Meltwater Hosing of the North Atlantic and Heinrich Events: Insights from CCSM3

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Motivation

Understanding global response of climate system to freshwater forcing using CCSM3 and paleoclimate records

- Mechanism and feedbacks in coupled system
- Transmission of signal by ocean and atmosphere
- Rates of change and recovery
- Dependence of response on background climate state
Heinrich Event 1 (H1, 17-15.5 kyr BP)

Heinrich events are generally thought to be associated with massive discharges of icebergs into the North Atlantic.
Signatures of Heinrich Events in the Paleo Record

Strength of the Atlantic Meridional Overturning Circulation (MOC)

Greenland Temperature

East Asian MonsoonIntensity

McManus, Nature, 2004

Wang, Science, 2001
“Simulation” of H1 Event - LGM Hosing Experiment

CMIP P
1 Sv / 100 years
North Atlantic 50 to 70°N

Water flux is 5 meters per year into this region
After 100 years, sea level would rise 9 meters

• Uplifted coral reefs in Papua New Guinea suggest that sea level rose 10-15 meters during Heinrich events

Yokoyama, EPSL, 2001
Last Glacial Maximum (LGM, ca. 21 ky BP)

Peltier, AnnRevEarthPlanSci, 2004
Sea Ice Concentration
Annual mean

Pre Industrial

Last Glacial Maximum

Land at LGM
NCAR CCSM3 Last Glacial Maximum

Sea Ice Concentration
Annual mean

Mixed Layer Depths
March

Pre Industrial

Last Glacial Maximum
NCAR CCSM3 Last Glacial Maximum

Sea Ice Concentration
Annual mean

Pre Industrial

Last Glacial Maximum

Mixed Layer Depths
March

Atlantic Meridional
Overturning
Annual mean

0.0  1.0  2.0  3.0  4.0  5.0  6.0
Depth (km)

0  250  500  750  1000  1250  1500  1750  2000

CCSM Workshop, 21-23 June 2005
NCAR CCSM3 Last Glacial Maximum

Sea Ice Concentration
Annual mean

Mixed Layer Depths
March

Atlantic Meridional
Overturning
Annual mean

Pre Industrial

Last Glacial Maximum
Transient “Scaled” Response – LGM “Hosing”
NH annual sea ice area and maximum Atlantic MOC

Scaled MOC Strength and NH Ice Area

NH ice area

Atlantic max MOC

1 Sv

Time (Years)
Anomalies of Sea Ice Concentration
LGM hosing – LGM control
Anomalies of Surface Air Temperature
LGM hosing – LGM control

year: 0400 TREFHT

°C

-14 -12 -10 -8 -6 -2 -1 0 1 2 4 6 8 10 12 14
Anomalies of Precipitation
LGM hosing – LGM control

year: 0400 PRECT

mm day\(^{-1}\)
Changes at End of LGM Hosing - Years 80-99
Atlantic Ocean

Meridional Overturning Streamfunction

- Weakening from 17 Sv at start of hosing to 6 Sv at end of hosing

Ocean Heat Transport

- LGM control expt has northward OHT entire basin
- At end of LGM hosing expt, Atlantic OHT has decreased and is southward in the SH
Transient “Scaled” Response – LGM “Hosing”
Recovery abruptly terminated

Sea ice thicker and less variable

Atlantic MOC continues to weaken

NH ice area

Atlantic max MOC

1 Sv
Changes: Recovery Attempt compared to During Hosing

Surface temperatures warm by 6-14°C
Changes: Recovery Attempt compared to During Hosing

Sea ice melts back, virtually ice free

Annual

Annual

DJF

DJF

Annual

Annual

Sea ice melts back,
virtually ice free

Scaled MOC Strength and NH Ice Area

Atlantic Max MOC - LGM
NH Ice Area - LGM

1 Sv

Time (Years)
Changes: Recovery Attempt compared to During Hosing

Sensible heat flux increases by 30-120 W/m²

Latent heat flux increases by 30-180 W/m²
Changes: Recovery Attempt compared to During Hosing

DJF precipitation increases by 1-3 mm/day
Changes: Recovery Attempt compared to During Hosing

Mixed layer depths increase by 50-150 m
Ocean Temperature before, during, and after LGM Hosing
Recovery
Years 180-199 minus Years 80-99

Surface Air Temperature
- Mean: 0.21 K
- RMSE: 1.16 K

Precipitation
- Mean: 0.04 mm/day
- RMSE: 0.41 mm/day

Atlantic OHT
- Yrs 180-199 (~ century after hosing turned off)
- Yrs 80-99 (at end of hosing)
The 8.2 ky BP Megaflood

Clarke, Science, 2003

Estimated discharge: 5 Sv in 6 months

CCSM3 8.2 Hosing Experiment:

1 Sv for 100 years
North Atlantic 50-70°N
Transient “Scaled” Response – 8.2 “Hosing”
NH annual sea ice concentration & Maximum Atlantic MOC

![Graph showing NH sea ice area and Atlantic MOC over time](image)

8.2 - NH ice area
8.2 - Atlantic max MOC
Comparison of CCSM3 LGM and 8.2 Hosing Expts
Surface temperature change during hosing

LGM hosing - LGM control

8.2 hosing - 8.2 control

<table>
<thead>
<tr>
<th>Mean</th>
<th>RMSE</th>
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<td>-1.05</td>
<td>2.46</td>
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Min = -13.77 Max = 1.83

<table>
<thead>
<tr>
<th>Mean</th>
<th>RMSE</th>
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<tbody>
<tr>
<td>-1.38</td>
<td>2.67</td>
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Min = -16.09 Max = 1.64
Rates of Response - 8.2 Hosing Experiment

Data

GISP2 (Grootes et al. 1993)

Data

Colder

Calendar kiloyears before present

Cariaco Basin (Peterson et al. 2000)

Calendar kiloyears before present

Cariaco (0-10N, 70-50W)

CCSM3 response

1 Sv

Temperature (°C)

Model Year

Precipitation rate (mm/day)

Model Year

Greenland (70-80N, 50-20W)

CCSM3 response

1 Sv

-44 -42 -40 -38 -36 -34 -32

-44 -42 -40 -38 -36 -34 -32

-33.0 -30.0 -27.0 -24.0 -21.0 -18.0 -15.0

0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190

0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190

2.4 2.0 1.6 1.2 0.8

3.2 2.8 2.4 2.0 1.6 1.2 0.8
Future Hosing Experiment? Could Greenland melt rapidly?

JJA Surface Temperature Change

CCSM2

Last Interglacial Expt
~ 130,000 yrs BP
Future Hosing Experiment? Could Greenland melt rapidly?

JJA Surface Temperature Change  Greenland Ice Sheet after 3000 yrs

CCSM2

Last Interglacial Expt
~ 130,000 yrs BP

Force a GIS model with monthly T and Precip anomalies
Future Hosing Experiment? Could Greenland melt rapidly?

CCSM2
Last Interglacial Expt
~ 130,000 yrs BP

CCSM2

JJA Surface Temperature Change

Greenland Ice Sheet after 3000 yrs

Force a GIS model with monthly T and Precip anomalies

Missing fast dynamics?

Braithwaite, Science, 2002
Future Hosing Experiment? Could Greenland melt rapidly?

JJA Surface Temperature Change

Greenland Ice Sheet after 3000 yrs

CCSM2
Last Interglacial Expt
~ 130,000 yrs BP

Force a GIS model with monthly T and Precip anomalies

Missing fast dynamics?

1% transient CO$_2$
3xCO$_2$

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Final Remarks

- Even with this very large hosing, for neither LGM or 8.2 kyrs BP is the Atlantic MOC completely shut down
- Recovery in the LGM hosing experiment may take many centuries
- Signal is transmitted to many parts of globe in decades
- Regional responses and recovery time may depend on background climate state
- More realistic freshwater forcings need to be imposed for detailed comparisons to the geologic record
Changes at End of Freshwater Pulse  Years 95-99

**Surface Temperature**
- mean = -1.04
- rmse = 2.60 K
- Min = -19.82
- Max = 2.66

**Precipitation**
- mean = -0.08
- rmse = 0.65 mm/day
- Min = -5.13
- Max = 3.34
Changes at End of Freshwater Pulse  Years 95-99
The 8.2 ky BP Megaflood

Estimated discharge: 10-15 Sv in one year

Orbital configuration:
- NH: increase summer, decrease winter TOA solar radiation
- SH: decrease summer, increase winter TOA solar radiation
- annual changes small

CCSM3 8.2 Hosing Experiment:

1 Sv for 100 years
North Atlantic 50-70°N
Changes at End of Hosing - Years 80-99

Atlantic MOC

Δ Ocean Temperature

Mixed Layer Depth

OHT
Recovery
Years 180-199 minus Years 80-99

Surface Air Temperature

Precipitation

Mixed Layer Depth

OHT