Simulations of the last deglaciation using the Glimmer ice-sheet model and a fully coupled GCM (GENMOM)

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Outline

1. Experimental setup
2. Build-up of Laurentide Ice Sheet
3. Deglaciation of Laurentide Ice Sheet
4. Sensitivity experiments
   – Fixed CO$_2$
   – Fixed insolation
5. PMIP3 model evaluation
(1) Experimental setup

• AOGCM GENMOM (v. 3 Genesis ATM model & v. 2 MOM OCN model: 3.75°x 3.75° [Alder et al. (2011)]

• Simulated climate at 8 time periods:
  – 21, 18, 15, 12, 9, 6, 3 ka and Pre-industrial

• Appropriate boundary conditions
  – Insolation [Berger and Loutre, 1991]
  – GHG [Monnin et al., 2001; Brook et al., 2000], Sowers et al., 2003]
• Orography:
  – ICE 4G for Fennoscandian and Cordilleran ice sheets [Peltier, 2002]
  – Oregon State University reconstruction of Laurentide Ice Sheet (OSU-LIS-MAX) [Licciardi et al., 1998].
(2) Build up of Laurentide Ice Sheet

- Used a constant LGM forcing of monthly means for temp./precip. (last 400 years of 21ka output).
- Default input parameters for Glimmer used (no isostasy).
- Initial run: Ice-sheet extent too large.
## Sensitivity to parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value Used</th>
<th>Min</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{PDD}_{\text{snow}}(\alpha_s)$</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>mm d$^{-1}$ °C$^{-1}$</td>
</tr>
<tr>
<td>$\text{PDD}<em>{\text{ice}}(\alpha</em>{\text{ice}})$</td>
<td>8</td>
<td>7</td>
<td>12</td>
<td>mm d$^{-1}$ °C$^{-1}$</td>
</tr>
<tr>
<td>Flow Factor</td>
<td>3</td>
<td>1</td>
<td>10</td>
<td>none</td>
</tr>
<tr>
<td>Mantle Relaxation time</td>
<td>1000</td>
<td>300</td>
<td>9000</td>
<td>years</td>
</tr>
<tr>
<td>Geothermal Heat Flux</td>
<td>50</td>
<td>35</td>
<td>65</td>
<td>W m$^{-2}$</td>
</tr>
<tr>
<td>Marine Limit</td>
<td>-200</td>
<td>-100</td>
<td>-500</td>
<td>m</td>
</tr>
</tbody>
</table>
Varying basal sliding

Brown: sediment thickness < 20m (i.e. Hard bed) – Basal sliding = 0.5 mm yr\(^{-1}\) Pa\(^{-1}\)
White: Sediment thickness > 20m – Basal sliding = 5 mm yr\(^{-1}\) Pa\(^{-1}\)

[Laske and Masters (1997)]
Results

PDD and basal sliding parameters have largest effect on ice-sheet extent and volume.

21ka “Un-tuned”

21ka “Tuned”
(3) Ice-sheet deglaciation

21ka

18ka

15ka

12ka

9ka

6ka

Ice thickness (m)
Volume Comparisons

<table>
<thead>
<tr>
<th>Ice Volume (10^6 km^3)</th>
<th>Age kyr BP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ice-5G</td>
<td>21, 18, 15, 12, 9</td>
</tr>
<tr>
<td>Glimmer</td>
<td>21, 18, 15, 12, 9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Glimmer-Licciardi Mask</th>
<th>Licciardi reconstruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>21, 18, 15, 12, 9</td>
<td>21, 18, 15, 12, 9</td>
</tr>
</tbody>
</table>
Results

• GENMOM climatology results in an ice sheet simulated by Glimmer comparable to reconstruction. Glimmer simulation validates GENMOM climatology.
(4) Sensitivity to forcings

Diagram:
- 21ka All forcings
  - 18ka CO₂ only
    - 15ka CO₂ only
      - 12ka CO₂ only
        - 12ka Insolation only
  - 18ka Insolation only
    - 15ka Insolation only
      - 12ka Insolation only
        - 9ka Insolation only

Fixed GHG

Fixed Insolation
GHG only

Insolation only
Volume Comparisons

Ice Volume (10^6 km^3)

- **All Forcings**
- **GHG Only**
- **Insolation Only**

Age kyr BP

21 18 15 12 9
Results

• Similar mass loss for all three forcing scenarios.
• Good agreement suggests strong influence of ice-sheet boundary condition in GENMOM in producing a climatology that results in an ice sheet simulated by Glimmer comparable to reconstruction, regardless of forcing.
(5) Sensitivity to GCM used (PMIP3)

Forced with constant LGM climate, but varied PDD factors.

<table>
<thead>
<tr>
<th>Label</th>
<th>pdd_ice</th>
<th>pdd_snow</th>
<th>notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>p0</td>
<td>0.006</td>
<td>0.001</td>
<td>high ice</td>
</tr>
<tr>
<td>p1</td>
<td>0.007</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>p2</td>
<td>0.008</td>
<td>0.003</td>
<td></td>
</tr>
<tr>
<td>p3</td>
<td>0.009</td>
<td>0.004</td>
<td></td>
</tr>
<tr>
<td>p4</td>
<td>0.01</td>
<td>0.005</td>
<td></td>
</tr>
<tr>
<td>p5</td>
<td>0.011</td>
<td>0.006</td>
<td></td>
</tr>
<tr>
<td>p6</td>
<td>0.012</td>
<td>0.007</td>
<td>low ice</td>
</tr>
</tbody>
</table>
Thickness (p3)
Thickness (p6)
Area Summary
Results

• Models exhibit different sensitivity to changes in pdd factors.

• Three models agree with the extent of the Laurentide Ice Sheet at the LGM, using the P3 factor (GENMOM, MPI-ESM-P, IPSL-CM5A-LR). Two models have too little ice, three models have too much ice in Beringia.

• Glimmer simulations used to validate GCM climatologies.
Conclusions and future work

• Glimmer is useful for addressing the performance of a GCM climatology in reconstructing ice-sheet extent.

• An interactive ice sheet-climate model (i.e., CESM) is needed to address ice-sheet sensitivity to insolation and GHG and the feedbacks associated with the changes.
Extras
Volume – by model

PDD Sensitivity Tests

Ice volume ($10^6 km^3$)

Year (x 1000)

CCSM4
CNRM-CM5
GENMOM
GISS-E2-R

IPSL-CM5A-LR
MIROC-ESM
MPI-ESM-P
MRI-CGCM3

p0  p1  p2  p3  p4  p5  p6
Area Summary

PMIP3/Glimmer NA ice area vs ICE6G

Ice area ($10^6$ km$^2$)

Models:
- CCSM4
- CNRM-CM5
- GENMOM
- GISS-E2-R
- IPSL-CM5A-LR
- MIROC-ESM
- MPI-ESM-P
- MRI-CGCM3

Legend:
- p0
- p1
- p2
- p3
- p4
- p5
- p6
- p7
- p8
Volume Summary

PMIP3/Glimmer NA ice volume

Ice volume (10^6 km^3)


Legend:
- p0
- p1
- p2
- p3
- p4
- p5
- p6
- p7
- p8
We projected the ETOPO1 data from a 1′ longitude-latitude grid onto our cartesian grids using a Lambert Equal Area Azimuthal projection (Snyder, 1987). This projection was chosen because it is an equal area projection and is suitable for continent size mapping.