Understanding the Middle Miocene Climatic Optimum: Evaluation of Deuterium Values ($\delta D$) Related to Precipitation and Temperature

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About this Project

• Interdisciplinary research was carried out in Bryant’s Laboratory for Terrestrial Environments
• A quantitative evaluation of an ancient climate
• We attempt to reconstruct the atmospheric conditions, specifically precipitation and temperature
Significance

• Understanding climate is particularly important today as we rush to forecast how global changes will influence society
  • Higher temperatures?
  • More droughts?
  • More severe storms?
  • Intensified rainfall events?
  • Extinction of vital species?
Significance

• Climate is a dauntingly complex, and there are thousands of variables to control when attempting to model and to forecast climate change
  • Some processes are more important than others for influencing climate
• A Global Circulation Model (GCM) is a 3-D simulation of the Earth’s climate as a whole
• Evaluating past climates helps us to predict what future climates will look like
Significance

• The Middle Miocene Climatic Optimum
  • A geologic time period, 15-17 million years ago (Böhme, 2003)
  • The Earth is believed to have been warmer than the modern climate, but also had lower levels of CO₂ (Yao, 2009)
  • What drove this change? What was the temperature distribution going from the Equator to the Poles?
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  • What drove this change? What was the temperature distribution going from the Equator to the Poles?
Atmospheric science, paleoclimatology, basic chemistry

BACKGROUND
What is climate?

Temperature, precipitation, humidity, air pressure, and wind characteristics at a location over an extended period of time
Climate Variations

Present day image of Banks Island, Canada, inside the Arctic Circle
Paleoclimatology

The same location, 40 million years ago
Hydrologic Cycle

Atmospheric water is evaporated, transported, and precipitated
Atmospheric Circulation

In general, most atmospheric water is evaporated at the equator, and transported poleward.
Isotopes

A variation in the number of neutrons in an atom of an element. Hydrogen most commonly has 0 neutrons. Its isotopes, deuterium and tritium, have one and two, respectively.
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$E(\theta)$ is the evaporation at a given latitude, $P(\theta)$ is the precipitation at a given latitude, $H$ and $L$ are the abundances of heavy and light isotopes respectively.

Isotopes in Precipitation

The ratio of isotopes at a given location is a direct function of atmospheric temperature.
Isotopes in Plants

After the isotope is “rained out” of the atmosphere, the water is absorbed by the roots of plants, and the isotope ratio is reflected in the wax of the leaf.
Recap

- Climate varies drastically over time
- Water is evaporated, transported, and precipitated out
- Generally, most atmospheric water is evaporated at the Equator and moves towards the poles
- As water is transported toward the poles, the hydrogen isotope ratio changes based on location and temperature
- We can find the isotope ratio of precipitation by analyzing leaves from plants
  - By knowing the latitude, we can then estimate temperature
METHODS AND MATERIALS
Sample Locations
Our data set includes 8 Northern Hemisphere samples (from 7 sites) at various latitudes

Sample Locations
1: Xianfeng, Lianghe County, Yunnan Province, China
2: Hunshuitang, Kunming City, Yunnan Province, China
3: Mizunami City, Gifu Prefecture, Japan
4: Sifangtai, Huanan County, Heilongjiang Province, China
5: Clarkia, Idaho, USA
6: Seládaur Botn, Iceland
7: Banks Island, Northwest Territories, Canada
Miocene Deposits

Collecting fossil samples from Clarkia, Idaho
Fossilized leaf samples

Having been fossilized into rock, some bio-matter from the leaf remains well-preserved, allowing us to run chemical analysis.
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Sample Preparation

Each sample under went a series of protocols to isolate the hydrogen isotope:

- Data plotted along latitudinal gradient, evaporation–precipitation model developed
- 2H/1H on the C-27, C-29, and C-31 n-alkane chains
- Deuterium Values
- Isotope Ratio Mass–Spectrometer
- Model Simulation
- Asses final sample concentration for IRMS
- Flame ionization detector
- Urea Addition
- Removal of cyclic and branched alkanes from straight n-alkanes
- Flame ionization detector
- Flume ionization detector
- Evaluation of sample quality
- Column chromatoaogy
- First fraction, containing isolated n-alkanes, collected
- Accelerated Solvent Extractor
- Total lipid extraction
- Collected from Northern Hemisphere Middle Miocene deposits
Sample Preparation

Each sample underwent a series of protocols to isolate the hydrogen isotope.

1. **Sediment/fossil material**
   - Collected from Northern Hemisphere Middle Miocene deposits

2. **Accelerated Solvent Extractor**
   - Total lipid extraction

3. **Column chromatography**
   - First fraction, containing isolated n-alkanes, collected

4. **Flame Ionization Detector**
   - Evaluation of sample quality

5. **Urea Adduction**
   - Removal of cyclic and branched alkanes from straight n-alkanes

6. **Flame Ionization Detector**
   - Assess final sample concentration for IRMS

7. **Isotope-Ratio Mass-Spectrometer**
   - Isotope measurement

8. **Deuterium Values**
   - δ 2H/1H on the C-27, C-29, and C-31 n-alkane chains

9. **Model Simulation**
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DATA ANALYSIS & RESULTS
Plotted Deuterium vs. Latitude
Modeling Middle Miocene Precipitation

By plotting δD values from the Miocene and modern time periods, we can model relative precipitation against a latitudinal gradient.
Adjusting Data

• In actuality, deuterium at a given location is controlled by a handful of factors
  • Latitude
  • Temperature
  • Altitude
  • Distance to coast
  • Seasonal effects
  • Amount of precipitation

• Using scientific literature, we are able to adjust each data point so it only reflects latitude and temperature
Modern Adjustments

For comparison, we apply the same method to modern data, and find the approach constrains the samples fairly well.
Adjusted Miocene Data

Having scaled the values based on altitude and distance to coast, we see a trend that decreases with latitude.
Parameter Estimation

Evaluating the relationship between evaporation and precipitation (modern)
Parameter Estimation

Evaluating the relationship between evaporation and precipitation (modern)
Evaporation vs. Precipitation Distribution

Miocene simulation of evaporation and precipitation at a given latitude
Parameter Estimation

Evaluating the relationship between evaporation and precipitation (modern)
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The Miocene evaporation and precipitation relationship is less distinct, but a linear trend can be discerned.
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Evaporation vs. Precipitation Distribution

The low $\tau_{\text{Evaporation}}$ (that is, steeper slope of the line) validates the assumption that most of the evaporation occurs near the equator. High $\tau_{\text{Precipitation}}$ indicates precipitation favoring high latitudes.
Conclusion and future work

• The numerical relationship between evaporation and precipitation is a direct indicator of meteoric water content.
• We find that the “drop-off” of evaporation is lower during the Miocene than in the present.
  • That is, evaporation is relatively higher at low latitudes, and lower at high latitudes.
• Precipitation is higher at high latitudes relative to the modern.
• With more precise estimations of these variables, the temperature distribution may be discerned.
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\begin{align*}
H & \rightarrow H + H_e - H_p \\
L & \rightarrow L + L_e - L_p \\
H_p(\theta) & = \frac{H(\theta)\alpha_p \cdot P(\theta)}{L(\theta) + H(\theta)\alpha_p} \\
H_e(\theta) & = \frac{R_{\text{SMOW}} \cdot \alpha_e \cdot E(\theta)}{1 + R_{\text{SMOW}} \cdot \alpha_e} \\
L_p(\theta) & = \frac{L(\theta) \cdot P(\theta)}{L(\theta) + H(\theta)\alpha_p} \\
L_e(\theta) & = E(\theta) - H_e = \frac{E(\theta)}{1 + R_{\text{SMOW}} \cdot \alpha_e}
\end{align*}
\]