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Sensitivity of the Younger Dryas climate to changes in freshwater, orbital, and greenhouse gas forcing in CESM1.

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Paleoclimate Working Group

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Overview

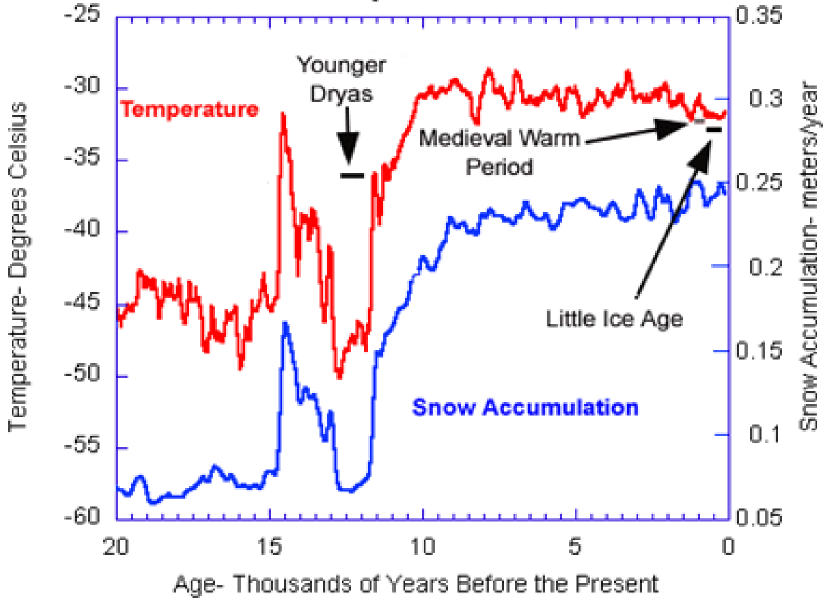
- Background
- Objectives & Hypotheses
- Experiment Design
- Results
- Conclusions
- Future Outlook

The Younger Dryas (YD)

- Dated to 12.9-11.5 ka
- Cooling period for the Northern Hemisphere
- Named for the tundra flower *Dryas octopetala*
- Rapid climate change in the North Atlantic region characterized by:
  - Decreased Atlantic meridional overturning circulation (AMOC)
  - Decreased storminess
  - Decreased temperature
  - Decreased snow accumulation
  - Increased dust accumulations

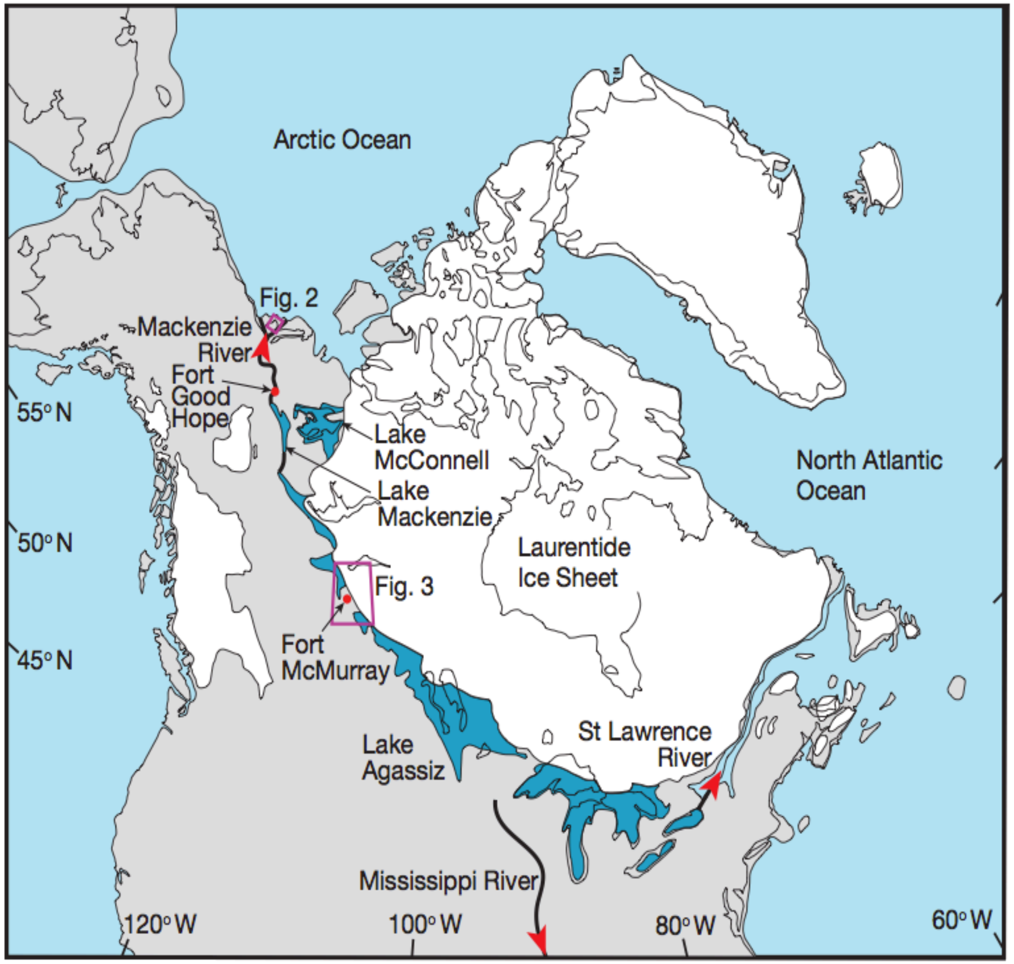
Dryas octopetala

GISP2 Ice Core Temperature and Accumulation Data
Alley, R.B. 2000



Freshwater Forcing Hypothesis

- Freshwater flux due to glacial melting during the Bølling-Allerød event (Broecker et al., 1989)
- Triggered significant cooling (~4.5°C, 15°C at Summit of Greenland) (Severinghaus et al., 1998)
- Rerouting of glacial meltwater drainage from the Mississippi River to the St. Lawrence River at onset (Licciardi et al., 1999; Fairbanks, 1990)
- New geological evidence suggests the Northern Route was the correct flood path from Lake Agassiz (He, 2011; Murton et al., 2010)



Source: Murton et al., 2010

Objectives

How does the Atlantic meridional overturning circulation respond to:

1. Reducing atmospheric pCO_2 to Younger Dryas concentrations
2. Increasing insolation due to orbital changes
3. Freshwater input from the Laurentide ice sheet
4. Implementation of a 13ka ice sheet

Initial and Boundary Conditions			
Parameter	Preindustrial	Younger Dryas	Reference
Incoming Solar Radiation	1,365 W m^{-2}	1,364 W m^{-2}	Adapted from Otto-Bliesner et al. (2006)
Orbital Parameters			
Year	1990	13.0 ka	
Precession	0.01690	-0.01824	Berger and Loutre (1991)
Eccentricity	0.017236	0.020175	
Obliquity	23.446°	24.093°	
Greenhouse Gases			
CO_2	284.7 ppmv	237.6 ppmv	Preindustrial values from Brady et al. (2013) YD values from Joos and Spahni (2008)
CH_4	791.6 ppbv	632.0 ppbv	
N_2O	275.7 ppbv	265.0 ppbv	
Other Parameters			
Vegetation	Preindustrial	Preindustrial	Brady et al. (2013)
Ice Sheet	Present Day	Ice5G	Peltier (2004)
Ocean Salinity	34.73 psu	35.71 psu	Present day from Labeyrie et al. (1992) Younger Dryas calculated from Chappell et al. (1996) and Siddall et al. (2003)

Experiment Design

Simulation	GHGs	Ice Sheet	Orbital Year	Length of Simulation
PI	CO_2 = 284.7 ppmv CH_4 = 791.6 ppbv N_2O = 275.68 ppbv	Modern Greenland and Antarctica	1990	100 yr
YDCO2	CO_2 = 237.57 ppmv CH_4 = 791.6 ppbv N_2O = 275.68 ppbv	PI	PI	500 yr
YDORB	CO_2 = 284.7 ppmv CH_4 = 791.6 ppbv N_2O = 275.68 ppbv	PI	13 ka	500 yr
YD	CO_2 = 237.57 ppmv CH_4 = 632.0 ppbv N_2O = 265.0 ppbv	13 ka	13 ka	500 yr

Radiative forcing changes from Younger Dryas to present

Atmospheric pCO_2

$$\Delta T = \lambda \times 6.3 \ln\left[\frac{(pCO_2)}{(pCO_2)_{ref}}\right]$$

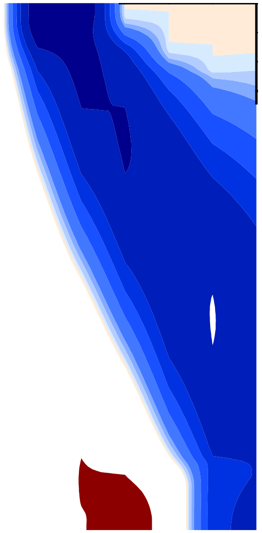
$$\text{Radiative Forcing} = 6.3 \ln\left[\frac{(pCO_2)}{(pCO_2)_{ref}}\right]$$

$$RF = 6.3\ {}^{W}/_{m^2} \ln\left[\frac{237.57\text{ ppmv}}{280\text{ ppmv}}\right] = -1.0353\ {}^{W}/_{m^2}$$

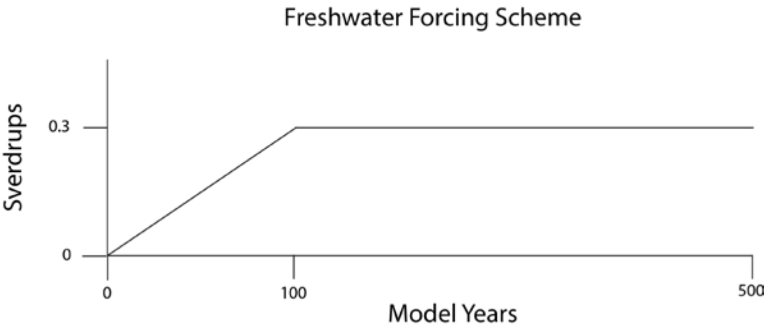
$$\Delta T = 0.733\ {}^{°C}/_{{}^{W}/_{m^2}} \times -1.0354\ {}^{W}/_{m^2} = -0.759\ °C$$

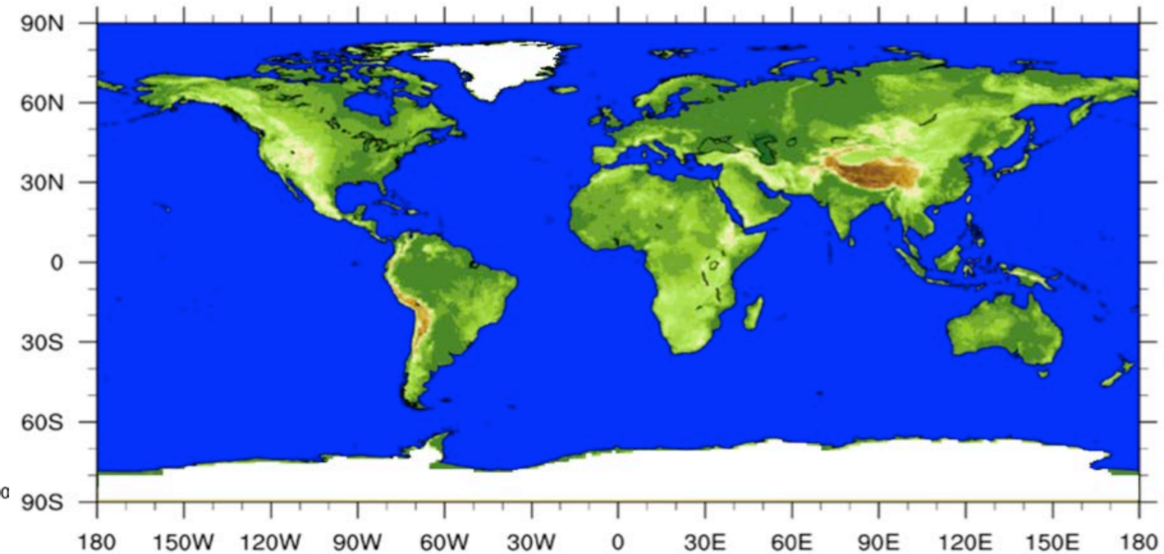
Hansen et al., 1988
Winguth et al., 2015

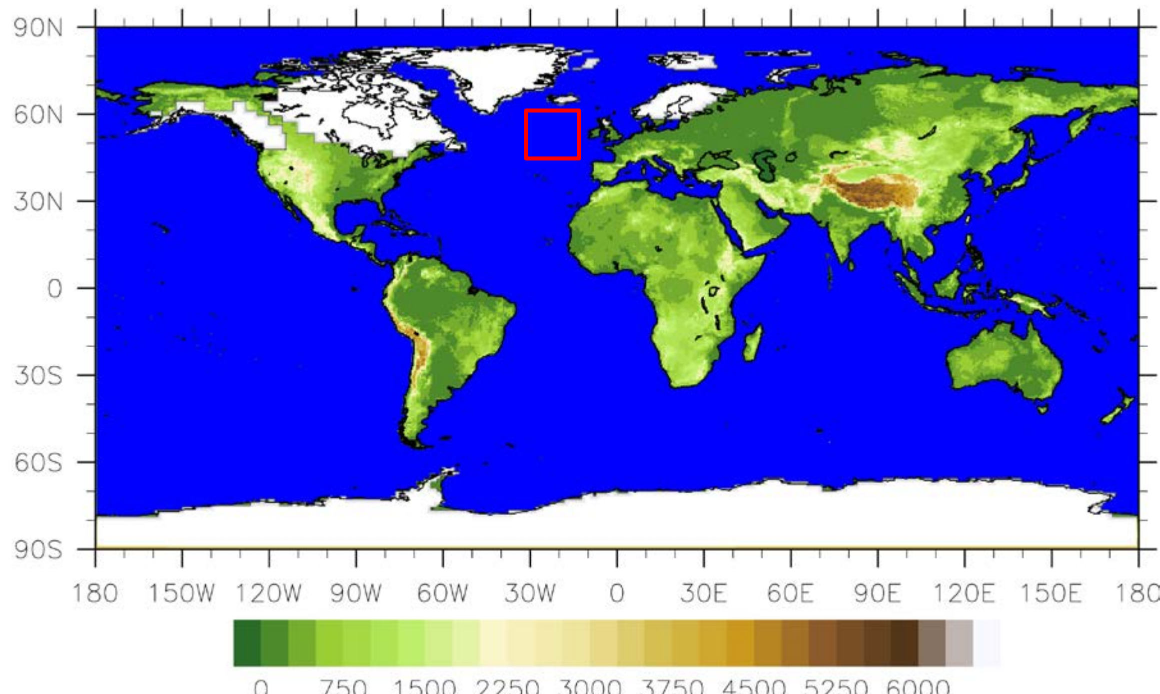
Orbital



Experiment Design

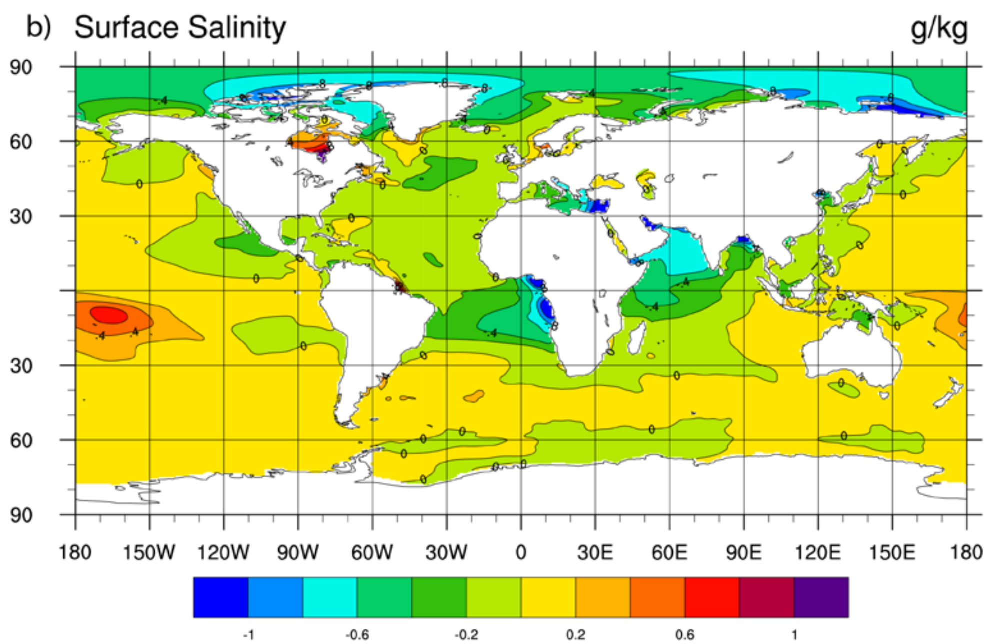


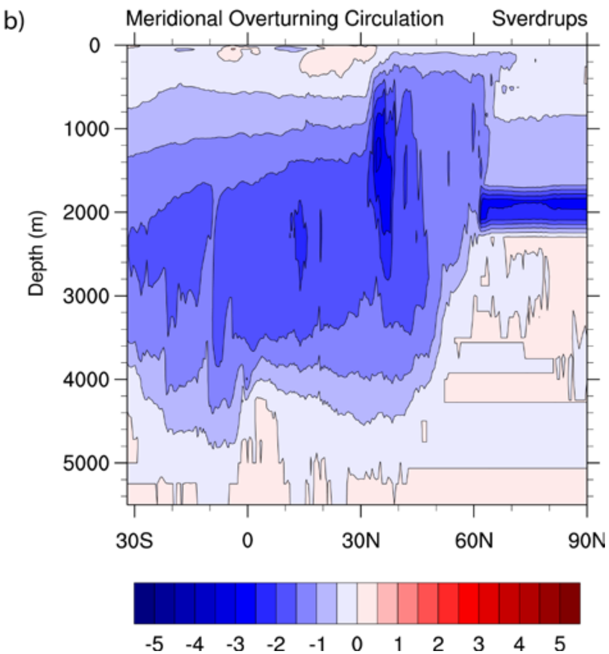


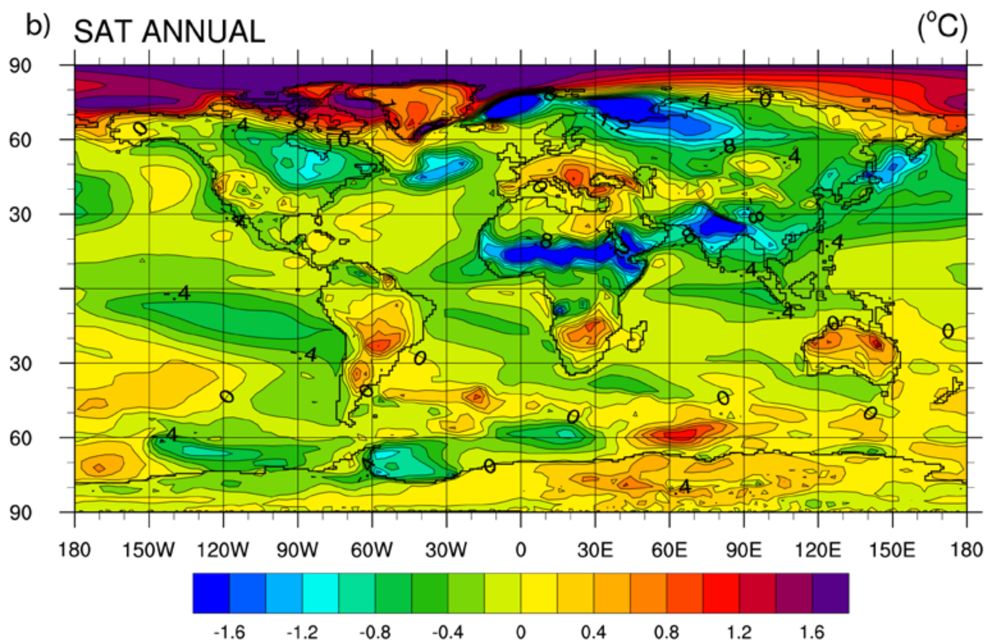


- Freshwater Forcing Location
  - 47.34-60.45°N latitude
  - 321.63-343.50°E longitude
- Freshwater Forcing Scheme
  - Ramped by 0.003 Sv for 100 years

YDORB



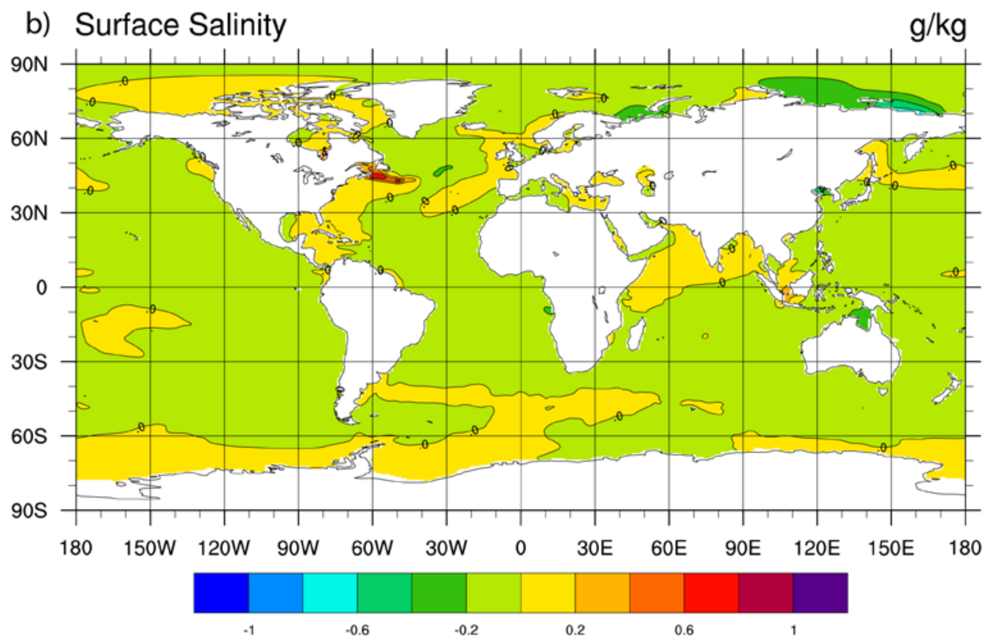


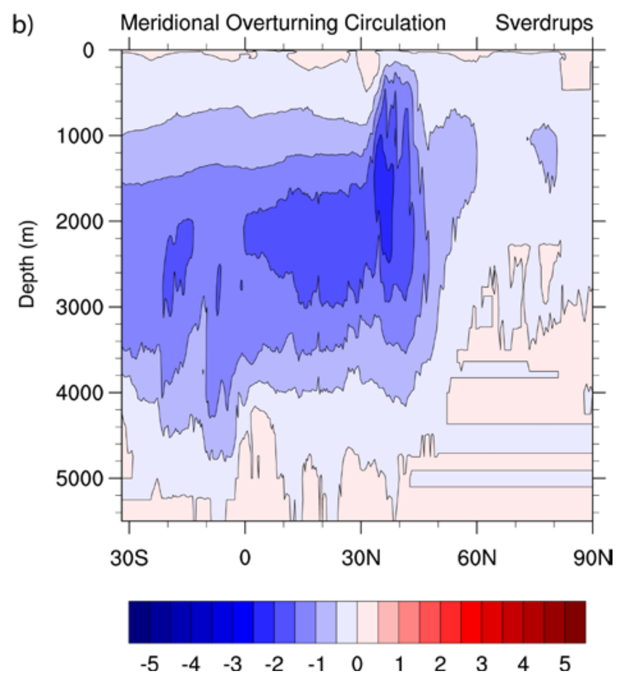


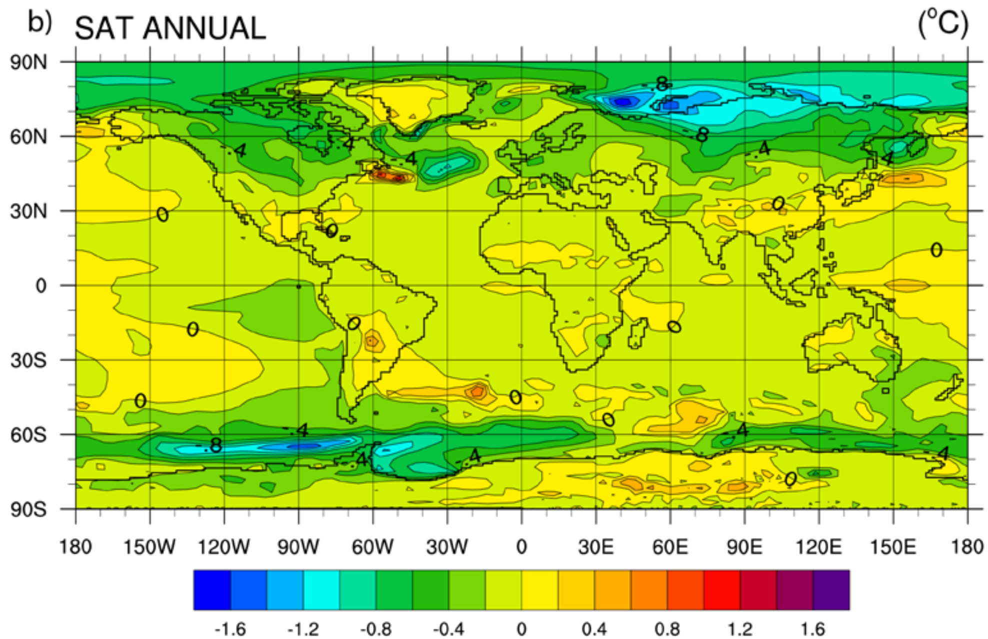
Decreased salinity leads to AMOC strength decrease, which leads to a decrease in surface air temperature due to a decrease in poleward heat transport

Temperature increases over Greenland

YDCO2

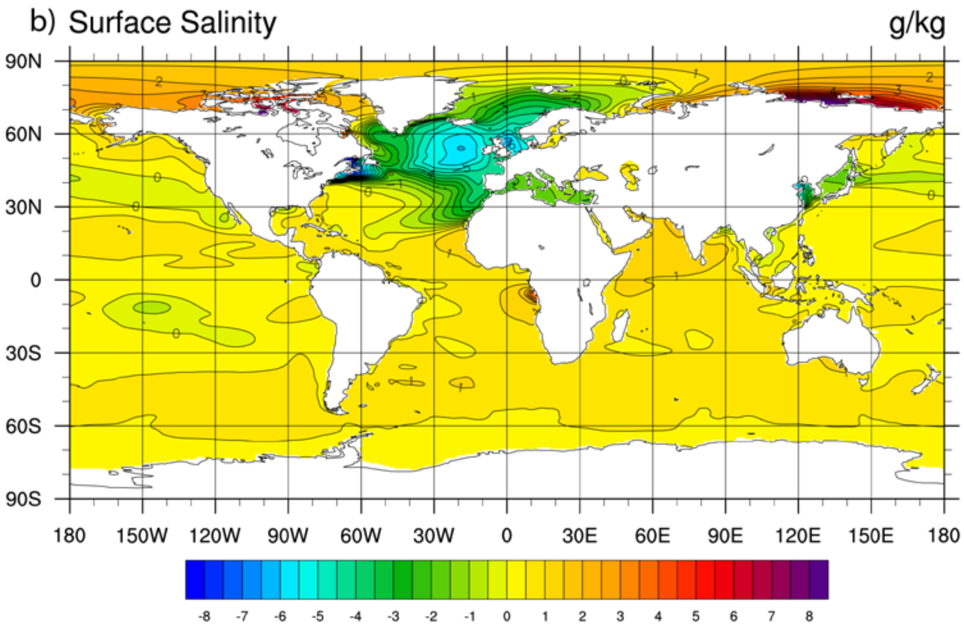


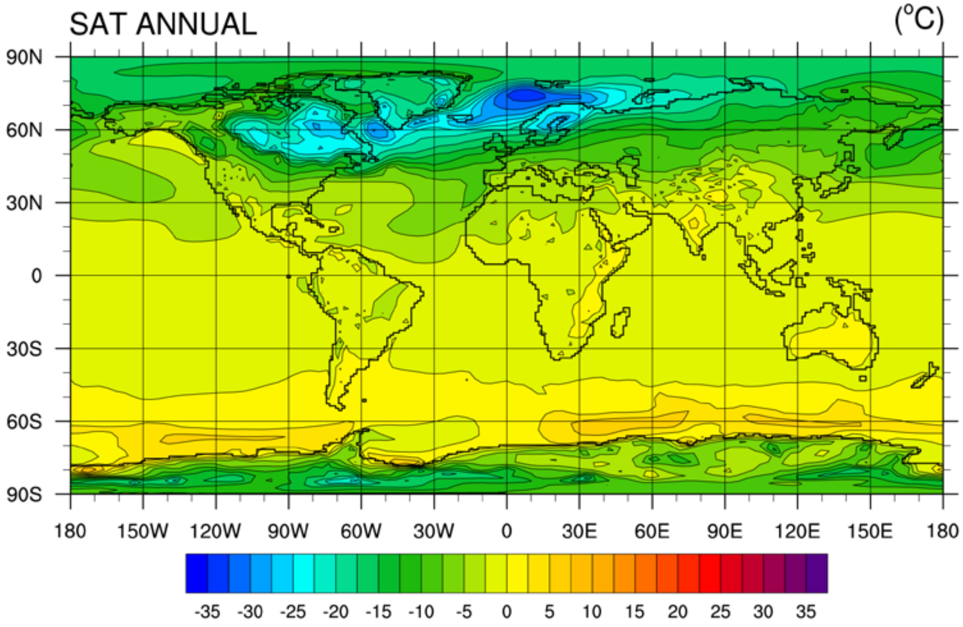




Decreased salinity leads to AMOC strength decrease, which leads to a decrease in surface air temperature due to a decrease in poleward heat transport

Temperature does not change over Greenland



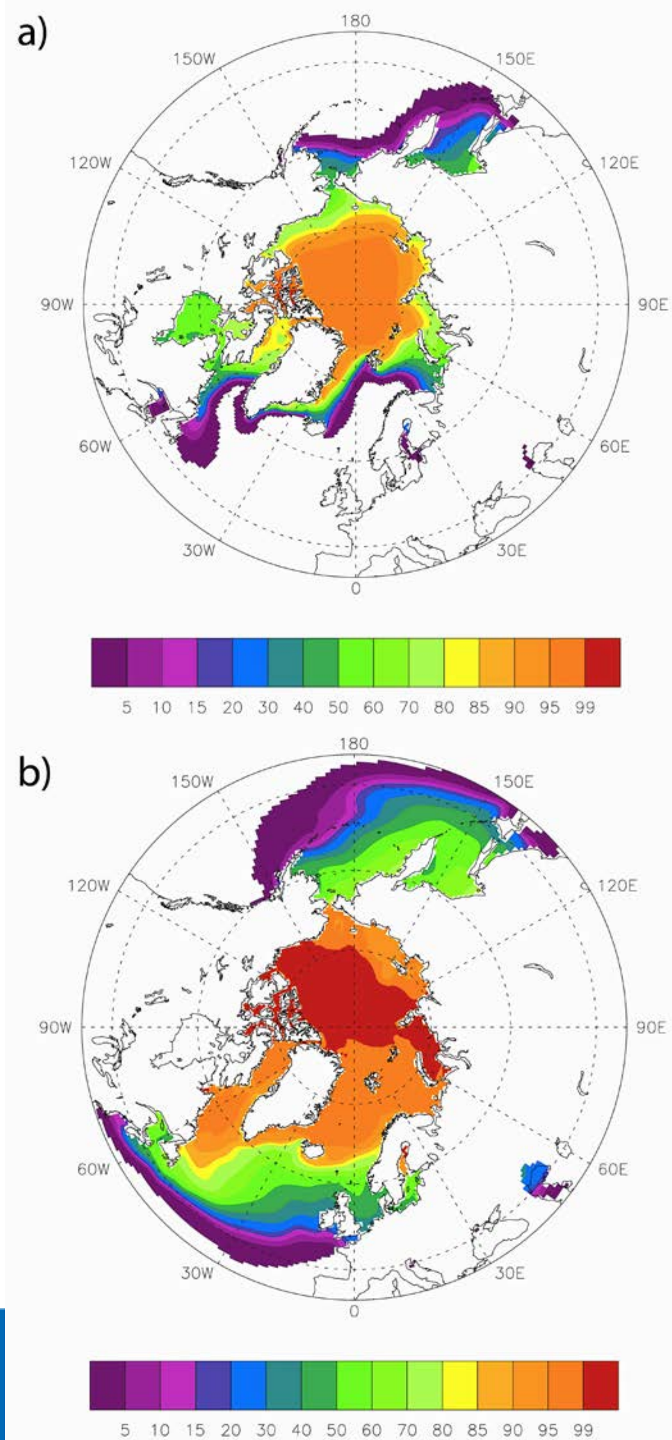


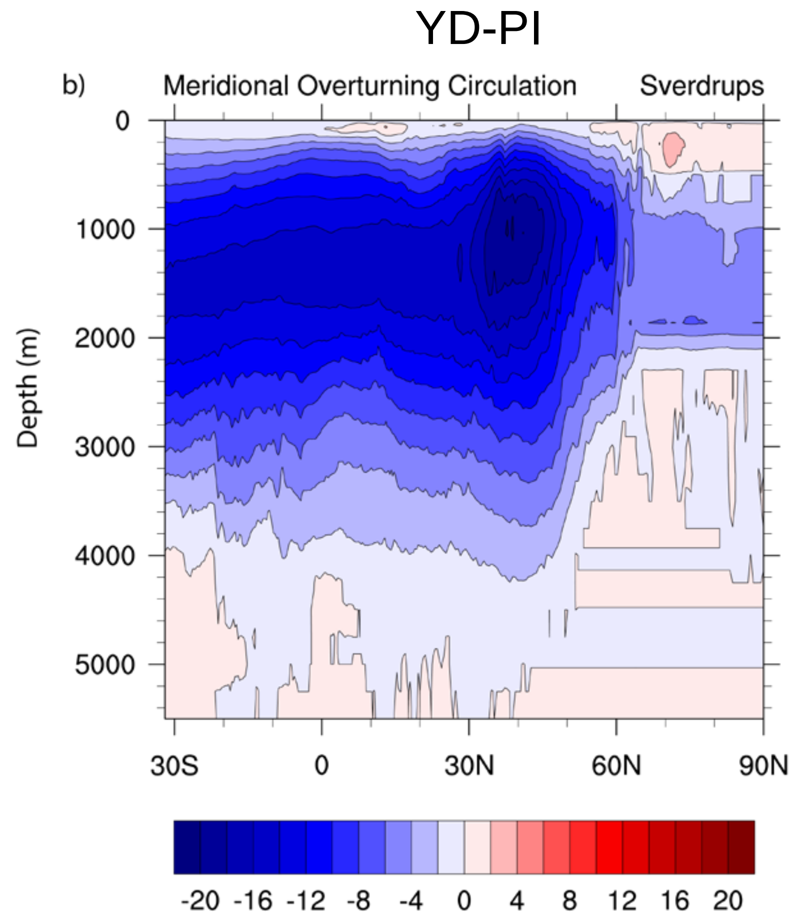
Decreased salinity leads to AMOC strength decrease, which leads to a decrease in surface air temperature due to a decrease in poleward heat transport

Temperature decreases over Greenland by ~15°C

PI

YD





Two reasons for surface air temperature decrease:

1) Ice Sheet Extent

2) Decrease in AMOC strength

Conclusions

- YD to preindustrial changes in the AMOC may be more affected by the seasonal radiative forcing changes by orbital parameters and associated changes in freshwater fluxes than by the relatively low changes in CO_2 radiative forcing.
- The climatic changes by orbital and CO_2 forcing alone are not sufficient enough to explain the YD cooling event, indicating that additional forcings are required.
- The addition of freshwater forcing into the Northern Atlantic ocean causes a decrease in AMOC strength and a decrease in surface air temperature in agreement with surface air temperature reconstructions for the Younger Dryas.
- The addition of the Younger Dryas freshwater forcing and 13 ka ice sheet were large enough to balance or even compensate the effects of the greenhouse gas and orbital forcing.

Future Outlook

- Isolation of freshwater discharge and ice sheet effects on convective overturning strength
- Ramping down the freshwater discharge in the full Younger Dryas experiment; How does the AMOC respond?
- How does ice sheet size affect the Younger Dryas climate?
- Could a bolide impact have caused the YD event?

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Questions?