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 $130 \pm 300$ 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
### Past Modeling of Greenland Ice Sheet during the Last Interglacial

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

<table>
<thead>
<tr>
<th>Study</th>
<th>SMB method</th>
<th>GIS melting (m of sea level equivalent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Huybrechts (2002)</td>
<td>Index</td>
<td>5.5</td>
</tr>
<tr>
<td>Tarasov and Peltier (2003)</td>
<td>Index</td>
<td>2.7–4.5</td>
</tr>
<tr>
<td>Lhomme et al. (2005)</td>
<td>Index</td>
<td>3.5–4.5</td>
</tr>
<tr>
<td>Born and Nisancioglu (2012)</td>
<td>GCM snapshots</td>
<td>4.2–5.9</td>
</tr>
<tr>
<td>Otto-Bliesner et al. (2006)</td>
<td>One-way GCM coupling</td>
<td>2.2–3.4</td>
</tr>
<tr>
<td>Stone et al. (2012)</td>
<td>One-way GCM coupling</td>
<td>0.6–3.5</td>
</tr>
<tr>
<td>Robinson et al. (2011)</td>
<td>Energy-moisture coupling</td>
<td>0.4–4.4</td>
</tr>
<tr>
<td>Quiquet et al. (2013)</td>
<td>Index method</td>
<td>0.7–1.5</td>
</tr>
<tr>
<td>Helsen et al. (2013)</td>
<td>Asynch, 2-way coupling reg model</td>
<td>1.2-3.5</td>
</tr>
<tr>
<td>Calov et al. (2015)</td>
<td>Asynch, 2-way coupling reg model</td>
<td>0.6-2.5</td>
</tr>
<tr>
<td>Yau et al. (2017)</td>
<td>Asynch, 2-way coupling reg model</td>
<td>4.1-6.2</td>
</tr>
<tr>
<td>Goezler et al. (2016)</td>
<td>Synch, 2-way coupling global model</td>
<td>1.4</td>
</tr>
</tbody>
</table>
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

Capron et al., QSR, 2017

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
Evolution of Greenland annual surface temperatures

**LIG simulation**
(Seasonal insolation anomalies)

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

YR 2000

NEEM Ann $\Delta T$: +4°C
Summit Ann $\Delta T$: ~0°C

Global Mean Ann $\Delta T$: 0°C

YR 4000

NEEM Ann $\Delta T$: +12°C
Summit Ann $\Delta T$: ~2°C

Global Mean Ann $\Delta T$: 0.7°C
Evolution of Greenland ice sheet thickness

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

LIG: SLR: 0.1 m/kyr

LIGveg: SLR: 0.7 m/kyr
• ~ 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]

Dutton et al., Science, 2015
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

Legend:
- Cushion forb tundra
- Graminoid and forb tundra
- Prostrate dwarf-shrub tundra
- Erect dwarf-shrub tundra
- Low- and high-shrub tundra
- Cold evergreen needleleaf forest
- Cold deciduous forest
Surface mass balance - Comparison to RACMO2.3

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

**Snow**

**Runoff**

![Solid precipitation (snow) [mmWE / yr]](image1)

![Runoff [mmWE / yr]](image2)
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

Land surface
(Ice sheet surface mass balance)

Ice sheet -> Atmosphere
(offline)
- Surface topography

Ice sheet -> Ocean
- Solid and liquid fluxes

CESM

Atmosphere

Coupler

Ocean

Sea Ice
CLIMATE: Greenland & Arctic sea ice

Seasonal cycle over Greenland

JAS Sea ice thickness
Preindustrial

Land: 60-90N, 60-20W

Surface meltwater

LIG
LIGveg

Surface meltwater