Past abrupt climate change

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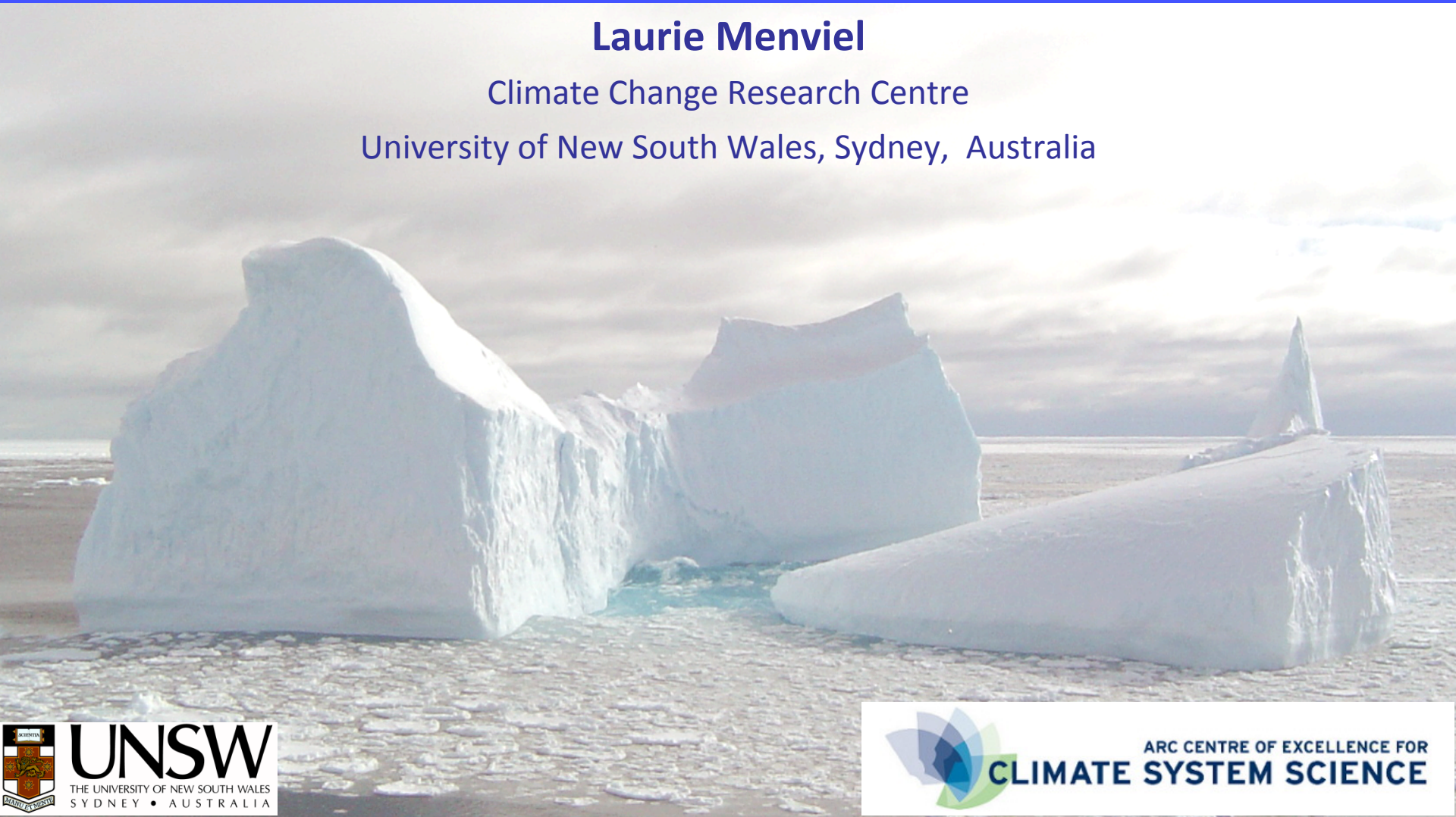


UNSW THE UNIVERSITY OF NEW SOUTH WALES SYDNEY • AUSTRALIA

ARC CENTRE OF EXCELLENCE FOR CLIMATE SYSTEM SCIENCE

Past abrupt climate change

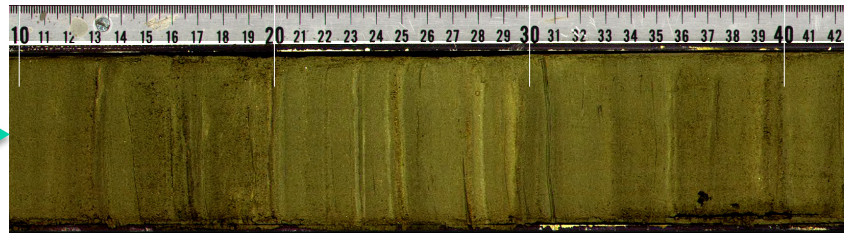
- Brief overview of Glacial-Interglacial cycles
- Millennial-scale variability of the last glacial period
- Relevance for past warm periods and future changes

How to estimate past climate change?

Paleoproxy records

Numerical experiments
with Earth System Models

Ice core records
Marine sediment cores

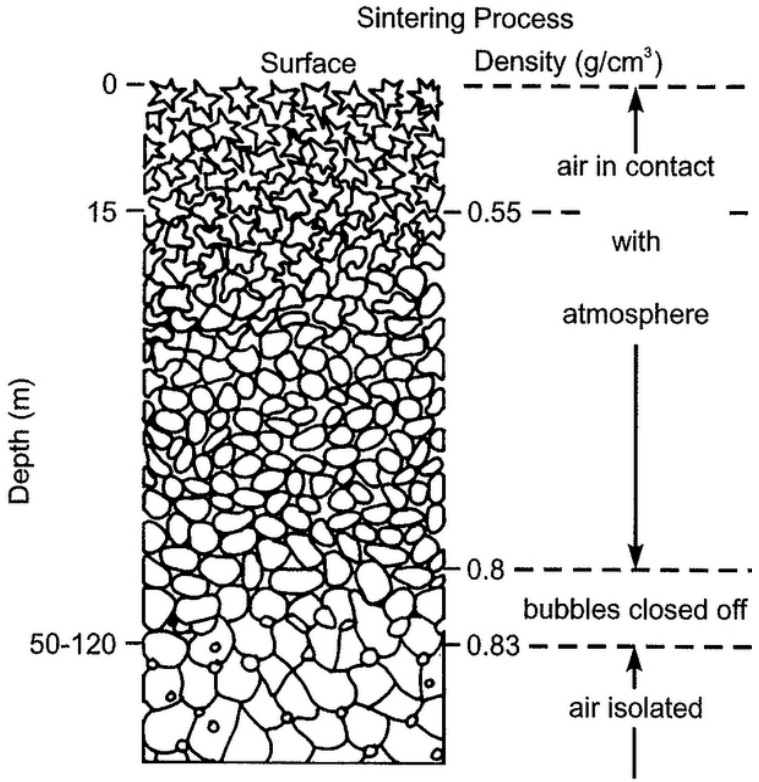


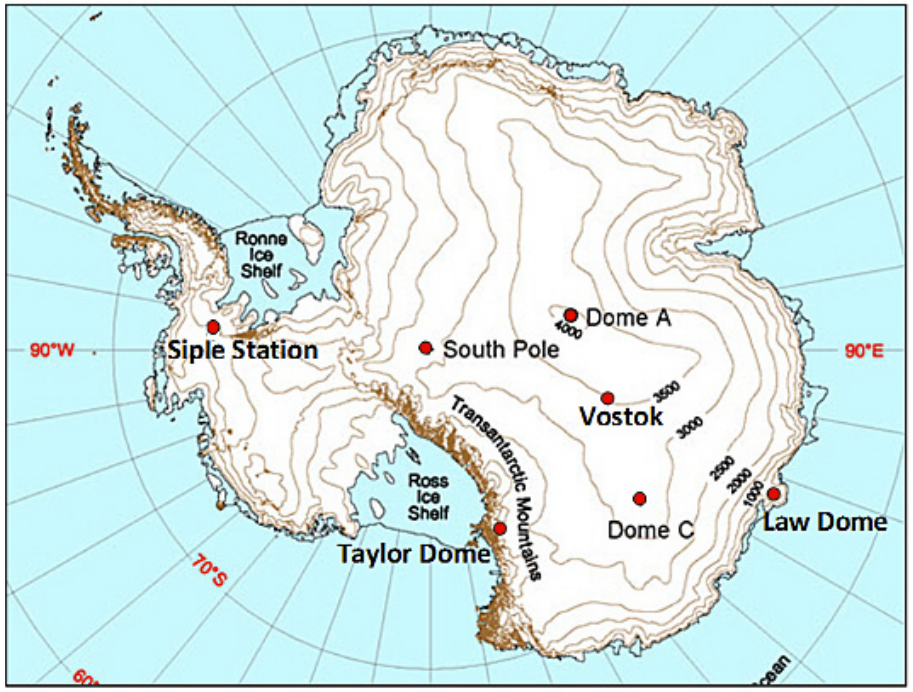
SST, Air temperature,
Precipitation,

Speleothems
Corals
Lacustrine sediment cores

Paleoclimate Archives

Ice Core Records





USED TO RECONSTRUCT:

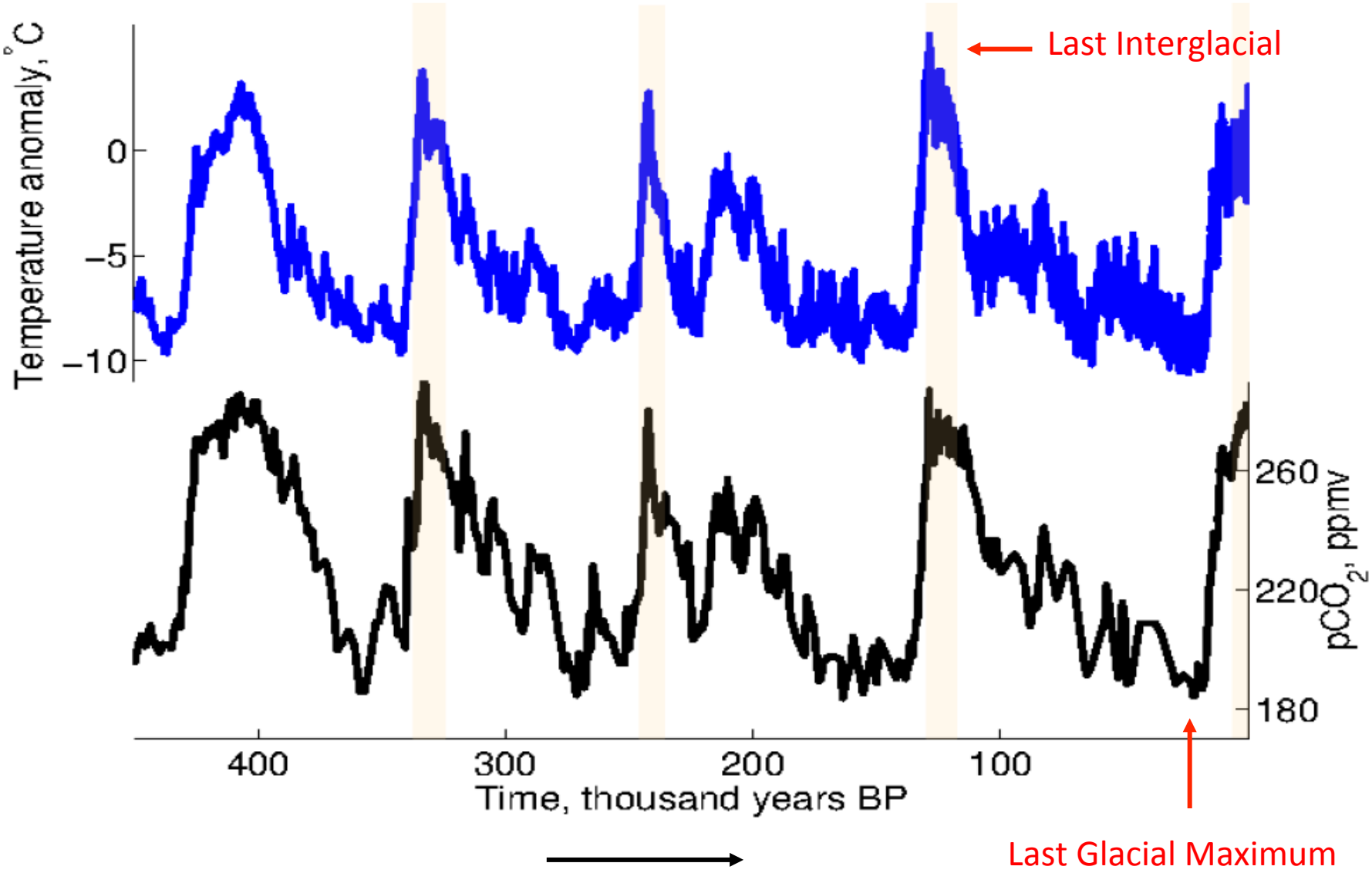
- Temperature:

$$\delta^{18}O = f(^{18}O/^{16}O) \text{ and } \delta D = f(^{2}H/^{1}H)$$

- Atmospheric gases: CO_2, CH_4, $\delta^{13}CO_2$…

Glacial - Interglacial Cycles

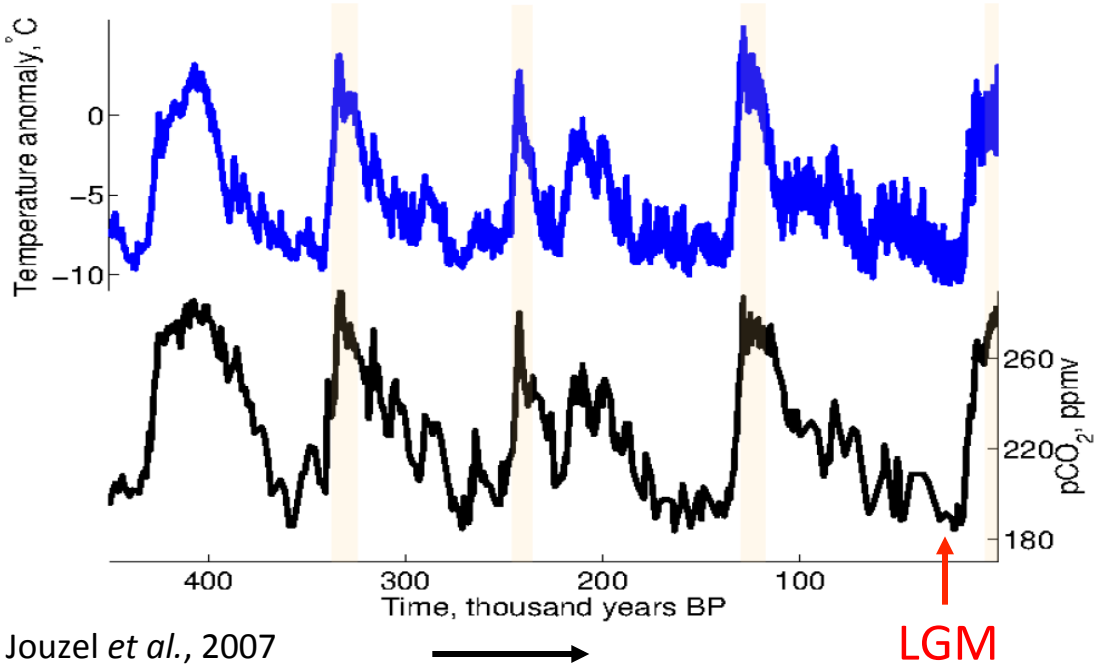
EPICA Dome C, Antarctica



Jouzel *et al.*, 2007

Glacial - Interglacial Cycles

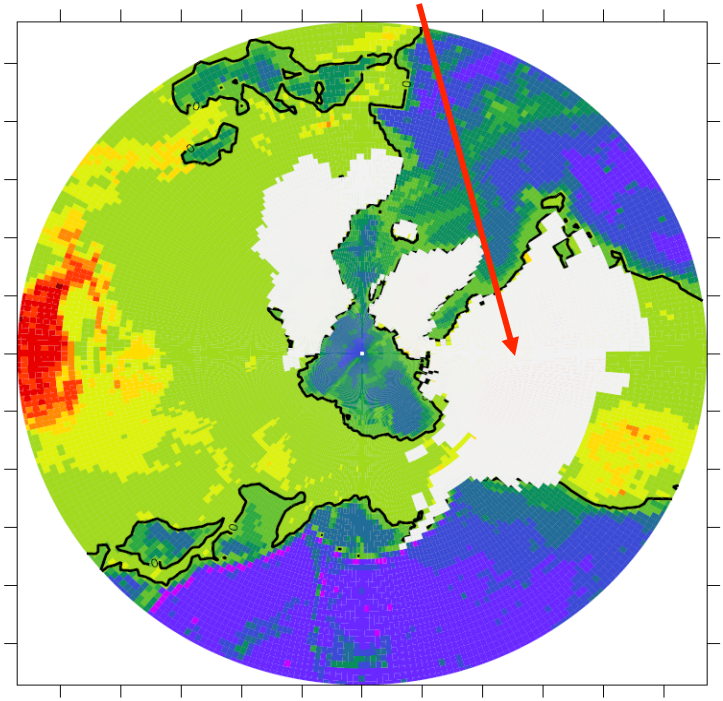
EPICA Dome C, Antarctica



Jouzel *et al.*, 2007

LGM

Laurentide Icesheet

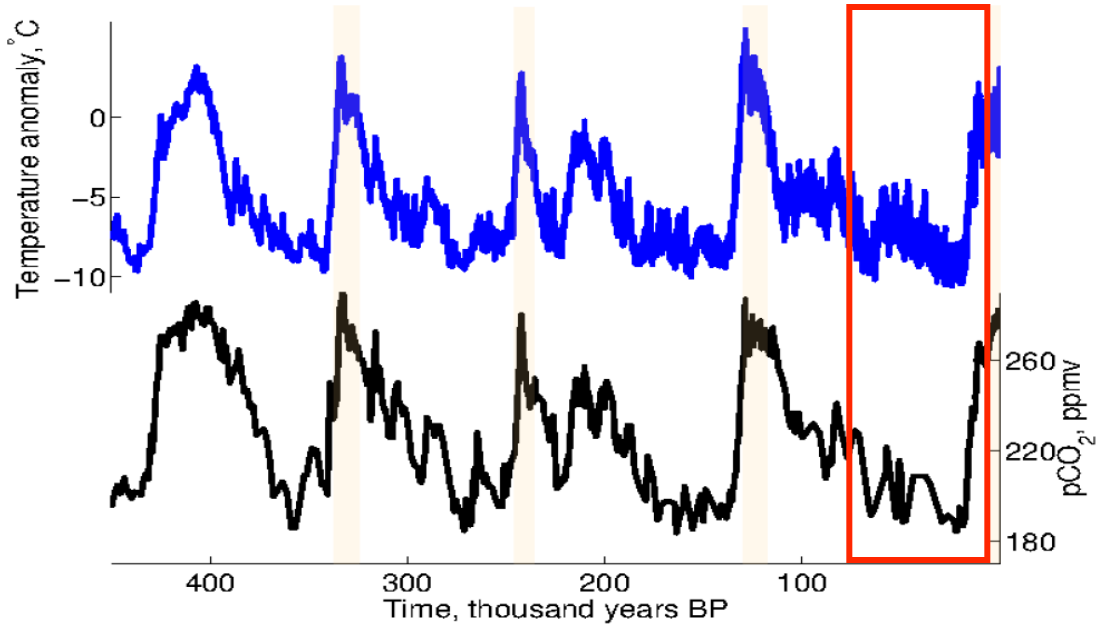


Last Glacial Maximum Ice Cover, ICE5G

Peltier, 2004

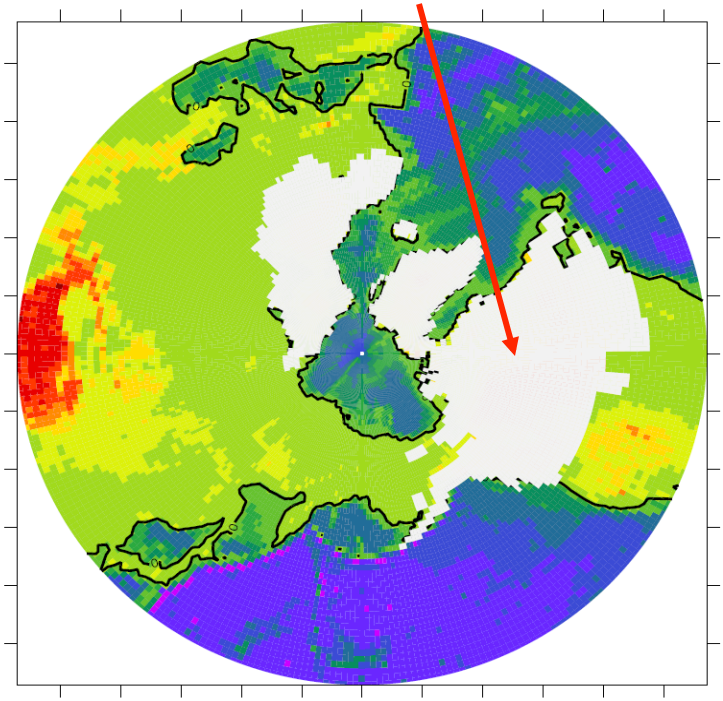
Glacial - Interglacial Cycles

EPICA Dome C, Antarctica



Jouzel *et al.*, 2007

Laurentide Icesheet



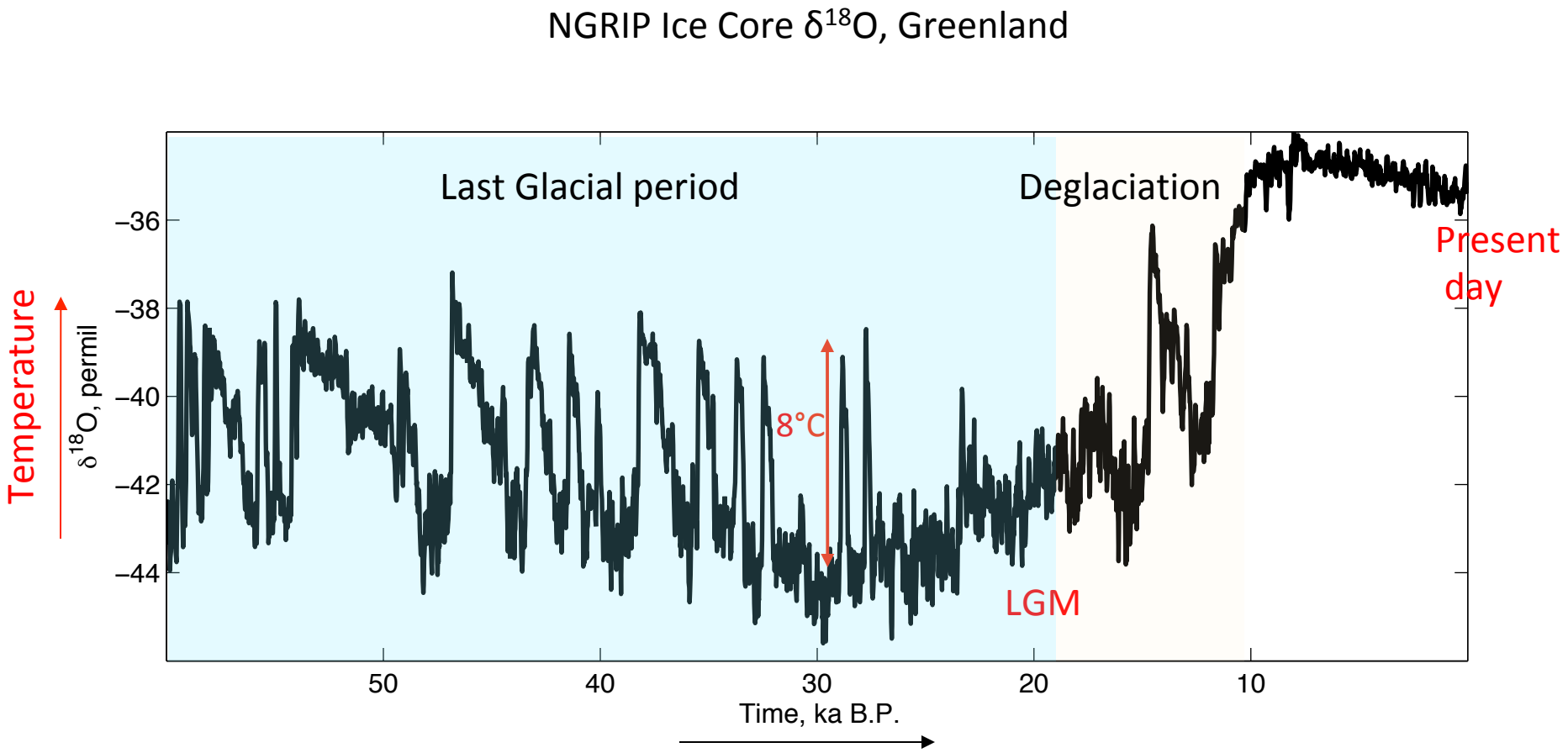
Last Glacial Maximum
Ice Cover, ICE5G

Peltier, 2004

- External forcing:
  Insolation
  Milankovitch Cycles, *(Changes in Earth's Orbit)*

- Internal forcing (*Positive Feedbacks*):
  Atmospheric CO_2
  Northern Hemisphere Icesheets

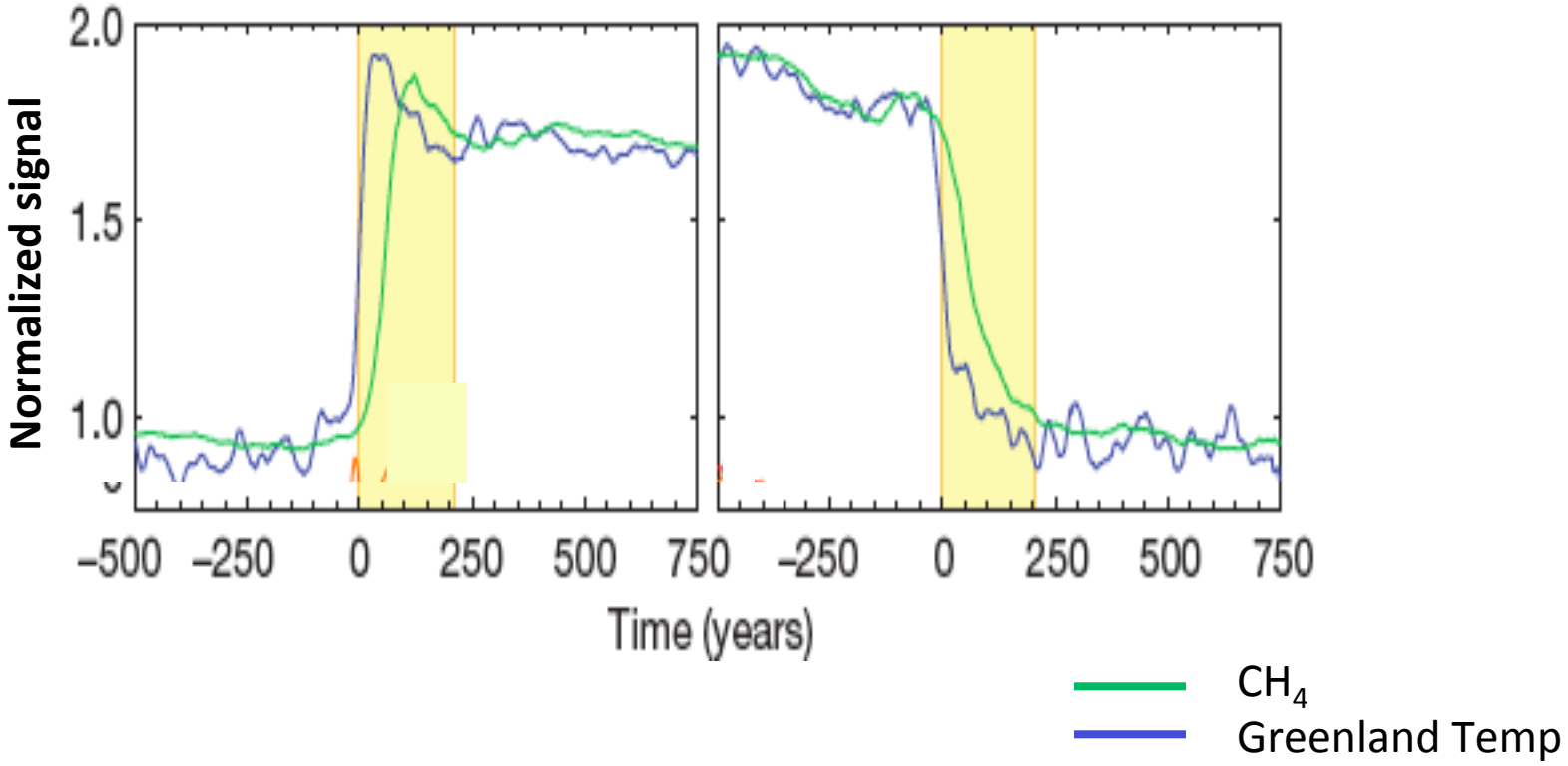
Dansgaard-Oeschger / Heinrich variability



Huber *et al.,* 2006

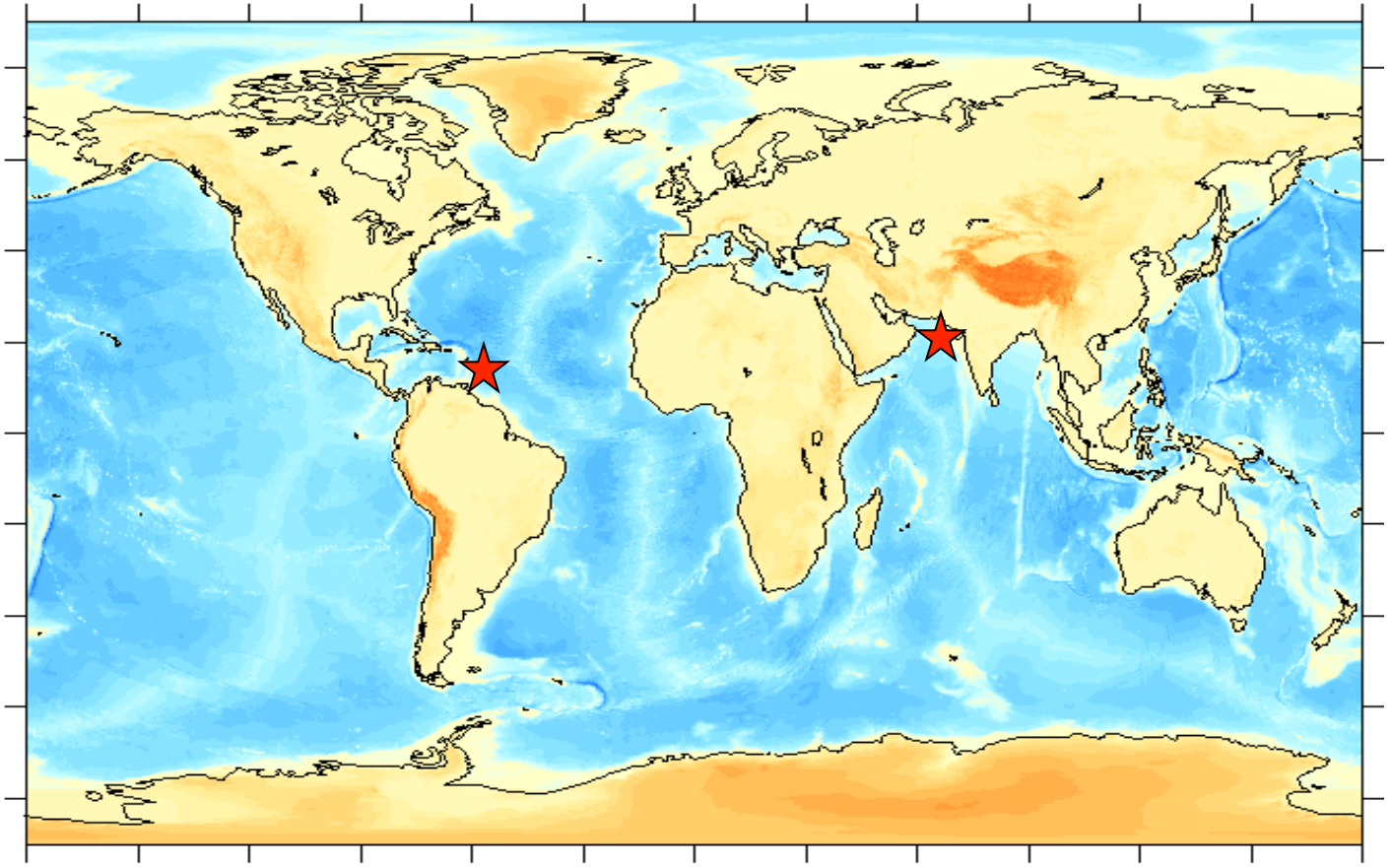
Dansgaard-Oeschger / Heinrich variability

Greenland and Antarctic Temperatures
WAIS (2015) and NGRIP (2004)



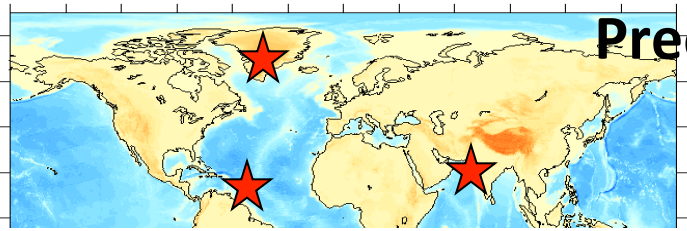
Greenland: +8ºC in <50 years
NH terr. biosphere ~ 100 years

Precipitation in the Tropics

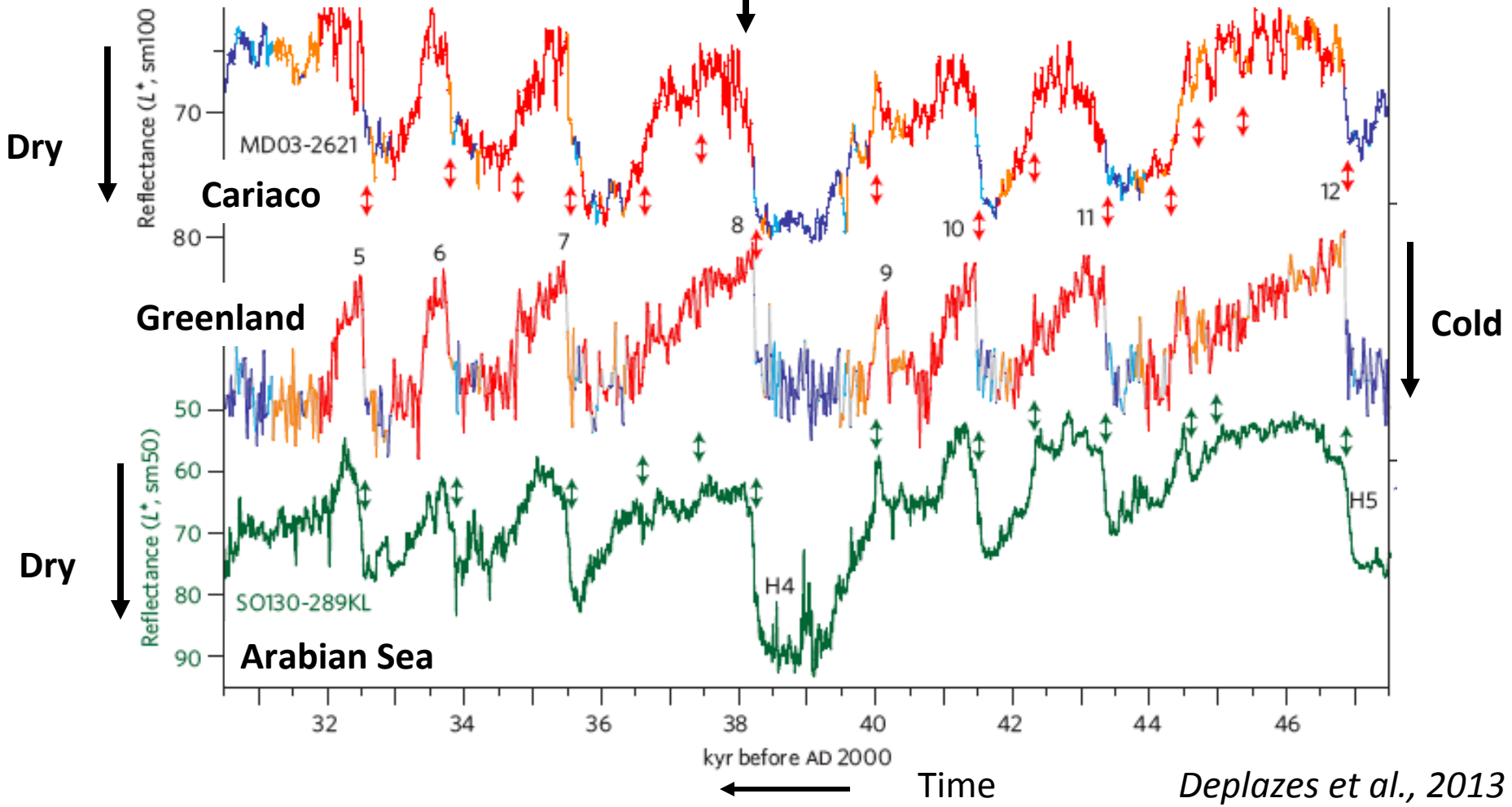


Deplazes et al., 2013

Dansgaard-Oeschger / Heinrich variability

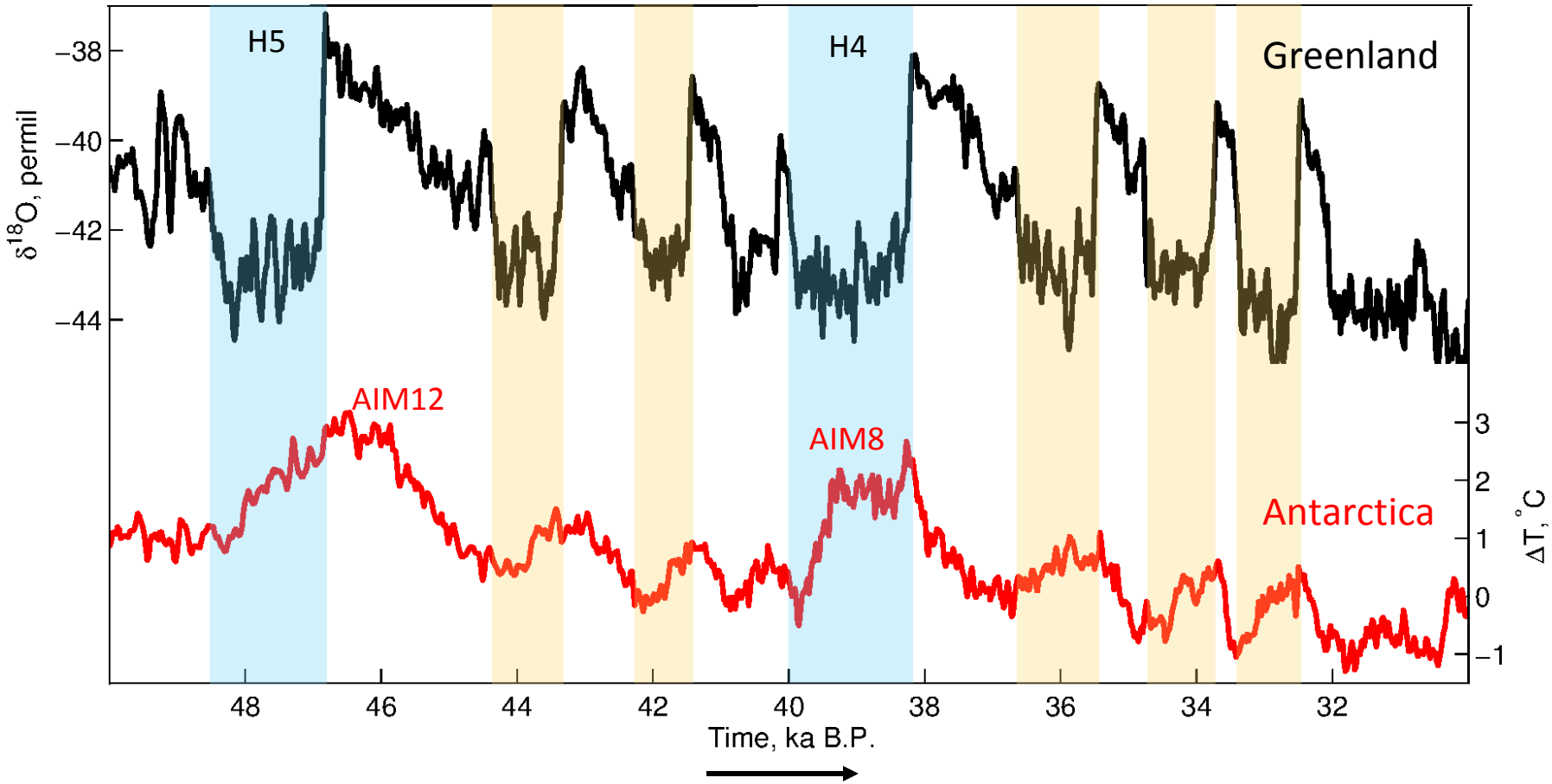


Precipitation in the Tropics



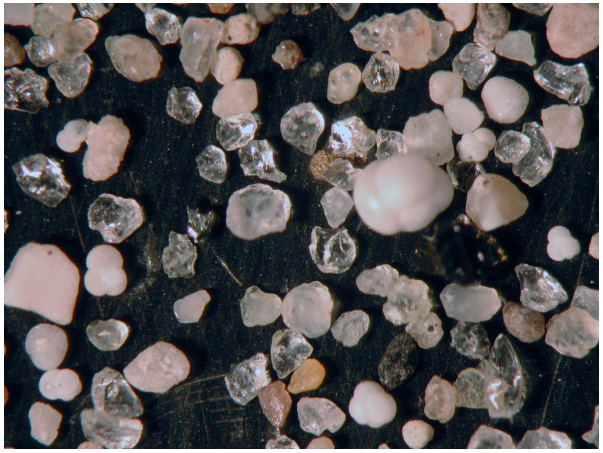
Deplazes et al., 2013

Dansgaard-Oeschger / Heinrich variability
Antarctic records



NGRIP $\delta^{18}O$ on GICC05
EDC Temp. (Jouzel et al. 2007) on AICC2012

Heinrich events

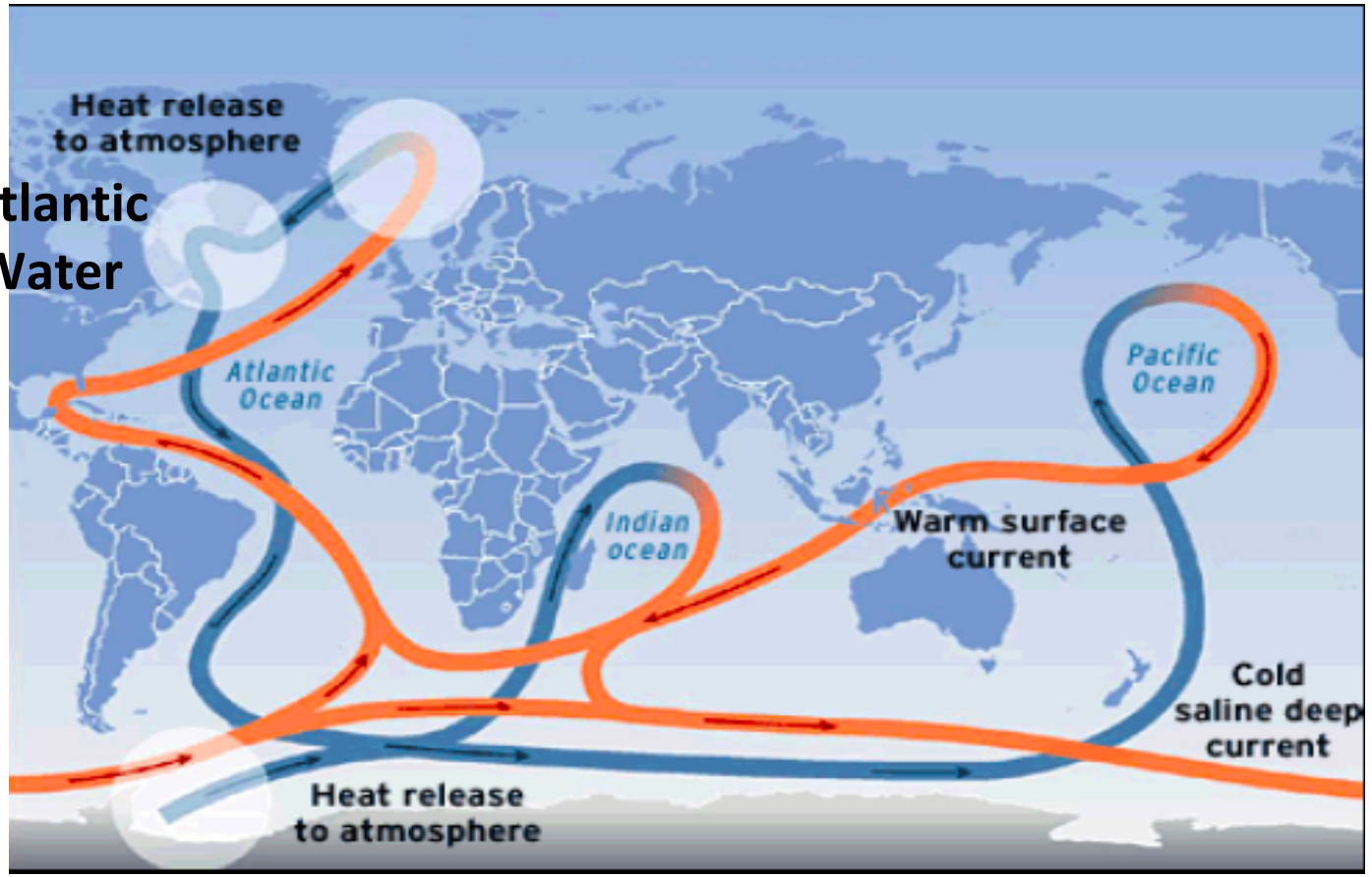


Ice rafted Debris (IRD)

Marine
sediment core

Oceanic circulation

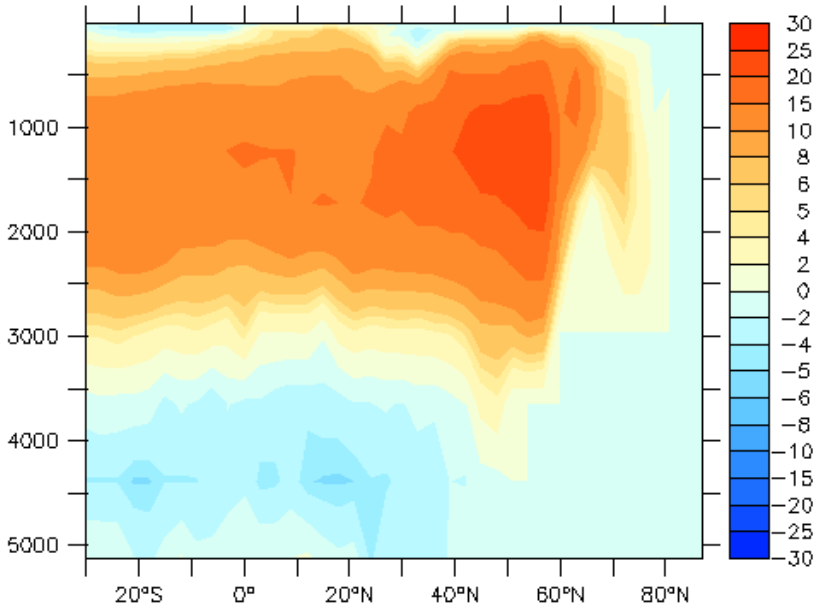
North Atlantic Deep Water



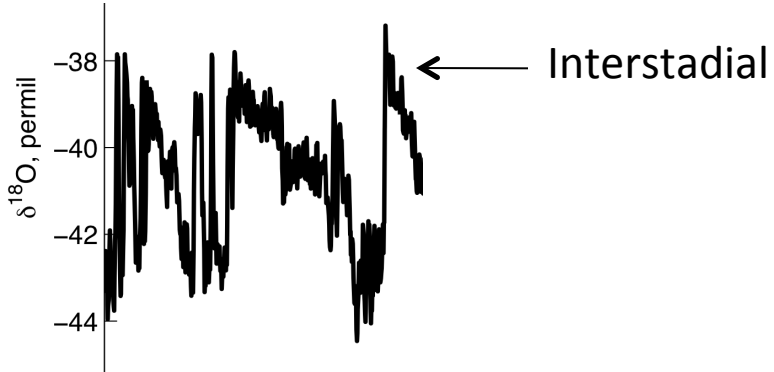
Antarctic Bottom Water

Dansgaard-Oeschger / Heinrich variability

Interstadial (warm): strong North Atlantic Deep Water

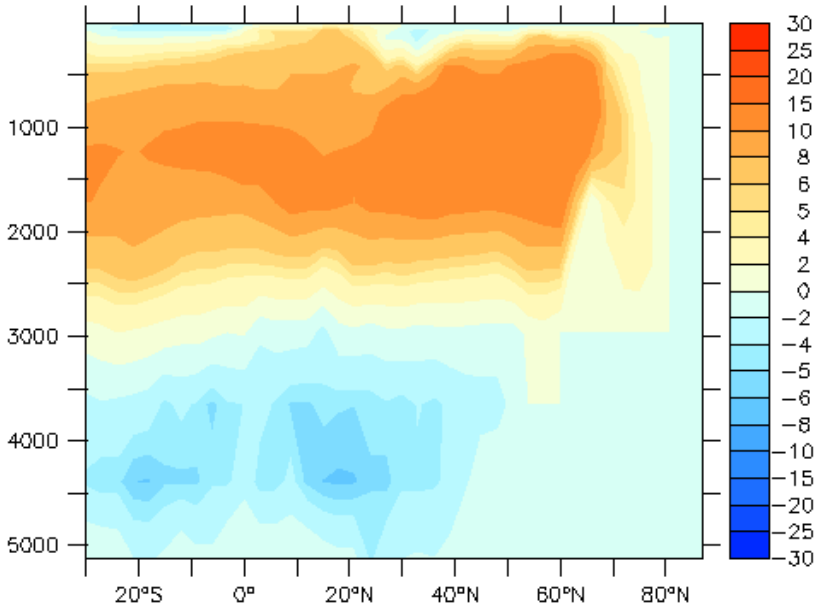


Atlantic meridional overturning streamfunction

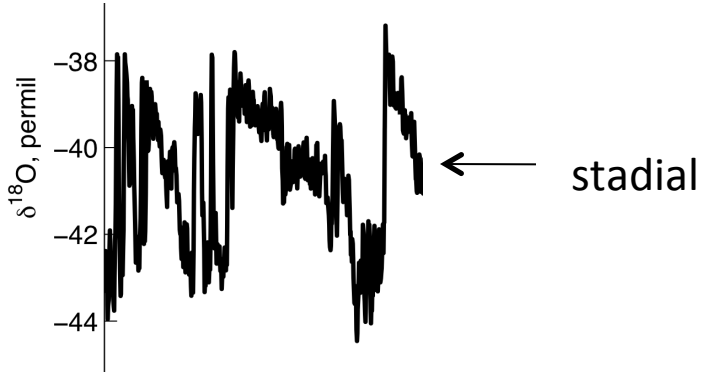


Dansgaard-Oeschger / Heinrich variability

Stadial (cold): weak North Atlantic Deep Water

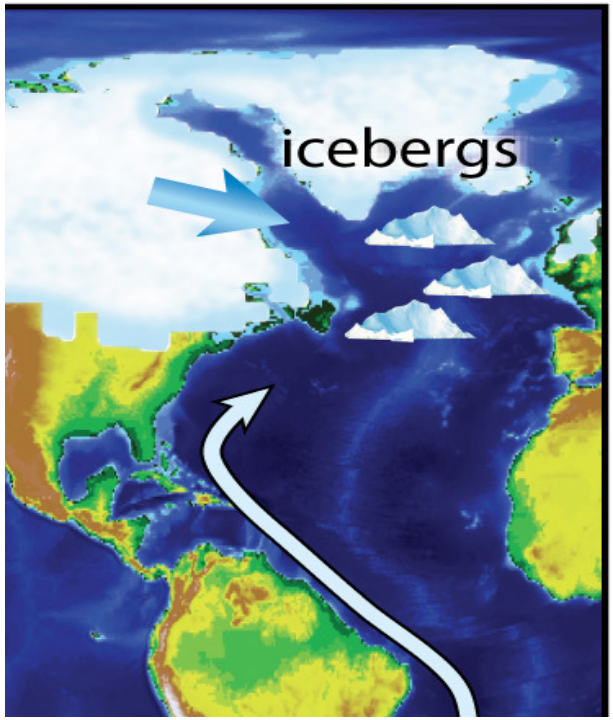


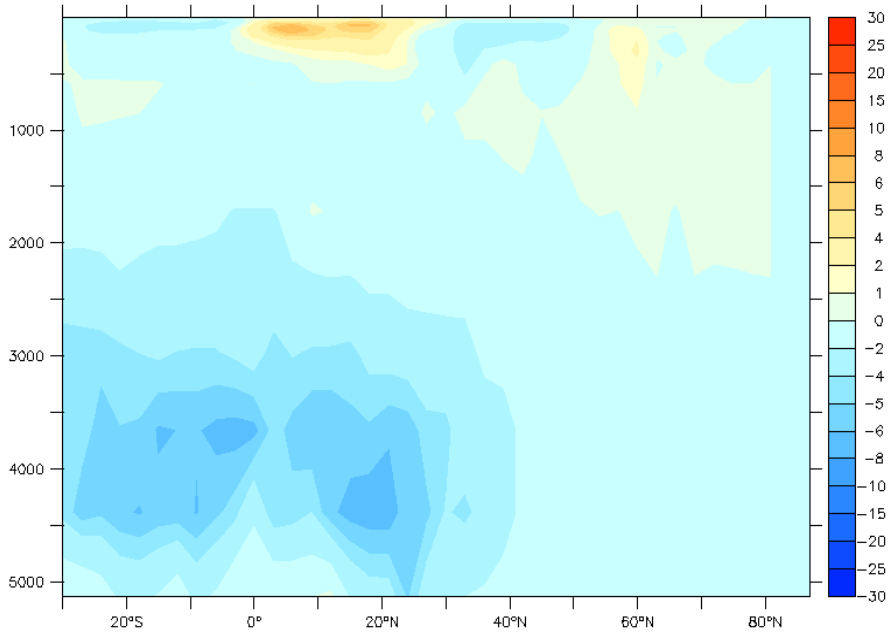
Atlantic meridional overturning streamfunction



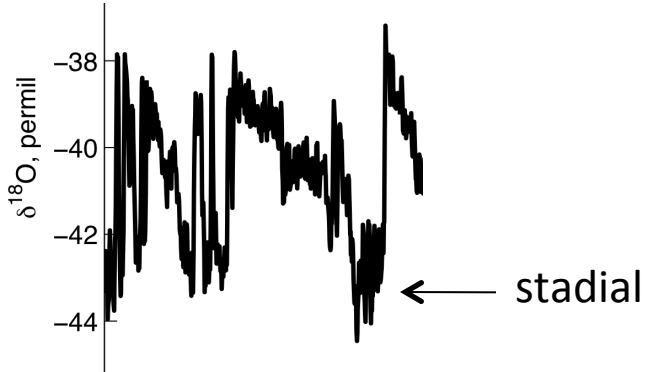
Dansgaard-Oeschger / Heinrich variability

Heinrich Stadial (cold): weak North Atlantic Deep Water

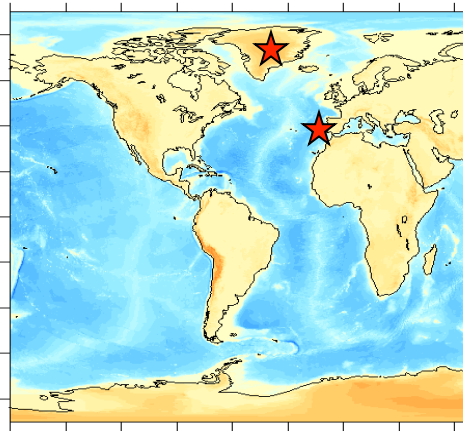




Atlantic meridional overturning streamfunction

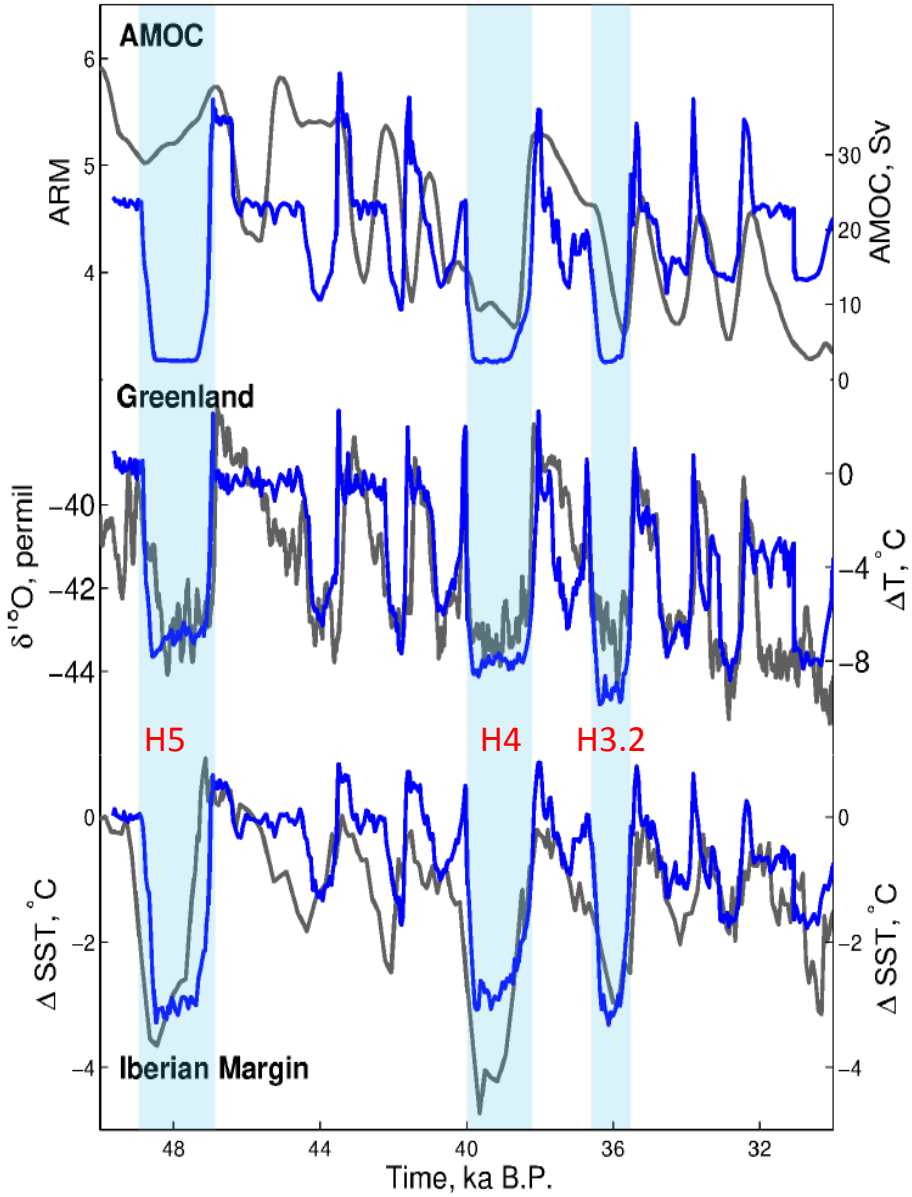


Dansgaard-Oeschger / Heinrich variability



Greenland

Iberian margin



cold

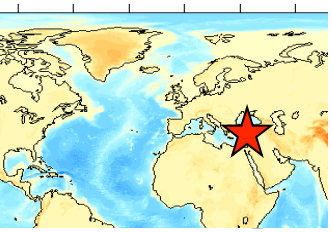
cold

Model

Proxy

Menviel *et al.*, 2014

Glacial hydroclimate variability in Southern Europe



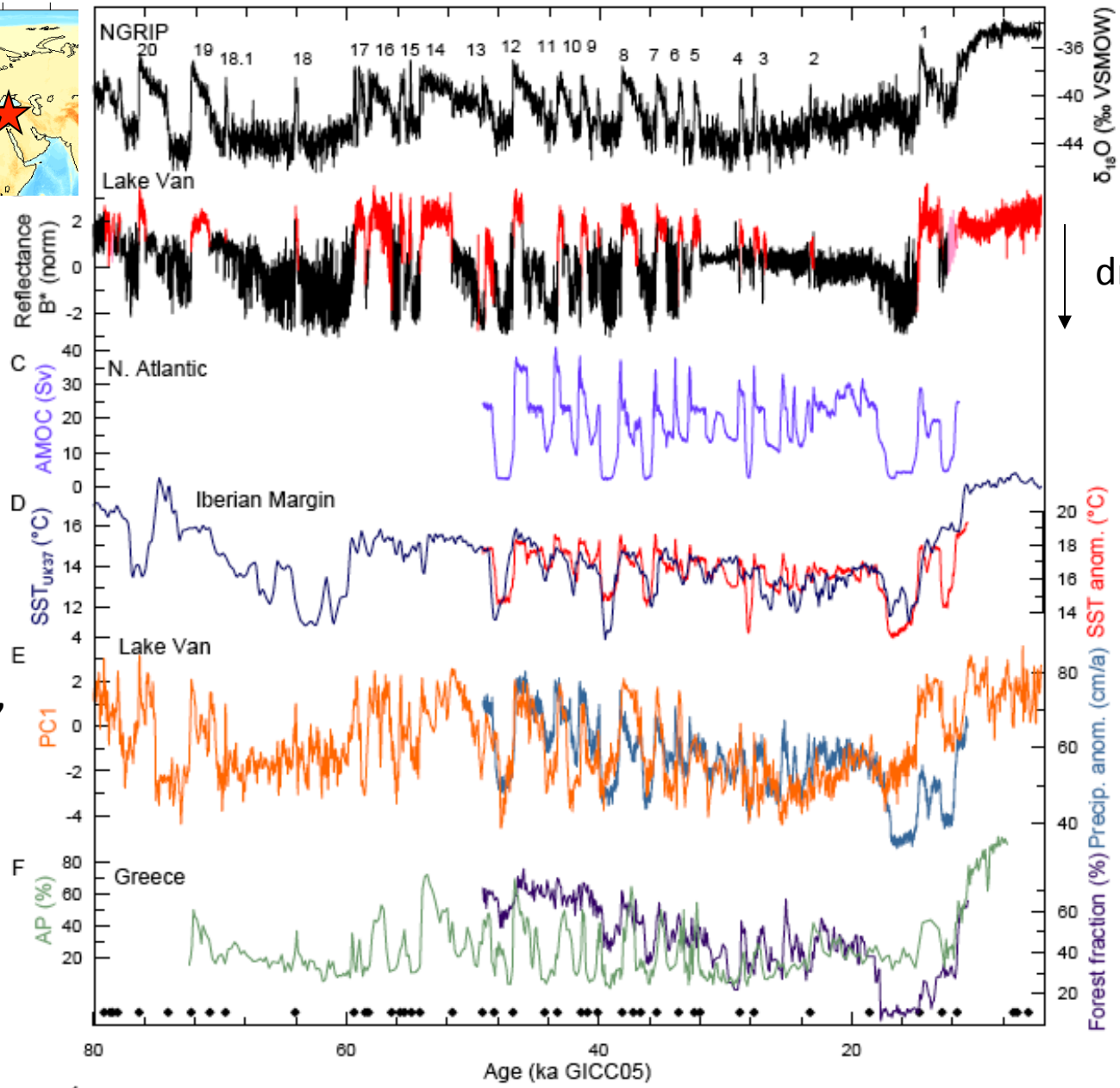
Lake Van, Turkey

AMOC

Iberian margin

Lake Van, Turkey

Greece



Greenland

cold

dry

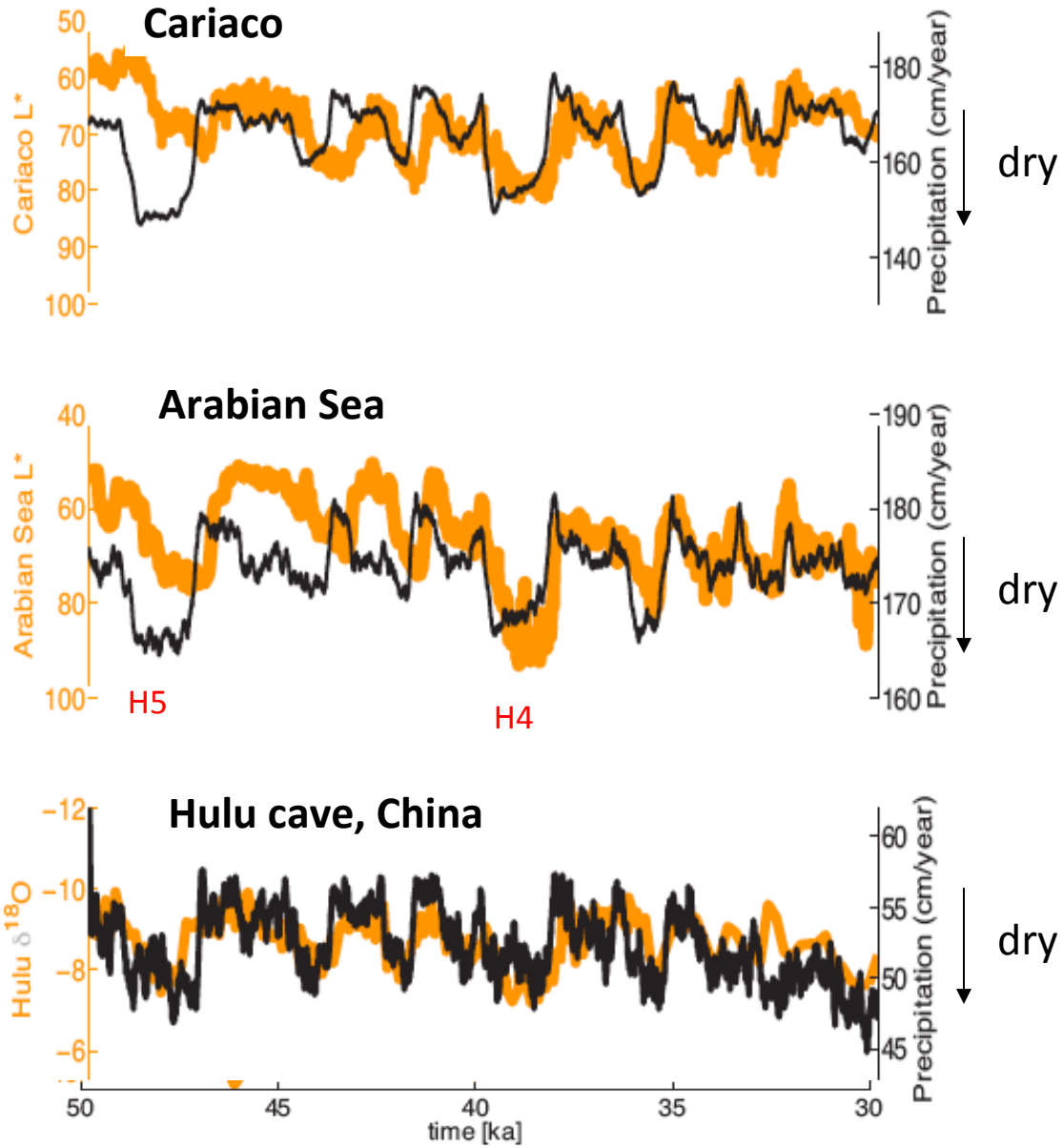
cold

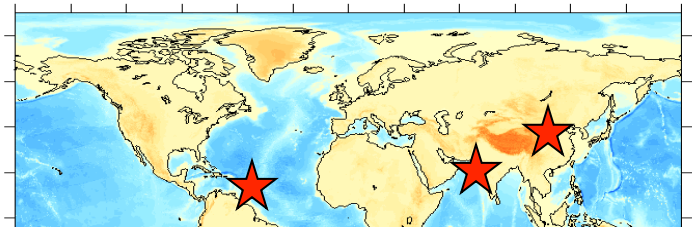
dry

dry

Stockhecke et al., 2016

Dansgaard-Oeschger / Heinrich variability





Weak AMOC leads to dry conditions in the Northern tropics and mid-latitude

Model

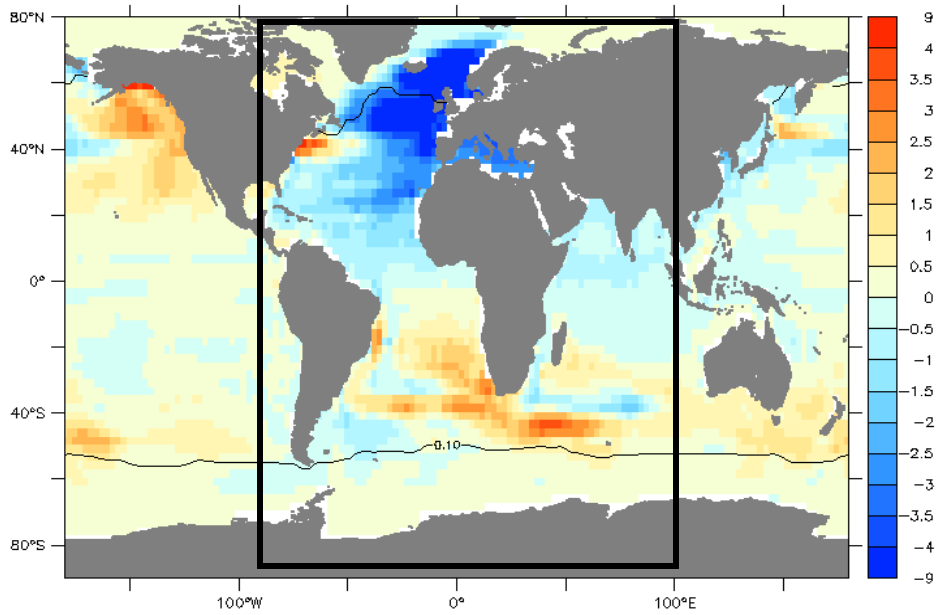
Proxy

Menviel *et al.*, 2014

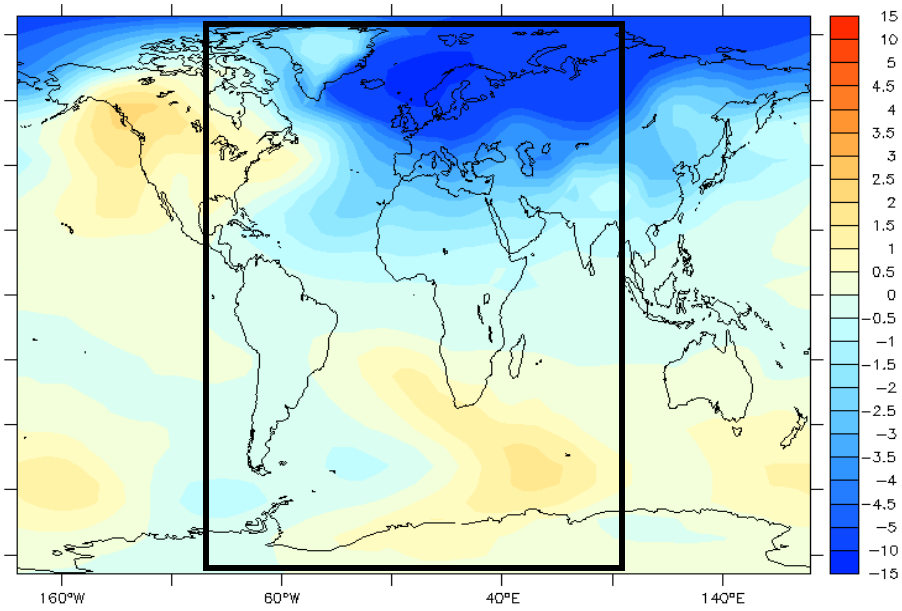
Heinrich Events / AMOC Shutdown
Climate Response

Climate anomalies AMOC off – AMOC on

SST anomalies (°C)



Air temperature (°C) anomalies

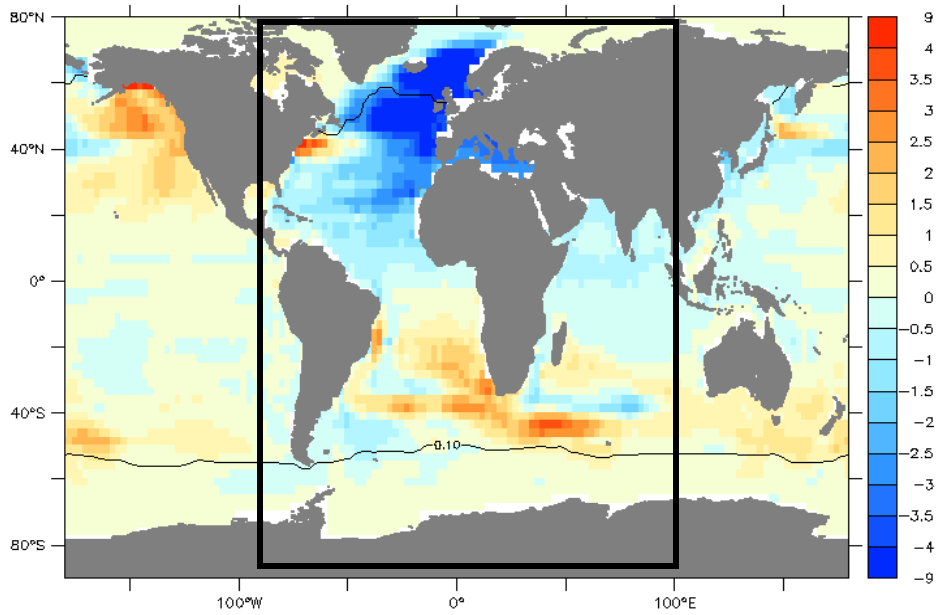


LOVECLIM – LGM boundary conditions

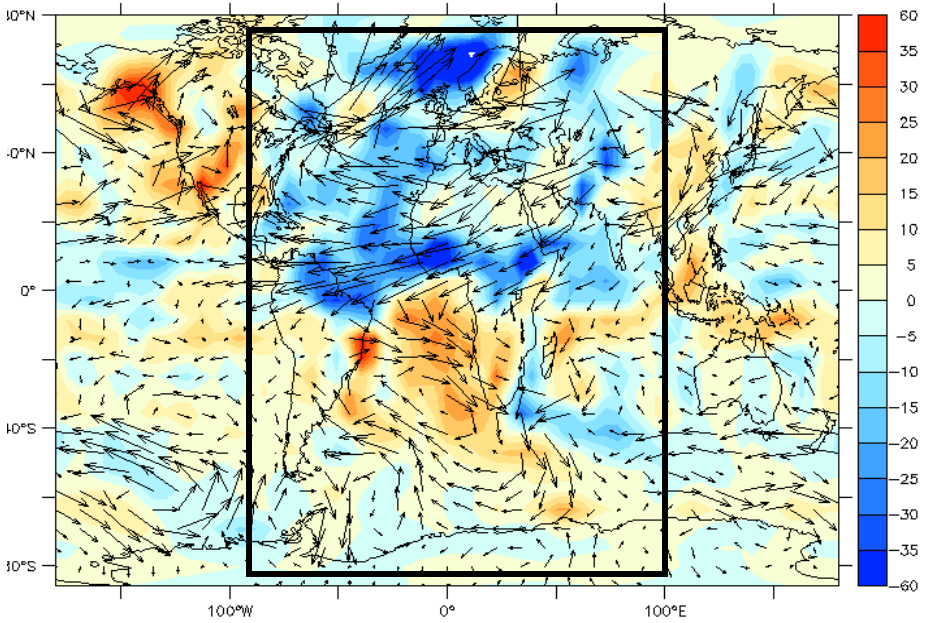
Heinrich Events / AMOC Shutdown
Climate Response

Climate anomalies AMOC off – AMOC on

SST anomalies (°C)



Precipitation (cm/yr) and wind anomalies



LOVECLIM – LGM boundary conditions

- Southward shift of the Inter Tropical Convergence Zone
- Bipolar seesaw pattern

(e.g. Stouffer et al. 2006, Kageyama *et al.*, 2013)

Dansgaard-Oeschger / Heinrich variability

NADW weakening

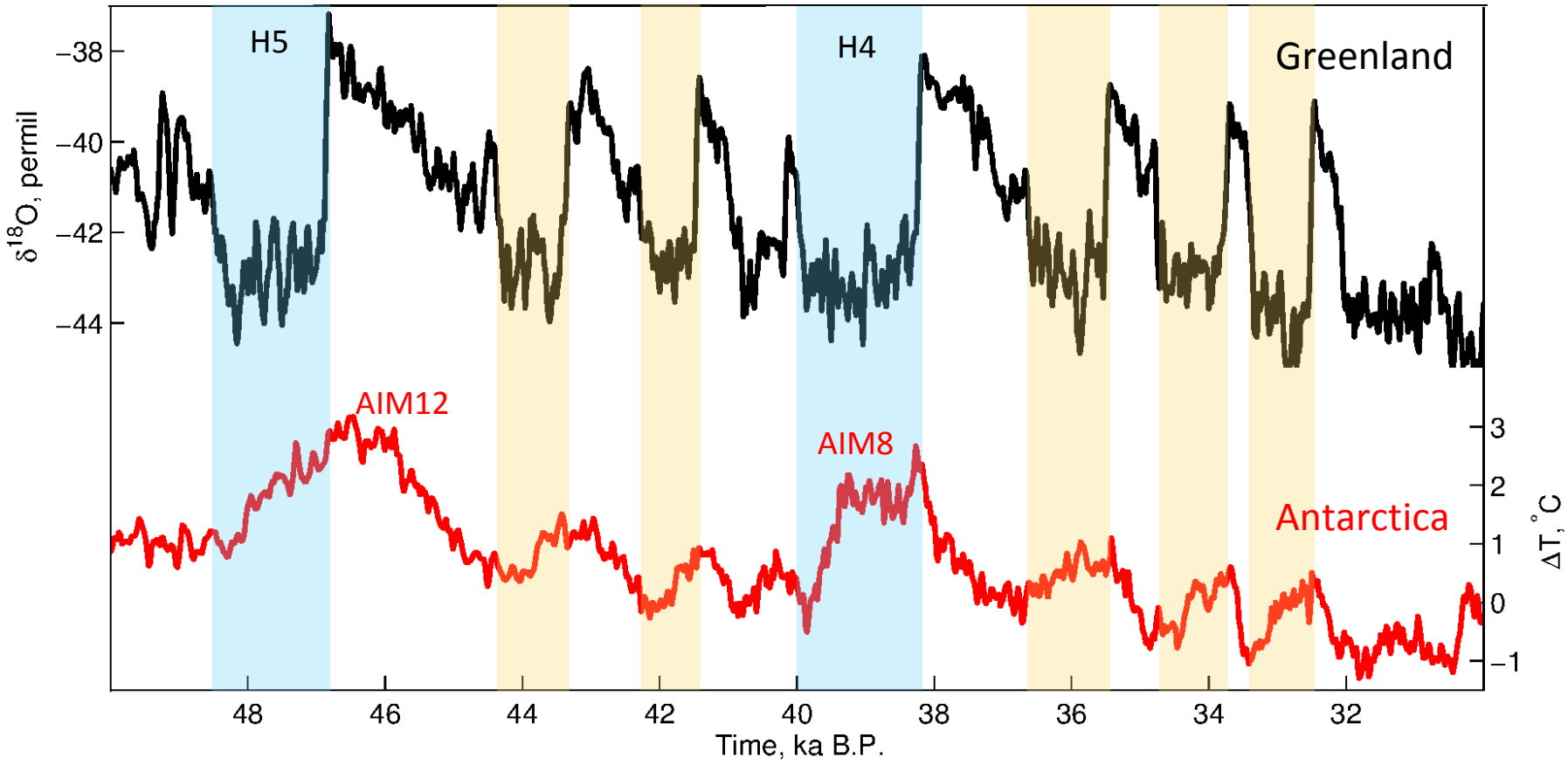
↓

Cold conditions in the North Atlantic region
Warmer conditions in the South Atlantic

↓

Southward shift of the ITCZ
Dry in northern tropics/wet in southern tropics

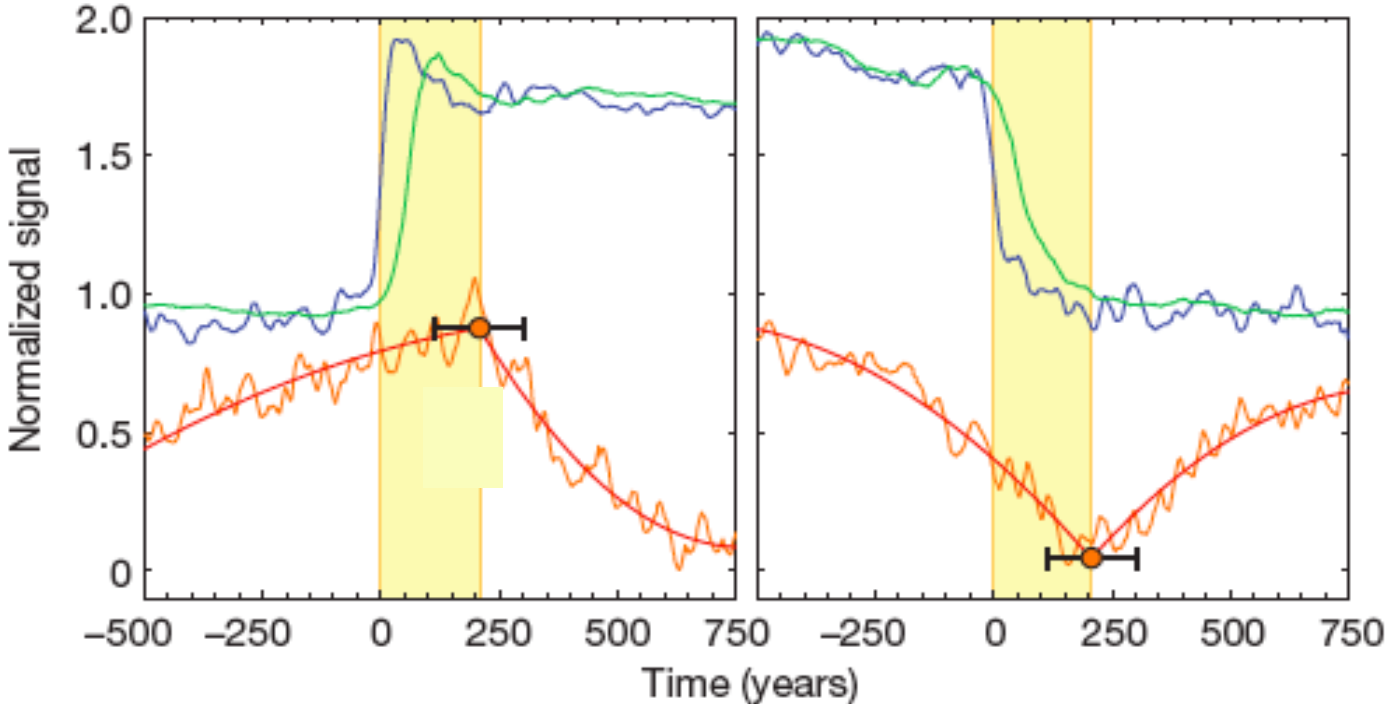
Dansgaard-Oeschger / Heinrich variability
Antarctic records



NGRIP $\delta^{18}O$ on GICC05
EDC Temp. (Jouzel et al. 2007) on AICC2012

Dansgaard-Oeschger / Heinrich variability

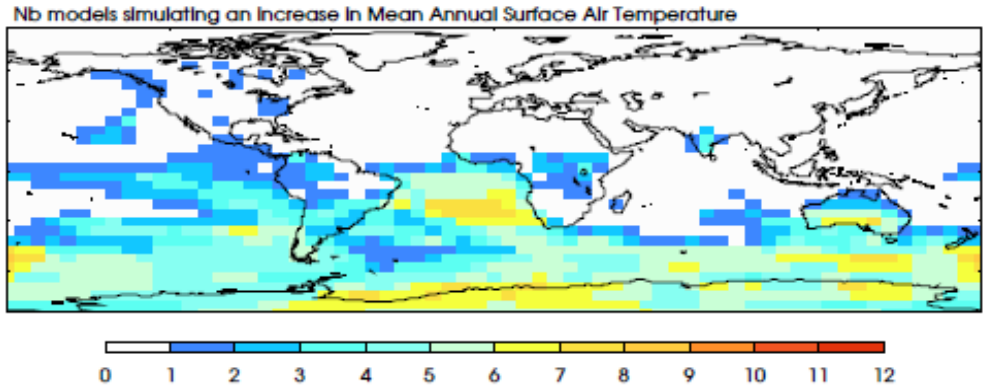
Greenland and Antarctic Temperatures
WAIS (2015) and NGRIP (2004)



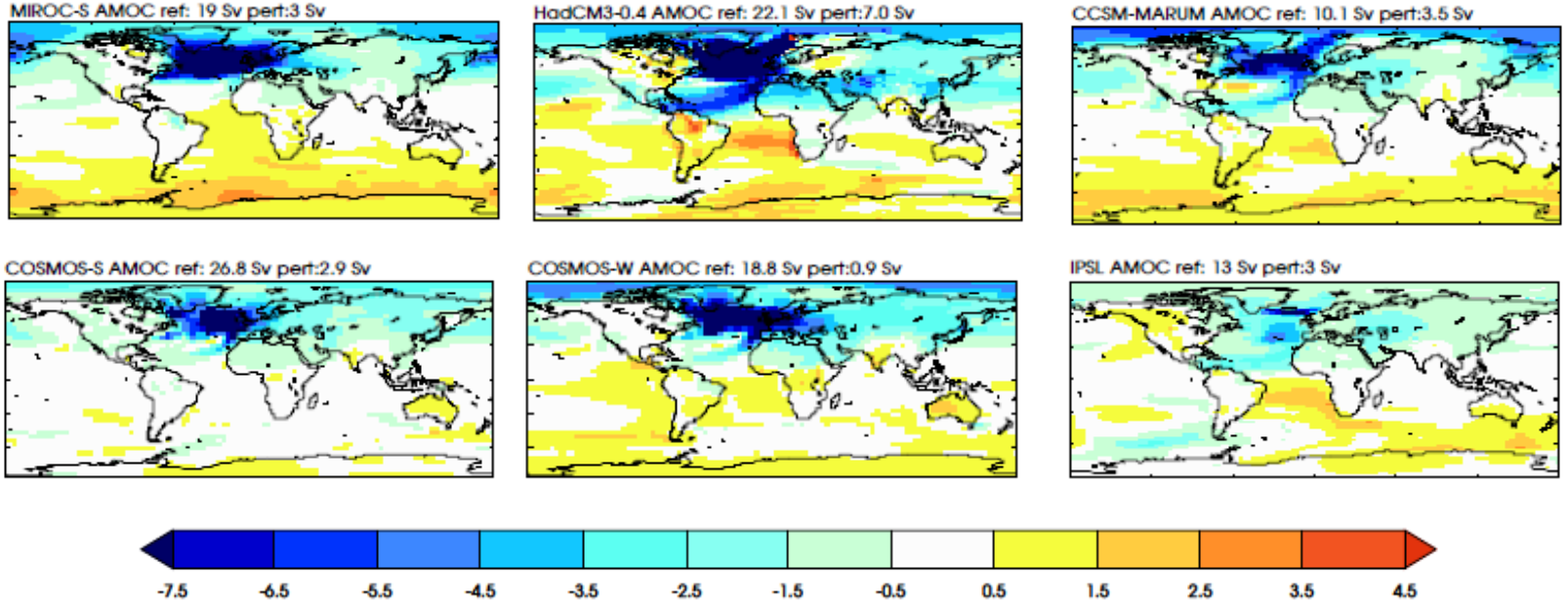
Greenland: +8ºC in <50 years

CH_4
Greenland Temp
Antarctic Temp

Dansgaard-Oeschger / Heinrich variability
Bipolar seesaw



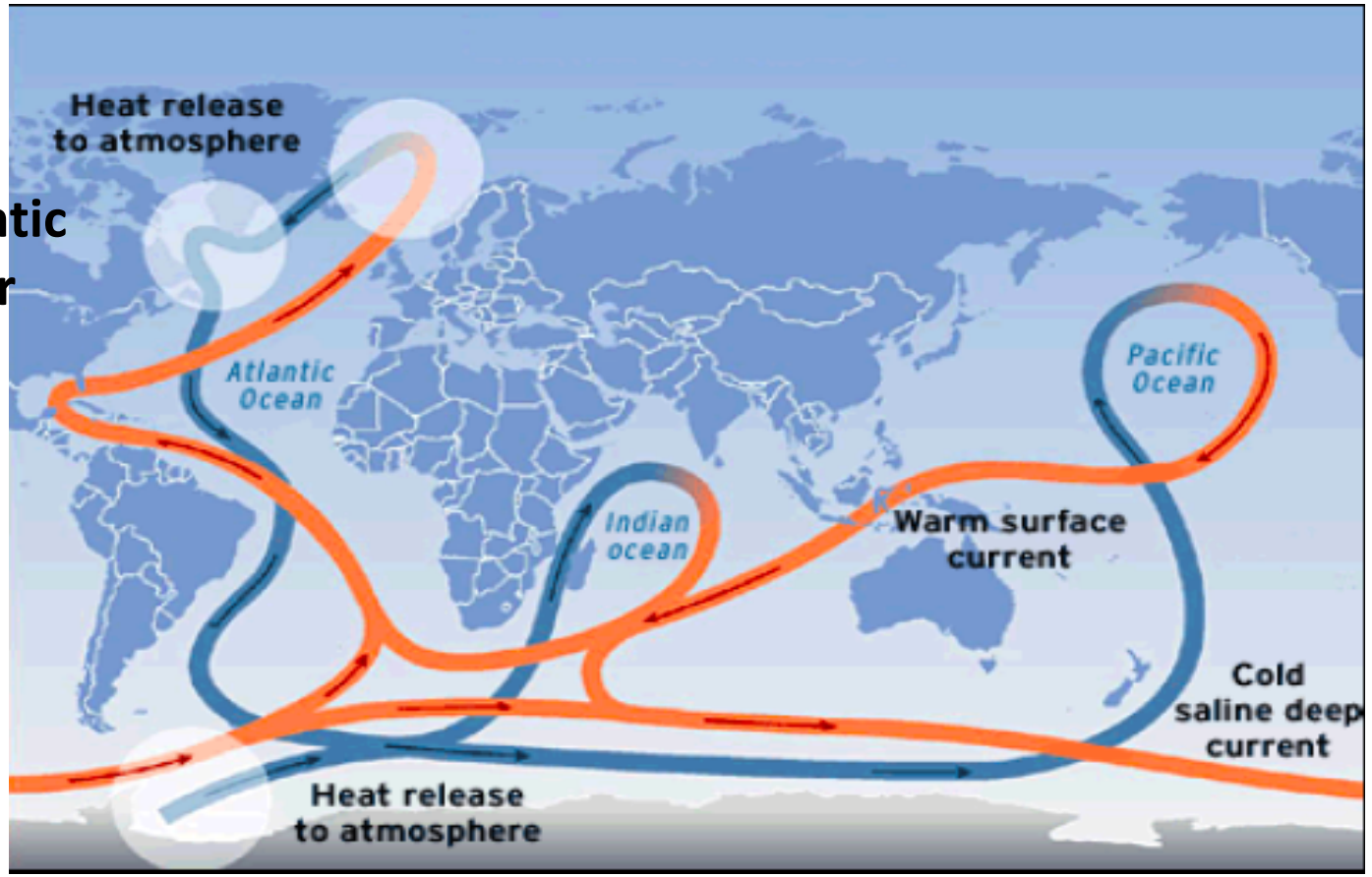
Δ Air temperature (°C)



Kageyama et al. 2012

Oceanic circulation

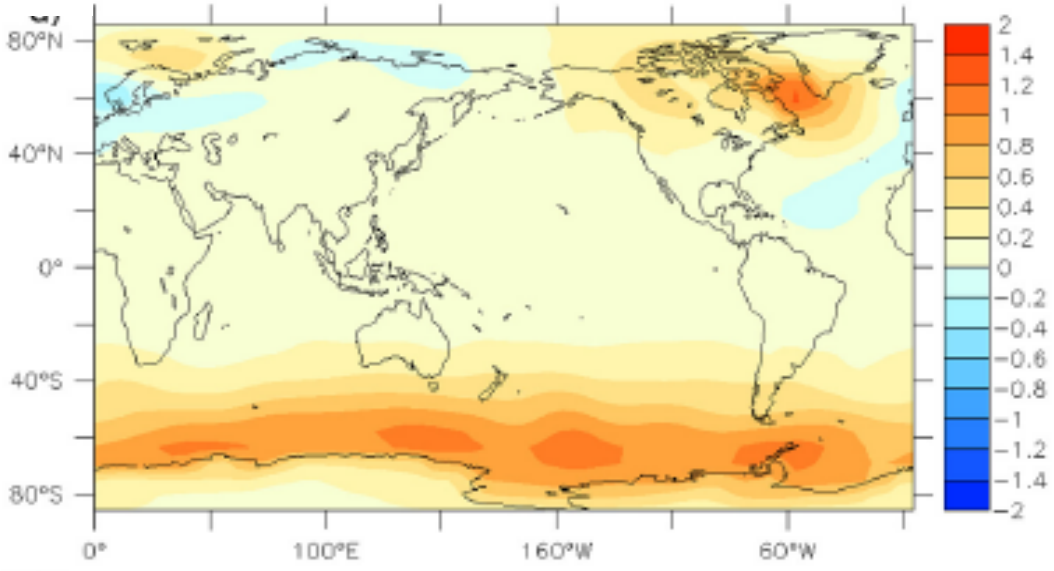
North Atlantic Deep Water



Antarctic BottomWater

Impact of enhanced AABW on climate

Air temperature anomalies

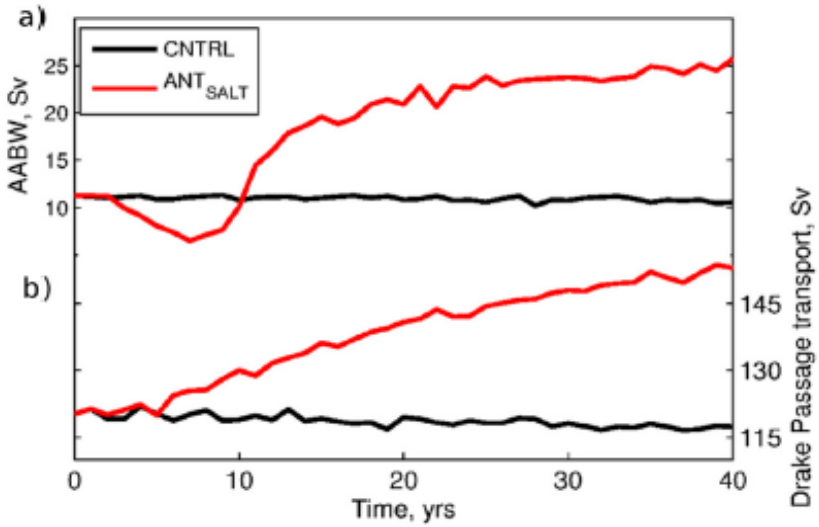


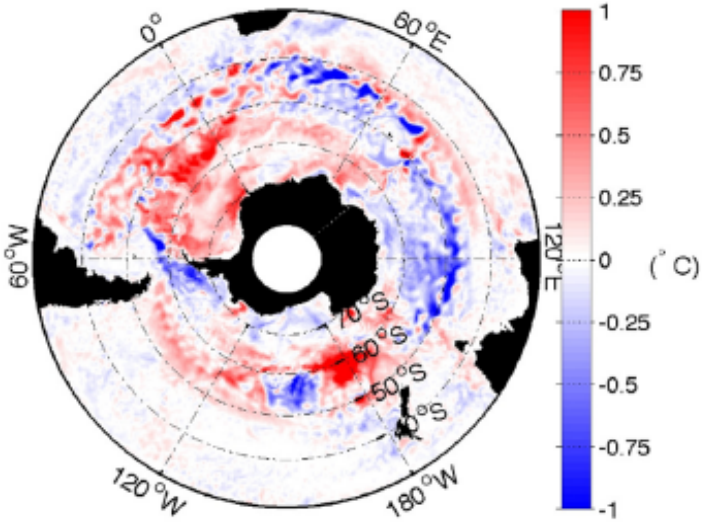
AABW strengthening

Enhanced AABW leads to stronger oceanic meridional heat transport to high southern latitudes

Menviel et al., 2015

Enhanced AABW in MOM5 (0.25° resolution, 50 levels)





SST anomalies (yrs 31-40)

SSS increased by 5 psu close to Antarctic coast in MOM5
→ AABW strengthen
→ SST increase due to enhanced meridional heat transport

Menviel et al., 2015

Dansgaard-Oeschger / Heinrich variability

NADW weakening

↓

Cold conditions in the North Atlantic region
Warmer conditions in the South Atlantic

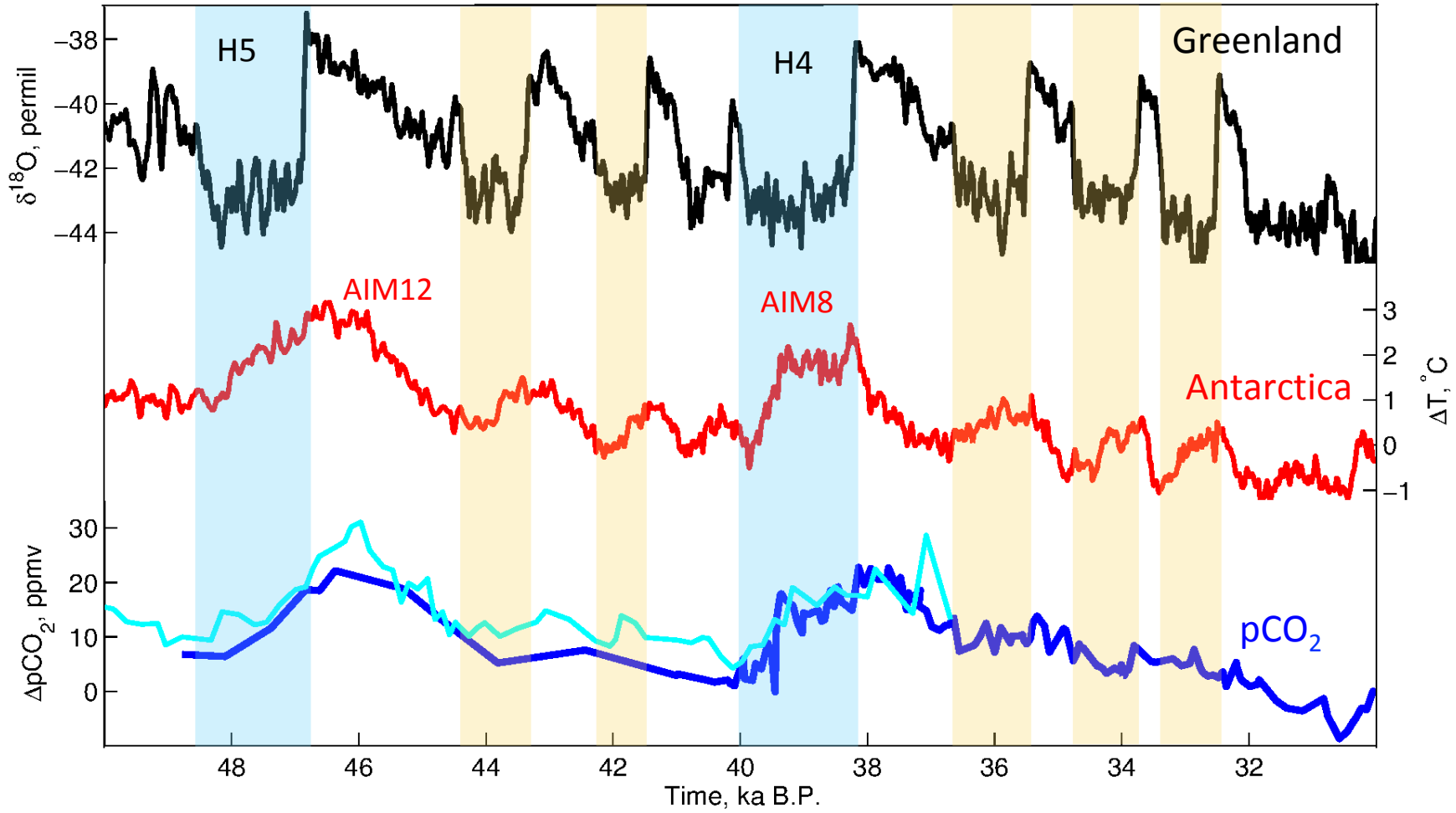
↓

Southward shift of the ITCZ
Dry in northern tropics/wet in southern tropics

↓

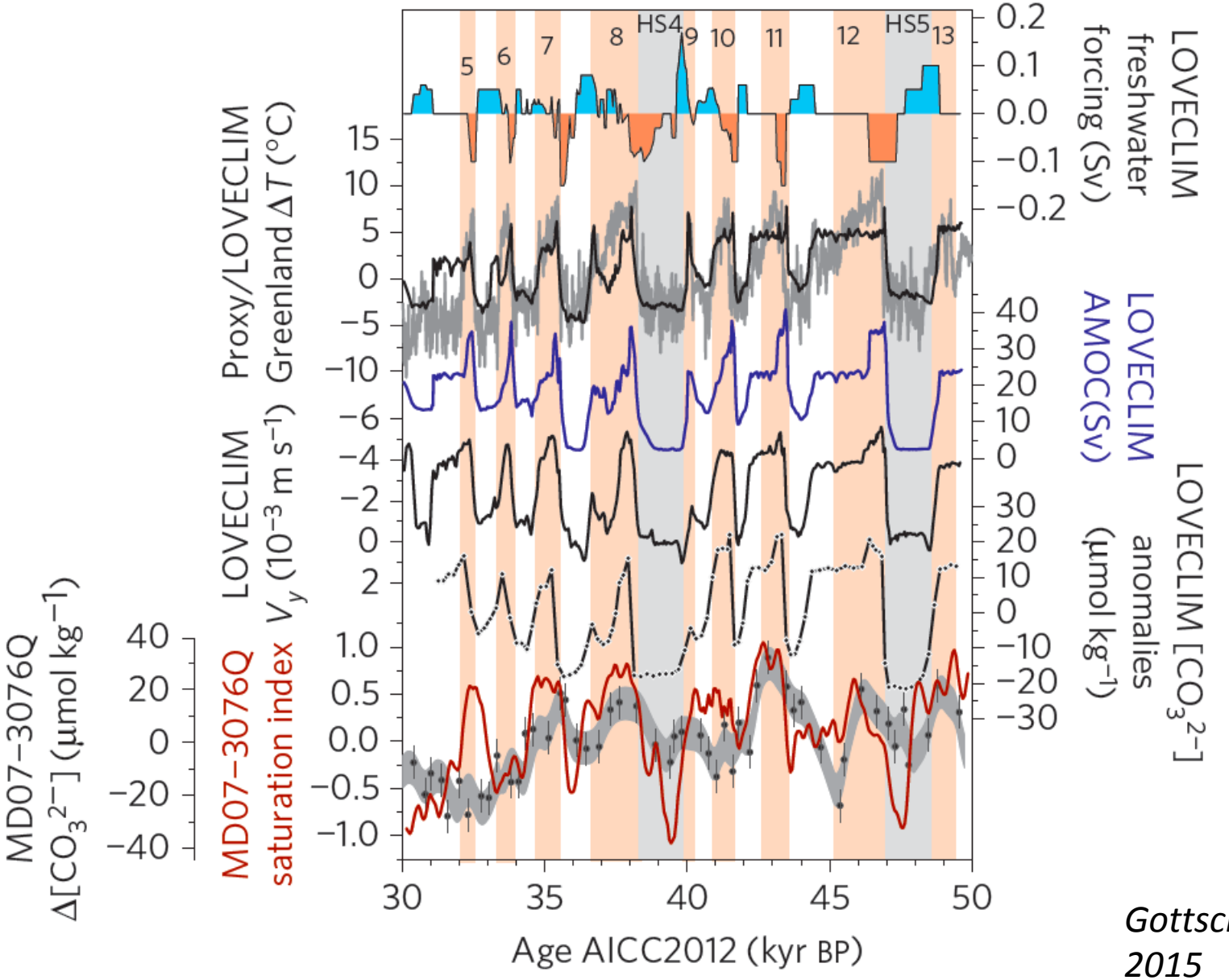
Atm. (winds) Or oceanic teleconnections
AABW strengthening
Warmer conditions at high southern latitudes

Dansgaard-Oeschger / Heinrich variability
Antarctic records



NGRIP $\delta^{18}O$ on GICC05
EDC Temp. (Jouzel et al. 2007) on AICC2012
EDML & Talos ice core pCO_2 (Bereiter et al. 2012)
Siple Dome ice core pCO_2 (Ahn and Brook 2014)

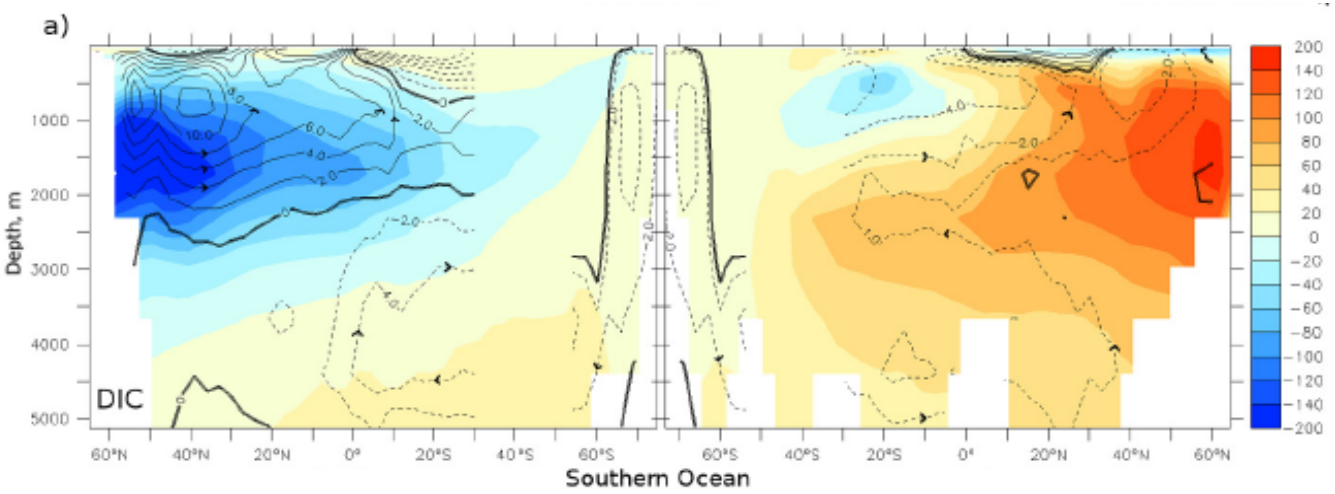
Glacial deep Atlantic carbonate ions variability



Gottschalk et al., 2015

Impact of enhanced AABW on pCO_2 and oceanic carbon

DIC anomalies (µmol/L): AMOC off-AMOC on
Weak AABW

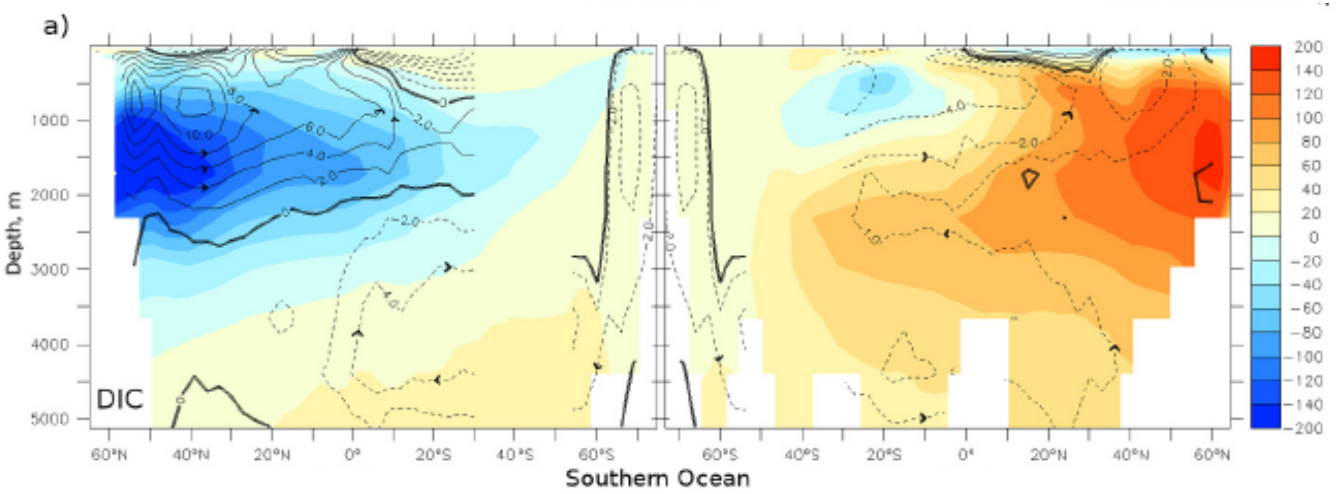


Pacific **Atlantic**

Impact of enhanced AABW on pCO_2 and oceanic carbon

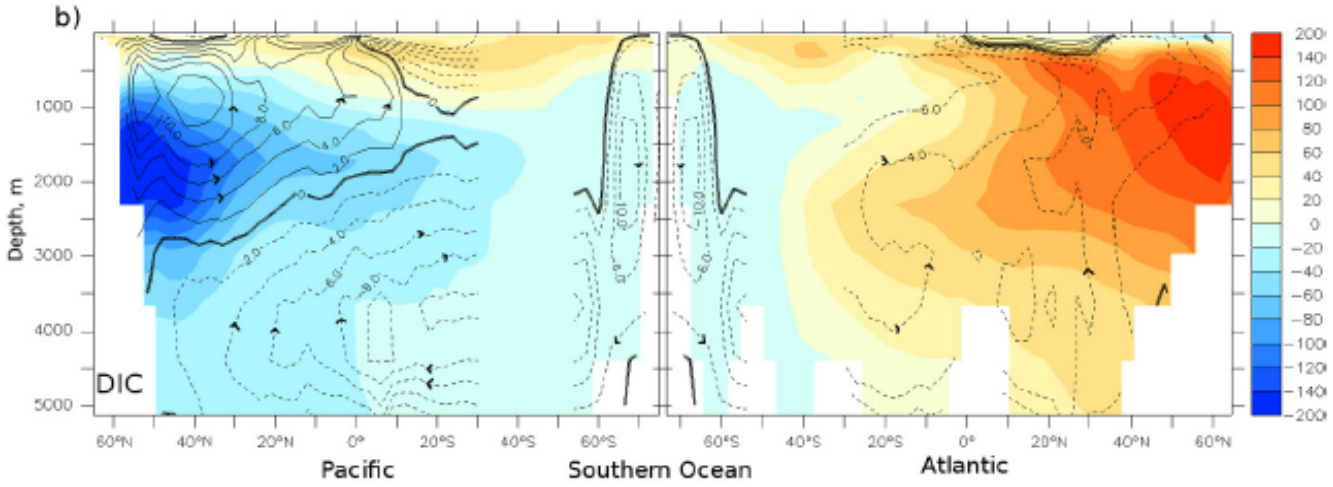
DIC anomalies (µmol/L): AMOC off-AMOC on

Weak AABW



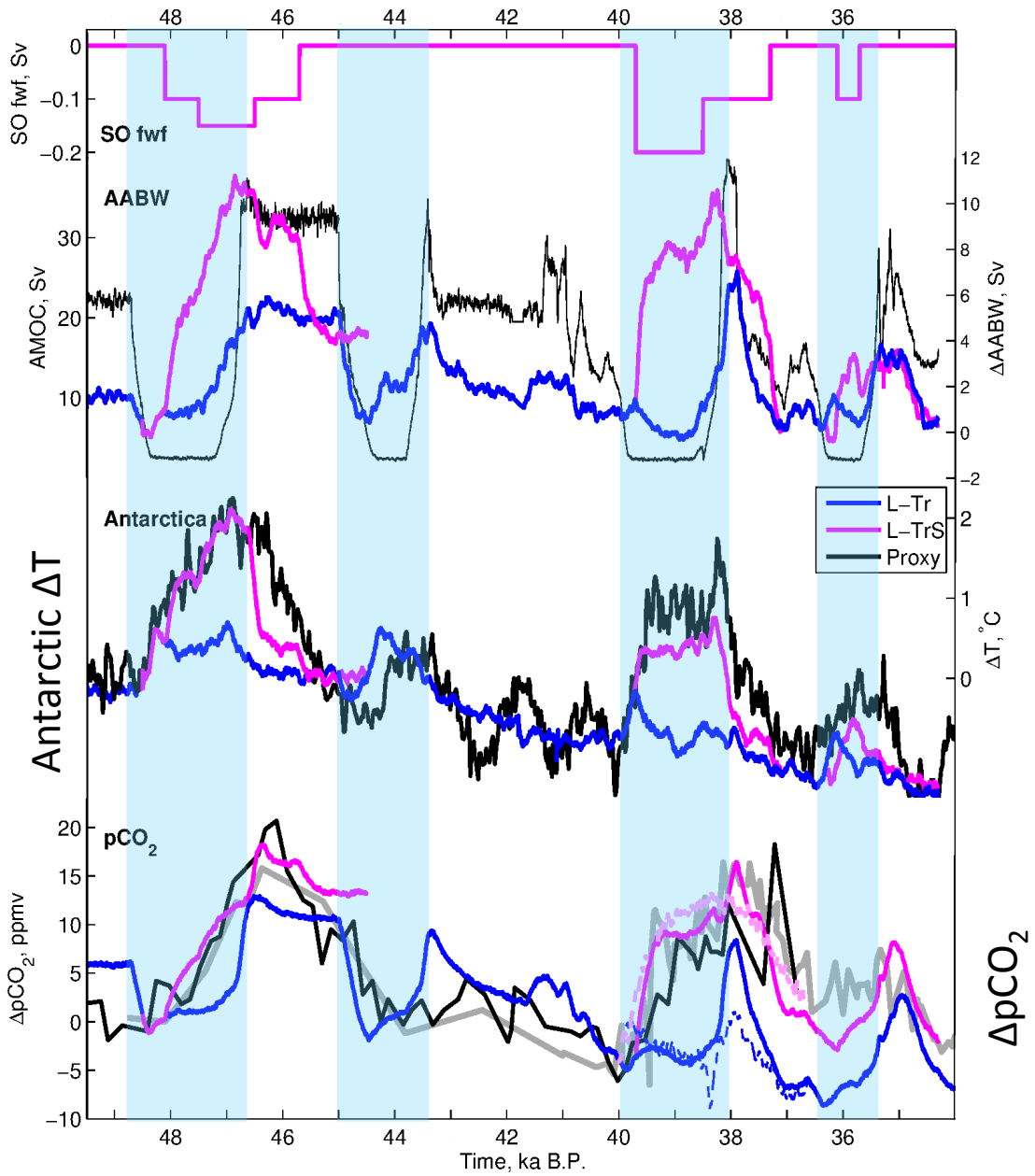
Pacific **Atlantic**

Strong AABW



Menviel et al., (2014)

Transient simulations of MIS3
Impact of enhanced AABW on pCO_2



LOVECLIM experiments

Strong AABW enhances the warming over Antarctica and leads to pCO_2 increase

Standard exp.
Exp. With enhanced AABW
Proxy

Dansgaard-Oeschger / Heinrich variability

NADW weakening

↓

Cold conditions in the North Atlantic region
Warmer conditions in the South Atlantic

↓

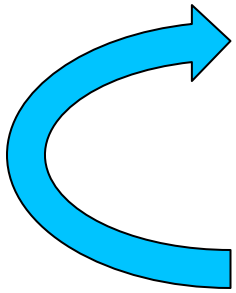
Southward shift of the ITCZ
Dry in northern tropics/wet in southern tropics

↓

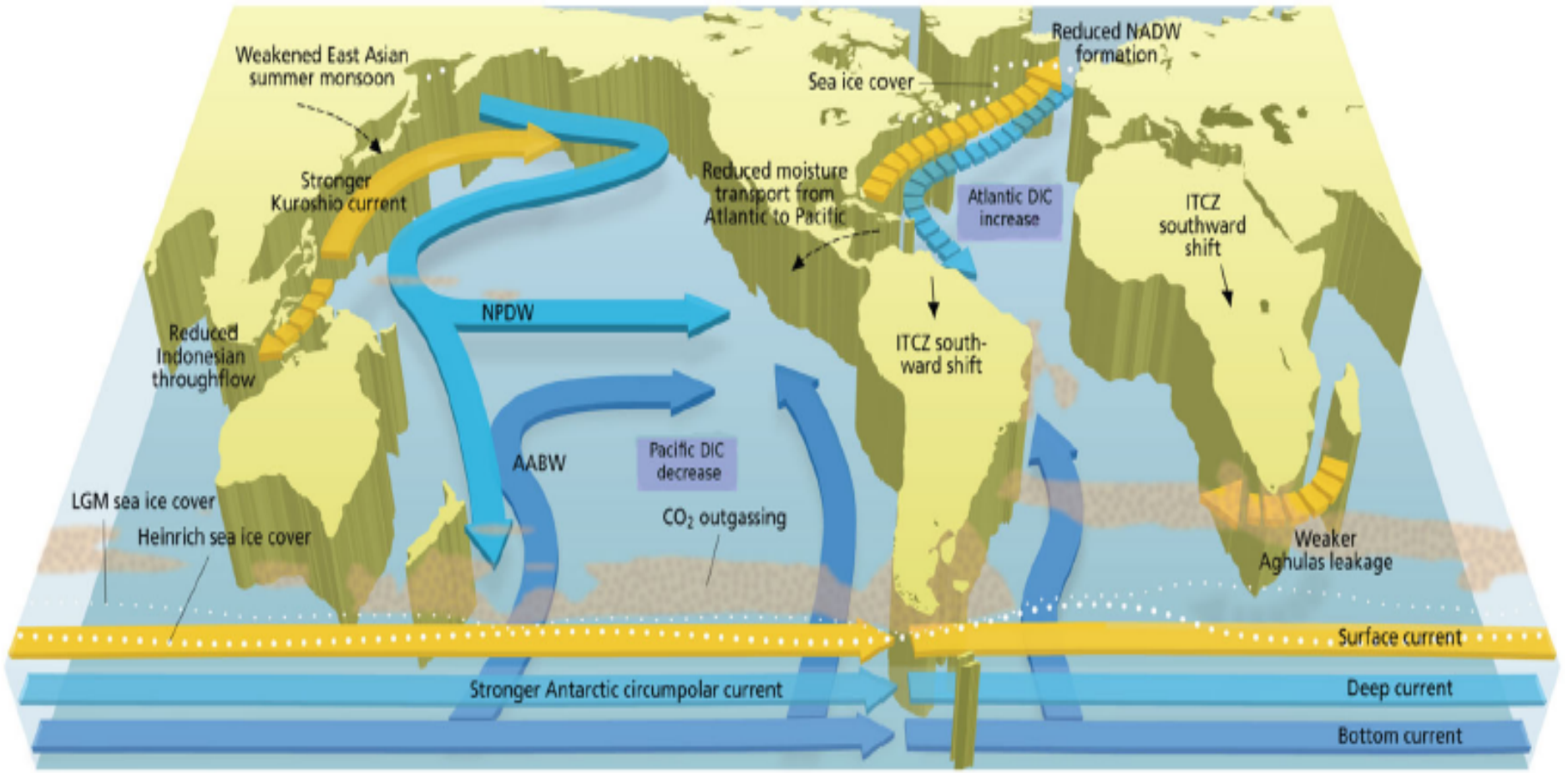
Atm. (winds) Or oceanic teleconnections
AABW strengthening
Warmer conditions at high southern latitudes

↓

Atm. CO2 increase



Millennial-scale variability last glacial period



Menviel et al. 2014

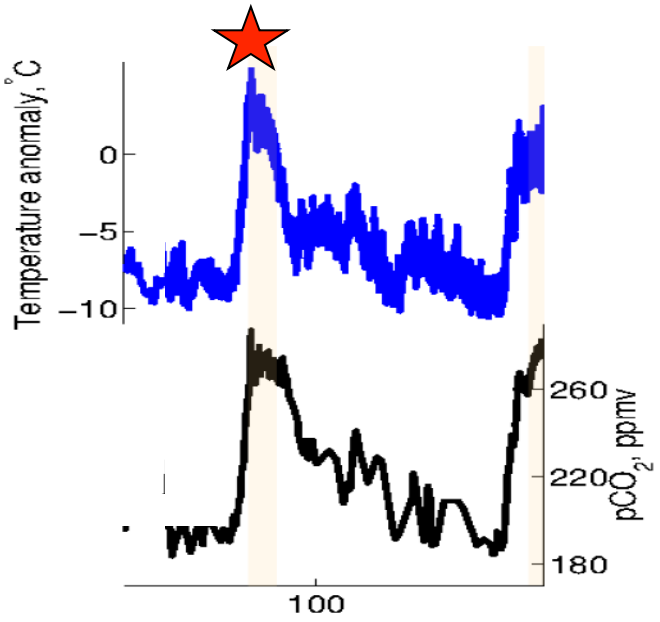
Glacial Dansgaard/Oeschger and Heinrich variability

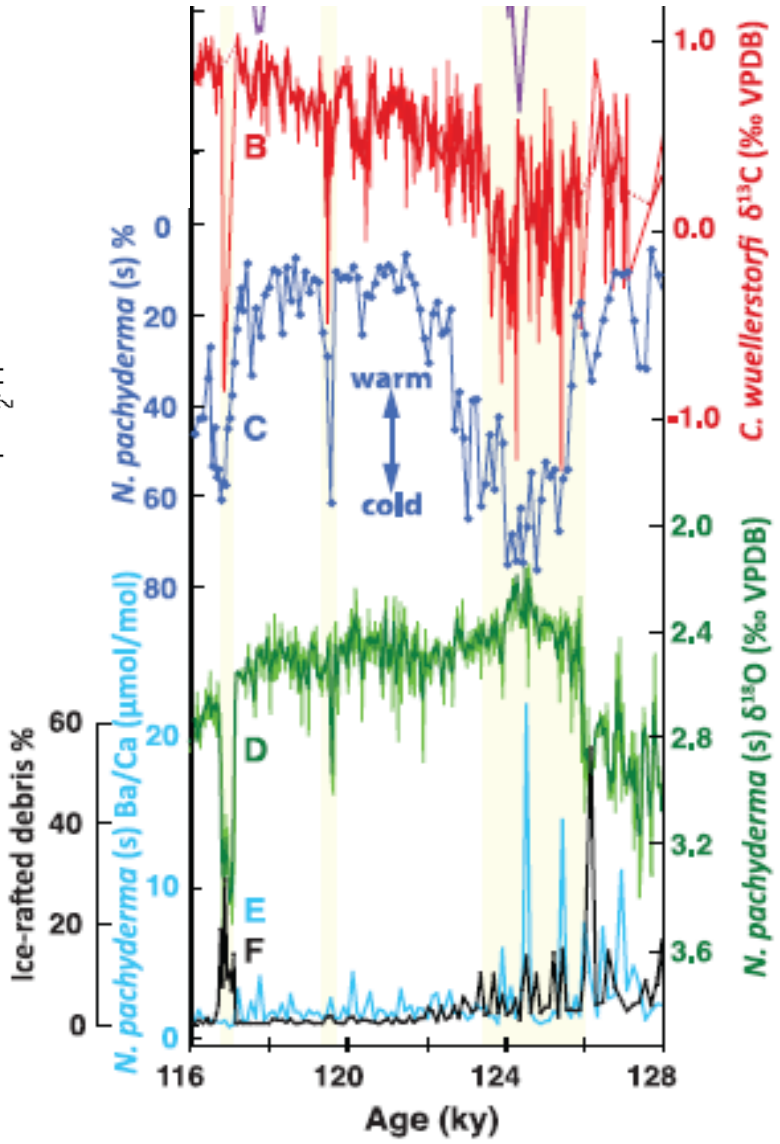
Dansgaard/Oeschger and Heinrich variability driven by AMOC variability

But what caused it?
Was there meltwater input into the North Atlantic?

Abrupt events during past warm periods

The Last Interglacial (~125ka)





Weaker ocean ventilation

Cold

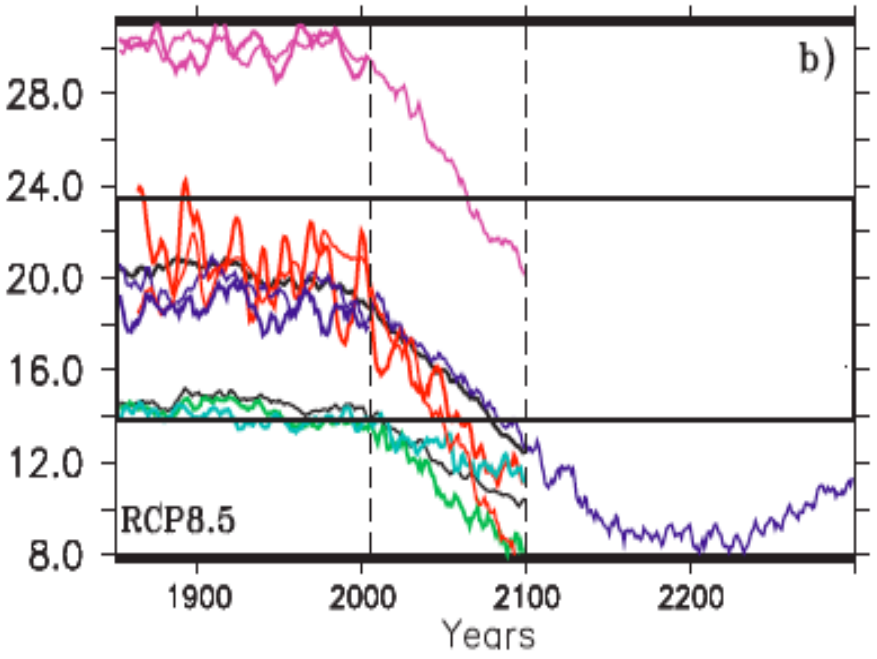
Fresh

Galaasen et al. 2014

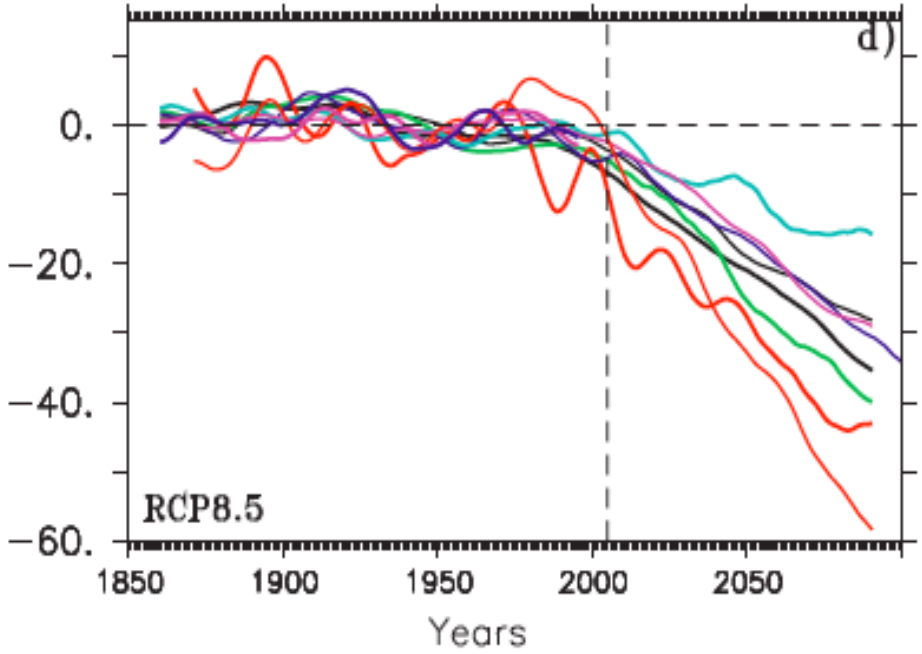
Future changes in NADW

RCP8.5 CMIP5 models

AMOC (Sv)



ΔAMOC (%)



Does not take into account changes in ice-sheets mass balance

Cheng et al., 2013

Conclusions

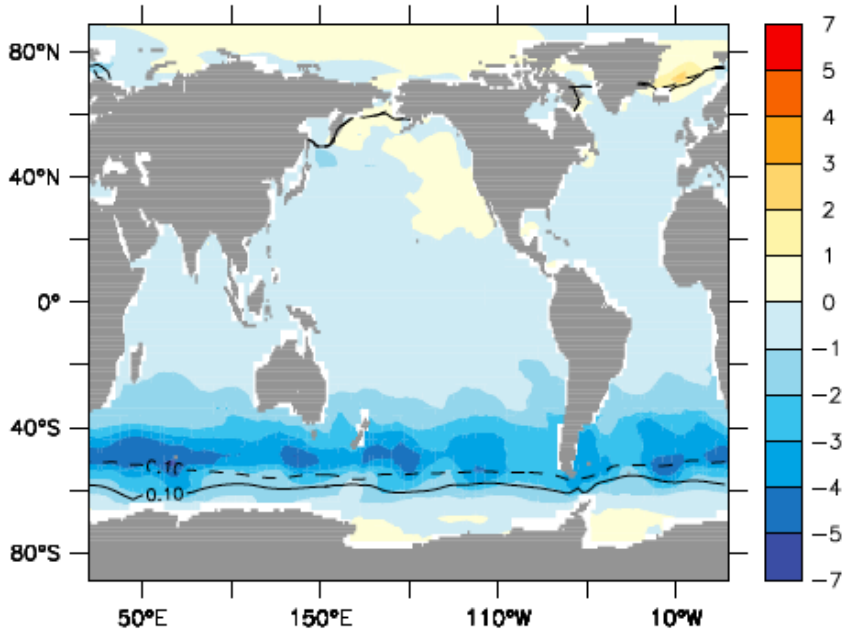
- Past records indicate periods of abrupt climate change (<100 yrs)
- Driven by AMOC variability
- Global climate/carbon cycle impact

- Evidence of such events during warm periods
- AMOC decrease likely in 21st century

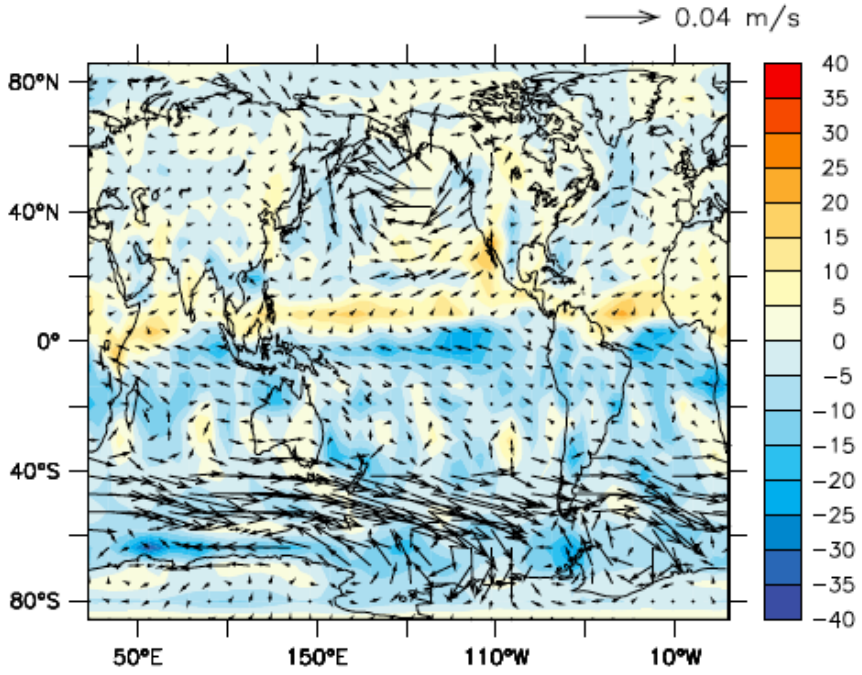
- Disintegrating Greenland and Antarctic ice-sheet might further disrupt oceanic circulation

Sensitivity studies

Impact of Antarctic ice-sheet melting



SST anomalies & sea-ice

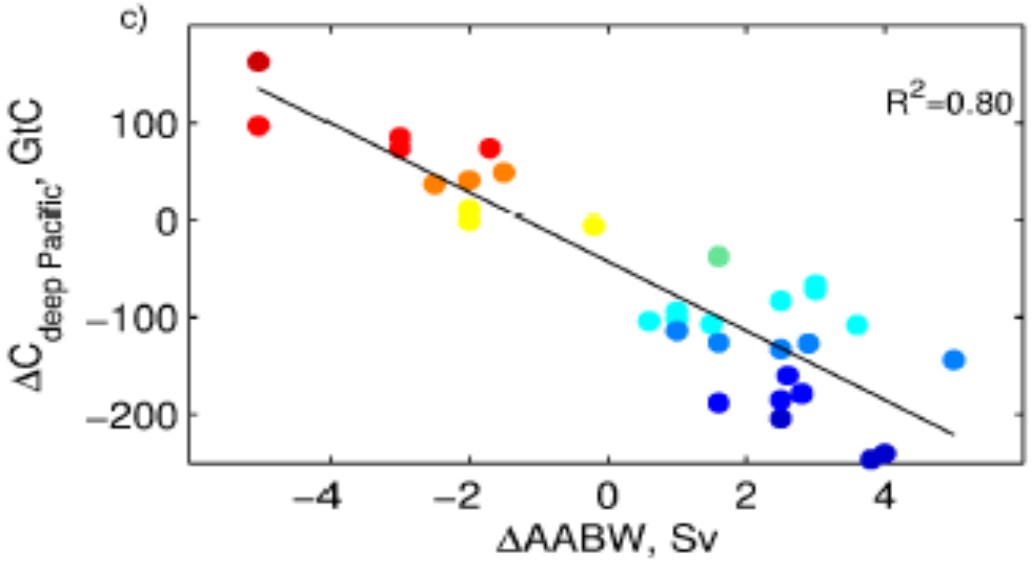


Precipitation (cm/yr) &
wind stress anomalies

Menviel et al., 2010

ΔDeep Pacific C vs ΔAABW

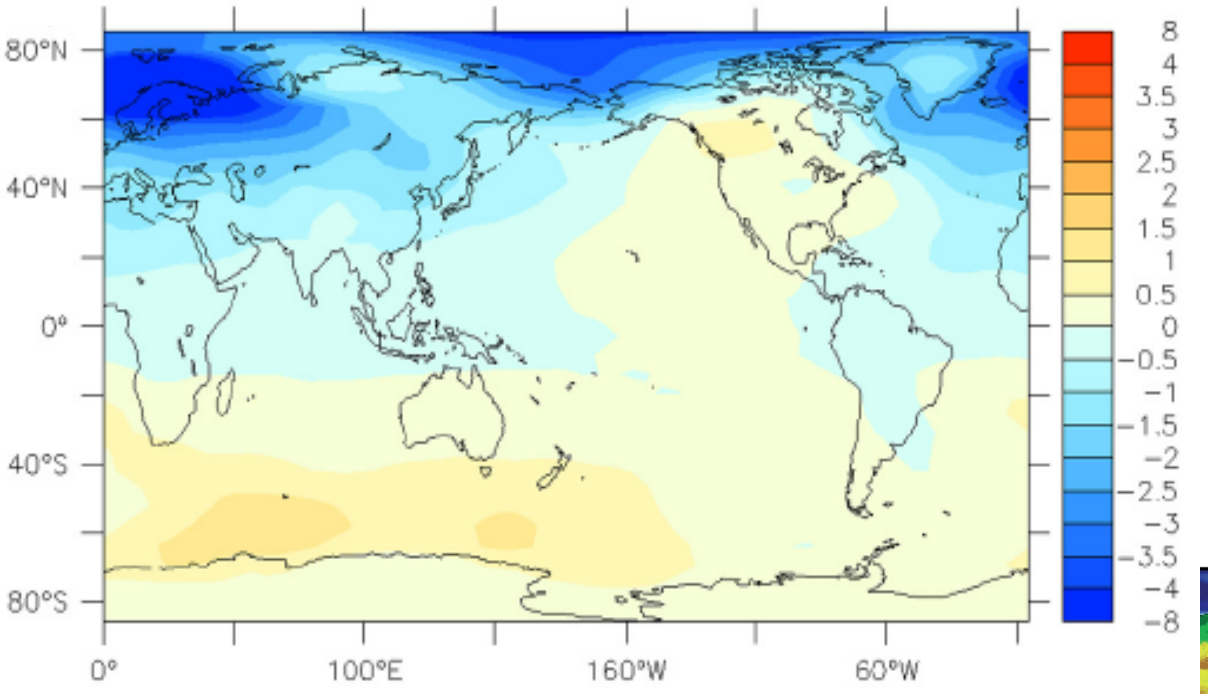
Deep Pacific carbon release as a function of changes in Antarctic Bottom Water



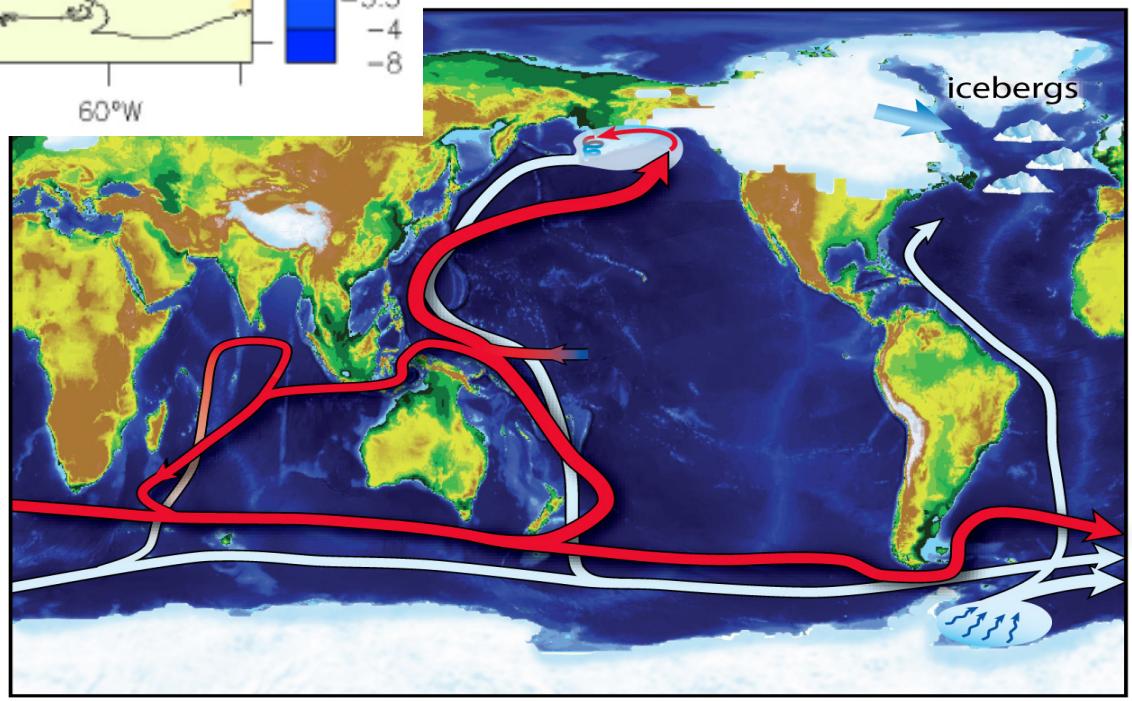
32 idealized meltwater experiments performed with LOVECLIM and the UVic ESCM
(Menviel et al. 2014, Pa)

The stronger the AABW the more C is released from the deep Pacific through the Southern Ocean

Dansgaard-Oeschger / Heinrich variability



Air temp. anomalies (°C)



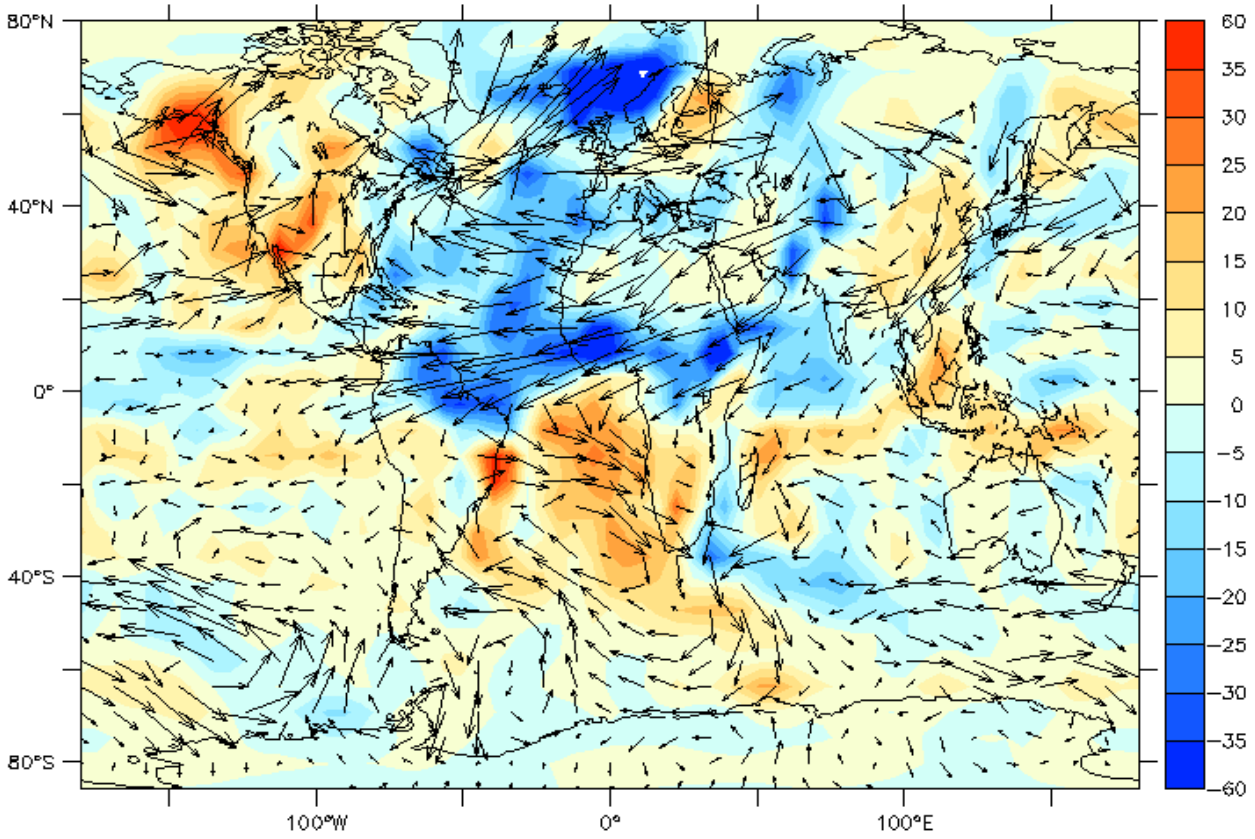
Timmermann, 2010

IPRC Press Release

Heinrich Events / AMOC Shutdown
Climate Response

Climate anomalies AMOC off – AMOC on

Precipitation (cm/yr) and wind anomalies



LOVECLIM – LGM boundary conditions