Using CESM and CISM to simulate the long-term evolution of climate and the Greenland Ice Sheet during the Last Interglacial (~129,000 to 116,000 yrs ago)

Bette Otto-Bliesner

Marcus Löfverström, Bill Lipscomb, Jeremy Fyke, Shawn Marshall, Ran Feng, Bill Sacks

Photo by Leo Kampenhout
Last Interglacial [129-116 ka] – Some Evidence from Data

**Ice cores**
- 6 deep ice-coring projects have reached ice layers back to LIG
- **NEEM**: surface elevation estimated 130 ± 300 m below present
- Annual temperatures
  - NEEM: +7 to +11°C
  - GISP2: +4 to +8°C
- **Dye 3**: new analysis suggests basal ice predates LIG

Raynaud et al., 1997; Johnsen et al., 2001; NorthGRIP, 2004; NEEM, 2013; Yau et al., 2016

**Marine cores**
- ODP sites offshore contain sediment sourced from Greenland
  - **ODP 626**: silt provenance suggests SGrIS present, smaller than in Holocene
  - **ODP 626**: shrub tundra and dense fern vegetation over S. Greenland
- **ODP 918 & 987**: stable ice sheet in E. Greenland for most of past million years

De Vernal et al, 2008; Colville et al., 2011; Hatfield et al., 2016; Bierman et al., 2016

Less sea ice
Northward extension of boreal forests
### Past Modeling of Greenland Ice Sheet during the Last Interglacial

**Global sea level highstand 6-9 meters**

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<th>Study</th>
<th>SMB method</th>
<th>GIS melting</th>
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<td>Stone et al. (2012)</td>
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<td>Goezler et al. (2016)</td>
<td>Synch, 2-way coupling global model</td>
<td>1.4</td>
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Early Last Interglacial (128 – 124 ka)

- Large boreal summer insolation anomalies (128-124ka) resulting from orbital forcing assume 127ka insolation anomalies representative.
- Stable GHG concentrations similar to late Holocene
- Continental and oceanic configurations almost identical to modern

**CESM1.5 (FV1x1) coupled to CISM1 (4km)**

1) LIG 127ka orbital forcing [LIG]
   - 2000 CISM yrs, 155 CESM yrs

2) LIG 127ka orbital forcing + (idealized) boreal forests to Arctic Ocean in North America and Eurasia [LIGveg]
   - + 2000 CISM yrs, 80 CESM yrs

Capron et al., QSR, 2017
Evolution of Greenland annual surface temperatures

**LIG simulation**
(Seasonal insolation anomalies)

**LIGveg simulation**
(+Boreal forests extended northward)

<table>
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<tr>
<th>Year</th>
<th>NEEM Ann ΔT</th>
<th>Summit Ann ΔT</th>
<th>Global Mean Ann ΔT</th>
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<tr>
<td>2000</td>
<td>+4°C</td>
<td>~0°C</td>
<td>0°C</td>
</tr>
<tr>
<td>4000</td>
<td>+12°C</td>
<td>~2°C</td>
<td>0.7°C</td>
</tr>
</tbody>
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Global Mean Ann ΔT: 0°C

Global Mean Ann ΔT: 0.7°C!
Evolution of Greenland ice sheet thickness

1) LIG simulation

- Overall SMB > 0
- Ice sheet area: ~96% modern
- SLE: 0.6 meters
Evolution of Greenland ice sheet thickness

2) LIGveg simulation
- Overall SMB < 0
- Ice sheet area: ~85% modern
- SLE: 1.8 meters

1) LIG simulation
- Overall SMB > 0
- Ice sheet area: ~96% modern
- SLE: 0.6 meters
Evolution of Greenland ice sheet

Sea-level equivalent

LIG: SLR: 0.1 m/kyr

LIGveg: SLR: 0.7 m/kyr

Calving
Summary

- Thickness change at ice cores
  - CampCentury: -450m
  - NEEM: -400m
  - NGRIP: -200m
  - Summit: -40m
  - Renland: +20m
  - Dye 3: -200m
Next steps

- Transient simulation
  - Rerun with final CESM2 configurations and spunup GrIS initial state
  - Refine vegetation map
  - New calving/marine basal melt parameterizations, possibly
Peak Global Mean Sea Level during the Last Interglacial

**Last Interglacial**

[129 – 116 ka]
Two Exploratory Simulations Last Interglacial (128 – 124 ka)

1) LIG 127ka orbital forcing [LIG]
   - 2000 CISM yrs, 155 CESM yrs

2) LIG 127ka orbital forcing + (idealized) boreal forests to Arctic Ocean [LIGveg]
   - + 2000 CISM yrs, 80 CESM yrs
Surface mass balance - Comparison to RACMO2.3

\[ \text{SMB} = \text{Snow} + \text{Rain} - \text{Runoff} - \text{Sublimation} \]

**Snow**
- PI ctrl ANN
- RACMO2.3 ANN 1970-1989

**Runoff**
- PI ctrl ANN
- RACMO2.3 ANN 1970-1989

Solid precipitation (snow) [mmWE / yr]

Runoff [mmWE / yr]
CESM (FV1x1) – CISM (4 km) – two-way coupling

Land -> Ice Sheet
- 10 elevation classes + bare land
  - Surface mass balance
  - Surface elevation
  - Surface temperature

Ice Sheet -> Land
- Ice extent
- Ice surface elevation
- SMB mask

Ice Sheet -> Ocean
- Solid and liquid fluxes

Ice Sheet -> Atmosphere (offline)
- Surface topography

Ocean
CLIMATE: Greenland & Arctic sea ice

Seasonal cycle over Greenland

JAS Sea ice thickness
Preindustrial

Surface meltwater

Land: 60-90N, 60-20W