Simulating hydrological changes in the Western US at the LGM with CESM

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Western US Background

- Wetter at the LGM
- Isotopic depletion at the LGM
- Mechanisms debated

Ruddiman (2000)

Oster et al. (2016)
Speleothems

- Chemical reaction as water flows through the surface
- Calcium carbonate formations via carbonate dissolution
  - Allows $\delta^{18}$O to be determined
- Absolute dating (U/Th)

Verheyden et al. (2008)
Oxygen Isotopes Complications

- Source
- Circulation
- Amount effect
- Temperature
- Changes through time
iCESM1 Model

- iCESM1.2 (Brady et al., 2019; JAMES)
- Fully coupled with water isotope tracers
Annual Temperature Response

- Well simulates present day isotopic distribution
Experiment Design

- 7 experiments spanning the deglaciation (PMIP protocol; ICE-6G)
- ~2° atmosphere / land and ~1° ocean / sea ice

<table>
<thead>
<tr>
<th>Run</th>
<th>Obliquity</th>
<th>Precession</th>
<th>Eccentricity</th>
<th>CO₂ (ppm)</th>
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<tbody>
<tr>
<td>Preindustrial</td>
<td>23.459</td>
<td>0.01690</td>
<td>0.016767</td>
<td>284.3</td>
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<tr>
<td>LGM (21 ka)</td>
<td>22.949</td>
<td>0.01772</td>
<td>0.018994</td>
<td>190</td>
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<tr>
<td>16 ka</td>
<td>23.756</td>
<td>-0.00544</td>
<td>0.019560</td>
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<td>15 ka</td>
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<td>-0.01069</td>
<td>0.019635</td>
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<td>14 ka</td>
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<td>12.5 ka</td>
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<td>6 ka</td>
<td>24.105</td>
<td>0.00</td>
<td>0.018682</td>
<td>264.4</td>
</tr>
</tbody>
</table>
Annual Temperature Response

• ~4.5°C of cooling globally
  • Still cooling...
• ~6.5°C of cooling over land
• Amplified cooling in North America
Annual Precip – Evap Response

- The western US gets wetter at the LGM
- Both increased precipitation and dampened evaporation
δ¹⁸O of Precipitation Response

- Western US depletion of ~1.5 per mil
  - In general agreement with speleothem records
Winter Focus (ONDJFM)

- Most precipitation increase happens in winter
- $\delta^{18}O_p$ in proxy records is weighted by precipitation amount ($\delta^{18}O_{pw}$)
Water Tags

• Track the amount and isotopic composition of water originating from different regions

• $\delta^{18}O \times \text{mass} = \sum (\delta^{18}O \times \text{mass})_{\text{tag}}$
Winter Precipitation Amount: Over Land

- Contributes ~6% less to the total precipitation at the LGM
- Related to cooling
Winter Precipitation Amount: Central East North Pacific

- Contributes ~7% more to the total precipitation at the LGM
- Likely related to shift in storm track
Winter Precipitation Amount: Central West North Pacific

• Contributes ~5% more to the total precipitation at the LGM
• Likely related to shift in storm track
Eddy Kinetic Energy

- Southward shift of the storm tracks at the LGM
- Potentially explains the central Pacific moisture increase at the LGM
  - Manabe and Broccoli, 1985
Winter Precipitation Amount: Southwest North Pacific

- Contributes \(~4\%\) more to the total precipitation at the LGM
- Atmospheric river contribution?
  - Lora et al. 2017
Winter Total Precipitable Water

• \(\text{delta precip} = \text{delta water vapor}\)
• \(\text{delta moist. transport} \rightarrow \text{precip increase}\)
Winter $\delta^{18}O$ of Precipitation: Central East North Pacific

- Short distance moisture transport leads to enriched signal over the western US
- Increased precipitation from this region increases $\delta^{18}O_{pw}$ despite small absolute $\delta^{18}O_p$ changes
Winter $\delta^{18}O$ of Precipitation: Central West North Pacific

- Long distance moisture transport leads to depleted signal over the western US
- Increased precipitation from this region decreases $\delta^{18}O_{pw}$ despite small absolute $\delta^{18}O_p$ changes
Winter $\delta^{18}O$ of Precipitation: Southwest North Pacific

- Long distance moisture transport leads to depleted signal over the western US
- Increased precipitation from this region decreases $\delta^{18}O_{pw}$ despite small absolute $\delta^{18}O_p$ changes
Winter Fractionation Effects

- Large signal over the ice sheets
- Small signal over the western US, suggesting source driven differences
Summary

• Greater western US precipitation at the LGM from increased moisture transport from the Southwest and Central North Pacific
  • Central North Pacific signal related to southward shift of synoptic storms
  • Southwest North Pacific signal possibly related to atmospheric rivers

• $\delta^{18} \text{O}$ of precipitation response reflects changes in the amount of precipitation sourcing from different regions
  • More depleted vapor from the western North Pacific
Ongoing Work

• Higher resolution and higher frequency
• Simulate other periods during the deglaciation
  • iTraCE - branched