THE UNIVERSITY OF CHICAGO

Sea-ice control on glacial-interglacial circulation changes, deep ocean ventilation, and carbon storage

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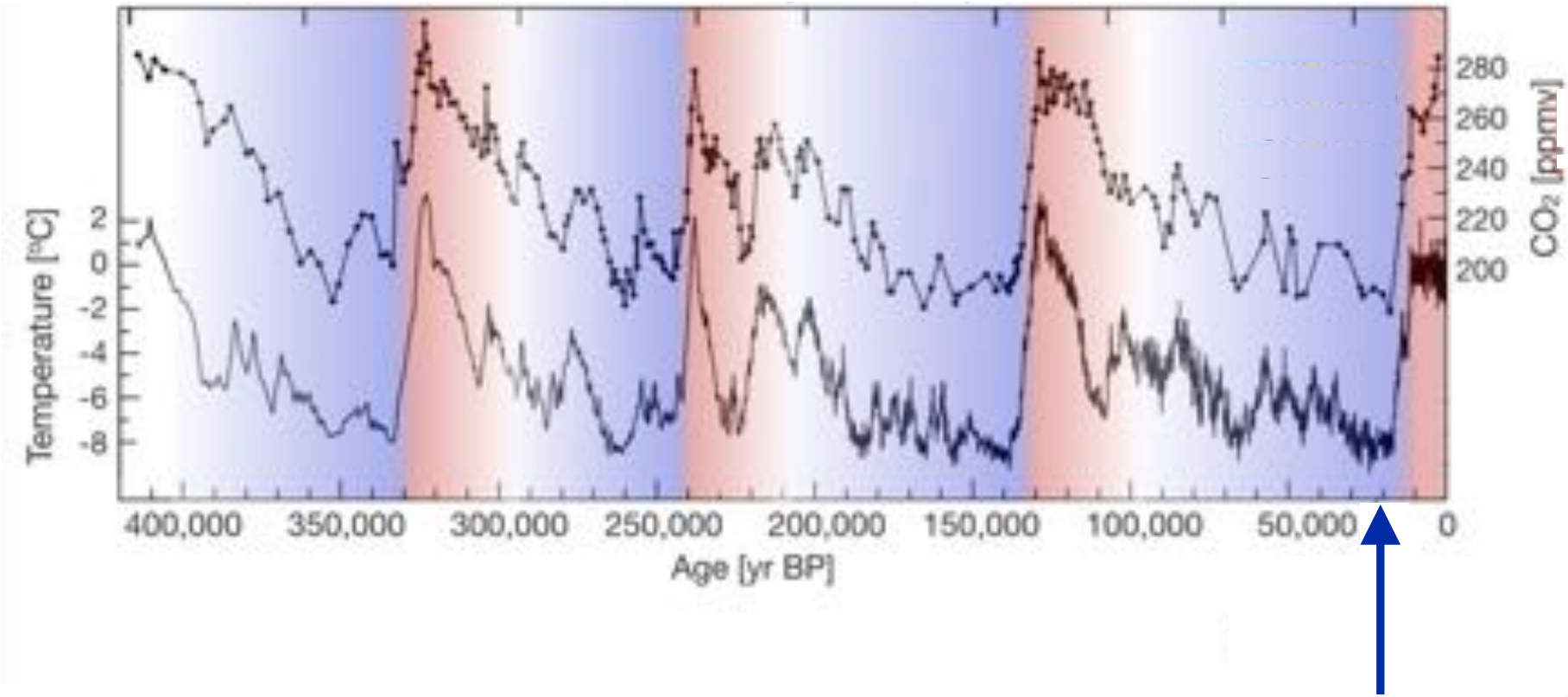
NATURAL ENVIRONMENT RESEARCH COUNCIL

Glacial-interglacial transitions: ocean's role?



Vostok ice core

CO_2 ~180-190 ppm

SAT ~ 2-6°C colder than present-day

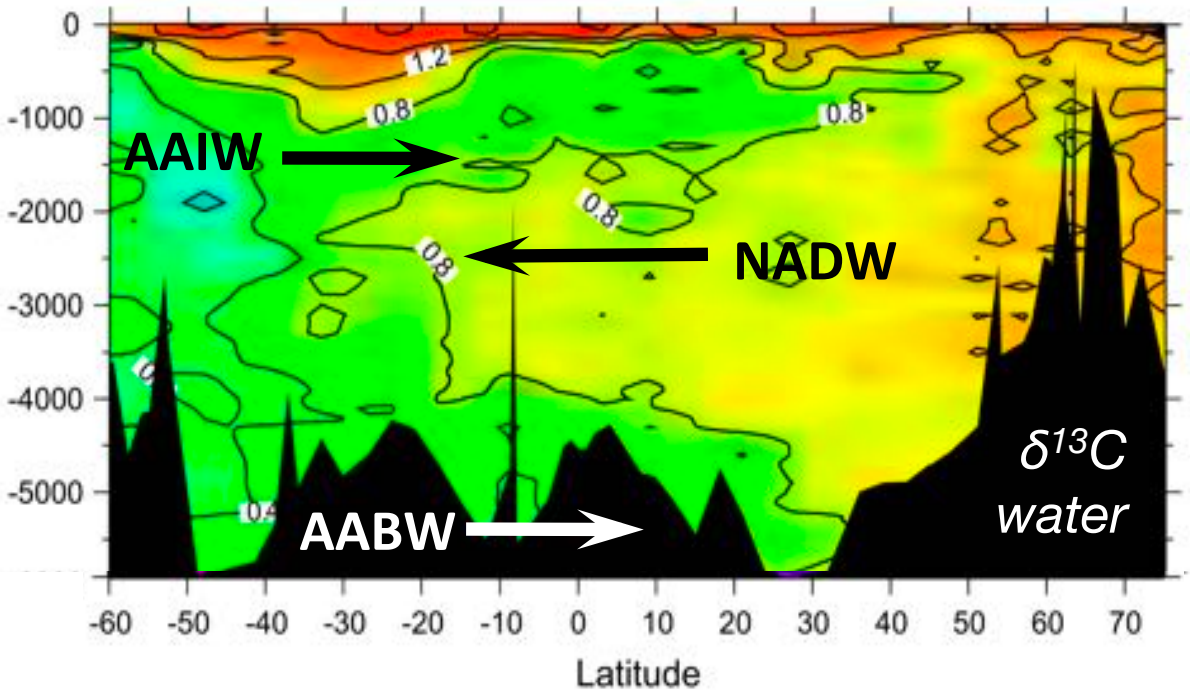
Last Glacial Maximum (LGM)

(~ 21,000 yrs ago)

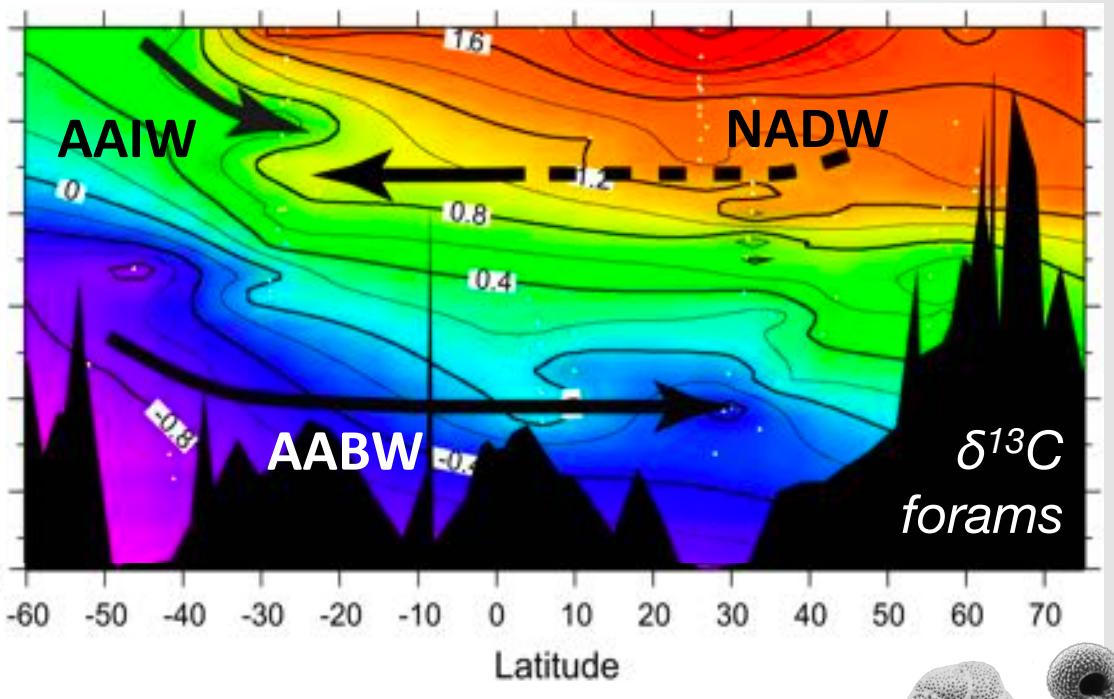
data from Petit et al. (1999)

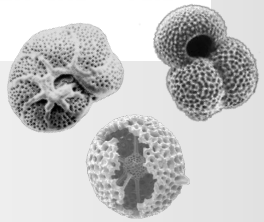
Observational and paleoclimate record

preindustrial



Last Glacial Maximum

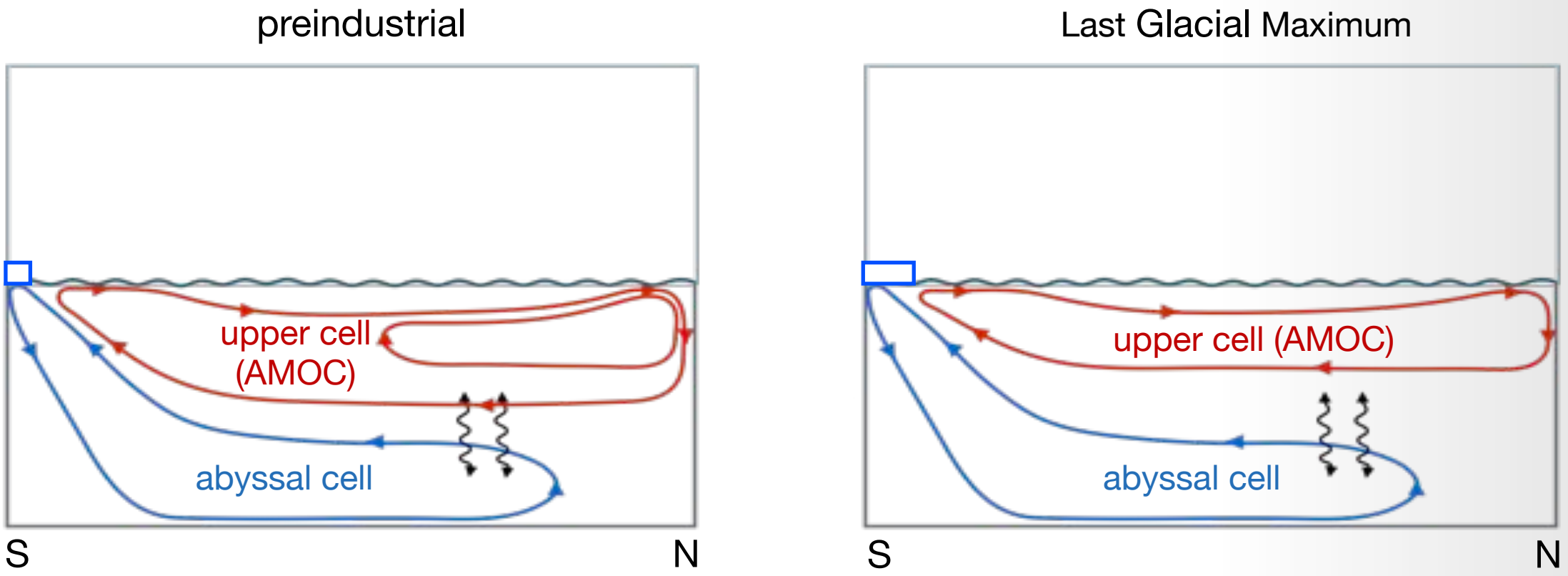




$\delta^{13}C$ data from Western Atlantic

Curry and Oppo (2005)

Changes in ocean circulation



What drives glacial-interglacial water masses reorganization?

Key player: Antarctic sea ice

Glacial Antarctic sea-ice expansion

©Ruddiman

Glacial Southern Ocean:

+++ sea-ice formation/export

+++ buoyancy loss rates

Globally:

+++ stratification

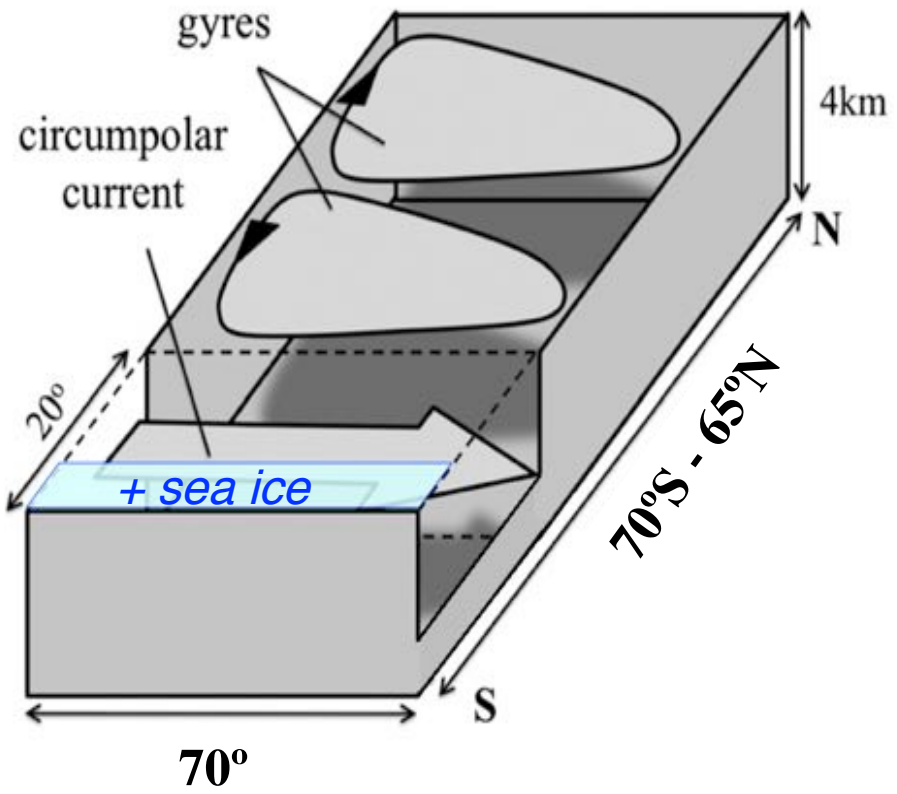
––– AMOC depth

(e.g. Shin et al., 2003; Ferrari et al., 2014; Jansen, 2017)

LGM: up to 7° equatorward expansion

(e.g. Gersonde et al., 2005; Benz et al., 2016)

Idealized ocean-sea-ice simulations



MITgcm

single basin with
re-entrant channel

1° × 1° horizontal resolution
29 vertical levels

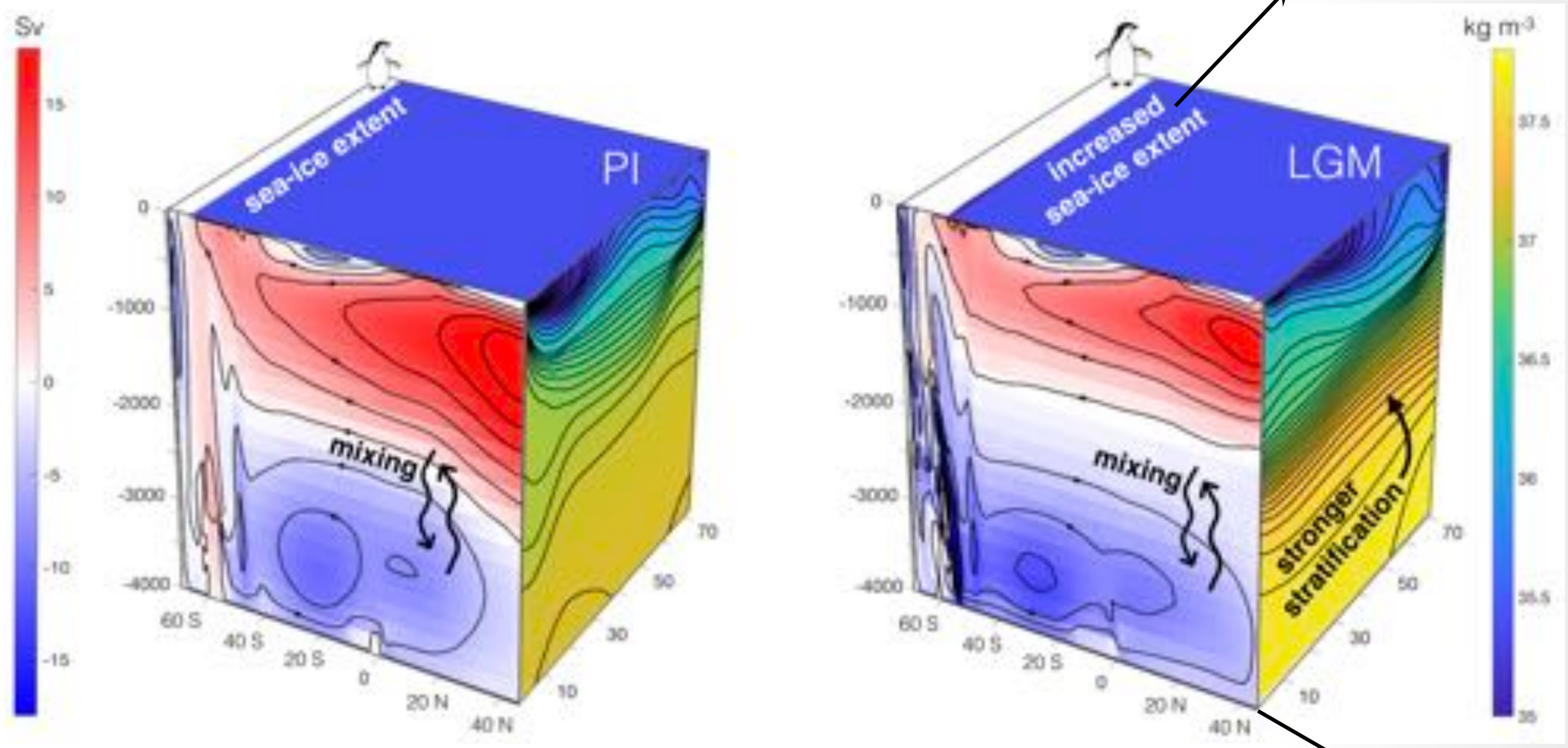
prescribed P-E, winds
and atm temperatures

Coupled to dynamic sea-ice model

Idealized ocean-sea-ice simulations

+++ sea ice expansion

+++ buoyancy loss

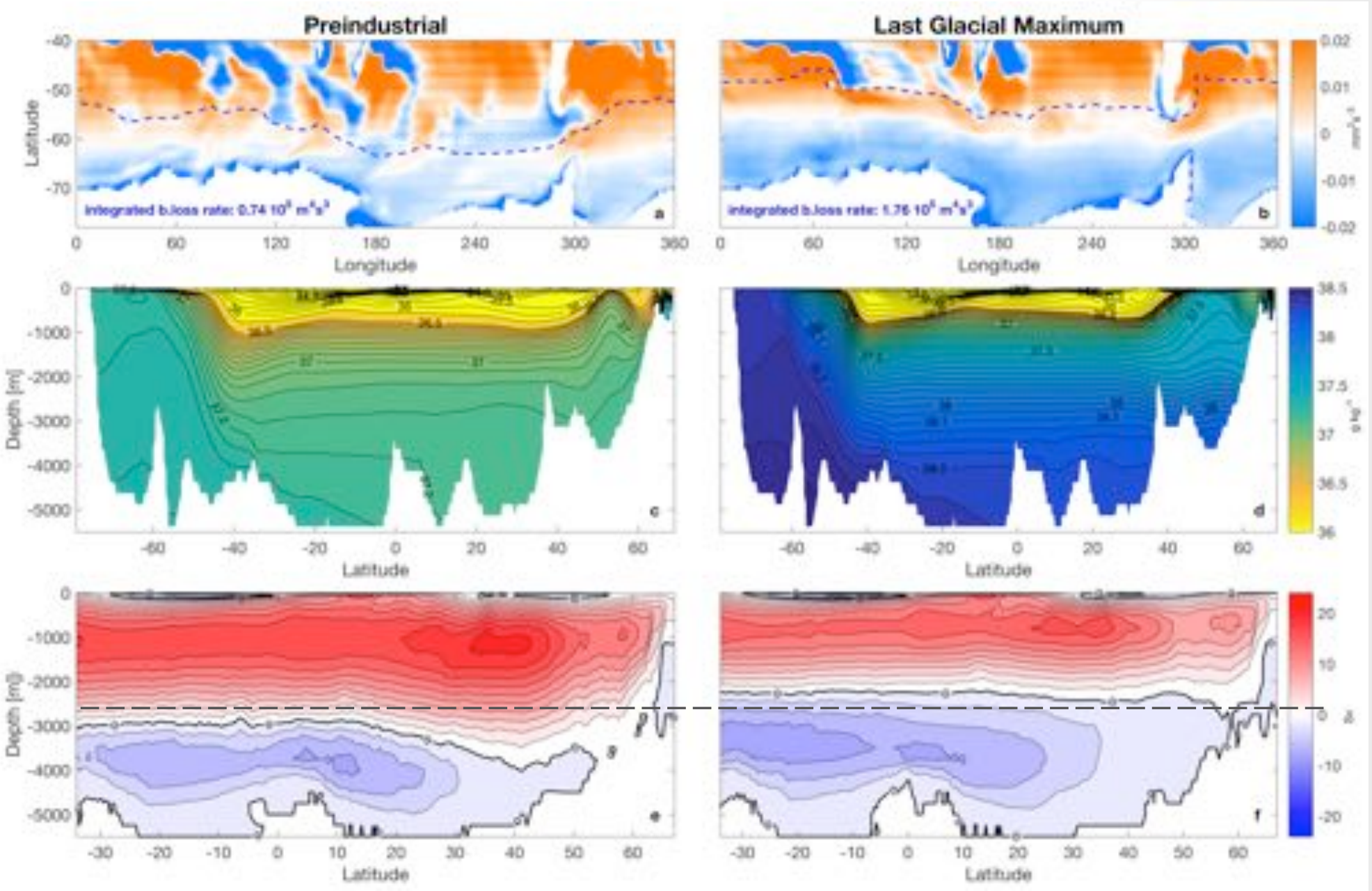


+++ stratifcation

––– AMOC depth

LGM forcing: atmospheric cooling (2–6°C)

coupled climate model



b. fluxes

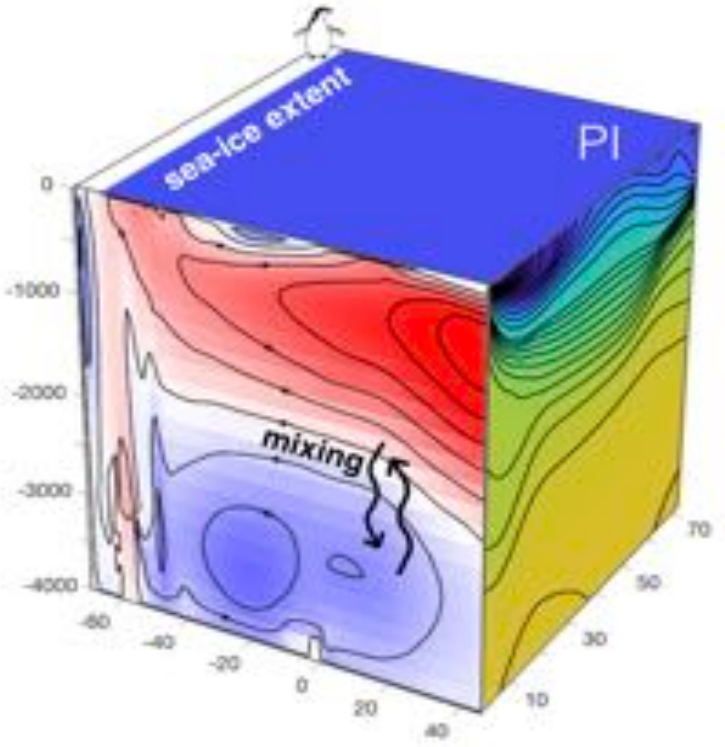
density

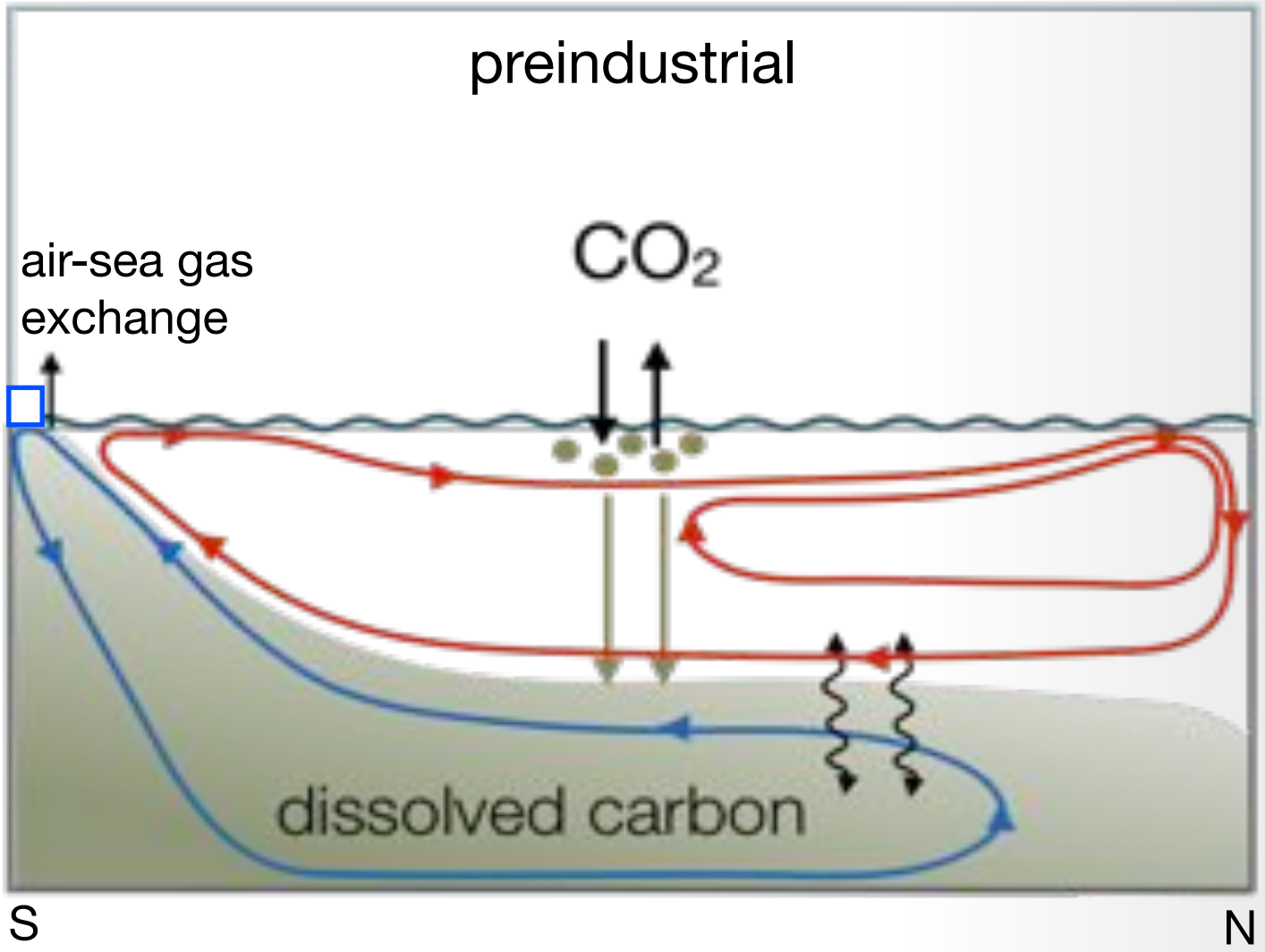
AMOC

CCSM3 simulation *(Otto-Bliesner et al., 2006)*

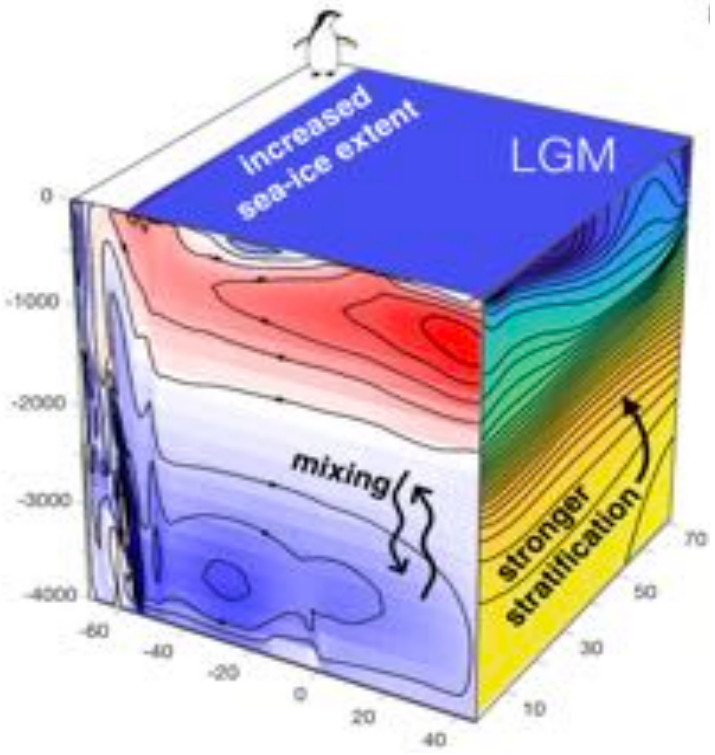
Marzocchi and Jansen (2017)

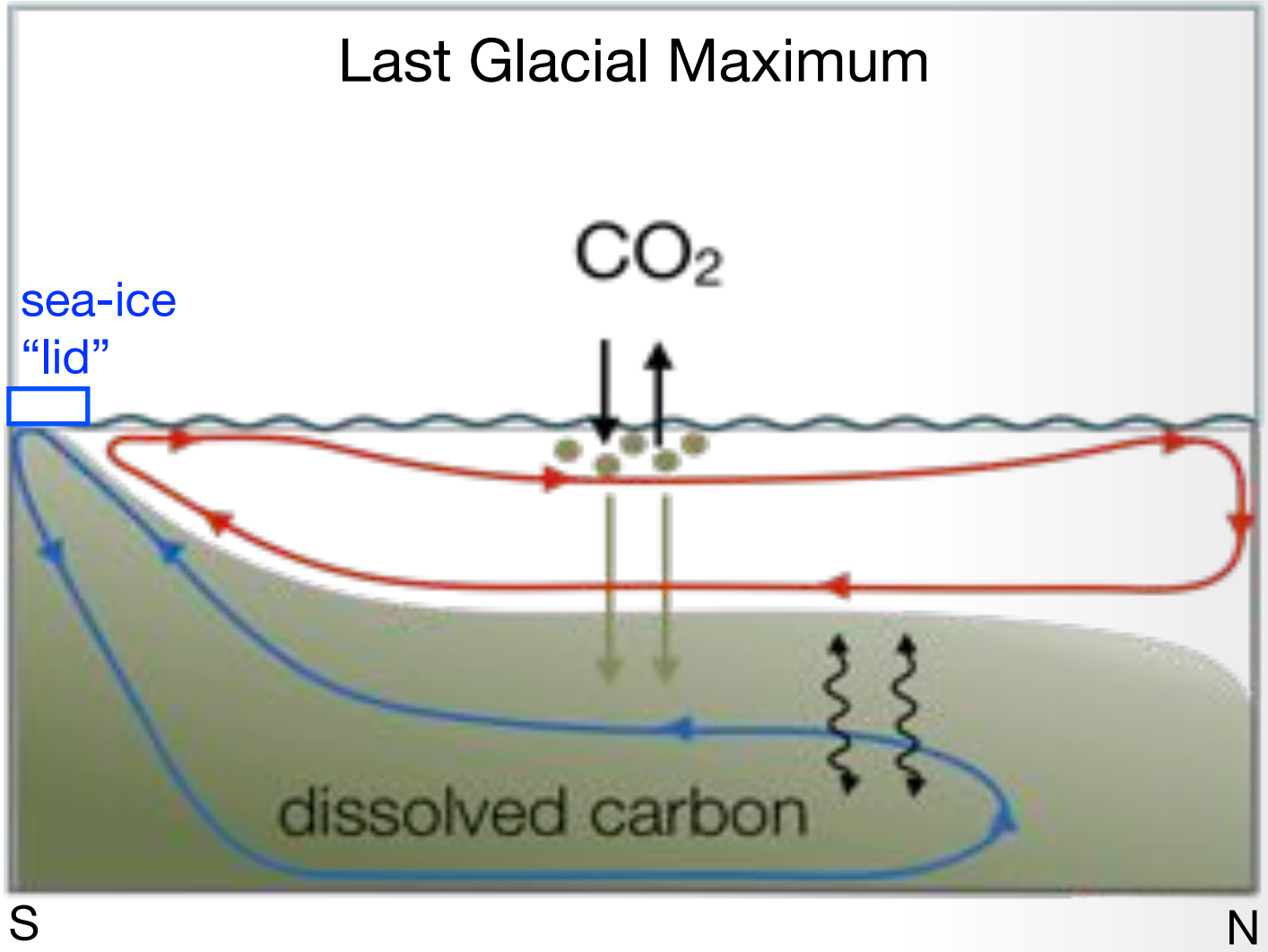
From ocean circulation to carbon storage



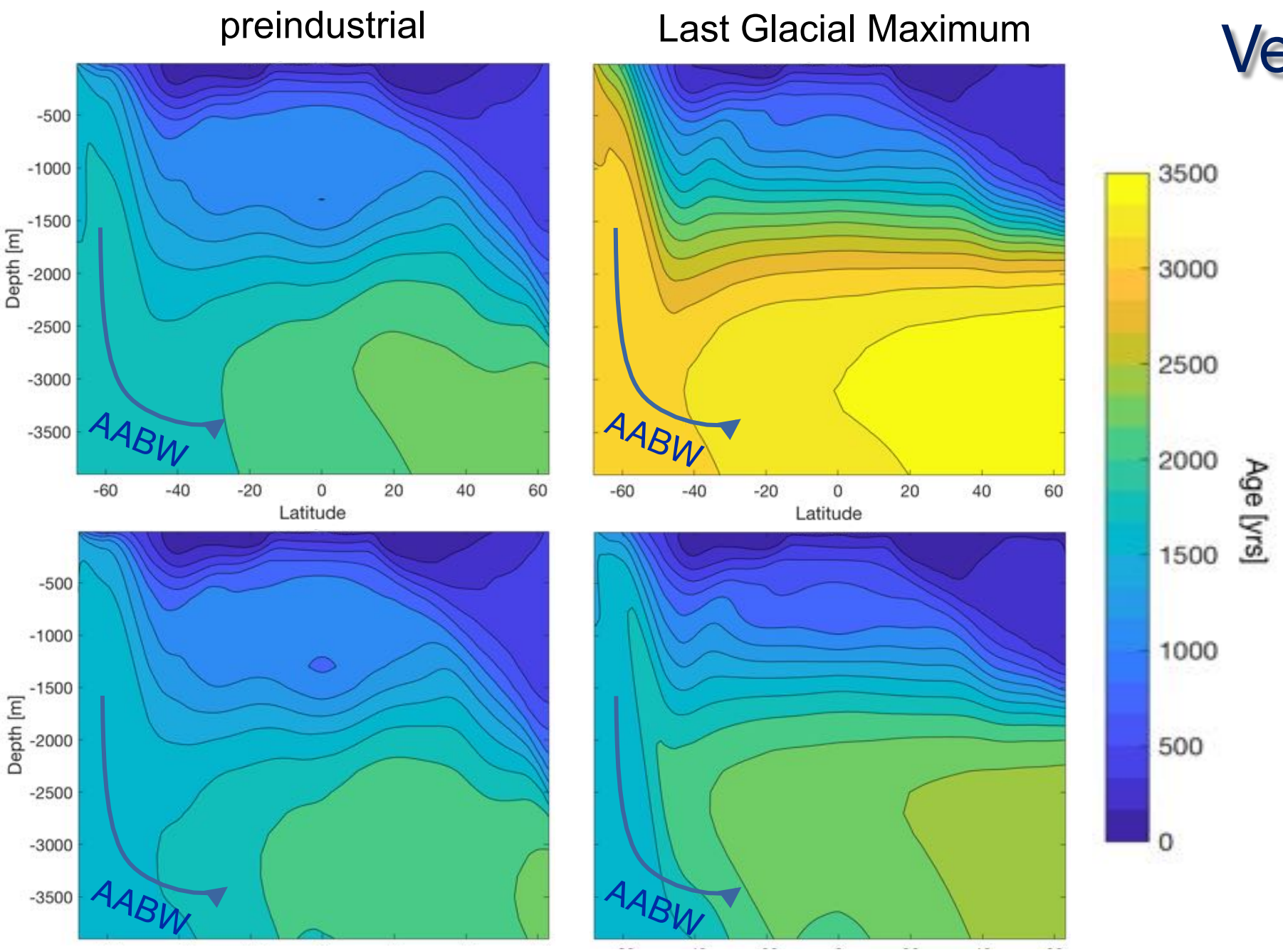


From ocean circulation to carbon storage





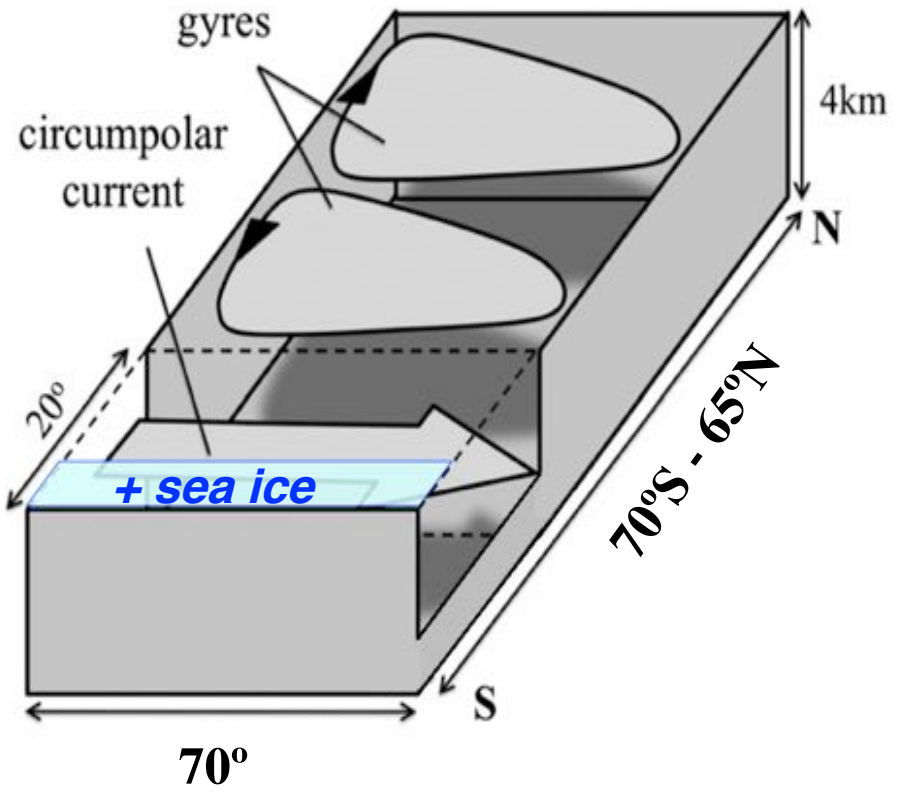
Ventilation age



age tracer = 0 at surface (not under sea ice)

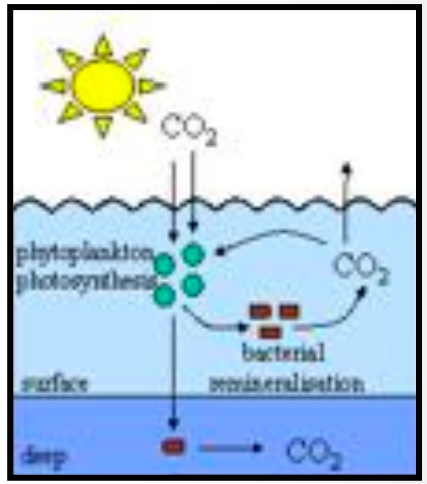
sea ice **NOT** inhibiting ventilation

Idealized simulations forced by atm cooling



+

coupled to
biogeochemical model

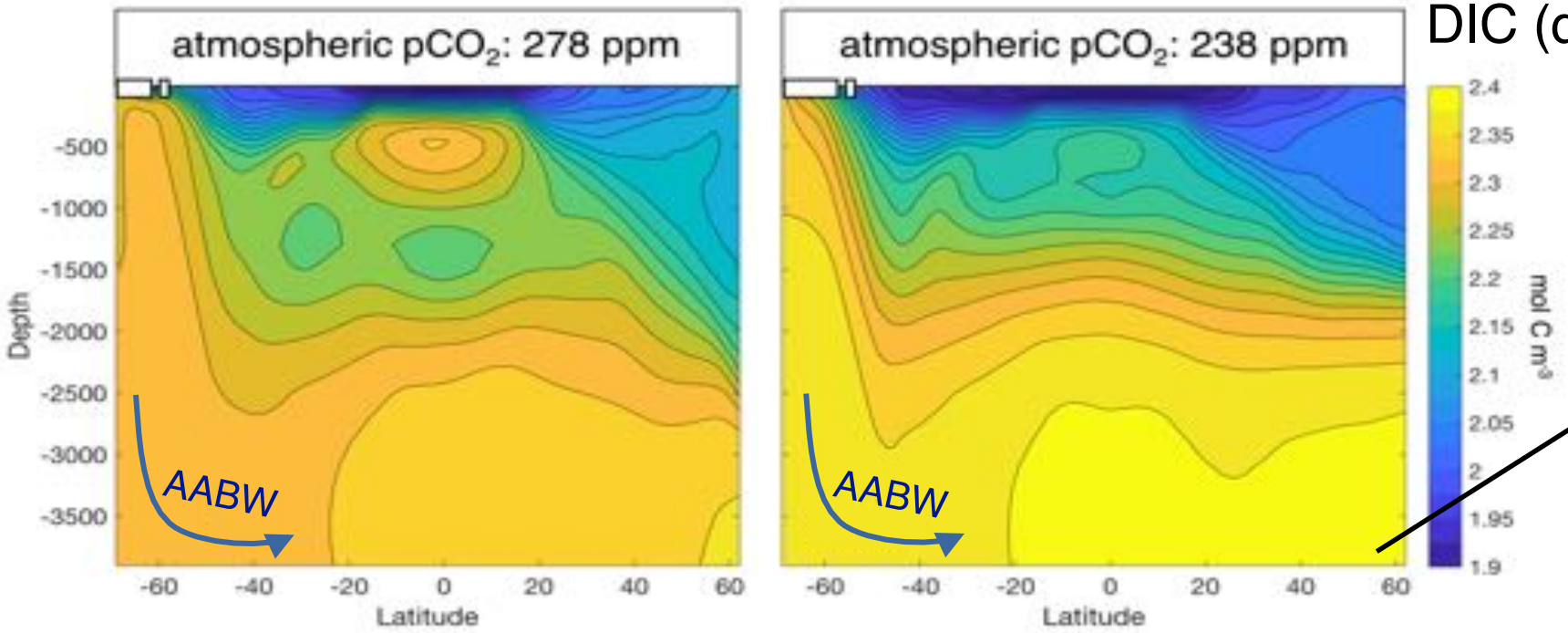


coupled to
atmospheric “box”

Marzocchi and Jansen (submitted)

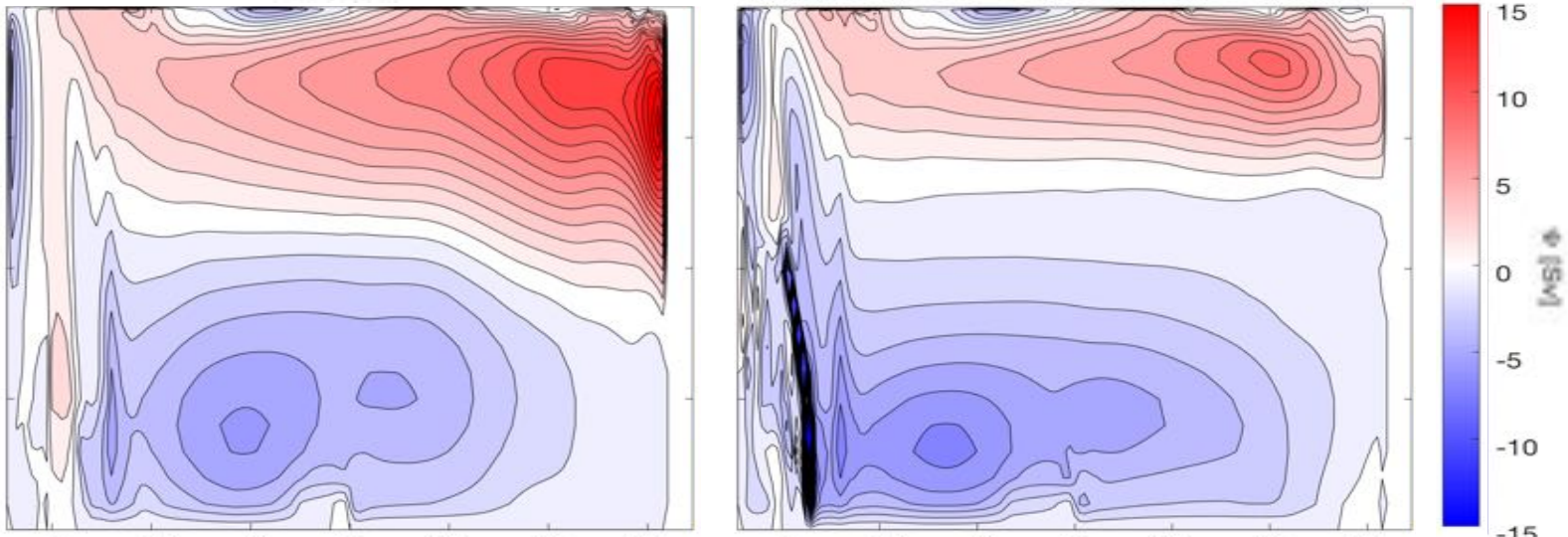
preindustrial

Last Glacial Maximum



DIC (dissolved inorganic carbon)

LGM: 40 ppm pCO_2 drawdown



AABW more isolated from surface due to

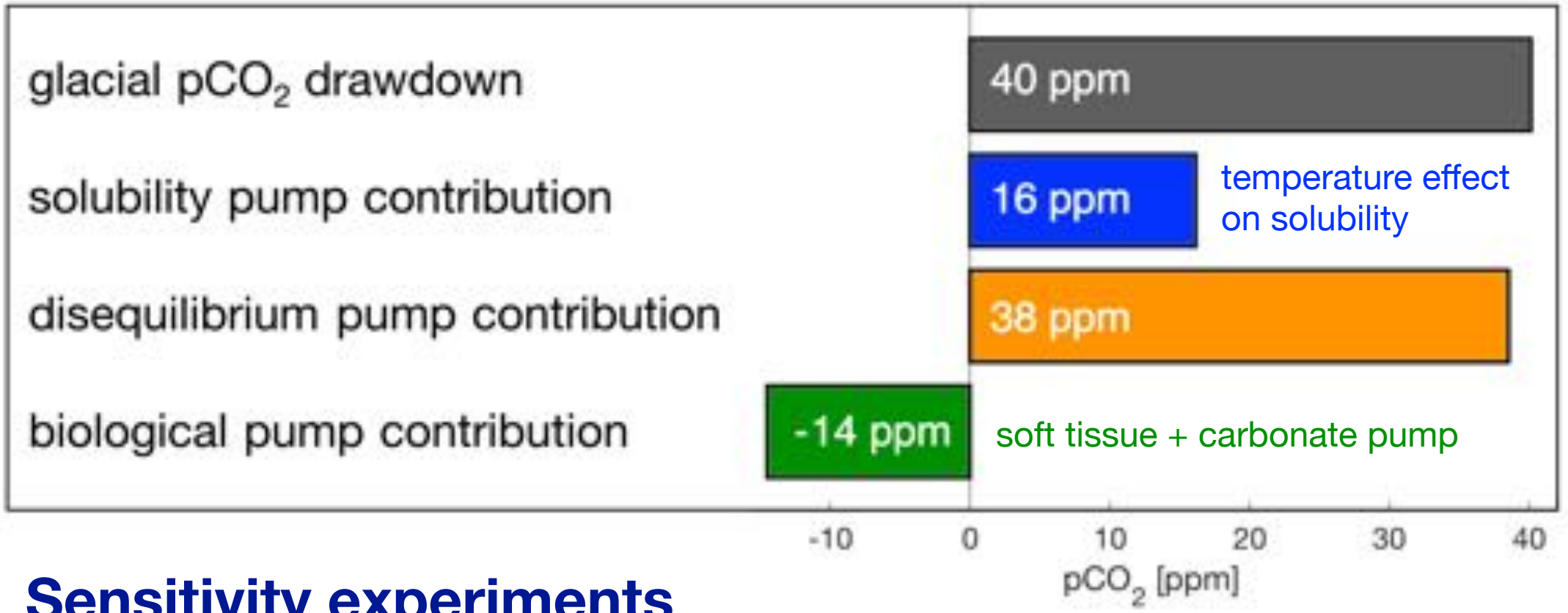
(1) Weaker mixing with NADW: shallower interface between northern/southern sourced water masses

(2) Reduced air-sea gas exchange: upwelling only under sea ice

Carbon pump decomposition

(e.g. Ito and Follows, 2005, 2013; Goodwin et al., 2008; Lauderdale et al., 2013)

glacial-interglacial pCO_2 variations: 80-90 ppm



Sensitivity experiments

	CTRL		No sea ice		Seas. cycle		Efficient bio
PI	278	40 ppm	278	10 ppm	270	34 ppm	170
LGM	238		268		236		150 →

From LGM reconstructions: 180-190 ppm

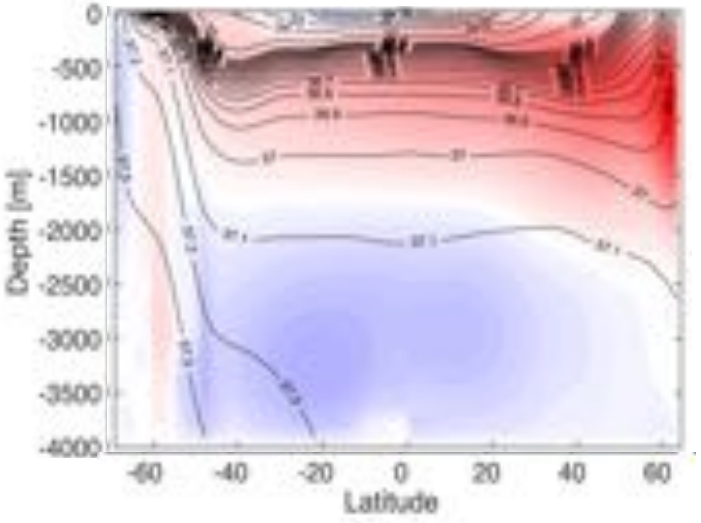
Summary and conclusions

Idealized ocean-ice-biogeochem. simulations:

- During glacials, enhanced Antarctic sea-ice formation/export increases buoyancy loss and stratification, leading to AMOC shoaling
- Circulation changes and expanded Antarctic sea-ice cover decrease glacial deep-ocean ventilation and increase carbon storage
- Physical changes alone result in about half of glacial-interglacial pCO_2 variation

AMOC transient & equilibrium solutions: a cautionary tale

reference/initial condition
preindustrial

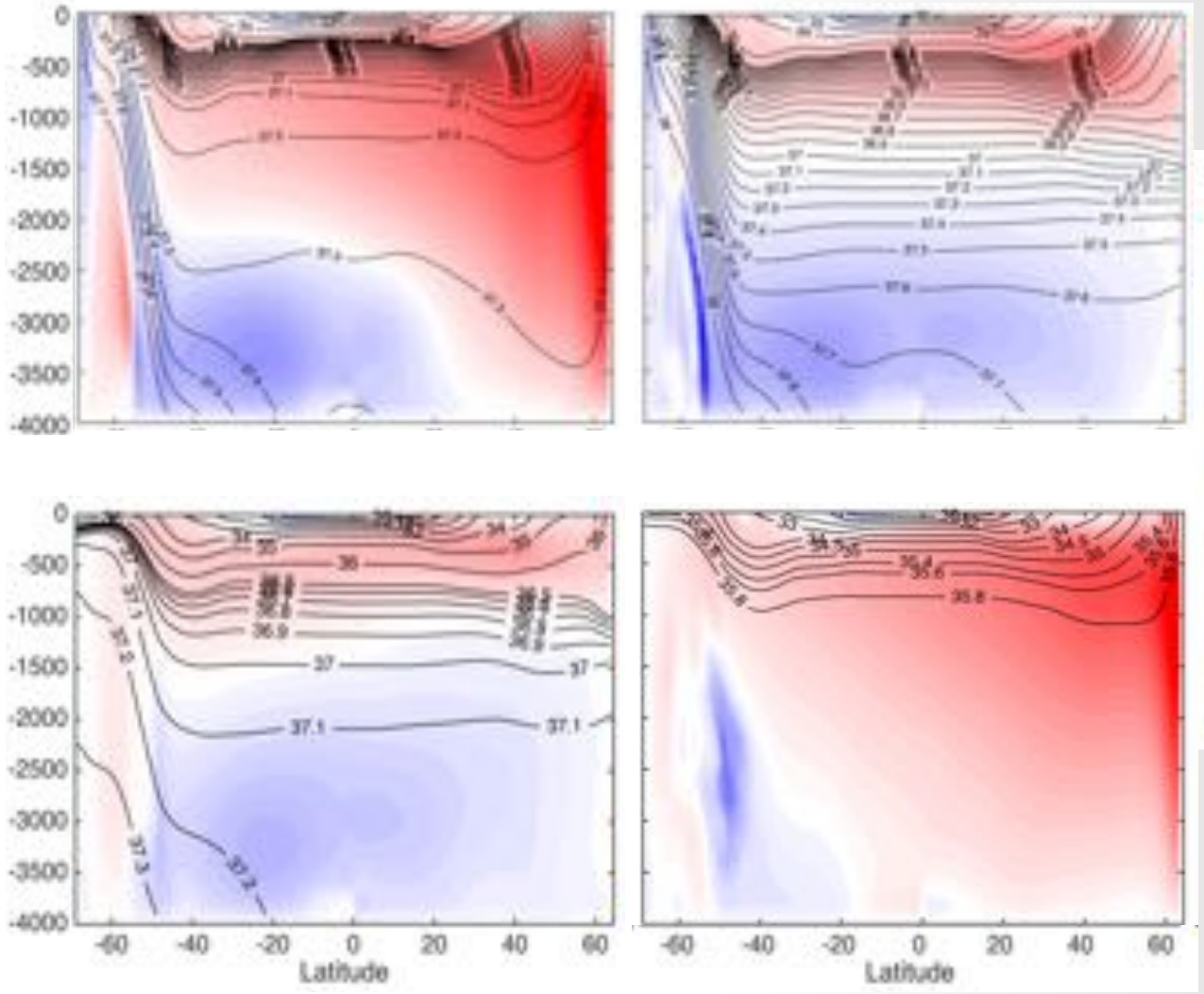


"glacial"

"hot house"

spin-up (transient)

equilibrium



forcing: 2-6°C atm cooling
warming

Jansen et al. (2018)