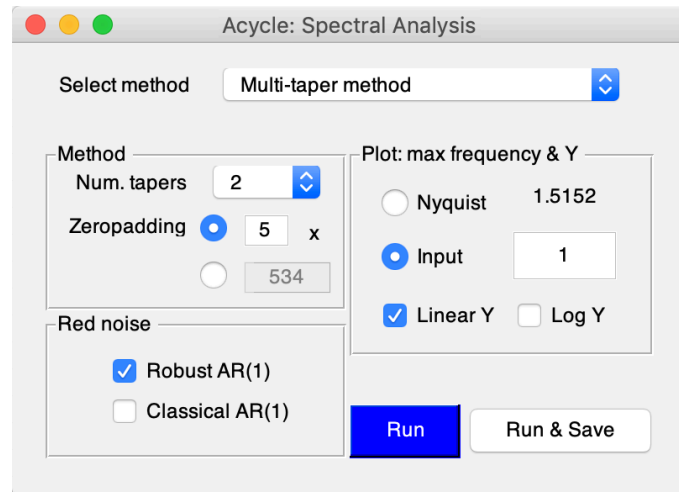
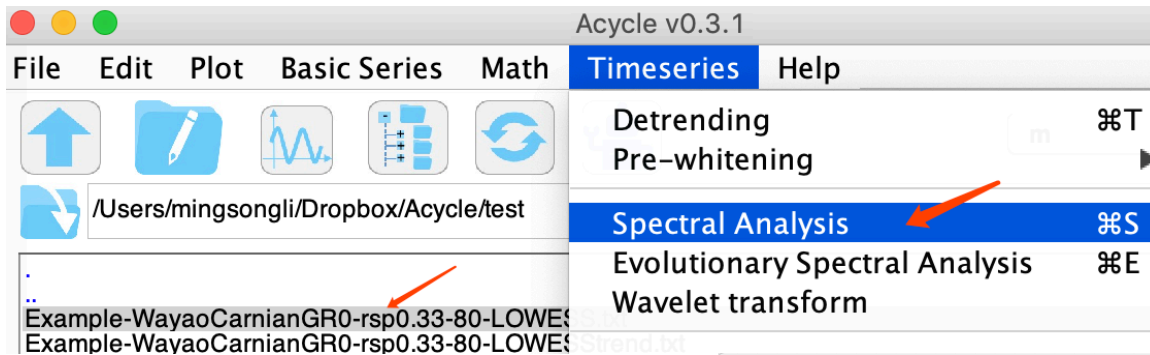
The plot, titled 'Raw data & 61.5615-m trend', shows 'Value' on the y-axis (1000 to 3000) and 'Depth (m)' on the x-axis (-160 to -20). The legend includes: Raw (black), Linear (Yellow), 2nd order (dashed red), LOWESS (Green), rLOWESS (Blue), and LOESS (Red).

At the bottom, a file list shows: 'Example-WayaoCarnianGR0-rsp0.33-80-LOWESS.txt' and 'Example-WayaoCarnianGR0-rsp0.33-80-LOWESStrend.txt' (both highlighted with a red box).

[Read More: Detrending](#)

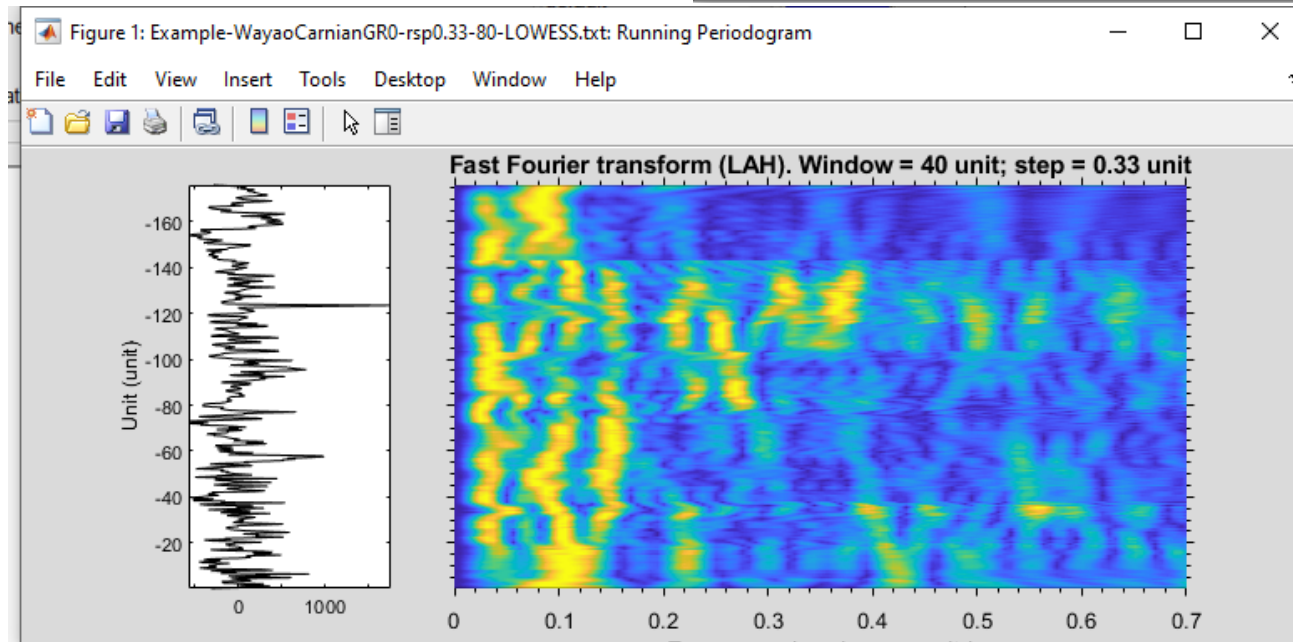
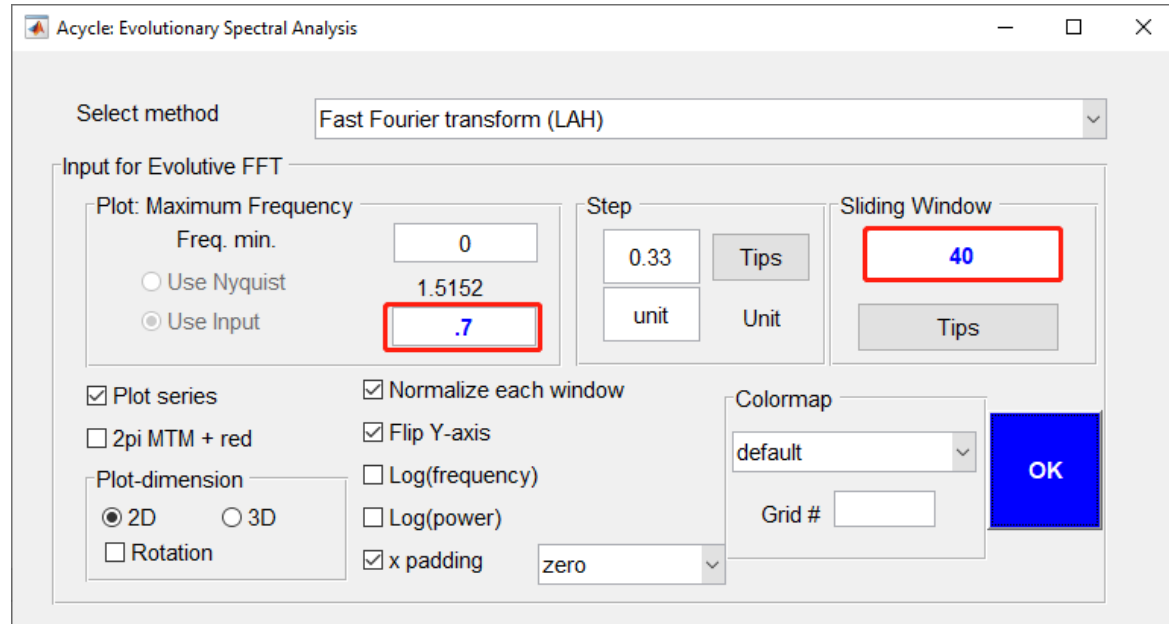
Step 5. Power spectral analysis

Power spectral analysis evaluates the distribution of time series variance (power) as a function of frequency. The primary use of power spectral analysis is for the recognition of periodic or quasi-periodic components in a data series



[Read More: Spectral Analysis](#)

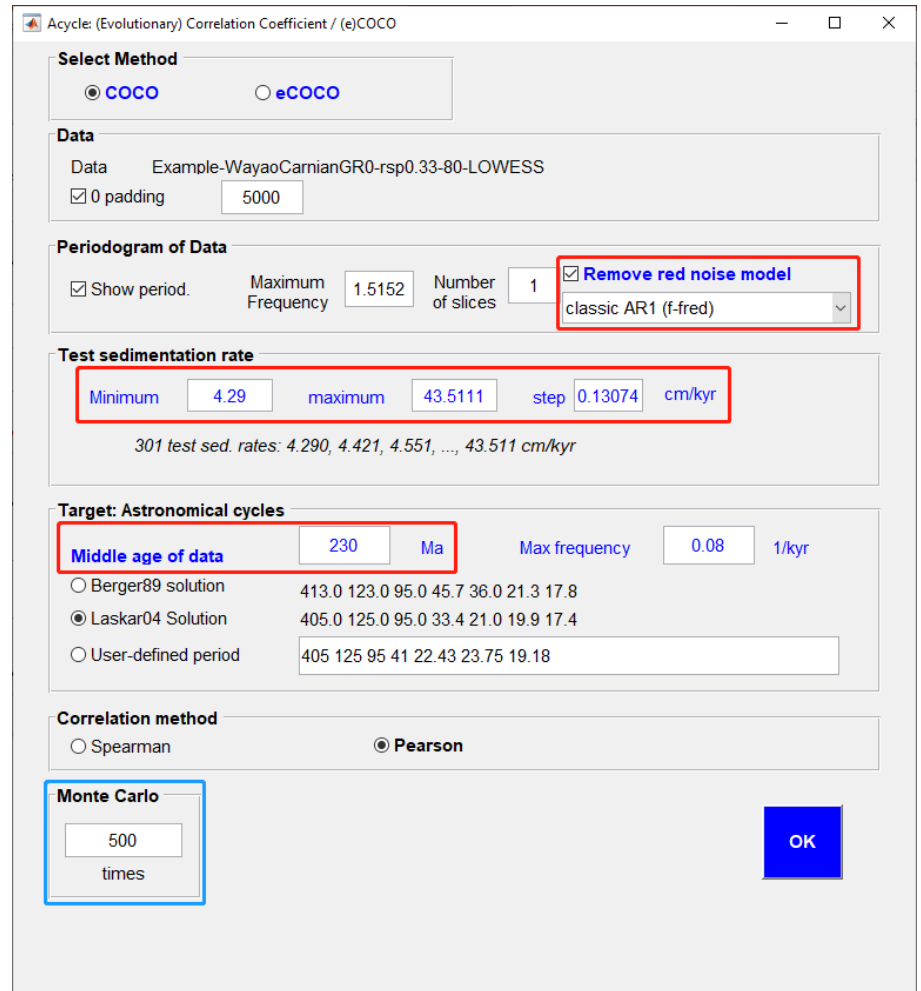
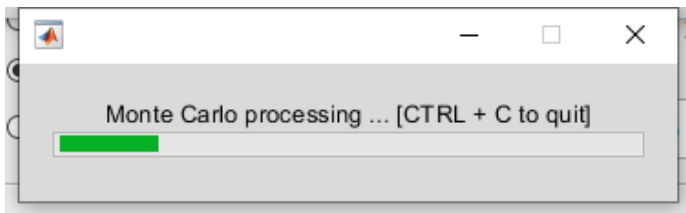
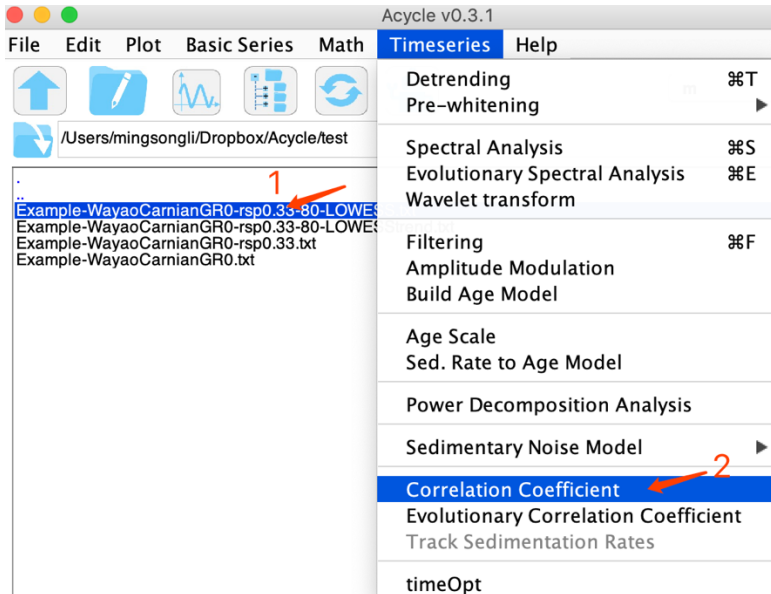
Step 6. Evolutionary power spectral analysis



[Read More](#)

Step 7. Correlation coefficient

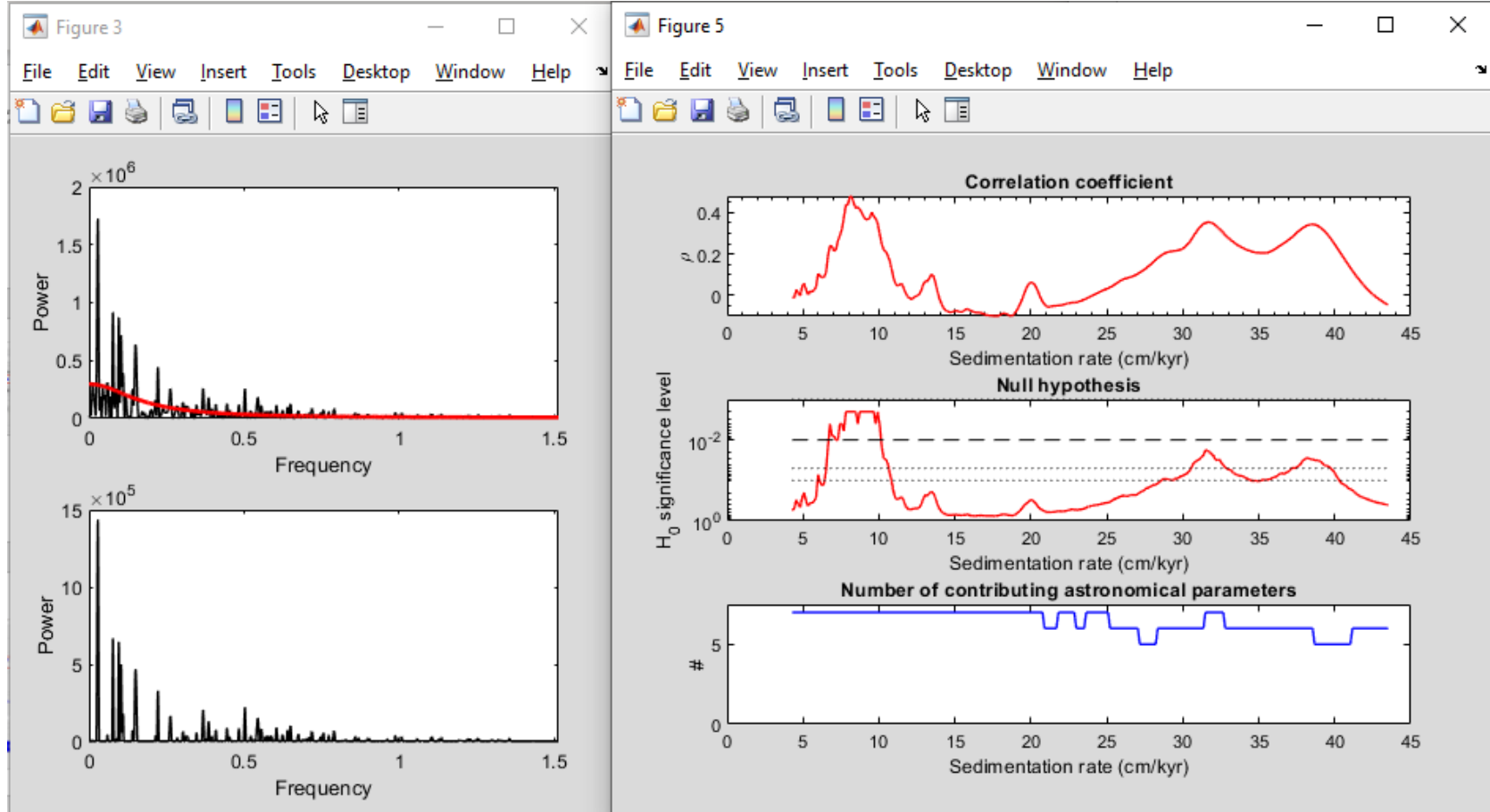
To estimate the optimal sedimentation rate.



[Read More: COCO/eCOCO](#)

Similar tool: [TimeOpt](#) / [eTimeOpt](#)

You will have the following figure and a log file saving all settings.



It tells the most likely sedimentation rate is ~ 9 cm/kyr,
with a null hypothesis (no orbital forcing) significance level of $< 1\%$
All seven orbital parameters are used in the estimation.

eCOCO analysis to track variable sedimentation rate

Acycle: (Evolutionary) Correlation Coefficient / (e)COCO

Select Method

COCO eCOCO

Data

Data Example-WayaoCarnianGR0-rsp0.33-80-LOWESS

0 padding 5000 0 padding edge zero Flip Depth (y axis)

Periodogram of Data

Show period. Maximum Frequency 1.5152 Number of slices 1 Remove red noise model classic AR1 (f-fred)

Test sedimentation rate

Minimum 4.29 maximum 43.5111 step 0.13074 cm/kyr

301 test sed. rates: 4.290, 4.421, 4.551, ..., 43.511 cm/kyr

Target: Astronomical cycles

Middle age of data 230 Ma Max frequency 0.08 1/kyr

Berger89 solution 413.0 123.0 95.0 45.7 36.0 21.3 17.8

Laskar04 Solution 405.0 125.0 95.0 33.4 21.0 19.9 17.4

User-defined period 405 125 95 41 22.43 23.75 19.18

Correlation method

Spearman Pearson

Monte Carlo 500 times

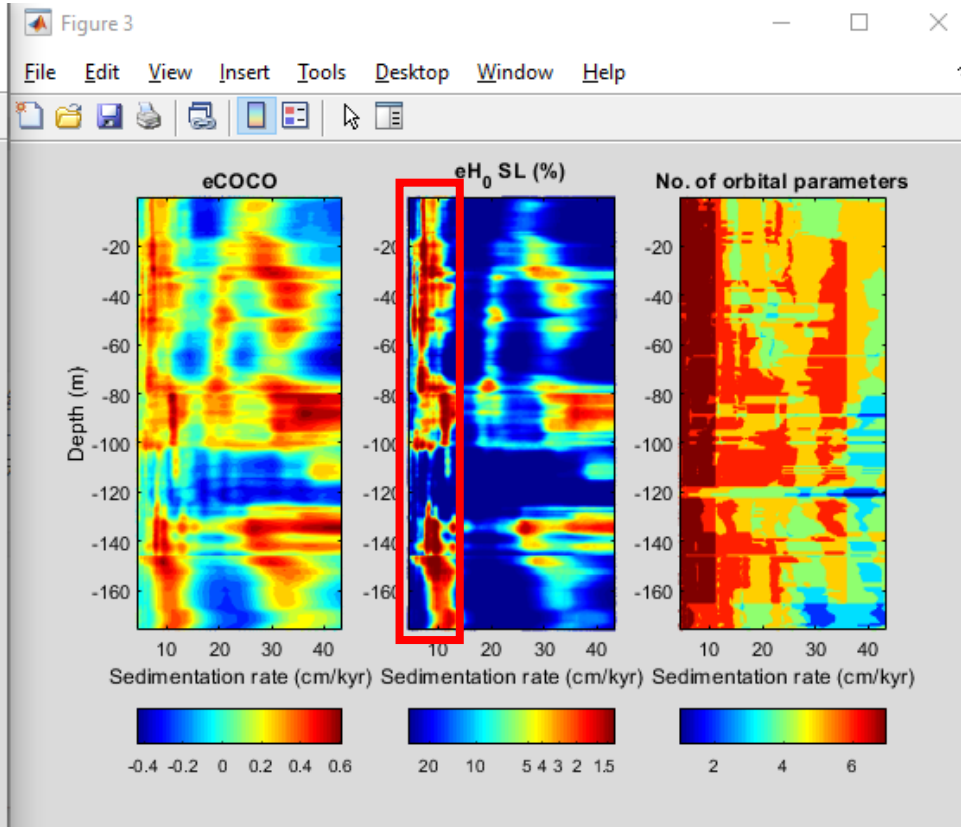
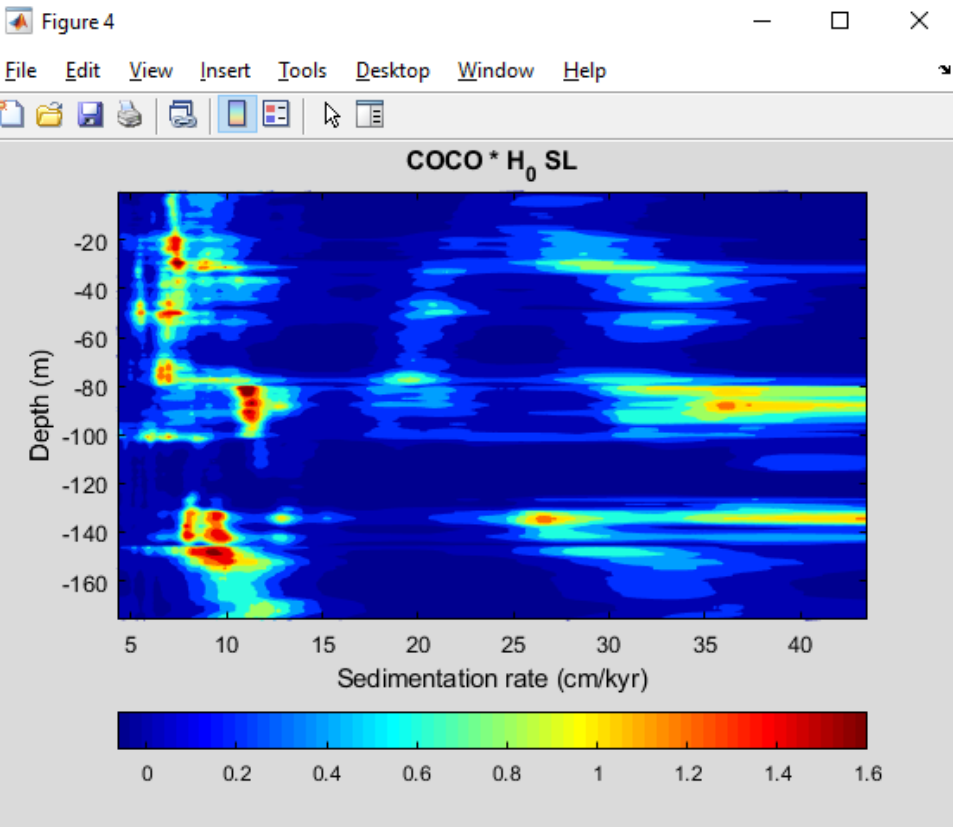
Sliding Window Size 45 m Step 0.33 m

eCOCO plot OK

Track sed. rates

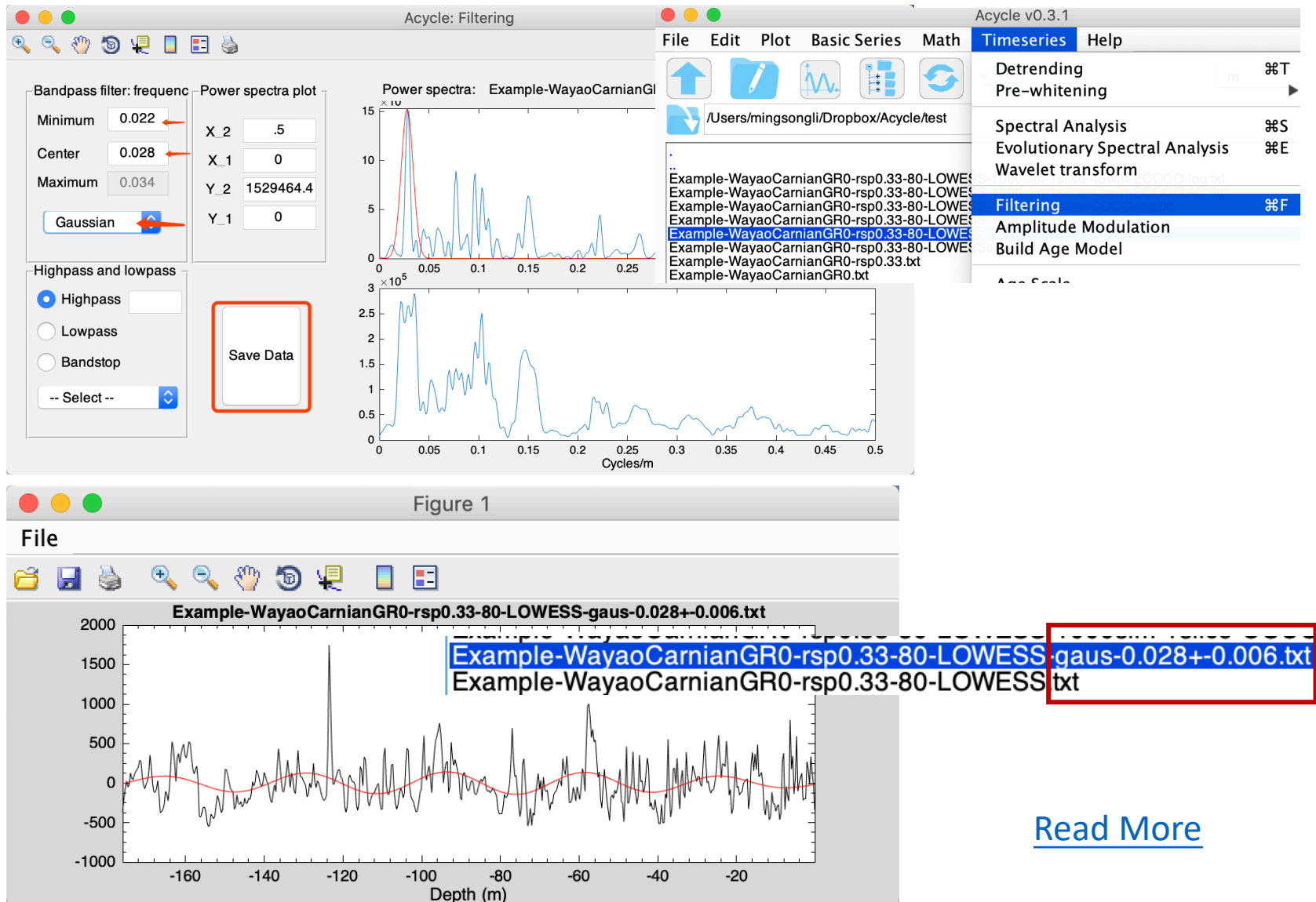
Similar tool: [eTimeOpt](#)

eCOCO analysis to track variable sedimentation rate



Step 8. Filtering

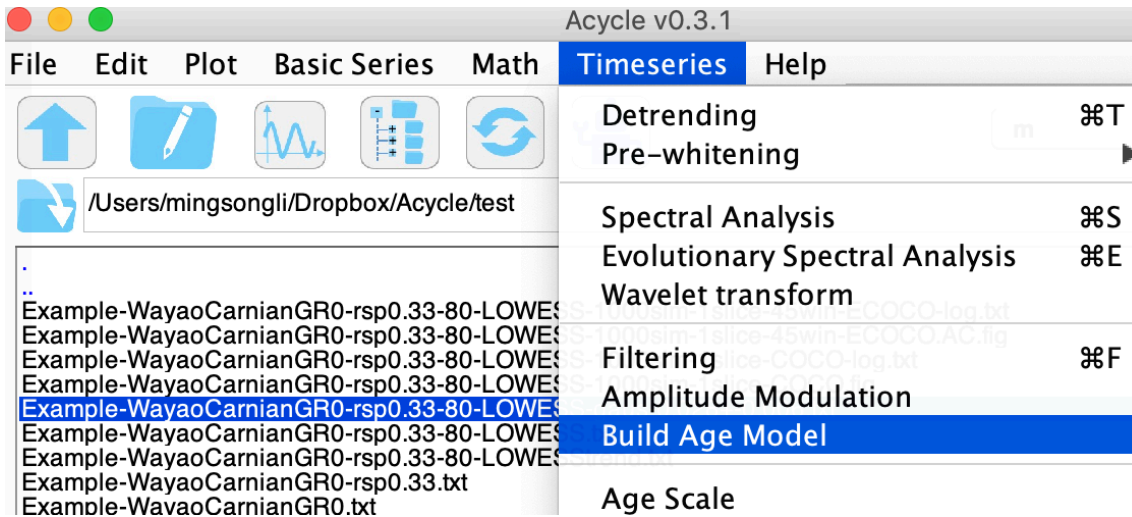
Filters are also essential tools to aid in the isolation of specific frequency components in the paleoclimate data series.



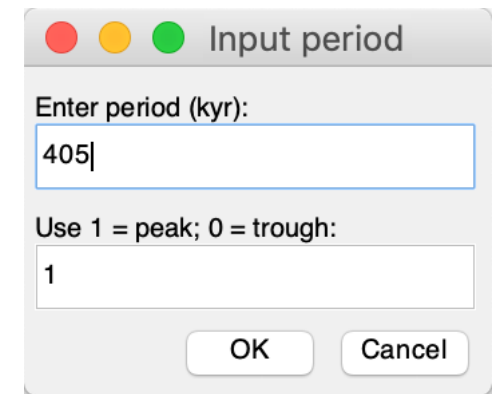
Step 9. Age model and tuning

transform original data (usually in the depth domain) to tuned data (usually in the time domain) when an **age model** file is available

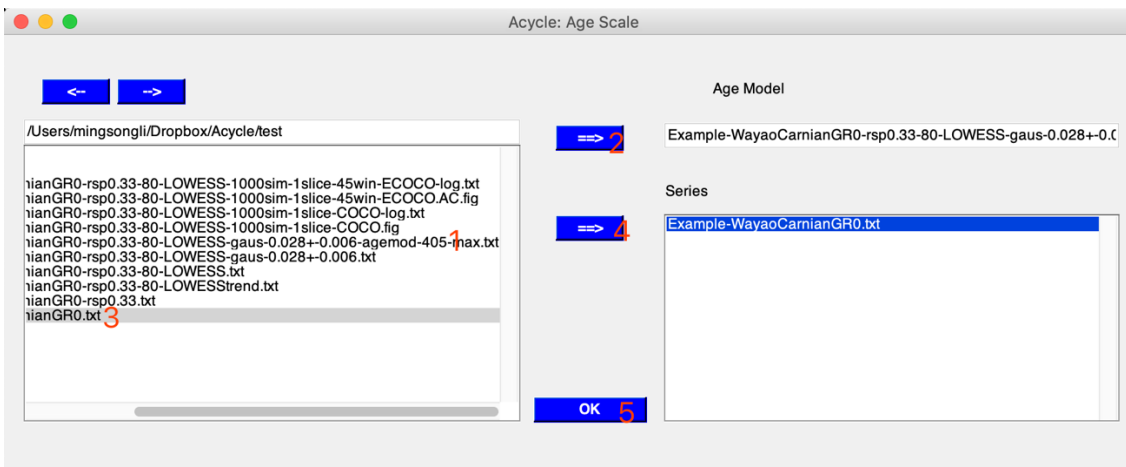
Select “*Example-WayaoCarnianGR0-rsp0.33-80-LOWESS-gaus-0.028+-0.006.txt*”



a, Build age model



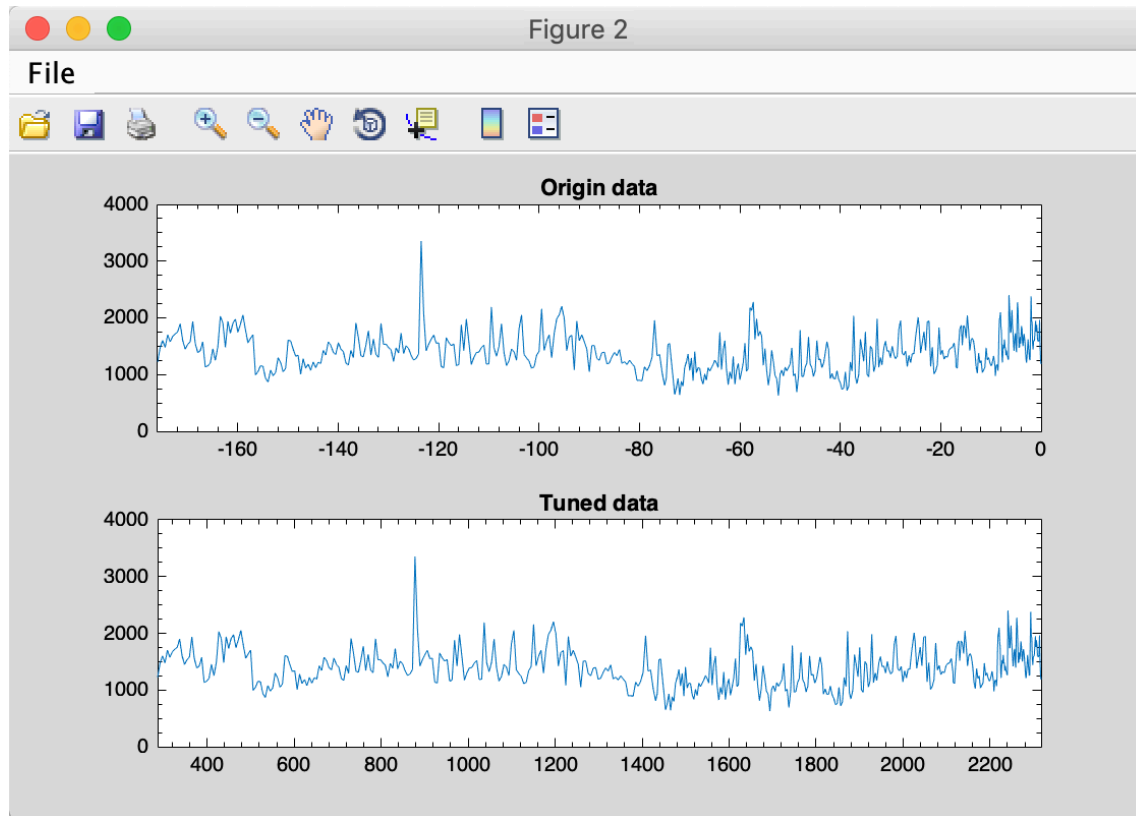
Example-WayaoCarnianGR0-rsp0.33-80-LOWESS-gaus-0.028+-0.006-agemod-405-max.txt



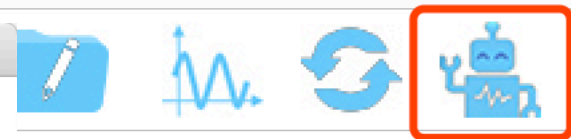
b, Age Scale

Tuned data:

“Example-WayaoCarnianGR0-TD-Example-WayaoCarnianGR0-rsp0.33-80-LOWESS-gaus-0.028+-0.006-agemod-405-max.txt”



Mini robot



ers/mingsongli/Dropbox/lectures/Acycle/demo

Mini-Robot

Prepare Data

Remove NaN Remove Empty Sort Unique

Interpolation

Yes mean

Detrending

Yes lowess Window size: 35 %

Spectral Analysis

Yes Multi-taper Max Frequency 1.4148 red noise

Evolutionary spectral

Yes Sliding window 61.6

Wavelet

Yes Period from 0.706 to 176

Settings

Pause 0.5 second Save data

Other useful tools

Sedimentary noise model

Lag-1 autocorrelation coefficient (ρ_1)

dynamic noise after orbital tuning (DYNOT) model



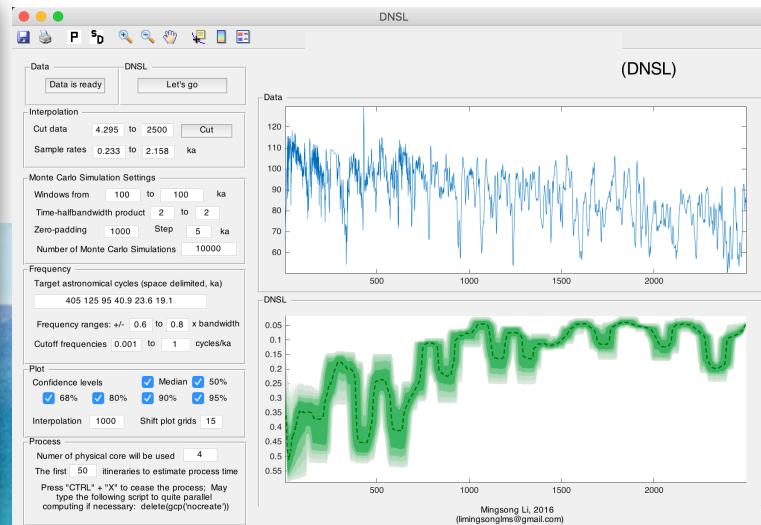
ARTICLE

DOI: 10.1038/n41467-018-0345a-y OPEN

Sedimentary noise and sea levels linked to land-ocean water exchange and obliquity forcing

Mingsong Li^{1,2,3}, Linda A. Hinno^{v2,1}, Chunju Huang^{1,4} & James G. Ogg^{5,1}

In ancient hothouses lacking ice sheets, the origins of large, million-year (myr)-scale sea-level oscillations remain a mystery, challenging current models of sea-level change. To address this mystery, we develop a sedimentary noise model for sea-level changes that simultaneously estimates geologic time and sea level from astronomically forced marginal marine stratigraphy. The noise model involves two complementary approaches: dynamic noise after orbital tuning (DYNOT) and lag-1 autocorrelation coefficient (ρ_1). Noise modeling of Lower Triassic marine slope stratigraphy in South China reveals evidence for global sea-level variations in the Early Triassic hothouse that are anti-phased with continental water storage variations in the Germanic Basin. This supports the hypothesis that long-period (1–2 myr) astronomically forced water mass exchange between land and ocean reservoirs is a missing link for reconciling geological records and models for sea-level change during non-glacial periods.



Li, et al., 2018
Nature Communications

Ancient ocean

Credit: Hewei Duan

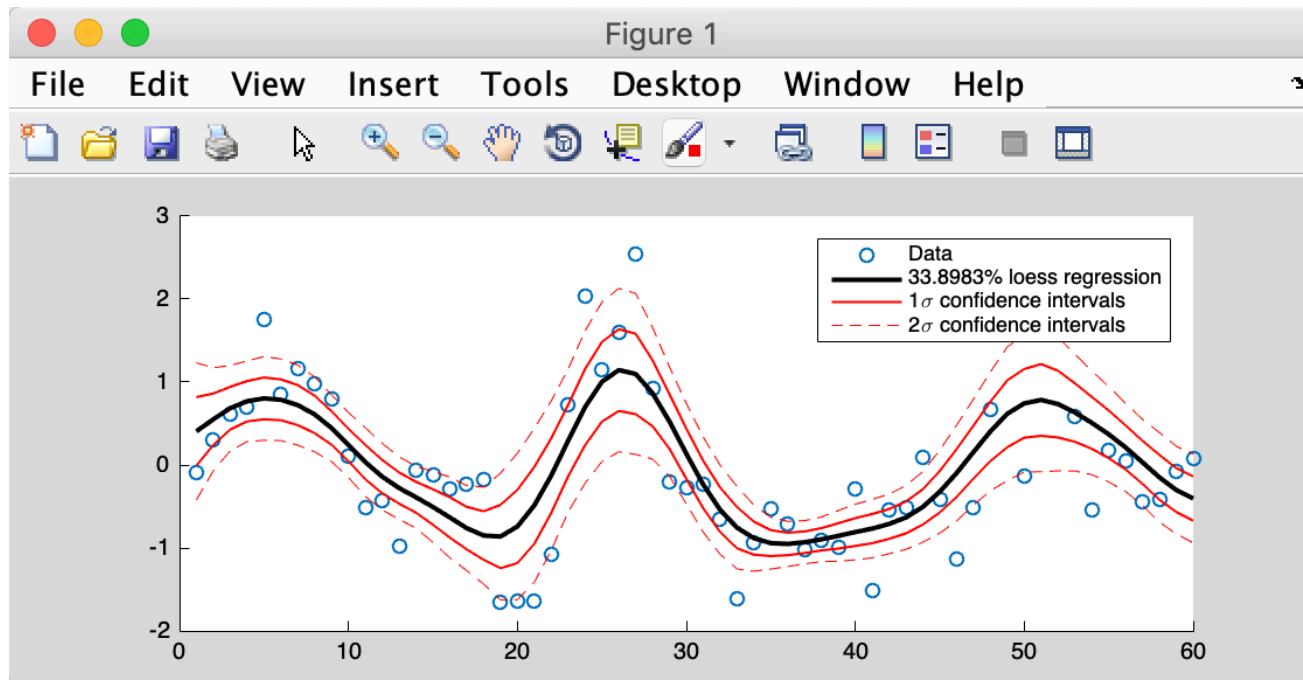
Smoothing

Math Timeseries Help

- Sort/Unique/Delete-empty ⌘U
- Interpolation ⌘I
- Select Parts
- Merge Series
- Add Gaps
- Remove Parts
- Remove Peaks
- Clipping
- Smoothing** ▶
- Changepoint
- Sampling Rate Sensitivity

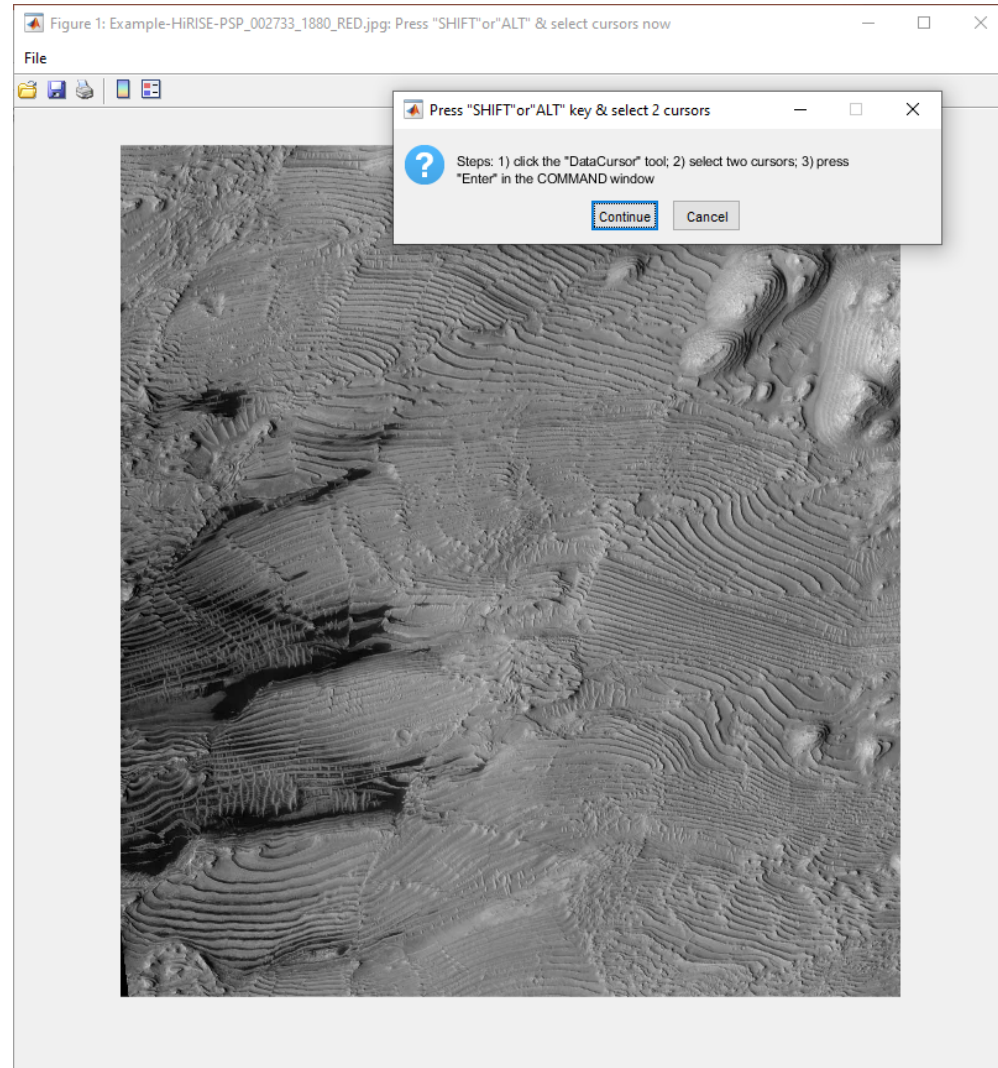
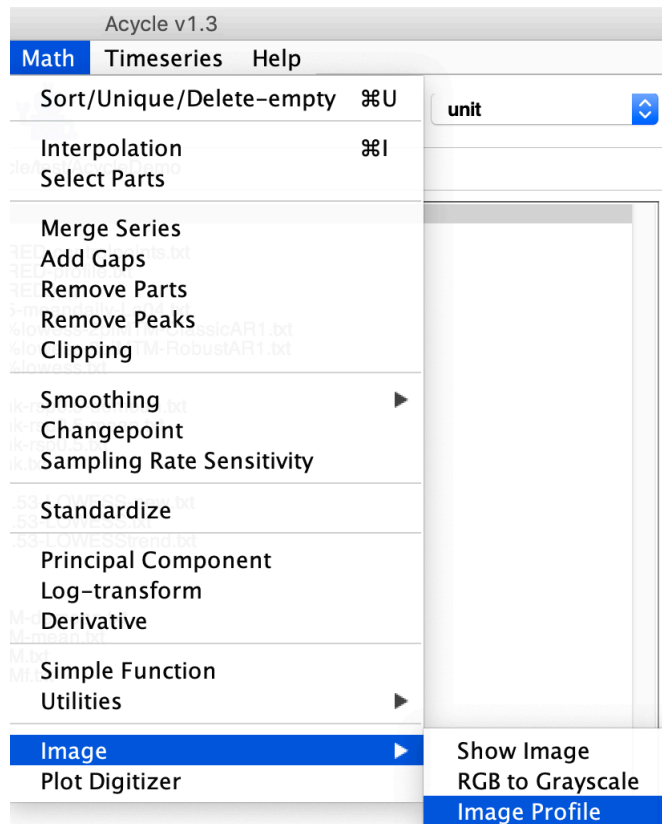
unit

- Moving Average
- Moving Median
- Bootstrap



'Image' Tool

1. Select an image file
2. Select "Show Image"
3. (Optional) Transfer an RGB image to Grayscale image:
Select "RGB to Grayscale"



'Image' Tool

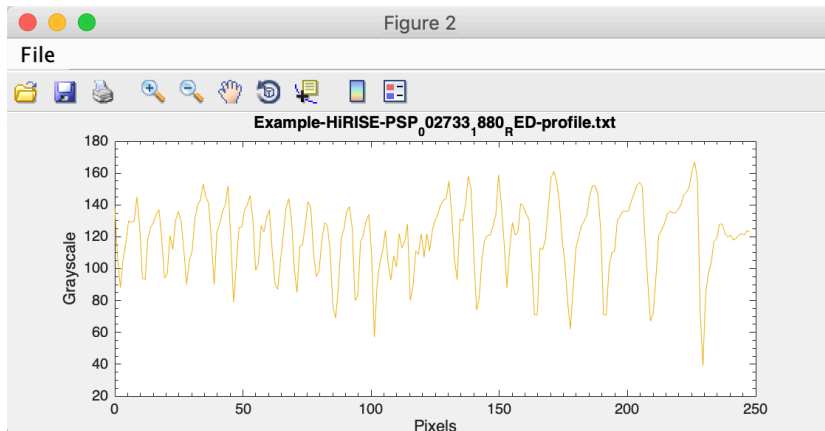
4: Image Profile

5: Press ALT key, select 2 cursors

6. Press "Enter" in the terminal window

Step 6

```
HiRISE-PSP_002733_1880_RED.browse-prof2pt.txt  
HiRISE-PSP_002733_1880_RED.browse-profile.txt  
HiRISE-PSP_002733_1880_RED.browse.jpg
```

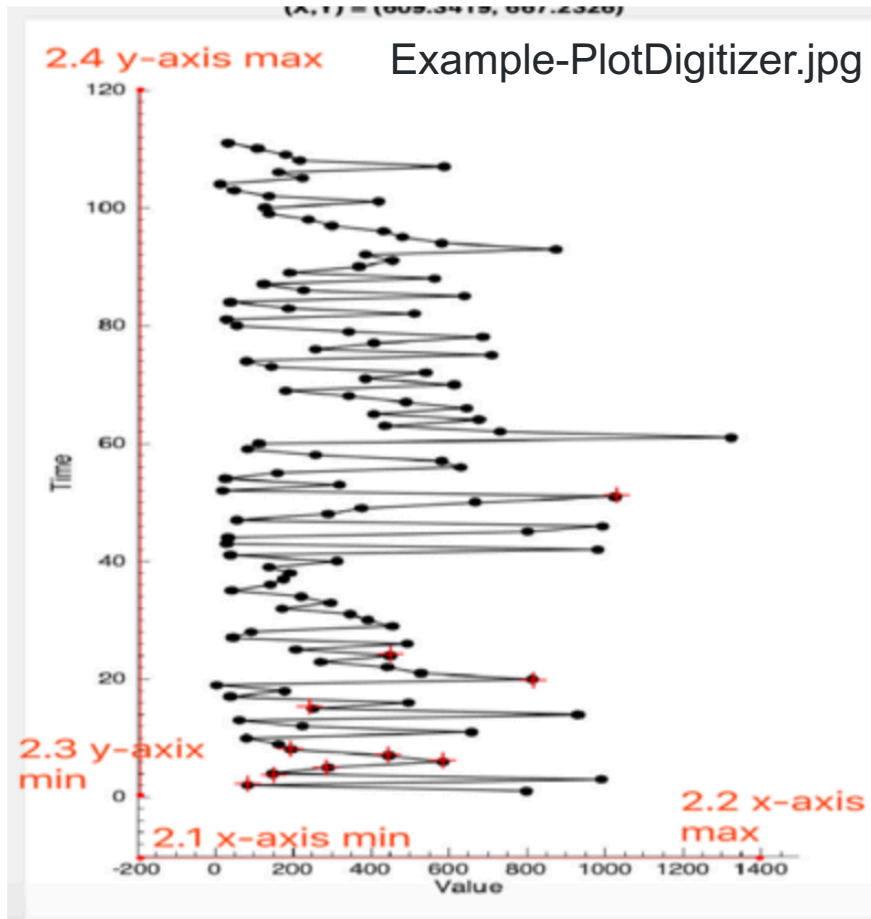
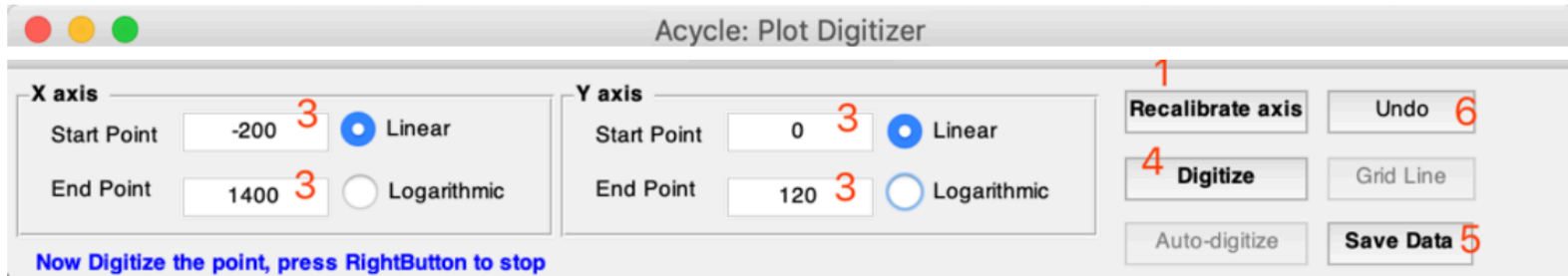


```
mingsongli — applauncher — Acycle > matlab_helper — 80x24  
Select 1 data  
>> Processing clipping:mergedseries.txt  
2019-08-30 14:52:58.487 Acycle[26367:2665410] WARNING: NSWindow drag regions should only be invalidated on the Main Thread! This will throw an exception in the future. Called from (  
 0 AppKit 0x00007fff31521607 -[NSWindow(NSWindow_Theme) _postWindowNeedsToResetDragMarginsUnlessPostingDisabled] + 378  
 1 AppKit 0x00007fff3151e9f7 -[NSWindow _initContent:styleMask:backing:defer:contentView:] + 1479  
 2 AppKit 0x00007fff3151e42a -[NSWindow initWithContentRect:styleMask:backing:defer:] + 45  
 3 libnativewindow_macosx.jnilib 0x0000000012c06afae Java_jogamp_nativewindow_macosx_OSXUtil_CreateNSWindow0 + 382  
 4 ??? 0x000000001199ce758 0x0 + 4724680  
536  
)  
>> See main window for amplitude modulation  
>> Large dataset, wait ...  
>> AC main window: see trend and detrended data  
>> See main window for amplitude modulation  
>> Large dataset, wait ...  
>> AC main window: see trend and detrended data  
Select 1 data  
>> Press "Enter"
```

[X,Y]: [978 600]
[R,G,B]: [123 123 123]

[X,Y]: [886 830]
[R,G,B]: [139 139 139]

Plot Digitizer



No.	X	Y
1	76.9231	1.9835
2	144.6154	3.4711
3	280.0000	4.7107
4	581.5385	5.9504
5	440.0000	6.9421
6	187.6923	7.9339
7	236.9231	15.1240
8	815.3846	19.5868
9	446.1538	24.0496
10	1.0308e+03	51.0744

Acknowledgement



Linda Hinnov



Lee Kump

Astronomical solution: Jacques Laskar, Richard Zeebe

Changepoint: Eric Ruggieri

Insolation: Jonathan Levine, Peter Huybers

Padding: Nicolas R. Thibault

Spectral Moments: Matthias Sinnesael

TimeOpt/eTimeOpt: Steve Meyers

Wavelet: Christopher Torrence, Gilbert Compo



Feng Cheng, Anne-Christine Da Silva, Hwei Duan, Yanan Fang, Marco Franceschi, Daniel R. Franco, Xiaoni Hu, Dorothée Husson, Arsenio Muñoz Jiménez, Dongyang Liu, James Ogg, Paul Olsen, J. Fred Read, Chen Shen, Chuanyue Wang, Mathieu Martinez, Meng Wang, Xu Yao, Qiyang Zhang, Yang (Wendy) Zhang, Christian Zeeden



Make it a better software for your own research.
ANY feedback is highly appreciated!!!

Email: mul450@psu.edu; limingsonglms@gmail.com
<https://github.com/mingsongli/acycle/issues>

Please cite:

Li, M., Hinnov, L., Kump, L. (2019) *Acycle*: Time-series analysis software for paleoclimate research and education. *Computers & Geosciences* 127, 12-22.

and [other relevant publications](#).

Thank you!