Climate Sensitivity Estimates From Paleoclimate (LGM) Data

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May 22, 2013
Lamont Doherty Earth Observatory
Columbia University
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With help from
N. Urban, J. Shakun, N. Mahowald, P. Clark, A. Mix, P. Bartlein, A. Rosell-Mele

Funded by NSF’s Paleoclimate Program

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Reconstructions from
- Sea Surface Temperatures
  Multiproxy: MARGO (2009)
- Land Surface Air Temperature
  Pollen: Bartlein et al. (2010)
- Additional data
  Shakun et al. (2012)

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ΔSST_{LGM} = -1.9±1.8 K

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Tuesday, May 28, 13
Climate Sensitivity

\[ CS = \frac{\Delta T}{\Delta F} \]

\( \Delta T \): global mean surface air temperature change [K]
\( \Delta F \): forcing = instantaneous perturbation of radiative balance at the top of the atmosphere [W/m\(^2\)]

\[ \text{ECS}_{2x} = \Delta T_{2x} \]

\( \text{ECS}_{2x} \): Equilibrium Climate Sensitivity for a doubling of atmospheric CO\(_2\)
\[ \Delta F_{2x} = 3.7 \text{ W/m}^2 \pm 10\% \]


small. Figure 3 further shows that studies that use information in a relatively complete manner generally find a most likely value between 2 and 3.5 °C and that there is no credible line of evidence that yields very high or very low climate sensitivity as a best estimate. However, the figure also quite dramatically illustrates that the upper limit for S is uncertain and exceeds 6 °C or more in many studies. The reasons for this, and the caveats and limitations,
Let’s assume a high climate sensitivity.

\[ \Delta T_{2xC} = 8K \]

Let’s also assume climate sensitivity does not depend on the background climate.

\[ \frac{\Delta T_{LGM}}{\Delta F_{LGM}} = \frac{\Delta T_{2xC}}{\Delta F_{2xC}} \]

\[ \rightarrow \Delta T_{LGM} = \frac{\Delta T_{2xC}}{\Delta F_{2xC}} \Delta F_{LGM} \approx \frac{8K}{4 \text{Wm}^{-2}} 6 \text{Wm}^{-2} = 12K \]
Approach:

1. Use models with different climate sensitivities
2. Numerical experiments:
   1. Control
   2. 2xCO$_2$
   3. LGM
3. Compare with LGM reconstructions

Schmittner et al. (2011) Science
University of Victoria Climate Model (Weaver et al. 2001) includes 2D (1 layer) energy moisture balance atmosphere, 3D ocean general circulation model, sea ice, vegetation (Model of Intermediate Complexity)

Symbols: Observations
Lines: Models with different ECS

Only one model parameter varied!

Schmittner et al. (2011) Science
LGM simulations include forcing due to:

- insolation changes
  \[ \Delta F_{\text{ins}} = 0 \text{ W/m}^2 \]
- greenhouse gases
  \[ \Delta F_{\text{GHG}} = \Delta F_{\text{CO}_2} + \Delta F_{\text{CH}_4} + \Delta F_{\text{N}_2\text{O}} = -2.8 \text{ W/m}^2 \]
- ice sheet
  \[ \Delta F_{\text{sfc}} = -2.2 \text{ W/m}^2 \]
- dust
  \[ \Delta F_{\text{dust}} = -0.9 \text{ W/m}^2 \]

\[ \Delta F_{\text{LGM}} = \Delta F_{\text{sfc}} + \Delta F_{\text{GHG}} + \Delta F_{\text{dust}} = -5.9 \text{ W/m}^2 \]

Mahowald et al., (2006) JGR
Zonally Averaged Temperature Changes
(LGM minus modern)

- black line: reconstructions
- grey shadings ± 1, 2, 3 K
- colored lines: models

Schmittner et al. (2011) Science
High climate sensitivity models simulate a completely snow and ice covered planet (Snowball Earth)

Schmittner et al. (2011) Science
Comparison of best-fitting model with reconstructions

\[ \Delta T_{LGM} = -3 \pm 0.7 \text{ K} \]

\[ \Delta SST_{LGM} = -1.7 \pm 0.4 \text{ K} \]

\( r = 0.5 \)

Schmittner et al. (2011) Science
Bayesian Statistics (Nathan Urban): Probability Distribution for $\text{ECS}_{2x\text{C}}$

- Best estimate (median) $2.3\text{ K}$ (may be biased)
- 66% probability $1.7 - 2.6\text{ K}$ (may be overconfident)
- 90% $1.4 - 2.8\text{ K}$ (may be overconfident)

Schmittner et al. (2011) Science

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Issues

• **Reconstruction bias**: e.g. low resolution cores

• **Model bias**: best fitting model underestimates polar amplification and land-sea contrast (perhaps related to atmospheric heat flux parameterization, see comment by Fyke and Eby (2012) Science)

• Results may be biased or overconfident since
  
  - Uncertainty due to cloud albedo changes not considered
  
  - Forcing uncertainty not considered
  
  - Relation between LGM and 2xCO₂ may be model dependent
Annan and Hargreaves (2013, CP): PMIP2 models scaled to match data

\[ \Delta T_{LGM} = (4 \pm 0.8) \, \text{K} \quad (95\% \, \text{CI}) \quad r=0.73 \]
mean(ECS) = 2.3 K
5 - 95% = 0.5 - 4 K

Hargreaves et al. (2013) GRL
LGM constraints on climate sensitivity

- High values (>6 K) seem exceedingly unlikely
- Median ~ 2.5 K
- Future work will need to incorporate more uncertainties in a larger model ensemble
### PMIP3 Models

<table>
<thead>
<tr>
<th>Model</th>
<th>ΔSAT (°C)</th>
<th>ΔSST (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCSM4</td>
<td>-4.9</td>
<td>-2.4</td>
</tr>
<tr>
<td>CNRM-CM5</td>
<td>-2.7</td>
<td>-1.2</td>
</tr>
<tr>
<td>GISS-E2-R</td>
<td>-5.3</td>
<td>-2.6</td>
</tr>
<tr>
<td>IPSL-CM5A-LR</td>
<td>-4.6</td>
<td>-2.5</td>
</tr>
<tr>
<td>MIROC-ESM</td>
<td>-4.9</td>
<td>-2.3</td>
</tr>
<tr>
<td>MPI-ESM-P</td>
<td>-4.4</td>
<td>-2.0</td>
</tr>
<tr>
<td>MRI-CGCM3</td>
<td>-4.7</td>
<td>-2.6</td>
</tr>
<tr>
<td>Model Mean</td>
<td>-4.5±0.8</td>
<td>-2.2±0.5</td>
</tr>
<tr>
<td>Observations</td>
<td>-4.0±0.8*</td>
<td>-1.9±1.8**</td>
</tr>
</tbody>
</table>

- ** MARGO

\[ r = 0.63 \]
Thanks
Climate sensitivity estimated through weighting of the PMIP models

median of 2.5°C.
5–95% range of 1.0–4.2°C

Hargreaves et al. (2013) GRL
Efficacy of LGM Forcing = $CS_{LGM}/CS_{2xC}$
