Ice age climate and the oceanic pathway between Pacific and Atlantic

Aixue Hu

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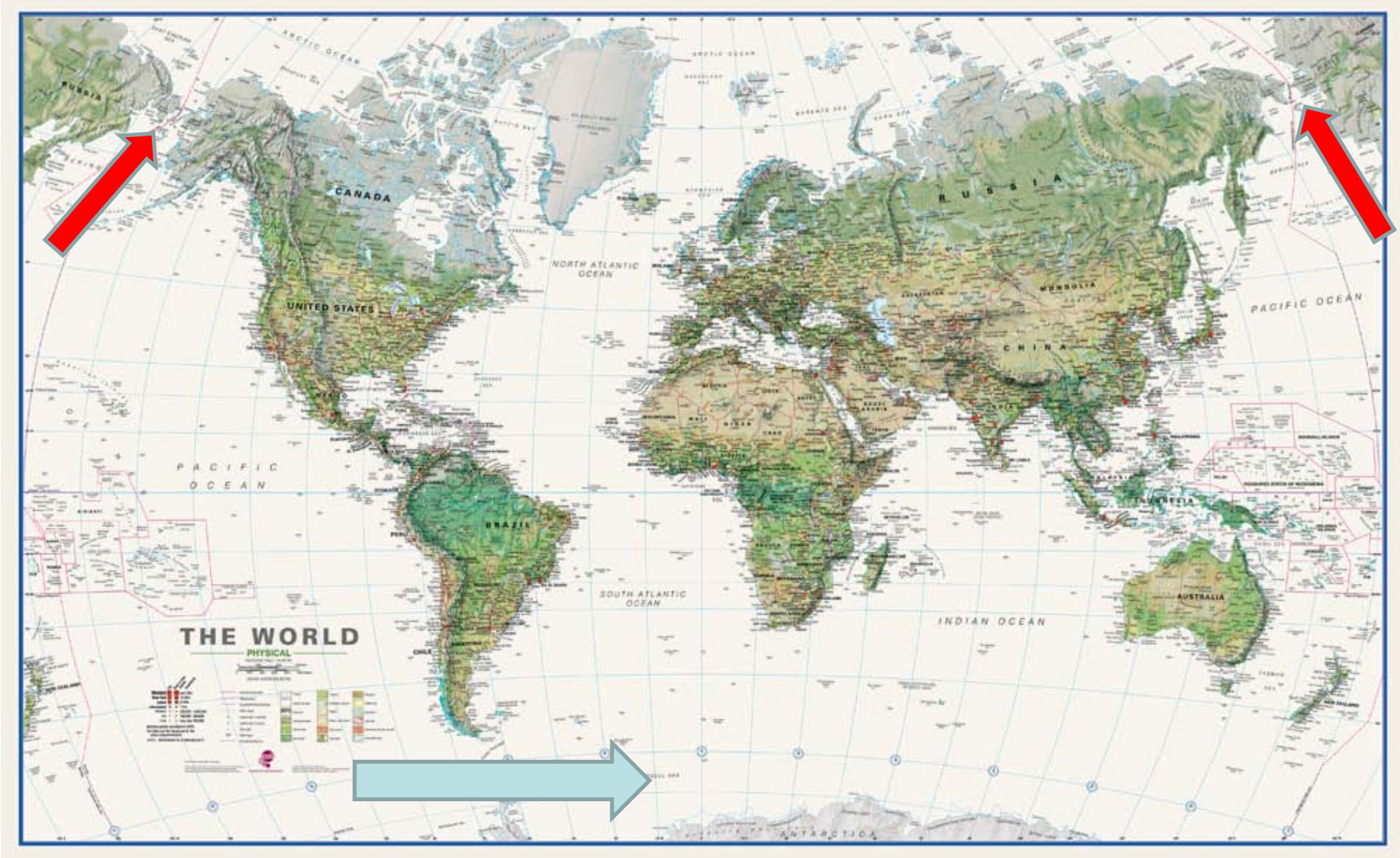
1. Northern Oceanic Pathway between Pacific and Atlantic



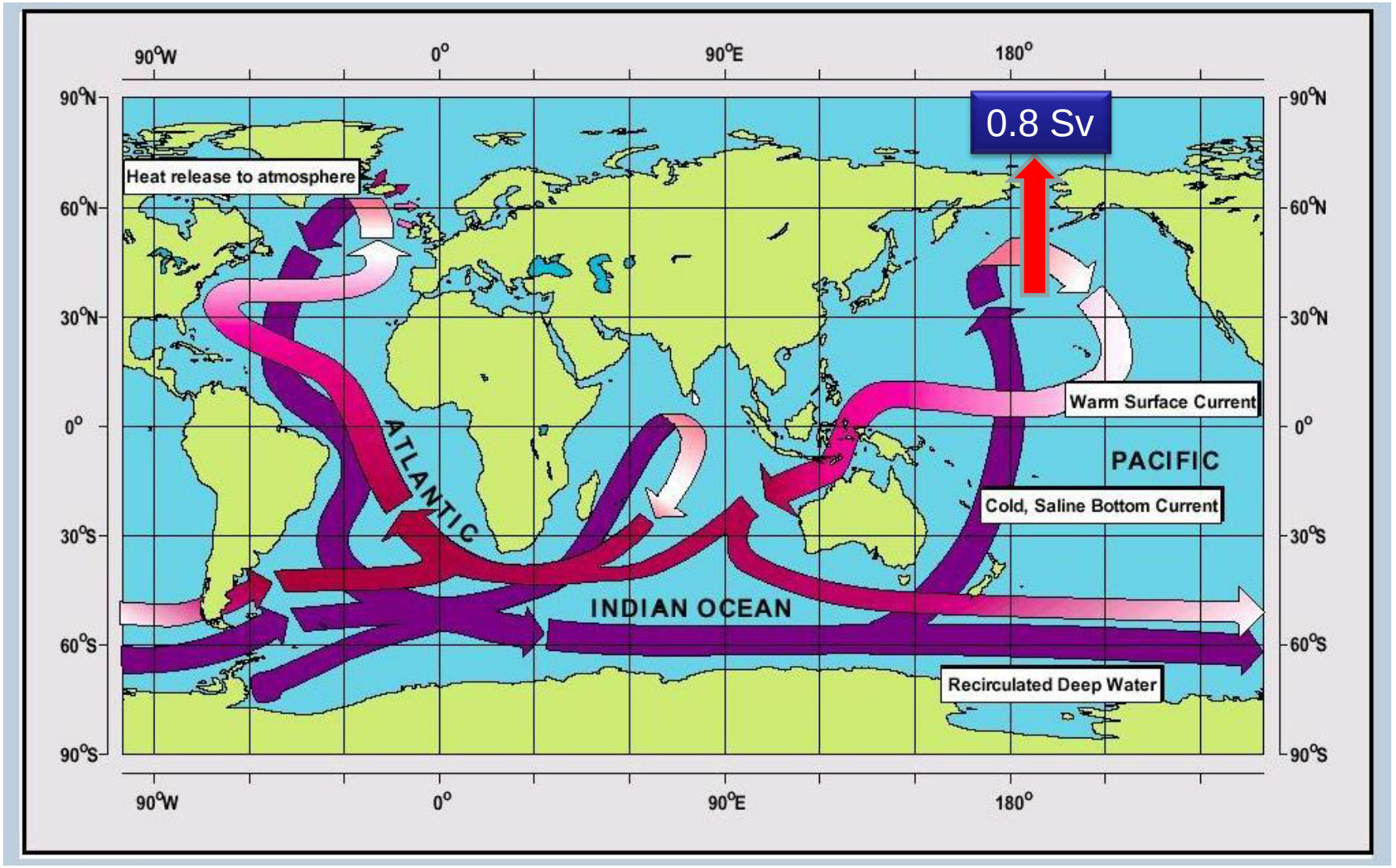
Facts about Bering Strait:

Present: Bering Strait is a narrow (~150 km) and shallow (~50 m) pathway connecting the Pacific and the Arctic between Alaska and Siberia.

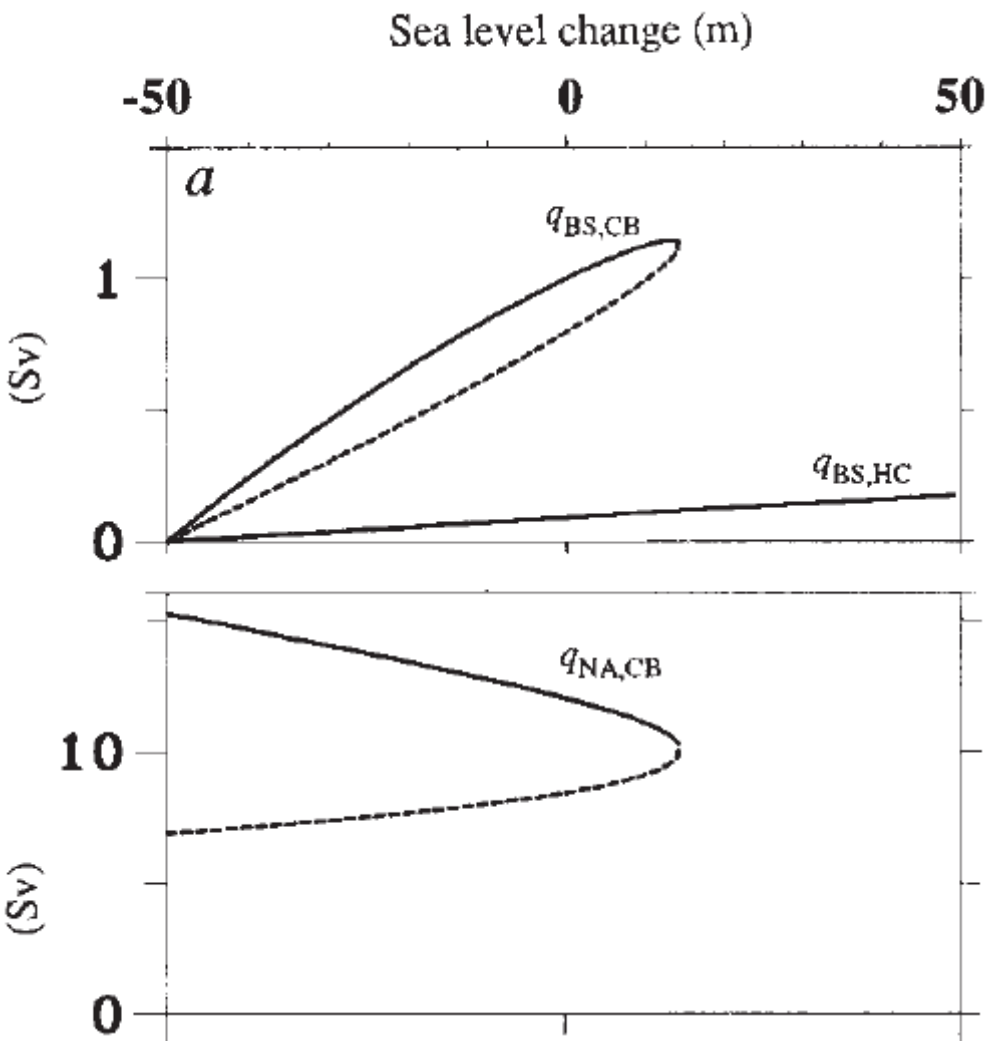
On average, about 0.8 Sv fresher North Pacific water flows through this strait into the Arctic, subsequently into the North Atlantic.

Sverdrup (Sv) ≡ 10^6 m^3s^{-1} or 1 million cubic meters per second

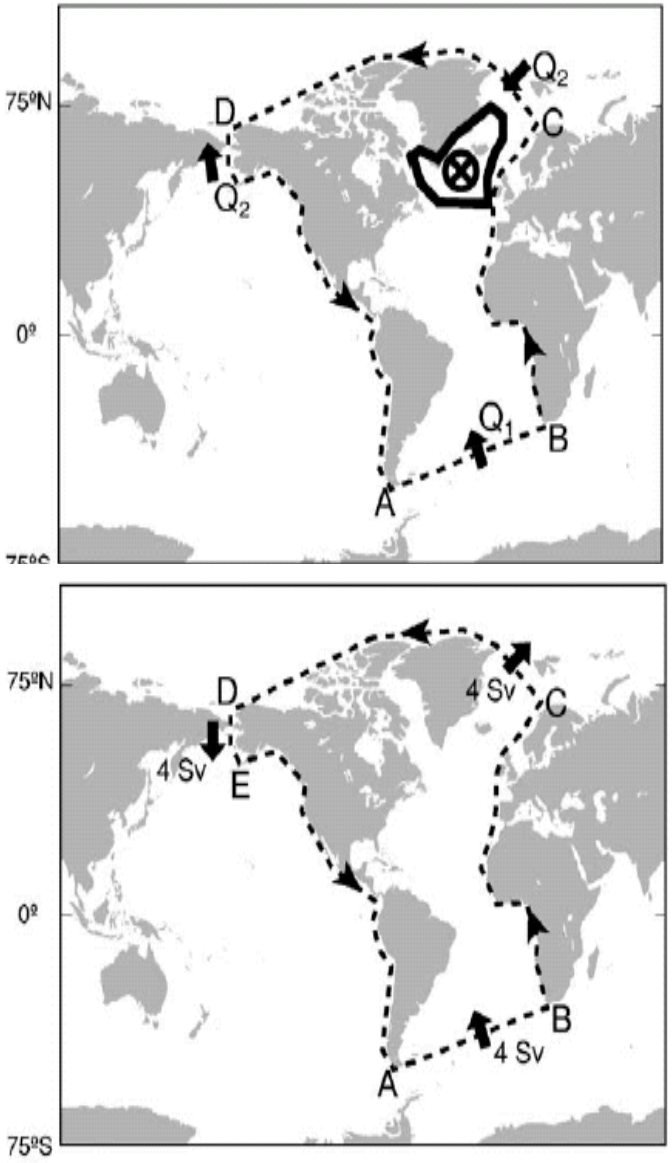
What is Meridional Overturning Circulation (MOC) or Thermohaline Circulation (THC)?



2. Why is this pathway important?



Shaffer and Bendtsen, 1994



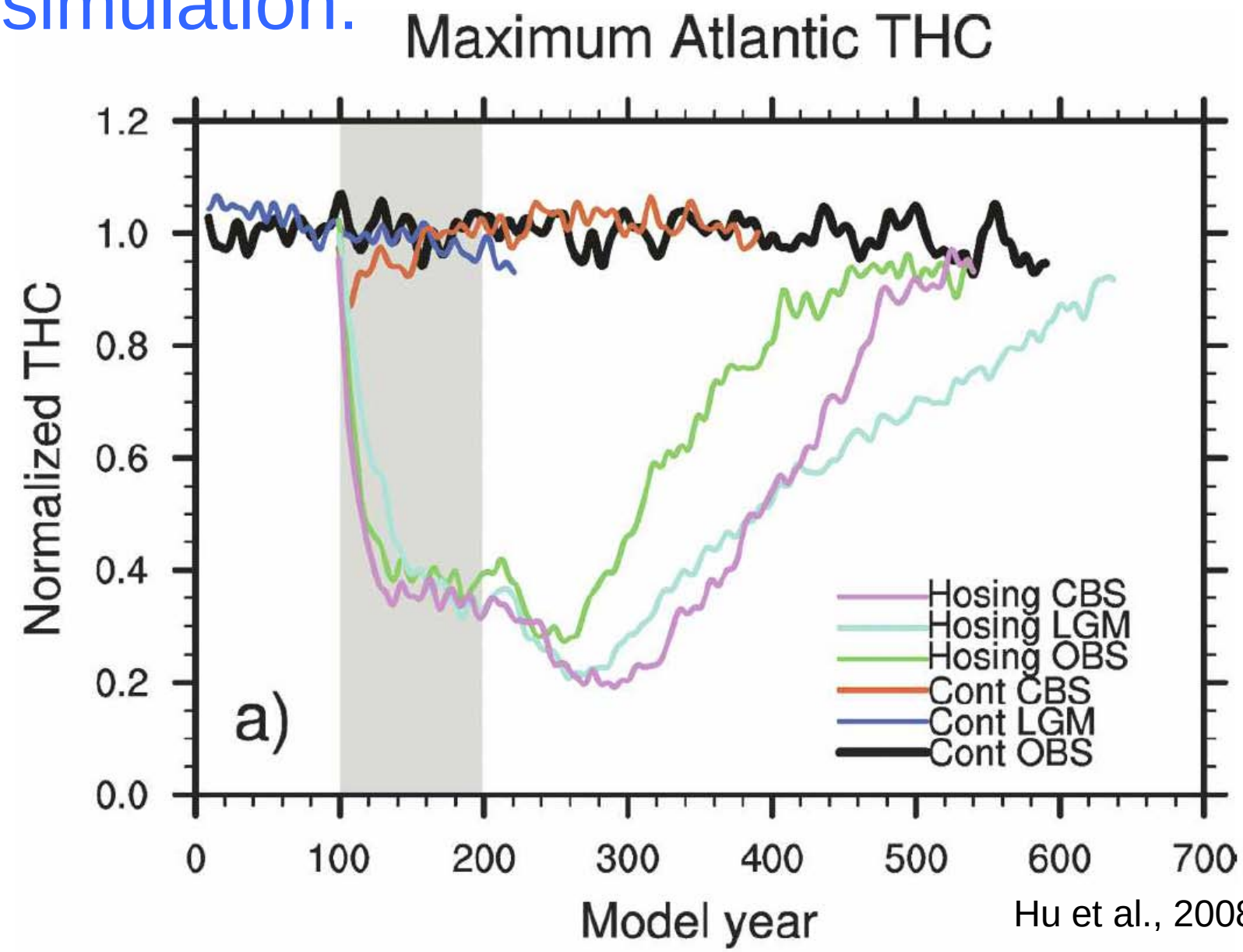
De Boer and Nof, 2004a,b

A comparison of Present day simulations to LGM simulation:

LGM: CCSM3, T42 by 1 ocean

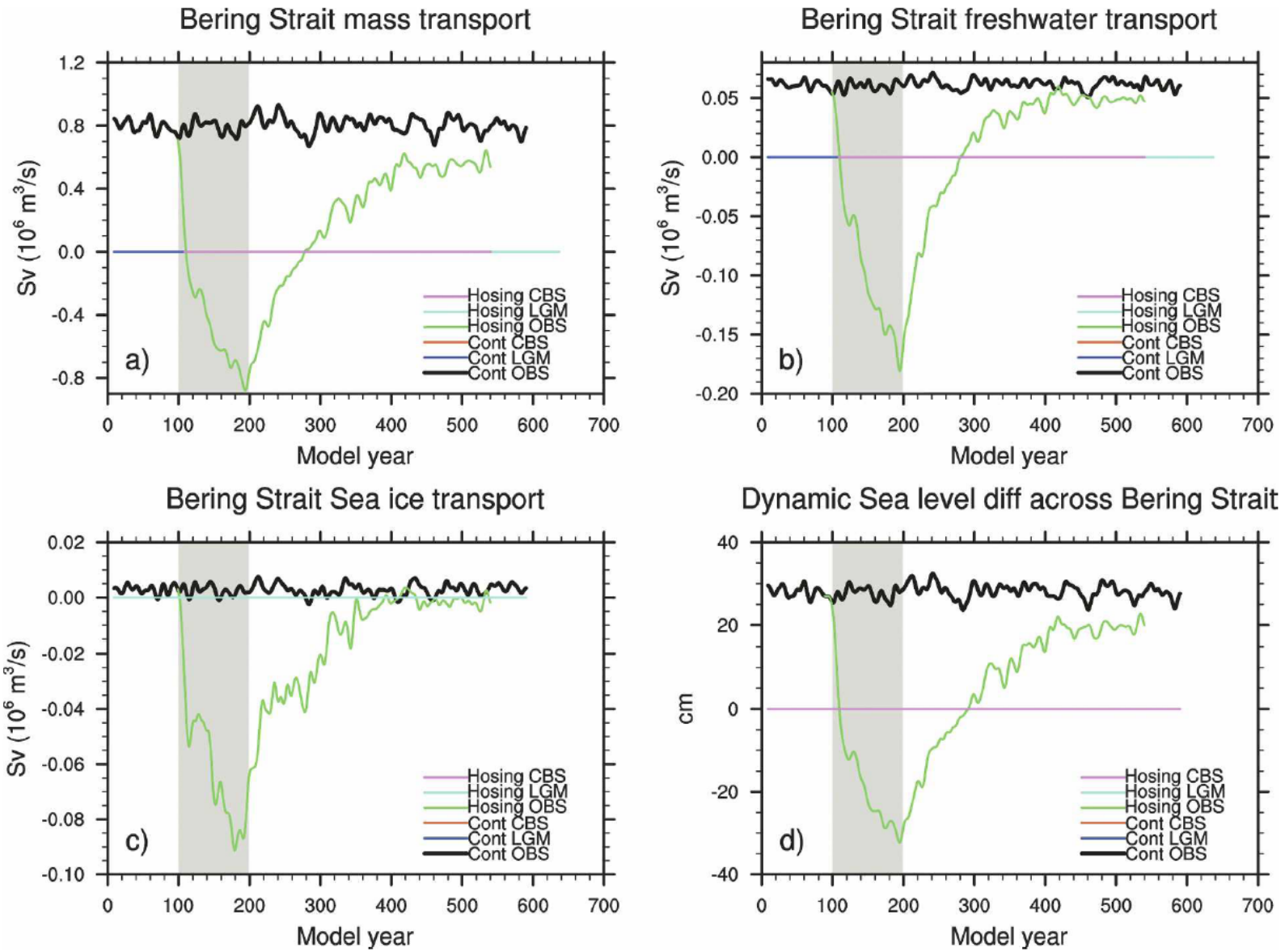
OBS, CBS: CCSM2, T42 by 1 ocean

1 Sv freshwater forcing in North Atlantic (50-70^{o}N)



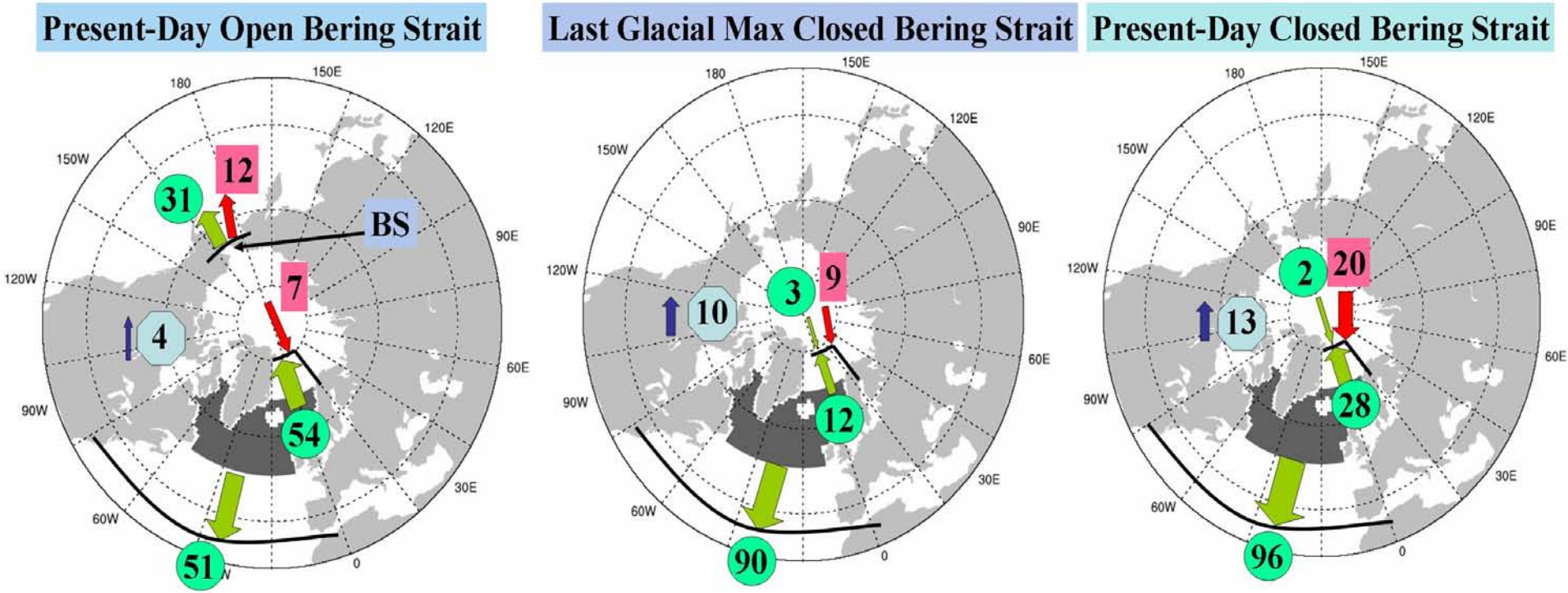
Hu et al., 2008

Changes at the Bering Strait



Hu et al., 2008

A summary of the comparison of the present day open Bering Strait, closed Bering Strait to LGM closed Bering Strait simulation



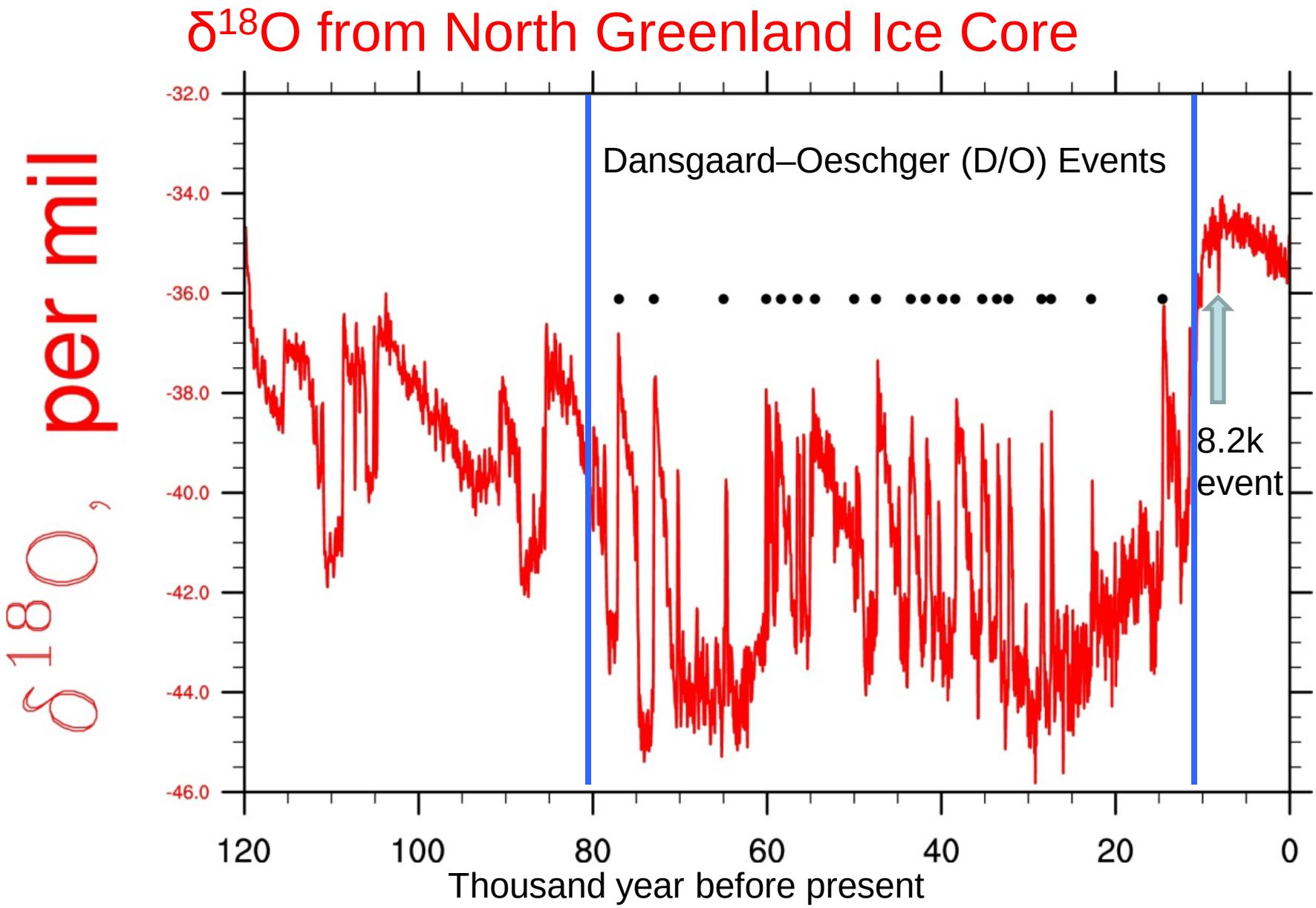
Arrows: Green, Oceanic freshwater transport; Blue: P-E+R (Atlantic 35°N~80°N); Red: Sea ice transport

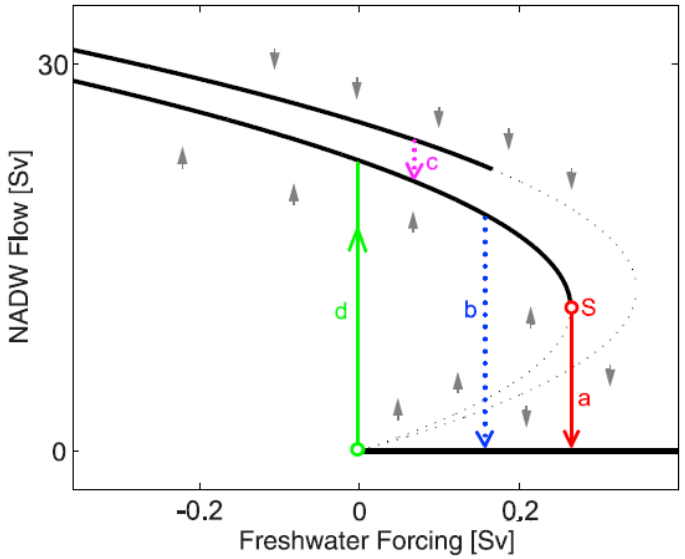
Shape: Circle, liquid freshwater transport; Hexagon, P-E+R (Atlantic 35°N~80°N); Square, sea ice transport

Numbers shown in this figure are the percentage of the total freshwater added into the subpolar North Atlantic during hosing

3. Effect on ice age climate

Abrupt climate change events

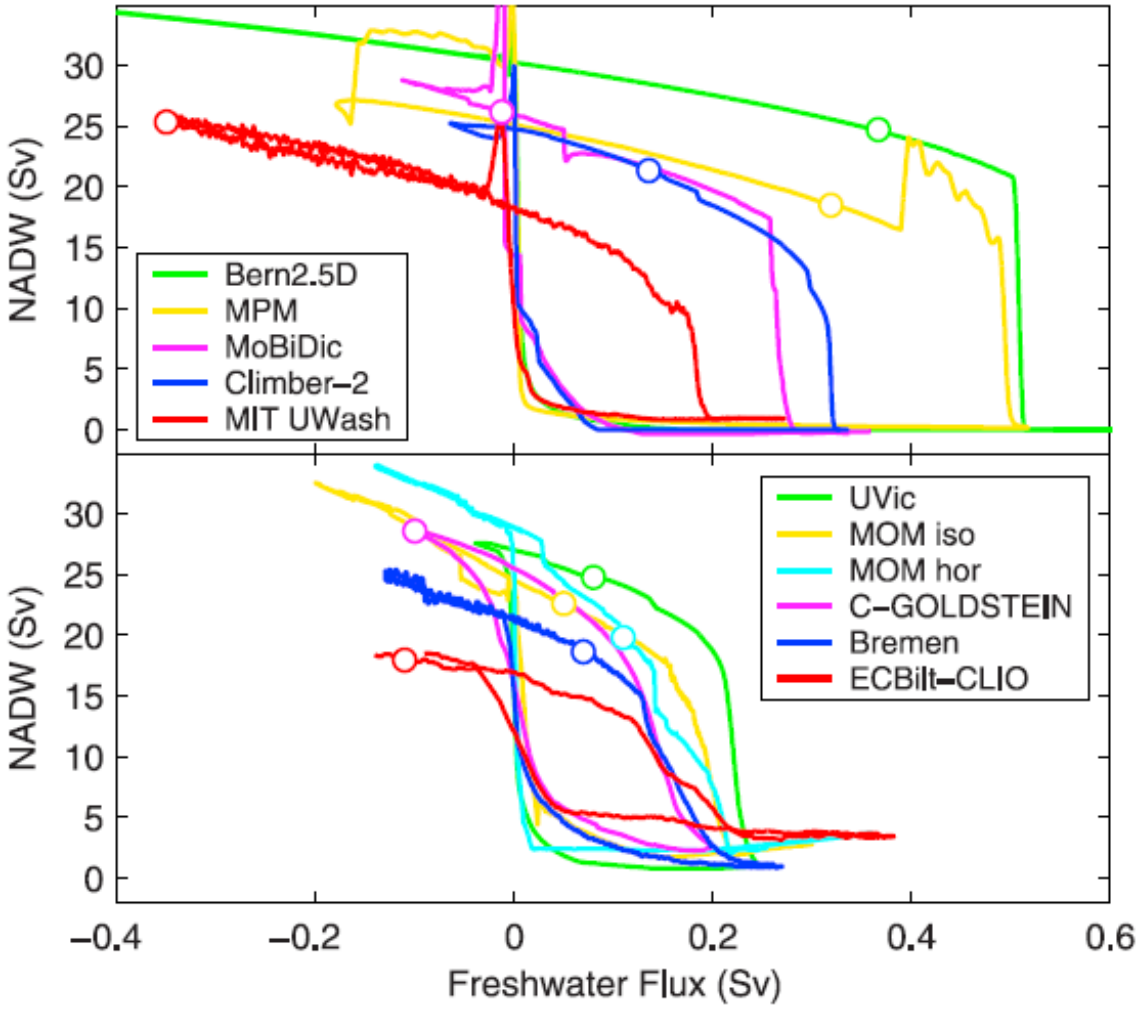


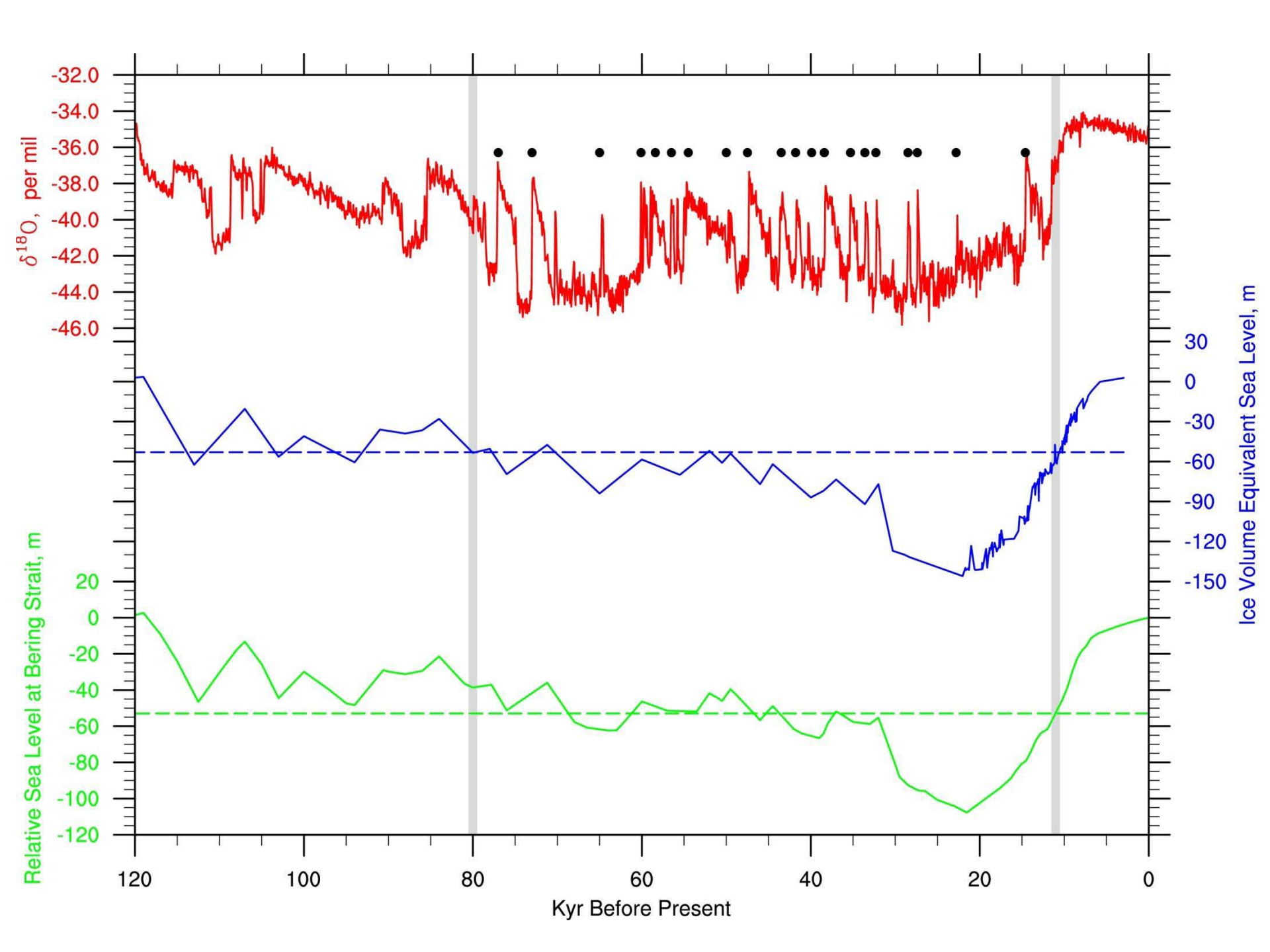


Different types of transition are indicated by colored arrows: (a) an advective spindown related to Stommel's salt transport feedback, (b) a convective shutdown related to Welander's "flip-flop" feedback, (c) a transition between different convection patterns, and (d) the restart of convection.

RAHMSTORF ET AL, 2005

Hysteresis in Earth System Model of Intermediate Complex (EMIC) Models




-32.0
-34.0
-36.0
-38.0
-40.0
-42.0
-44.0
-46.0
δ18O, per mil
30
0
-30
-60
-90
-120
-150
Ice Volume Equivalent Sea Level, m
20
0
-20
-40
-60
-80
-100
-120
Relative Sea Level at Bering Strait, m
120
100
80
60
40
20
0
Kyr Before Present

Model and Experiments:

Here we use the National Center for Atmospheric Research Community Climate System Model version 3.

Atmospheric model (CAM3): T42 (2.8 degree), 26 hybrid levels
Land model (CLM3): T42
Ocean model (POP): 1 degree, 40 levels
Sea ice model (CSIM5): 1 degree

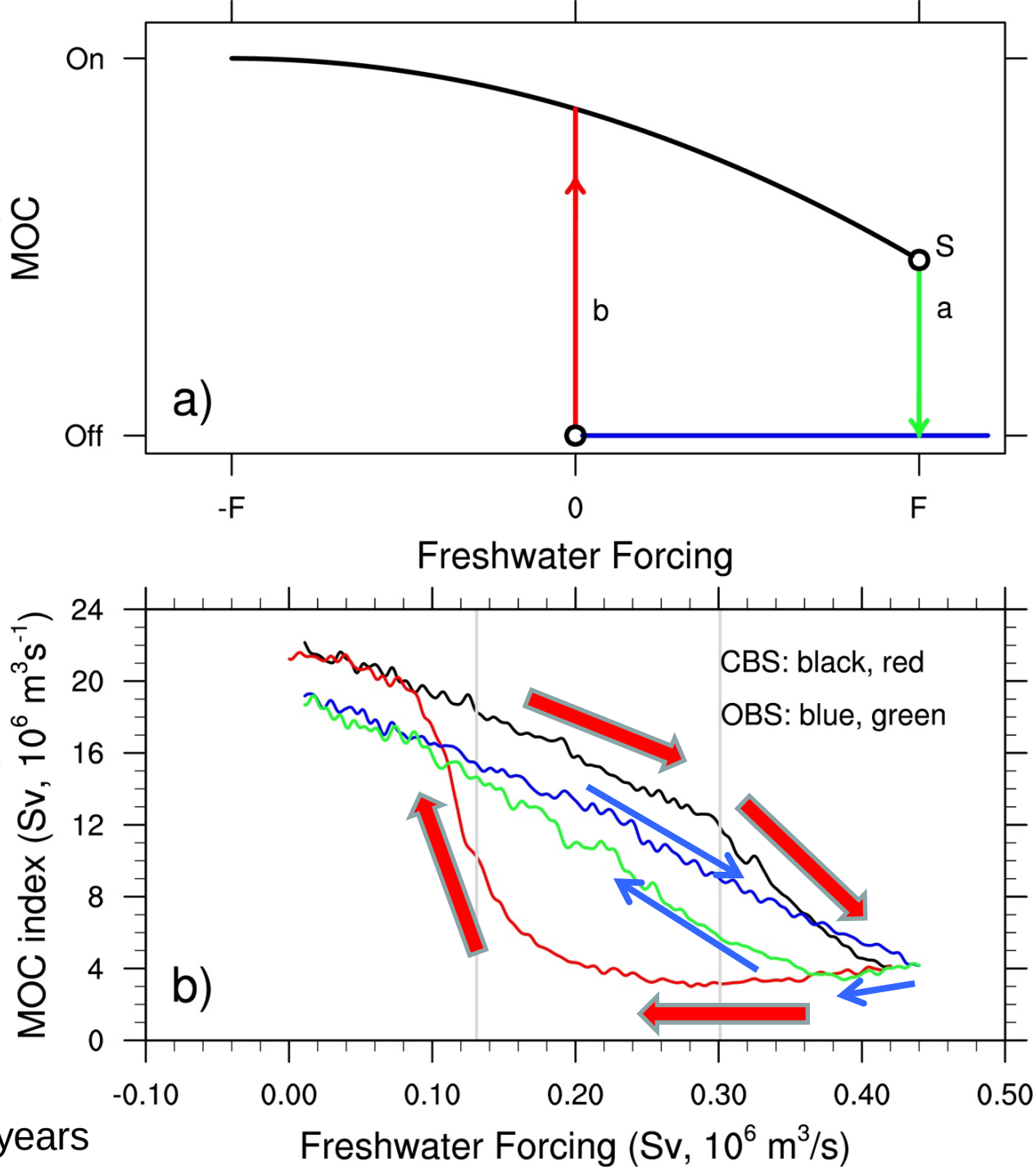
Climate boundary condition: present day

Hysteresis Experiments:
Two experiments are carried out with everything identical, except one with an open Bering Strait (OBS) and the other with a closed one (CBS). Following Rahmstorf et al. (2005), the freshwater forcing is added uniformly in the Atlantic between 20 and 50^{o}N at an initial rate of 0.0002 Sv, with a linear annual increment of 0.0002 Sv (200m^{3}/s). Note: it takes 500 years for the freshwater forcing to increase 0.1 Sv.

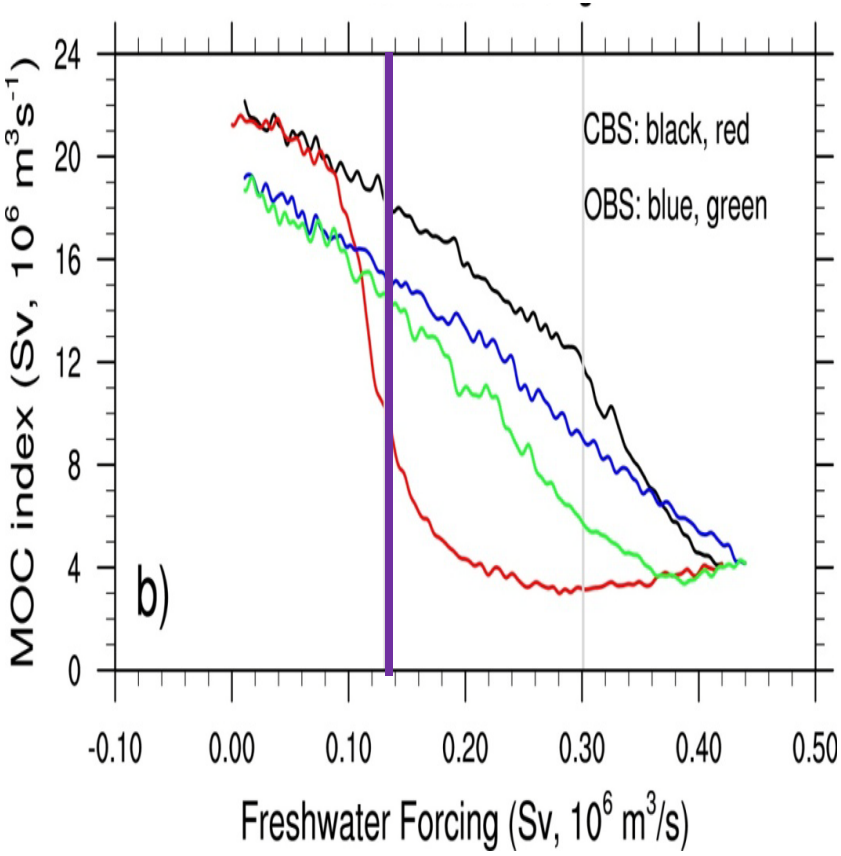
Theoretical MOC hysteresis diagram

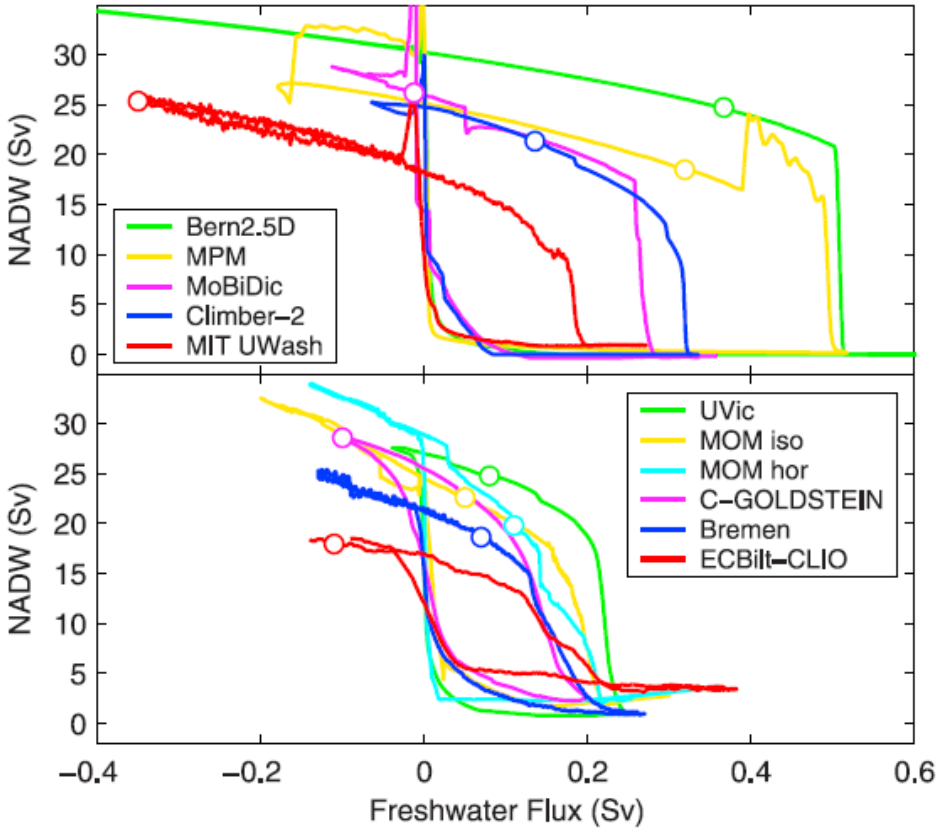
When the Bering Strait is closed, MOC's hysteresis behavior is much clear. When the Bering Strait is open, MOC's hysteresis behavior is much weaker.

MOC hysteresis diagram in CCSM3



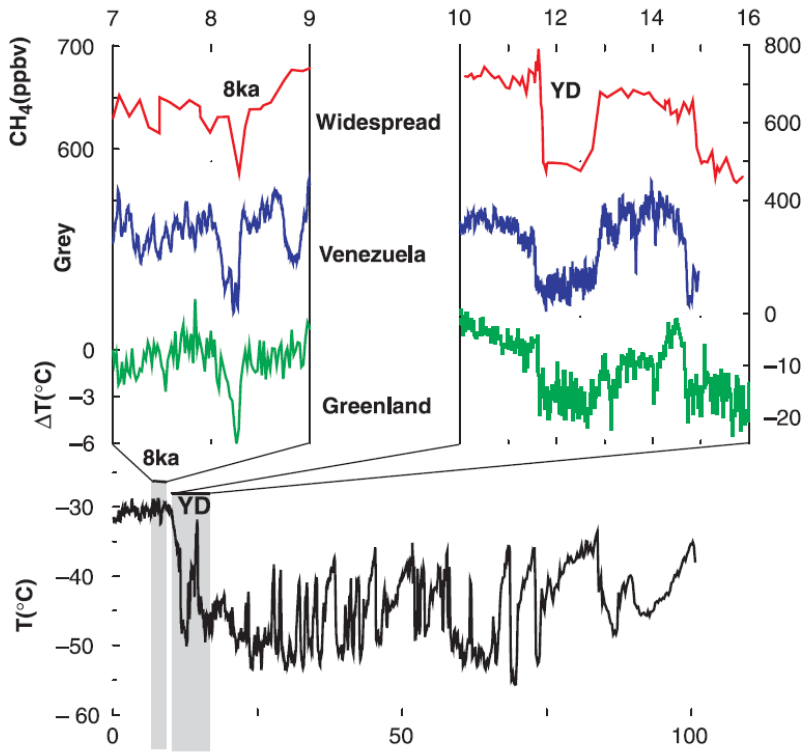
A 0.1 Sv FW change = 500 years

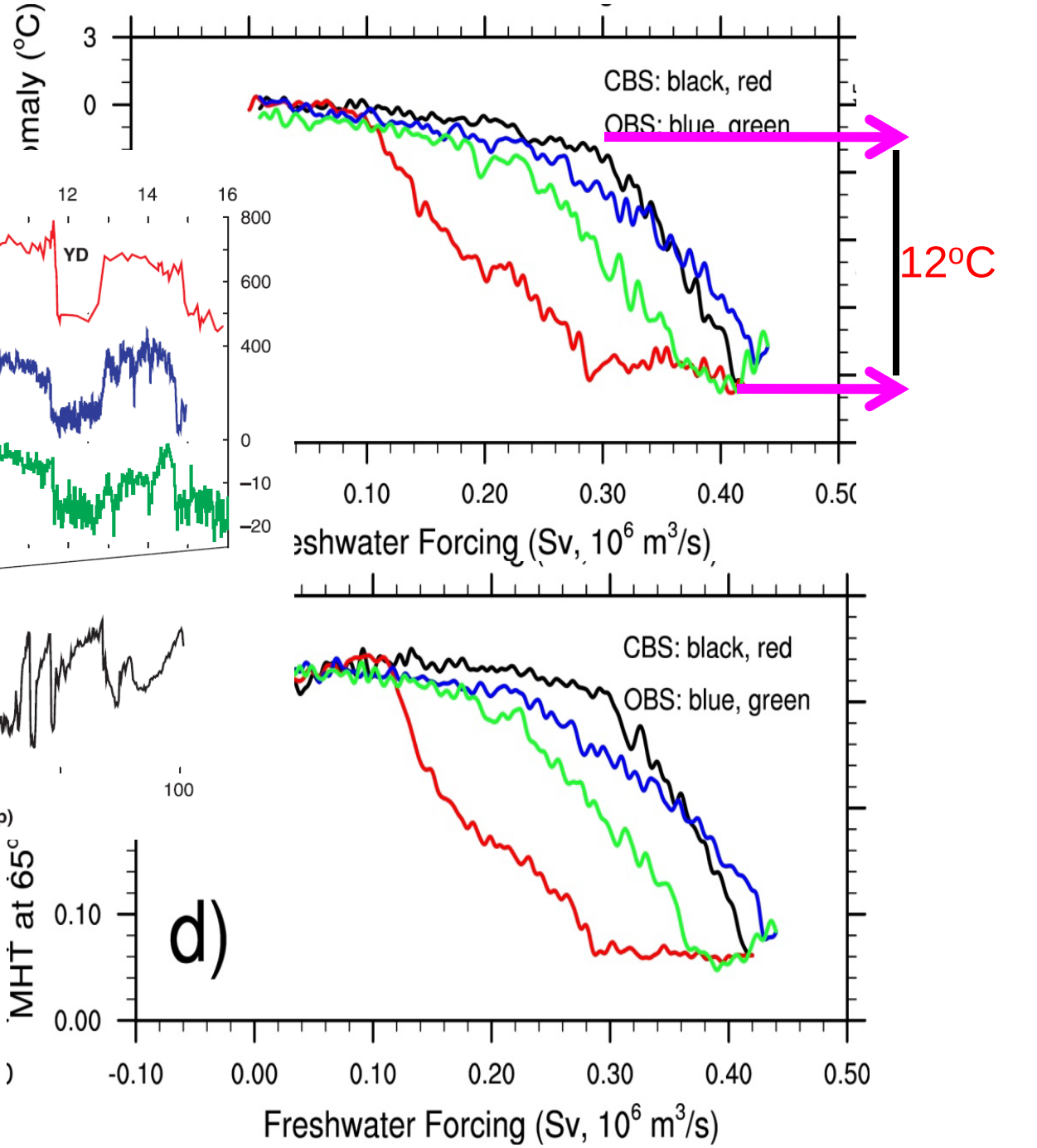

MOC index (Sv, 10^6 m^3s^{-1})
24
20
16
12
8
4
0
CBS: black, red
OBS: blue, green
b)
-0.10
0.00
0.10
0.20
0.30
0.40
0.50
Freshwater Forcing (Sv, 10^6 m^3/s)


NADW (Sv)
30
25
20
15
10
5
0
Bern2.5D
MPM
MoBiDic
Climber–2
MIT UWash
NADW (Sv)
UVic
MOM iso
MOM hor
C–GOLDSTEIN
Bremen
ECBilt–CLIO
–0.4
–0.2
0
0.2
0.4
0.6
Freshwater Flux (Sv)

Greenland surface
te
ai

M
tra
at 65°N in Atlantic





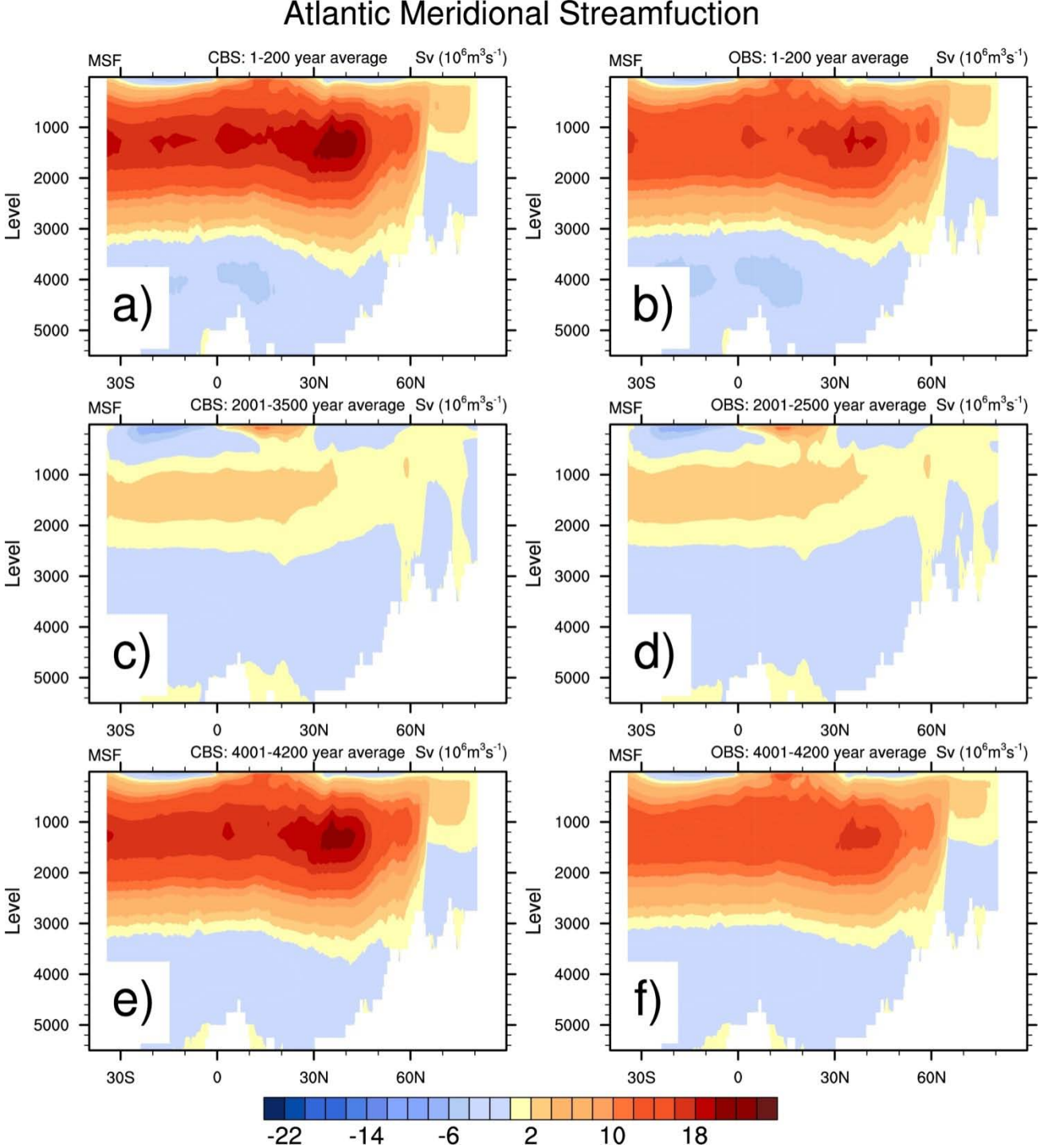
Hu et al, 2010

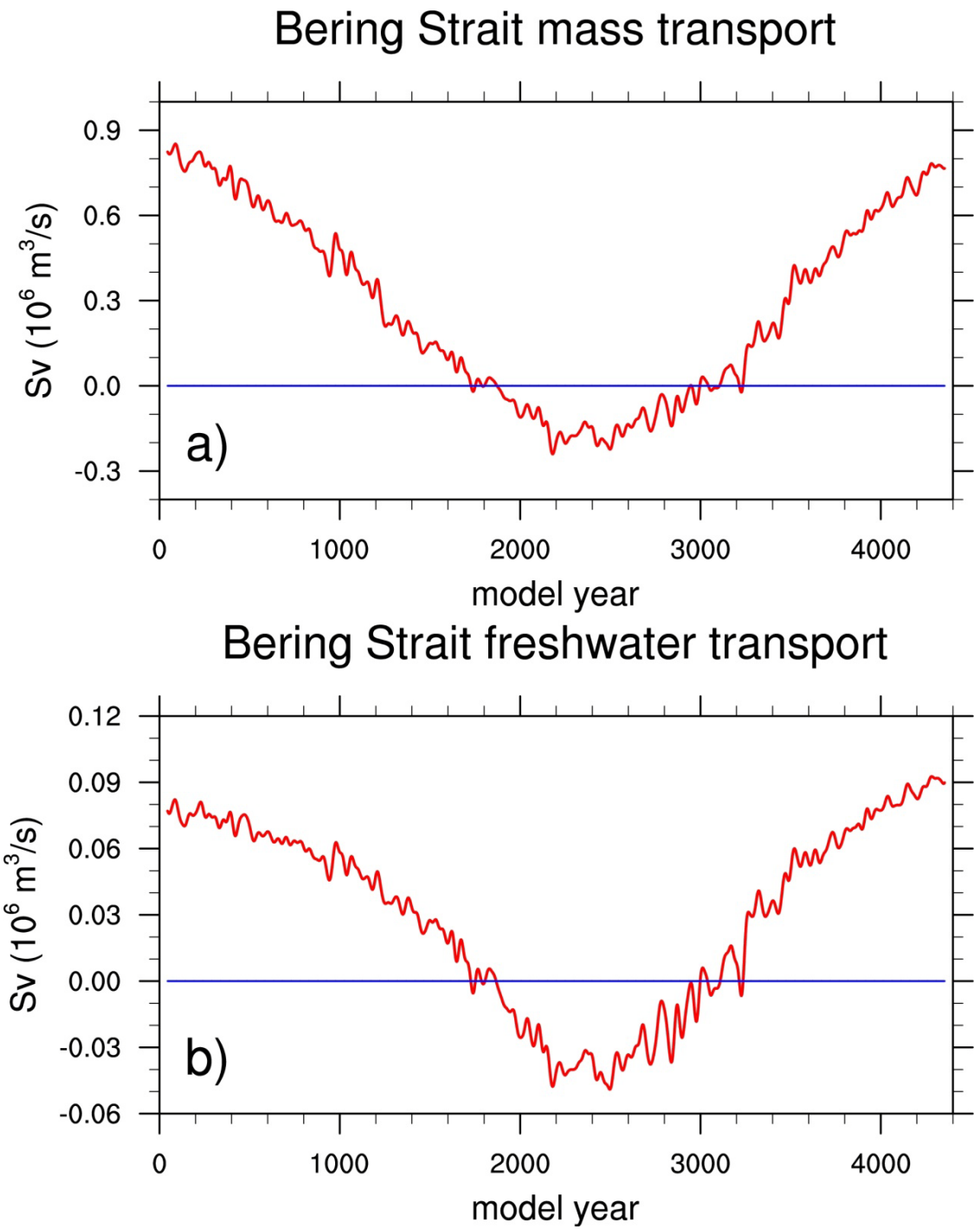
Averaged over
years 1-200

CBS: averaged over
years of 2001-3500

OBS: averaged over
years of 2001-2500

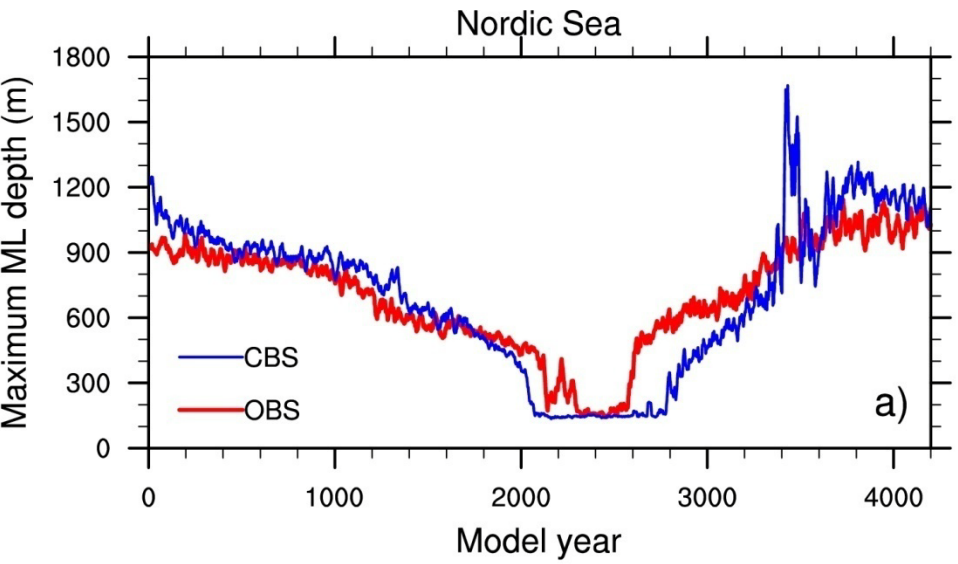
Averaged over
years 4001-4200

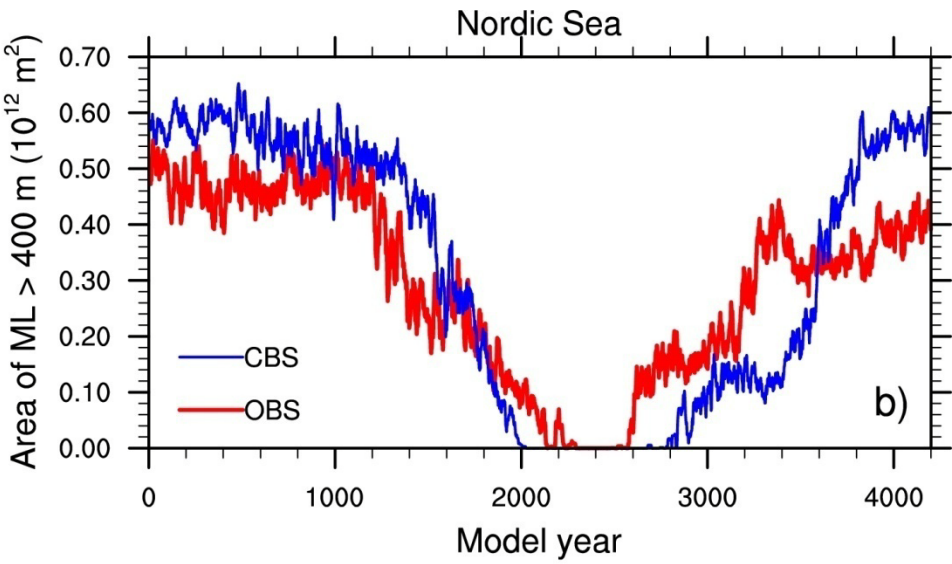


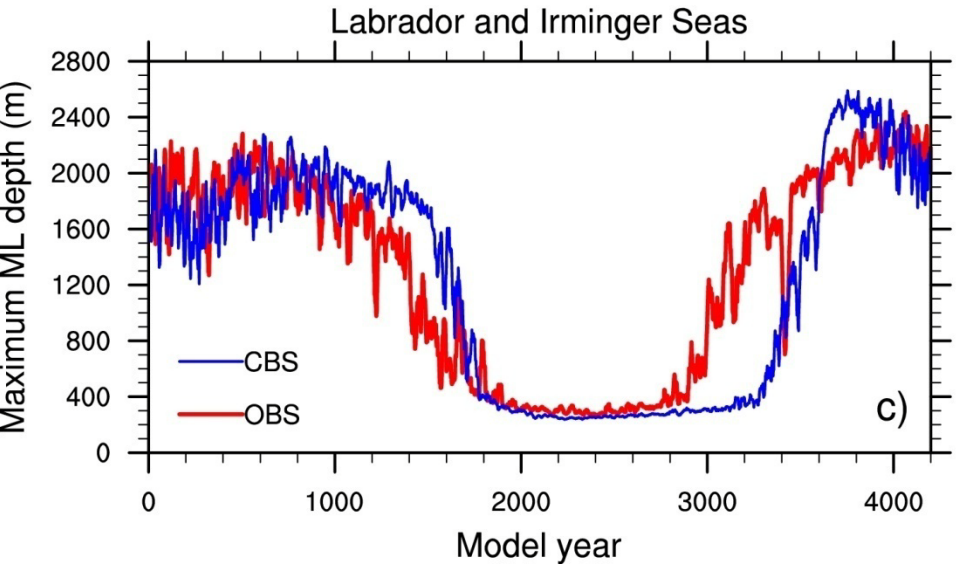

Bering Strait mass transport
Sv (10^6 m^3/s)
0.9
0.6
0.3
0.0
-0.3
a)
0
1000
2000
3000
4000
model year
Bering Strait freshwater transport
Sv (10^6 m^3/s)
0.12
0.09
0.06
0.03
0.00
-0.03
-0.06
b)
0
1000
2000
3000
4000
model year

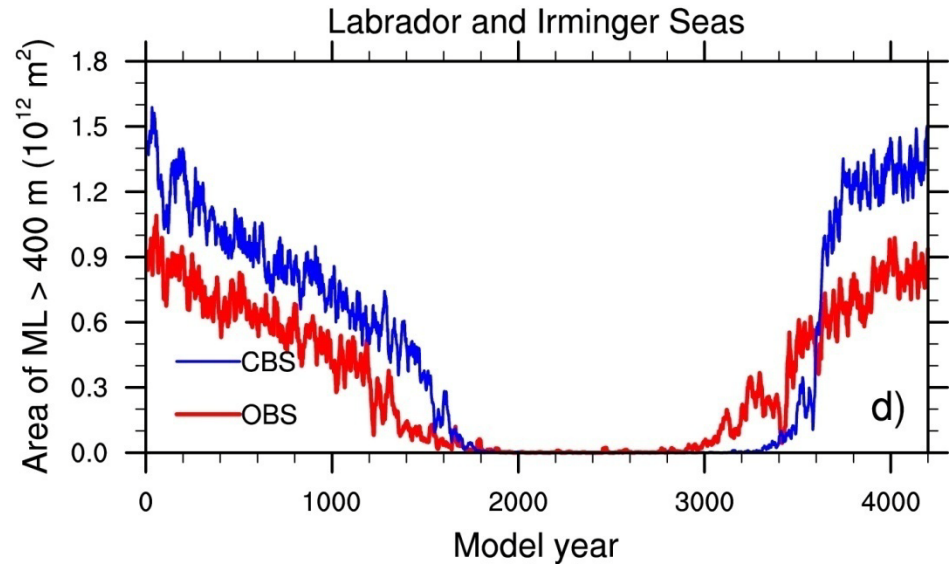
March mean maximum mixed layer depth

Area of the March mean mixed layer deeper than 400 meters

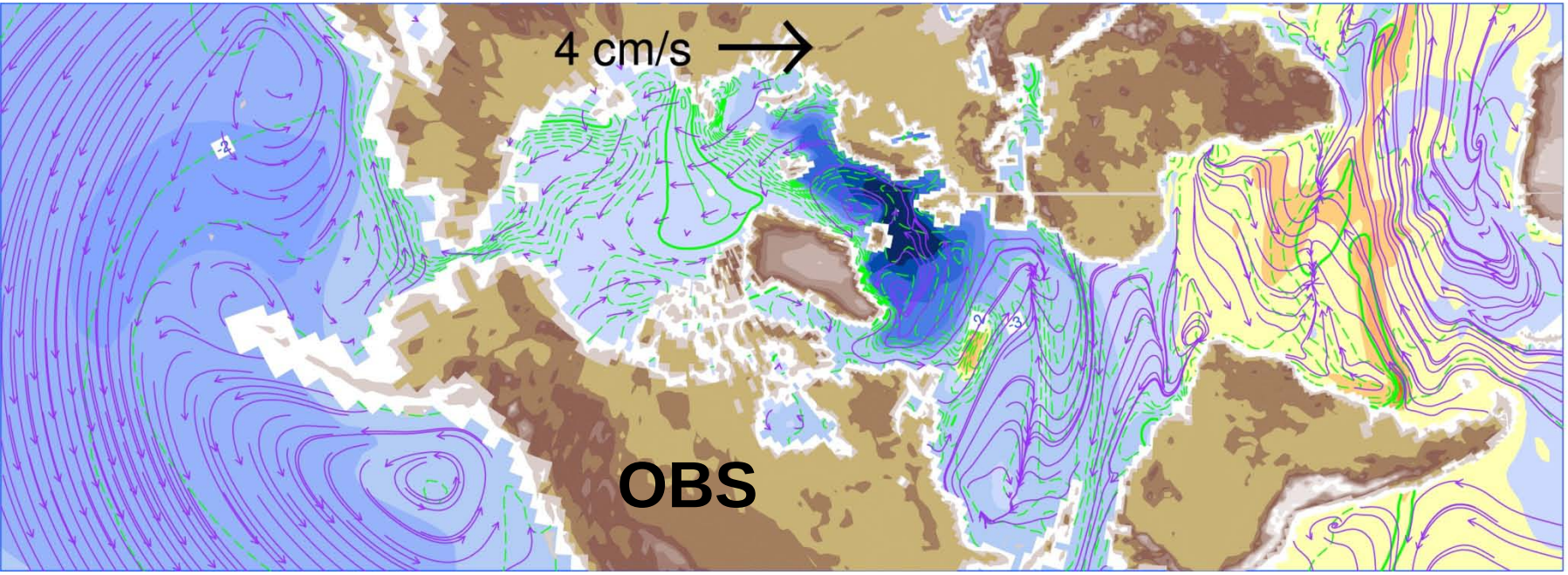


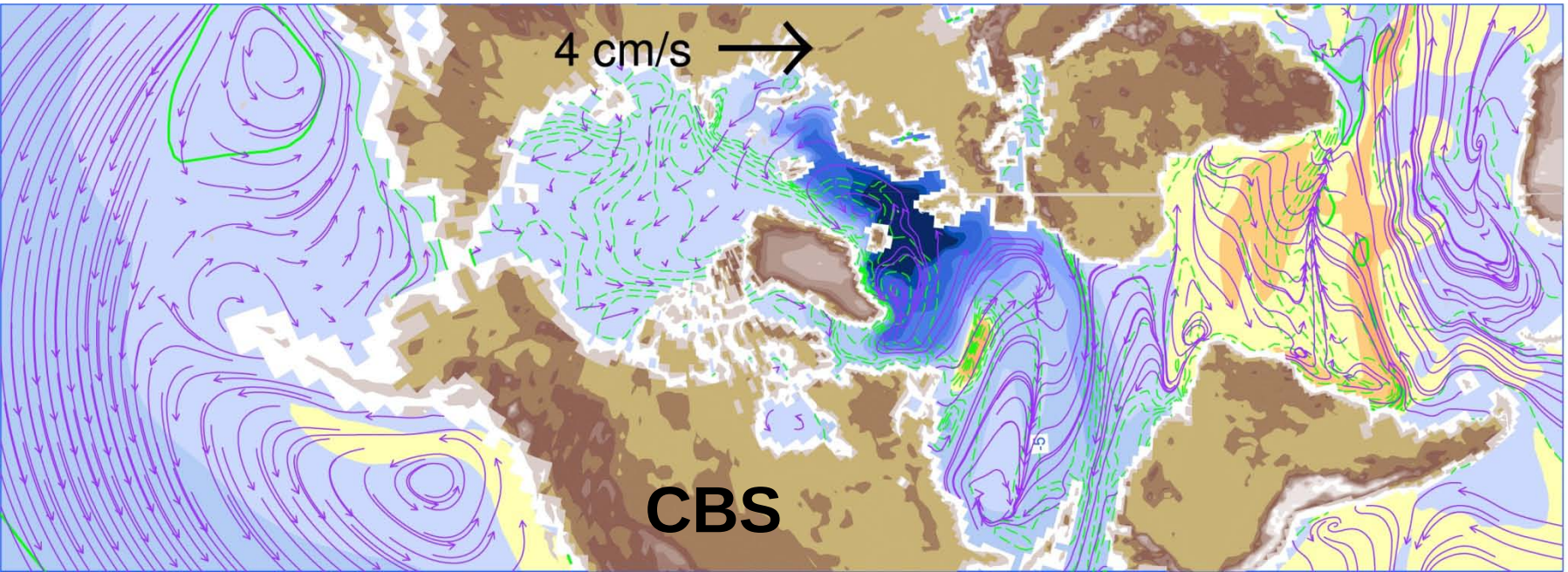


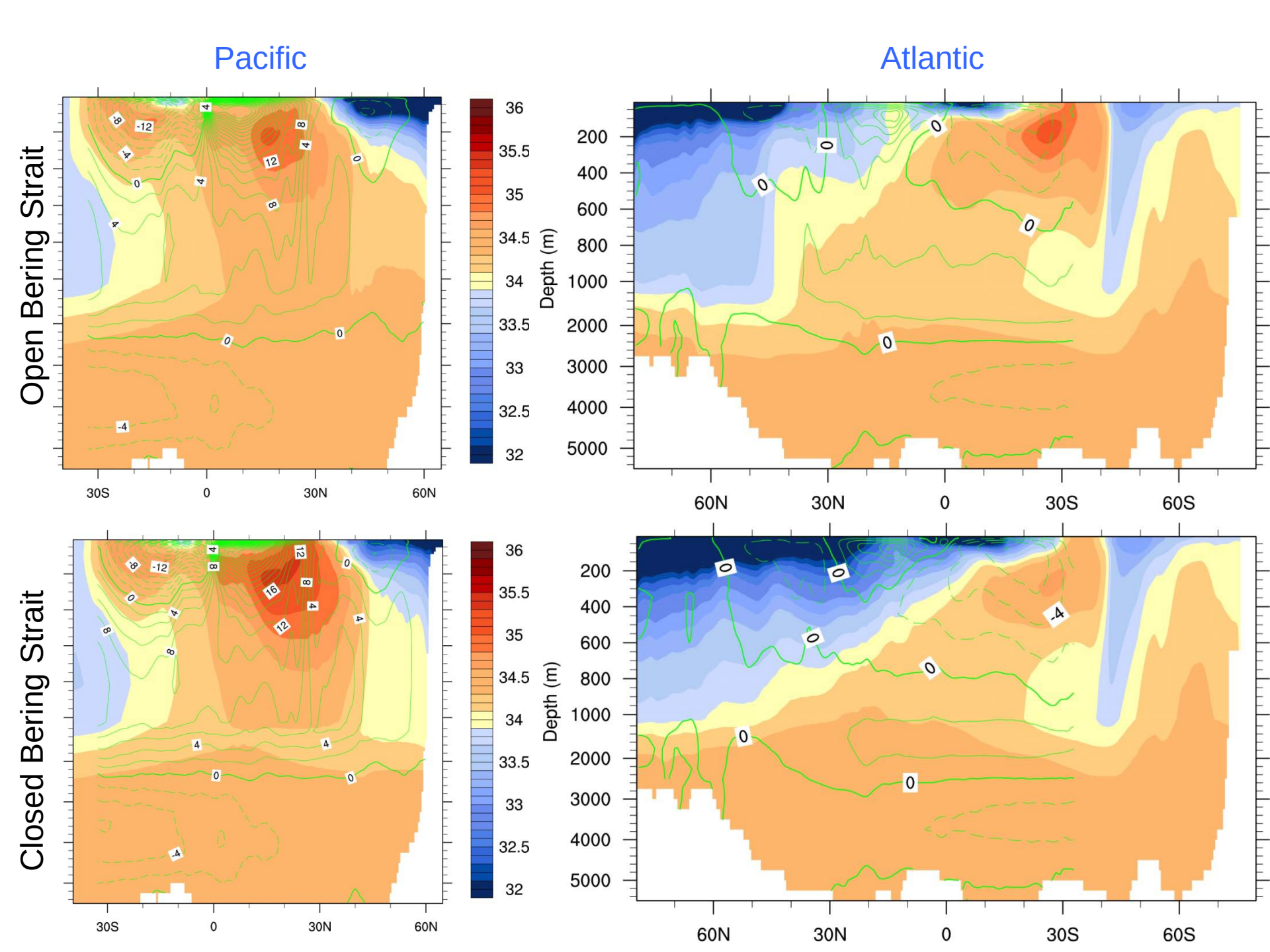




Surface property changes in open/closed Bering Strait simulations






Pacific
Atlantic
Open Bering Strait
Closed Bering Strait
Depth (m)
200
400
600
800
1000
2000
3000
4000
5000
36
35.5
35
34.5
34
33.5
33
32.5
32
30S
0
30N
60N
60S

Summary

Our results suggest that the northern oceanic pathway between Pacific and the Atlantic may have played an important role in modulating the MOC and ice age climate, e.g.

i. The closing of the Bering Strait may have changed the characteristics of the ocean circulation to a state which is in favour of abrupt climate transitions.
ii. Since the open Bering Strait can transport water mass in both direction depending on the MOC strength, it intends to prevent the abrupt climate transitions.

Thank You

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To provide facility support to the wider community; and,
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