Simulating the last deglaciation with the isotope-enabled CESM

Presenter: Esther Brady

Collaborators: B. Otto-Bliesner\textsuperscript{1}, Z. Liu\textsuperscript{2}, R. Tomas\textsuperscript{1}, A. Jahn\textsuperscript{3}, K. Lindsey\textsuperscript{1}, S. Gu\textsuperscript{2}, C. He\textsuperscript{2}, J. Zhang\textsuperscript{2}, J. Zhu\textsuperscript{2}

\textsuperscript{1}NCAR/CGD Paleoclimate group  
\textsuperscript{2}Univ. of Wisc./Madison  
\textsuperscript{3}Univ. of Colorado/Boulder

Paleoclimate Working Group  
NCAR CESM Workshop  
June 22, 2017
Abrupt Climate Changes over the last deglacial

Dome C δD (per mil) | Hulu/Dongge δ¹⁸O (per mil)
---|---
0 | Present
8.2 ka
14 | Bolling-Allerod
16 | Heinrich 1
22 | Last Glacial Maximum

Age (ka)

Courtesy, B. Otto-Bliesner

NCAR | Last Deglacial with iCESM

air • planet • people
Outline

• Review of TraCE-21
  – Introduce new tool for data-model comparison: Paleoview
• Overview of iTraCE, stable water isotope-enabled long transient simulation of the last deglaciation
  – Design of experiments
  – Spin up and status
• iCESM comparison to Obs.
• Preliminary Results
• Update status on iCESM2
TRACE-21ka Project

- Simulation of deglacial climate evolution from 22ka to 0ka
  - Co-Pis: B. Otto-Bliesner & Z. Liu (Univ. Wisc.)
  - T31x3 CCSM3
  - Transient Forcing (GHG, Orbital, Ice sheet, Land/ocean mask)
  - Many sensitivity runs for different meltwater scenarios
  - Full forcing, and Single forcing runs

Evolution of Surface Temperature
22ka to 14ka, through HS1

Liu et al. Science, 2009
Community Usage of TraCE-21 output

• Time series on the Earth System Grid (https://www.earthsystemgrid.org/project/trace.html)

• Many publications by external community
PaleoView 1.0


- Freeware (https://github.com/GlobalEcologyLab/PaleoView)
- Inputs CCSM3 TRACE-21 monthly time series (Liu et al. 2009)

Mean, min, max Temp;
Precipitation;
Rel. Humidity;
Sea Level Pressure;

Fig. 1, Fordham et al. 2017
Last Deglaciation Experiment with iCESM


- Isotope-enabled, multi-tracer enabled CESM1.3

- iTRACE: NCAR-UW/Madison collaboration
  - Spin up for 21ka conditions,
  - Transient simulation (20ka -> 14ka)

Fig. from Ivanovic et al. 2016
ITRACE Project

- Goals:
  - Improve Model-Proxy comparisons
  - Investigate the proxy-climate relationships that provide inferences of deglacial climate change. These have many assumptions built in like stationarity and locality.

- Joint NCAR/UWisc., NSF-funded project

- PIs: Z. Liu (U Wisc.) and B. Otto-Bliesner (NCAR) with: R. Tomas, E. Brady (NCAR) J. Zhu, C. He, S. Gu, J. Zhang (Univ. Wisc./Madison) A. Jahn (Univ. CO, Boulder)

- Using NCAR CISL project resources (Glade and Yellowstone)

- Eventually published SVF output on ESG
iTRACE design

- CESM1.3 (CAM5.3, POP2, CLM4, RTM, CICE4; isotope tag)
- Updated Deglacial Forcing from PMIP4 design protocols

- Improved resolution vs. TraCE-21 (T31x3):
  - FV1.9x2.5 CAM5.3
  - gx1 POP2, 60 vertical levels, Greenland grid

- Updated LGM Boundary Conditions to PMIP4
  - LGM land/ocean mask and KMT from Dinezio et al. Paleoceanog. 2016
  - ICE6G ice sheets (Peltier et al. 2015; PMIP4 protocols)

- Forcing ‘Factorization’ simulations:
  - Ice: Transient Ice Sheet “ice” from ICE6G
  - Ice+orbital
  - Ice+orbital+ghg
  - Ice+orbital+ghg+meltwater flux

- Multiple Tracers
  - Stable water isotopes (Atmosphere, Land, ocean, sea ice, runoff)
  - Abiotic 14C and 12C (ocean only, A. Jahn)
  - Abiotic Protactinium, Thorium (ocean only, S. Gu)
  - Neodymium isotopes (ocean only, S. Gu)
Factorization Experiments

- Will provide the minimal set of factorization experiments:
  - Preindustrial, LGM (21ka) controls
  - ICE ICE-6G_C (Peltier et al. 2015)
    - Change TOPO, land surface at 20ka, 18ka, 17ka, 16ka, 15ka, 14k
  - ICE+ORB
    - Same as ICE, plus orbital parameters change yearly
  - ICE+ORB+GHG
    - Same as ICE+ORB, plus ghg from Ivanovic et al. 2016
  - ICE+ORB+GHG+MELT
    - Same as ICE+ORB+GHG, plus meltwater from TraCE-21
**Factorization vs. Single Forcing**

--A minimal set of factorization experiments:

- \(dT_{ice} = T_{ice} - T_{LGM \text{ Control}}\)  
  Run vs. Control
- \(dT_{orb} = T_{ice+orb} - T_{ice}\)
- \(dT_{ghg} = T_{ice+orb+ghg} - T_{ice+orb}\)
- \(dT_{melt} = T_{ice+orb+ghg+melt} - T_{ice+orb+ghg}\)
- \(dT_{full} = T_{ice+orb+ghg+melt} - T_{control}\)

Includes non-linear responses in combinations of forcings
Spin-up Procedure

- LGM ocean bathymetry, land/ocean mask from DiNezio et al. 2016
- New Orography from ICE-6G_C as per PMIP4 protocol

- Ocean TEMP, SALT IC from DiNezio et al. 2016, which came from CCSM4 PMIP3 21ka simulation (Brady et al. 2012)
  - Ocean physical state spun up: ~2570 years
  - Ocean isotopes spun up: ~920 years

- Newton-Krylov method for radiocarbon, IAGE (K. Lindsay)
  - After 900 years at 21ka

- Transient forcing applied at start of iTRACE at 20ka.
Cooling response over Spin Up

Newton-Krylov spin up of abiotic radiocarbon tracers (w/K. Lindsay)

<table>
<thead>
<tr>
<th>Case</th>
<th>$T_{SLGM} - T_{SPI}$ (°C)</th>
<th>RESTOM (W m$^{-2}$)</th>
<th>#years</th>
<th>BCs</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCSM4</td>
<td>-5.5</td>
<td>-0.26</td>
<td>+1350</td>
<td>21ka PMIP3</td>
</tr>
<tr>
<td>CESM1.2-CAM5</td>
<td>-6.3</td>
<td>-0.01</td>
<td>+300</td>
<td>21ka PMIP3 (no CN)</td>
</tr>
<tr>
<td>CESM1.3-CAM5</td>
<td>-7.5</td>
<td>-0.15</td>
<td>+911</td>
<td>21ka PMIP4 (no CN)</td>
</tr>
<tr>
<td>CESM1.3-iTRACE</td>
<td>-7.5</td>
<td>-0.07</td>
<td>+2000</td>
<td>20ka PMIP4 (no CN)</td>
</tr>
</tbody>
</table>
Preindustrial d18Op vs. Obs.

(a) and (b) show maps of weighted d18Op with per mil values. The maps illustrate distinct geographical patterns of d18Op values.

Courtesy, J. Zhu, 2017
$\delta^{18}O$ in Precipitation vs. Polar Observations

Greenland Icecore & Snow Obs. (Faber, 2016)

Antarctica Snow Obs. from ITASE, Masson-Delmotte et al. 2008
Preindustrial Model vs. Obs: d18Osw

\[^{18}\text{O}_{sw}\] vs. SSS vs. Obs.

Courtesy J. Zhu, 2017

Obs from Legrande and Schmidt, 2006
LGM – PI $\delta^{18}$O

$\delta^{18}$Ow

$\delta^{18}$Oc

$T = 16.9 - 4.38(\delta^{18}$Oc - $\delta^{18}$Ow - 0.27‰) \text{ ‘Paleotemperature’}$

Pore water Estimates (Adkins et al. 2002; Schrage et al. 2002; Malone et al. 2004)

Bentic Foram $\delta^{18}$Oc

LGM – PI $\delta^{18}Op$ over Polar IS

Courtesy, J. Zhu, 2017
Full Forcing Simulation (ICE+ORB+GHG+Melt)

Courtesy Chengfei He, Univ. of Wisc./Madison
Posters with iCESM1 applications

• Jesse Nusbaumer (NASA-GISS) Water Isotopes in CAM6: First results and a comparison to previous versions
• Kyle Niegoza (OSU) Characterizing the Mid-Holocene the tropical hydrologic cycle using simulated water isotopes
• Ran Feng (NCAR) Simulating mid-Piacenzian warm period with water isotope tracking enabled CESM
• Clay Tabor (NCAR) Interpreting speleothem records from the Asian Monsoon region with iCESM
• Aaron Schroeder (CU-Boulder) Assessing ocean circulation changes at the LGM using radiocarbon simulations with the iCESM
Isotope-enabled CESM2

- CAM6 --- J. Nusbaumer, D. Noone, A. Gettelmann
- CLM5 --- B. Andre, D. Noone, J. Tang, W. Riley, A. Wong
- POP2 --- J. Zhang, E. Brady, J. Zhu
- CICE5 --- D. Bailey, J. Zhu
- MOSART --- H. Li, B. Andre
- CPL --- M. Vertenstein

- SEs: C. Craig, B. Andre, M. Vertenstein

- To be released as “CESM2.1” Late 2017.
#### Status: iCESM2

<table>
<thead>
<tr>
<th>CESM1dev</th>
<th>Current Dev.</th>
<th>CESM 2.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAM5.3</td>
<td>CAM6 Poster: Nusbaumer et al. 2017</td>
<td>CAM6</td>
</tr>
<tr>
<td>Nusbaumer et al. 2017</td>
<td></td>
<td>In Development</td>
</tr>
<tr>
<td>CLM4.0</td>
<td>CLM5 In Development</td>
<td>CLM5</td>
</tr>
<tr>
<td>Wong et al. 2017</td>
<td></td>
<td>Isotopes added to BeTR scheme</td>
</tr>
<tr>
<td>CICE4</td>
<td>CICE5 Further testing with CICE5 physics needed</td>
<td>CICE5</td>
</tr>
<tr>
<td>Isotope enabled in ‘tag’ version</td>
<td></td>
<td></td>
</tr>
<tr>
<td>POP2</td>
<td>POP2 Testing/Evaluation, to be added to trunk</td>
<td>POP2</td>
</tr>
<tr>
<td>Water isotopes in development tag, Carbon in Trunk</td>
<td></td>
<td>EBM tested</td>
</tr>
<tr>
<td>RTM</td>
<td>MOSART Implemented, to be tested in coupled</td>
<td>MOSART</td>
</tr>
<tr>
<td>Implementation in development tag</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**NCAR** | Last Deglacial with iCESM
Thank You
Equilibrated Start at 20ka

~900 years from start of 20ka Ice-only run shows near equilibrium with fixed ice, ghg, orb at 20ka values.
PaleoView 1.0

- **Target Community:**
  - Ecologists, biogeographers, and evolutionary biologists
  - To improve understanding of how deglacial climate change has affected macro-ecological communities.
  - Test ecological theories and identify drivers of eco-diversity

- **User-defined masks and downscaling for regional foci**


Fig. 2, Fordham et al. 2017

NCAR | Last Deglacial with iCESM
Preliminary Results: AMOC response to Glacial Forcing

- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forcing
- Preliminary Results: AMOC response to Glacial Forging
AMOC response to 19ka Meltwater forcing

ICE+GHG+ORB+MWTR vs. ICE+GHG+ORB
AMOC response to 19ka Meltwater forcing

ICE+GHG+ORB+MWTR vs. ICE+GHG+ORB

d18Ow
Preliminary Results: AMOC response to Glacial Forcing

+1000 yrs

20ka

Preliminary Results: AMOC response to Glacial Forcing

NCAR | Last Deglacial with iCESM

air • planet • people 32