Presence of Millennial-Scale Climatic Cycles during the Middle Eocene Climatic Optimum

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Introduction

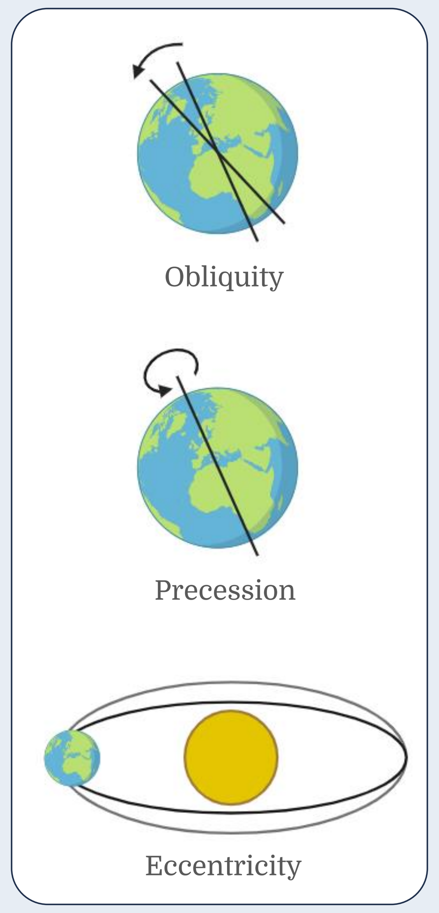

Figure 1 – Milankovitch cycles [1]

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

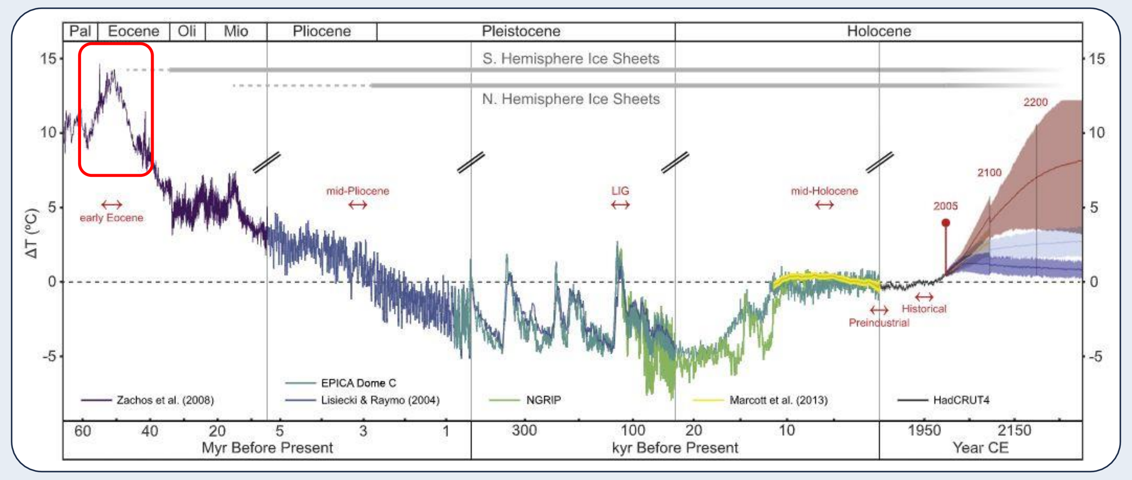

Figure 2 – Global paleotemperatures, with the area of study highlighted in red, can be seen along with their analog to modern climate predictions [2]

Research Questions

- Were any millennial-range orbital cycles present during the MECO?
- If so, are the periods of the identified cycles observed during any other periods?

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

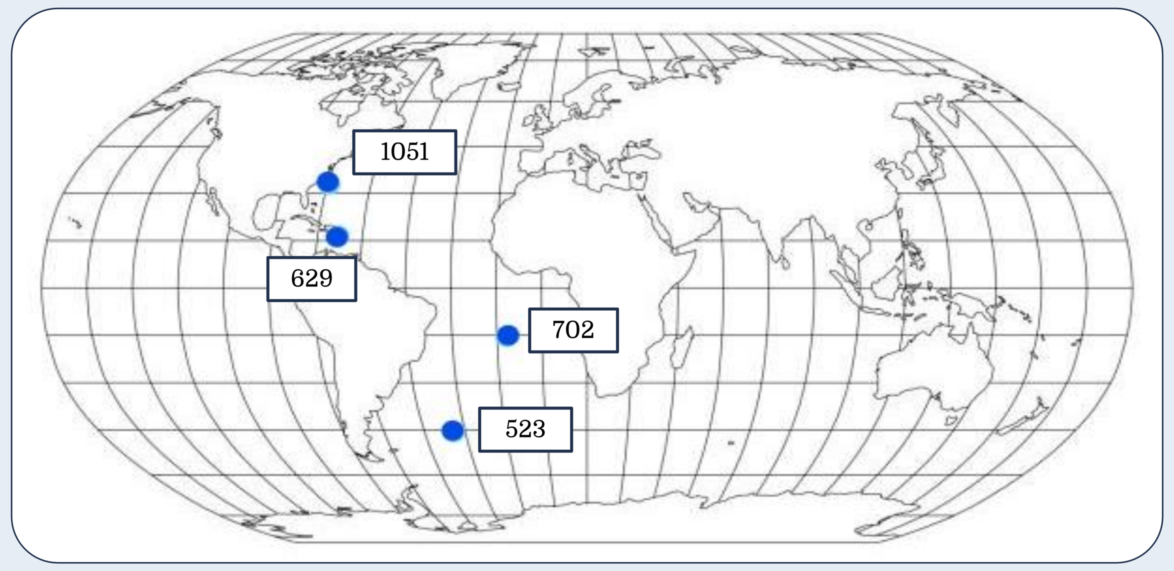

Figure 3 – Selected sample locations from IODP program, retrieved from NOAA's NCEI paleodatabase [3]

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

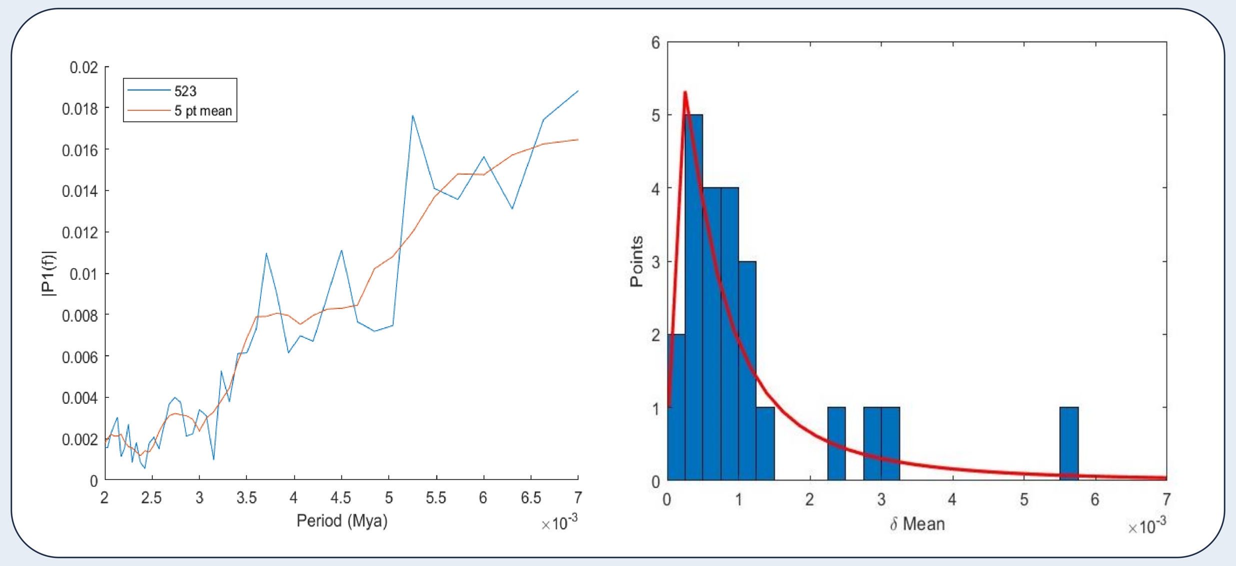

Figure 5 – IODP site 523

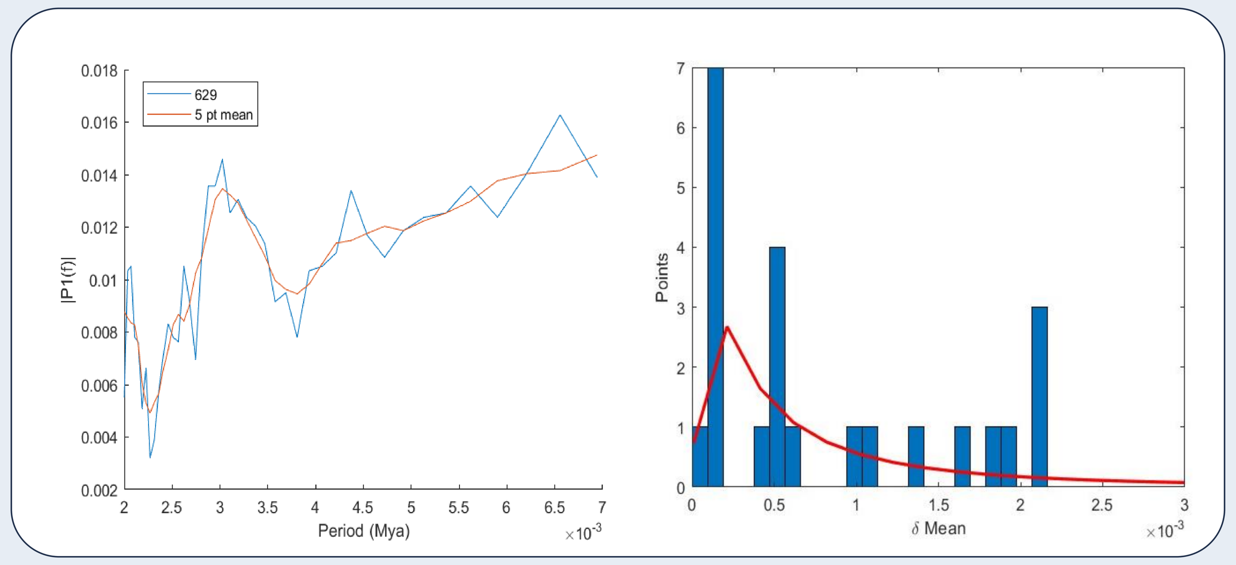

Figure 6 – IODP site 629

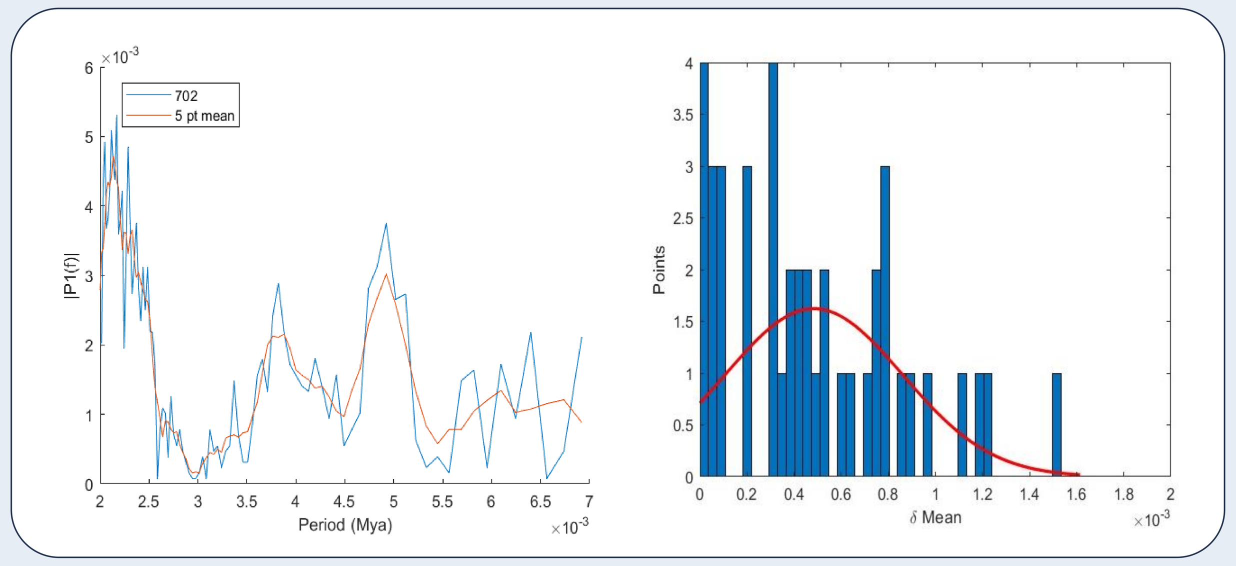

Figure 7 – IODP site 702

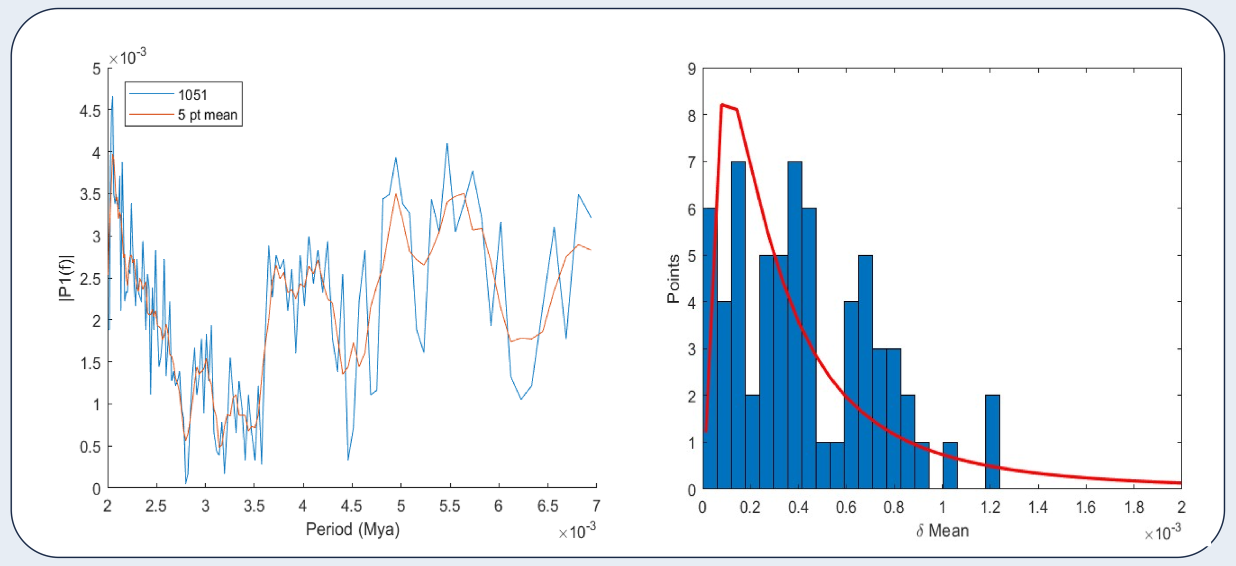

Figure 8 – IODP site 1051

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 629	Site 1051	Site 523	Site 702
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

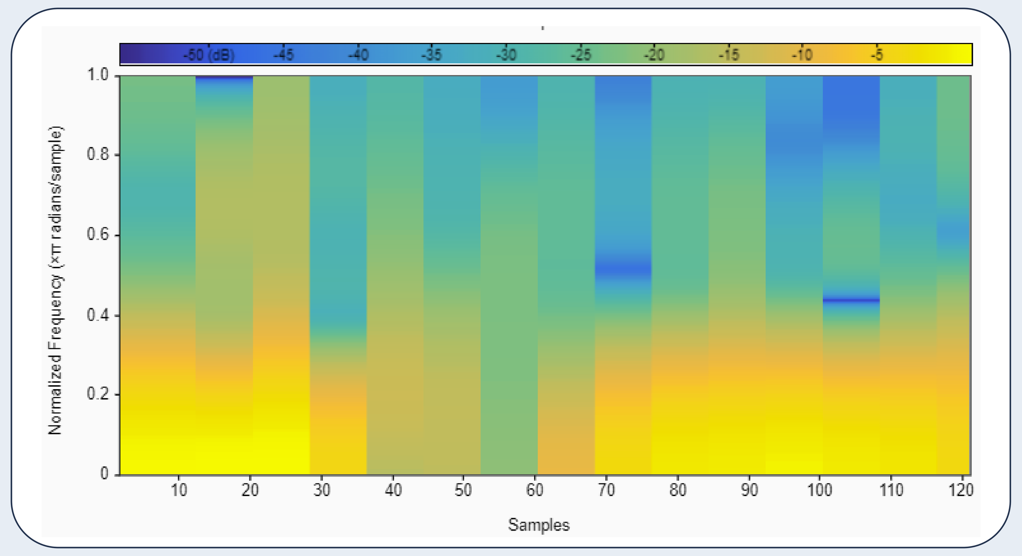

Figure 9 – Spectral persistence plot of IODP site 523

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]

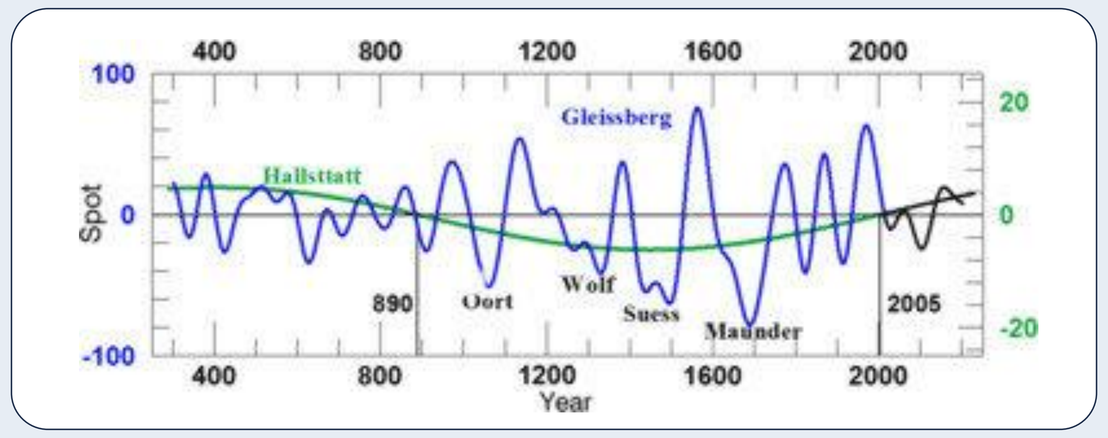

Figure 10 – Hallstatt cycle's modulation of sunspot cyclicity

- Most prominent signal varied by site – correlation between site's hemisphere and strongest signal
  - Potential link to ocean/atmospheric circulation

Future Work

- **Perform further analysis in Astrochron**, an R package designed specifically for paleoclimatology applications
- **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.

Interested in this work? Check out what the rest of the group is up to! Our overall goal is to link lessons from the preserved sedimentary record with modern process and experimental studies, with the aim to improve our ability to interpret the sedimentary record, and to integrate the deep-time perspective into geomorphology and climate research.