Update on the simulation of the Last Glacial Maximum using CESM2

Jiang Zhu


Acknowledgements: AMWG, LMWG, …

Credit: J. Tierney
CESM2 has an ECS > 5°C

Kiehl et al., 2006; Bitz et al., 2011; Gettelman et al., 2012, 2019; Danabasoglu et al., 2020; Bacmeister et al., 2020; Bjordal et al., 2020
Constraining ECS using the Last Glacial Maximum (LGM)

- LGM global cooling correlates with ECS
  (Shin et al., 2003; Otto-Bliesner et al., 2006; Brady et al., 2013; Zhu et al., 2017, 2020)

- The latest LGM global cooling: ~6°C
  (Tierney et al., Nature, 2020)
LGM simulations

- CESM2 (∼CMIP6 configuration)
  - BGCs off; No-Anthro; RTM; …
  - PI climate and ECS not impacted

- Boundary conditions
  - Lower GHGs
  - Land ice sheets: topography, land surface properties & shelf exposures
  - PI aerosol, vegetation & tidal mixing

- Initial condition: CESM1 LGM
CESM2 LGM is too cold in global mean surface temperature
CESM2 LGM is too cold in sea-surface temperature
SW cloud feedback explains the excessive LGM cooling in CESM2

<table>
<thead>
<tr>
<th></th>
<th>ΔGMST</th>
<th>ΔN</th>
<th>F_{eff}</th>
<th>λ_{eff}</th>
<th>ΔGMST</th>
<th>ΔN</th>
<th>F_{eff}</th>
<th>λ_{eff}</th>
<th>4×CO2</th>
<th>4×CO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CESM2</td>
<td>−11.3</td>
<td>−0.2</td>
<td>−5.2</td>
<td>−0.48</td>
<td>0.76</td>
<td>0.87</td>
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<tr>
<td>CESM1</td>
<td>−6.8</td>
<td>0.06</td>
<td>−6.0</td>
<td>−0.88</td>
<td>0.35</td>
<td>0.48</td>
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<tr>
<td>Diff.</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
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LGM \( \lambda_{\text{sw\_cloud}} \propto 4\times\text{CO2} \lambda_{\text{sw\_cloud}} \)

![Graph showing LGM and 4xCO2 SW λ_{\text{sw\_cloud}} variations](image)
CESM2 LGM is too cold, ECS is too high, and it’s the cloud.

Why?

Gettelman et al., 2019
Cloud microphysics and/or ice nucleation produces unrealistic LGM

- CAM6
- HetFrzOff: old ice nucleation
- Mg2Off: old microphysics
- ClubbOff: old turbulence & ShCu
- SB2001: alternative autoconversion/accretion

Proxy data
### Lower ECS in LGM constrained configurations

<table>
<thead>
<tr>
<th>Model</th>
<th>$\Delta T_{\text{LGM}}$</th>
<th>ECS</th>
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</thead>
<tbody>
<tr>
<td>CAM6</td>
<td>$-9.0^*$</td>
<td>6.1</td>
</tr>
<tr>
<td>HetFrzOff</td>
<td>$-5.9$</td>
<td>3.8</td>
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<tr>
<td>Mg2Off</td>
<td>$-6.3$</td>
<td>4.3</td>
</tr>
<tr>
<td>ClubbOff</td>
<td>$-8.9^*$</td>
<td>6.2</td>
</tr>
<tr>
<td>SB2001</td>
<td>$-7.0^*$</td>
<td>5.2</td>
</tr>
<tr>
<td>CAM5</td>
<td>$-6.5$</td>
<td>3.7</td>
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</tbody>
</table>

* Far from equilibrated

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**Graph:** The graph shows the relationship between LGM SW $\lambda_{\text{clgd}}$ on the x-axis and 2xCO2 SW $\lambda_{\text{clgd}}$ on the y-axis. The data points indicate a positive correlation, with most models showing a lower ECS in LGM constrained configurations. The dashed line represents the equilibrated condition, while the dots represent the models with different ECS values.
Cloud microphysics and/or ice nucleation is not working well within CAM6

- Challenging to do it correctly
  - Simulate past cold & warm climates (e.g., Eocene)
  - Simulate present-day observation and historical warming
  - Agree with process understanding

- CESM2(CAM5): No WACCM5; Bad mean state mixed phase clouds