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

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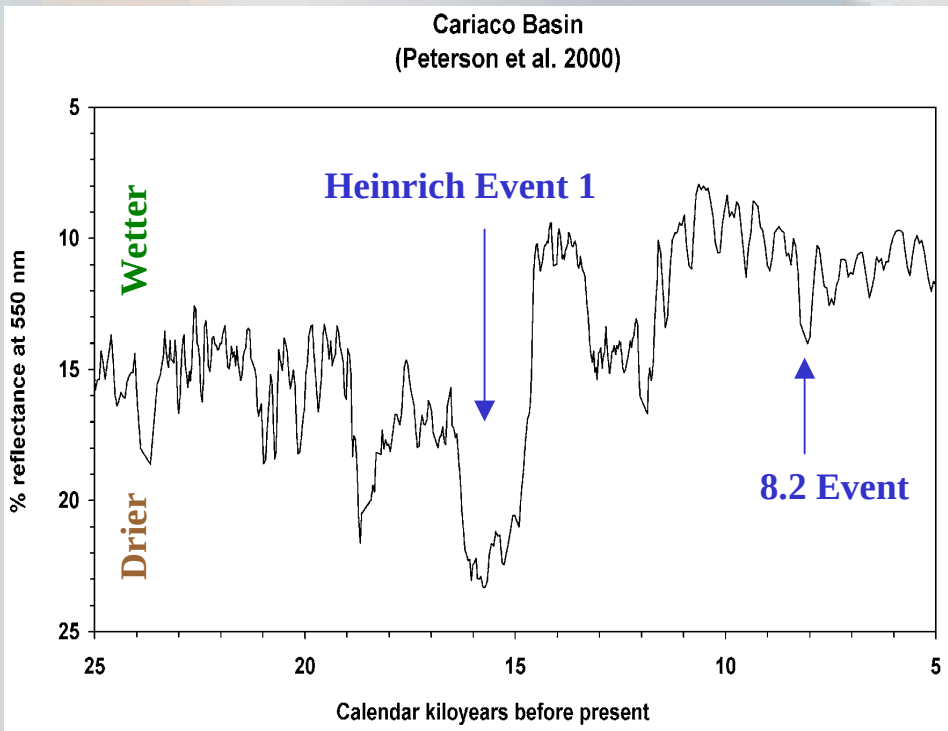
Motivation

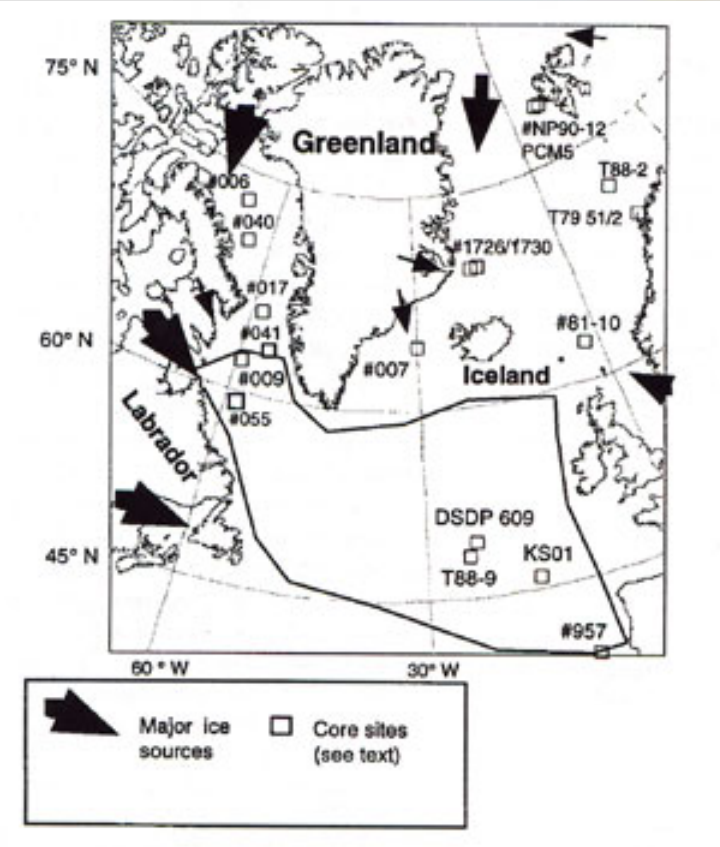
Understanding global response of climate system to freshwater forcing using CCSM3 and paleoclimate records

- 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

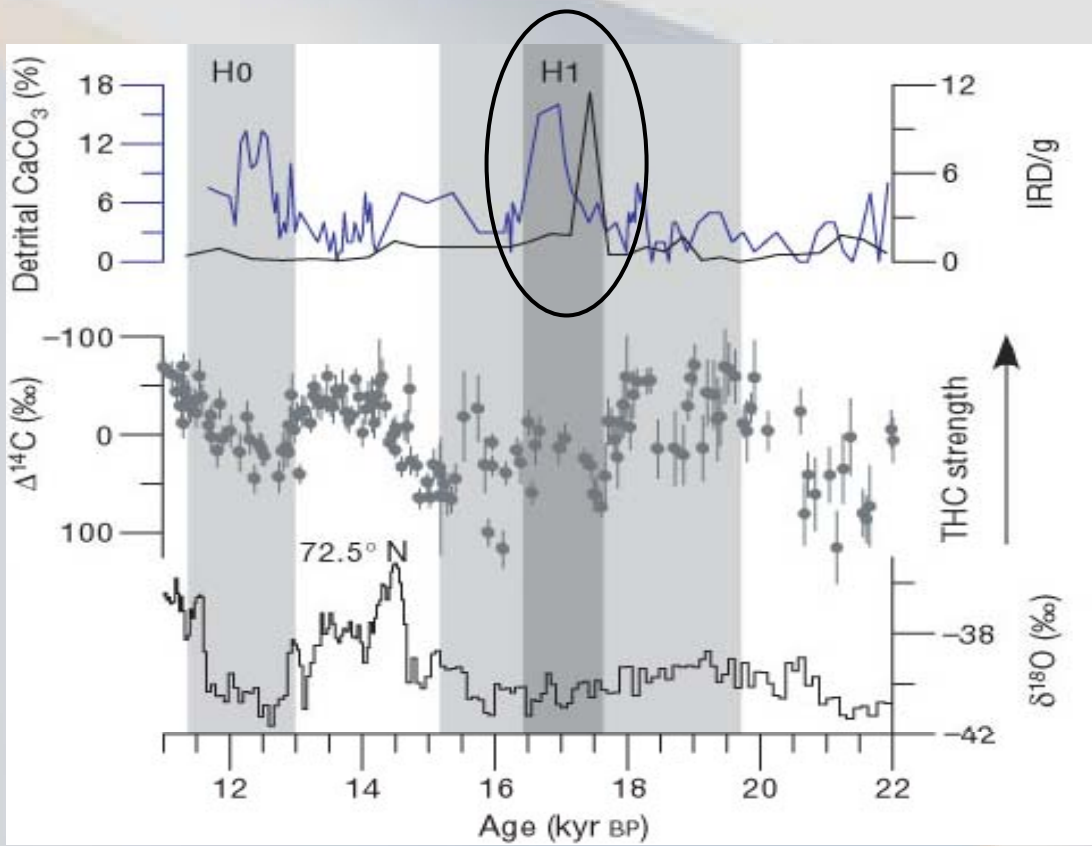


Heinrich Event 1 (H1, 17-15.5 kyr BP)

Heinrich events are generally thought to be associated with massive discharges of icebergs into the North Atlantic



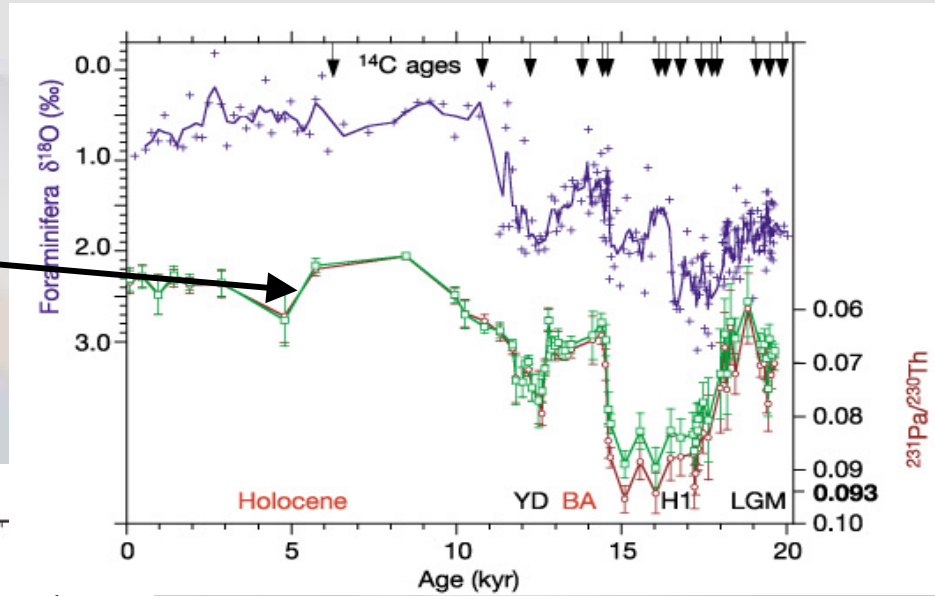
Andrews, J. Quat. Sci., 1998



Clark, Science, 2002

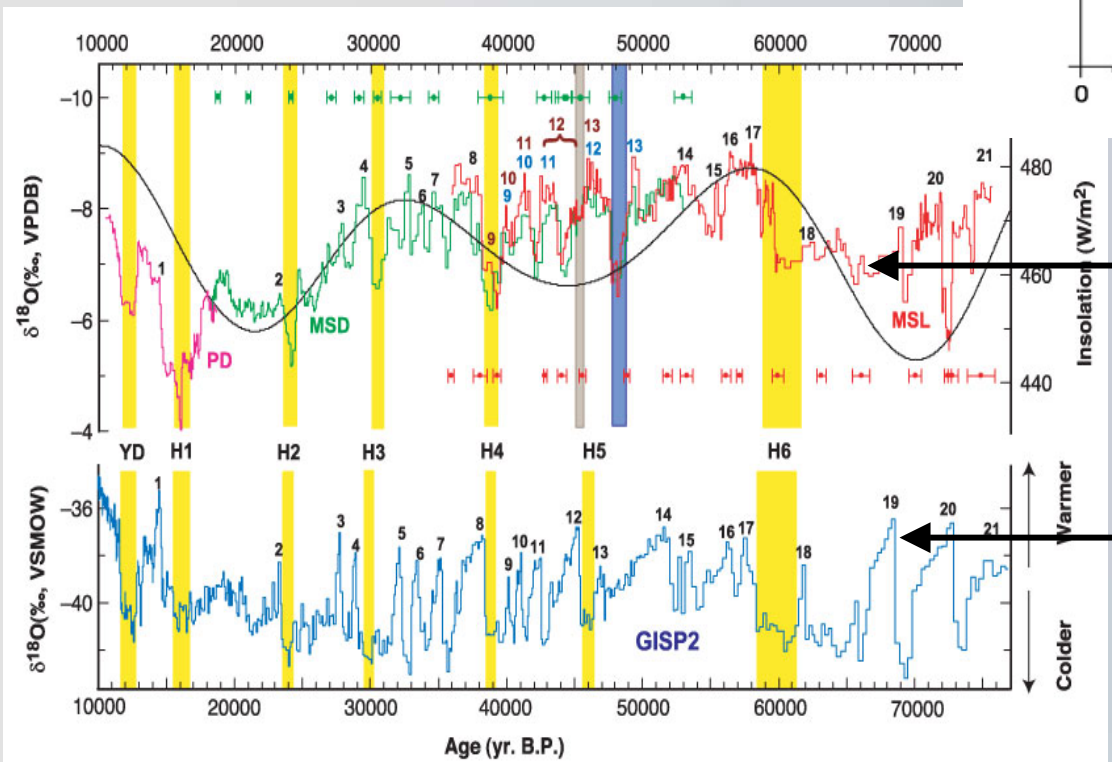
Signatures of Heinrich Events in the Paleo Record

Strength of the Atlantic Meridional Overturning Circulation (MOC)



McManus, Nature, 2004

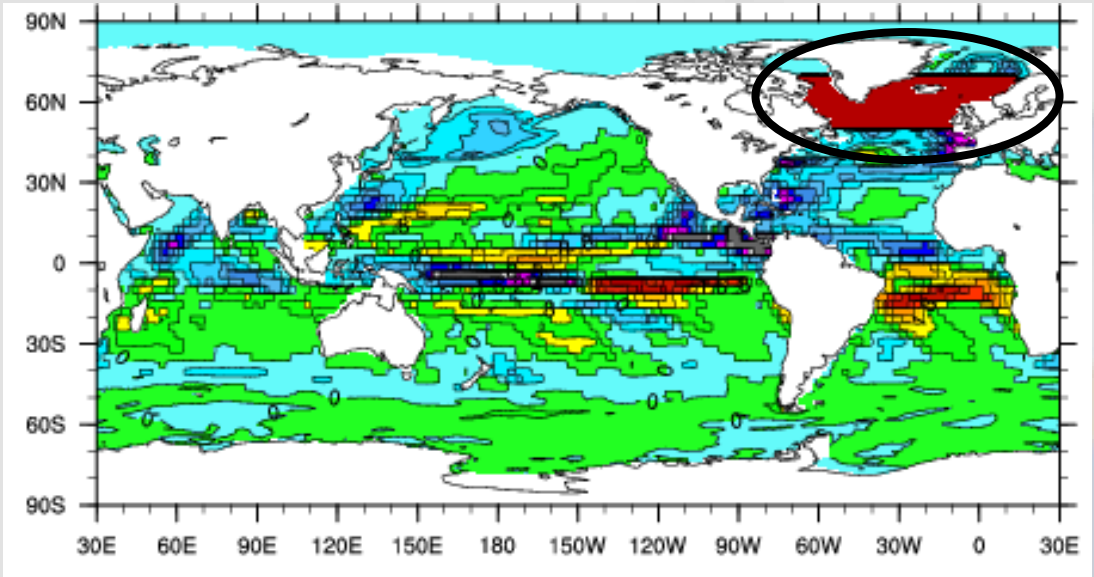
East Asian Monsoon Intensity



Greenland Temperature

Wang, Science, 2001

“Simulation” of H1 Event - LGM Hosing Experiment

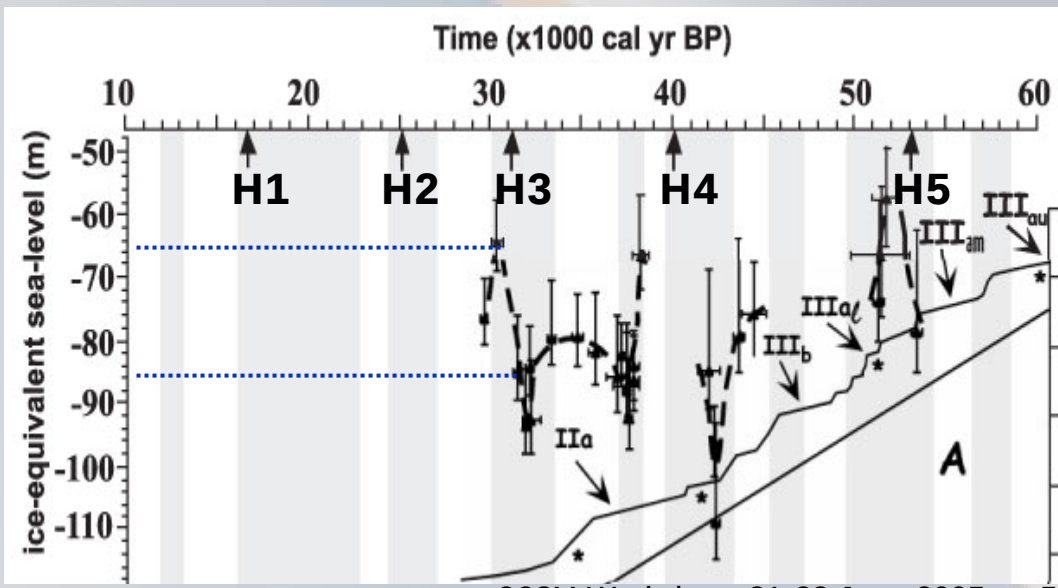


CMIP
1 Sv / 100 years
North Atlantic 50 to 70°N

Water flux is 5 meters per year into this region

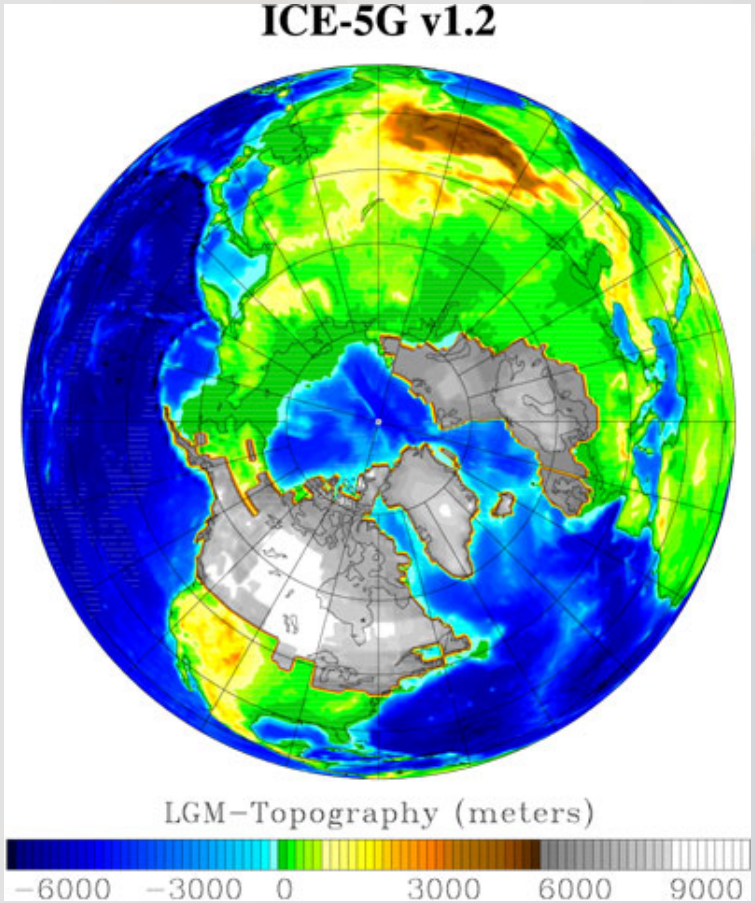
After 100 years, sea level would rise 9 meters

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

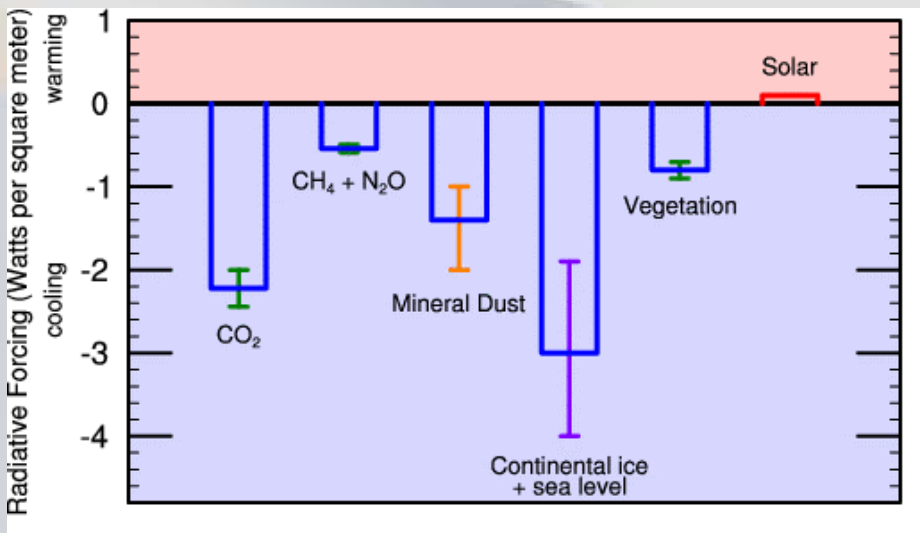


Yokoyama, EPSL, 2001

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



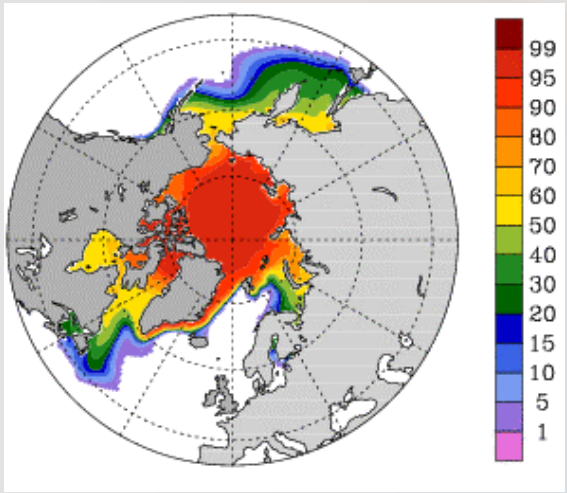
Peltier, AnnRevEarthPlanSci, 2004



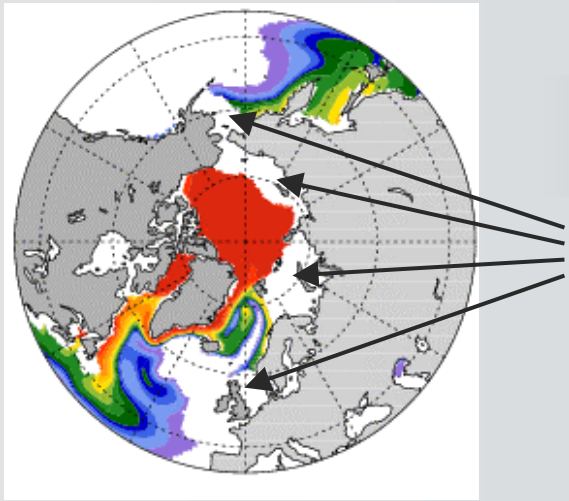
NCAR CCSM3 Last Glacial Maximum

Sea Ice Concentration
Annual mean

Pre Industrial



Last Glacial Maximum



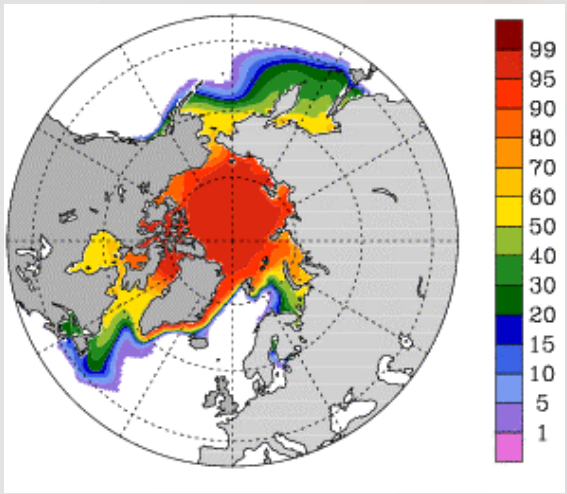
Land at LGM

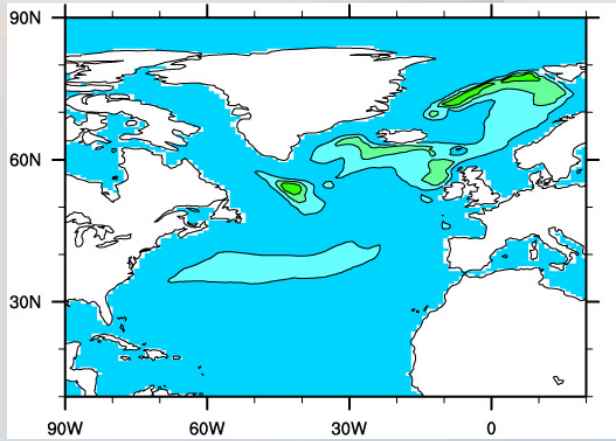
NCAR CCSM3 Last Glacial Maximum

Sea Ice Concentration
Annual mean

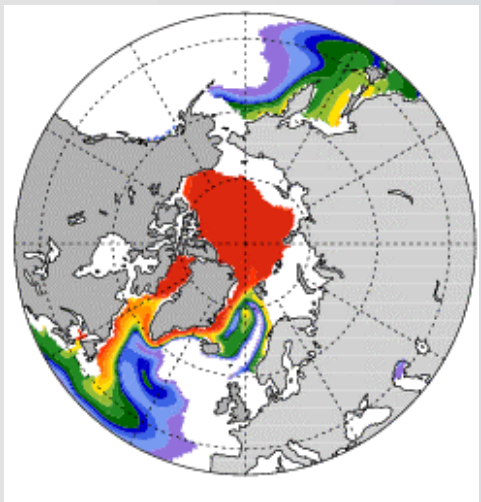
Mixed Layer Depths
March

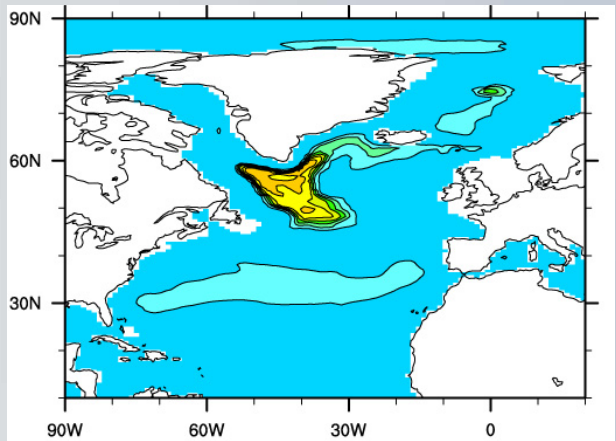
Pre Industrial

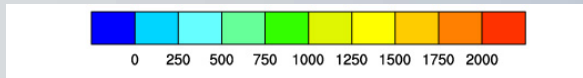




Last Glacial Maximum







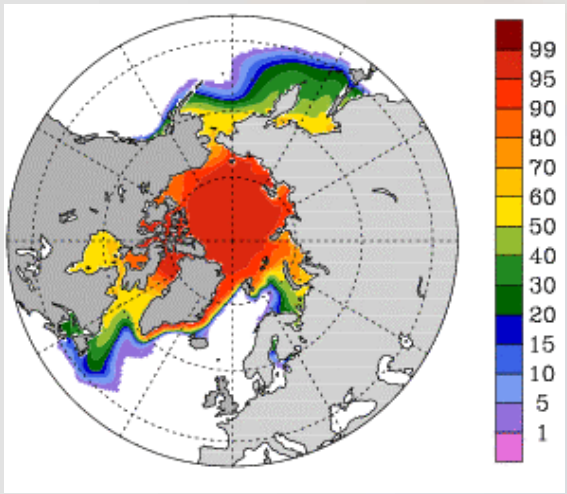
NCAR CCSM3 Last Glacial Maximum

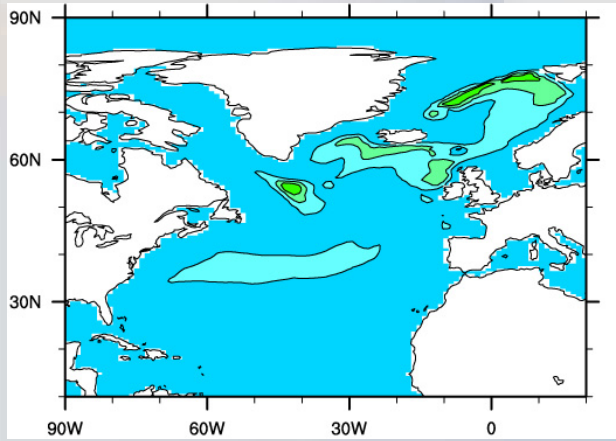
Sea Ice Concentration Annual mean

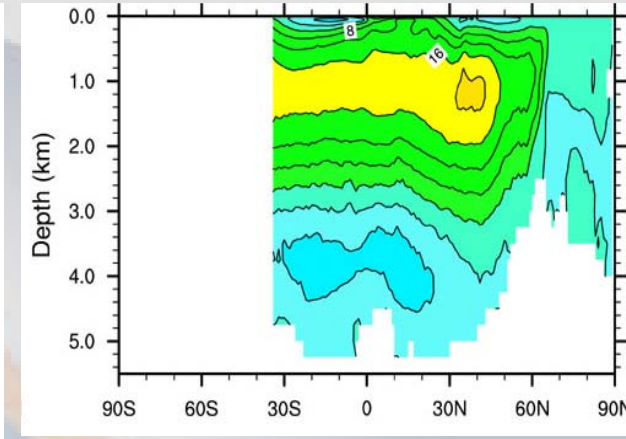
Mixed Layer Depths March

Atlantic Meridional Overturning Annual mean

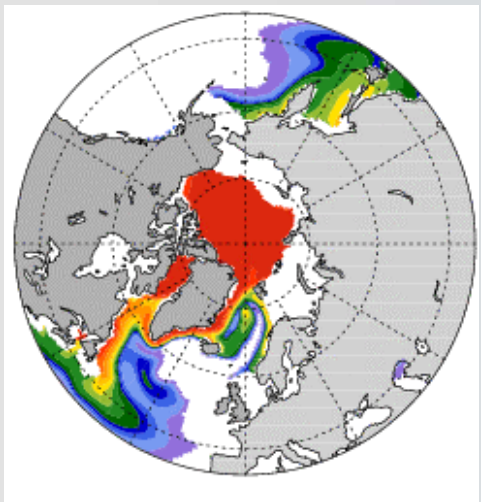
Pre Industrial

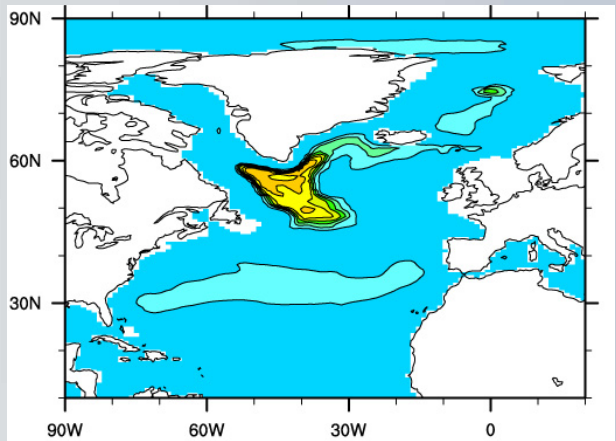


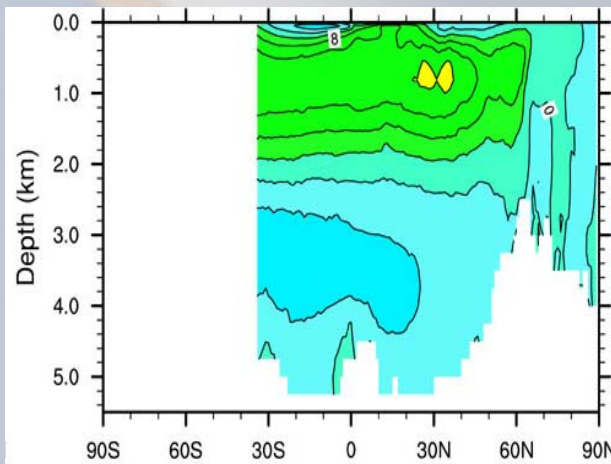


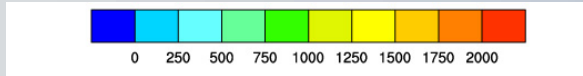


Last Glacial Maximum









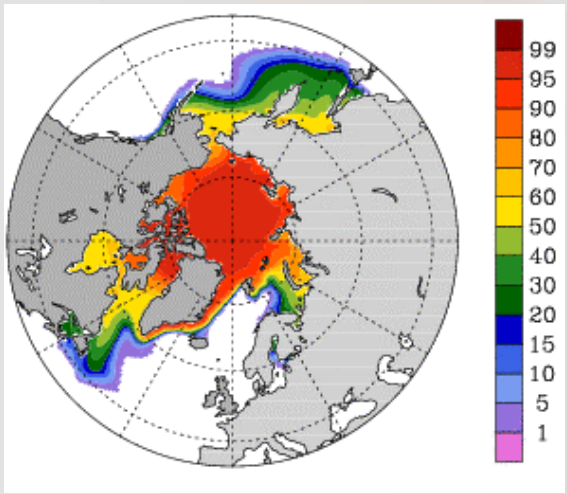
NCAR CCSM3 Last Glacial Maximum

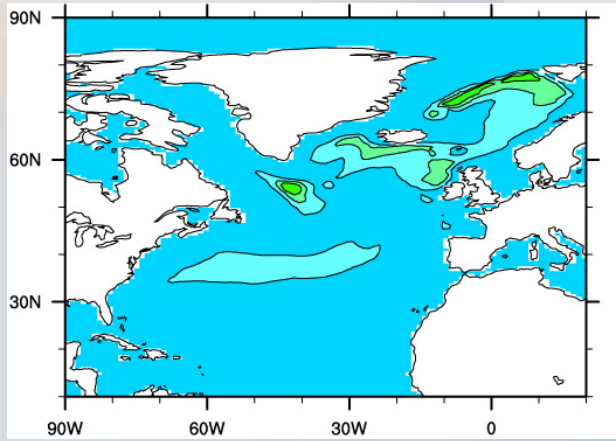
Sea Ice Concentration Annual mean

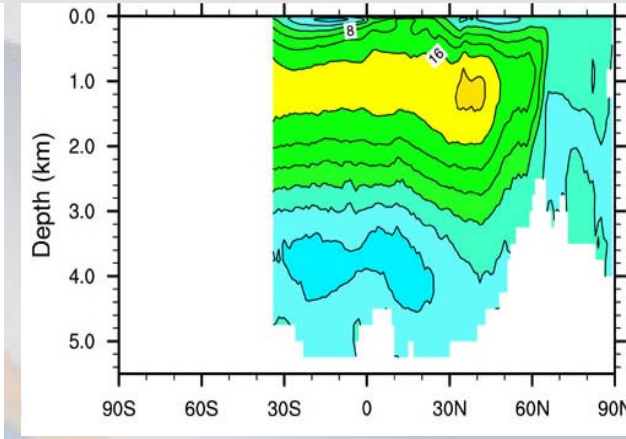
Mixed Layer Depths March

Atlantic Meridional Overturning Annual mean

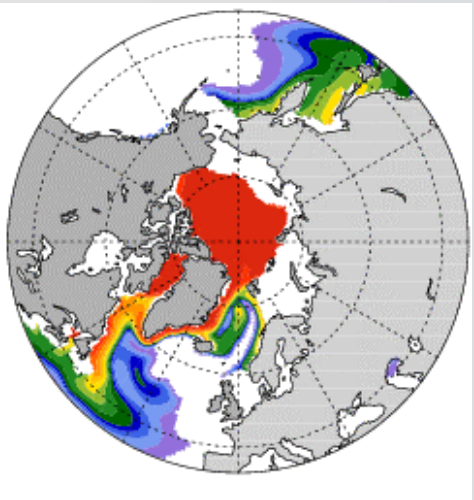
Pre Industrial

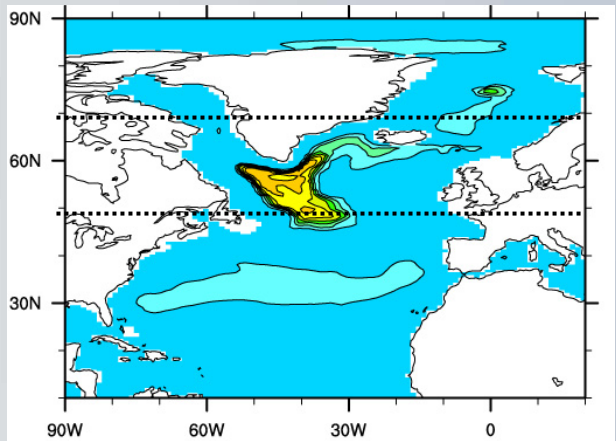


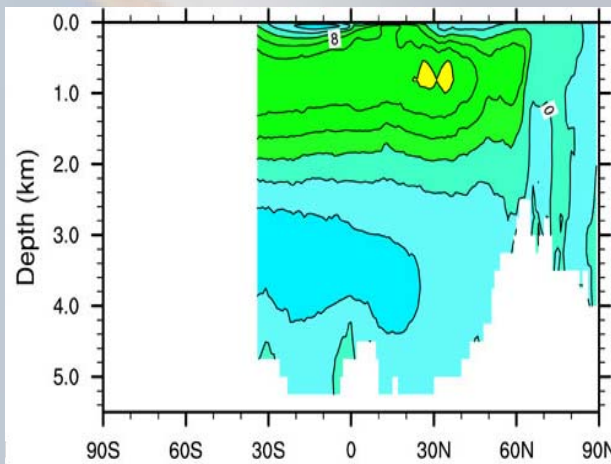


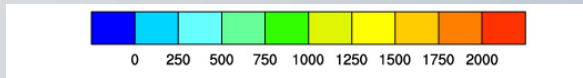


Last Glacial Maximum

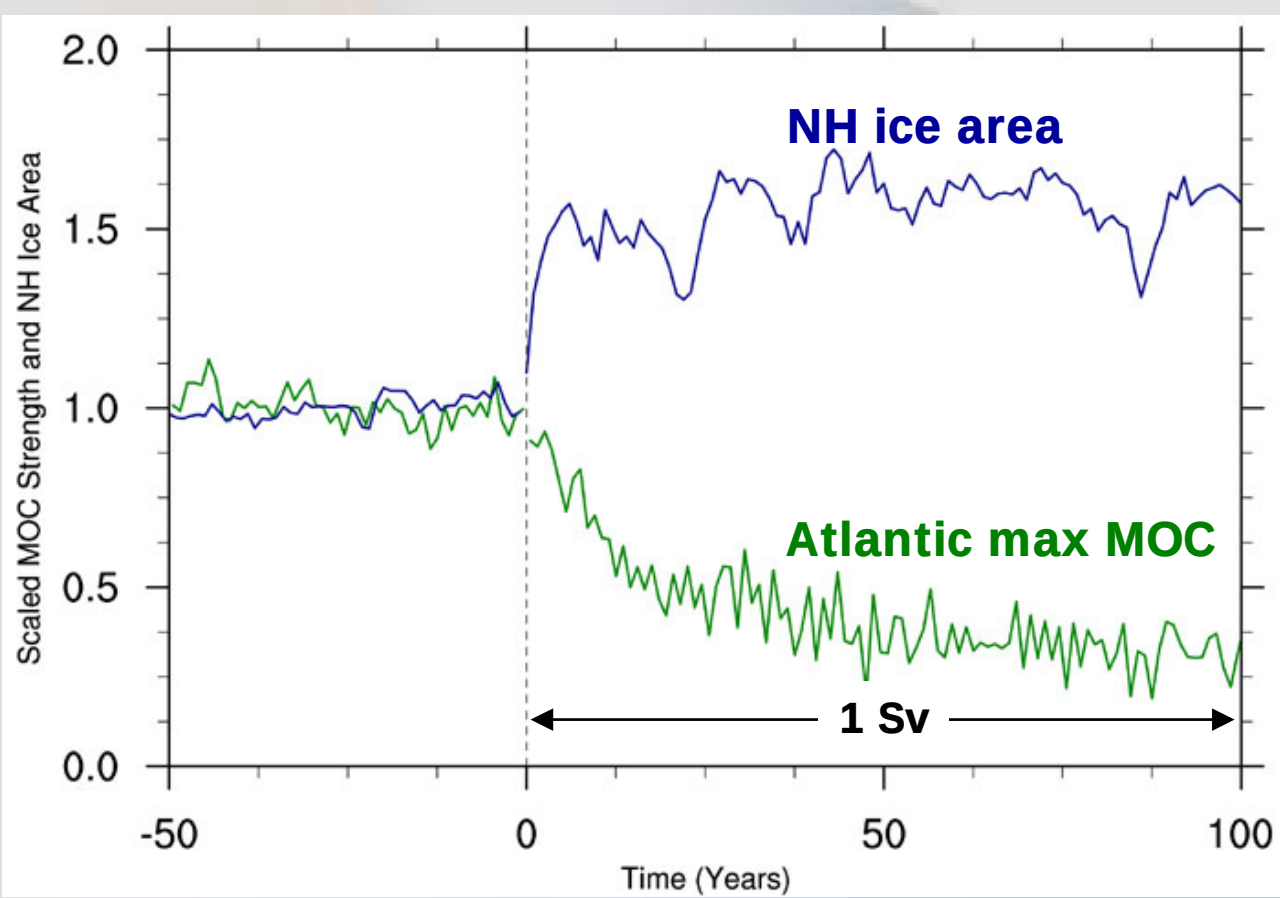




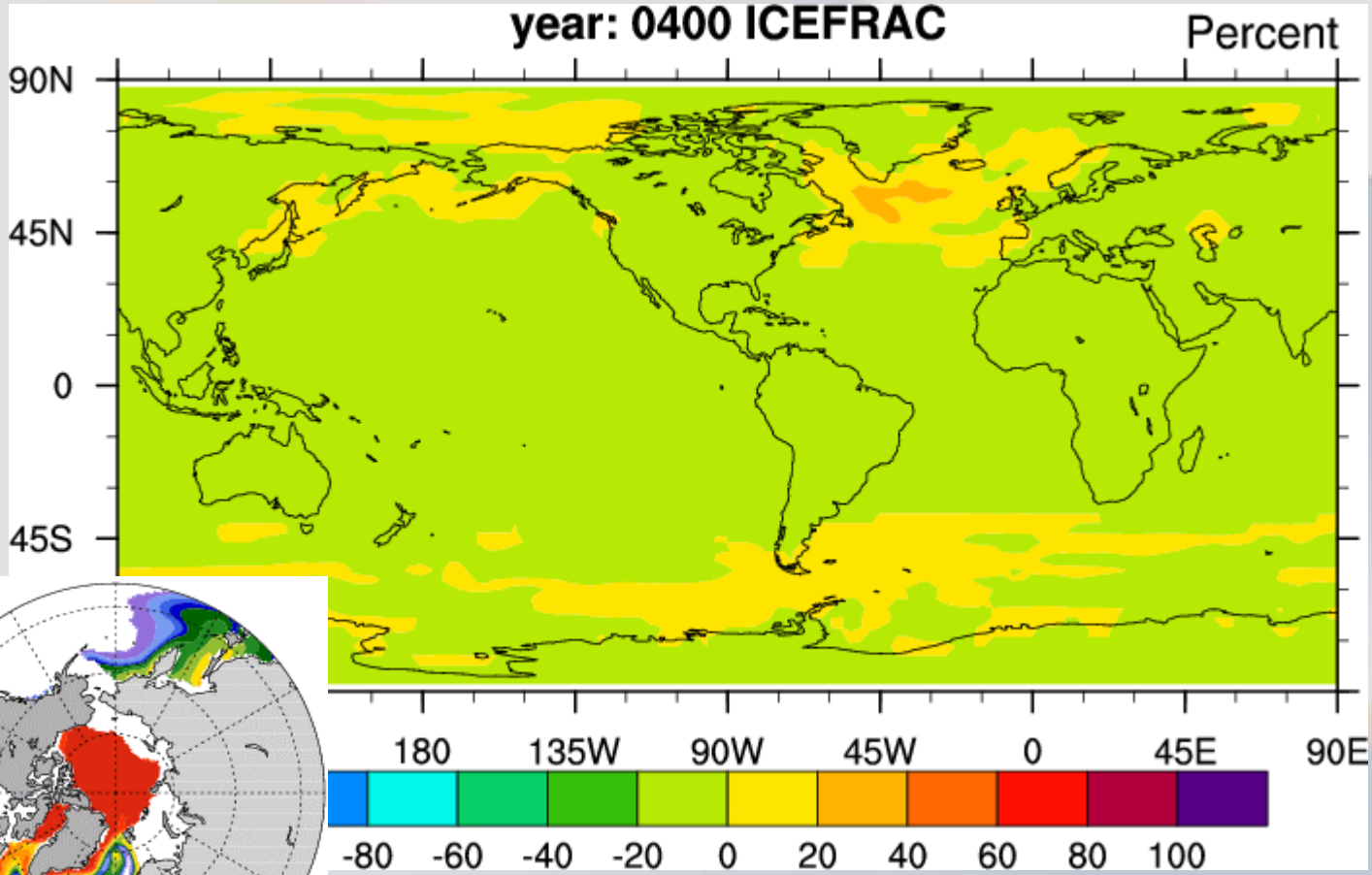




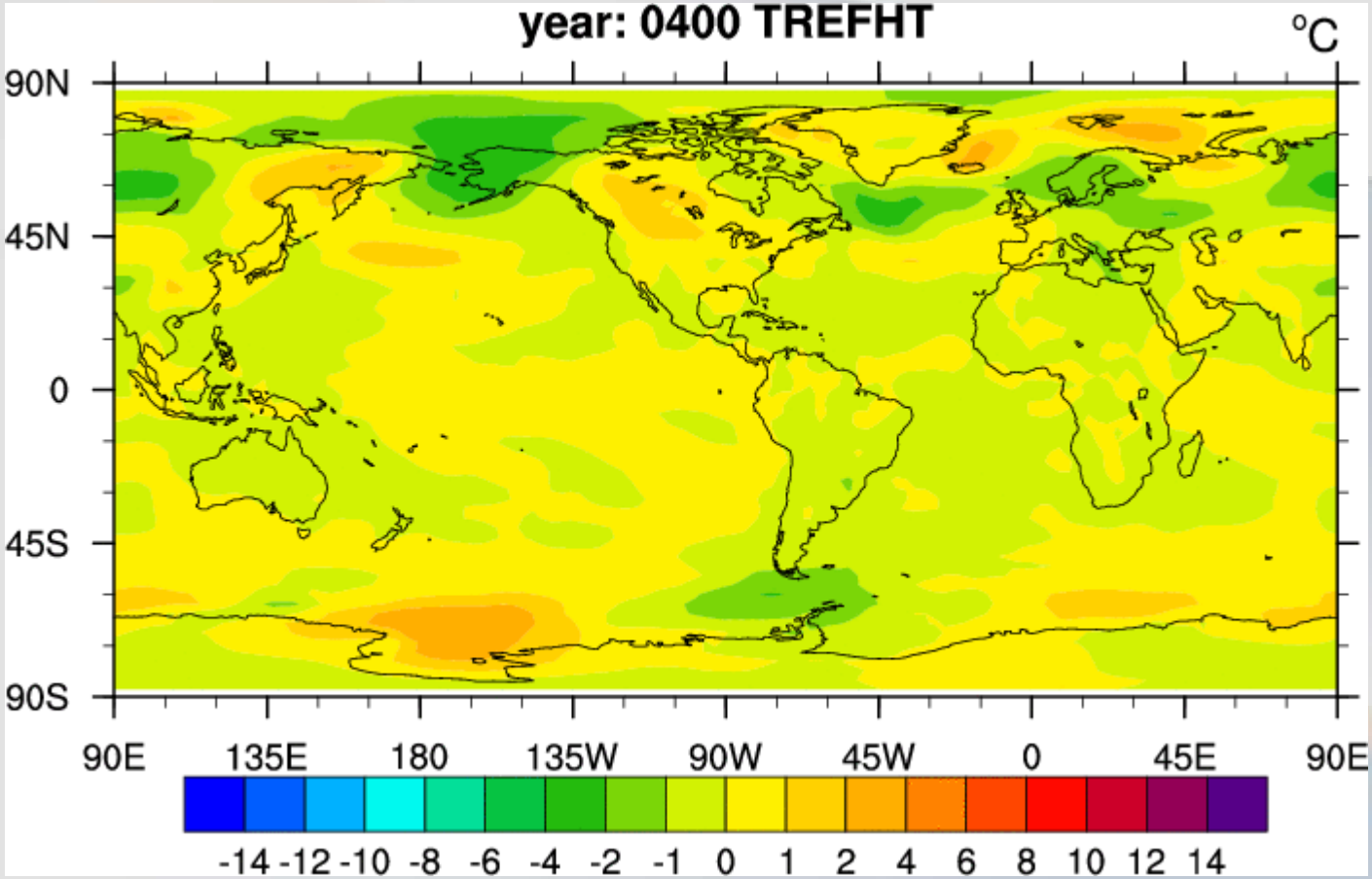
Transient "Scaled" Response – LGM "Hosing"
NH annual sea ice area and maximum Atlantic MOC



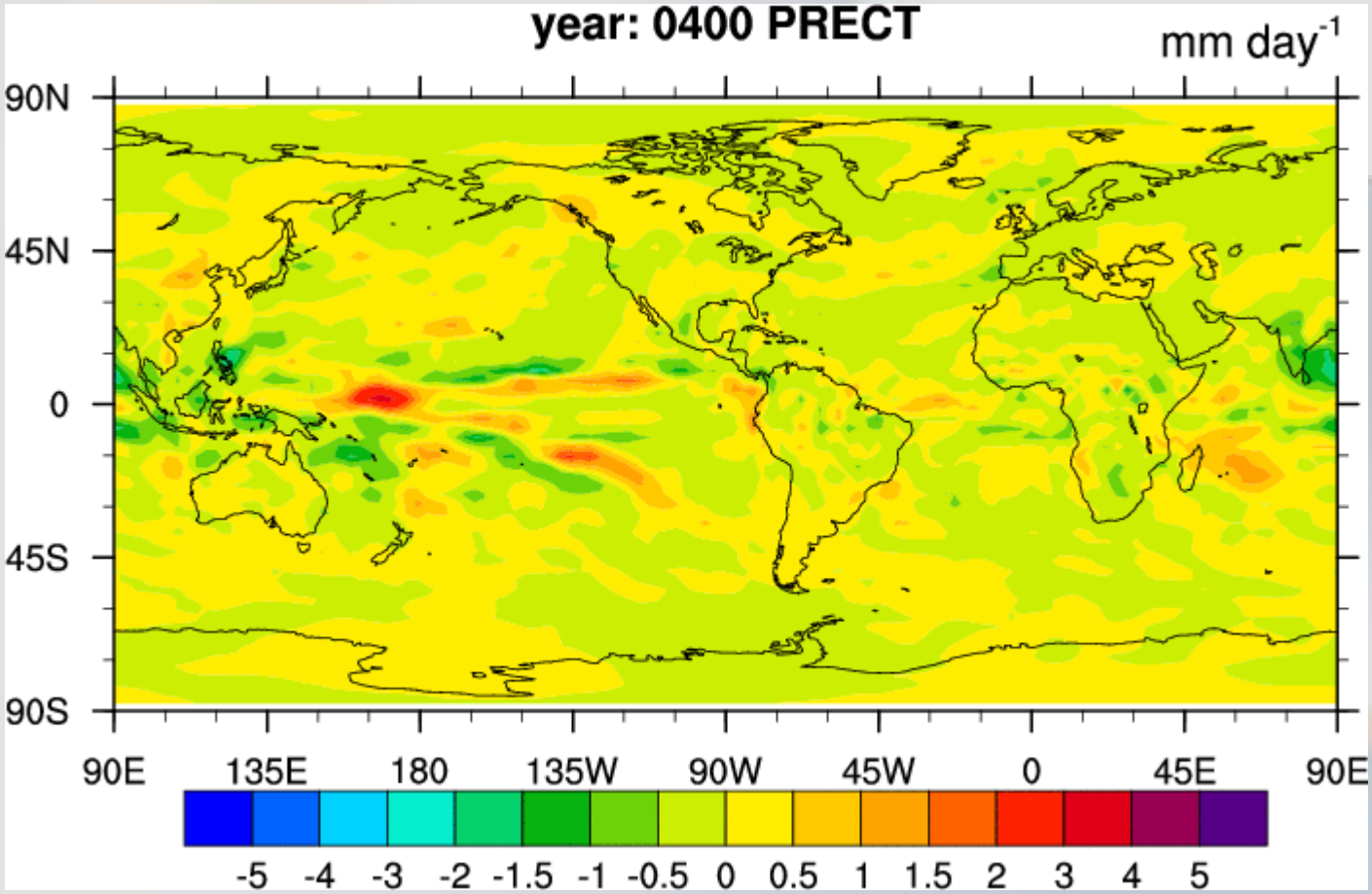
Anomalies of Sea Ice Concentration
LGM hosing – LGM control



Anomalies of Surface Air Temperature
LGM hosing – LGM control

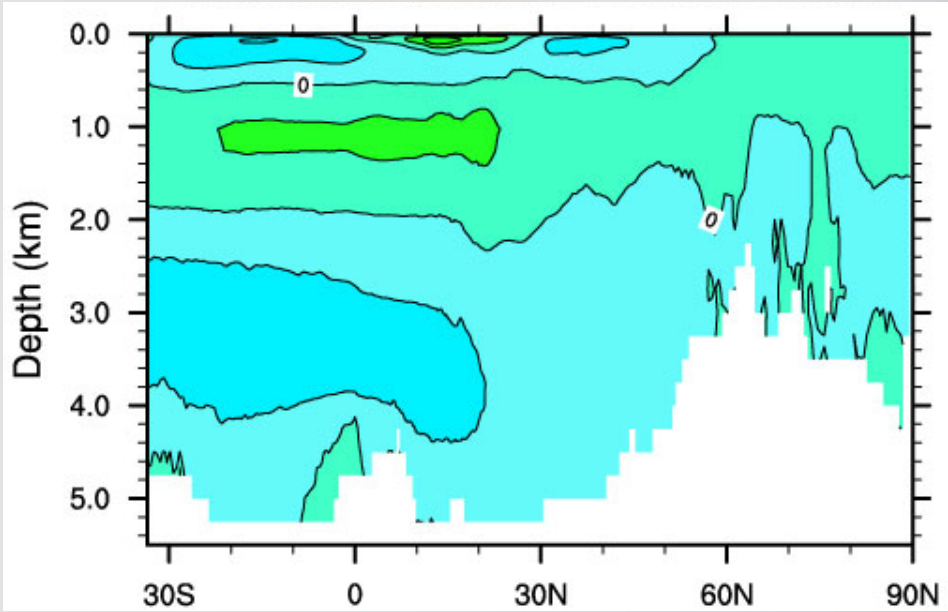


Anomalies of Precipitation
LGM hosing – LGM control



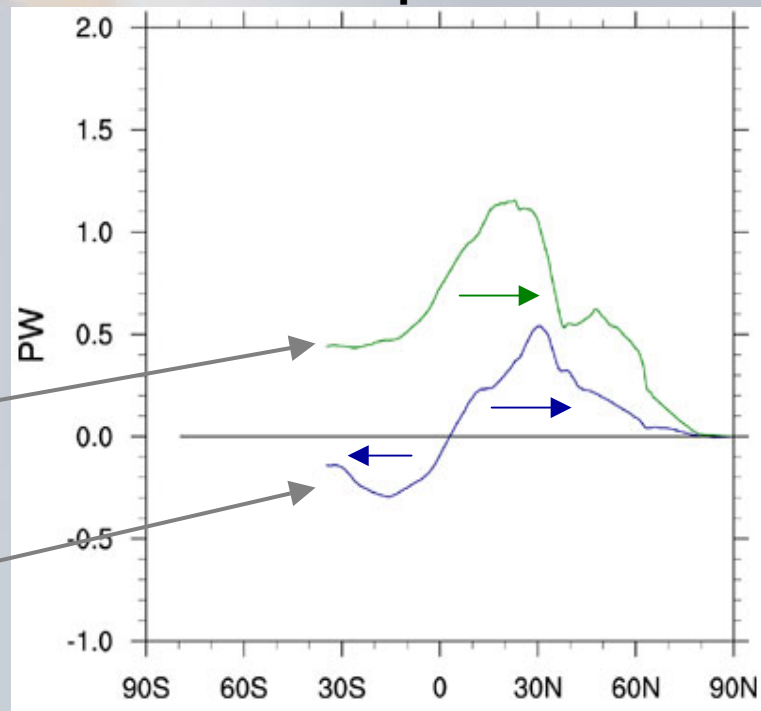
Changes at End of LGM Hosing - Years 80-99
Atlantic Ocean

Meridional Overturning Streamfunction



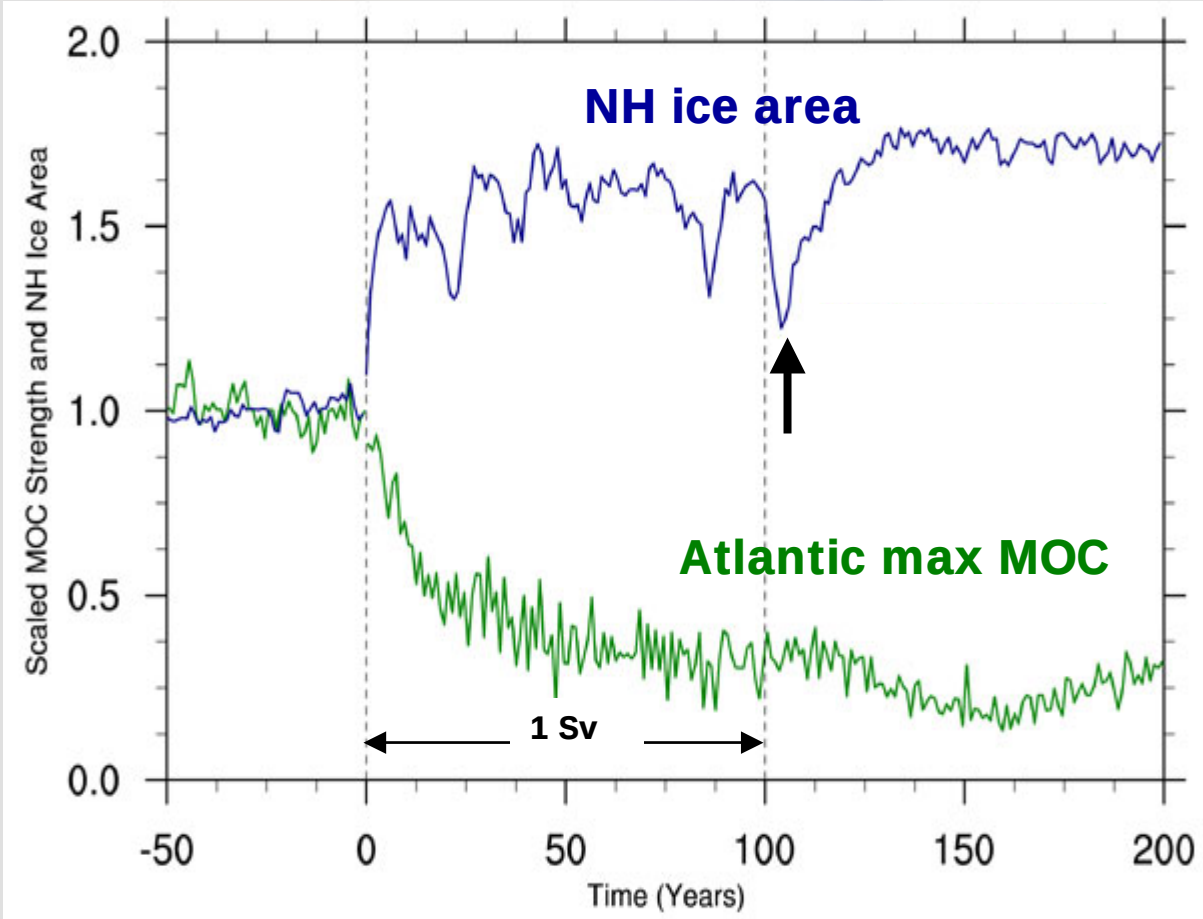
- Weakening from 17 Sv at start of hosing to 6 Sv at end of hosing

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

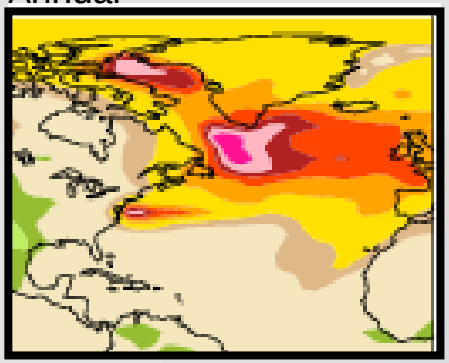


Sea ice thicker and less variable

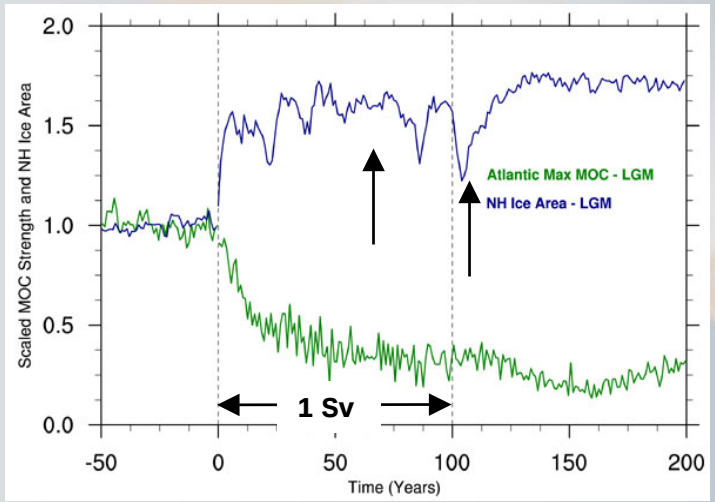
Atlantic MOC continues to weaken

Changes: Recovery Attempt compared to During Hosing

Annual



Surface temperatures warm by 6-14°C



Annual

DJF

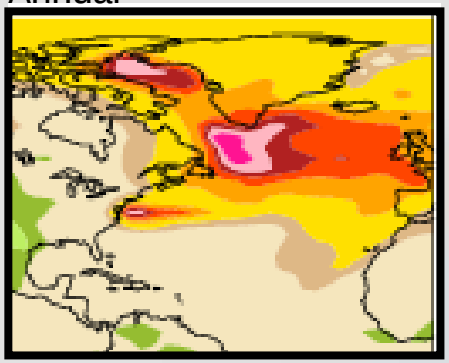
DJF

Annual

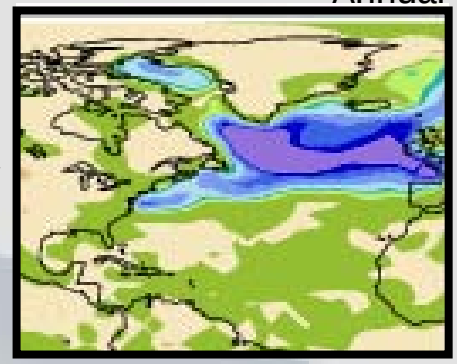
DJF

Changes: Recovery Attempt compared to During Hosing

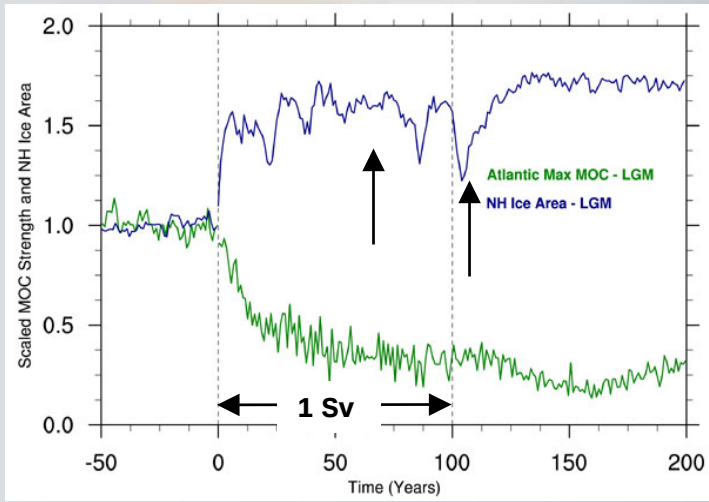
Annual



Annual



Sea ice melts back, virtually ice free →



DJF

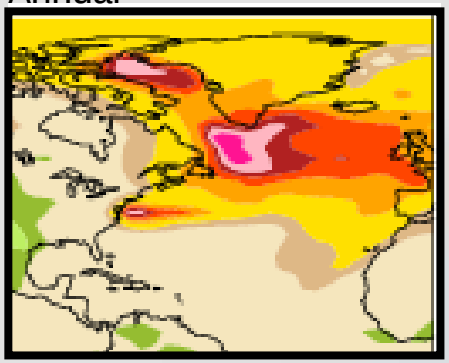
DJF

Annual

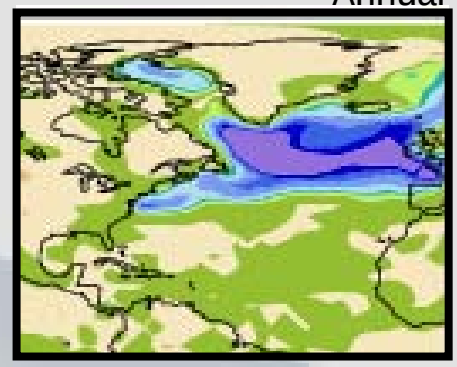
DJF

Changes: Recovery Attempt compared to During Hosing

Annual

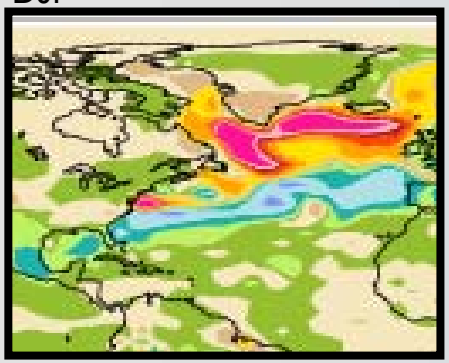


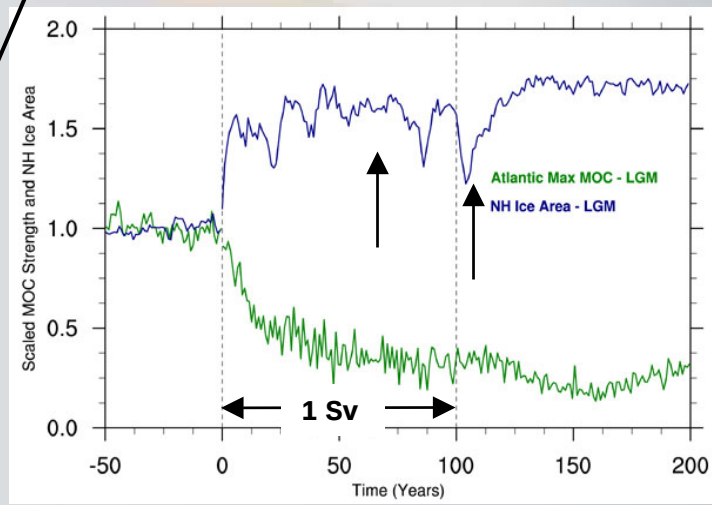
Annual



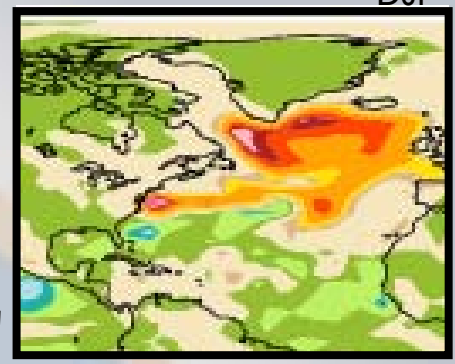
Sensible heat flux increases by 30-120 W/m^2

DJF





DJF



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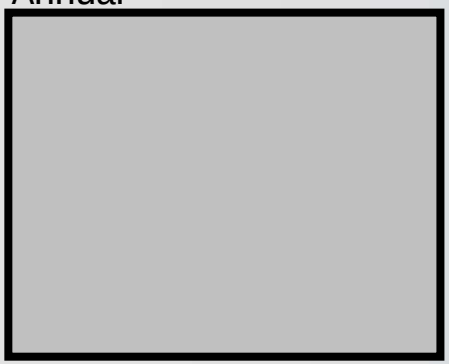
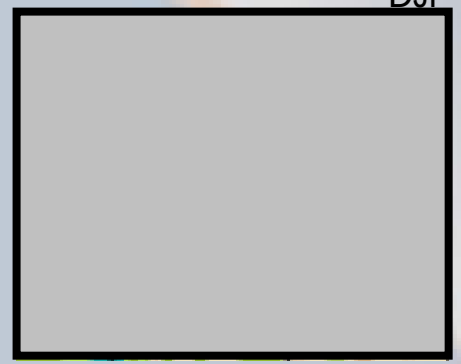


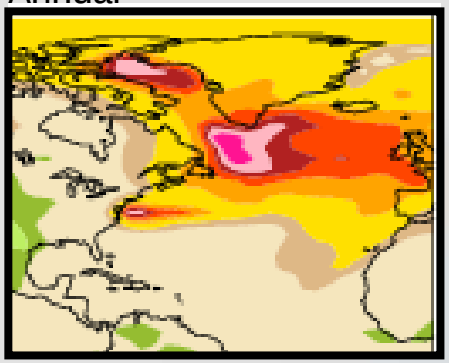
Latent heat flux increases by 30-180 W/m^2

DJF



Changes: Recovery Attempt compared to During Hosing

Annual



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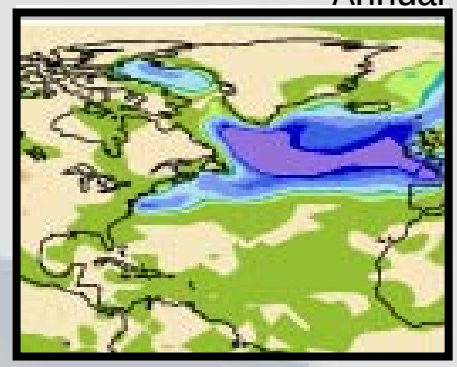

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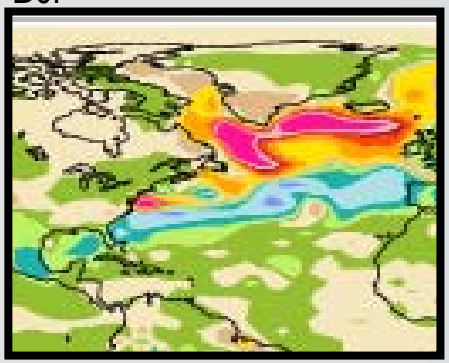

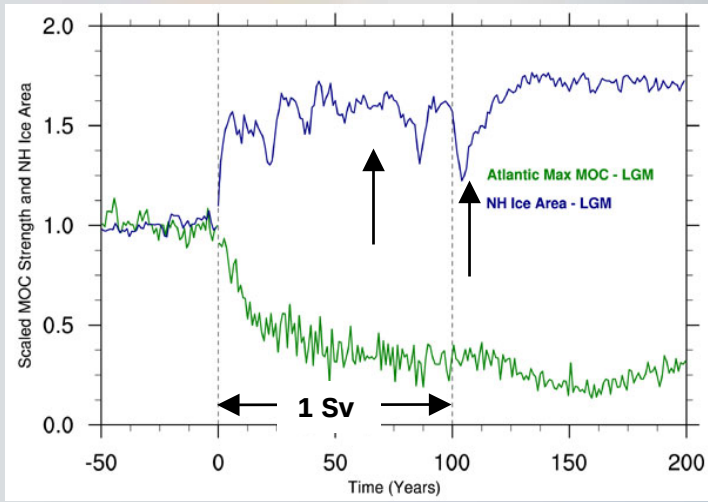

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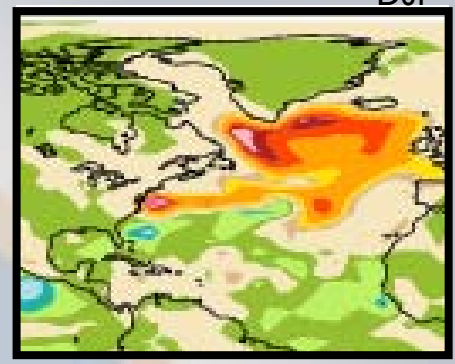
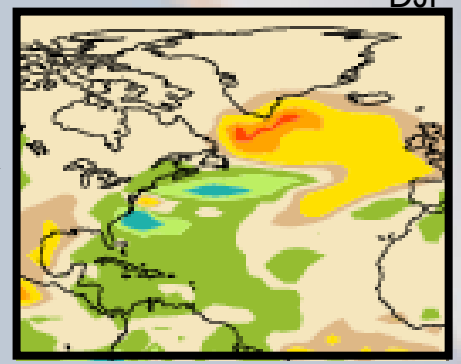


Annual

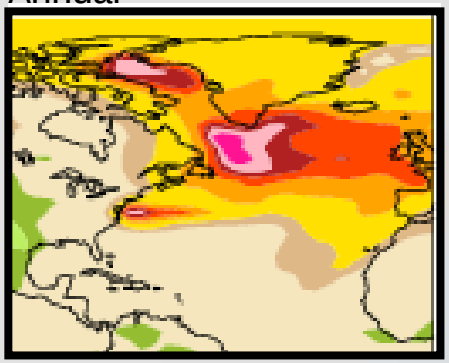
DJF precipitation
increases by 1-3 mm/day

DJF

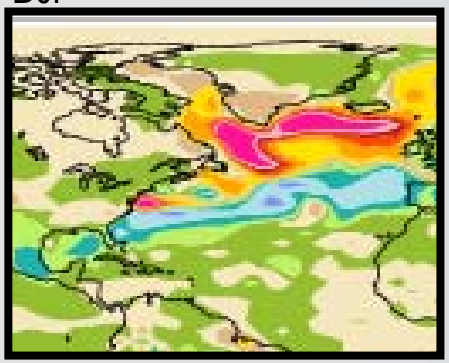


Changes: Recovery Attempt compared to During Hosing

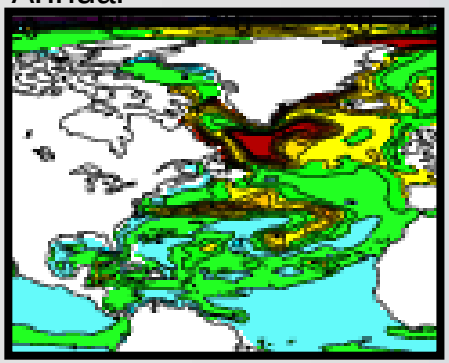
Annual

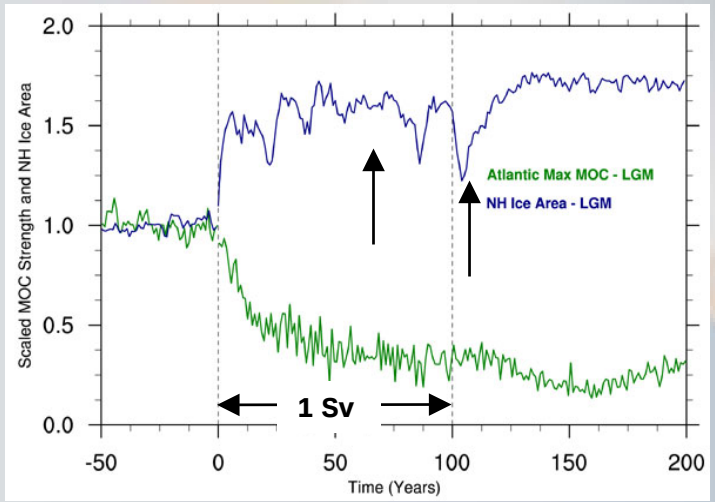


DJF



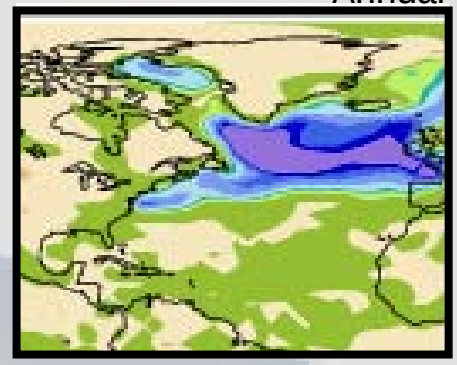
Annual





Mixed layer depths increase by 50-150 m

Annual



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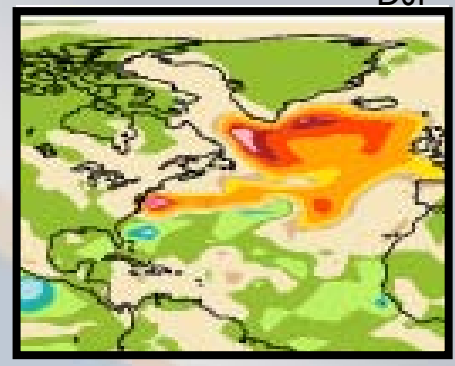

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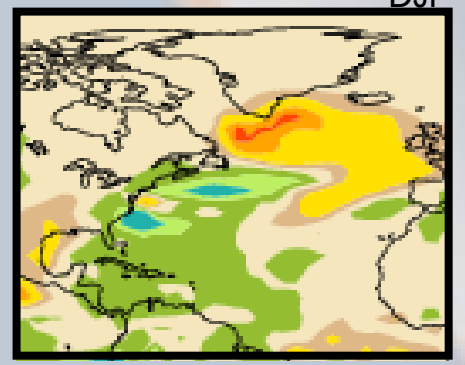
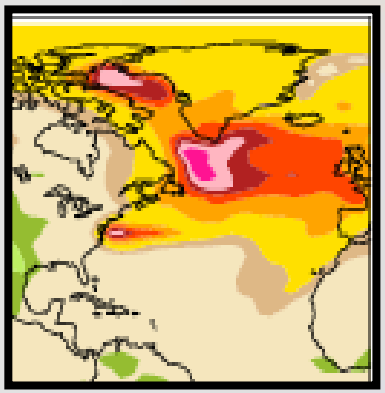
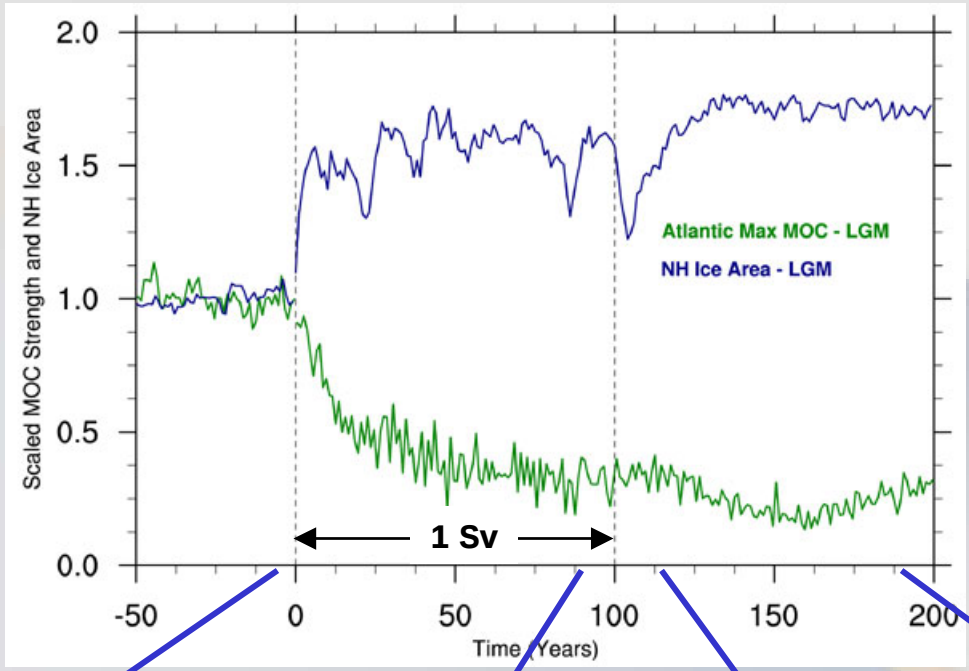
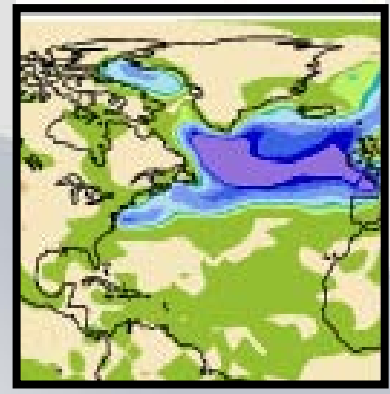
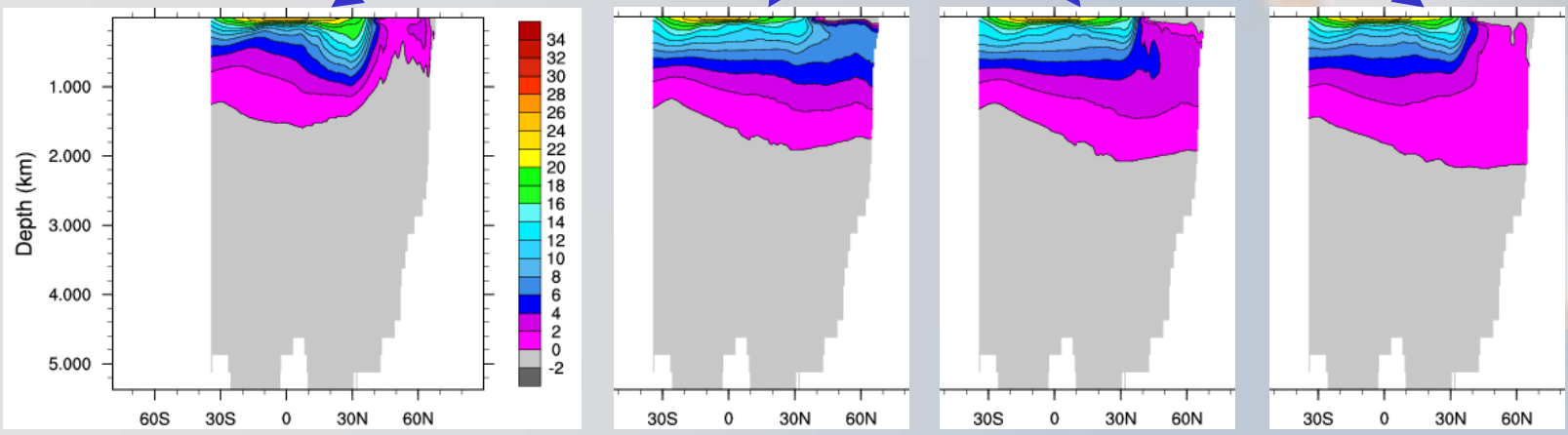


Ocean Temperature before, during, and after LGM Hosing



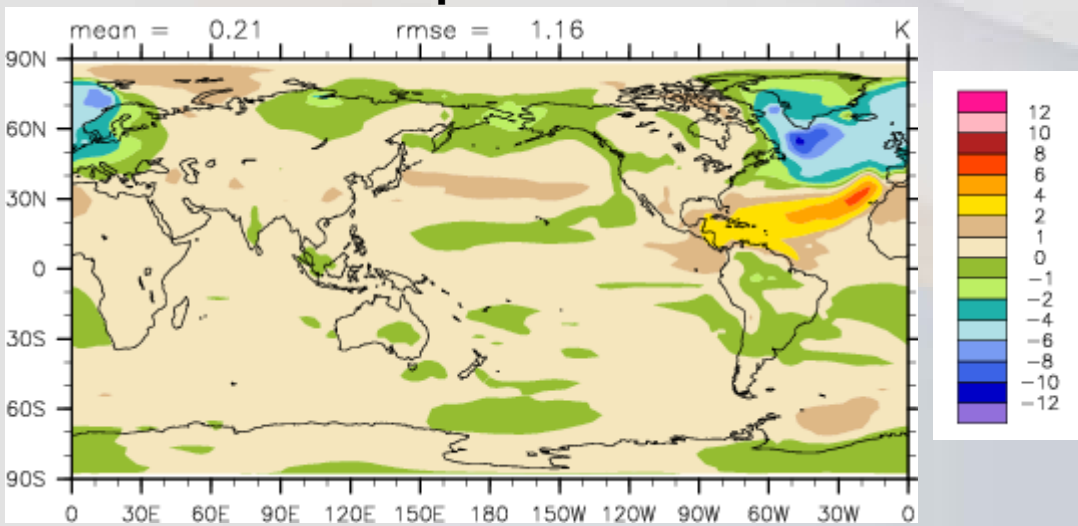




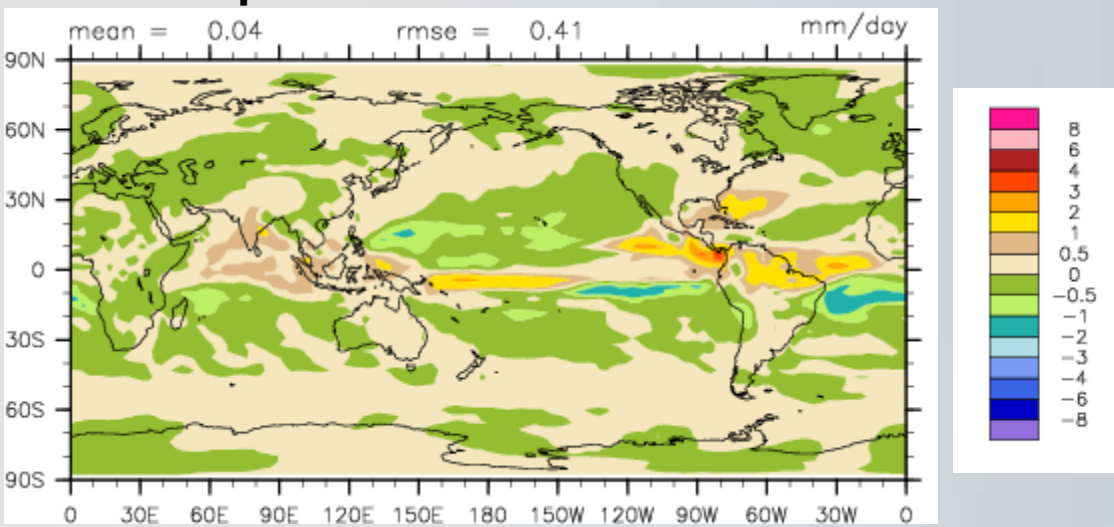


Recovery
Years 180-199 minus Years 80-99

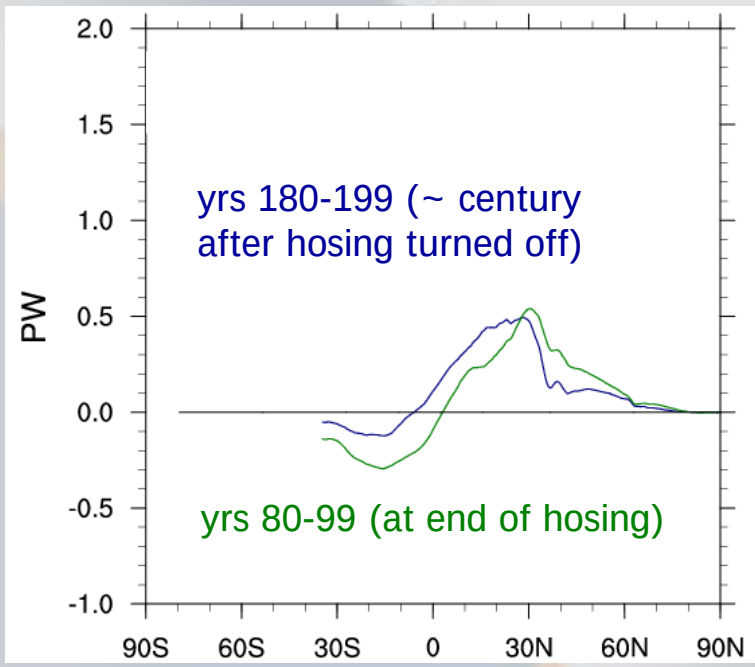
Surface Air Temperature



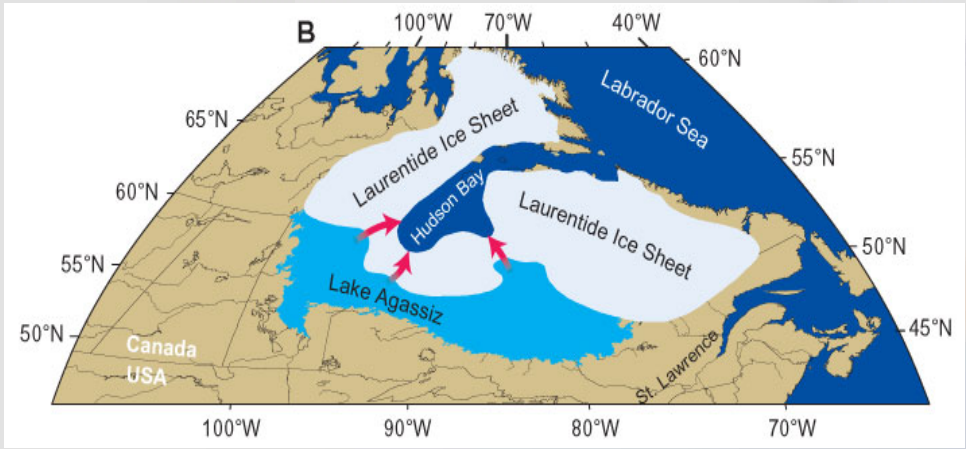
Precipitation



Atlantic OHT



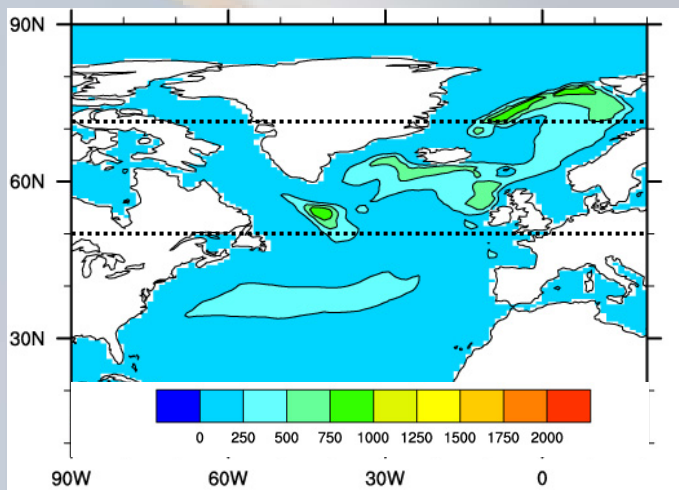
The 8.2 ky BP Megaflood



Clarke, Science, 2003

Estimated discharge: 5 Sv in 6 months

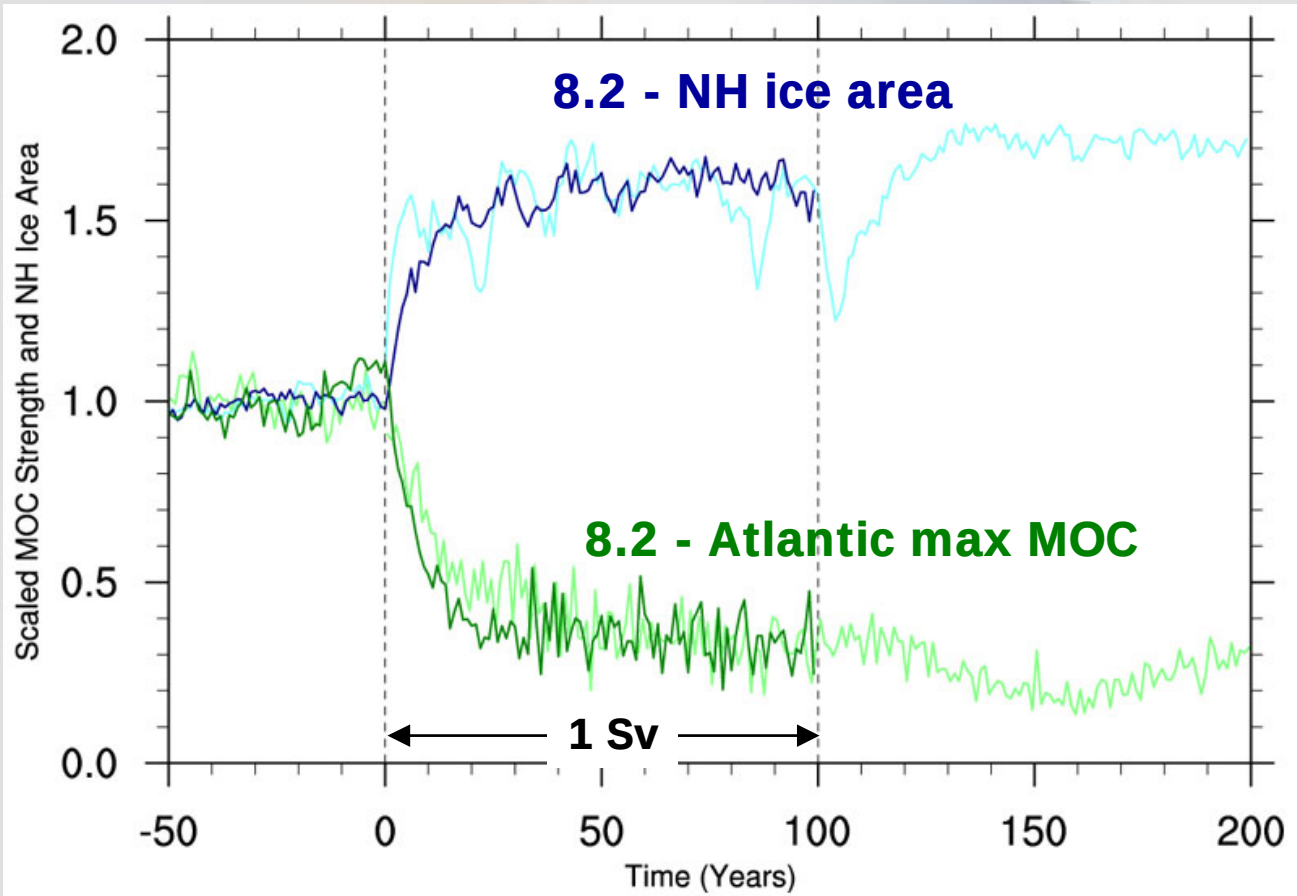
Mixed Layer Depths - March



CCSM3 8.2 Hosing Experiment:

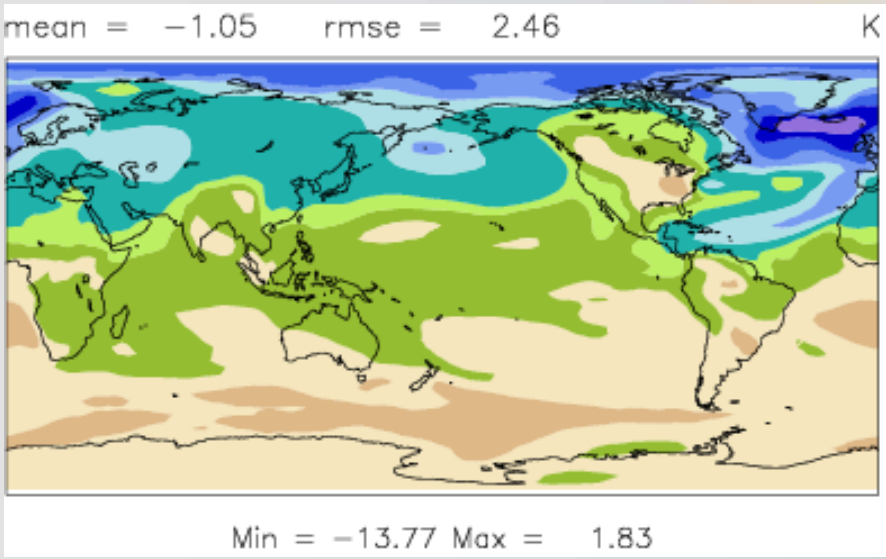
1 Sv for 100 years
North Atlantic 50-70°N

Transient “Scaled” Response – 8.2 “Hosing”
NH annual sea ice concentration & Maximum Atlantic MOC

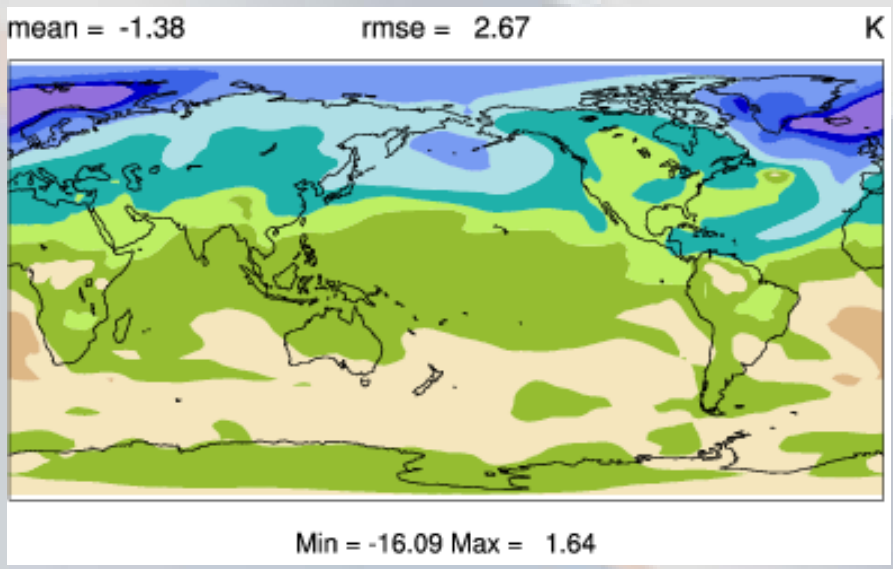


Comparison of CCSM3 LGM and 8.2 Hosing Expts
Surface temperature change during hosing

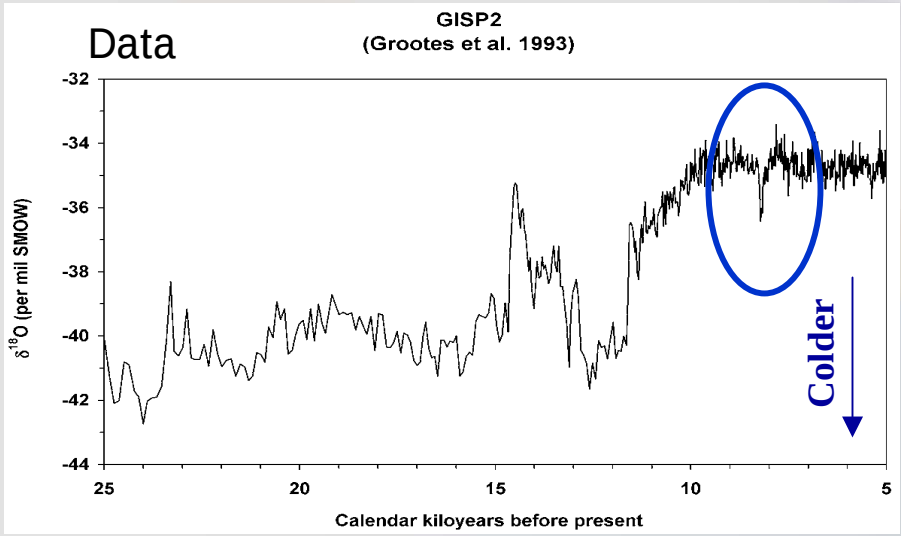
LGM hosing – LGM control

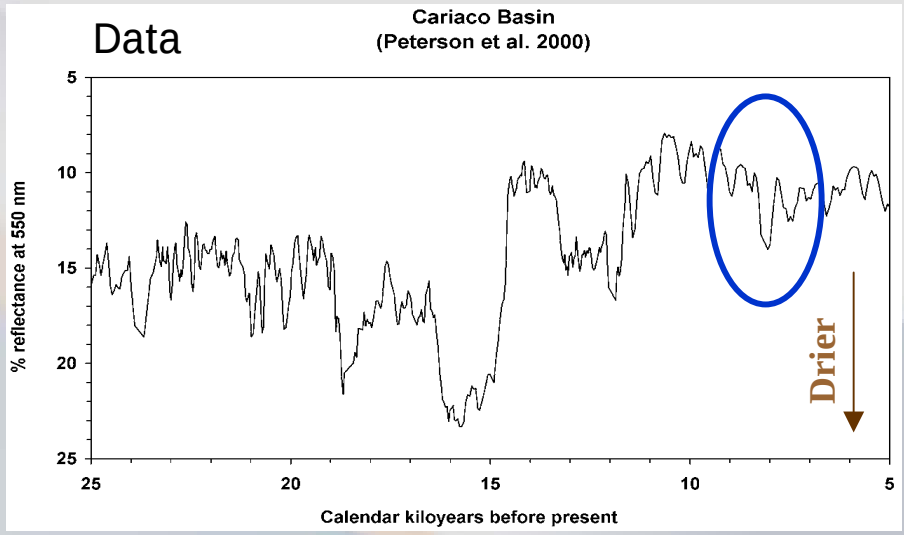


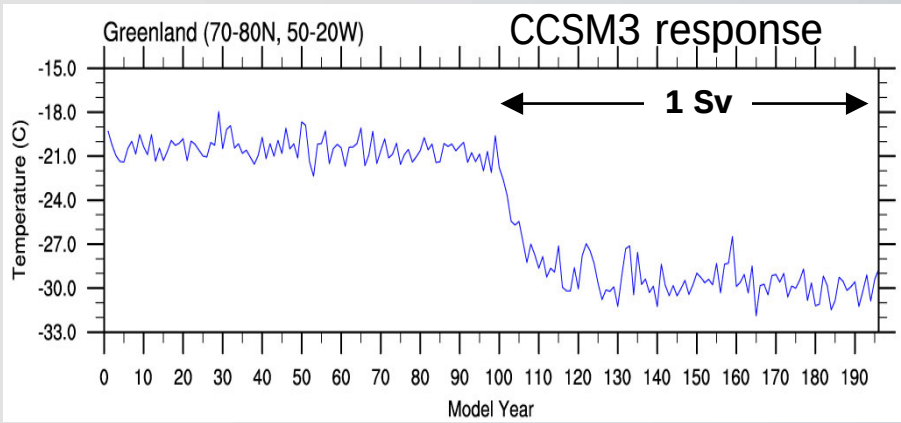
8.2 hosing – 8.2 control

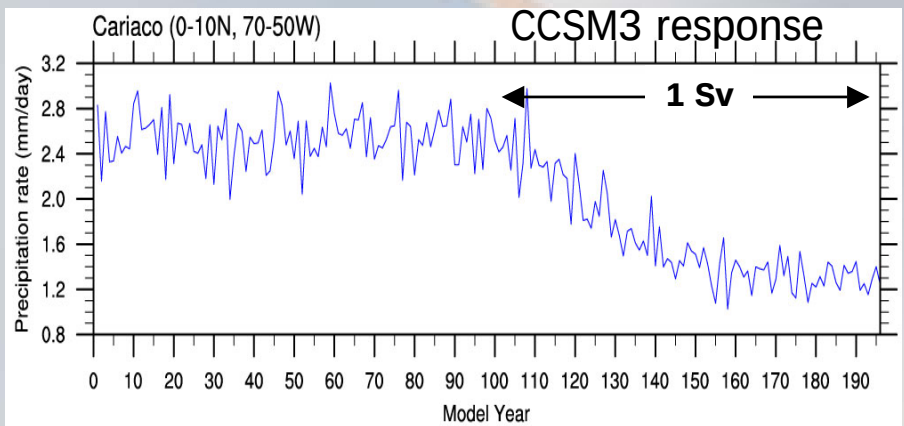


Rates of Response - 8.2 Hosing Experiment







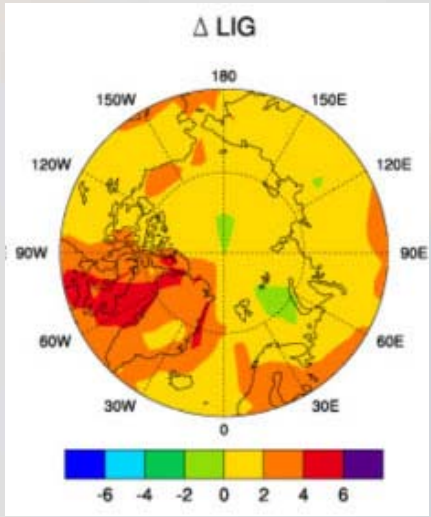


Future Hosing Experiment? Could Greenland melt rapidly?

JJA Surface Temperature Change

CCSM2

Last Interglacial Expt
~ 130,000 yrs BP



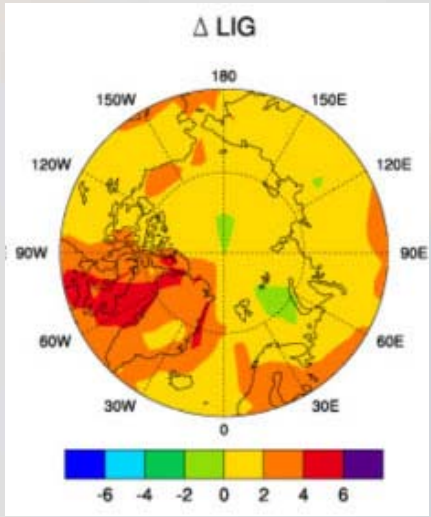
Future Hosing Experiment? Could Greenland melt rapidly?

JJA Surface Temperature Change

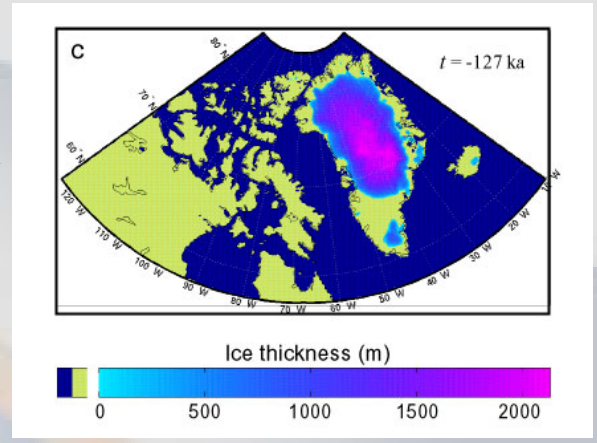
Greenland Ice Sheet after 3000 yrs

CCSM2

Last Interglacial Expt
~ 130,000 yrs BP



Force a GIS model with monthly T and Precip anomalies



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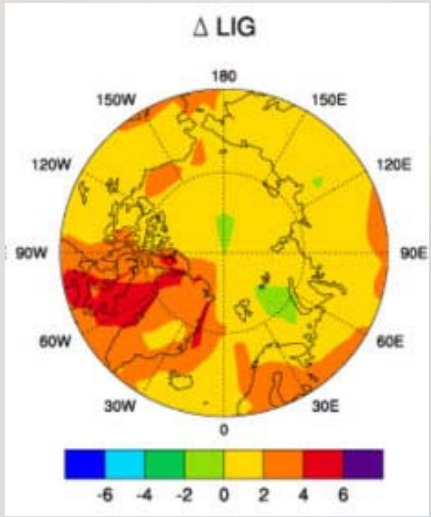

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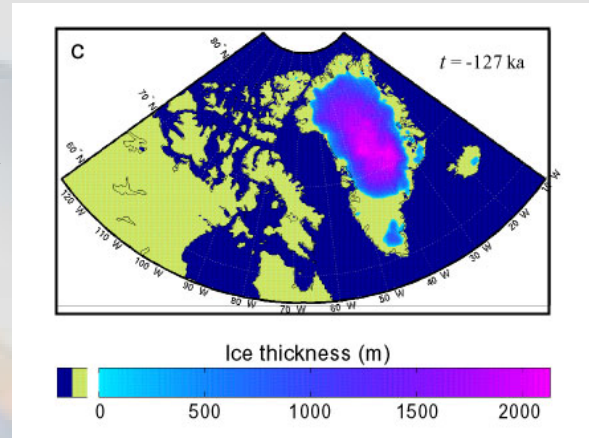


Missing fast dynamics?

Braithwaite, Science, 2002

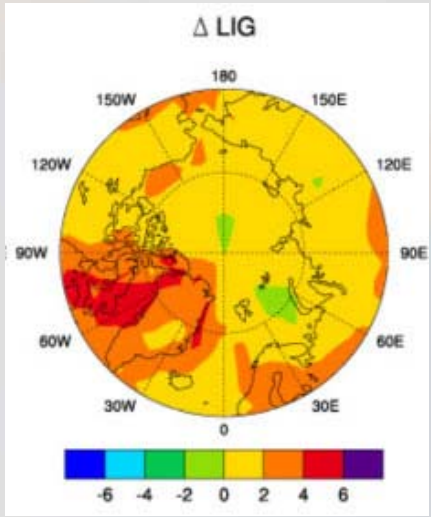
Future Hosing Experiment? Could Greenland melt rapidly?

JJA Surface Temperature Change

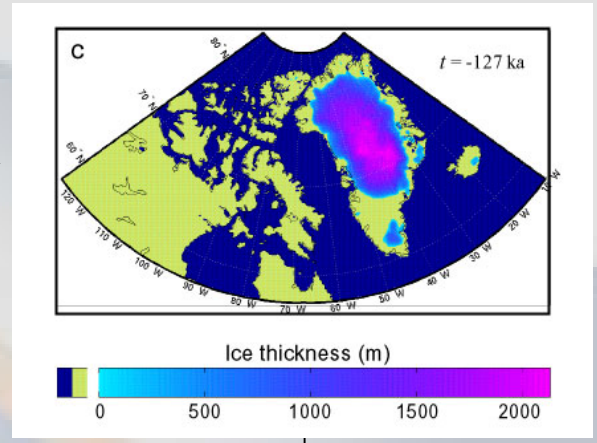
Greenland Ice Sheet after 3000 yrs

CCSM2

Last Interglacial Expt
~ 130,000 yrs BP

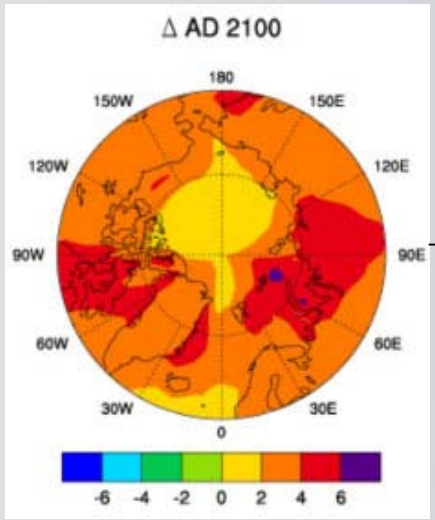


Force a GIS model with monthly T and Precip anomalies



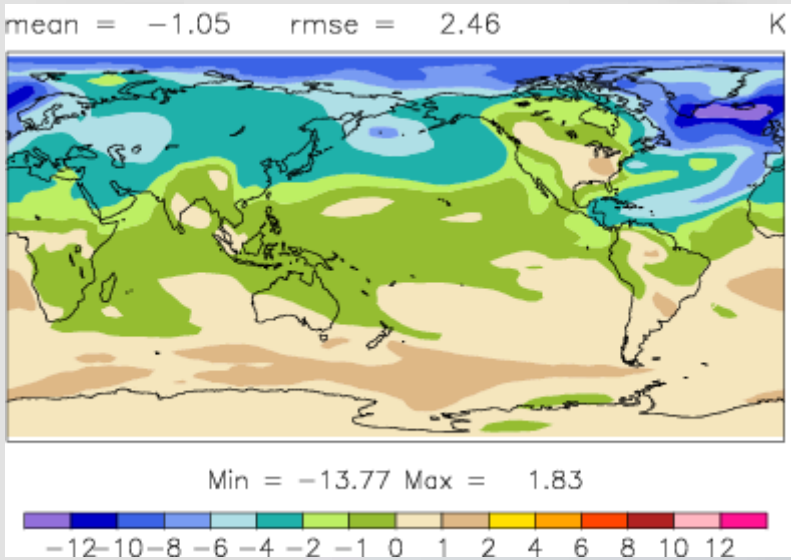
Missing fast dynamics?

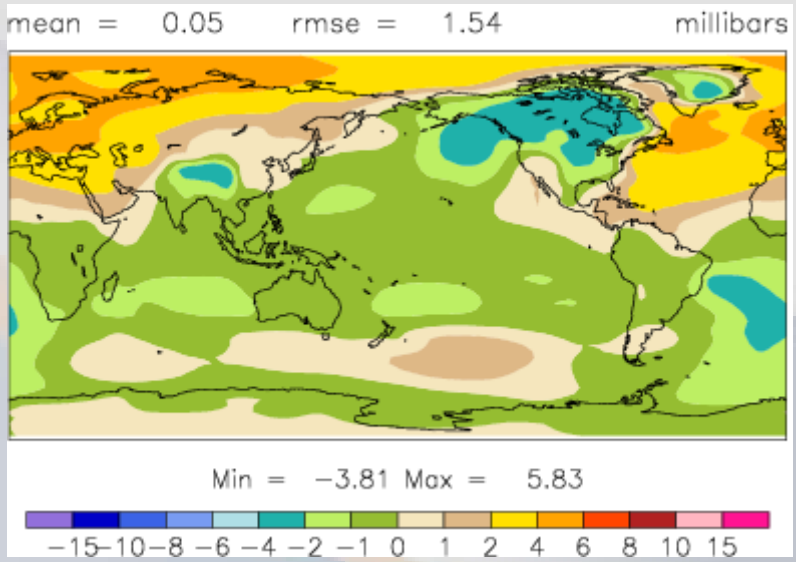
1% transient CO_2
$3xCO_2$

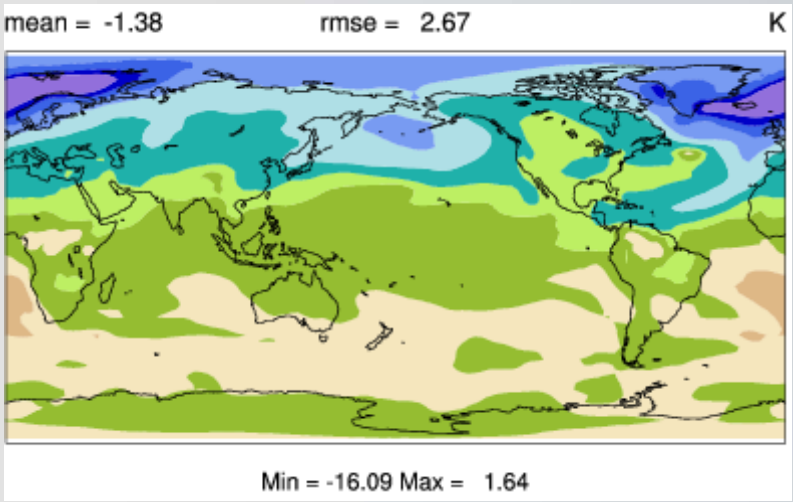


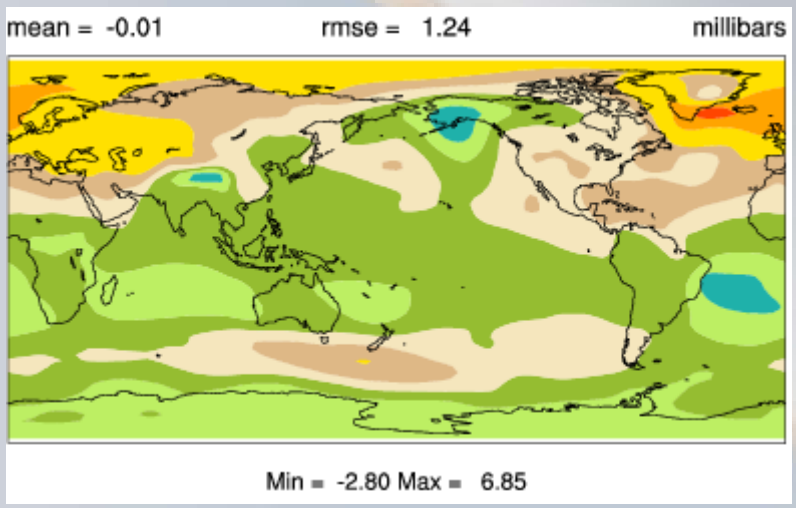
Final Remarks

- 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


mean = −1.05 rmse = 2.46 K
Min = −13.77 Max = 1.83
−12 −10 −8 −6 −4 −2 −1 0 1 2 4 6 8 10 12

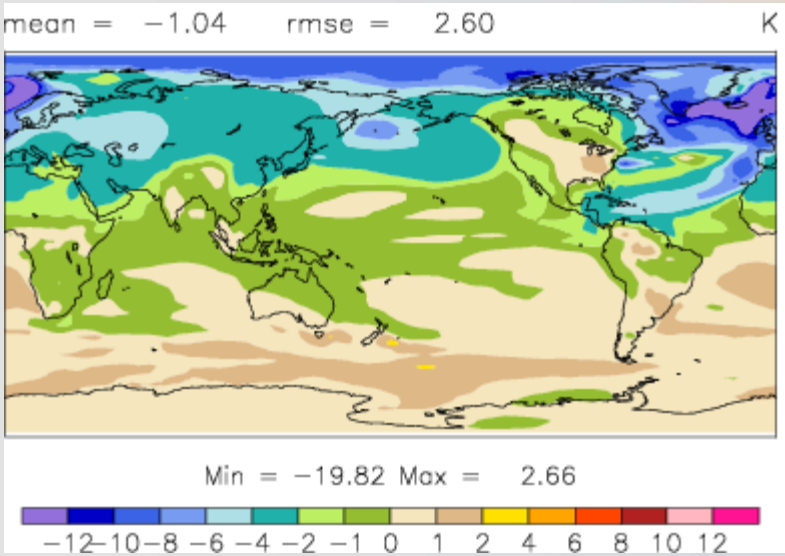

mean = 0.05 rmse = 1.54 millibars
Min = −3.81 Max = 5.83
−15 −10 −8 −6 −4 −2 −1 0 1 2 4 6 8 10 15


mean = -1.38 rmse = 2.67 K
Min = -16.09 Max = 1.64

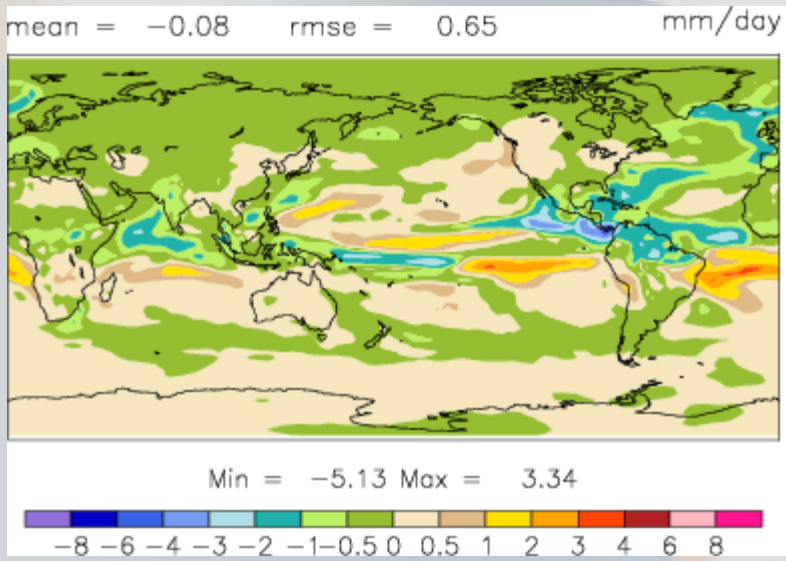

mean = -0.01 rmse = 1.24 millibars
Min = -2.80 Max = 6.85

Changes at End of Freshwater Pulse Years 95-99

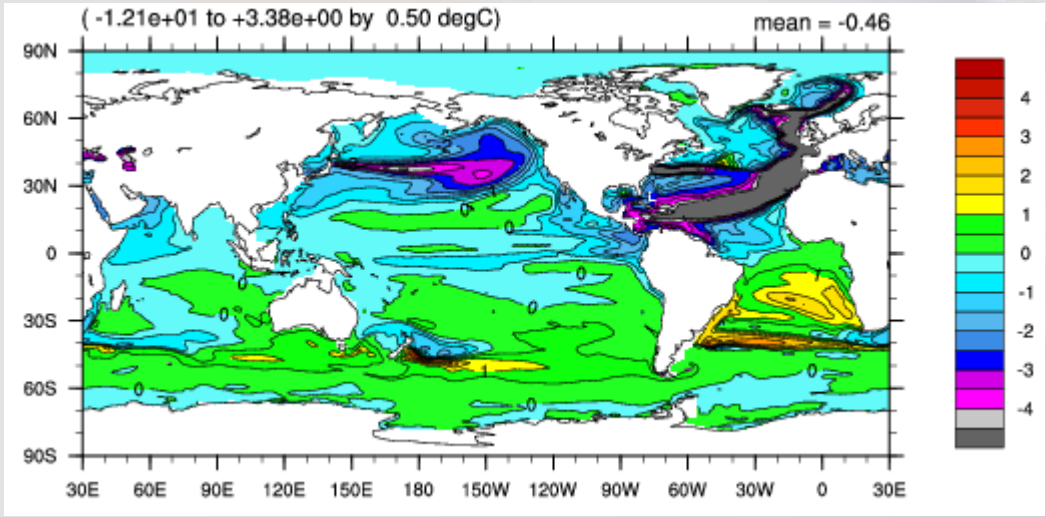
Surface Temperature

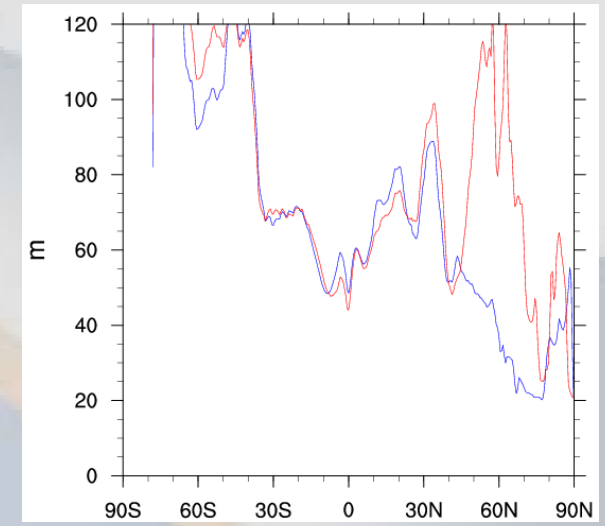


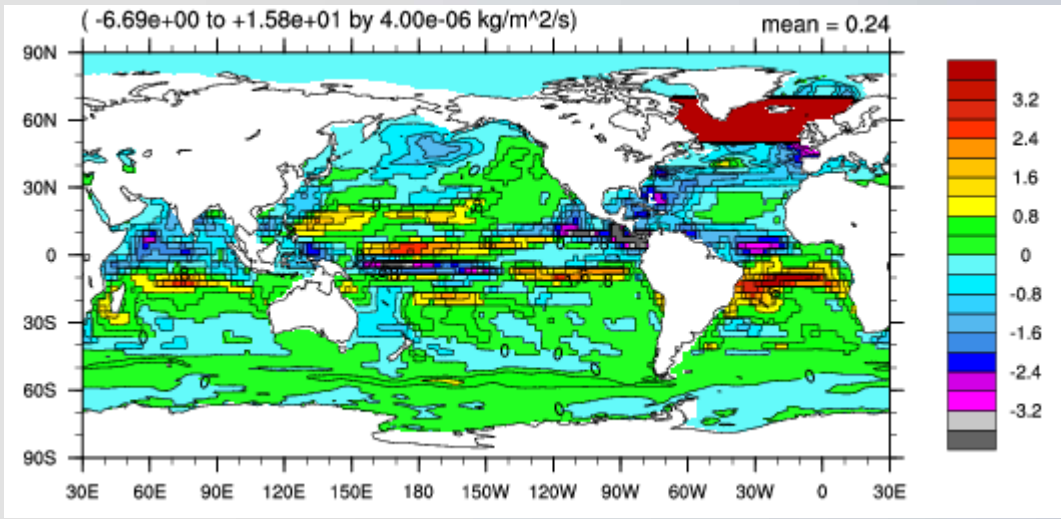
Precipitation

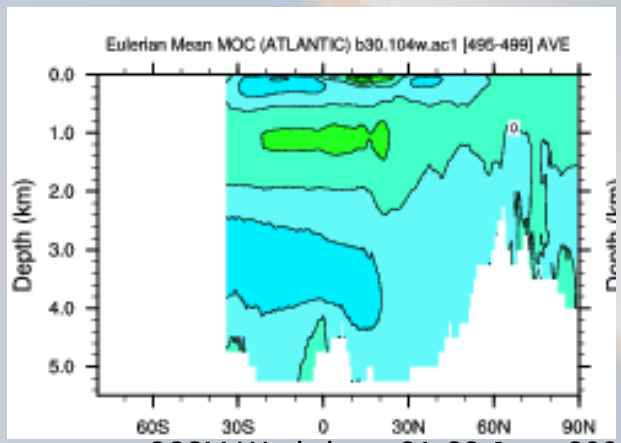


Changes at End of Freshwater Pulse Years 95-99

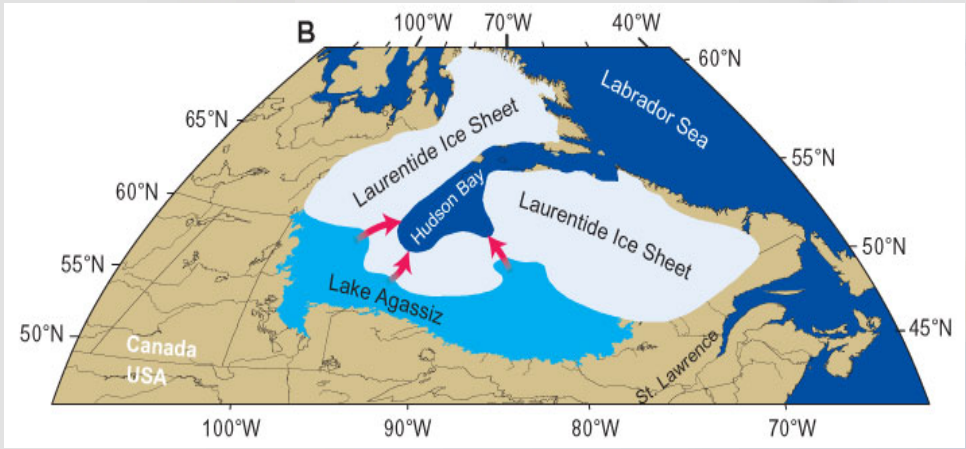








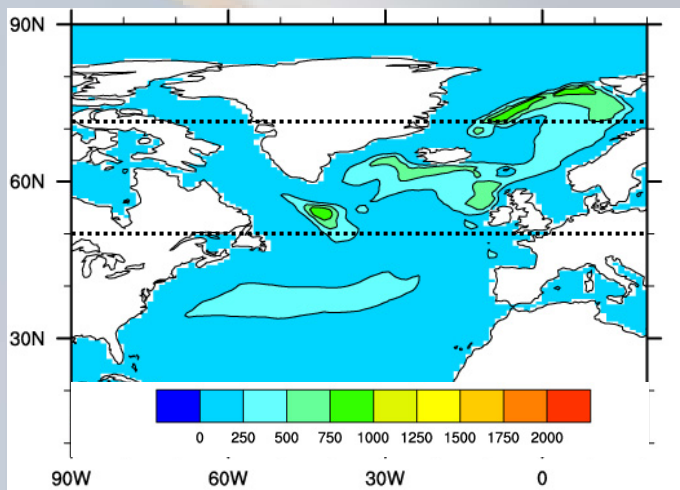
The 8.2 ky BP Megaflood



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

Mixed Layer Depths - March

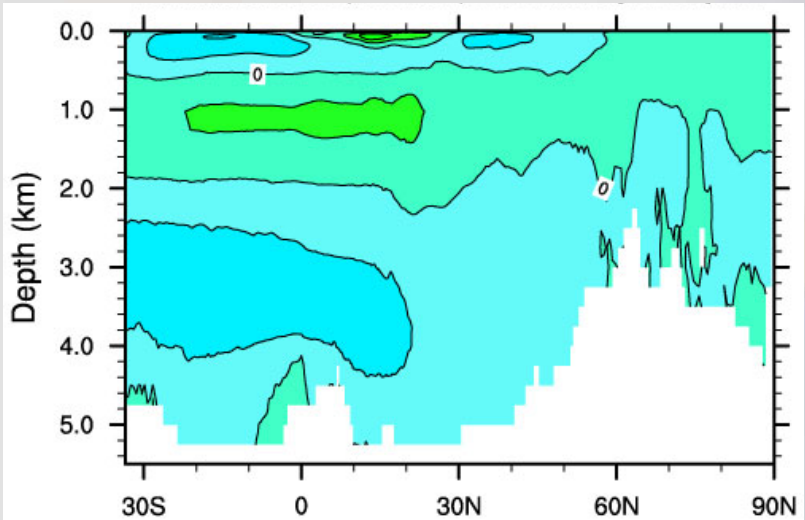


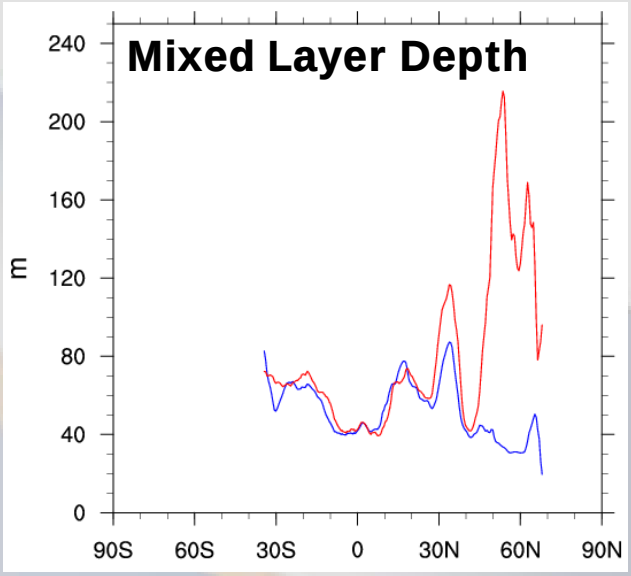
CCSM3 8.2 Hosing Experiment:

1 Sv for 100 years
North Atlantic 50-70°N

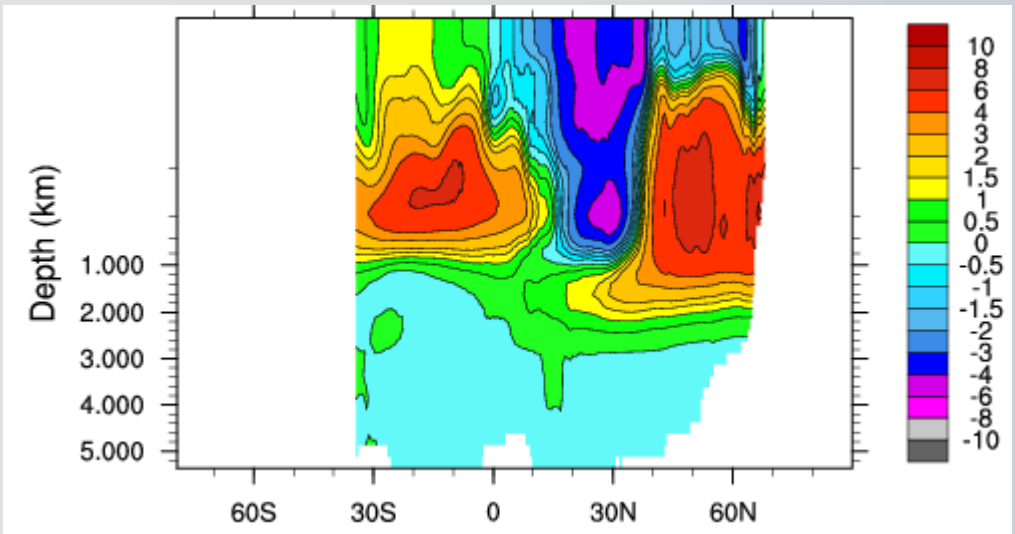
Changes at End of Hosing - Years 80-99

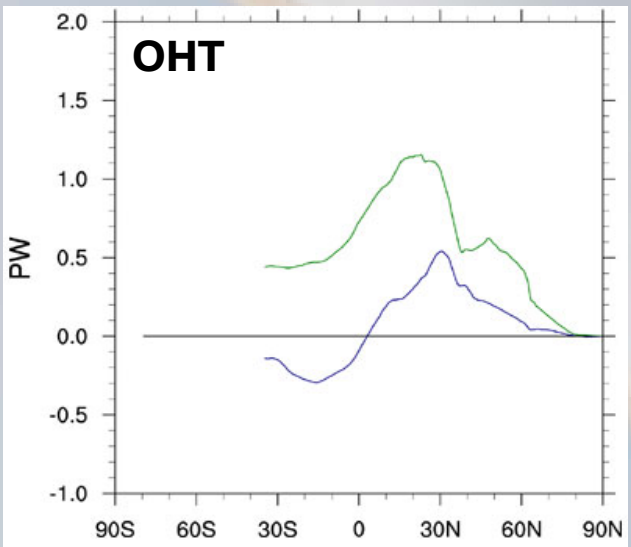
Atlantic MOC





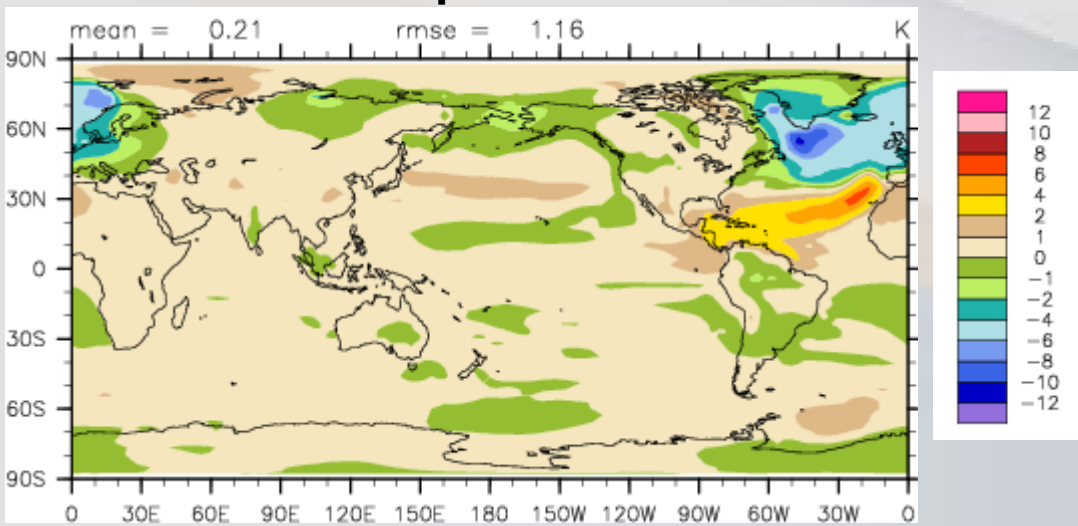
Δ Ocean Temperature

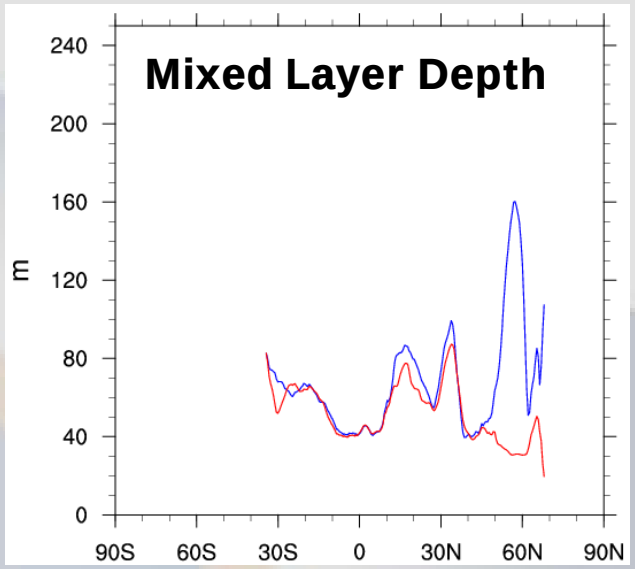




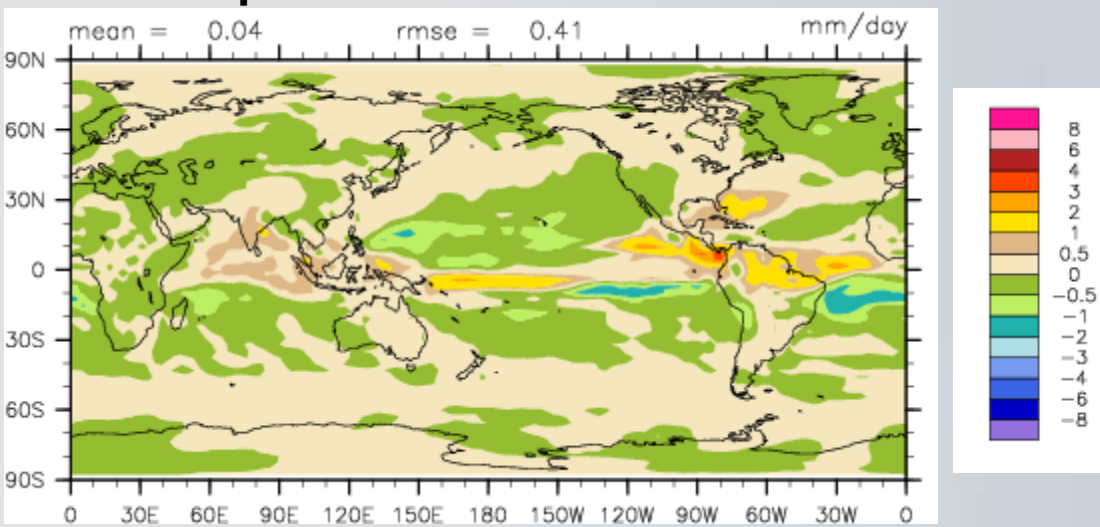
Recovery
Years 180-199 minus Years 80-99

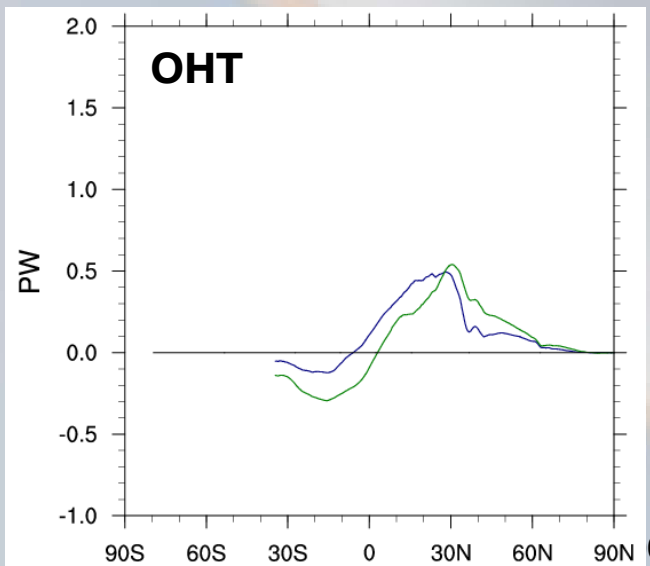
Surface Air Temperature

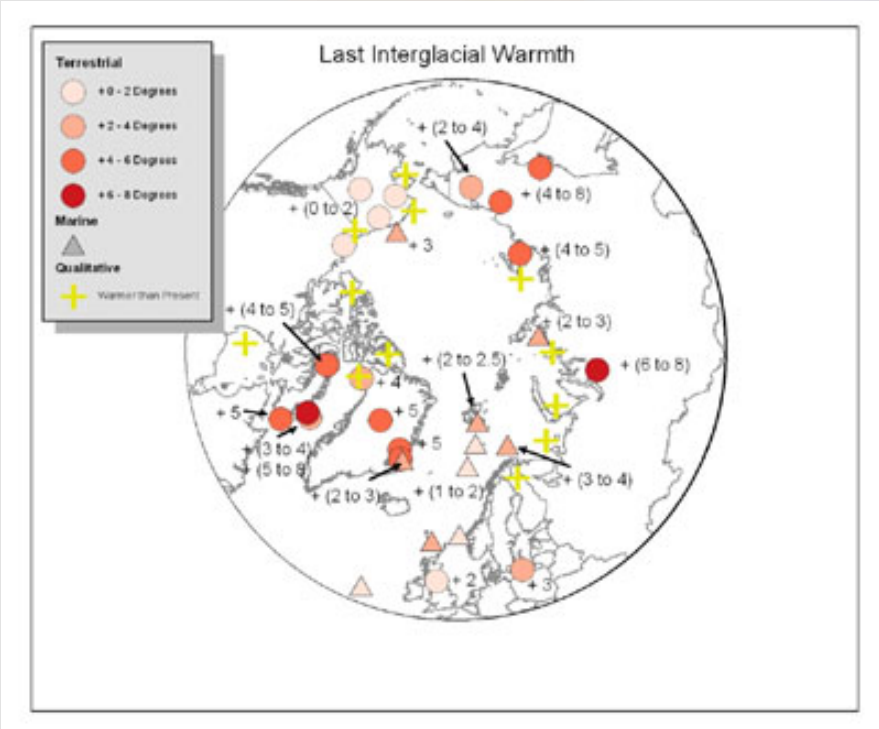


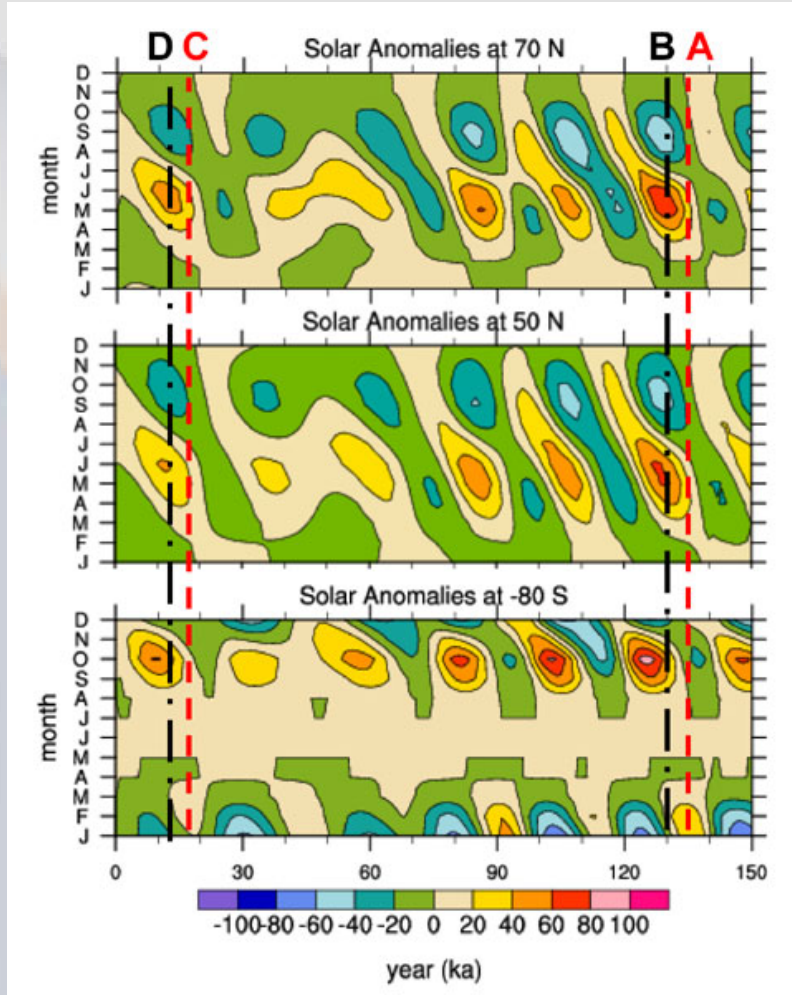


Precipitation






Last Interglacial Warmth
Terrestrial
+0 - 2 Degrees
+2 - 4 Degrees
+4 - 6 Degrees
+6 - 8 Degrees
Marine
Qualitative
+ (2 to 4)
+ (4 to 8)
+ (0 to 2)
+ 3
+ (4 to 5)
+ (4 to 5)
+ (2 to 3)
+ (2 to 2.5)
+ (6 to 8)
+ 4
+ 5
+ 5
+ 5
+ (3 to 4)
+ (5 to 8)
+ (2 to 3)
+ (1 to 2)
+ (3 to 4)
+ 2
+ 3


D C
Solar Anomalies at 70 N
B A
Solar Anomalies at 50 N
Solar Anomalies at -80 S
month
D N O S A J J M A M F J
0 30 60 90 120 150
-100 -80 -60 -40 -20 0 20 40 60 80 100
year (ka)