National Oceanography Centre

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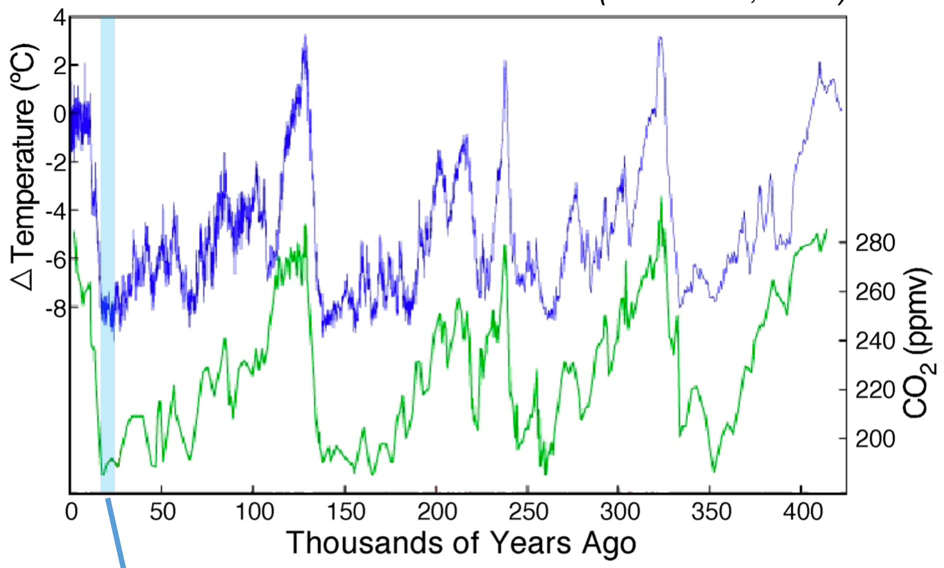
Global cooling linked to increased glacial carbon storage via changes in Antarctic sea ice

Alice Marzocchi & Malte Jansen

Vostok ice core (Petit et al., 1999)

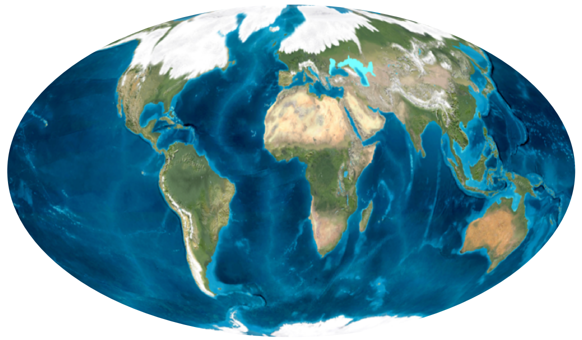


Last Glacial Maximum (LGM)

~21,000 years ago

CO_2 ~190 ppm

SAT ~2-6 ºC colder



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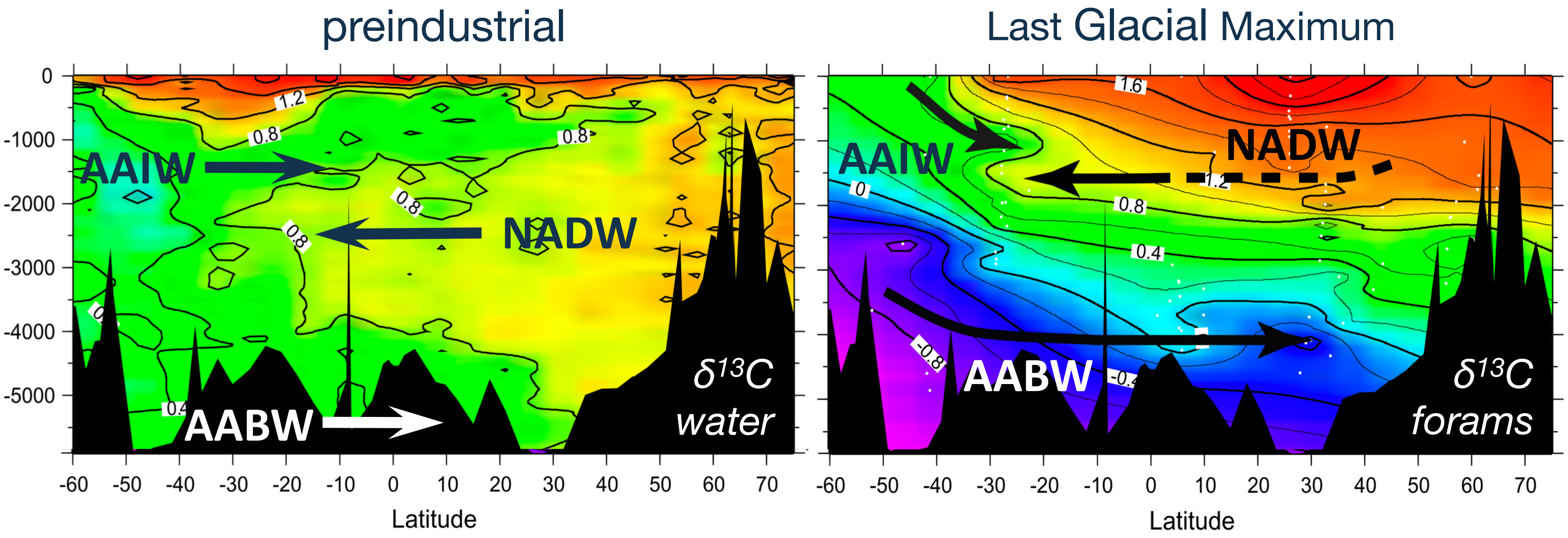
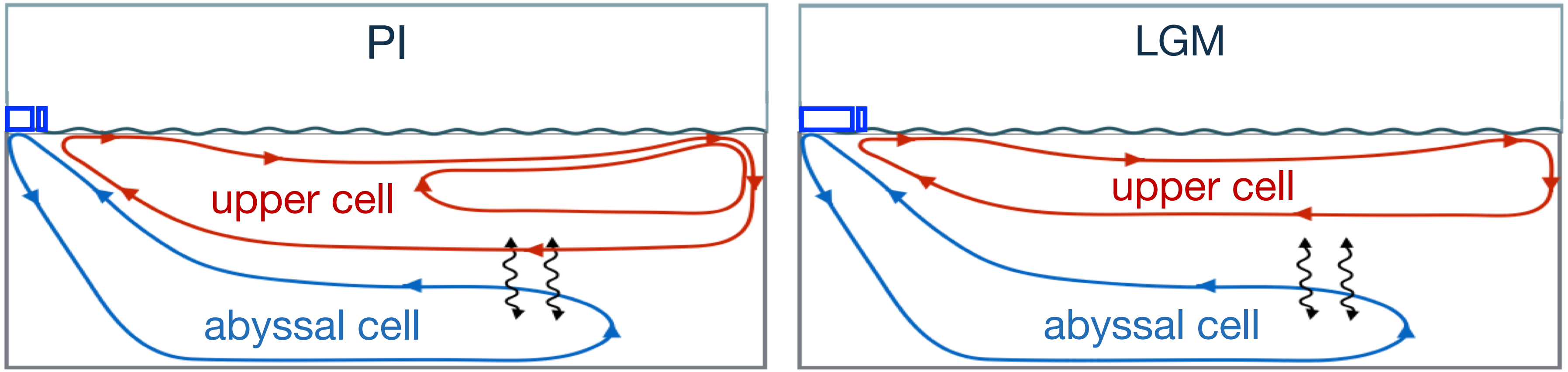
What drives glacial-interglacial reorganisation of water masses?



Curry and Oppo (2005)

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

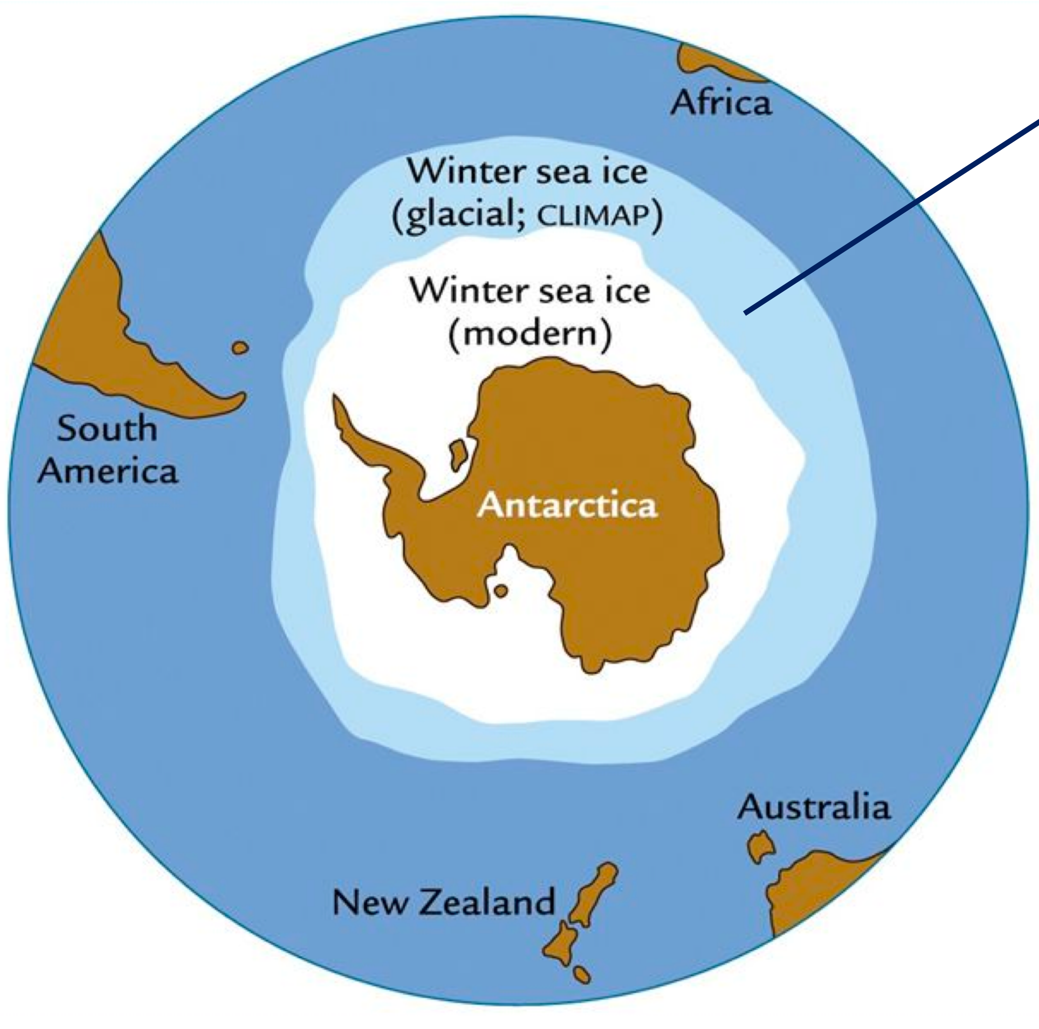


Key LGM feature: shallower upper overturning cell (AMOC)

But not consistent in coupled models (CMIP/PMIP)

see e.g. Marzocchi and Jansen (2017, GRL)

Key player in water mass changes: Antarctic sea ice



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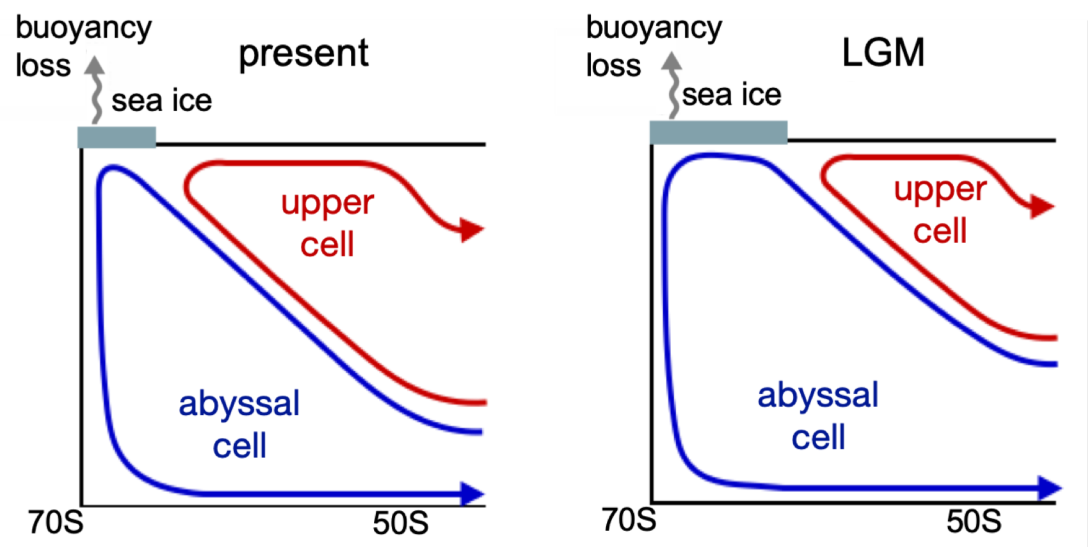
Antarctic sea ice cover
LGM: up to 7º equatorward expansion
(e.g. Gersonde et al., 2005; Benz et al., 2016)

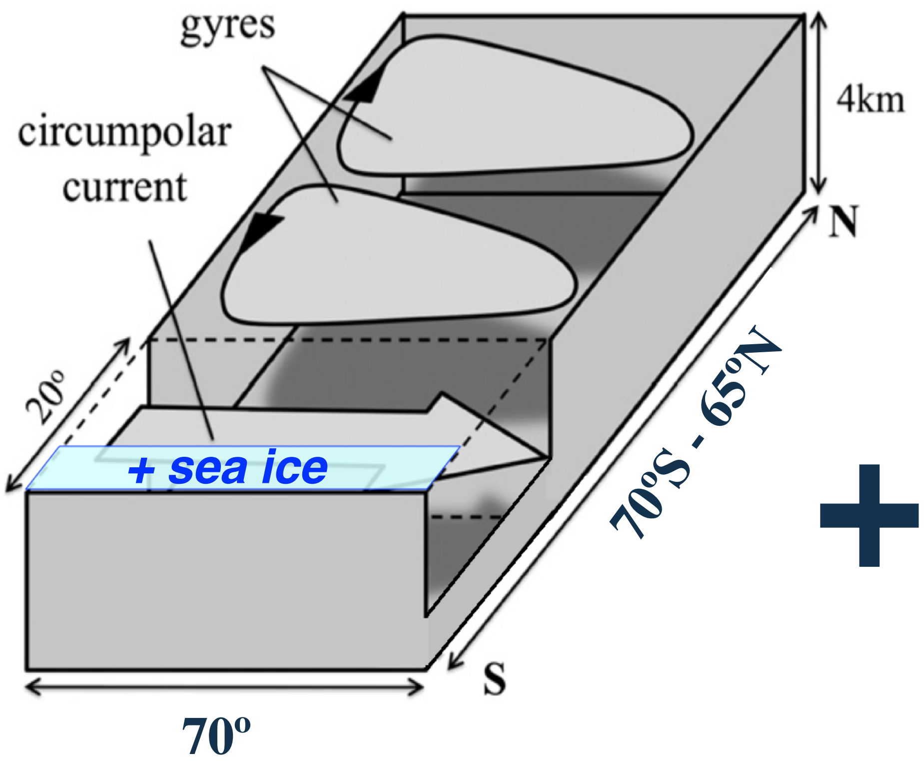
e.g. "geometrical" argument *(Ferrari et al., 2014)*



Sea-ice expansion "shrinks" the upper cell

Simulations: MITgcm single-basin model with re-entrant channel

(e.g. Nikurashin and Vallis, 2011)



Ocean model coupled to dynamic sea-ice model

1º X 1º horizontal resolution with 29 vertical levels

Prescribed P-E, winds and atm temperatures

Coupled to:

+

biogeochemical model

atmospheric "box"

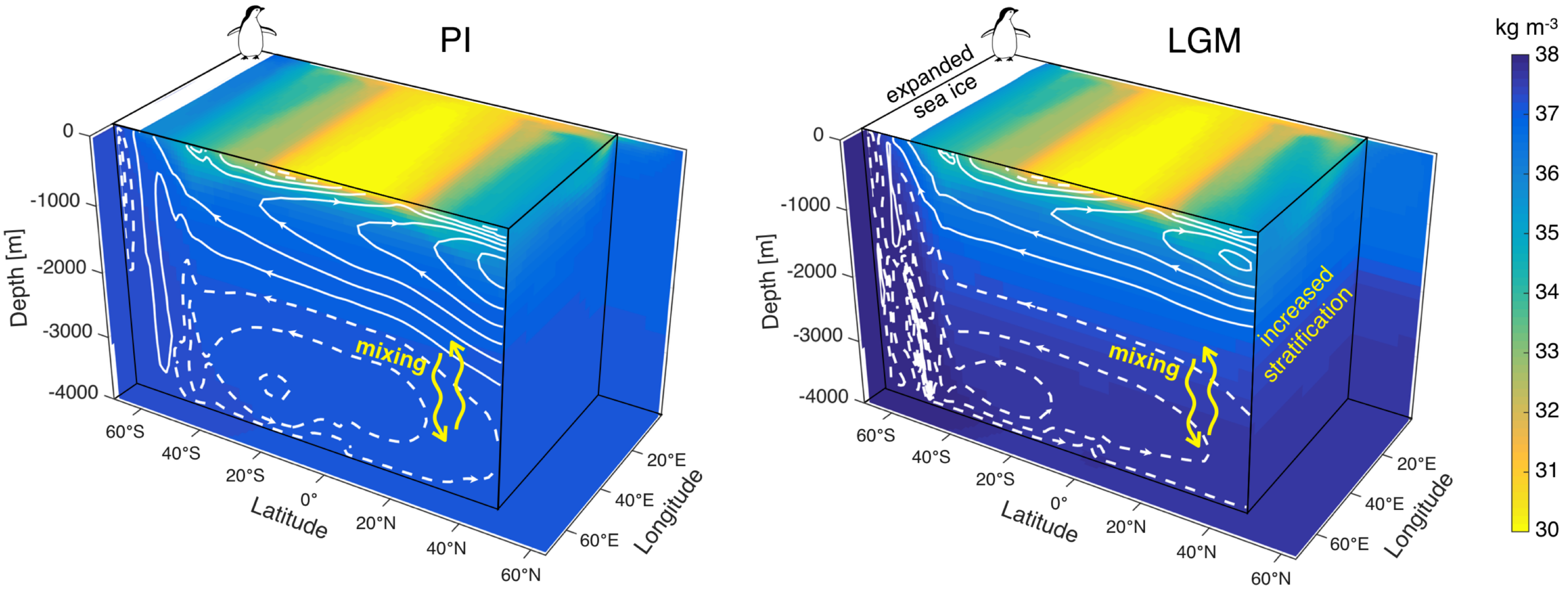
[standard MITgcm packages]

LGM simulations: forced solely by atmospheric cooling (2-6°C, polar-amplified)

Linking atmospheric cooling to increased ocean carbon storage

atmospheric cooling → **increased Antarctic sea-ice formation** → **more brine rejection and buoyancy loss** → **stronger deep stratification** → **abyssal cell isolation and less air-sea gas exchange** → **more deep-ocean carbon storage** ?

see Jansen (2017, PNAS)



Shading: potential density (ref: 2km) Contours: overturning streamfunction

Marzocchi and Jansen (2019, Nat.Geosci)

Linking atmospheric cooling to increased ocean carbon storage

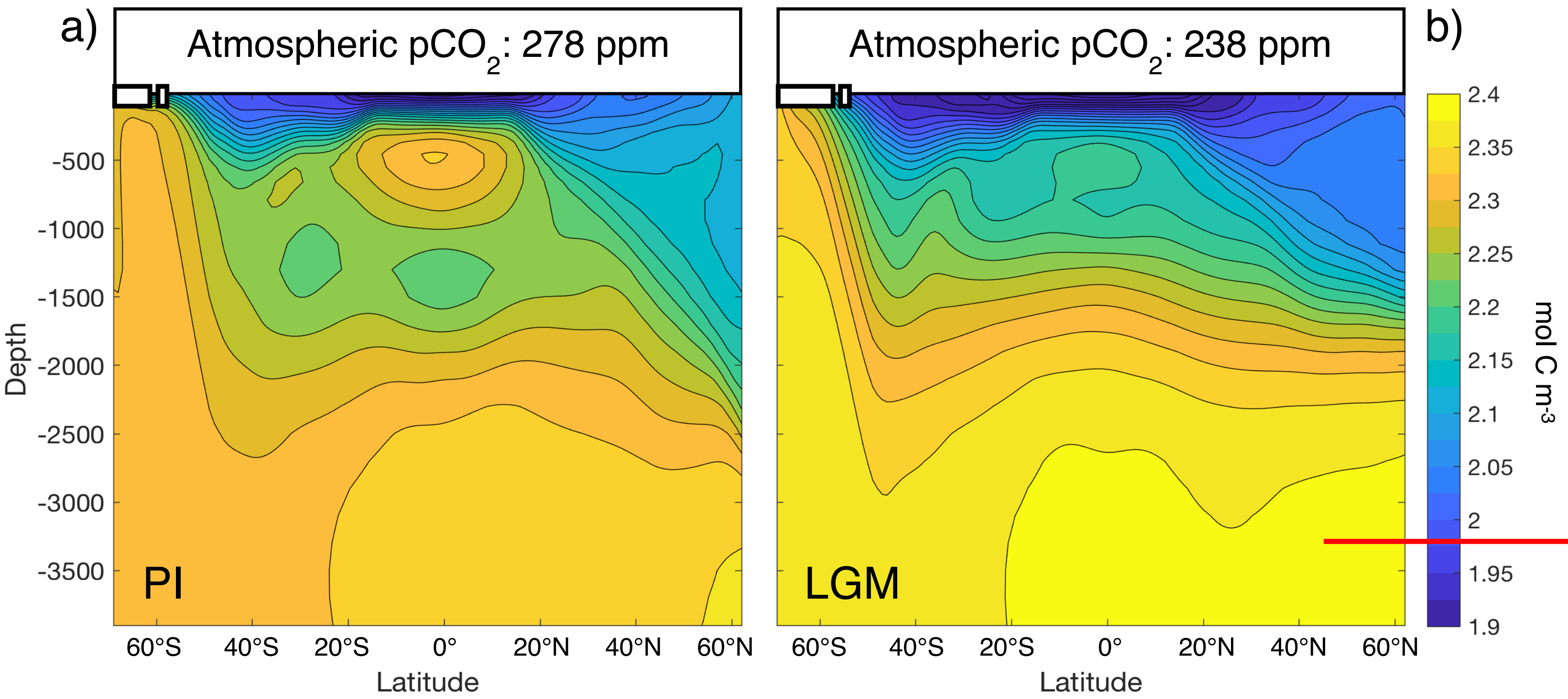
Antarctic Bottom Water (AABW) more isolated from surface at LGM due to:

(1) Weaker mixing with the upper cell (shallower water masses' interface)

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

more deep-ocean carbon storage ?

YES!



Shading and contours: Dissolved Inorganic Carbon (DIC) in the model (meridional cross-section)

LGM simulation:

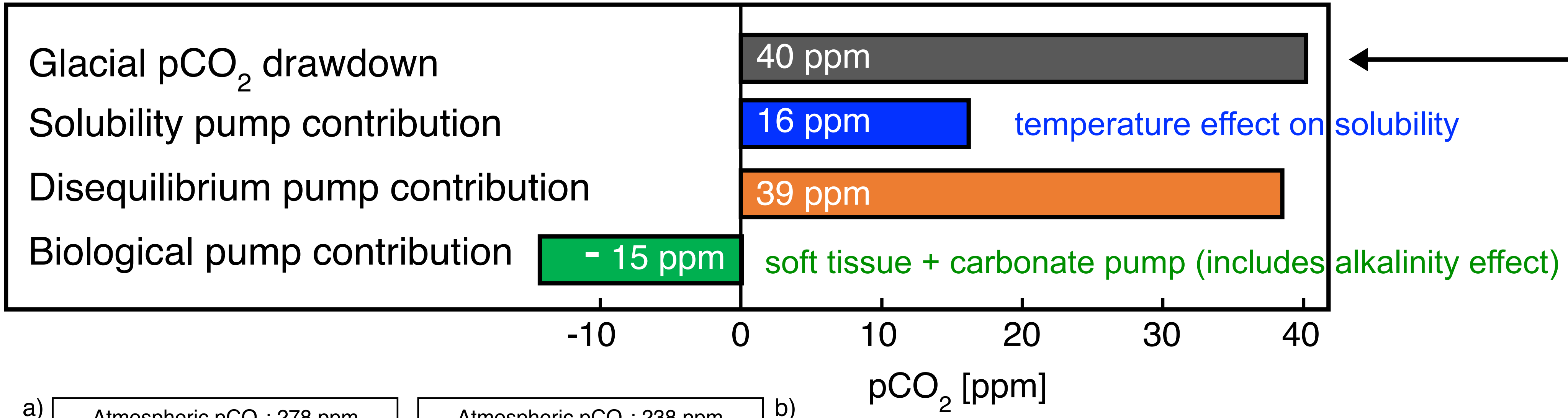
40 ppm pCO_2 drawdown

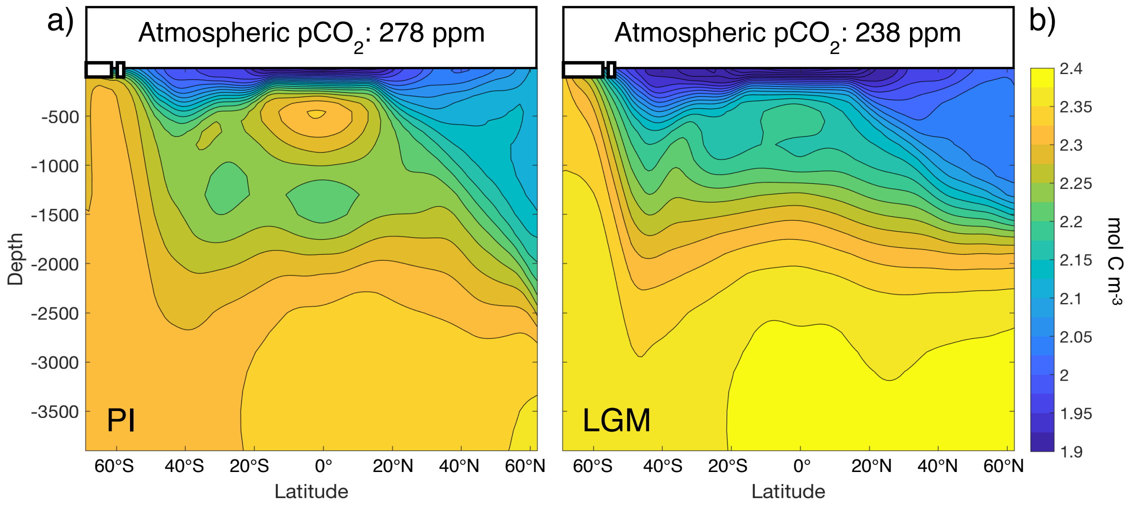
(from data: ~80 ppm)

Marzocchi and Jansen (2019, Nat.Geosci)

Linking atmospheric cooling to increased ocean carbon storage

Carbon pump decomposition (following *Ito and Follows, 2005*)





LGM simulation:
40 ppm pCO_2 drawdown
(from data: ~80 ppm)

Marzocchi and Jansen (2019, Nat.Geosci)

Sensitivity experiments: pCO_2 and carbon pump decomposition

	Control	$\kappa-50\%$	$\kappa+50\%$	No ice	Seasonal cycle	Max bio.
p_{CO_2} PI (ppm)	278			278	270	
p_{CO_2} LGM (ppm)	238	244 ??	255 ++	268 ++	236	153 −−−
PI-LGM solubility pump (ppm)	16	20	16	17	15	12
PI-LGM biological pump (ppm)	−15	−42	−15	−16	5 ++ ??	122
PI-LGM disequilibrium pump (ppm)	39	57 ++	22 −−	10 −−	14	−10

Run is forced with seasonally-varying atm temperatures

→ slight decrease in pCO_2 drawdown ??

+50% diapycnal diffusivity (κ)
→ more mixing with upper cell
→ stronger disequilibrium pump
→ less pCO_2 drawdown

−50% diapycnal diffusivity (κ)
→ less mixing with upper cell
→ weaker disequilibrium pump
→ drawdown should increase?

Sea-ice "lid" effect removed
→ only 10 ppm drawdown
→ much weaker diseq. pump
(from circulation changes only)

Max biological productivity
(e.g. glacial iron fertilisation)
→ model's drawdown potential
(LGM data: ~190 ppm)

Marzocchi and Jansen (2019, Nat.Geosci)

Summary and conclusions

- LGM ocean circulation changes and expanded Antarctic sea-ice cover lead to further Antarctic Bottom Water (lower overturning cell) isolation from the upper cell, favouring increased deep-ocean carbon storage.

- In these simulations, physical changes alone (forced solely by atmospheric cooling) result in 40 ppm pCO_2 drawdown (half of glacial-interglacial variations from data)

  Close coupling between CO_2 and Antarctic air temperatures (e.g. ice core record)

- Ocean circulation changes contribution: ~10 ppm drawdown

  Sea-ice capping contribution: ~30 ppm drawdown

  Can't fully separate contributions → sea-ice expansion leads to circulation changes.

- Changes in disequilibrium pump (main contribution to drawdown in LGM ctrl simulation) are consistent in sensitivity experiments, but some changes in pCO_2 are less straightforward.

- Idealised sensitivity experiment reaching maximum model's drawdown potential shows that increasing contribution from biological pump can push pCO_2 below LGM concentrations.

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Marzocchi, A. and Jansen, M.F. (2019) Global cooling linked to increased glacial carbon storage via changes in Antarctic sea ice. *Nature Geoscience*, 12(12), pp.1001-1005 → link

Jansen, M.F. (2017) Glacial ocean circulation and stratification explained by reduced atmospheric temperature. *Proceedings of the National Academy of Sciences*, 114(1), pp.45-50 → link

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