A new estimate of climate sensitivity using Last Glacial Maximum model-data constraints that includes parametric, feedback, and proxy uncertainties

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Introduction

As the most recent period of large climate change, the Last Glacial Maximum (LGM) has been a useful target for analysis by model-data comparison. In addition, significant changes in greenhouse gas forcing across the last deglaciation and the relative wealth of LGM temperature reconstructions by proxy data provide a potentially useful opportunity to quantify equilibrium climate sensitivity (ECS), the change in global mean surface air temperature due to a doubling of atmospheric CO₂. ECS is in part defined by the radiative forcing of CO₂, but the amplifying (dampening) nature of positive (negative) feedbacks in the climate system play a large role in how global mean temperature will respond to a change in forcing. Uncertainties in both the proxy data and climate feedbacks must be considered in a LGM-based assessment of ECS. Here, we present a new LGM-based assessment of ECS using the latter approach along with a simple linear parameterization of the longwave and shortwave cloud feedbacks derived from the CMIP5/PMIP3 results applied to the University of Victoria Earth System Intermediate Complexity model (UVIC).1,2

LGM: 2xCO₂ ensemble

We conducted 280 paired simulations of the LGM and a doubling of CO₂ (2xCO₂) in which we adjust model ECS across a range of possibilities. The LGM simulations are used to compare with proxy data, while the 2xCO₂ simulations are used to estimate ECS. In addition, we have sampled the range of uncertainty in other model parameters that potentially impact global mean temperature:

- **Ensemble Member Values**
  - **Climate Sensitivity**: 0.5 - 7.5 °C
  - **GCM Forcings**: from 7 models in the CMIP5/PMIP3 archive
  - **Anomalous Diffusion Factor**: 0 - 0.09 °C⁻¹
  - **Global Dust Forcing**: 0.0 - 2.0 W m⁻²
  - **Snow Albedo**: 0.7 - 0.8

Simulation Results

The ensemble resulted in a large variety of LGM and 2xCO₂ climate states. However, 77 of the ensemble members led to a runaway ice-albedo feedback during the LGM simulation, mostly under high climate sensitivity ensemble states. Such a “snowball earth” scenario is inconsistent with the geologic record for the LGM; therefore such failed simulations were discarded from subsequent analysis.

Conclusions

- New parameterization of cloud feedbacks applied in UVIC generally captures the relative range of CMIP5/PMIP3 top of the atmosphere feedbacks, although absolute magnitude of feedbacks may be slightly diminished.
- Ensemble of LGM and 2xCO₂ simulations with different ECS leads to a large variety of climate states, some of which do not match proxy data synthesis.
- Ensemble results indicate an ECS range of 1.3 - 5.9 K (95% confidence), suggesting the incorporation of cloud feedback model spread from CMIP5/PMIP3 greatly increases the uncertainty from the IPCC3 estimate of 1.5 - 4.5 K. Higher ECS values cannot be ruled out.
- There may be a possible threshold in LGM AMOC for global temperature anomalies lower than -6 °C, below which the model shows a large reduction in AMOC, consistent with other models.14

References

7. Stouffer, R. J., Nat. Geosci. 9, 467 (2016).