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Influence of Millennial Range Orbital Cycles on the Middle Eocene Climatic Optimum Hyperthermals

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Introduction

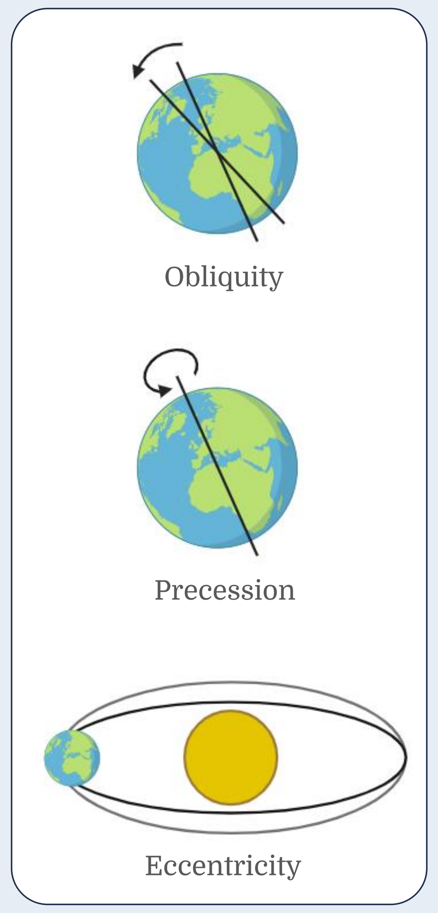


Figure 1 – Milankovitch cycles [1]

Background

- The Middle Eocene Climatic Optimum (40 Mya) was a **major climatic shift during the Eocene epoch**
- Short warming periods, called hyperthermal events, caused by rapid increases in atmospheric carbon concentration created rapid, high magnitude changes
- Well-understood orbital drivers, including Milankovitch cycles and solar variability, do not completely explain this unusual behavior
- **Millennial range orbital cycles are not yet well-understood**, but could aid in explaining the climate patterns seen in the MECO

Significance

- Accurately understanding past climate allows for better predictions of future trends
- **Understanding the drivers of prior rapid climate change events is an important step** in understanding modern climate change

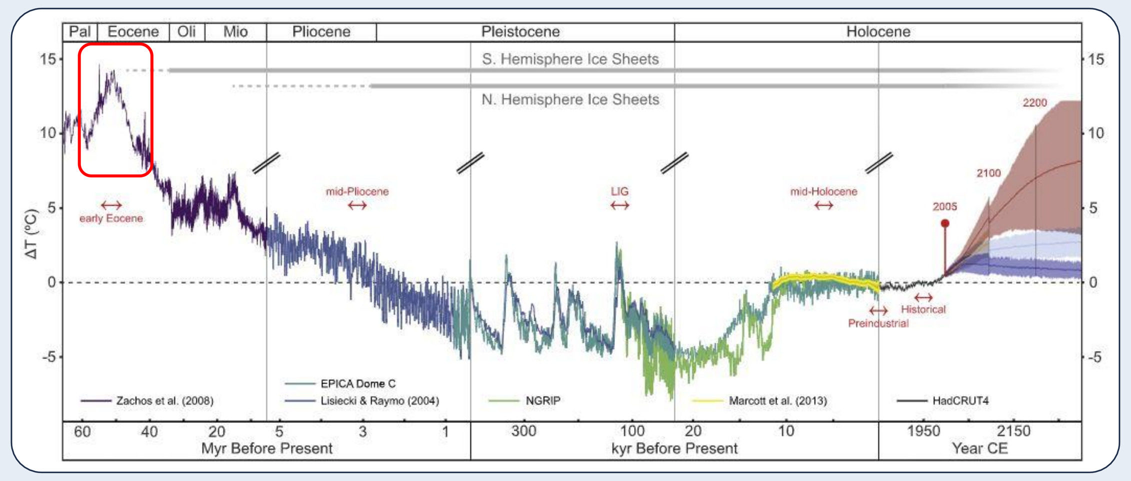


Figure 2 – Global paleotemperatures, with the area of study highlighted in red, can be seen along with their analog to modern climate predictions [2]

Objectives

Determine if **millennial-range orbital cycles had an observable influence** on climate dynamics during the MECO

- Perform spectral analysis of temperature proxy records
- Compare known orbital cycles to observed periodicities
- Identify potential astronomic origins of periodicities

Data Acquisition

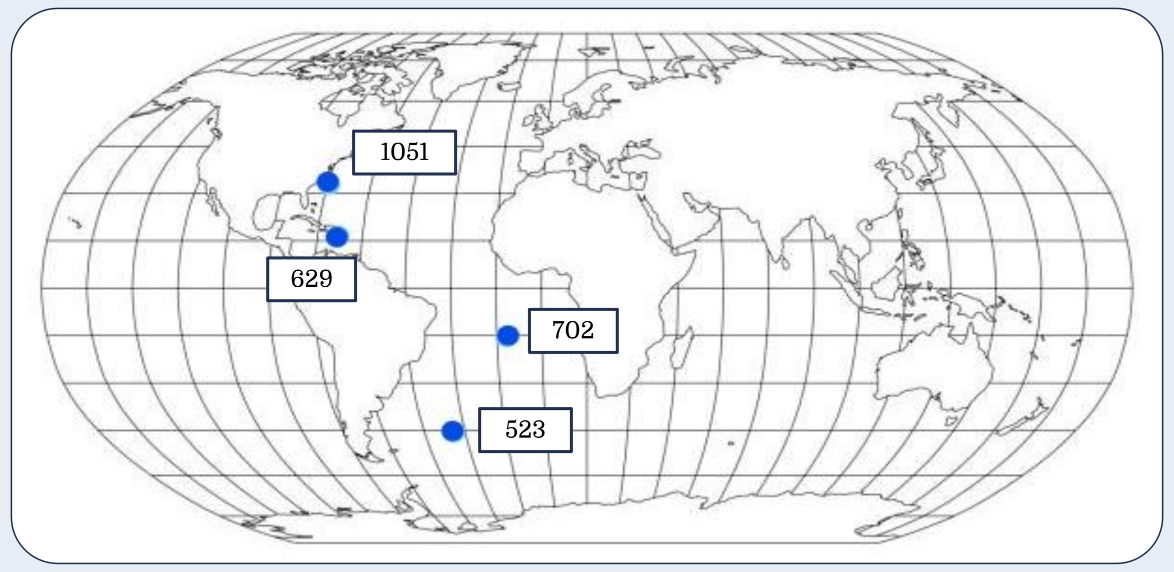
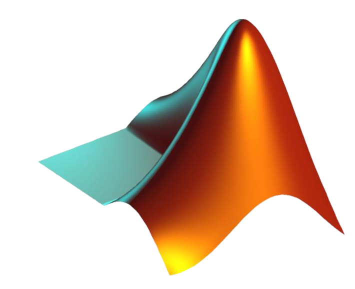


Figure 3 – Selected sample locations from IODP program, retrieved from NOAA's NCEI paleodatabase [3]

Data Analysis

- All analysis done with MATLAB R2022a
- **Developed analysis framework**
  - Modified FFT Cooley-Tukey algorithm
  - White noise isolation and mean variance analysis



```
for i = 1:length(P11win)
    if P11win(i) > P11movmean(i)
        P11final(i) = P11win(i)-P11movmean(i);
    end
    P11final = nonzeros(P11final);
end

data_pnts_per_bin1 = floor(length(P11final)/20);
nbins = floor(length(P11final)/data_pnts_per_bin1);
```

Figure 4 – Selected code snippet for variance analysis

Results

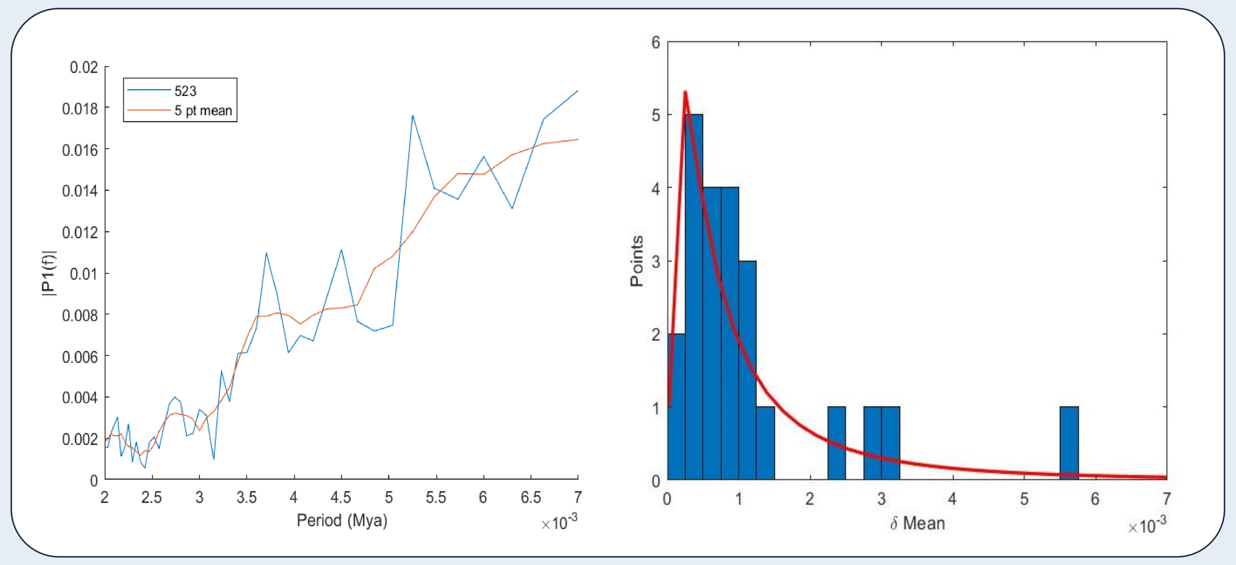


Figure 5 – IODP site 523

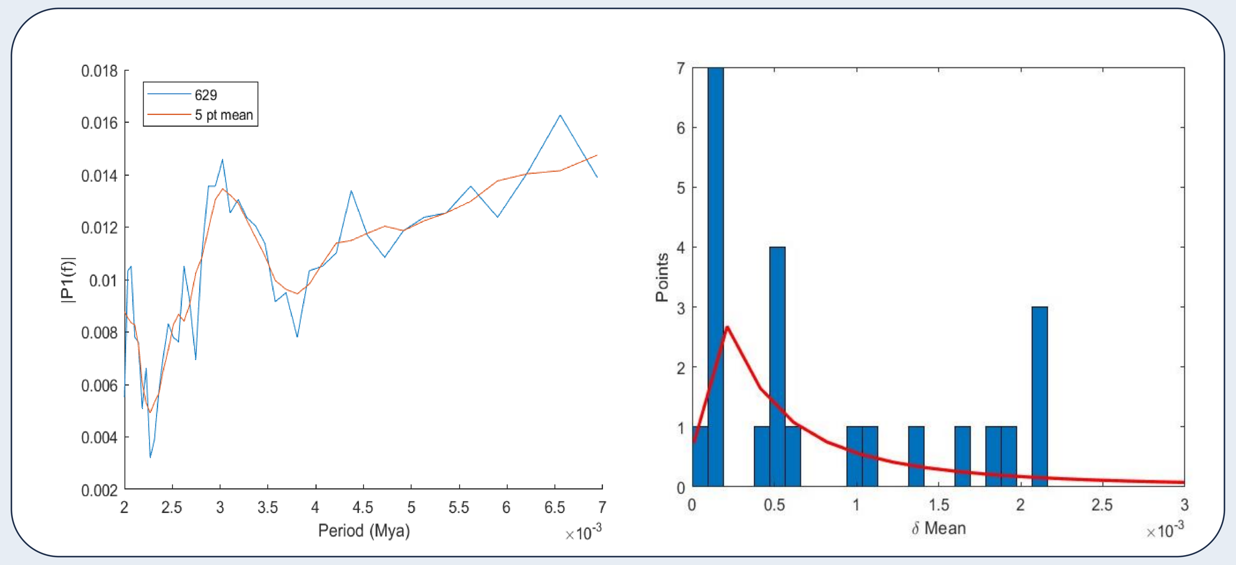


Figure 6 – IODP site 629

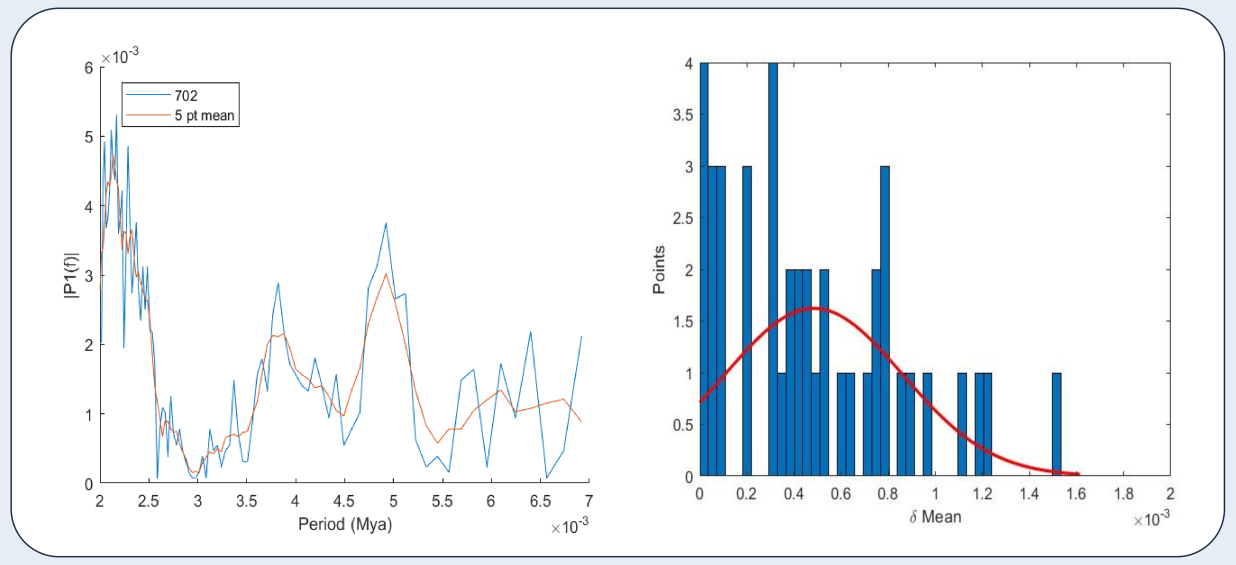


Figure 7 – IODP site 702

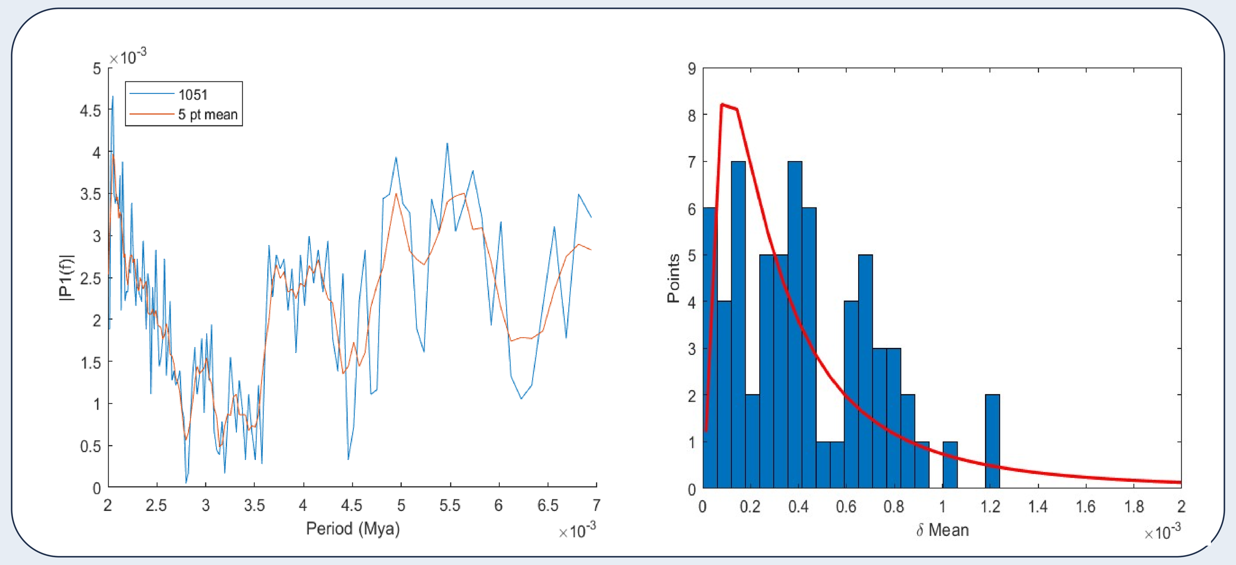


Figure 8 – IODP site 1051

Figures 5-8 – Results of analysis framework for listed site including isolated white noise spectra from FFT of isotope records and a rolling five-point mean (left), and lognormally distributed histograms of signals stronger than the mean (right)

Period (yrs.)	Site 523	Site 629	Site 702	Site 1051
2500 +/- 250				
3000 +/- 250				
3500 +/- 250				
4000 +/- 250				
4500 +/- 250				
5000 +/- 250				

Key: Most Prominent; Prominent

Table 1 – 4 most prominent periodicities observed at each site

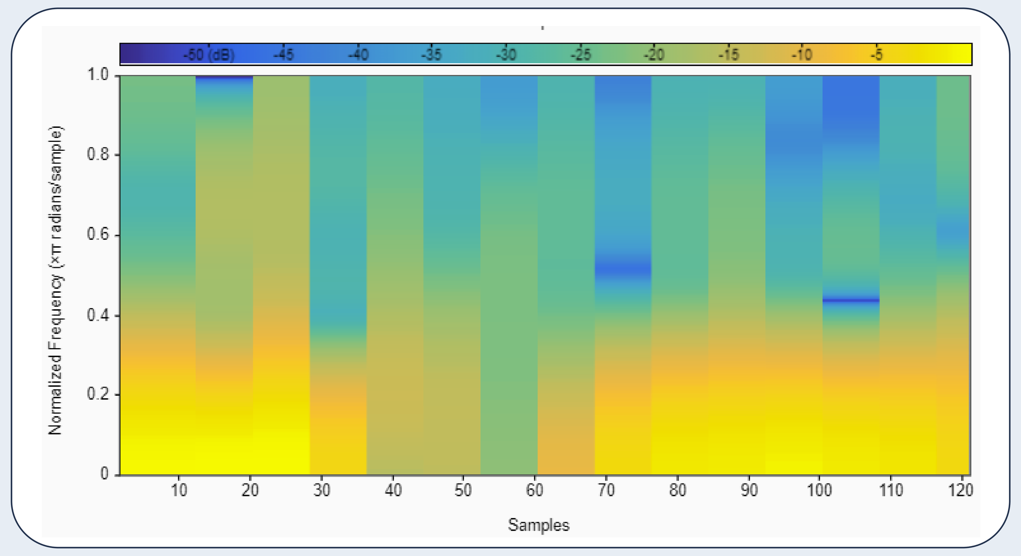


Figure 9 – Spectral persistence plot of IODP site 523

Discussion

- All sampled sites had a signal in the **2500 +/- 250-year** range
  - **Potential correlation to the Hallstatt cycle,** observed throughout the Holocene
  - Hallstatt cycle **modulates the 11-year sunspot (Schwabe) cycle** and affects amount of solar insolation reaching Earth
  - Suggested astronomical origin of the Hallstatt cycle relating to spin-orbit coupling of the Jovian planets, which have been shown to modulate solar behavior – consistent with solar system chaos during the MECO [4]

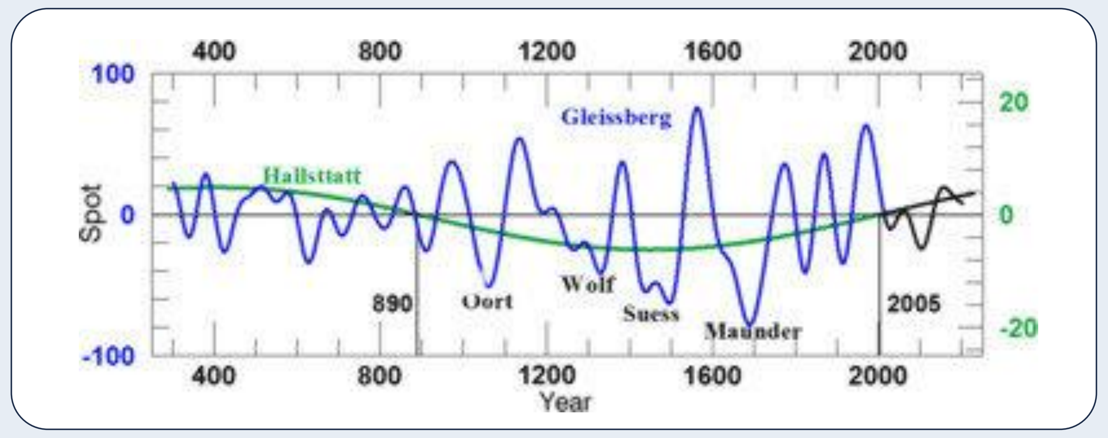


Figure 10 – Hallstatt cycle's modulation of sunspot cyclicity

- Three of the sampled sites had a signal in the 5000 +/- 250-year range
  - Potential Milankovitch lag correlation

Future Work

- **Repeat analysis with a dataset from the late Pleistocene,** another period with punctuated hyperthermal events
  - Far more data is available due to well preserved stratigraphic record
  - Have identified several potential datasets suitable for analysis

Acknowledgements & References

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[1] Fox, M., 2023, created with BioRender
[2] Burke, K. D., et al. "Pliocene and Eocene provide best analogs for near-future climates." *Proceedings of the National Academy of Sciences*, vol. 115, no. 52, 2018, pp. 13288–13293.
[3] Bohaty, Steven M., et al. "Coupled greenhouse warming and deep-sea acidification in the Middle Eocene." *Paleoceanography*, vol. 24, no. 2, 2009.
[4] Scafetta, Nicola, et al. "On the astronomical origin of the Hallstatt oscillation found in radiocarbon and climate records throughout the Holocene." *Earth-Science Reviews*, vol. 162, 2016, pp. 24–43.