How do models inform paleoclimate, and how does paleoclimate inform (validate) models?

A perspective from Earth System Models (AOGCMs)

Bette Otto-Bliesner

With contributions by Esther Brady, Ran Feng, Clay Tabor, Jiang Zhu, and many more
How do models inform paleoclimate?

- LGM ENSO
  - Low CO₂
- Eocene ocean temperatures
  - High CO₂
- African hydroclimate
  - Deglaciation – increasing CO₂
Models informing paleoclimate: ENSO

Stronger ENSO at LGM

Individual Foraminifera Analysis (IFA)

Core V21-30 (1°13’S, 89°41’W) $\delta^{18}O$ of G. Ruber

IPCC AR4 WG I, 2007

Koutavas and Joanides, Paleoceanography, 2012
Weaker ENSO at LGM

Zhu, Liu, Brady, Otto-Bliesner, GRL, 2017
Weaker LGM ENSO primarily caused by lowered concentration of GHGs; secondly by large and extensive LGM ice sheets.

Future ENSO should be stronger

Zhu, Liu, Brady, Otto-Bliesner, GRL, 2017
Models informing paleoclimate: Eocene CO$_2$

Zhu et al., in prep, 2019
Models informing paleoclimate: Hydroclimate in Africa

Deglacial period – 20ka to 11ka
Increasing moisture availability

A   EOF1, proxy data
B   EOF1, TraCE
C   EOF2, proxy data
D   EOF2, TraCE
PC1, proxy data
PC1, TraCE
PC2, proxy data
PC2, TraCE

Age (ka)

Otto-Bliesner et al., Science, 2014
How does paleoclimate inform models?

Equilibrium Climate Sensitivity

Indices of Climate
Paleoclimate informing models: Climate Sensitivity

**ECS (Equilibrium Climate Sensitivity):** Equilibrium (steady state) change in the annual global mean near-surface air temperature for a doubling of atmospheric CO$_2$

Commonly estimated by running atmosphere models coupled to a slab ocean model

Relatively fast responses (i.e. next 150 years or so) of atmosphere and Earth’s surface

For paleomodeling, need to include additional radiative forcing by imposed boundary conditions (e.g. ice sheets in LGM simulations)

*IPCC AR5 WG I, 2013*
Paleoclimate informing models: ECS

Equilibrium Climate Sensitivity (2 x CO₂)
Nominal 1° resolution with a Slab Ocean Model (SOM)

CCSM3: 2.9°C  CMIP3 (AR4)
CCSM4 (CAM4): 3.2°C  CMIP5 (AR5)
CESM1 (CAM5): 4.1°C
CESM2.0: 5.3°C  CMIP6 (AR6)

Figure from Eyring, CMIP6 Barcelona Workshop
Paleoclimate informing models: Energy Balance Analysis

Tropics dominated by changes in GHGs

High latitudes dominated by changes in cryosphere

Figure from courtesy of Ran Feng
Paleoclimate informing models: SSTs

Tropics: n=166
MPWP 3.3–3 Ma: n=37
EECO 54–48 Ma: n=10

IPCC AR5 WG I, 2013
Paleoclimate informing models: Example from LGM

**Change in surface temperature**

<table>
<thead>
<tr>
<th>Model</th>
<th>Temperature Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCSM4 LGM</td>
<td>-5.5°C</td>
</tr>
<tr>
<td>CESM1.2</td>
<td>-6.8°C</td>
</tr>
</tbody>
</table>

**Change in SST**

- Simulated Tropical ΔTS: -2.4°C
- Simulated Tropical ΔTS: -3.6°C
Paleoclimate informing models: Data vs Model

Tropical

\[\Delta T \text{ (}\degree\text{C)}\]

- LGM
- LGM
- LGM-CO2
- mPWP-MIP1
- mPWP-MIP1
- mPWP-MIP2
- 4xCO2
- EECO-3xCO2
- EECO-6xCO2

\[\blacktriangledown = \text{CCSM4}\]
\[\blacktriangle = \text{CESM1.2}\]

CESM1_PlioMIP2 vs. Marine-based Proxy

- CESM1_PlioMIP2
- SST-Proxy

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Paleoclimate informing models: Other indices

Tropics (23S-23N)

- Greater cooling/warming over land than ocean [1.5:1]

Pacific Equatorial E-W ΔTS Slope

- Flatter
- Greater cooling/warming in Eastern than Western Pacific
- Steeper

NH Meridional ΔTS

- Reduced
- Enhanced
- Greater cooling/warming at high than low latitudes

Still needed: Data!
How should models inform paleoclimate?
How should paleoclimate inform models?
Together
How should models inform paleoclimate? How should paleoclimate inform models?

1. Useful information for future climate change can also be provided from times in the geologic past when CO$_2$ and other GHGs were lower than today, and from times with transient increases in CO$_2$.

2. Simulation of water isotopes and other geotracers in models, and understanding the climatic and non-climatic factors influencing their signals in geologic archives, will enhance model-data comparisons.

3. Should look across multiple time periods, for multiple climate indices (not just ECS), and with multiple models and proxies in answering these questions.