Transient simulation of AMOC and climate through the last deglaciation in CCSM3

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Objective

- Model validation and development
- Abrupt climate changes
- Earth system climate sensitivity to GHGs
Climate Sensitivity

400 Thousand Years of Atmospheric Carbon Dioxide Concentration and Temperature Change


Graphic: Michael Ernst, The Woods Hole Research Center
Climate Evolution of Last Deglaciation

- Insolation
- CO₂
- Sea Level
- Greenland SAT
- Antarctic SAT
- AMOC
GISP2 Ice Core Temperature and Accumulation Data
Alley, R.B. 2000

Temperature - Degrees Celsius
Snow Accumulation - meters/year

Age - Thousands of Years Before the Present

Younger Dryas
Medieval Warm Period
Little Ice Age
Climate Evolution of Last Deglaciation

Insolation

$\text{CO}_2$

Sea Level

Greenland SAT

Antarctic SAT

AMOC
INCITE Supercomputing Support

Model: CCSM3 (T31_gx3v5) + dynamic vegetation

ATM  3.75(lon) x 3.75(lat) x 26(level)
OCN  ~3 (lon/lat) x 25 (level)

Peak performance: 120 model years per day
21,000 years in 6 months
Climate Forcing (boundary condition)

- Orbital forcing
- GHGs, and other atm trace gases
- Sea level (Bering strait opening etc)
- Ice sheets
- Meltwater forcing (AMOC)
Strategy

- Use AMOC and Greenland temperature (GISP2) as target to experimentally derive meltwater forcing from sea level record.
- Special attention paid to abrupt climate events 19ka, H1, BA, MWP1a and YD.
- Several sensitivity runs with the same initial condition but different routing/rates of freshwater pulses.
- Select the run that closely resembles AMOC to continue the transient experiment.
Some Challenges

C1: From 19ka, AMOC linearly decreases and collapses at H1. Greenland SAT drops ~3 °C

C2: Keep AMOC off for ~2300 years with ~3 °C increase of Greenland SAT

C3: AMOC abruptly recovers with ~13 °C abrupt increase of Greenland SAT
AMOC sensitivity to the location of freshwater forcing

AMOC response to 0.1 Sv freshwater forcing in eight regions at LGM condition
Ramped v.s. Constant forcing

Hosing Rate (m/kyr)

Greenland temperature

AMOC
Heinrich Event I

Hosing Rate (m/kyr)

Time (ka)

3
17.0
17.5
18.4

20
10
How to keep AMOC off for ~2300 years? Depends on hysteresis of AMOC in CCSM

Rahmstorf et al., 2005

Liu et al., 2009
How to keep AMOC off for ~2300 years?

Abrupt Cessation v.s. Linear Ramping
How to keep AMOC off for ~2300 years?

**Ablrupt Cessation**

**Linear Ramping**
AMOC Overshoot in CCSM3

Liu et al., 2009
AMOC Overshoot in CMIP

Stouffer et al. 2006
A New Mechanism For BA Warming

Liu et al., 2009
Climate Sensitivity & Abrupt Climate Change

Model: Red/blue
Proxy data: Gray

Liu et al., 2009

Insolation
CO2
Sea Level
Freshwater forcing
AMOC

Greenland temperature
Antarctic temperature
Subtropical SST
Tropical SST
Tropical precipitation
Climate Sensitivity & Abrupt Climate Change Since LGM

Model: Red/blue Proxy data: Gray

He et al., in prep

Insolation CO₂ Sea Level Freshwater forcing AMOC Greenland temperature Antarctic temperature Southern Ocean SST Tropical Pacific SST Indian Ocean SST
Conclusion

- **CCSM3 reproduces several major features of the deglacial climate evolution**
  Suggests there is a good agreement in climate sensitivity between the model and observations

- **Abrupt BA warming mechanism**
  Transient CO2 forcing (precondition)
  AMOC recovery from Heinrich Event 1
  AMOC overshoot.

- **CCSM3 doesn’t exhibit substantial hysteresis**
  Accurate reconstructions of the rate of melting water are needed to clarify whether the hysteresis is a fundamental feature of the real-world AMOC