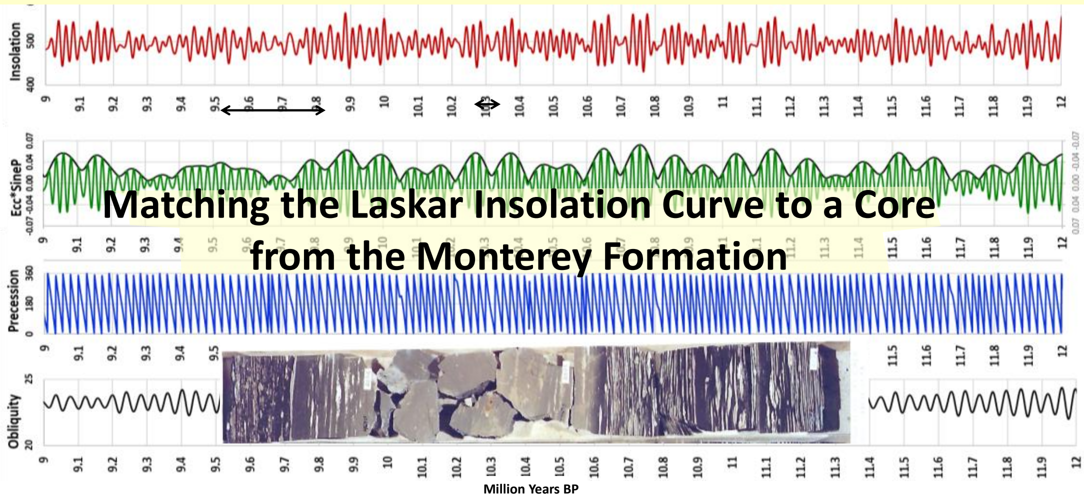
SEPM–ISGC Research Conference

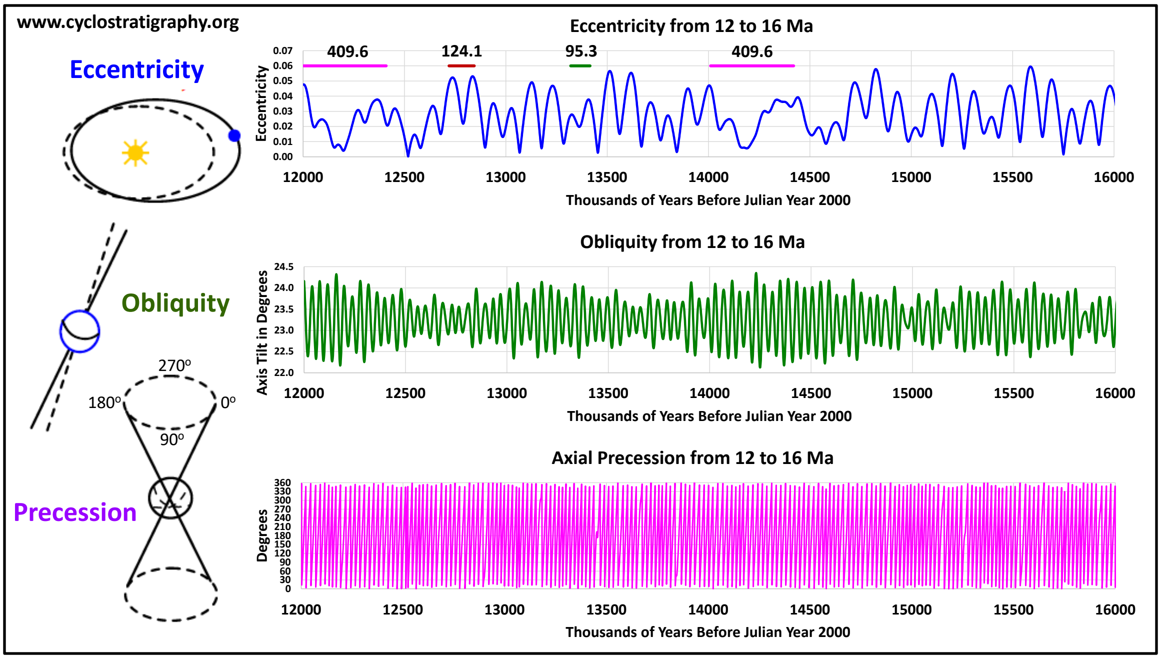
Matching the Laskar Insolation Curve to a Core from the Monterey Formation



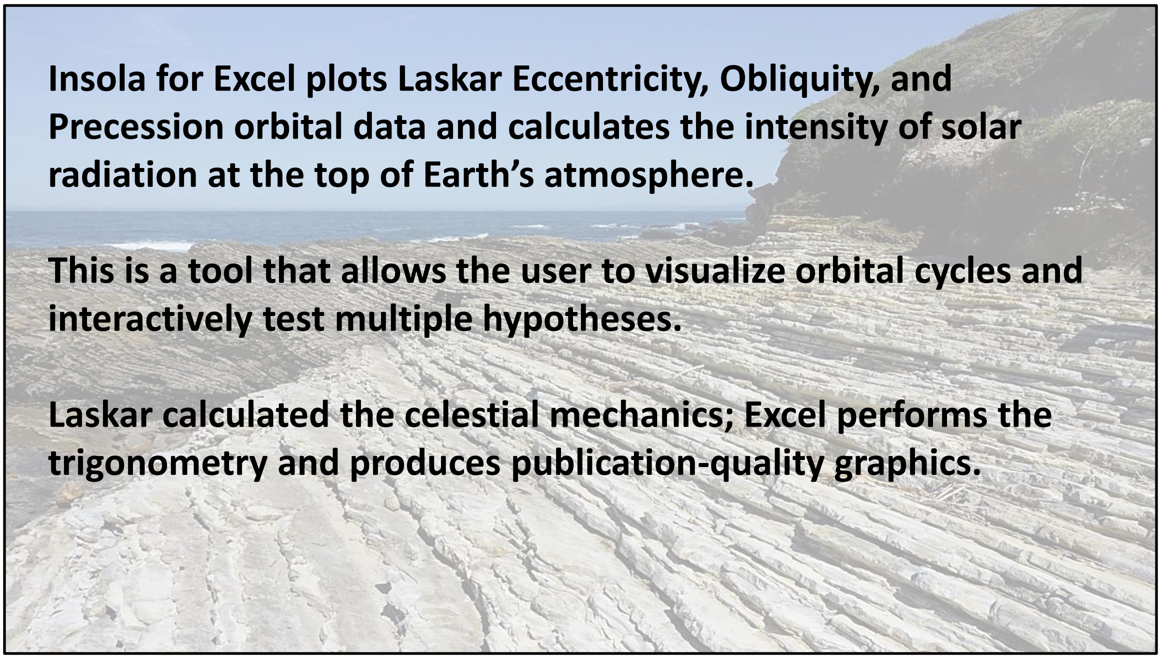
by John Dunham: jdunham76@gmail.com

This presentation introduces Insola for Excel, a spreadsheet that displays earth's orbital cycles and calculates intensity of solar radiation at one-thousand-year intervals from 0 to 250 million years BP.

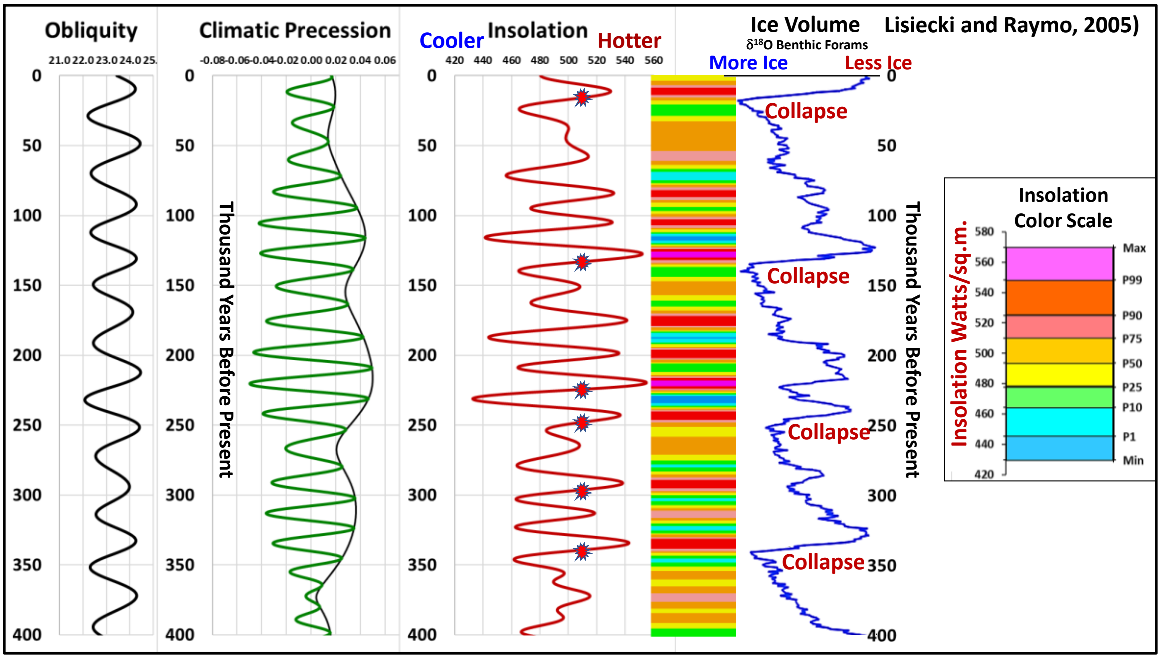
The Monterey Formation is famous for its rhythmic cyclicity of biogenic and detrital sediment. Each cycle reflects variations in plankton rainout and detrital influx.



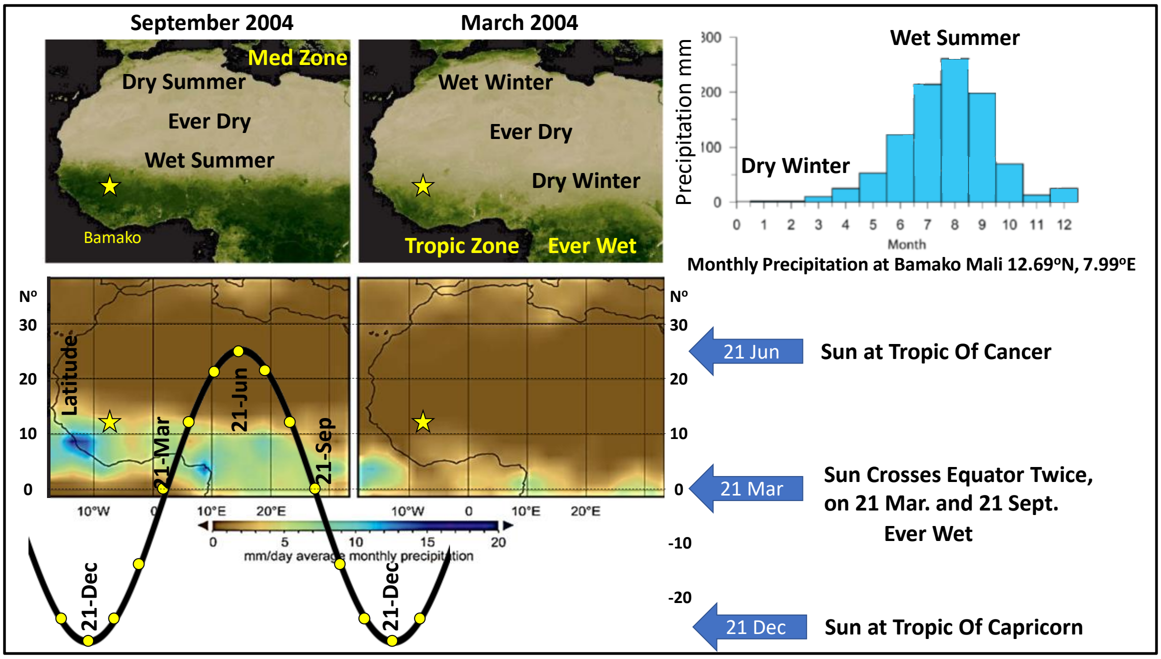
Jacques Laskar and his team from the French Center for Astronomy are the modern successors to Milankovich. They modeled Earth's orbital parameters for the past 250 million years and wrote program Insola, which calculates the intensity of the sun's energy at the top of Earth's atmosphere.



Insola for Excel plots Laskar's orbital solutions and calculates variations in solar radiation. Excel's widespread availability makes Insola accessible to a broad user base without requiring new programming skills.



Here's an example of what you can do with this tool. Professor Lis-ecki of UC Santa Barbara showed that insolation peaks trigger climatic tipping points that resulted in repeated collapse and regrowth of Pleistocene continental ice sheets.

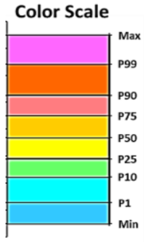


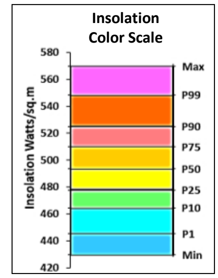
This example is for those interested in wet-dry cycles. The intertropical convergence zone of high rainfall migrates north and south over a year, following the straight-up position of the sun. The sun is straight up at the equator on March 21 and September 21, creating a double-rainy season that produces an Ever Wet Zone at the equator. But at the Tropic of Cancer at 23.5 degrees north, the sun is overhead only on the Summer Solstice, resulting in rainy summers and dry winters. Long-term orbital changes in Obliquity force the Tropics of Cancer and Capricorn to migrate north and south, producing changes in the length and intensity of wet-dry cycles.

Laskar Program Insola written as an Excel Spreadsheet -

Kyr BP	Ecc	Obliq	Preces	AU Sun	Insolation
0	0.0167	23.44	167.1	1.0163	480.39
-1	0.0172	23.57	184.2	1.0171	481.73
-2	0.0175	23.69	201.2	1.0163	484.63
-3	0.0178	23.81	218.2	1.0139	488.90
-4	0.0182	23.92	235.0	1.0102	494.32
-5	0.0185	24.02	251.9	1.0054	500.74
-6	0.0187	24.10	268.6	1.0001	507.50
-7	0.0189	24.17	285.2	0.9947	514.15
-8	0.0192	24.21	301.9	0.9896	520.25
-9	0.0193	24.23	318.4	0.9854	525.12
-10	0.0194	24.23	334.7	0.9824	528.34
-11	0.0196	24.21	351.3	0.9806	529.78
-12	0.0196	24.16	7.6	0.9806	528.98
-13	0.0197	24.09	24.1	0.9820	526.15
-14	0.0197	24.00	40.3	0.9848	521.46
-15	0.0196	23.89	56.7	0.9890	515.14
-16	0.0196	23.76	73.1	0.9940	507.70
-17	0.0195	23.61	89.3	0.9994	499.73
-18	0.0193	23.46	105.7	1.0049	491.65
-19	0.0192	23.30	122.1	1.0099	484.03
-20	0.0190	23.13	138.3	1.0140	477.42
-21	0.0188	22.96	154.8	1.0170	471.99
-22	0.0186	22.81	171.1	1.0184	468.14
-23	0.0183	22.66	187.5	1.0182	465.96
-24	0.0181	22.52	203.8	1.0165	465.37
-25	0.0179	22.41	220.1	1.0135	466.28

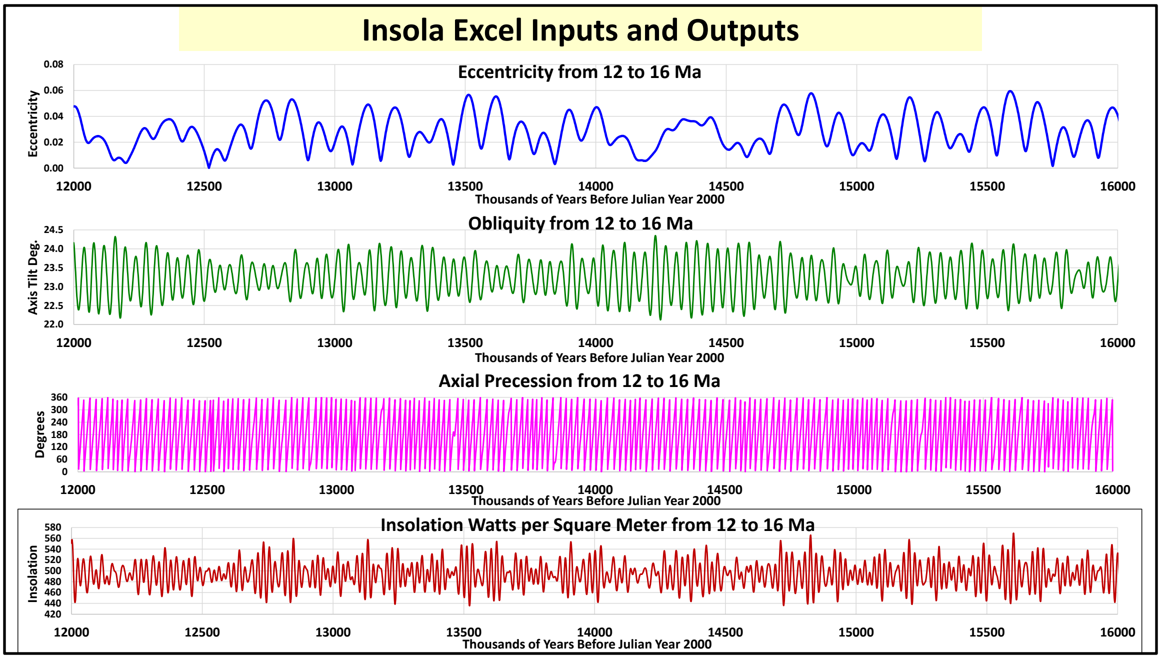
Parameter Color Scale



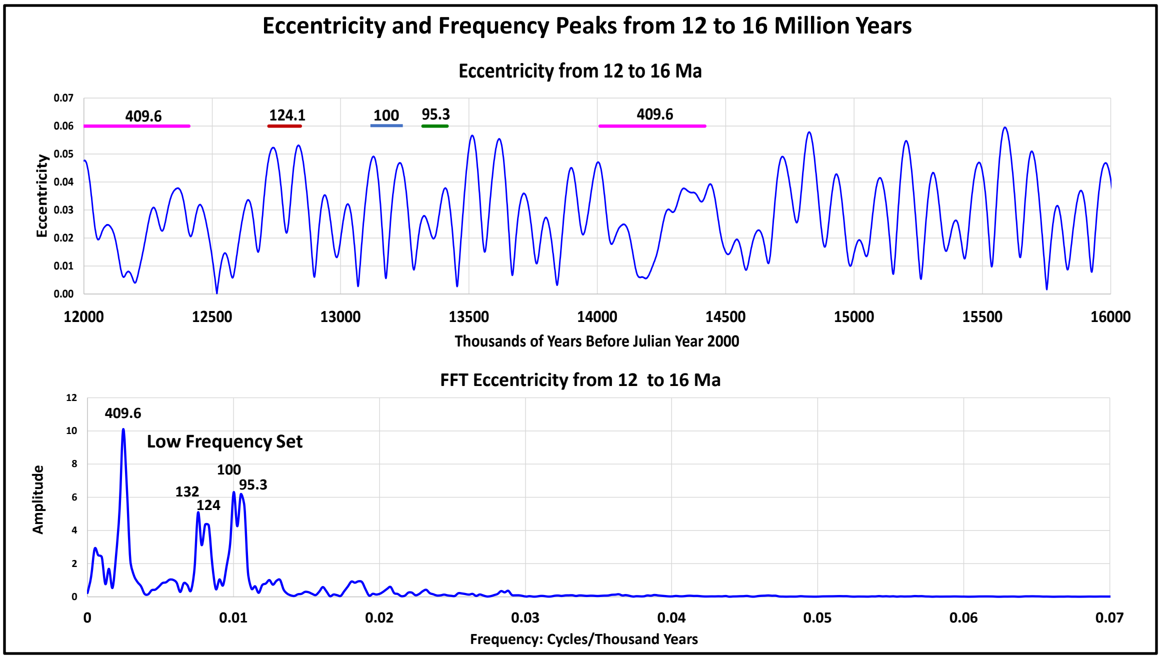


Positive and Negative Interference of Cycles -

I reformatted Laskar's Program Insola as an Excel spreadsheet. Hot colors in orbital-parameter cells show conditions conducive to high insolation. The effects of each interfere with one another both constructively and destructively.

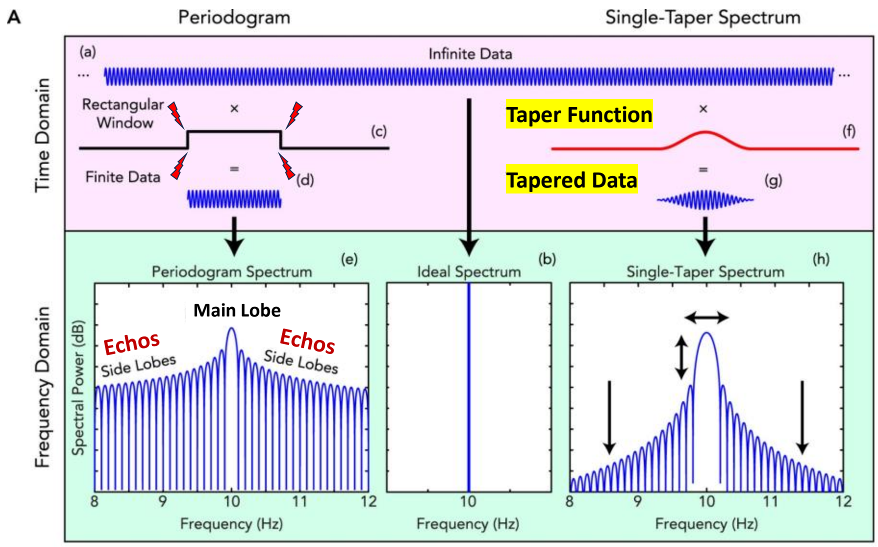


These three orbital parameters determine the amount of solar radiation reaching the earth, which ranges from 425 to 575 Watts per Square Meter. The effects of each orbital cycle are visible as frequency changes within the insolation curve.

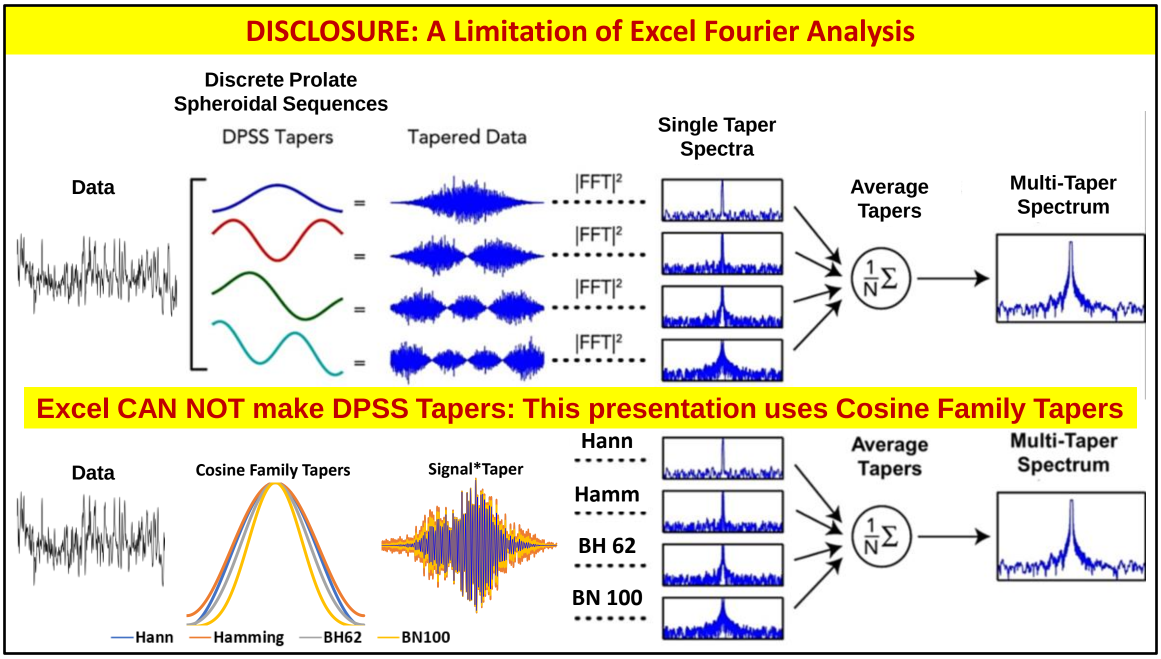


Fourier analysis of eccentricity cycles reveals a set of low-frequency peaks with a long eccentricity cycle of about 400 thousand years and short eccentricity cycles ranging from 135 to 95 thousand years. The download package for this talk includes an Excel Fourier Transform spreadsheet that you can use on your own data.

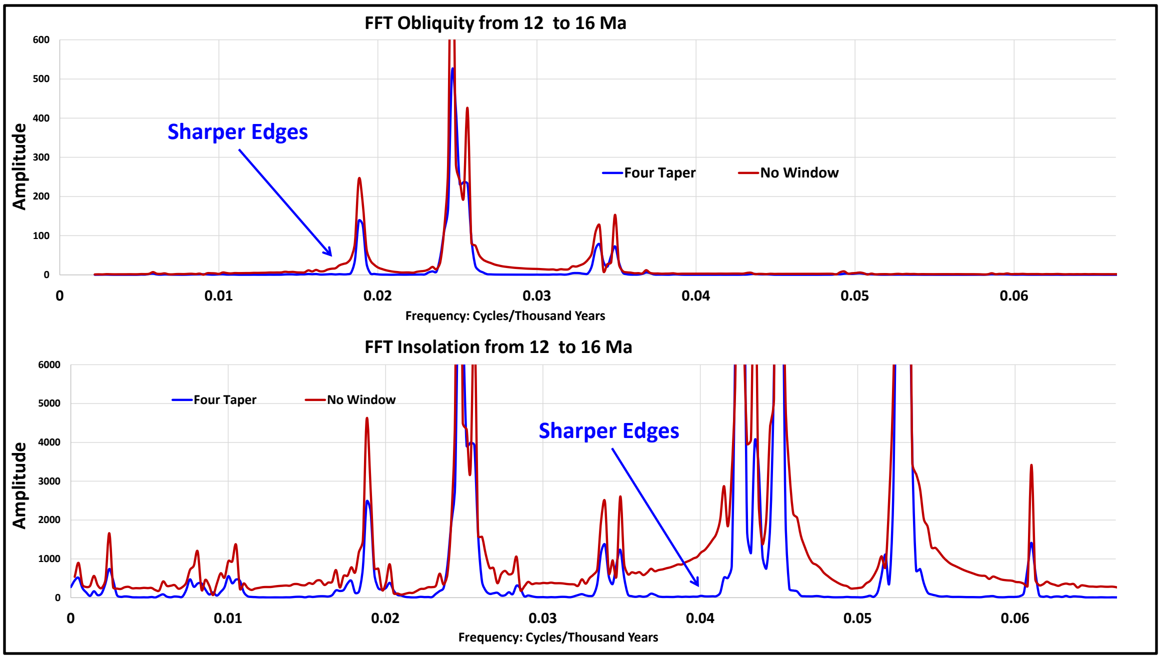
DISCLOSURE: A Limitation of Excel Fourier Analysis



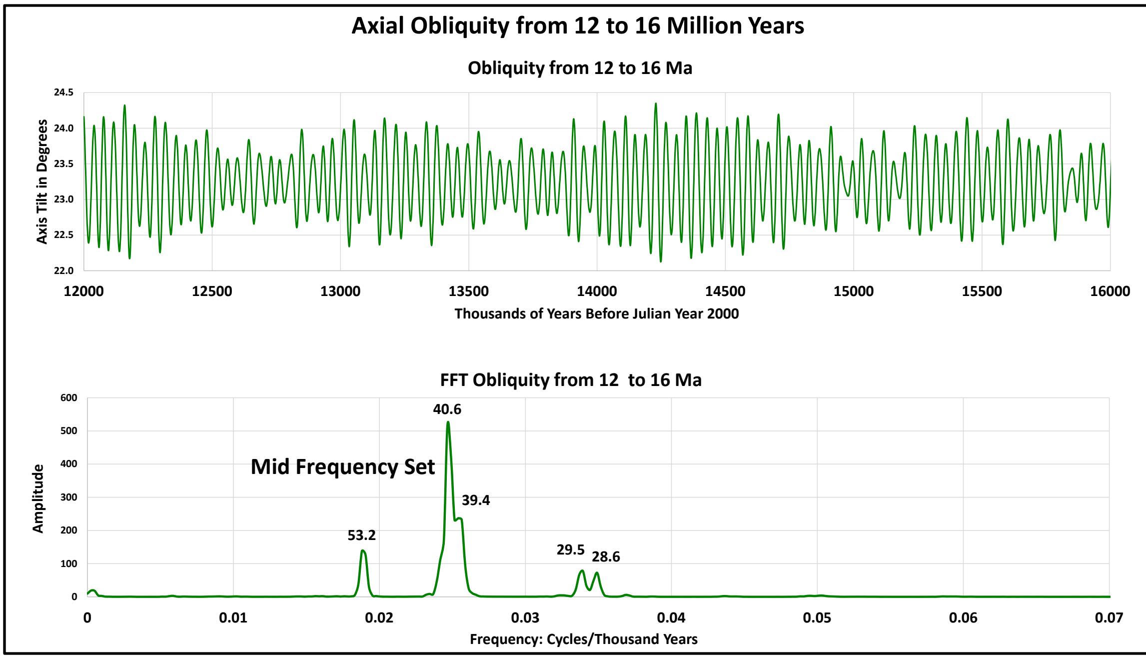
Fourier Analysis identifies the individual frequencies within a complex wavetrain like the eccentricity curve. However, the method assumes an infinite data stream, while in reality, the eccentricity curve starts and stops at set times. The sharp edges of the signal produce “echos” that show up as side lobes on either side of a central peak that records the actual frequency. Side lobes are NOT actual frequencies. Taper functions smooth the edges of the signal, which dampens sidelobes and reduces the appearance of false “ghost” frequencies.



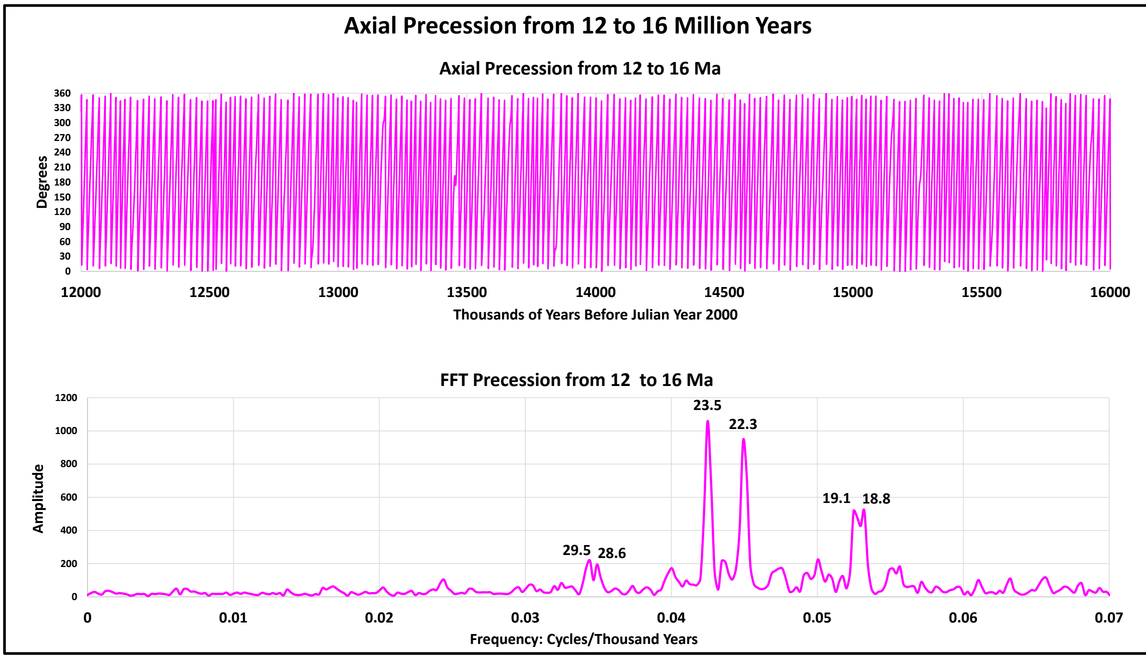
The Multi-Taper method of Fourier Analysis uses the average of several different tapers to produce a frequency spectrum. Standard Multi-Taper Analysis uses Discrete Prolate Spheroidal Sequence Tapers for maximum control of sidelobes. However, Excel can't make DPSS tapers, so Excel uses Cosine Family Tapers to produce a Multi-Taper Spectrum.



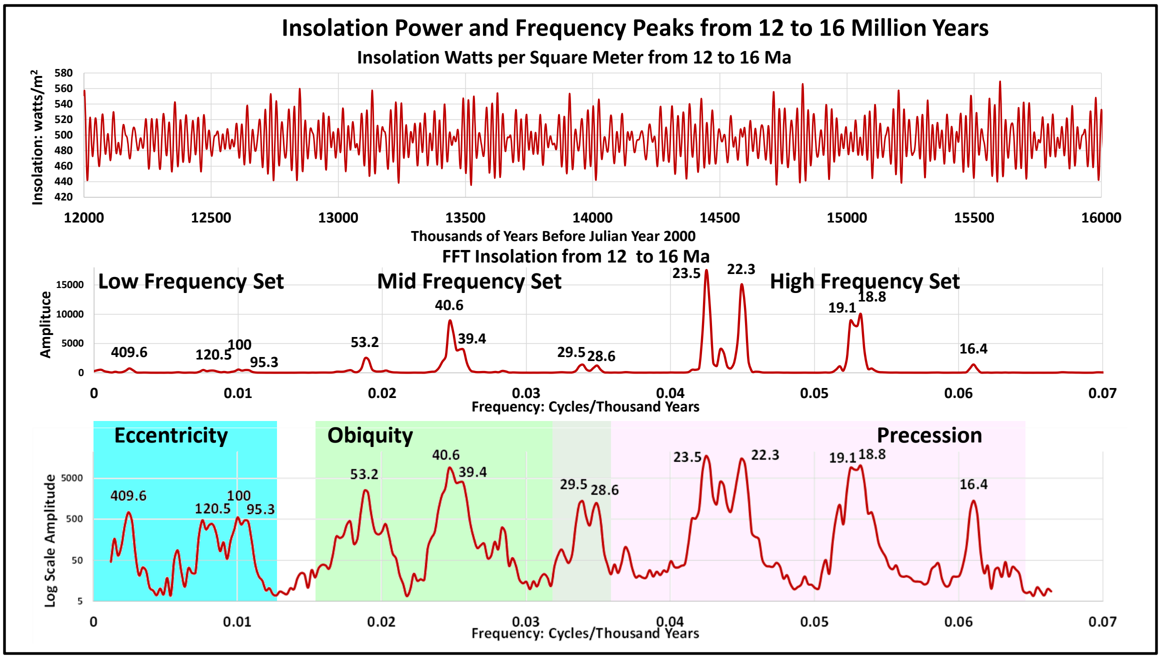
The sharper edges on the multi-taper window show the effectiveness of these Cosine-Family Tapers.



Taper windows are effective in controlling side lobes, as demonstrated by this example. Obliquity accounts for the mid-frequency peaks in the insolation curve, with a characteristic set centered on 40 thousand years.



Precession accounts for the high-frequency peaks on the insolation curve with characteristic periods less than 30 thousand years.

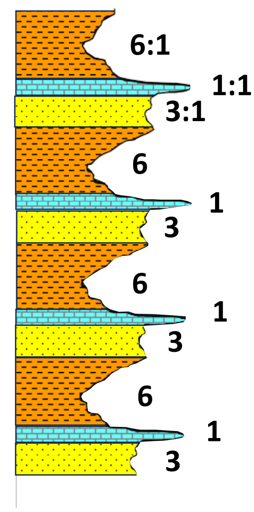


The top plot shows solar radiation in the Middle Miocene. You can make your own plots for any interval down 250 million years. The middle plot is a Fourier Transform that separates the insolation wave-train into different frequencies. Your eye immediately focuses on high-frequency waves with periods of just a few thousand years, but a further look reveals longer waves of several tens to hundreds of thousands of years. The bottom plot uses a log scale to highlight the low-frequency components. The periods of the different waves range from over 400,000 down to 16 thousand years. The component frequencies of the insolation curve correspond to eccentricity, obliquity, and precession cycles.

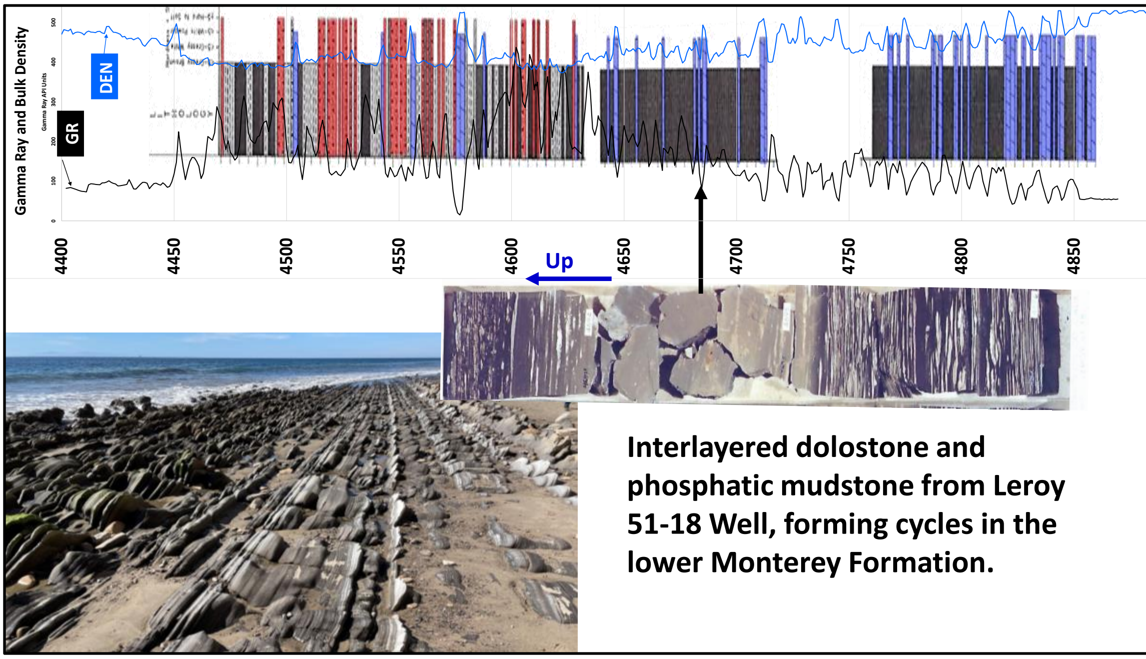
Time Ratios Are Proportional to Thickness Ratios

Parameter	Cycle (kyr)	Interval Ratio	Cutoffs
Long Eccentricity	409.6	25.0	Ratio > 20
Short Eccentricity	124.1	7.6	Ratio 8 to 5
Short Eccentricity	105.0	6.4	Ratio 8 to 5
Short Eccentricity	97.5	5.9	Ratio 8 to 5
Short Eccentricity	95.3	5.8	Ratio 8 to 5
Obliquity	53.2	3.2	Ratio 3 to 2
Obliquity	40.6	2.5	Ratio 3 to 2
Obliquity	39.0	2.4	Ratio 3 to 2
Precession	23.5	1.4	Ratio < 2
Precession	22.3	1.4	Ratio < 2
Precession	19.9	1.2	Ratio < 2
Precession	19.0	1.2	Ratio < 2
Precession	18.1	1.1	Ratio < 2
Precession	16.4	1.0	Ratio < 2

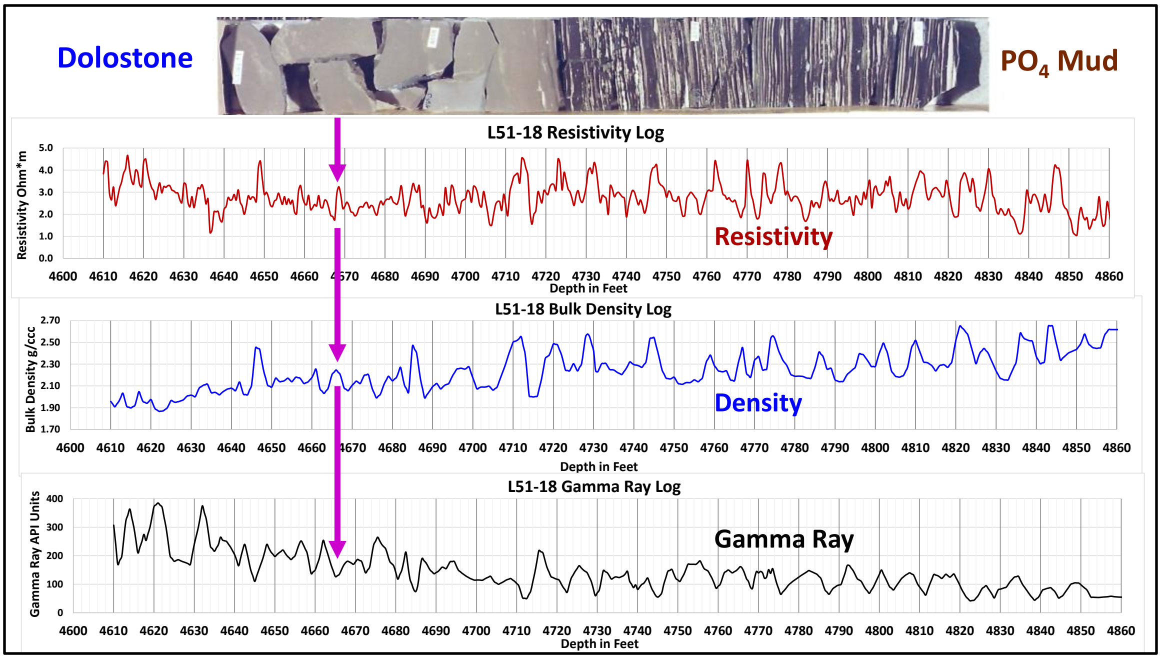
Thickness Ratio



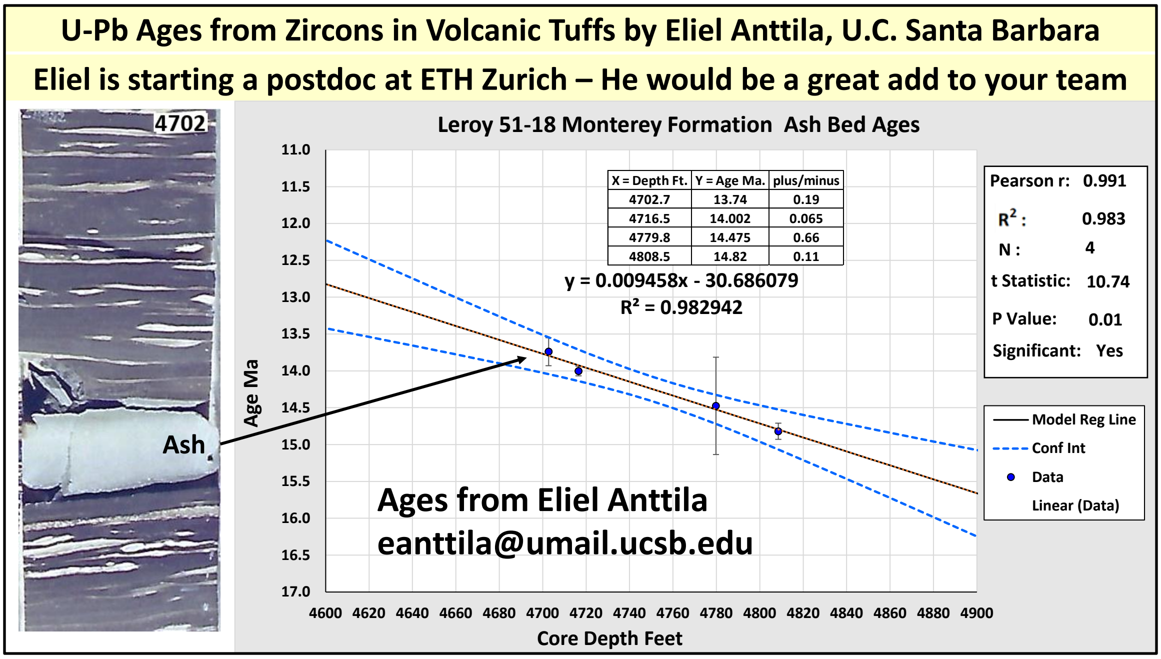
You can discern the different orbital signals in well-logs, cores, or outcrops by using bed-thickness ratios. Measure the thinnest repeating bed in a cyclic sequence, then divide all other beds by that thickness. The Thickness Ratio indicates the likely parameter producing the cycle. Precession accounts for the thinnest layers; obliquity ratio ranges from 2 to 3, while Eccentricity ratios are greater than 5. Then, use the Insola spreadsheet to look at orbital cycles and insolation curves for the approximate time interval of your section.



I have a core and well logs from the Monterey Formation on the central coast of California. The Monterey is well-known for cyclic repeats of dolostone and phosphatic mudstone layers. Fourier transforms were run on the logs.

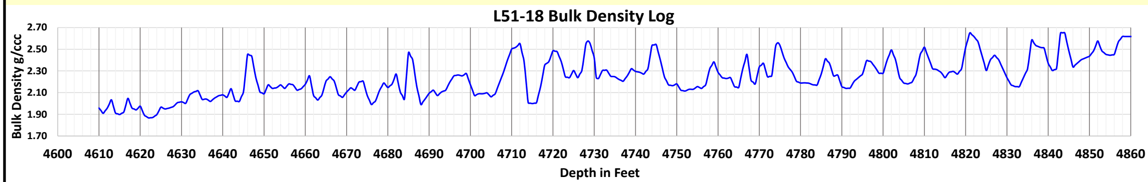


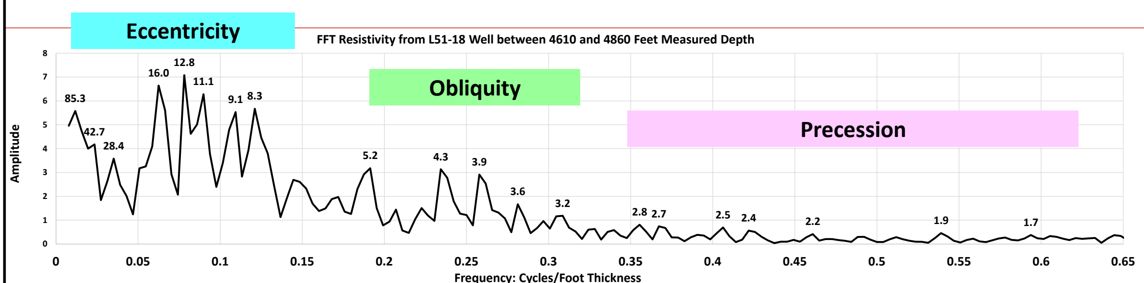
The core was matched to gamma ray, density, and resistivity logs. Dolostone has low gamma, high density, and high resistivity. Phosphatic claystone has opposite properties. Fourier analysis can identify cycle frequencies within log data. Many studies focus on gamma-ray logs, but if you look closely at this plot, you'll see that the density and resistivity logs have sharper, better-defined bed boundaries. Look at your data and choose the logs with the best resolution. Depth units of the original data are in feet. I prefer using original units to avoid roundoff errors. Final outputs in feet can then be converted to centimeters and meters.



Age dates from zircons in volcanic tuffs set a well-defined linear trend with little scatter from a best-fit line. Depth to age fit is 9.458 thousand years per foot of core depth. Note that this is NOT a sedimentation rate. Compaction reduced the claystone layers to at least half their original thickness. An uncompacted sedimentation rate would be closer to 7 cm per thousand years. Ph.D. graduate Eliel Anttila of UC Santa Barbara is the first to use laser ablation-inductively coupled plasma mass spectrometry to obtain high-resolution ages from Monterey tuffs. Eliel begins a postdoc at ETH Zurich this fall. He would be an excellent addition to any research institution.

Fourier Transform of Density Log Shows Cycle-Thickness Peaks in Feet

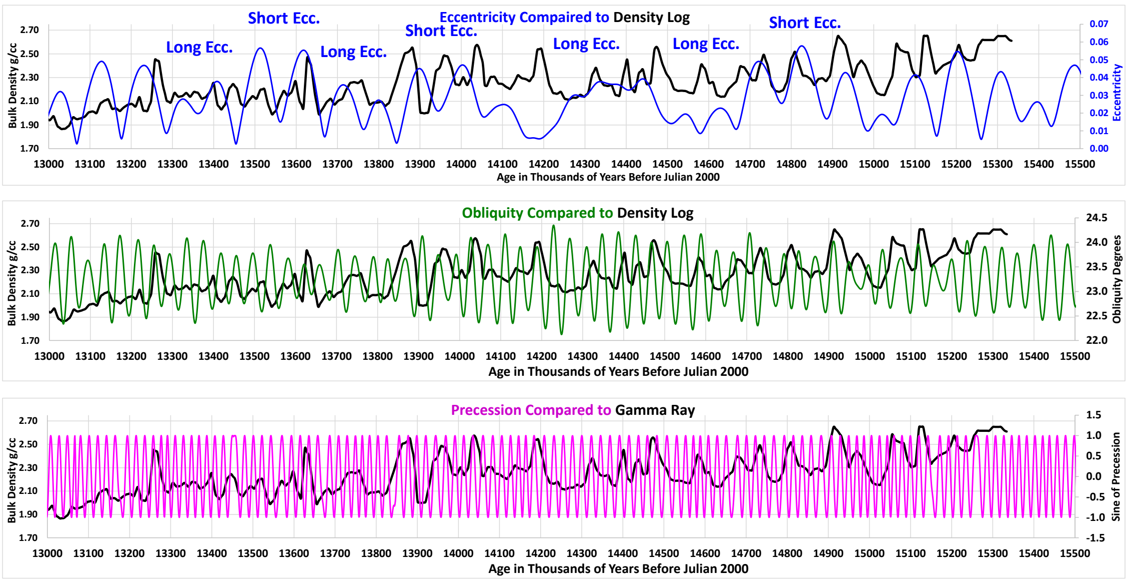




Thickness Ft.	85.30	42.70	28.40	16.00	12.80	11.14	9.14	8.26	5.20	4.34	3.94	3.60	3.20	2.80	2.70	2.50	2.40	2.20	1.88	1.70
Ratio	50.18	25.12	16.71	9.41	7.53	6.55	5.38	4.86	3.06	2.55	2.32	2.12	1.88	1.65	1.59	1.47	1.41	1.29	1.11	1.00
Period Kyrs	806.77	404	269	151	121.1	105.4	86.4	78.1	49.2	41.0	37.3	34.0	30.3	26.5	25.5	23.6	22.7	20.8	17.8	16.1
	Long Ecc.				Short Ecc.				Obliquity					Precession						

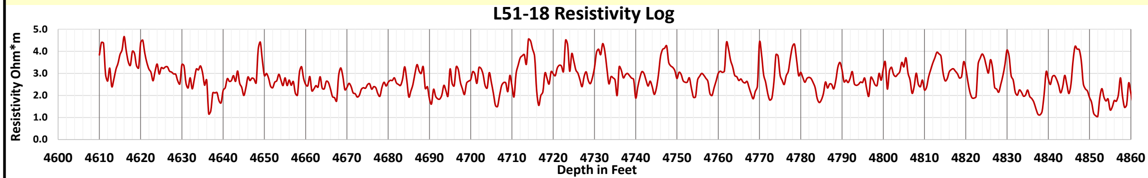
Fourier analysis of the density curve shows peaks with ratios and ages characteristic of eccentricity, obliquity, and precession cycles. However, the precession peaks are muted.

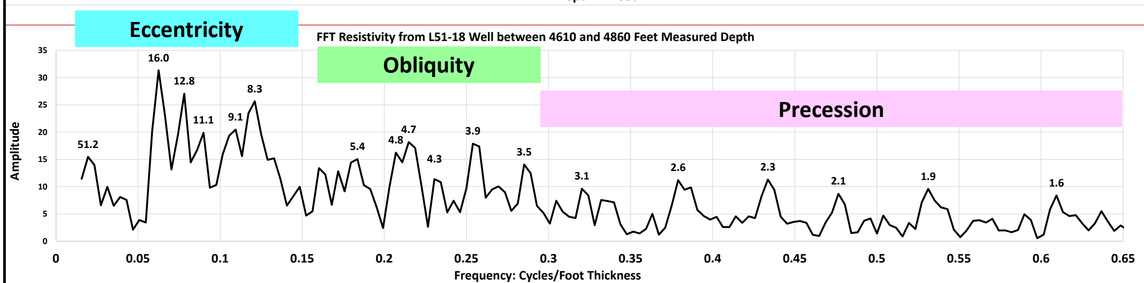
Density Log Depth Converted to Age and Compared to Orbital Parameters



Density responds to the long eccentricity cycle. The frequency of density peaks seems comparable to obliquity frequency. However, this curve does not have sufficient resolution to define precession cycles.

Fourier Transform of Resistivity Log Shows Cycle-Thickness Peaks in Feet

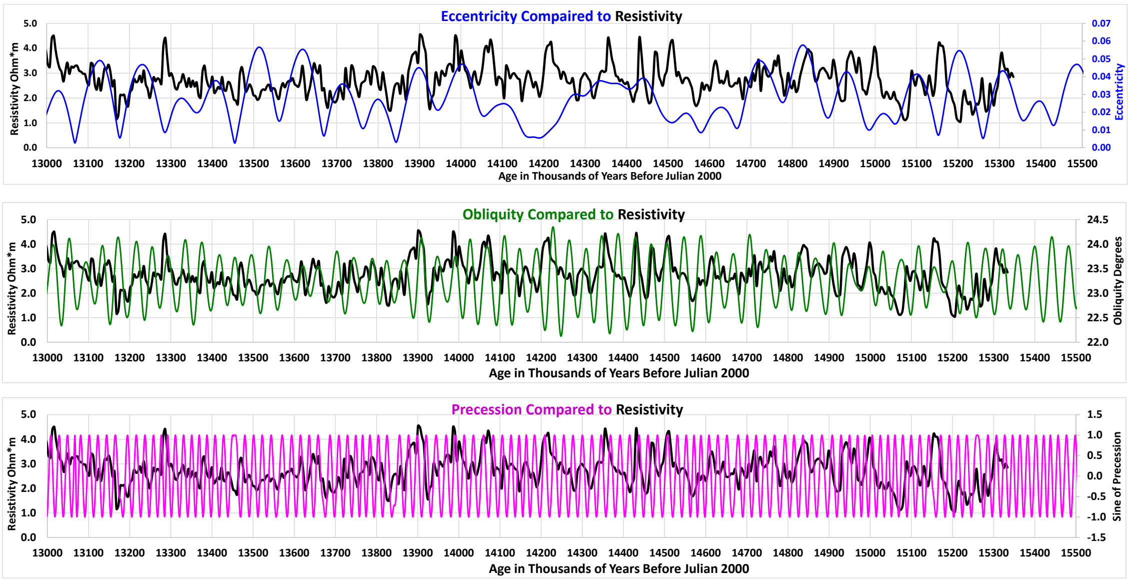




Thickness Ft.	51.20	16.00	12.80	11.14	9.14	8.26	5.44	4.84	4.66	4.34	3.94	3.50	3.12	2.64	2.31	2.10	1.88	1.64
Ratio	31.22	9.76	7.80	6.79	5.57	5.04	3.32	2.95	2.84	2.65	2.40	2.13	1.90	1.61	1.41	1.28	1.15	1.00
Period Kyrs	484	151	121	105	86.4	78.1	51.5	45.8	44.1	41.0	37.3	33.1	29.5	25.0	21.8	19.9	17.8	15.5
	Long Ecc.		Short Ecc.				Obliquity						Precession					

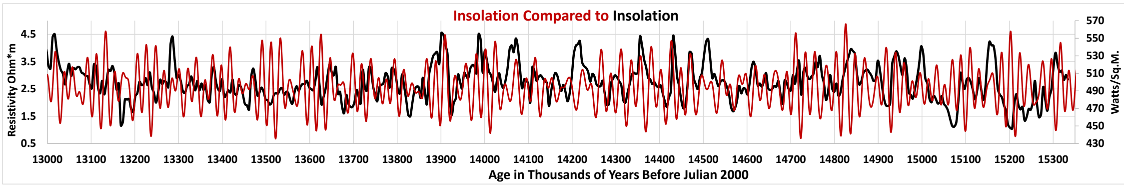
Fourier analysis of the resistivity curve shows peaks with ratios and ages characteristic of eccentricity, obliquity, and precession cycles. However, the precession peaks are more prominent here due to the ability of the resistivity log to resolve thinner beds.

Resistivity Log Depth Converted to Age and Compared to Orbital Parameters



Eccentricity Cycles are prominent, obliquity matches well to dolostone beds, and the Resistivity curve does have a high enough resolution to show high-frequency precession cycles.

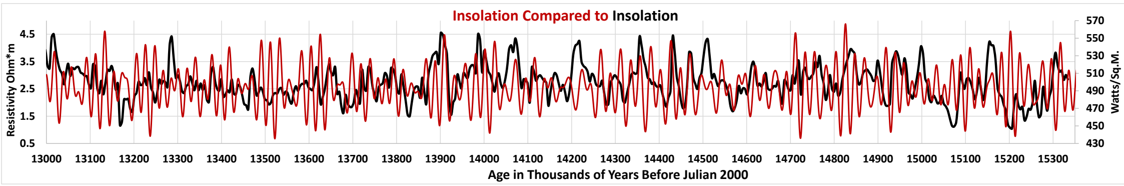
High Resistivity Spikes: Dolostones with Low Gamma Ray and High Density due to Low Porosity and Low Clay Content.



Cores show that resistivity peaks are dolostones with high resistivity, low gamma, and high density due to low porosity and clay content.

High Resistivity Spikes: Dolostones with Low Gamma Ray and High Density due to Low Porosity and Low Clay Content.

Low Resistivity Spikes: Clay Mudstone with High Gamma Ray and Low Density, due to High Porosity, High Clay Content, and High TOC Content.

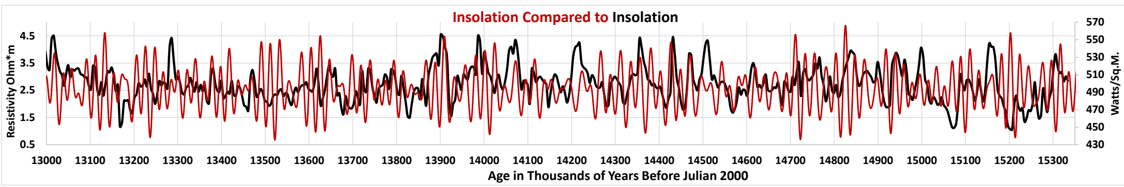


Low resistivity spikes are clay mudstones with high porosity, clay content, and total organic carbon content, resulting in high gamma, low density, and low resistivity.

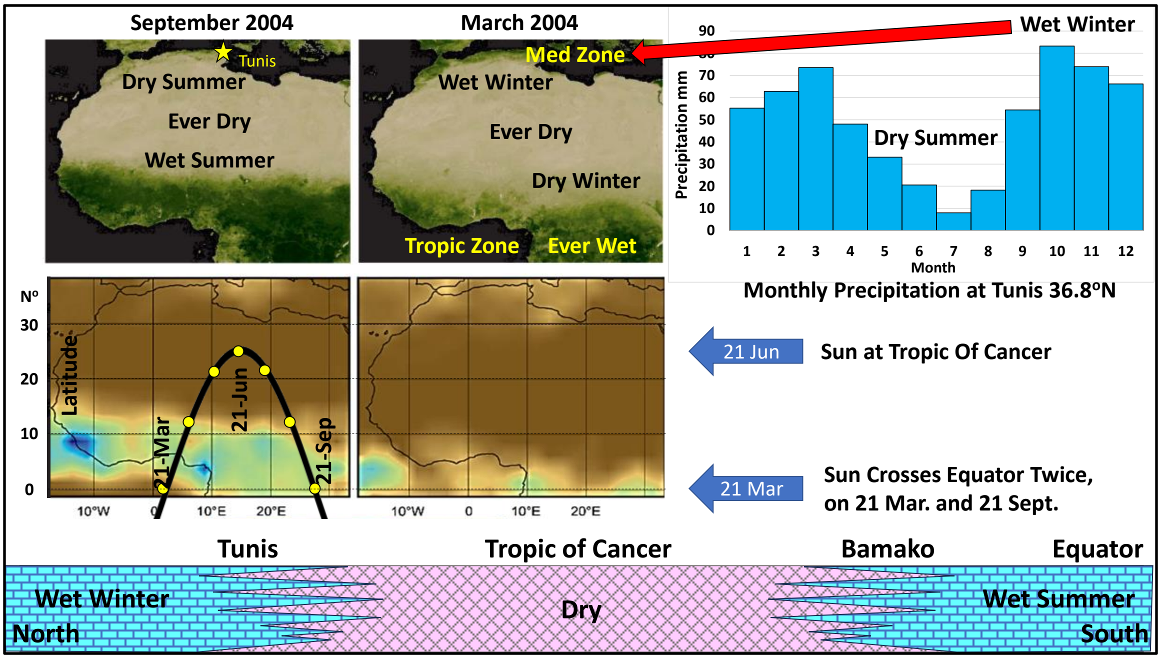
High Resistivity Spikes: Dolostones with Low Gamma Ray and High Density due to Low Porosity and Low Clay Content.

Low Resistivity Spikes: Clay Mudstone with High Gamma Ray and Low Density, due to High Porosity, High Clay Content, and High TOC Content.

Dolostone (calcareous nannoplankton) favored during periods of high insolation = Warm Dry conditions at approximate latitude of basin during the Miocene.



Dolostone peaks generally align with insolation peaks. Interpretation is that sediment was enriched in calcareous nannoplankton and depleted in terrigenous clay during periods of high insolation. In the Miocene, this basin was in a Mediterranean climate zone north of an ever-dry zone. High insolation expanded the ever-dry zone to the north and produced warm and dry conditions.



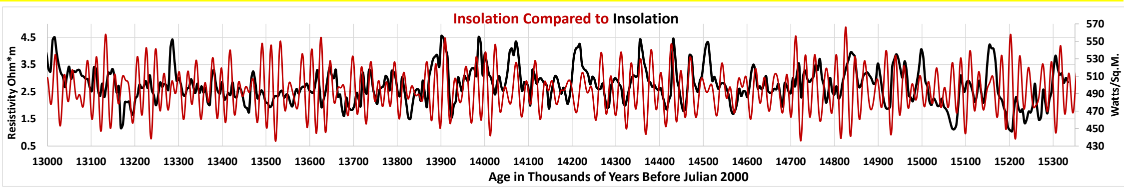
A quick review of the Mediterranean zone north of the ever-dry zone, with wet winters driven by cold northern fronts and hot, dry summers driven by seasonal expansion of the dry zone as the sun moves north toward the solstice.

High Resistivity Spikes: Dolostones with Low Gamma Ray and High Density due to Low Porosity and Low Clay Content.

Low Resistivity Spikes: Clay Mudstone with High Gamma Ray and Low Density, due to High Porosity, High Clay Content, and High TOC Content.

Dolostone (calcareous nannoplankton) favored during periods of high insolation = Warm Dry conditions at approximate latitude of basin during the Miocene.

Organic mudstone favored during cooler periods of strong wind-driven coastal upwelling and higher winter precipitation and terrigenous runoff.



Low insolation leads to cooler conditions of strong wind-driven coastal upwelling, causing higher precipitation and runoff of terrigenous detritus.

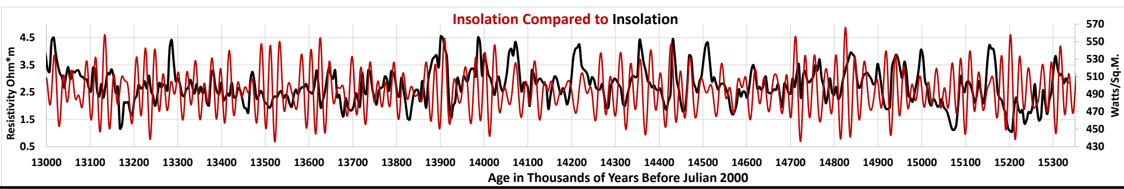
High Resistivity Spikes: Dolostones with Low Gamma Ray and High Density due to Low Porosity and Low Clay Content.

Low Resistivity Spikes: Clay Mudstone with High Gamma Ray and Low Density, due to High Porosity, High Clay Content, and High TOC Content.

Dolostone (calcareous nannoplankton) favored during periods of high insolation = Warm Dry conditions at approximate latitude of basin during the Miocene.

Organic mudstone favored during cooler periods of strong wind-driven coastal upwelling and higher winter precipitation and terrigenous runoff.

Low Frequency Eccentricity Cycles correlate with thicker mudstone intervals.
Higher Frequency Obliquity Cycles produce hotter periods leading to dolostone peaks.
Very High-Frequency Precession peaks produce thin intervals of lower and higher detrital content between the Obliquity Cycles.



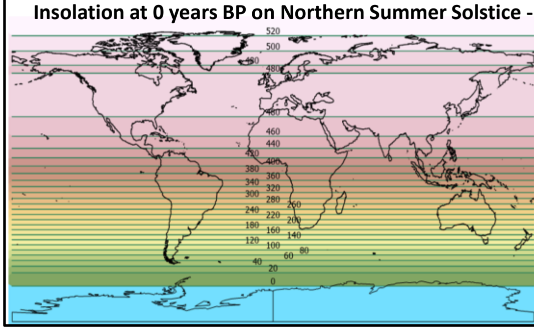
Low-frequency eccentricity Cycles correlate with thicker mudstone intervals. Higher-frequency obliquity Cycles produce hotter periods, leading to dolostone peaks. Very High-Frequency Precession peaks result in thin intervals of lower and higher detrital content between the Obliquity Cycles.

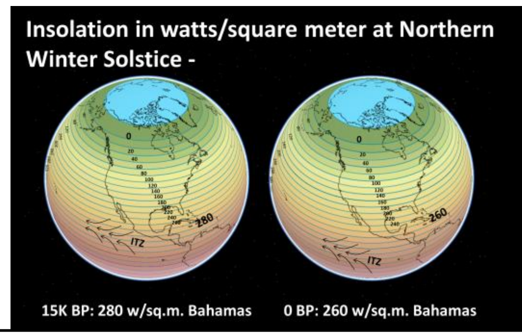
In Summary:

- Insola for Excel is based on the work of the Laskar Team. Default is set to 65° North Latitude on the Northern Summer Solstice, the standard used broadly in the literature. However, this workbook calculates Insolation for any Latitude on Earth between 0 and 250 Million Years BP.
- This multi-taper FFT differs from standard MTM because it does not use DPSS tapers. The R-program ASTROCHRON does use DPSS tapers. See more about ASTROCHRON at:

www.geology.wisc.edu/~smeyers/software.html

Insolation at 0 years BP on Northern Summer Solstice -





Insola default is set to 65 degrees North latitude on the summer solstice. However, the spreadsheet can be set for any latitude and will compute insolation for any interval from zero to 250 million years BP. The fast Fourier transform presented here uses multiple taper functions that effectively remove side lobes, but these are not DPSS tapers. The R-based program Astrochron does use DPSS tapers. You can find more information about Astrochron on Professor Stephen Meyers' website.

Questions?

Download Insola and FFT at:

https://Github.com/jdunham76/ISGC24

jdunham76@gmail.com

Copy this github address or use your phone to capture the qr code to download the data package. Send me a note with any questions. Are there any questions now?

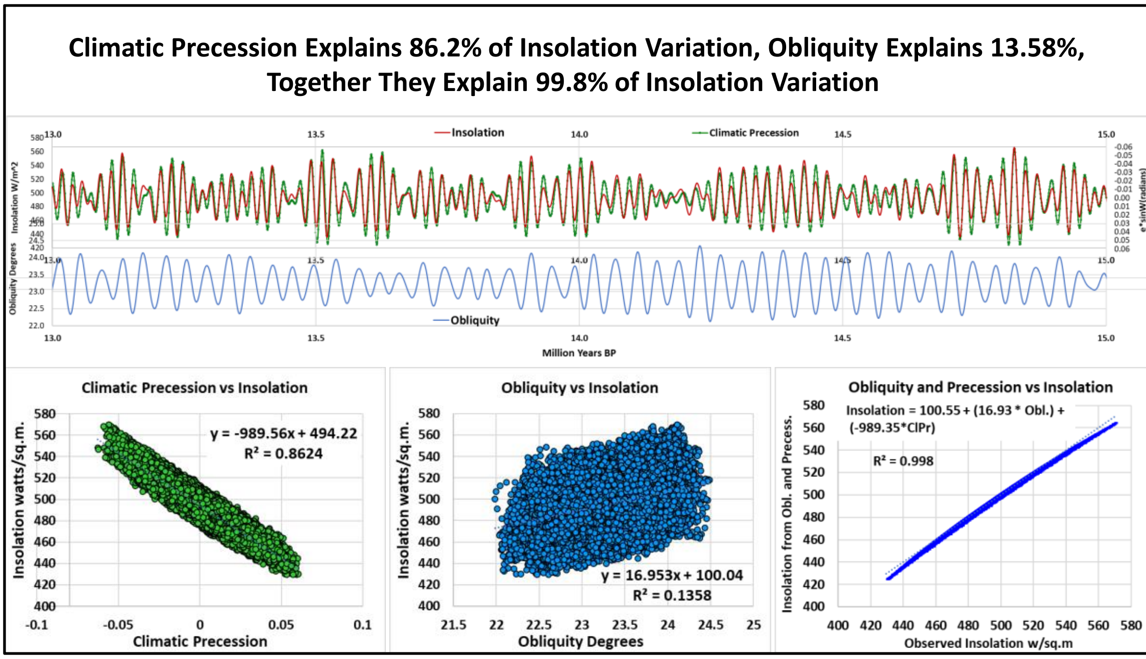
Backup

Does this Spreadsheet Really Work?

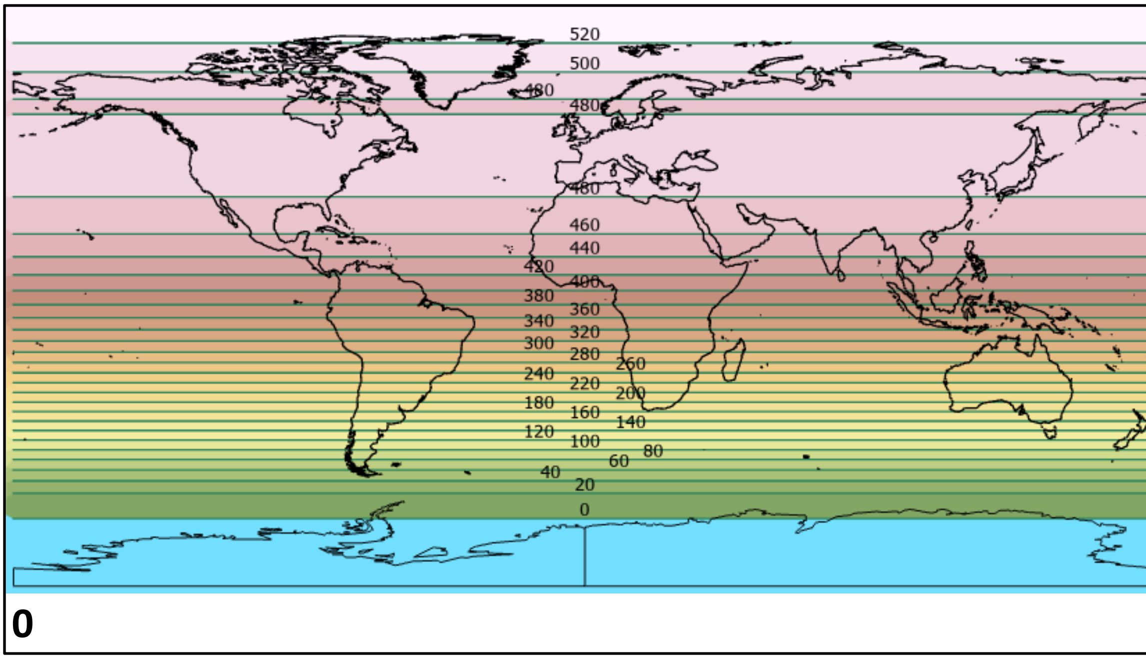
- **Laskar posted this file which reports Insolation values, but it is based on the 2004 eccentricity model: http://vo.imcce.fr/insola/earth/online/earth/online/index.php**
- **To check this yourself, use these inputs: Start -50 Myr, End 0 Myr, Mean Daily Insolation / True Longitude, Latitude 65, Longitude 90.**
- **Here is the comparison between Laskar online calculation and the calculation produced by this spreadsheet. The values are identical to 6 decimal places. It works.**

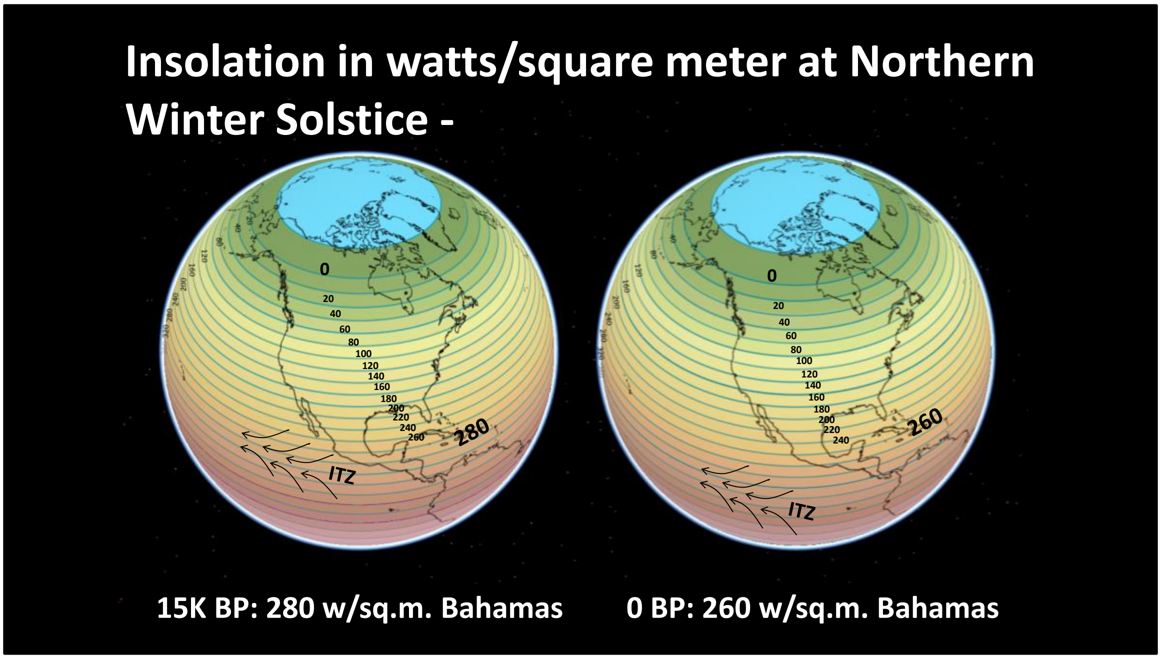
Spreadsheet Calculation Mean Daily Insolation W/m^2	Laskar Input: Lat_65, Long_90, Start -50 Myr, End 0 Myr, True Longitude, Output: Time from J2000 in Thousand Years	Laskar Insolation http://vo.imcce.fr/insola/earth/online/earth/online/index.php	Excel Spreadsheet minus Laskar website for same Lat - Long
480.394908	0	480.394908	0.000000
481.727752	-1	481.727752	0.000000
484.626343	-2	484.626343	0.000000
488.902144	-3	488.902144	0.000000
494.323301	-4	494.323301	0.000000
500.740129	-5	500.740129	0.000000
507.495856	-6	507.495856	0.000000
514.146390	-7	514.146390	0.000000
520.245668	-8	520.245668	0.000000
525.120938	-9	525.120938	0.000000
528.340437	-10	528.340437	0.000000
529.783585	-11	529.783585	0.000000

But does this spreadsheet really work? Laskar wrote Insola in Fortran. Other workers have used statistical languages Python and R to run Insola. This Excel spreadsheet was checked against output published online by Laskar, and the spreadsheet matches Laskar to 6 decimal places. It does work, and you don’t have to be a Python or R guru to use it.



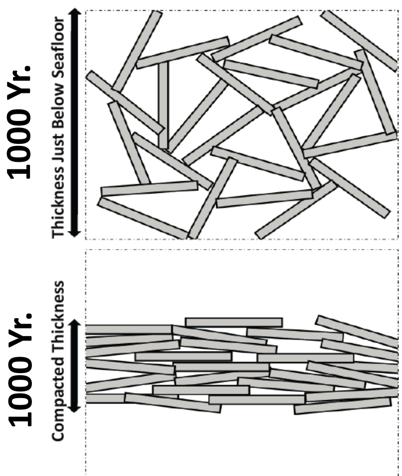
Is there a dominant orbital parameter that controls insolation? The answer is yes. The curve at the top shows a close correspondence between insolation and climatic precession which is eccentricity times the sine of precession angle. The match is better when reinforced by obliquity and worse when interfered by obliquity. Multiple regression shows that Climatic Precession explains 86% of insolation variation, with the balance explained by Obliquity. So, Climatic Precession is the dominant influence and is the place to start for curve matching.

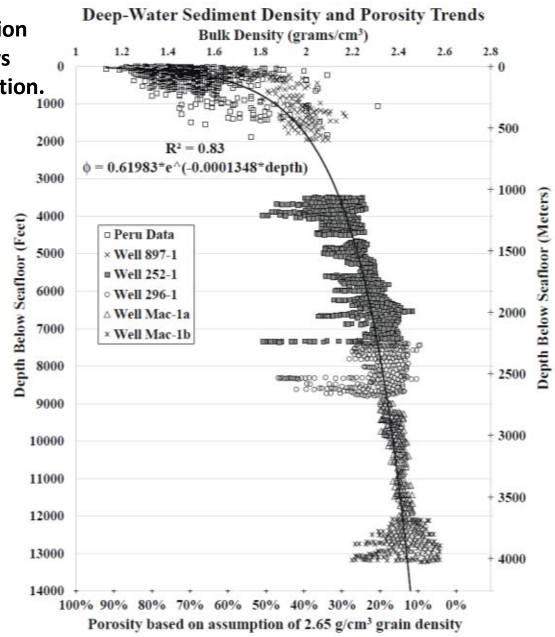

520
500
480
480
480
460
440
420
400
380
360
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
0

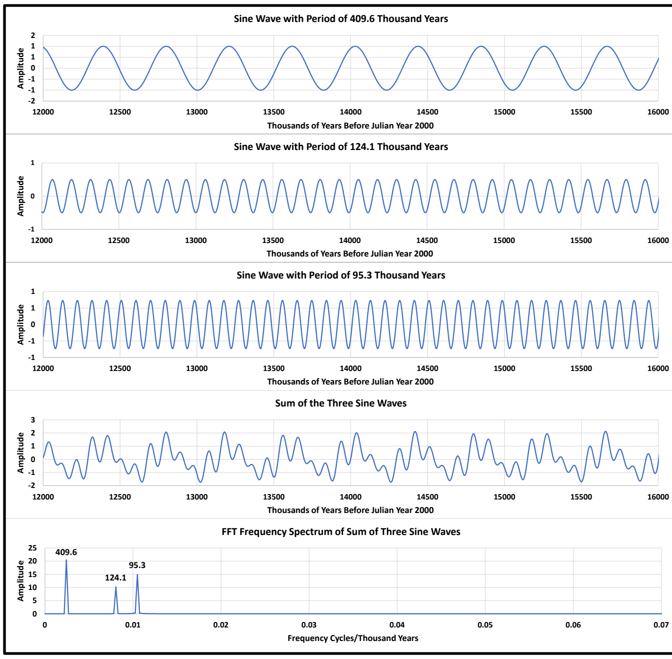


My interest in climate cycles comes from work on shallow water carbonates. Changes in intensity of solar radiation produce expansions and contractions of the intertropical convergence zone. These produce wet and dry cycles on carbonate platforms.

Age versus Depth does not equal Sedimentation Rate in Mudstones, due to compaction. Age vs Depth converts interval thickness to age duration.

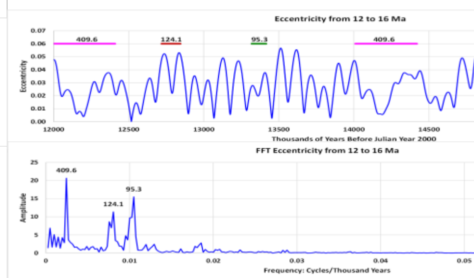


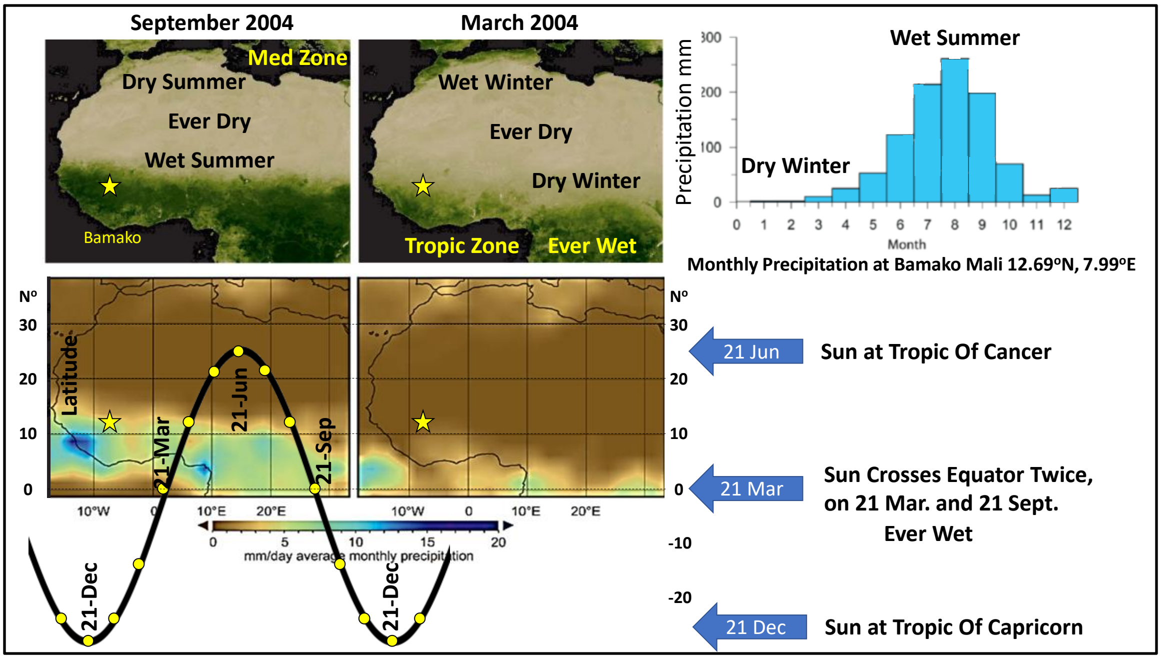




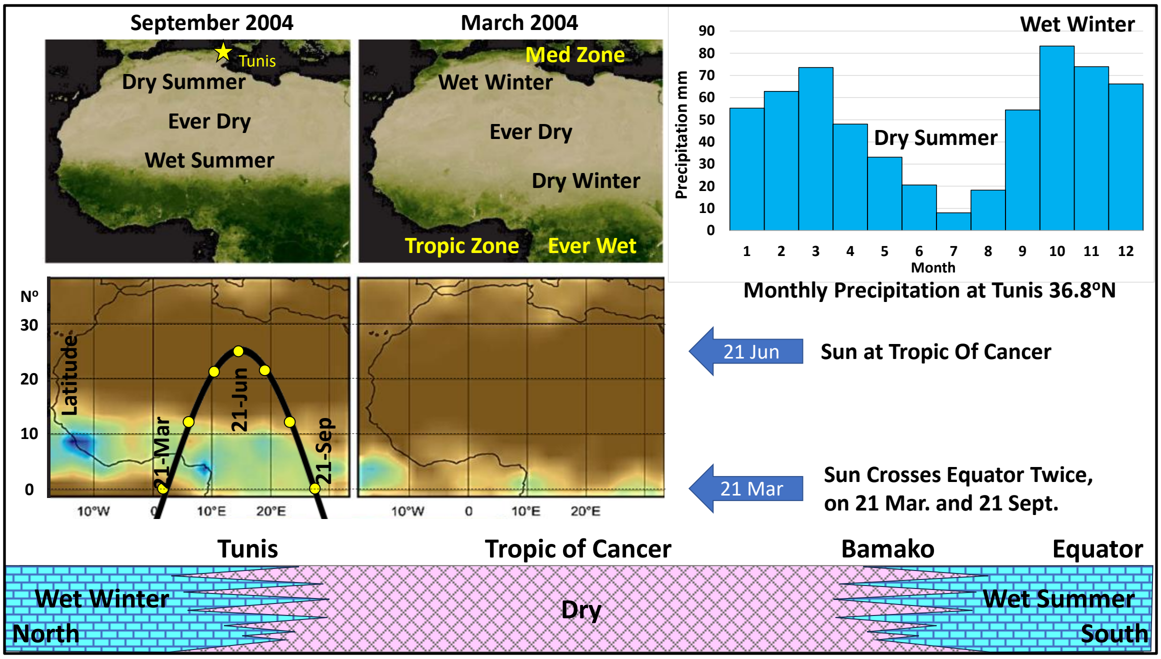
Reverse Fourier Transform:
Merging of 3 Sine Waves of Differing Period into a Single Wave Train.

Fourier Transform:
Extraction of Separate Sine Waves from a Single Wave Train.



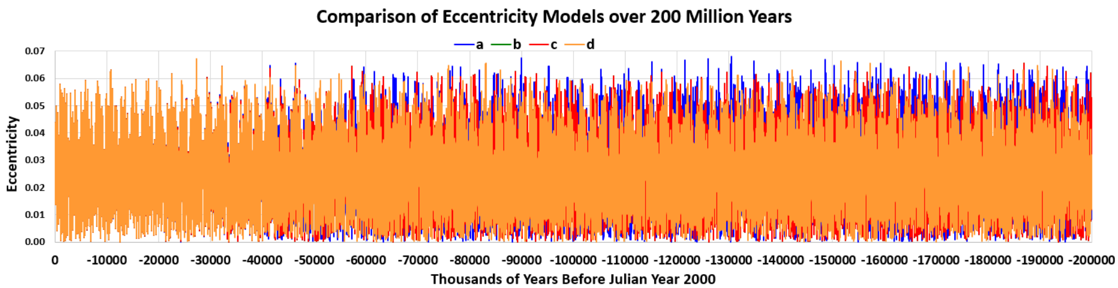


Those interested in wet-dry cycles can note this example which shows the relation between changes in yearly insolation and the position of the intertropical convergence zone of high rainfall. The intertropical convergence zone migrates north and south over the course of a year, following the straight-up position of the sun. Sun is straight up at the equator on March 21 and September 21. The sun is straight up at 23.5 North only at Summer Solstice. Long-term orbital changes would produce longer-term wet-dry cycles tuned to obliquity as the Tropics of Cancer and Capricorn migrate north and south, while coincident insolation changes driven by eccentricity and precession would expand and contract the width of the intertropical convergence rain zone. North of the tropics, polar fronts bring rain during the winter, while summers are hot and dry.



A quick review of the Mediterranean zone north of the ever-dry zone with wet winters driven by cold polar fronts, and hot dry summers driven by yearly expansion of the dry zone as the sun moves north toward the solstice.

Multiple Eccentricity Models Based on Chaotic Motion of Major Astroids



	A	B	C	D	E
1	t = time from	e = eccentricity La2010a	e = eccentricity La2010b	e = eccentricity La2010c	e = eccentricity La2010d
2	0	0.016702362	0.016702362	0.016702362	0.016702362
3	-1	0.017161382	0.017161382	0.017161386	0.017161383
4	-2	0.017496814	0.017496815	0.017496824	0.017496815
5	-3	0.017845736	0.017845736	0.017845745	0.017845739
6	-4	0.018210895	0.018210895	0.018210910	0.018210893
7	-5	0.018453476	0.018453476	0.018453488	0.018453479
8	-6	0.018748365	0.018748365	0.018748375	0.018748368
9	-7	0.018937360	0.018937360	0.018937374	0.018937357

In 2011, the Laskar team published a paper that acknowledged they could not be certain about their Eccentricity model due to chaotic motion of objects in the asteroid belt. They produced 4 different models. The plot at the top shows that the four different models are virtually identical for 40 million years, and after 60 million years they are significantly different from one another. Eccentricity model La2010a is the nominal solution but not the certain solution. Laskar states that it will take convincing geological evidence to make the determination, asking for feedback from geology to celestial mechanics.

Link to original La2010 and La2004 Data Files:

http://vo.imcce.fr/insola/earth/online/earth/earth.html

Frequencies Identified by Laskar for Orbital Parameters for Time Interval -15 to +5 Myrs.

Row	Eccentricity Thousand Years/Cycle
1	2373.3
2	977.6
3	688.0
4	486.2
5	405.1
6	346.3
7	134.3
8	130.8
9	127.1
10	123.9
11	118.1
12	109.9
13	105.2
14	103.2
15	100.8
16	98.9
17	96.7
18	94.9
19	76.9
20	55.0

Row	Obliquity Thousand Years/Cycle
1	54.0
2	53.7
3	53.4
4	41.9
5	41.7
6	41.3
7	41.2
8	41.0
9	40.8
10	40.6
11	40.5
12	40.3
13	40.1
14	39.8
15	39.6
16	29.9
17	29.8
18	29.8
19	29.0

Row	Precession Thousand Years/Cycle
1	29.5
2	28.6
3	23.5
4	22.3
5	19.1
6	18.8
7	18.0
8	17.5
9	16.4