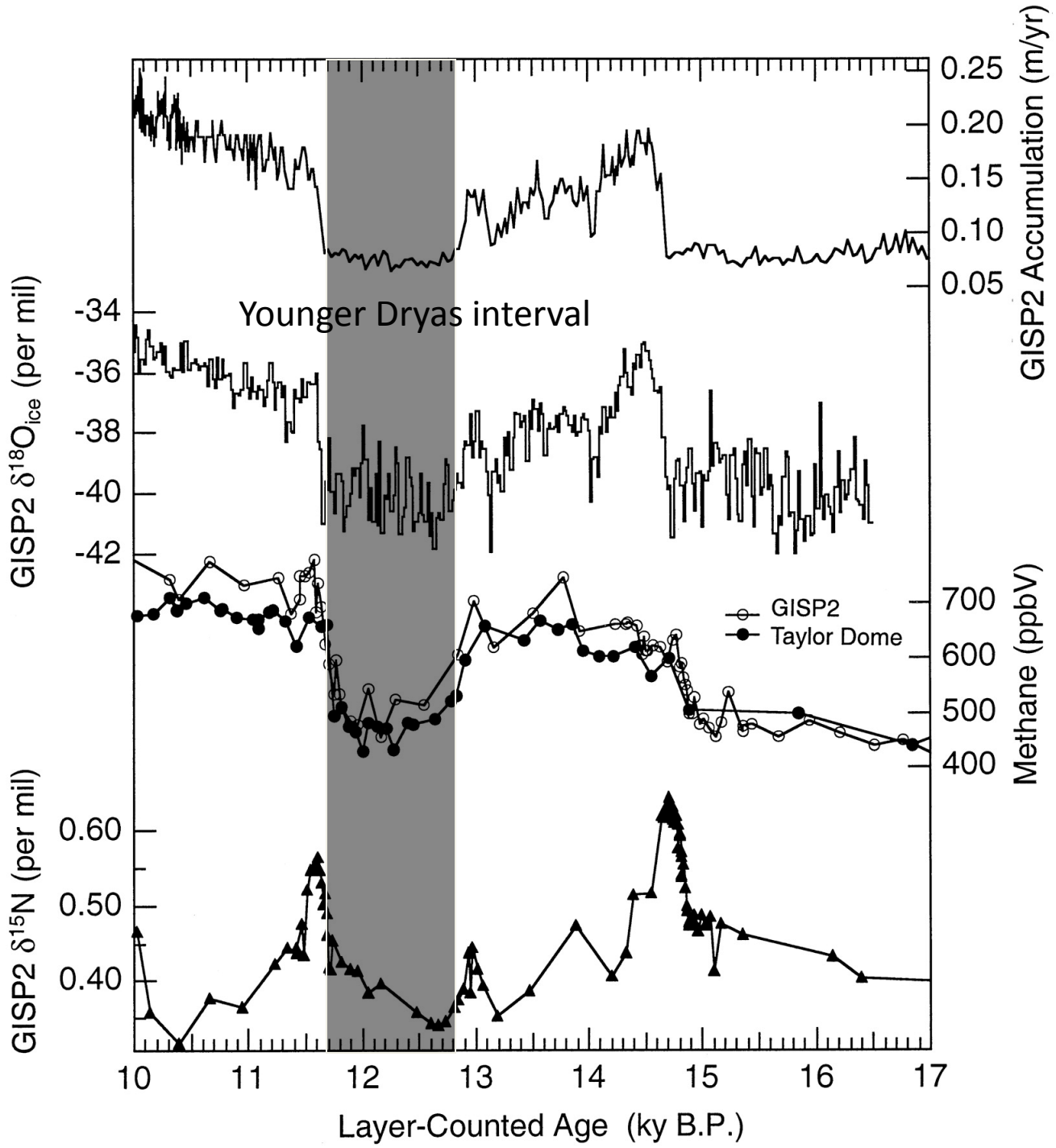
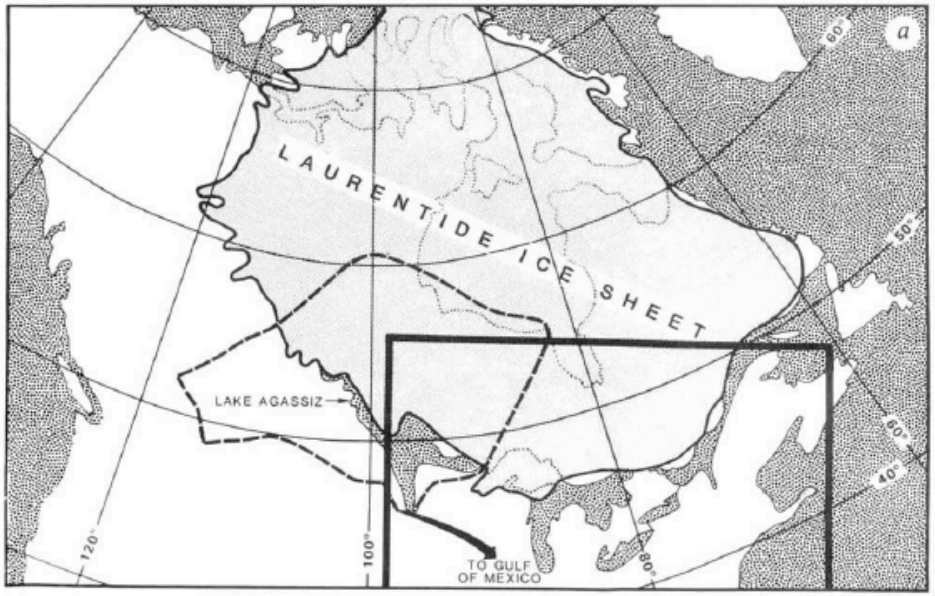
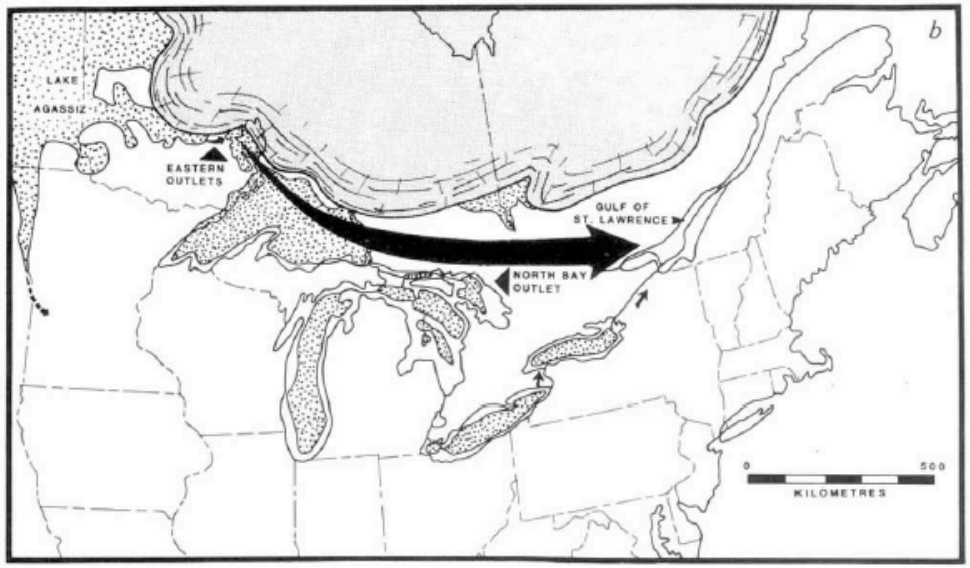
# Abrupt climate change

The standard model


Younger Dryas interval
GISP2 $\delta^{18}O_{ice}$ (per mil)
-34
-36
-38
-40
-42
GISP2 Accumulation (m/yr)
0.25
0.20
0.15
0.10
0.05
GISP2
Taylor Dome
Methane (ppbV)
700
600
500
400
GISP2 $\delta^{15}N$ (per mil)
0.60
0.50
0.40
10
11
12
13
14
15
16
17
Layer-Counted Age (ky B.P.)




Area enlarged in *b*



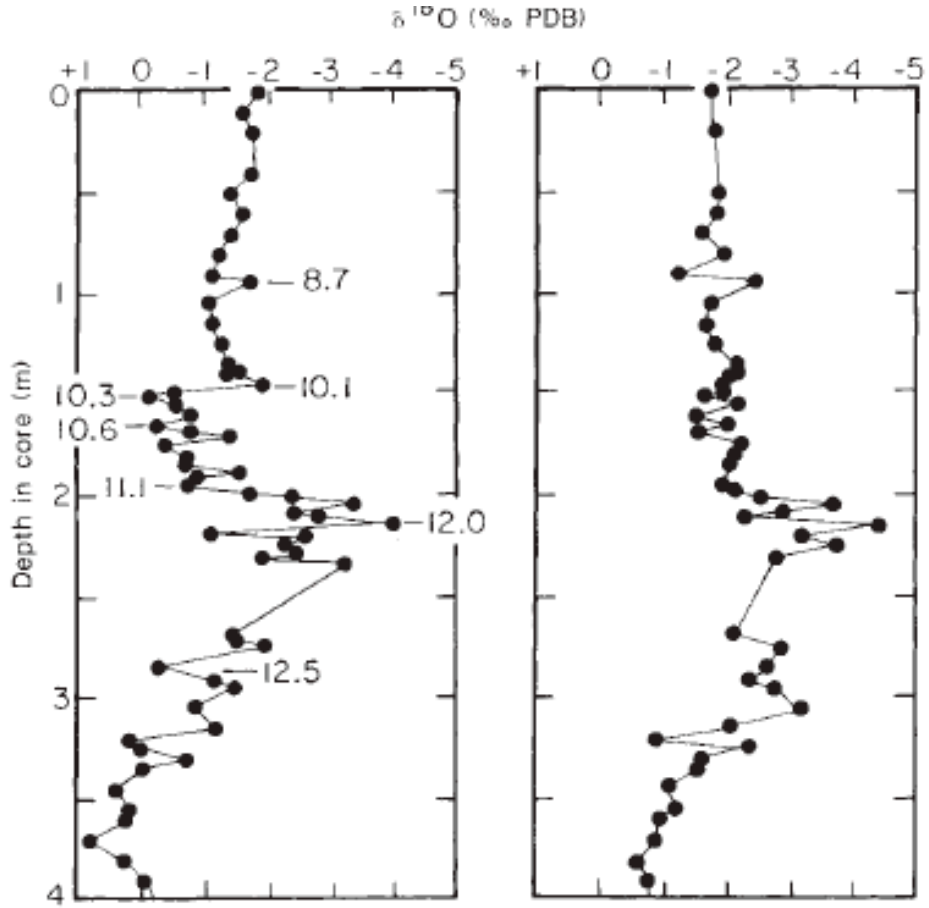
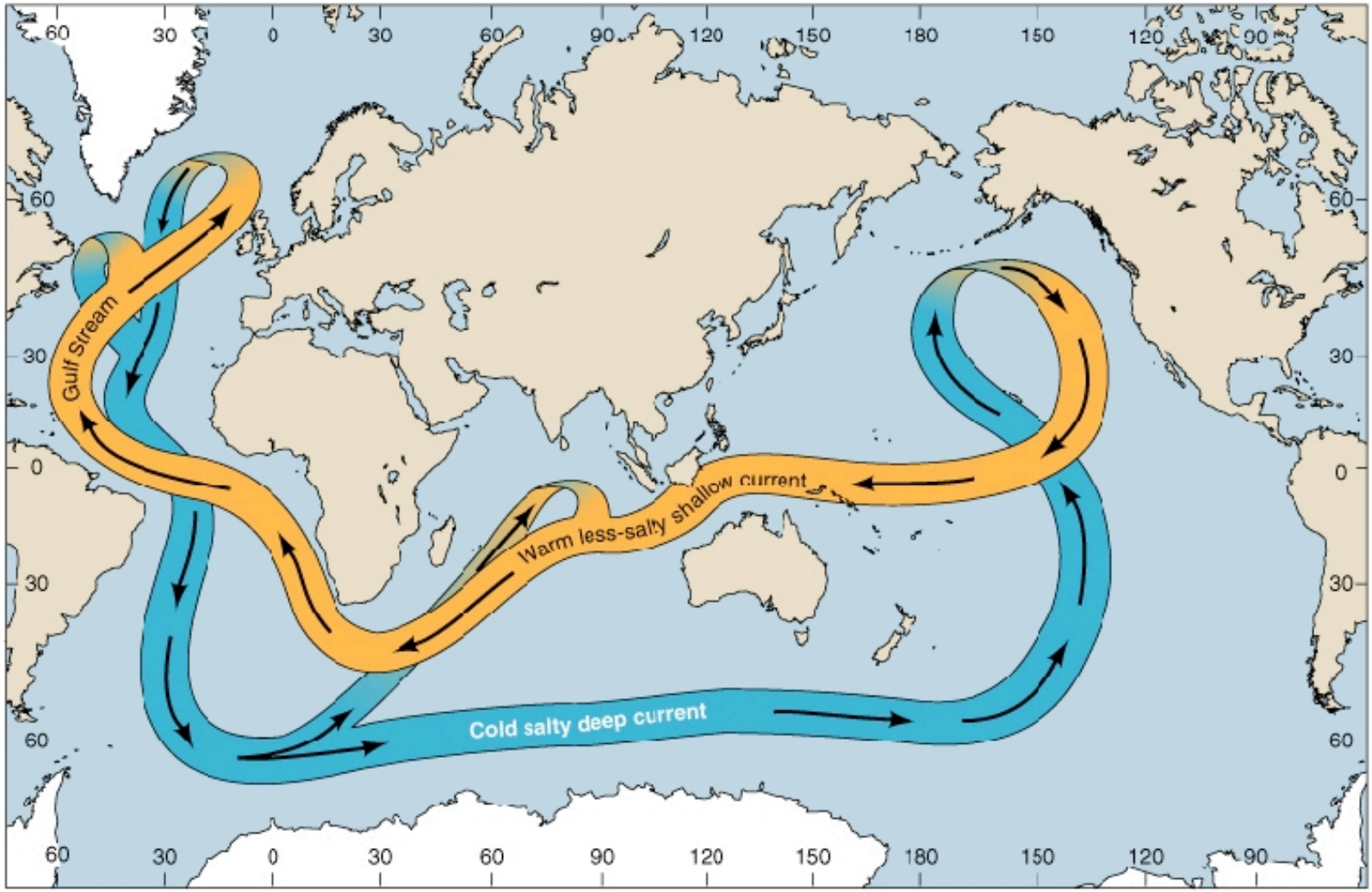
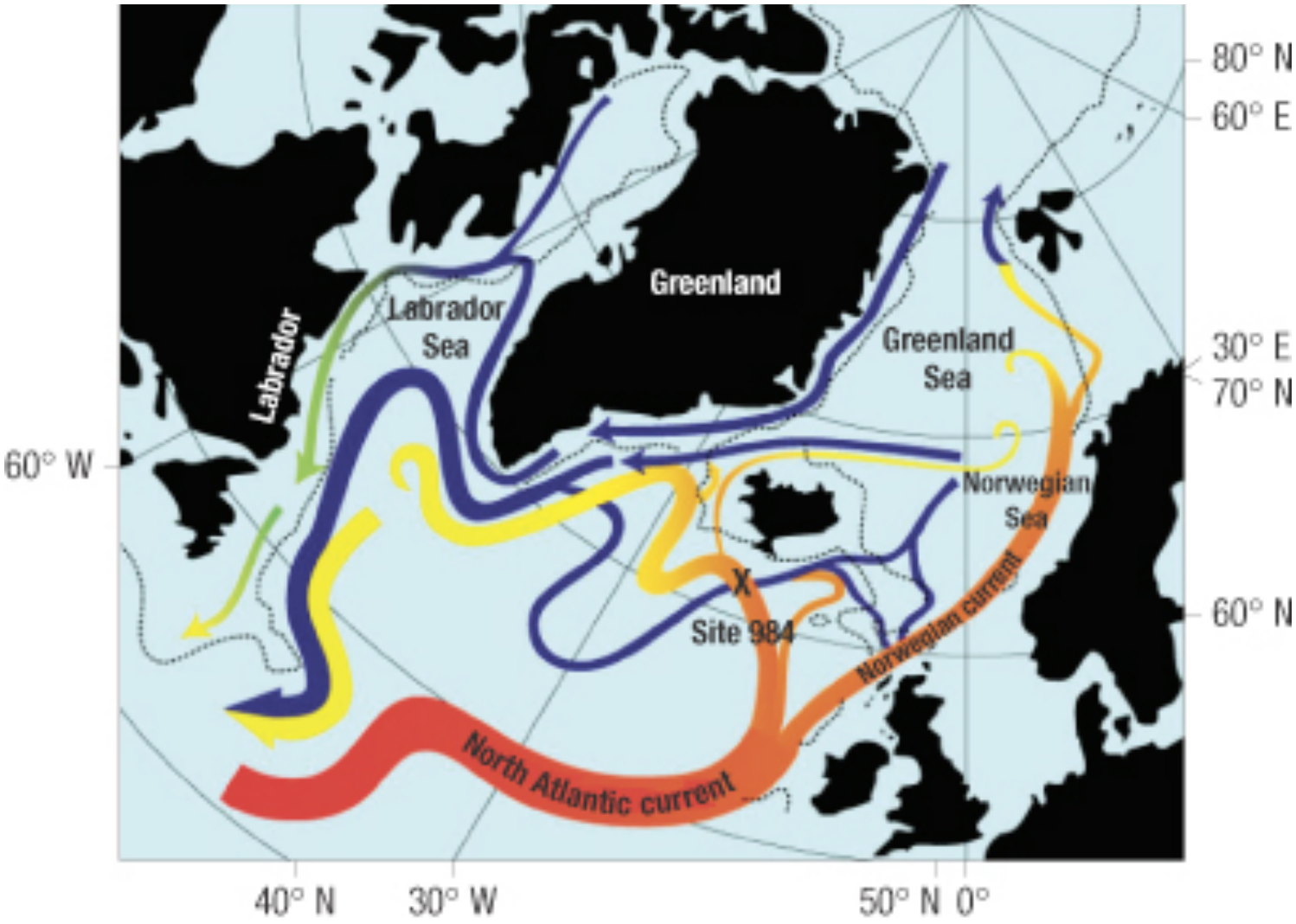


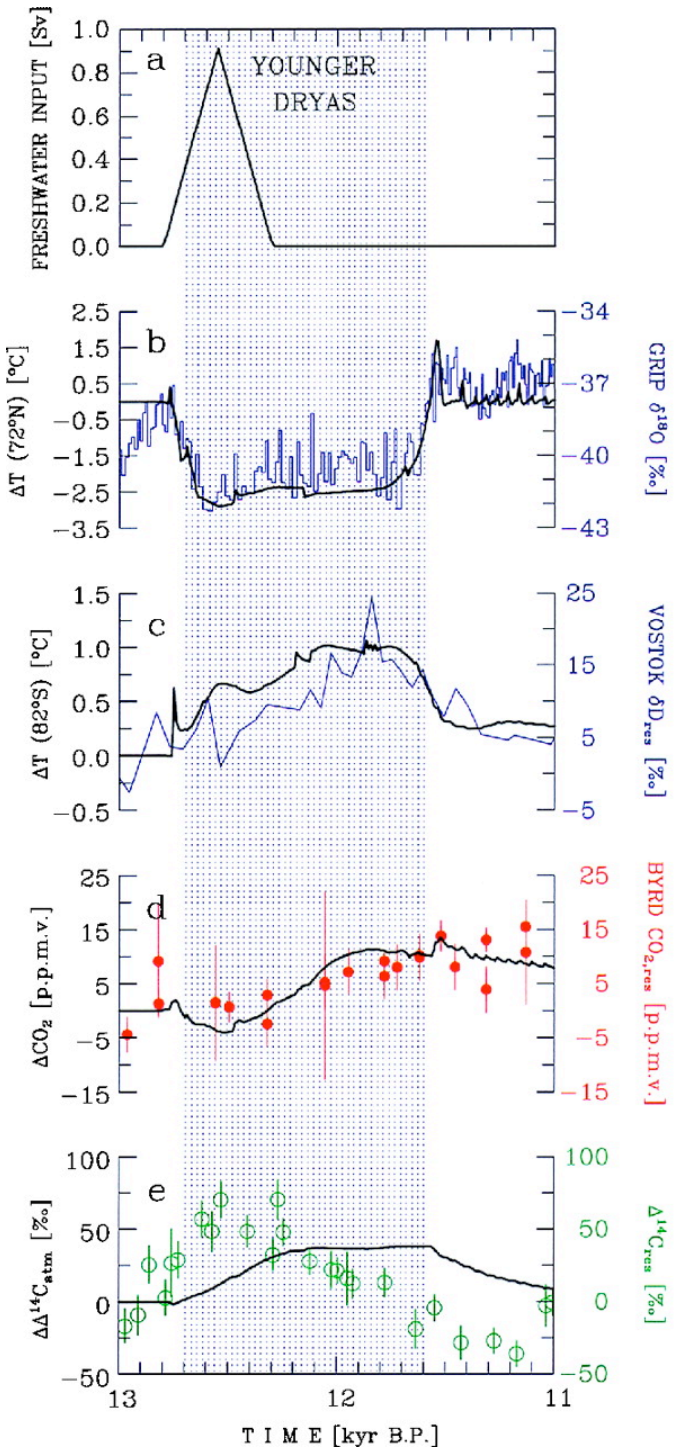

FIG. 2 Oxygen isotope changes in two varieties of *Globigennoides ruber* (white and pink, left and right, respectively) from EN32-PC4 during latest Quaternary are plotted against depth. Ages shown are accelerator radiocarbon ages. Both varieties show a major 'meltwater spike' from ~320–200 cm. *G. ruber* (white variety) shows increased $\delta^{18}O$ 1‰ relative to PDB standard values at the beginning of the Younger Dryas cold episode, consistently high values during the episode (~11,000–10,000 yr BP), and a sudden decrease at 10,000 yr BP termed the 'cessation event'.

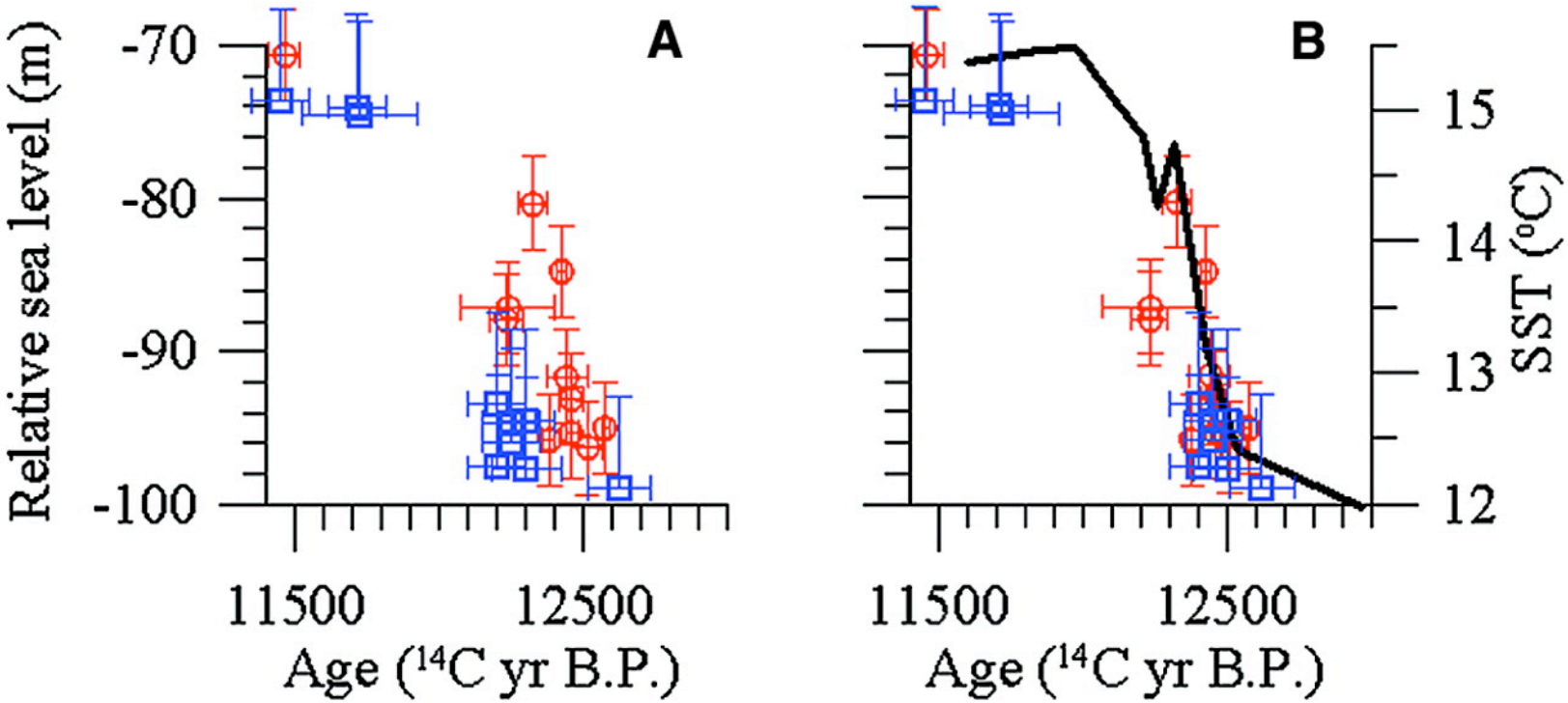
# The ocean “conveyer belt”

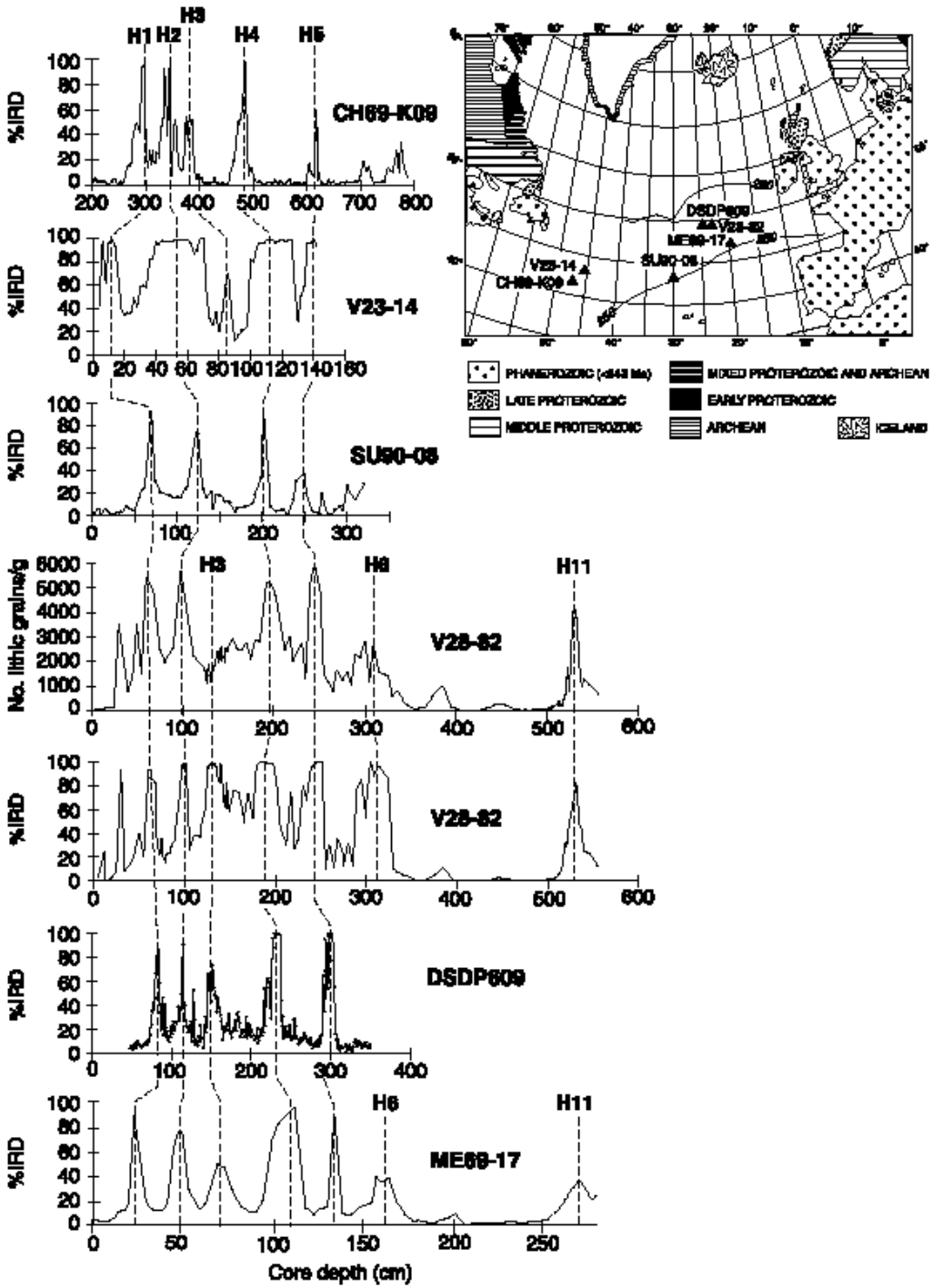


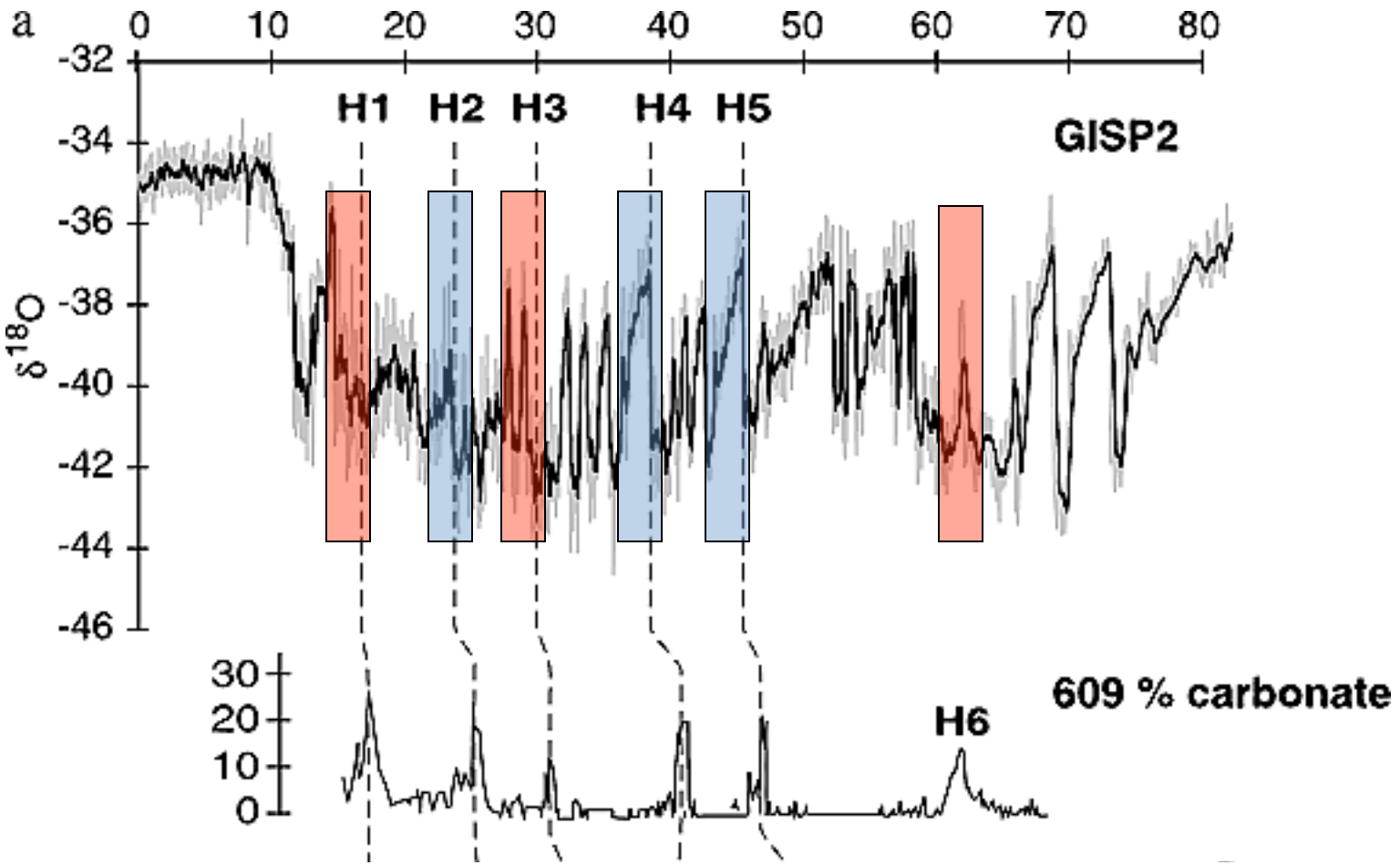
# More realistic picture of N. Atlantic circulation

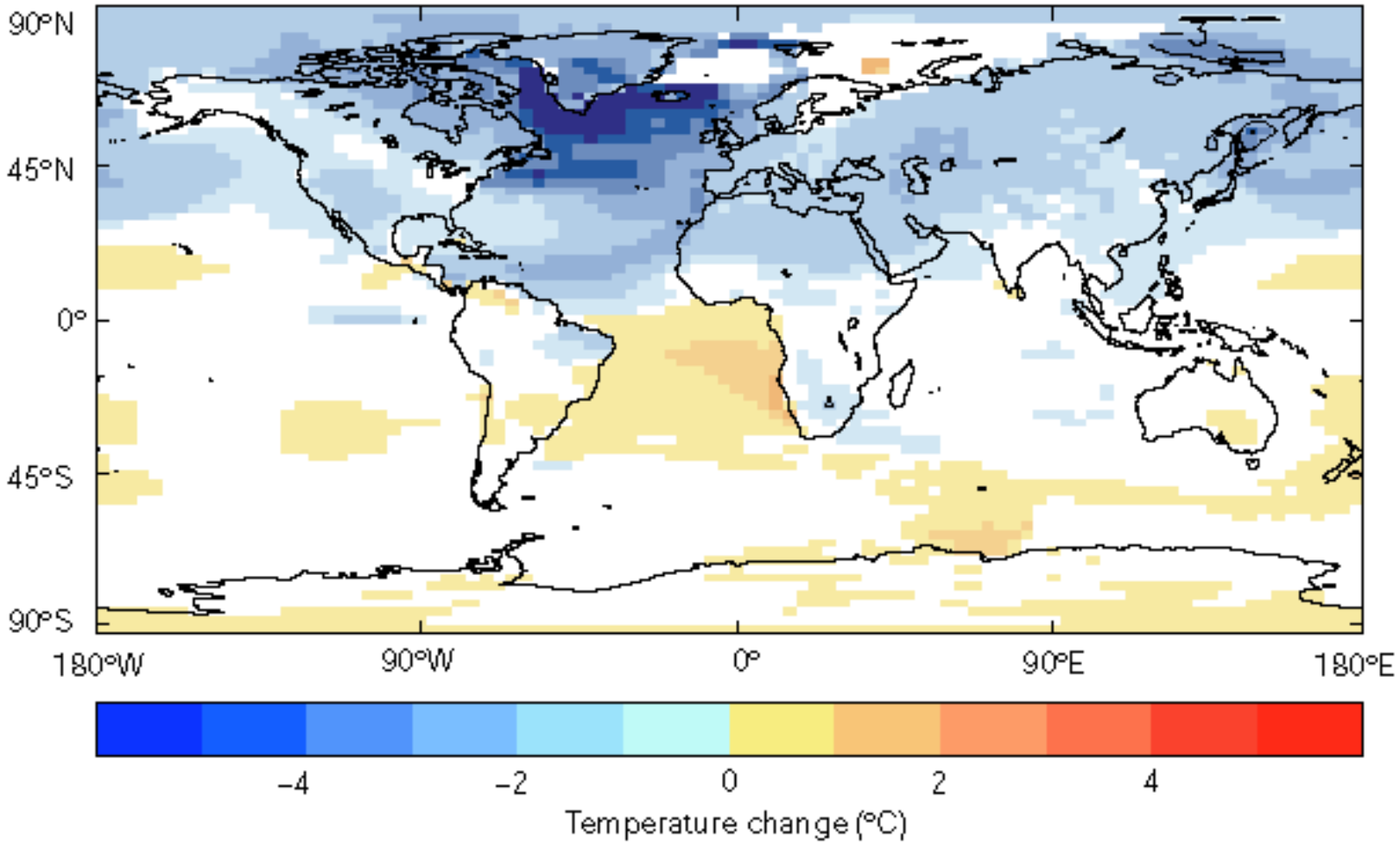



a
YOUNGER
DRYAS
FRESHWATER INPUT [Sv]
1.0
0.8
0.6
0.4
0.2
0.0
b
ΔT (72°N) [°C]
2.5
1.5
0.5
−0.5
−1.5
−2.5
−3.5
GRIP δ18O [‰]
−34
−37
−40
−43
c
ΔT (82°S) [°C]
1.5
1.0
0.5
0.0
−0.5
VOSTOK δDres [‰]
25
15
5
−5
d
ΔCO2 [p.p.m.v.]
25
15
5
−5
−15
BYRD CO2,res [p.p.m.v.]
25
15
5
−5
−15
e
ΔΔ14Catm [‰]
100
50
0
−50
Δ14Cres [‰]
100
50
0
−50
13
12
11
TIME [kyr B.P.]

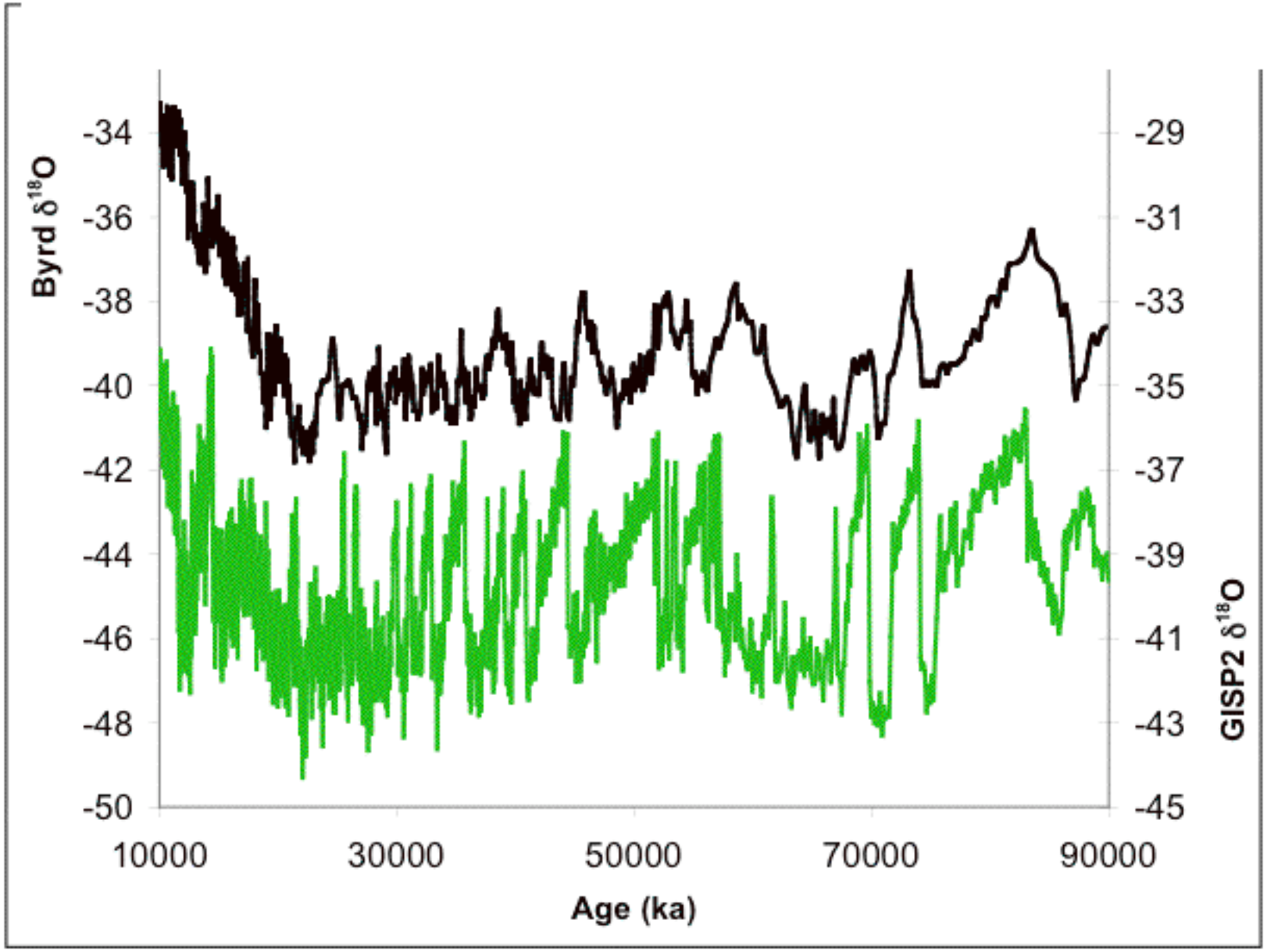

A
B
Relative sea level (m)
-70
-80
-90
-100
11500
12500
Age (14C yr B.P.)
15
14
13
12
SST (°C)


H1
H2
H3
H4
H5
%IRD
CH69-K09
V23-14
SU90-08
H3
H6
H11
No. lithic grains/g
V28-82
DSDP609
ME69-17
Core depth (cm)
PHANEROZOIC (<543 Ma)
LATE PROTEROZOIC
MIDDLE PROTEROZOIC
MIXED PROTEROZOIC AND ARCHEAN
EARLY PROTEROZOIC
ARCHEAN
ICELAND


a
0
10
20
30
40
50
60
70
80
-32
-34
-36
-38
-40
-42
-44
-46
δ18O
H1
H2
H3
H4
H5
H6
GISP2
30
20
10
0
609 % carbonate

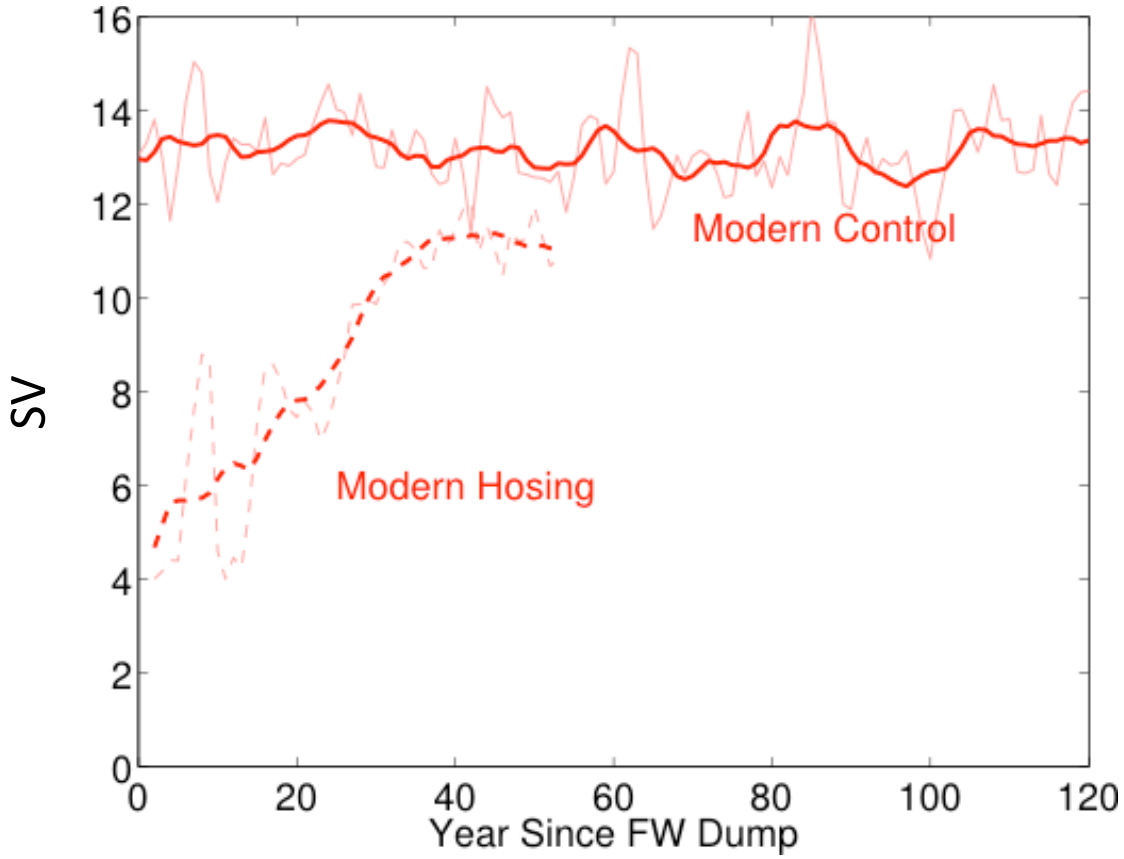



Vellinga and Wood, 2002

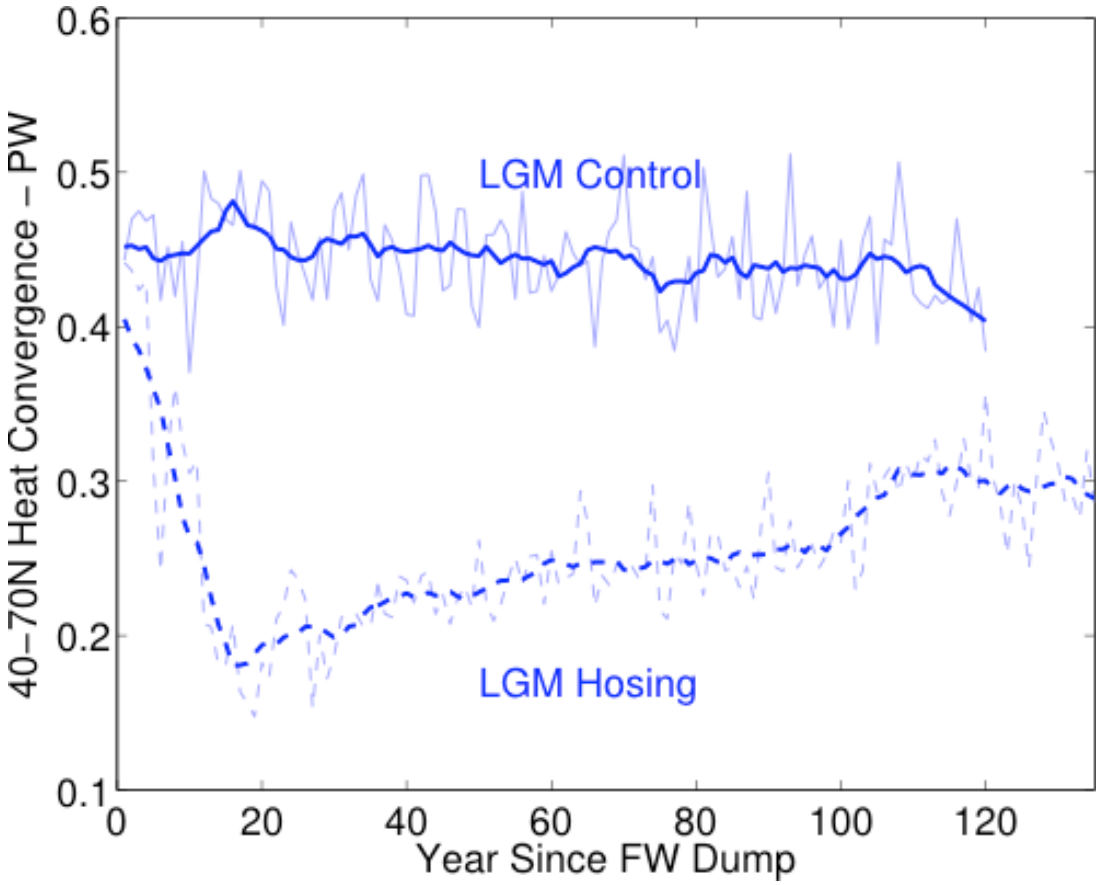

Byrd δ18O
-34
-36
-38
-40
-42
-44
-46
-48
-50
-29
-31
-33
-35
-37
-39
-41
-43
-45
GISP2 δ18O
10000
30000
50000
70000
90000
Age (ka)

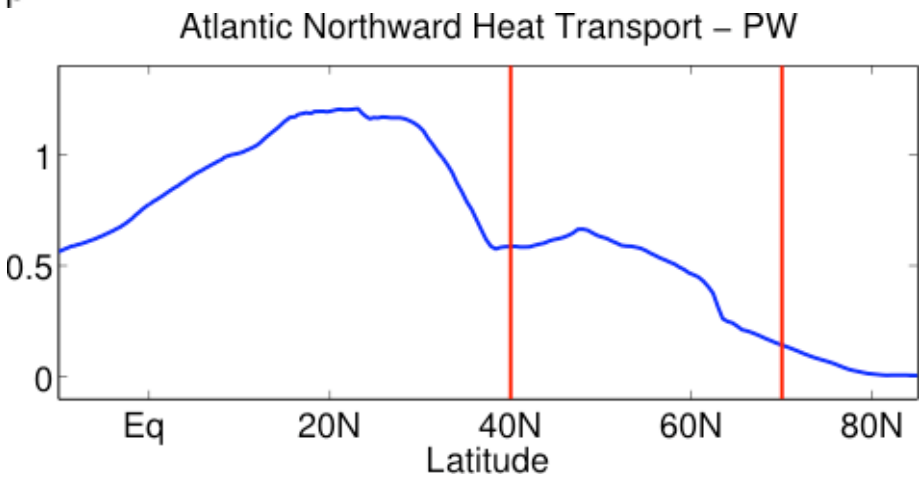
# Thermohaline Circulation

Mean transport across 800 m depth from 40-60°N



# Horizontal Heat Flux Convergence into 40-70N



# CLIMBER-2 model

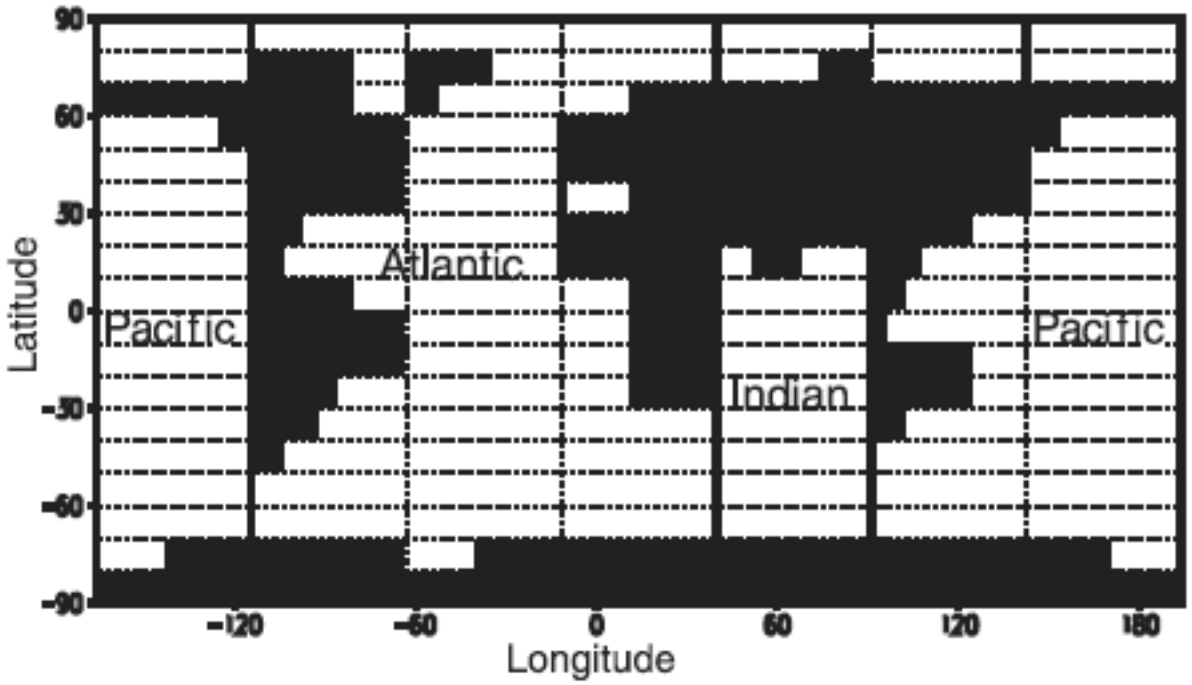


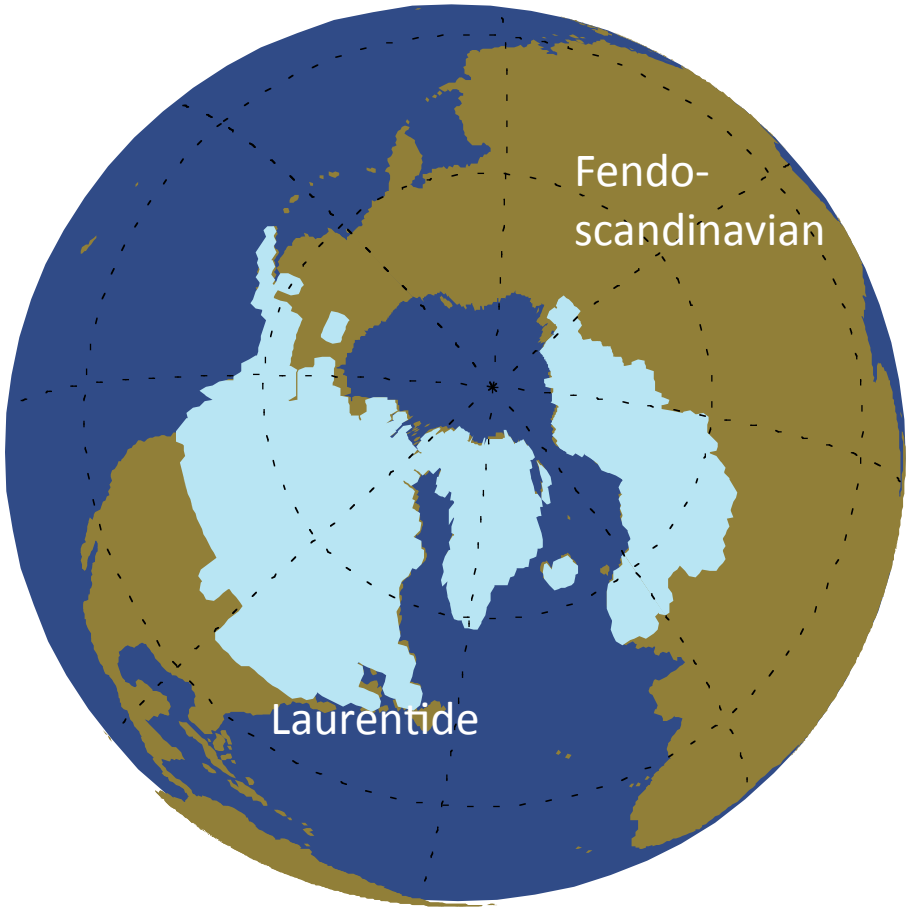

**Fig. 1** Representation of the Earth's geography in the model. *Dashed lines* show atmospheric grid, *solid lines* separate ocean basins

Basic features of a GCM, but without far more variables parameterized rather than calculated from physics. It has 11 atmospheric layers, 6 ocean layers

CLIMBER = CLIMate-BiosphERe

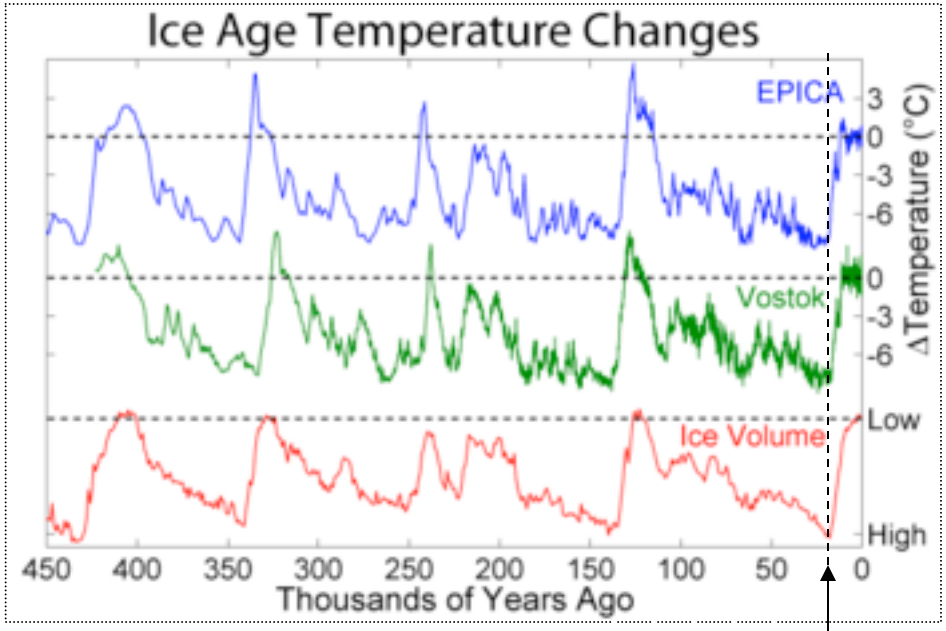
# The Last Glacial Maximum (LGM)

the “observations”

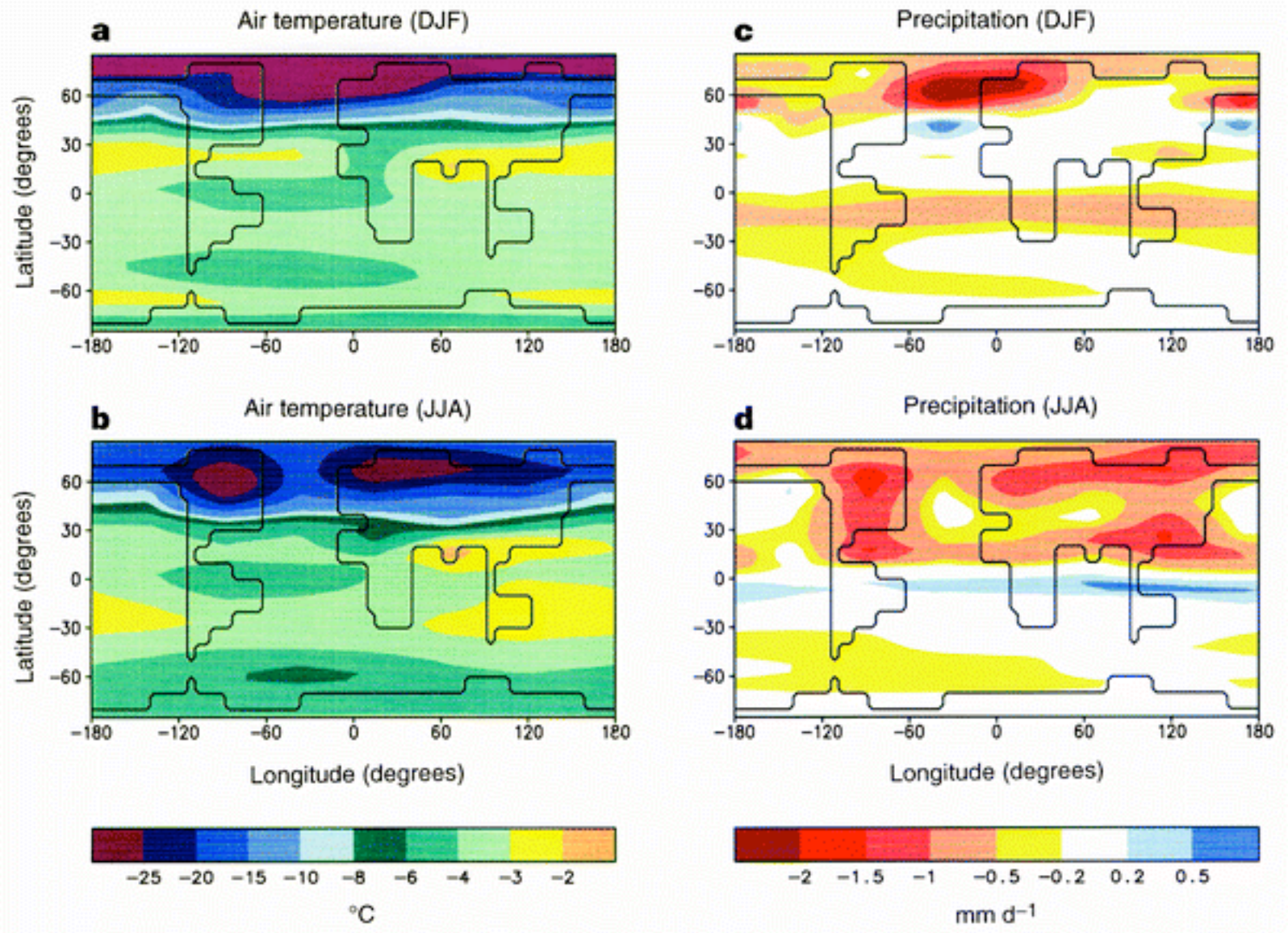



<u>The LGM was 19-23 kyr BP</u>

200ppm $CO_2$
Land ice in NH



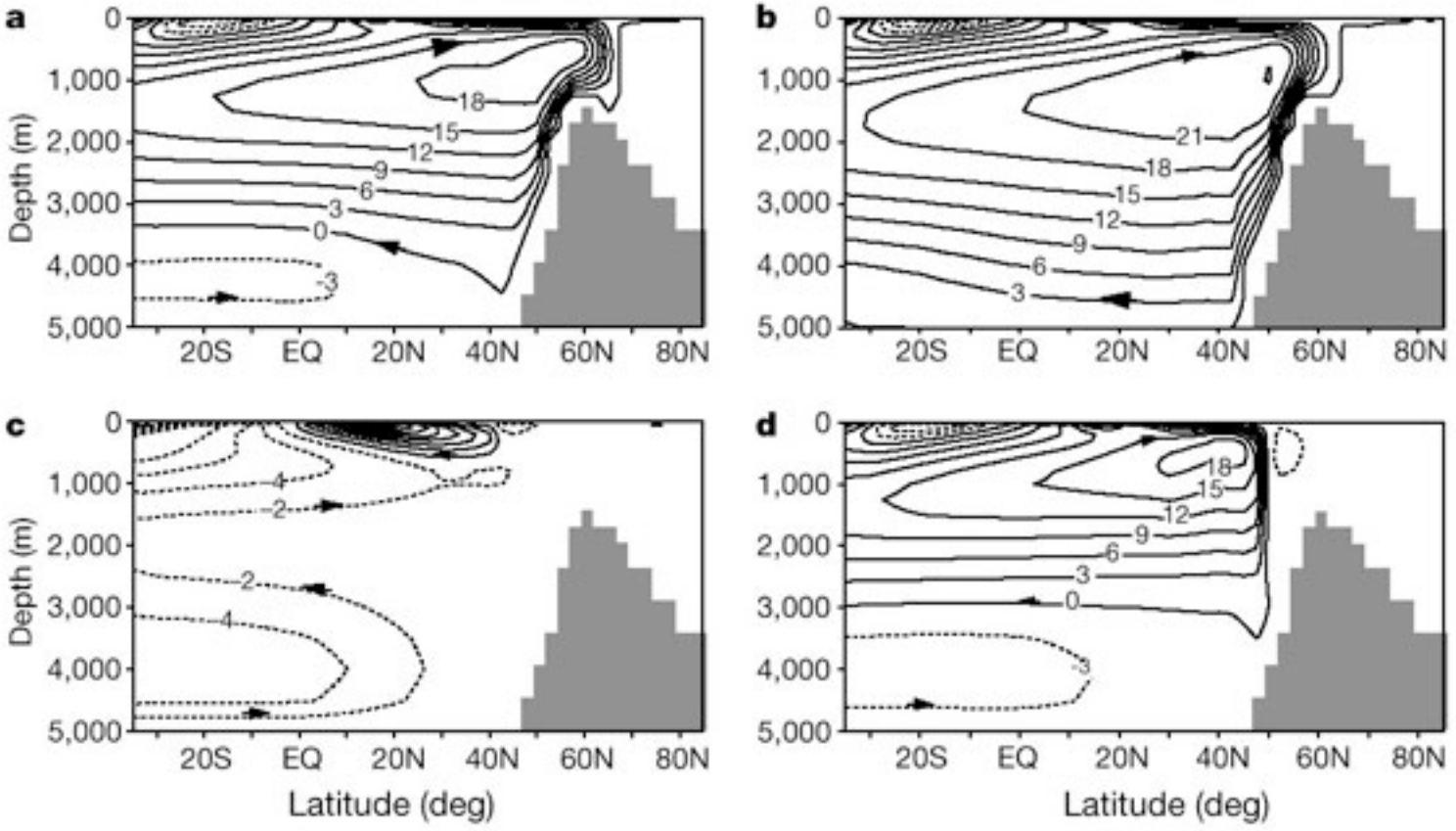
# LGM Climate of CLIMBER2



# North Atlantic meridional overturning circulation in CLIMBER2

Holocene warm mode

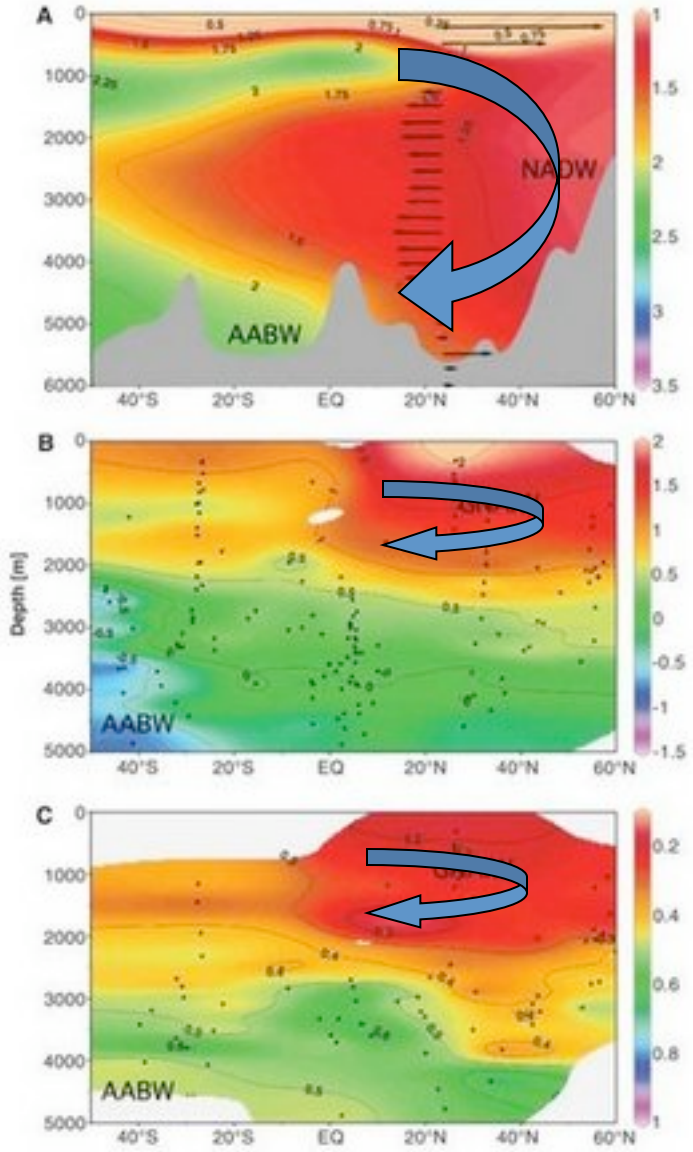
Glacial warm mode




'Off' mode

Glacial 'cold' mode

# The Reconstructed Atlantic Ocean



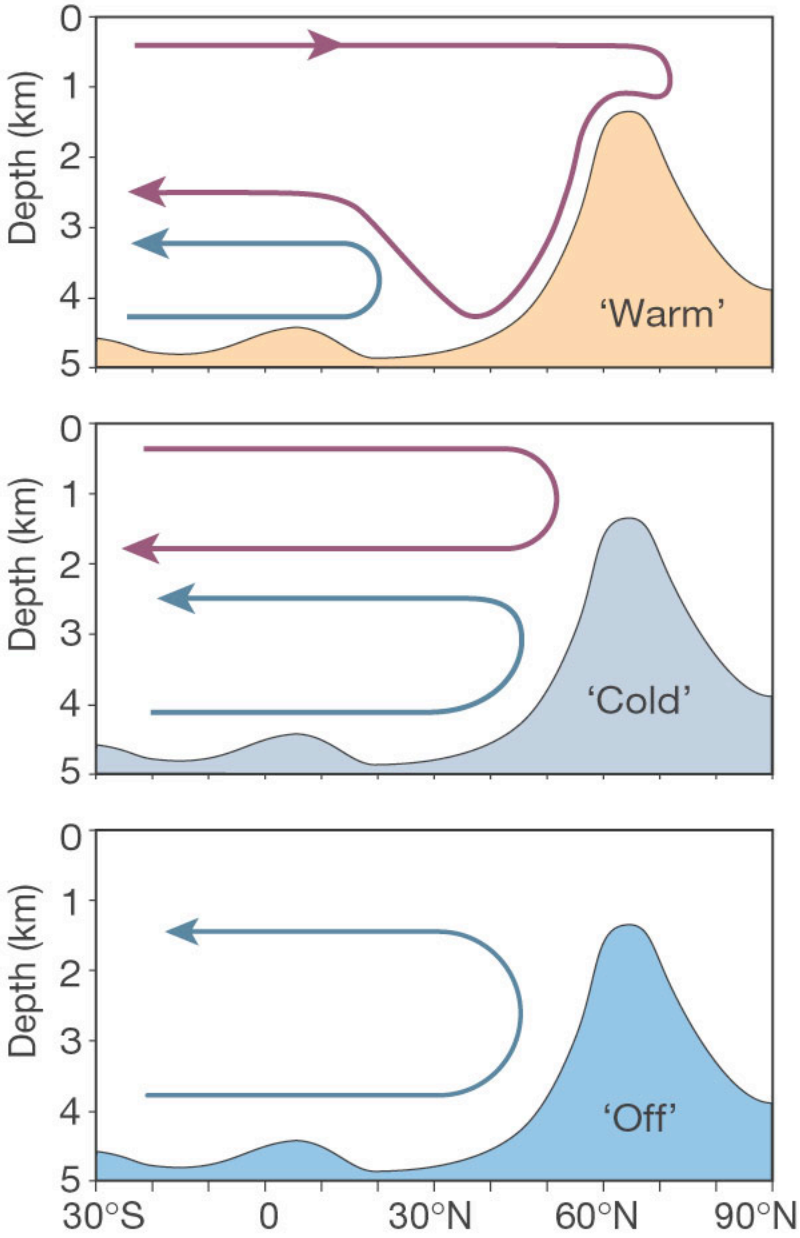

Modern Ocean

LGM Ocean (from $C_{13}$)

LGM Ocean (from Cd/Ca)

Steiglitz et al 2007

Key feature of CLIMBER2
it that it has one stable mode
of ocean circulation
depending on the
boundary conditions

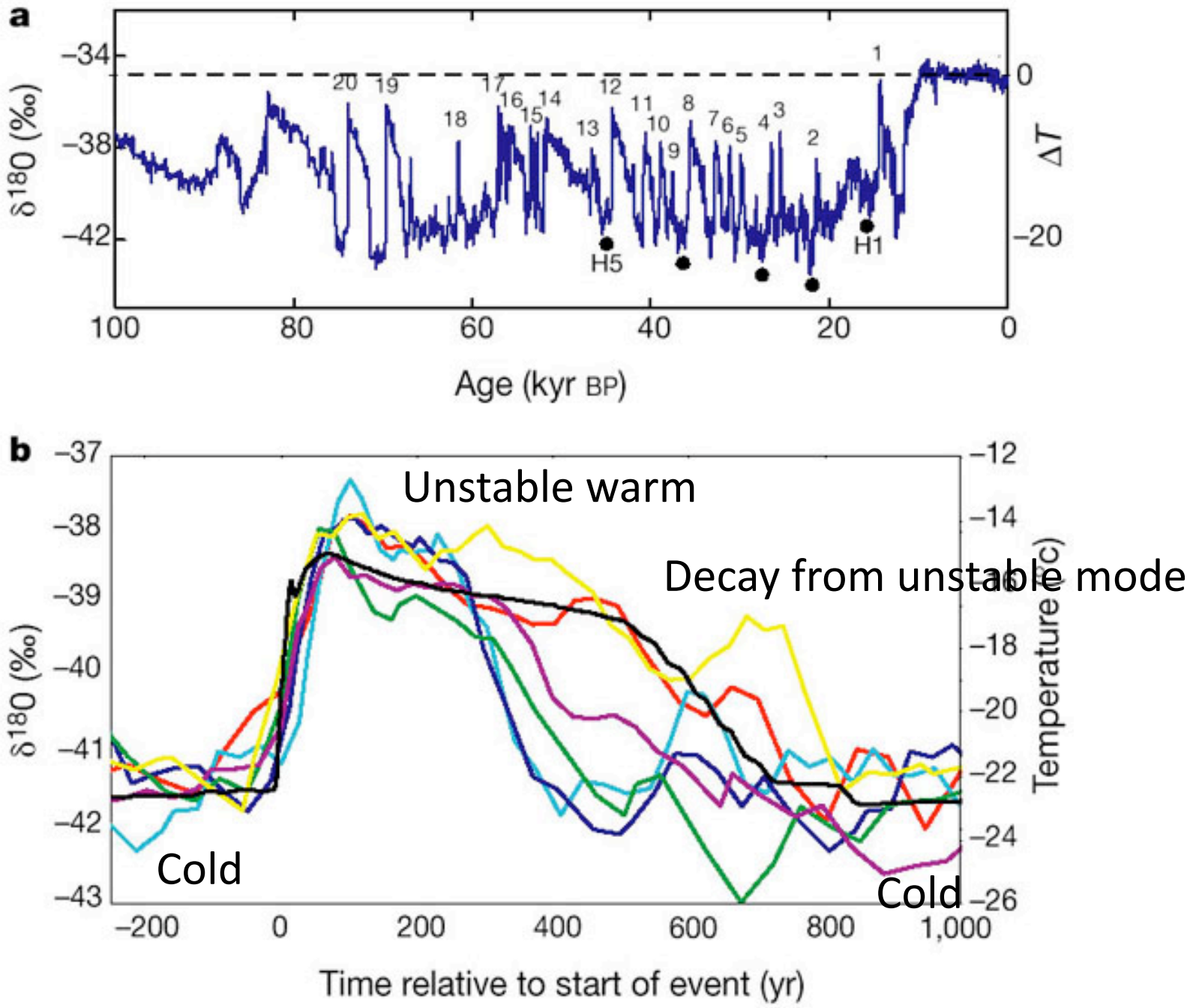


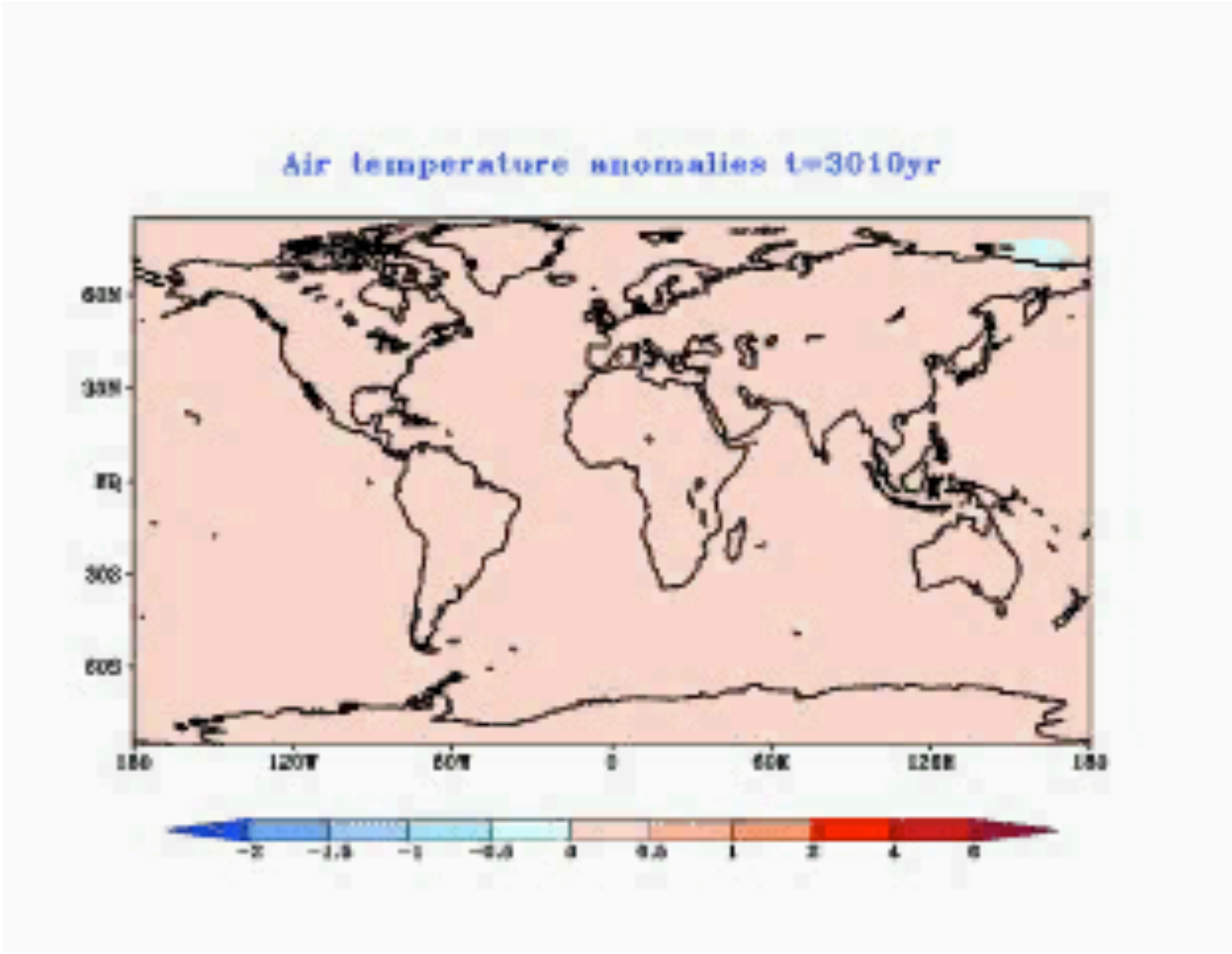

Stable
during
Holocene

Stable
during
glacial

Conceptual model resulting from CLIMBER2 Simulations

1. Climate in glacial mode (‘cold’)
2. Small decreases in meltwater flux can shift to ‘warm’ mode.
3. Instability returns model to ‘cold’ mode
4. Large increases in meltwater (Heinrich events) lead to longer-lasting ‘off’ mode, with global consequences


a
δ18O (‰)
ΔT
Age (kyr BP)
H1
H5
b
Unstable warm
Decay from unstable mode
Cold
Cold
Temperature (°C)
Time relative to start of event (yr)


Air temperature anomalies t=3010yr

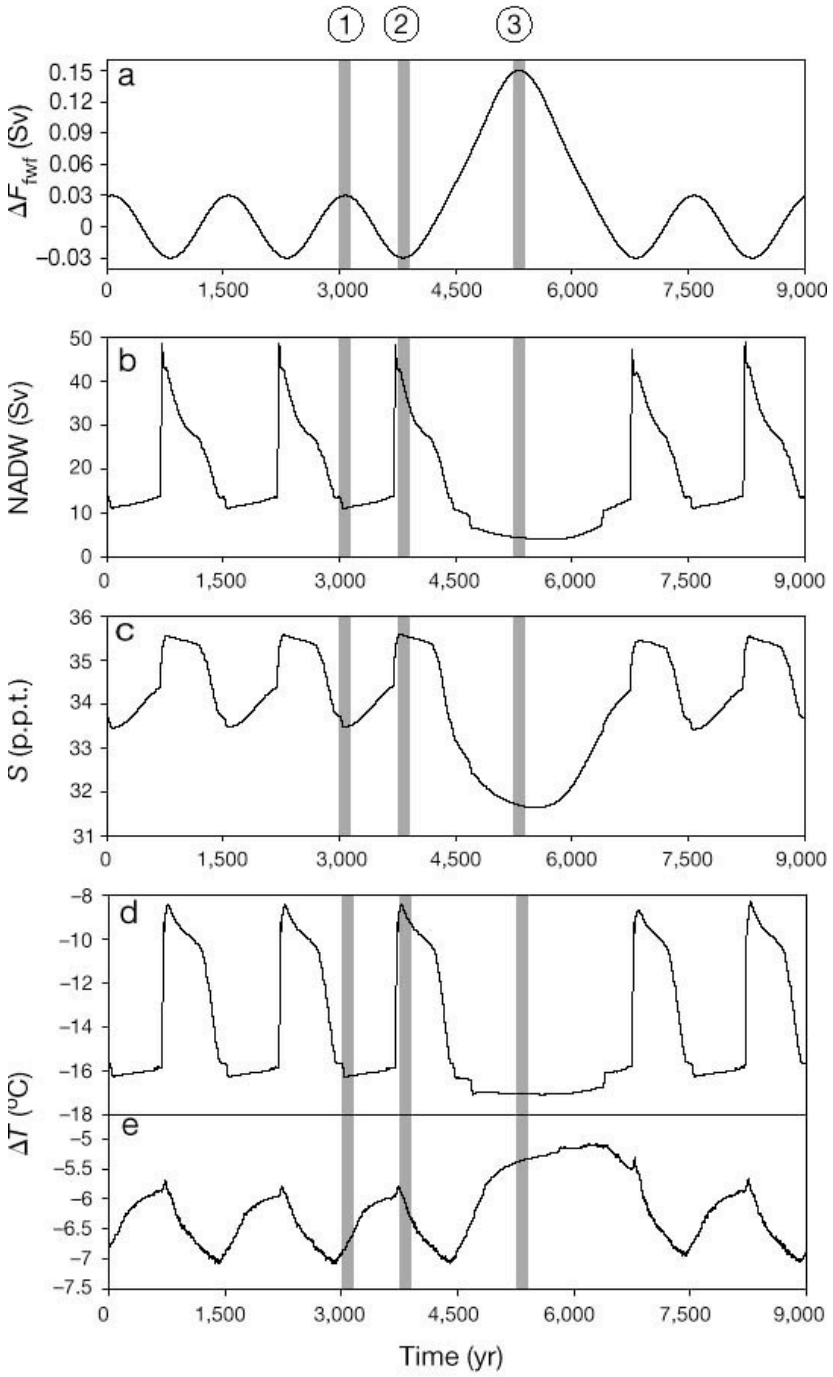
Forcing

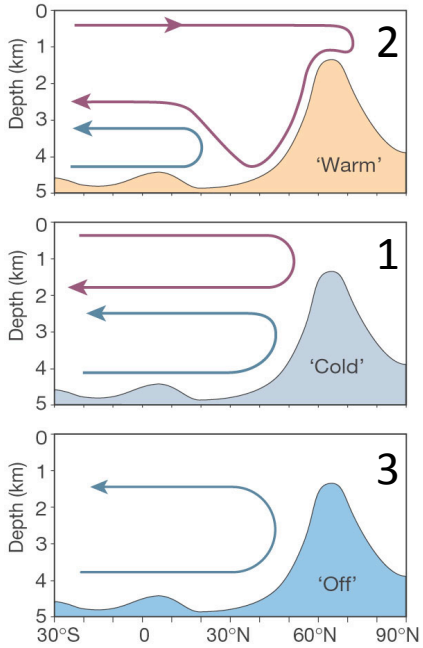
Circulation response

Salinity (North Atlantic)

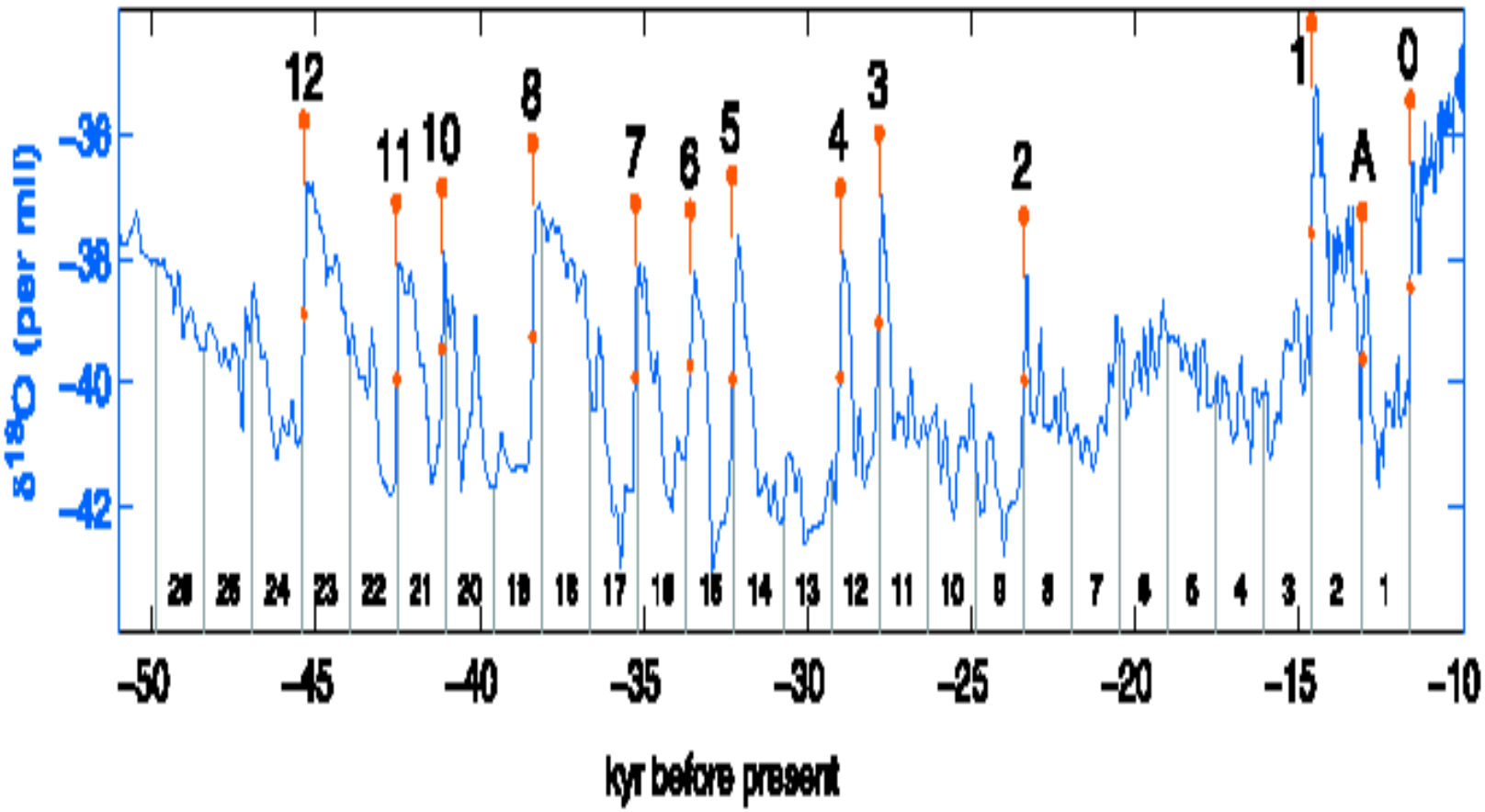
Greenland temperature

Antarctic temperature

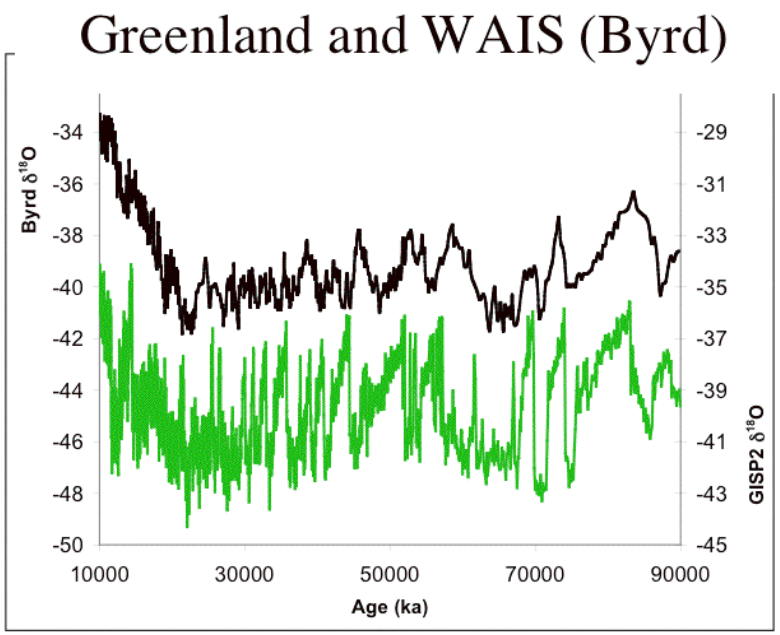


# The GISP2 “1500-year cycle”




Rahmstorff, 2002



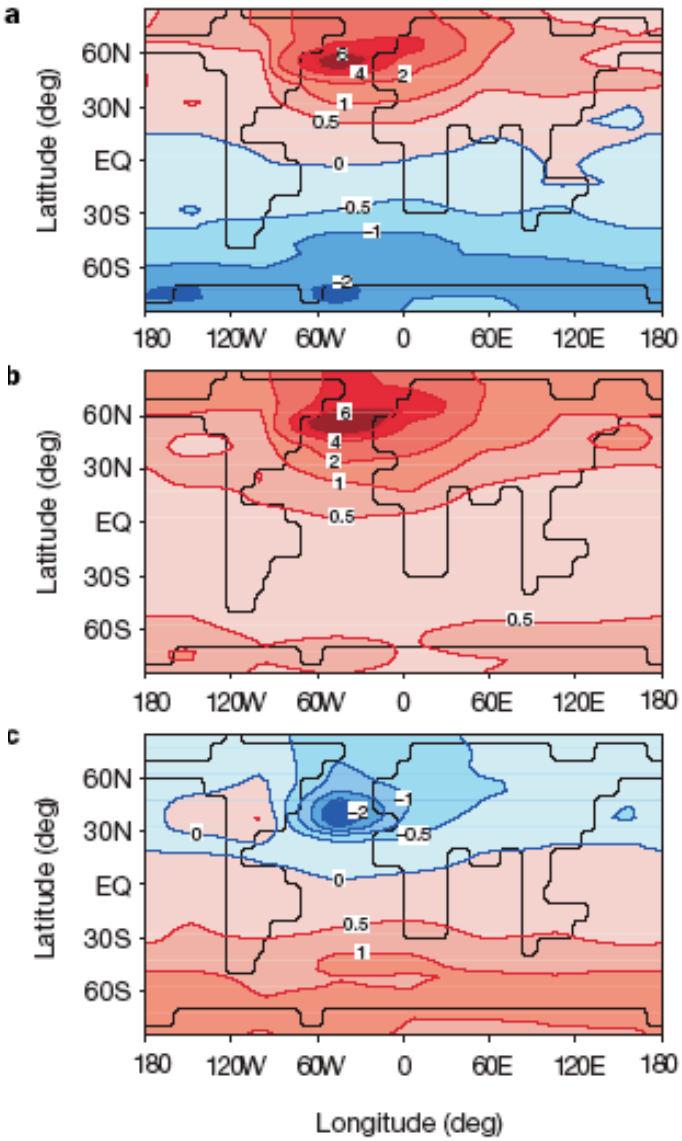
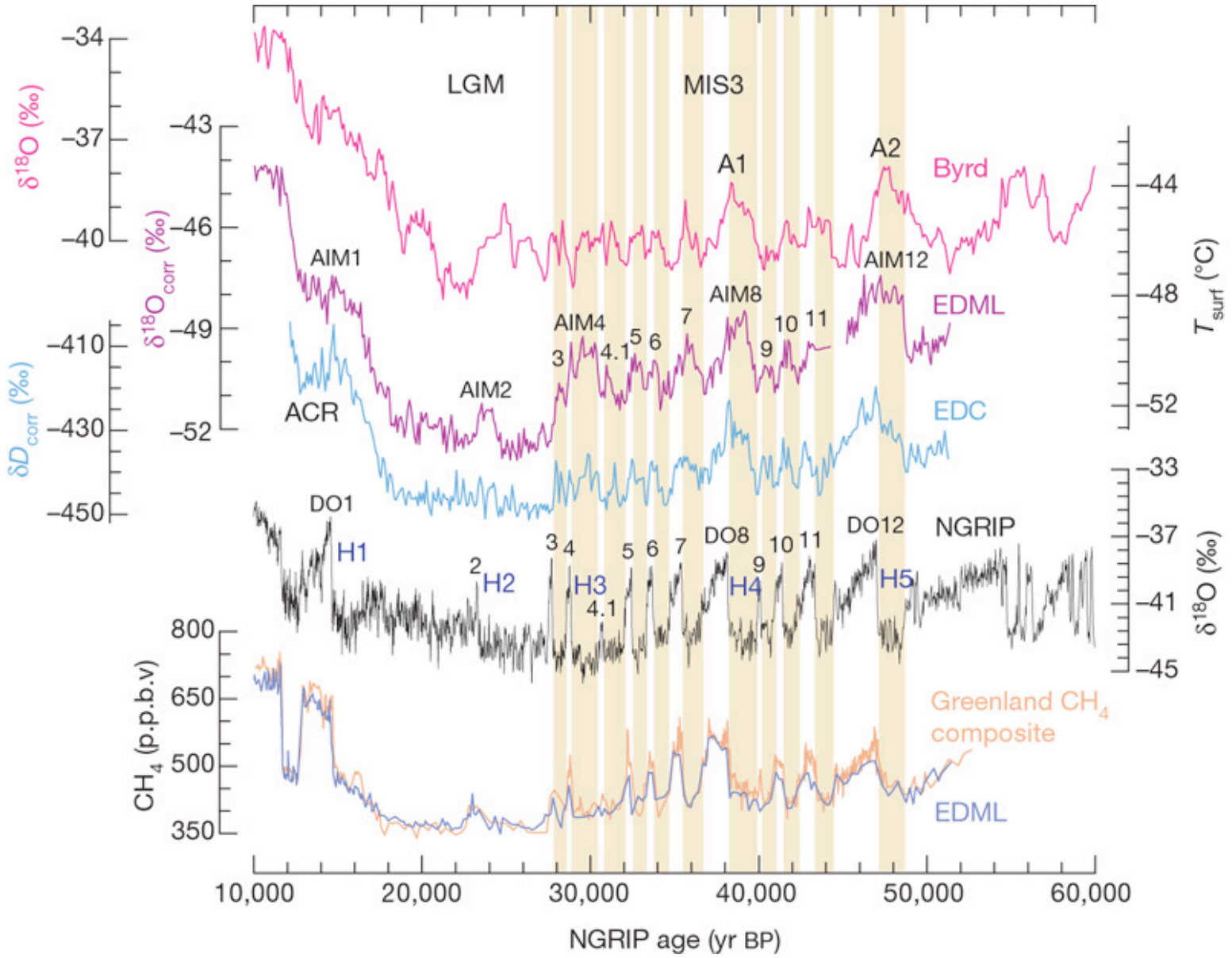
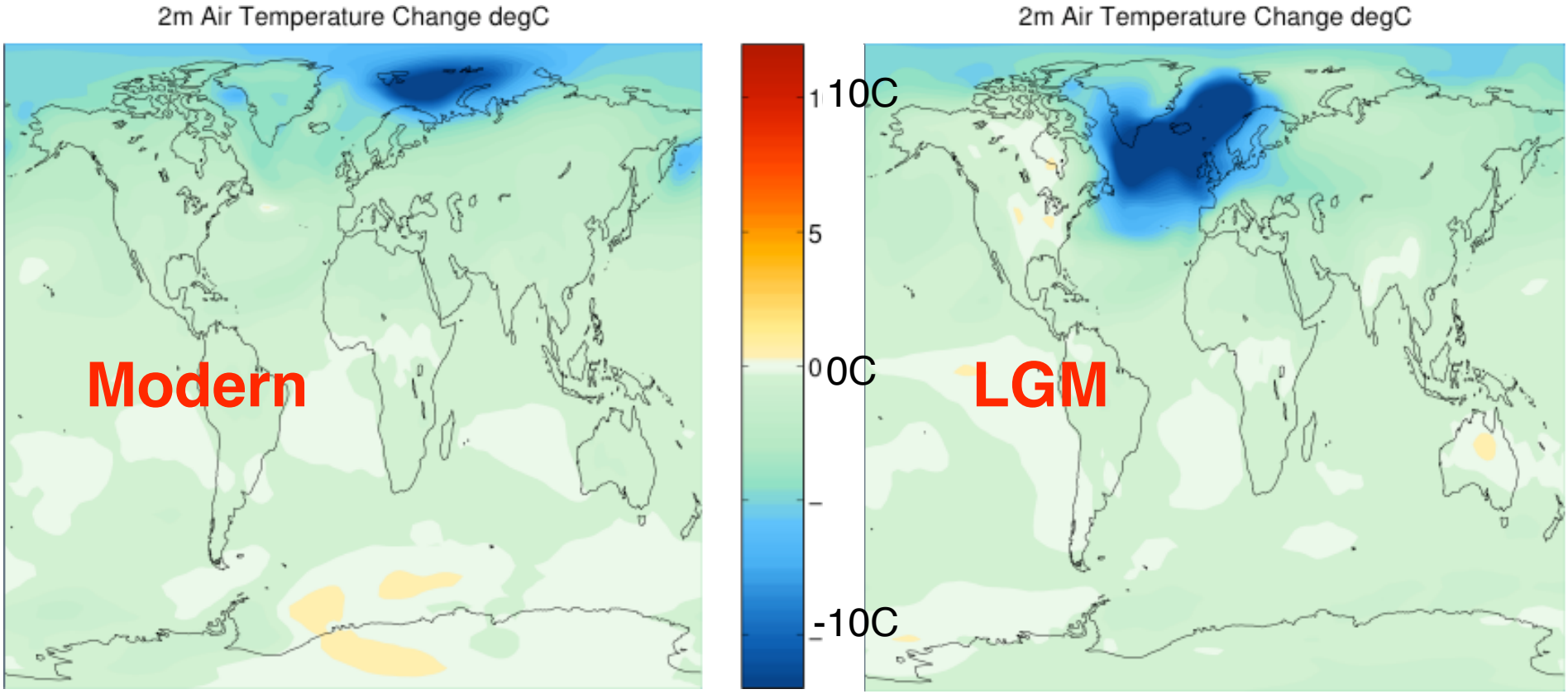




**Figure 3** Differences in model-simulated annual mean surface air temperature (°C). **a**, Glacial 'warm' mode (Fig. 2b) minus stadial mode (Fig. 2d) in equilibrium. **b**, Warmest phase of a Dansgaard–Oeschger cycle minus stadial phase, 750 years apart (see Fig. 5d). **c**, Conditions during a Heinrich event minus stadial mode (see Fig. 5d). The full time evolution of surface temperature can be viewed as a movie (see Supplementary Information).


LGM
MIS3
A1
A2
Byrd
AIM1
AIM12
AIM8
EDML
AIM4
AIM2
ACR
EDC
DO1
H1
DO12
NGRIP
DO8
H2
H3
H4
H5
Greenland CH4 composite
EDML
δ18O (‰)
δ18Ocorr (‰)
δDcorr (‰)
CH4 (p.p.b.v)
Tsurf (°C)
δ18O (‰)
NGRIP age (yr BP)
10,000
20,000
30,000
40,000
50,000
60,000

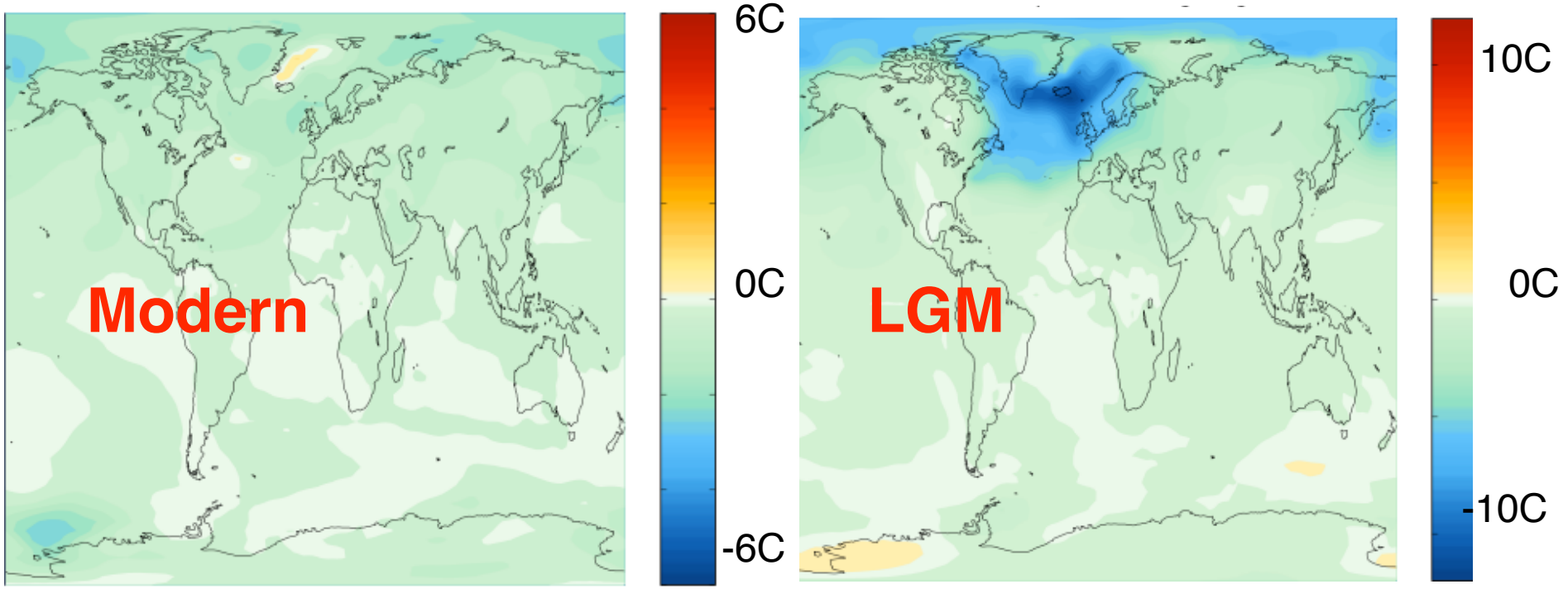
# CCSM3, 10-20 Years After Hosing

16 Sv!




Courtesy of Cecelia Bitz

# CCSM3, 40-50 Years After Hosing




Courtesy of Cecelia Bitz

- Read Ganopolski and Rahmstorf for Tuesday– on web site

- Problem set due Thursday

Related Bracconot paper on web site