CESM Sensitivity to Aerosol Forcing in the PETM (55 Million Years Ago)

Christine A. Shields¹
Jeff Kiehl², Mathew Rothstein¹, Mark Snyder², Will Rush²

¹NCAR, ²U.CA Santa Cruz

CESM Tutorial Applications Presentation, Wednesday, August 7, 2019, Boulder, Colorado
Our Science Question:
How do different aerosol forcings affect the climate of the Paleocene Eocene Thermal Maximum (PETM)?

- How do models supplement proxy data?
- How can we use models and data together to answer questions?
How do models supplement proxy data?

- Proxy data are measurements applied to specific latitude and longitude sites (fossils of flora and fauna, sediments, etc.)

- Models estimate climates: a) globally b) regionally diverse areas (topography, biomes) assuming the model has the appropriate resolution

- Models test mechanisms, i.e. What dynamics drive the monsoon? What do different aerosol forcings affect the global climate? Regional climates?

How can we use proxy data and models together?

- Evaluate model simulations at specific paleo latitude and longitude locations

- Models can test theories by synthesizing proxy data

- Model sensitivity tests (to understand mechanisms) can be designed using proxy data and uncertainties around the proxy data
Model Details

Model:
DT-CESM (CAM5) 2deg Fully Coupled
(CESM1.2 release + code modifications for warm worlds)

Boundary Datasets:
DeepMIP protocol
(The Deep-Time Model Intercomparsion Project,
https://www.deepmip.org/)

Aerosol emissions datasets:

Based on Markwick et al.
Proxy Examples

<table>
<thead>
<tr>
<th>Region</th>
<th>Latitude Range (degrees)</th>
<th>Longitude Range (degrees)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bighorn Basin</td>
<td>53-55N</td>
<td>89-90W</td>
<td>Snell et al., 2013</td>
</tr>
<tr>
<td><strong>New Jersey</strong></td>
<td>41-43N</td>
<td>49-51W</td>
<td>John et al., 2008</td>
</tr>
<tr>
<td>Maryland</td>
<td>40-42N</td>
<td>52-54W</td>
<td>Self-Trail et al., 2017</td>
</tr>
<tr>
<td>China</td>
<td>30-32N</td>
<td>110-112E</td>
<td>Chen et al., 2016</td>
</tr>
<tr>
<td>Spanish Pyrenees</td>
<td>34.5-36.5N</td>
<td>0-2E</td>
<td>Pujalte et al, 2015</td>
</tr>
</tbody>
</table>

Example of proxy data points translated to geography of the time, i.e. “Paleogeography”

Figure 1. Location and paleogeography. (a) Location during the Paleocene-Eocene of the two margins discussed in this article. (b) Paleogeography of the Lodo formation (California) during the late Paleocene to early early Eocene. (c) New Jersey margin sites.
## PETM Climate Simulations (4)

<table>
<thead>
<tr>
<th>Forcing Type</th>
<th>PETM Control Simulation</th>
<th>Low SOAG Simulation</th>
<th>High SOAG Simulation</th>
<th>DMS Sensitivity Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CO₂ (ppmv)</strong></td>
<td>1590</td>
<td>1590</td>
<td>1590</td>
<td>1590</td>
</tr>
<tr>
<td><strong>CH₄ (ppmv)</strong></td>
<td>16</td>
<td>16</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td><strong>⁺SOAG</strong></td>
<td>4X MEGAN</td>
<td>2X MEGAN</td>
<td>8X MEGAN</td>
<td>4X MEGAN</td>
</tr>
<tr>
<td><strong>⁺⁺DMS</strong></td>
<td>+++Paleotize PI *0.1</td>
<td>Paleotize PI *0.1</td>
<td>Paleotize PI *0.1</td>
<td>Paleotize PI</td>
</tr>
</tbody>
</table>

### Additional SOAG-only Sensitivity Experiments (3)

<table>
<thead>
<tr>
<th></th>
<th>Control except Paleotized SOAG</th>
<th>Control except 0.5 X SOAG MEGAN</th>
<th>Control except 2 X MEGAN</th>
</tr>
</thead>
</table>

*⁺SOAG* = secondary organic aerosols, biogenic (Isoprene and Terpene)

*⁺⁺DMS* = Dimethylsulfide (naturally occurring in the ocean produced by phytoplankton)

*+++Paleotize* = compute zonal averages from Pre-Industrial and distribute by latitude band for new geography
How can we use proxy data and models together?

- Develop forcing (SOAG, DMS) by running experiments and comparing model data to proxy data
- Which gives the best guestimate of these values for model world?

<table>
<thead>
<tr>
<th>Precipitation (mm)</th>
<th>Big Horn Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proxy Data</td>
<td>1150* (range 800-1400)</td>
</tr>
<tr>
<td>PETM 4xSOAG</td>
<td>875</td>
</tr>
<tr>
<td>PETM 2xSOAG</td>
<td>942</td>
</tr>
<tr>
<td>PETM 8xSOAG</td>
<td>772</td>
</tr>
<tr>
<td>PETM DMS</td>
<td>783</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sfc Air Temp (°C)</th>
<th>Big Horn Basin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature Type</td>
<td>MAT</td>
</tr>
<tr>
<td>Proxy Data</td>
<td>20</td>
</tr>
<tr>
<td>PETM 4xSOAG</td>
<td>22</td>
</tr>
<tr>
<td>PETM 2xSOAG</td>
<td>25</td>
</tr>
<tr>
<td><strong>PETM 8xSOAG</strong></td>
<td><strong>19</strong></td>
</tr>
<tr>
<td>PETM DMS</td>
<td>16</td>
</tr>
</tbody>
</table>

Note: shaded box is best global fit, Bold text is best local fit.

PETM (Paleocene Eocene Thermal Maximum, 55 Mya)
How can we use proxy data and models together?

- Looking at non-traditional variables across different model components may give you an indication of potential model pathologies.

- Example: CAM5 tends to run hot over the land, so by looking at TLAI (Leaf Area Index) to see if vegetation/leaves are dying can give you an indication how model is doing!

PETM (Paleocene Eocene Thermal Maximum, 55 Mya)
How do models supplement proxy data?

Varying responses to aerosols across the entire globe

- More SOAG cools the climate
- More DMS cools the climate
- Temperature response due to SOAG is more pronounced at high latitudes
- Temperature response due to DMS is most pronounced in the N. Atlantic.
How do models supplement proxy data?

Varying responses to aerosols across the entire globe

- Precipitation response to SOAG is most pronounced in tropical bands where intense convection occurs.

- Precipitation response to increasing DMS is diverse across different sections of the globe, however the largest impacts are again in the deep tropics, and over oceans where DMS is sourced.
How do models supplement proxy data?

Low clouds and solar radiation at the surface have opposite responses, where there are more clouds due to aerosols, there is less solar reaching the surface.
Understanding How Model Forcing Works: Amount of Aerosols Matter!

MEGAN X 2 = Cooling compared “Paleotized” aerosols

MEGAN X 0.5 = Warming compared to “Paleotized” aerosols

Accumulation (Mode 1) primary aerosol source in MEGANX2

Accumulation in MEGAN X0.5 is half of what it is in X2

Aerosols in CAM5 are divided into three modes:
- Aitken (small) – Mode 2
- Accumulation (medium) – Mode 1
- Coarse (large) -- Mode 3

- With increased CCN, the transition from Aitken to Accumulation will change the radiative impact.
- This transition threshold will be different for different periods depending on aerosol type and amount.
Take away points...

- Models and proxies can be used together to create a more comprehensive picture of Earth’s climate for paleoclimatic time periods.

- Models and proxies can be used together to diagnose pathologies in the model.

- Aerosol size distributions and amount matter. Simulation design and aerosol forcing should be considered thoughtfully especially for simulations of the deep past.