# Asynchronous warming and $\delta^{18}O$ evolution of deep Atlantic water masses during the last deglaciation

Jiaxu Zhang[a], Zhengyu Liu[a,b], Esther C. Brady[c], Delia W. Oppo[d], Peter U. Clark[e], Alexandra Jahn[f], Shaun A. Marcott[g] & Keith Lindsay[c]

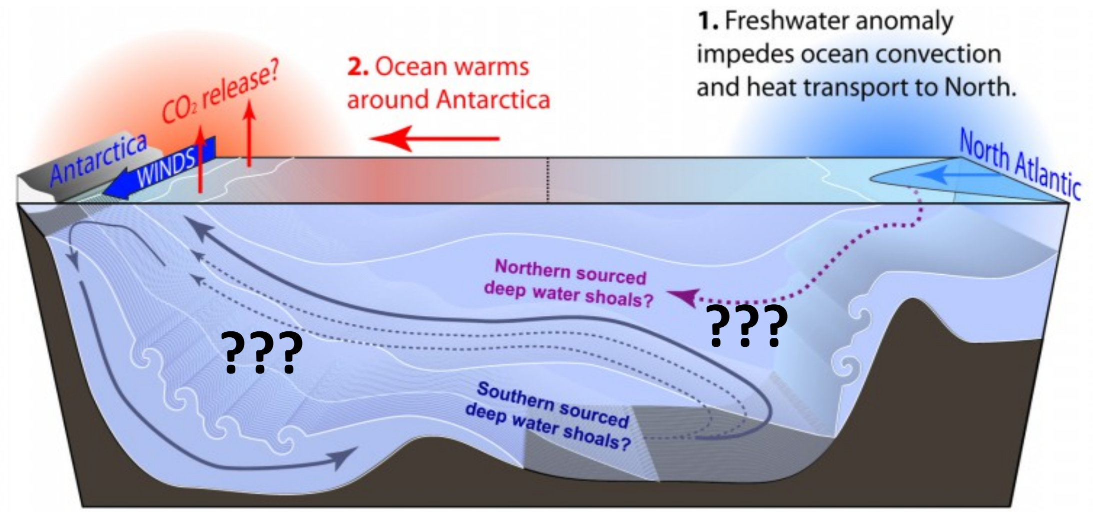
[a] Department of Atmospheric and Oceanic Sciences and Center for Climatic Research, University of Wisconsin-Madison
[b] Climate and Global Dynamics Division, National Center for Atmospheric Research
[c] Atmospheric Science Program, Department of Geography, Ohio State University
[d] Department of Geology and Geophysics, Woods Hole Oceanographic Institution
[e] Department of Geosciences, Oregon State University
[f] Department of Atmospheric and Oceanic Sciences and the Institute of Arctic and Alpine Research, University of Colorado Boulder
[g] Department of Geoscience, University of Wisconsin-Madison

*(Zhang et al., 2017, PNAS)*

Contact: jiaxu@lanl.gov

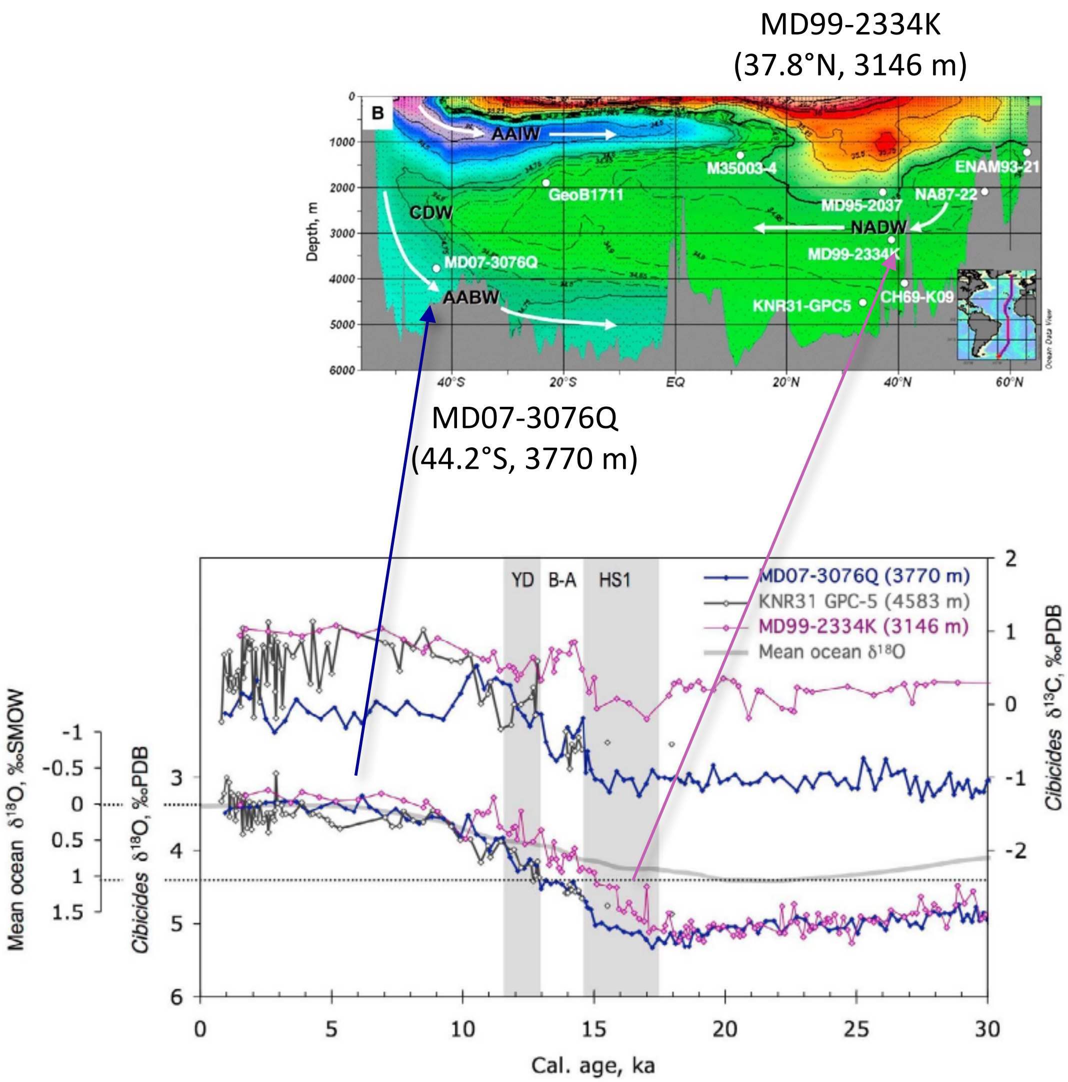
# The last deglaciation (19-11 ka)

- During the last deglaciation, the warming of the Earth was punctuated by a few abrupt cooling and warming events → AMOC changes
- Heinrich Stadial 1 (HS1, ~17.5 ka) event
- ocean surface: bipolar seesaw effect
- deep ocean: circulation? temperature? water masses?
- Why do we care:
  - ❖ Atmospheric $CO_2$ changes
  - ❖ Precondition for the Bølling-Allerød warming event
  - ❖ Assessing model fidelity for future prediction



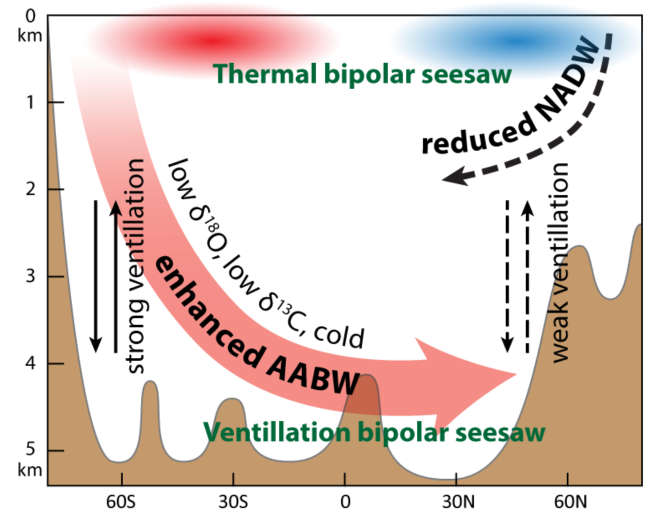

(From Luke Skinner research homepage)

# HS1 $\delta^{18}O$ phasing: Southern- vs. Northern-source hypotheses

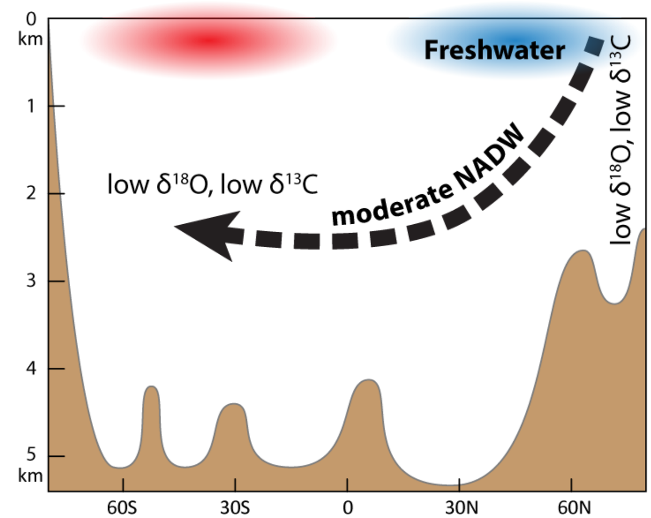



(Waelbroeck et al. 2011)

"Southern-source" hypothesis



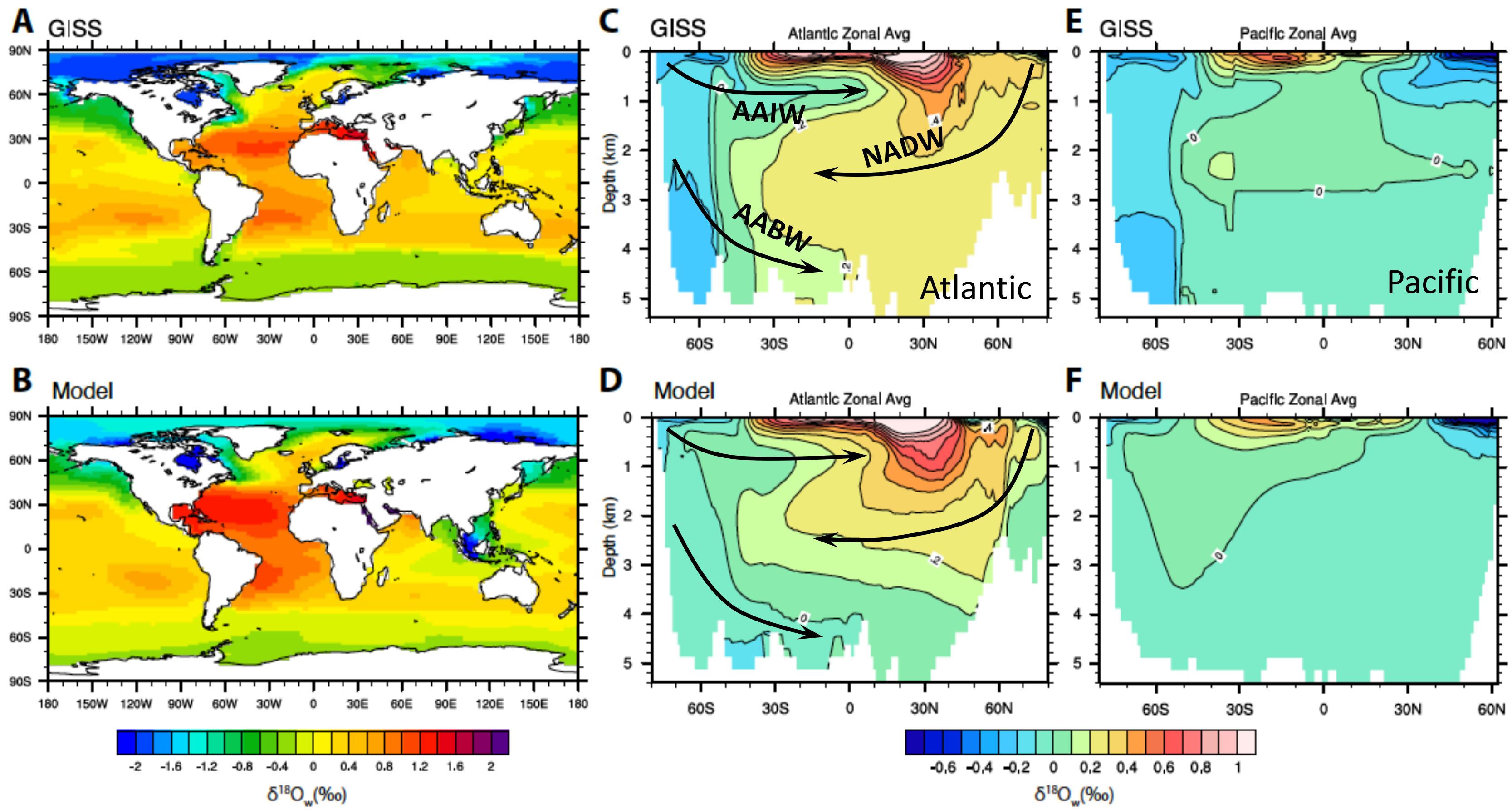

"Northern-source" hypothesis



# δ18O-enabled POP2 ocean model

GISS Observation

Model

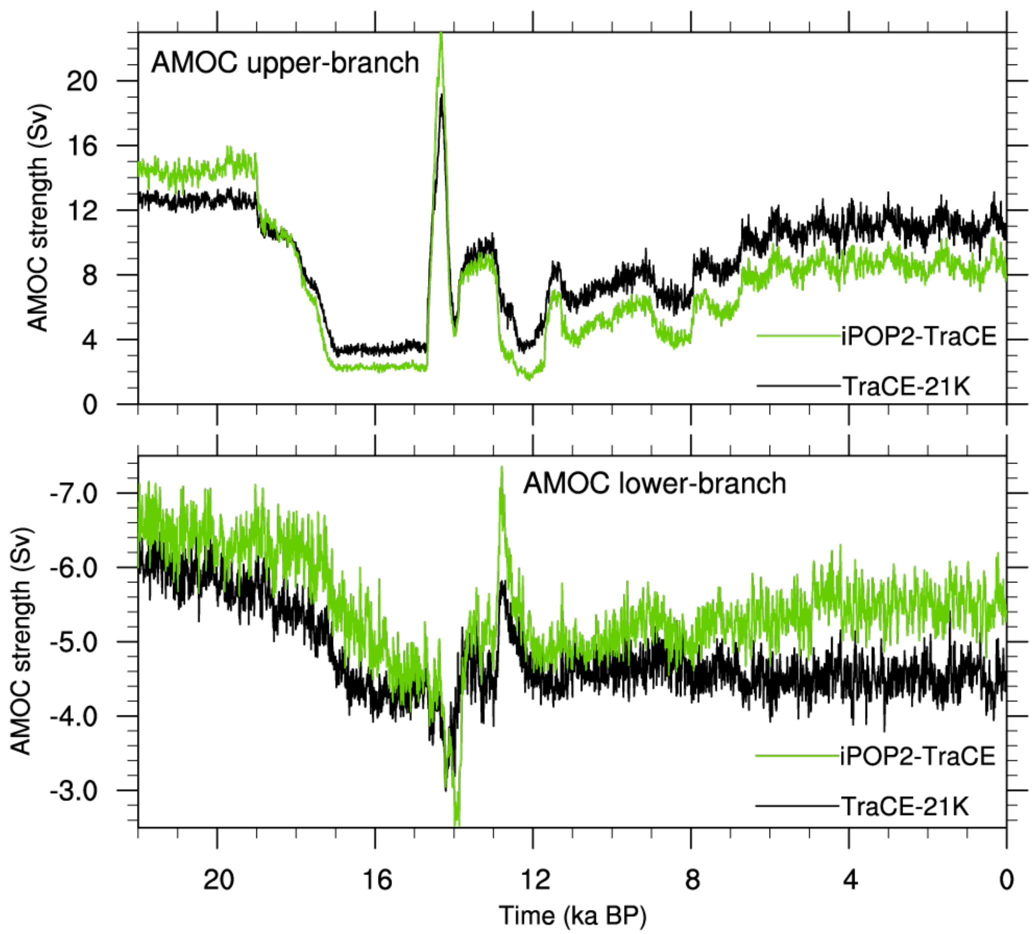



- Model is able to resolve AAIW, NADW and AABW water signatures.
  ➔ Suitable for paleoclimate research purposes

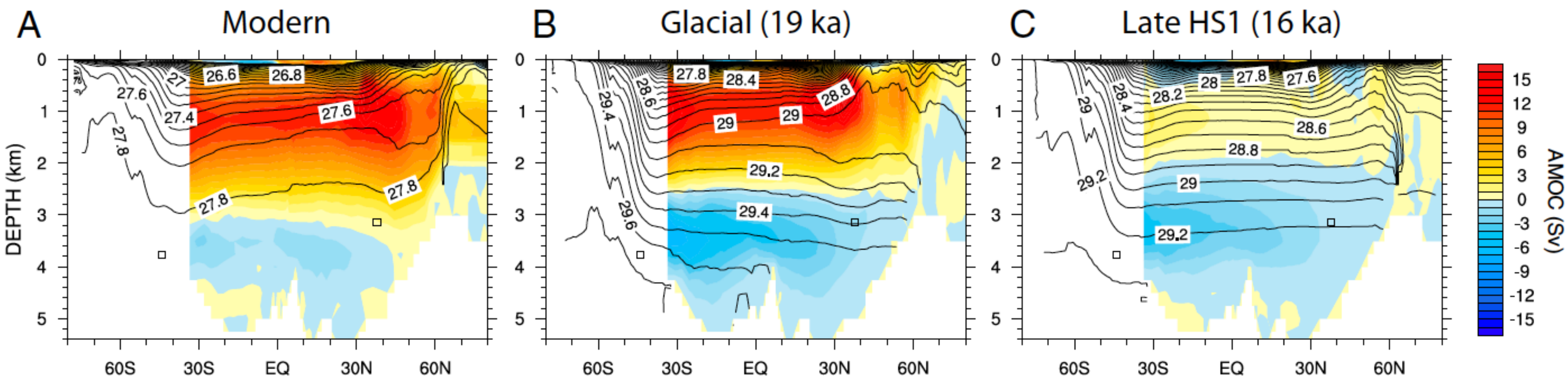
# iPOP2-TRACE (22,000 yr) comparing with TRACE21

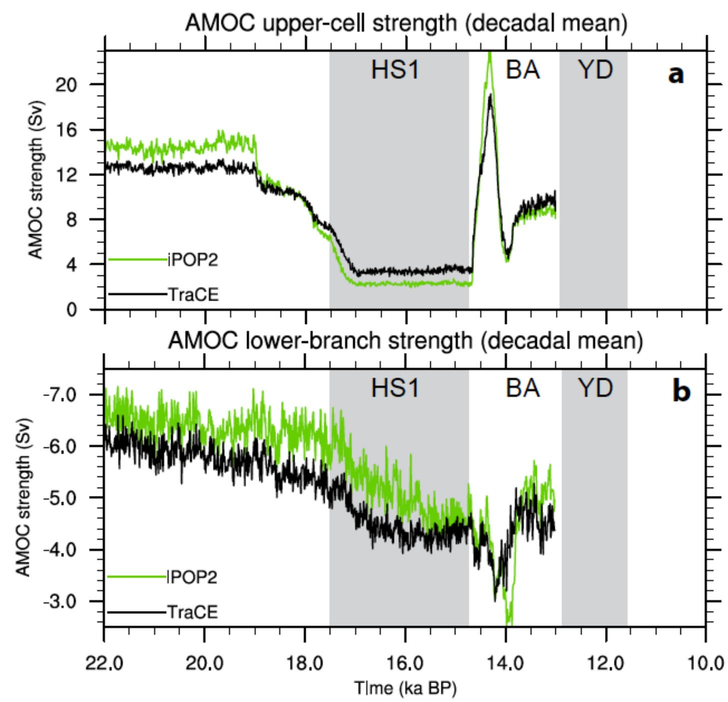
- TRACE21 (22 ka to present), fully coupled GCM (CCSM3) simulation forced by transient
  - Insolation, greenhouse gases, land ice sheet, and meltwater flux
- Hybrid surface boundary condition
  - Monthly history files
  - Heat flux + strong restoring SST
  - Freshwater flux + weak restoring SSS

Model simulated AMOC intensity



# Deep circulation scenario

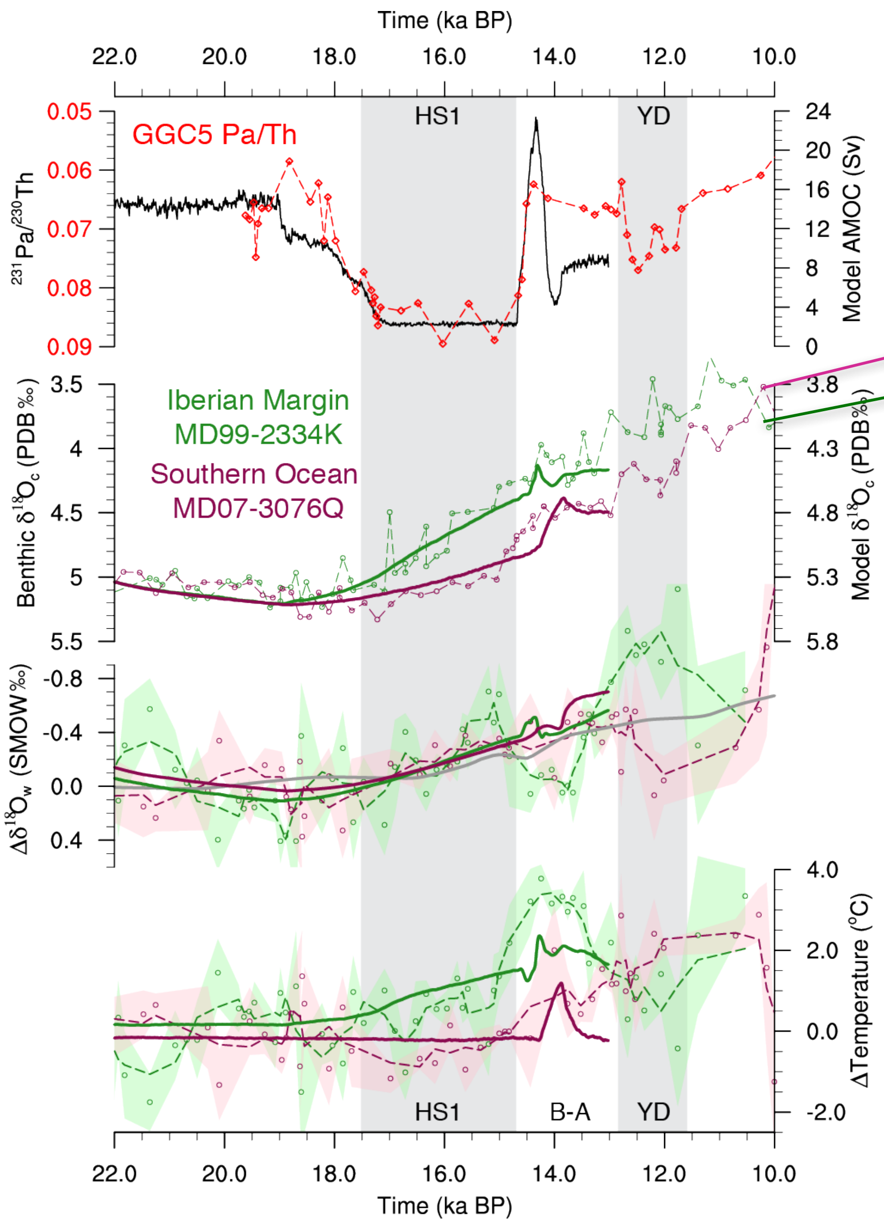


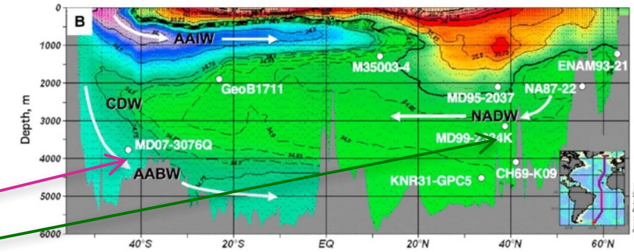

- During the LGM: strong AABW formation, strong abyssal overturning, basin-wide expansion of AABW.

- **Key point #1**: During HS1, both NADW and AABW formation decreased, with the former decreasing much more.

# Contribution of $\delta^{18}O_w$ and temperature




Iberian Margin MD99-2334K
(37.8°N, 3146 m)

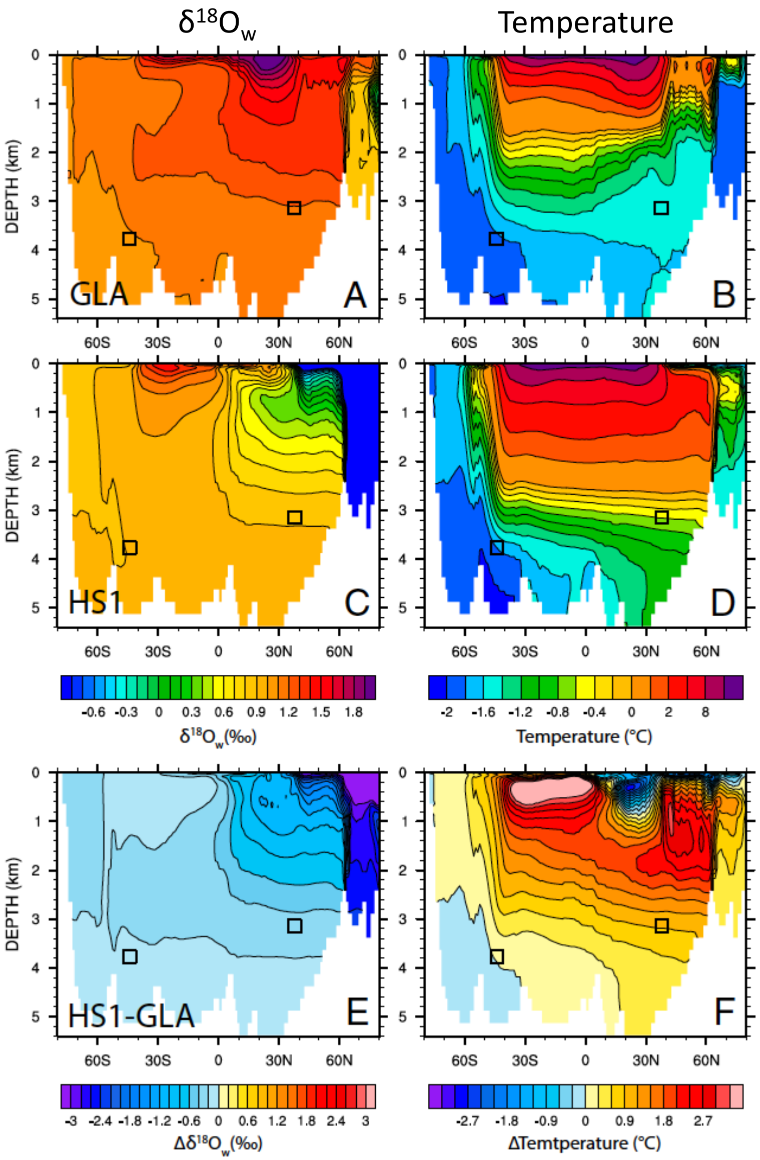



Southern Ocean MD07-3076Q
(44.2°S, 3770 m)

$$\Delta\delta^{18}O_c = \Delta\delta^{18}O_w + \Delta\delta^{18}O_{temp}$$

- **Key point #2:** The greater warming in the NA, rather than changes of the water $\delta^{18}O$, is the main cause of the observed lead of the deglacial NA benthic $\delta^{18}O$ decrease over that of the SA.

# Atlantic zonal mean $\delta^{18}O_w$ and temperature




## What we learn from the model $\delta^{18}O_w$

1. Trapped in the upper NA and within the Nordic Seas

   ← collapsed deep-water formation and the associated Nordic Sea overflows.

2. Bottom occupied by AABW, limited penetration.

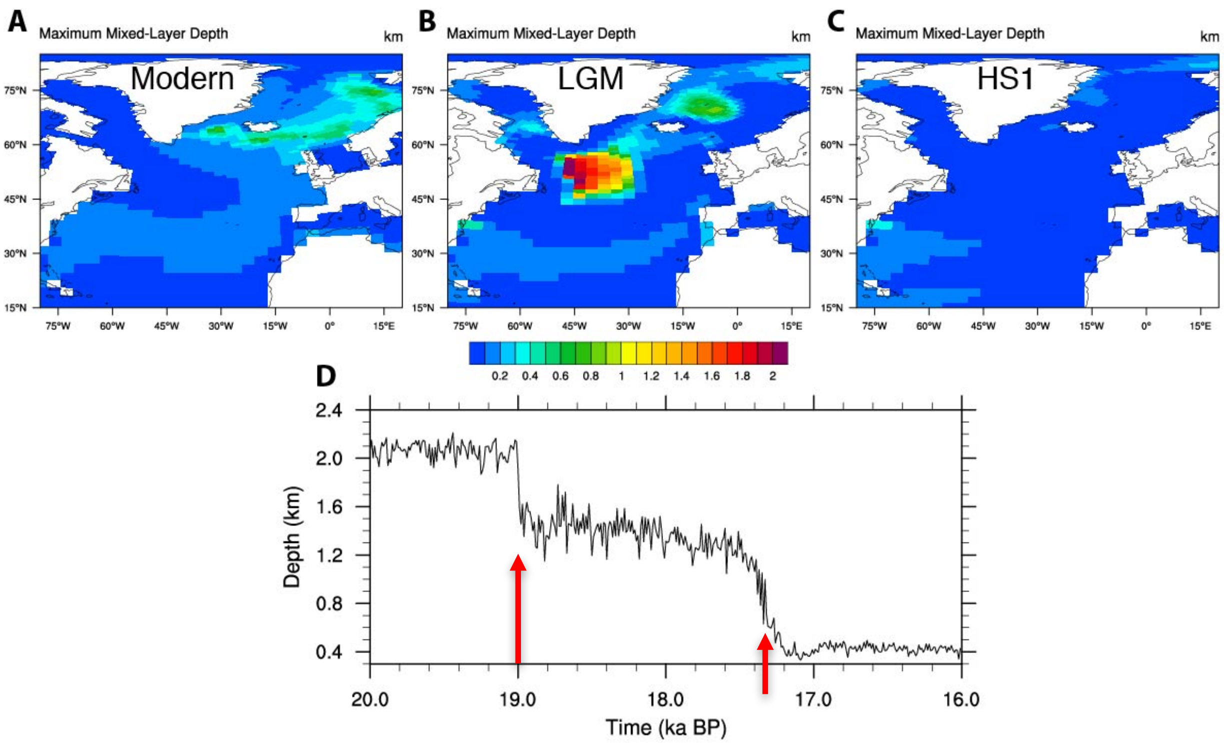
   → mild depletion in the whole deep Atlantic.

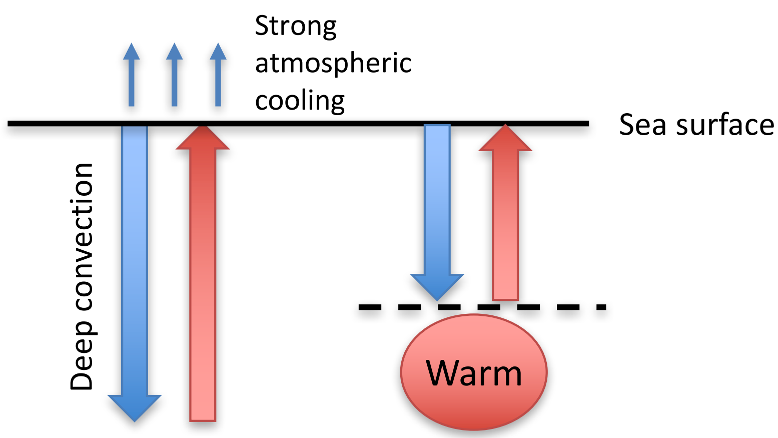
## What we learn from the model temperature

1. NH cooling and SH warming: bipolar seesaw
2. NH subsurface warming centers at 1500 m, 1000 m deeper than that of the SH.
3. Tilted warming.
4. Why asymmetric deep warming?

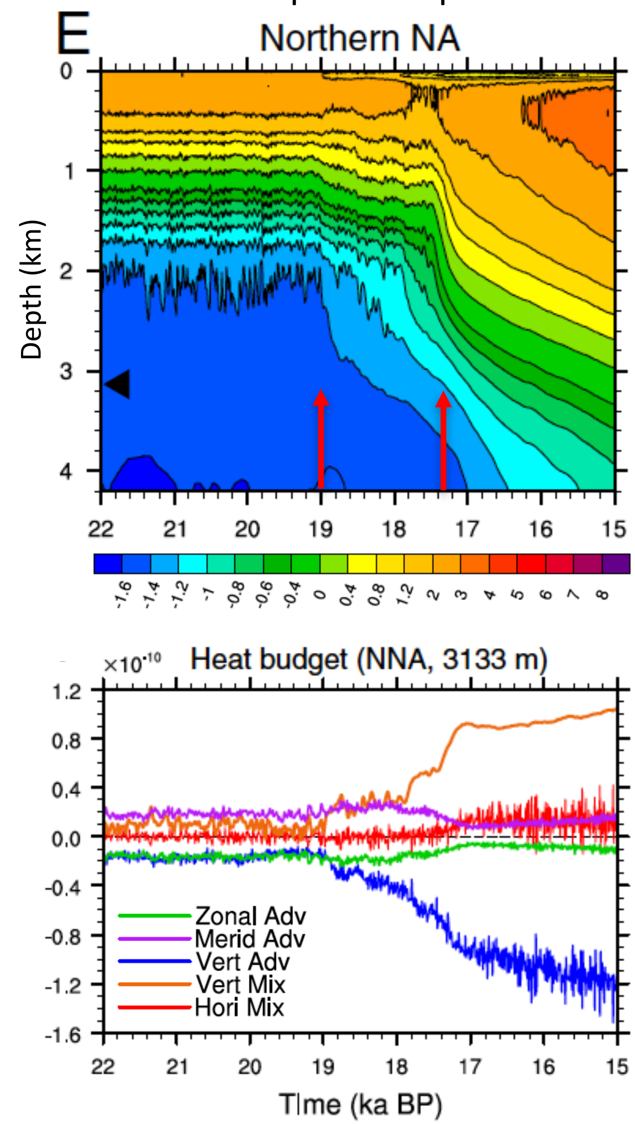
# How did the deep North Atlantic warm up?

Winter (DJF) maximum mixed layer depth

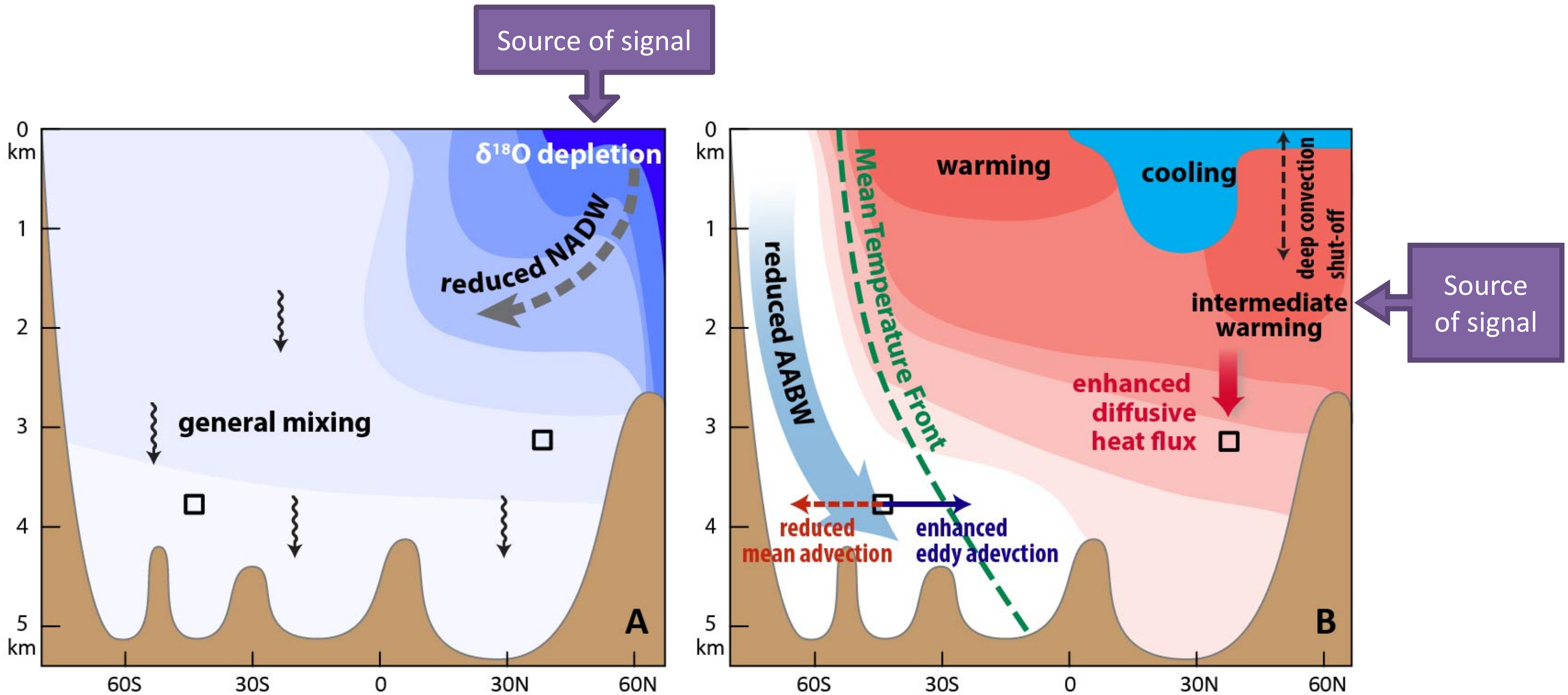



Hovmöller diagram of
the temperature profile



# Passive tracers ($\delta^{18}O_w$) vs. dynamic tracers (temperature)




- **Key point #3:** Warming mechanism: Winter-time deep convection retreat → a mid-depth warming → enhanced vertical diffusive heat flux brings down heat to the deep ocean
- **Key point #4:** Different responses between passive tracers and dynamic tracers.

# Summary

**Isotope-enabled climate models are useful tools for paleoclimate studies.**

- Debate: Southern- vs. northern-sourced deep-water input during the HS1.
- Transient ocean simulation of the past 22,000 years in iPOP2.
- Major findings:
  a) Reduced AABW production and transport with a reduced AMOC.
  b) Early warming in the North Atlantic, no warming in the Southern Ocean → explains the lead of the northern benthic $\delta^{18}O$.
  c) Warming mechanism in the North Atlantic: Winter-time deep convection retreat → a mid-depth warming → enhanced vertical diffusive heat flux brings down heat to the deep ocean.
  d) Different responses of passive tracers and dynamic tracers. We call for caution when inferring water mass changes from $\delta^{18}O$ records while assuming uniform changes in deep temperatures.