Environmental change 60 Ma in Zumaia, Spain was not paced by periodic changes in Earth’s orbit.
Paleocene Eocene Thermal Maximum (PETM)

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Image credit: Zachos et al. (2001)
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- closest rate of carbon emissions to present day (Cui et al. 2011)
- mass extinction of benthic foraminifera, largest mammalian turnover of Cenozoic (McInerny and Wing 2011)
- don’t know exactly how long ancient warming or extinction took → study geologic record of this time period to find out for anthropocene

Image credit: Zachos et al. (2001)
Orbital Components

- Eccentricity - the shape of Earth’s orbit around the sun
  - varies from elliptical to near circular
  - every \( \sim 400 \text{ kyr and 100 kyr} \)
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- **Obliquity** - the tilt of Earth’s axis
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- Obliquity - the tilt of Earth’s axis
  - varies between 22.1° and 24.5°
  - every 41 kyr
- Precession - the wobble of the axis of rotation
  - when modulated by eccentricity, determines where on the orbit the seasons occur
  - increases seasonal contrast in one hemisphere, decreases in other
  - every 19 kyr and 23 kyr
Orbital forcing of Earth’s climate

Changes in Earth’s orbital geometry (eccentricity, tilt, precession)

Changes in the seasonal distribution of Insolation (heat) as a function of latitude

Glacial-interglacial climate change

Amplified by other processes

ice albedo feedback: cooling leads to increased ice, increases reflectivity (albedo), reduces solar energy absorbed, increases cooling and vice versa

Milutin Milankovitch (Serbian mathematician, 1879-1958)
- studied Earth’s orbit while imprisoned during WWI
• limestone-marl couplets show cyclic variation of bioproductivity dependent on orbital forcing (Batenburg et al. 2012)
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- warm periods - increased organic production (plankton)
  - thicker limestone beds
- limestone-marl couplets show cyclic variation of bioproductivity dependent on orbital forcing (Batenburg et al. 2012)
  - warm periods - increased organic production (plankton)
    - thicker limestone beds
  - cool periods - decreased organic production
    - thin limestone beds
    - accounts for adjacent marl layers - “crowded couplets”
Batenburg et al. 2012

- each couplet represents precessional cycle (~20kyr)
Batenburg et al. 2012

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- bundles of five couplets represent short eccentricity cycle (~100kyr)
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- used to decrease age uncertainties, provide dates for planktonic events
New Methodology
New Methodology

1. Did not assume coupling
LIMESTONE

MARL

Image credit:
Adam Maloof
Image credit: Adam Maloof
New Methodology

1. Did not assume coupling       2. Removed turbidites

vs

vs
marl beds

missing bases

Image credit: Adam Maloof
TURBIDITE

< 1 day

thousands of years
New Methodology

1. Did not assume coupling
2. Removed turbidites
3. Did not tune data

vs

marl beds

missing bases
Tuning

signal

time

signal

time

The diagram illustrates the process of tuning, showing how the signal changes over time.
1. Better not to tune if signal-to-noise ratio is less than ~1 (Proistosescu et al. 2012)
Tuning

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2. tuning was employed in previous work because data were defined as Milankovitch cycles to begin with
   - artificially increased signal
Tuning

1. better not to tune if signal-to-noise ratio is less than ~1 (Proistosescu et al. 2012)
2. tuning was employed in previous work because data were defined as Milankovitch cycles to begin with
   ○ artificially increased signal
3. our data were too noisy for reliable tuning → did not tune
New Methodology

1. Did not assume coupling
2. Removed turbidites
3. Assessed applicability of tuning

---

vs

marl beds
missing bases
Check percent marl per meter for Milankovitch cycles using fast Fourier transform.
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None, maybe some parts of section were noisier than others.
1. Check percent marl per meter for Milankovitch cycles using fast Fourier transform → None, maybe some parts of section were noisier than others → Apply wavelet analysis to look at power spectra
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Check percent marl per meter for Milankovitch cycles using fast Fourier transform.

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Apply wavelet analysis to look at power spectra.

No consistent frequencies.

Define couplets and checking them for cyclicity using fast Fourier transform.
Check percent marl per meter for Milankovitch cycles using fast Fourier transform

None, maybe some parts of section were noisier than others

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Fast Fourier Transform of a Couplet Thickness

27.0 = 175.6 kyr
3.00 = 19.51 kyr
3.47 = 22.54 kyr

No consistent frequencies
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![Fast Fourier Transform Graph]

Power

Frequency [cycles/couplet]
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2. Define couplets and checking them for cyclicity using fast Fourier transform
   - Found 19/22 kyr peaks (precession)
   - Try to improve: Remove turbidites
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     Remove turbidites

   32.27 = 412.1 kyr
   4.30 = 54.94 kyr
   2.63 = 33.63 kyr
   6.79 = 86.75 kyr
Check percent marl per meter for Milankovitch cycles using fast Fourier transform → None, maybe some parts of section were noisier than others → Apply wavelet analysis to look at power spectra → No consistent frequencies

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Applying wavelet analysis to look at power spectra

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Turbidites are periodic

Everything is a turbidite

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Summary

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Questions?

