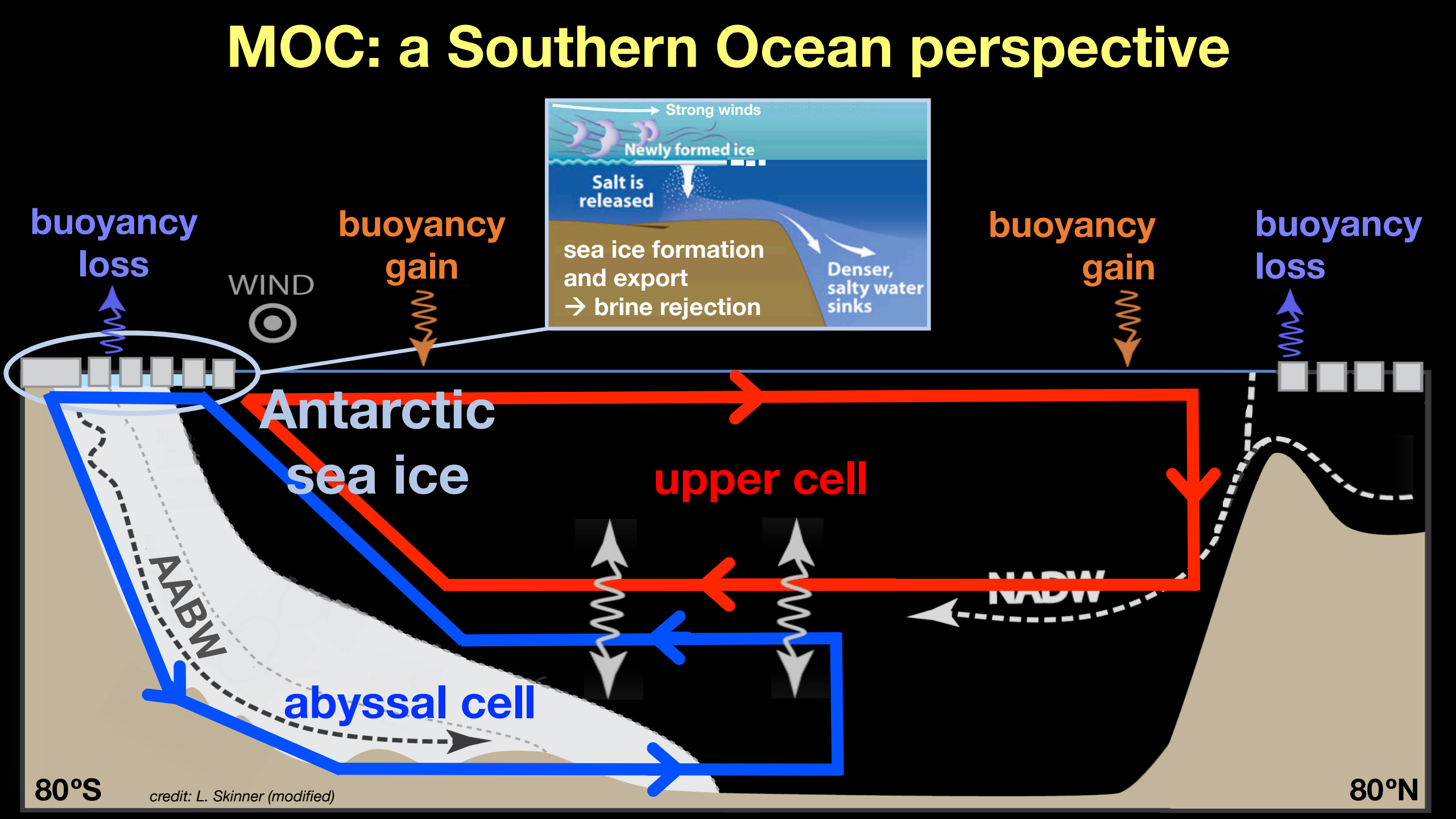
THE UNIVERSITY OF CHICAGO

The role of sea ice and buoyancy fluxes in shaping glacial and modern overturning circulation

Alice Marzocchi and Malte Jansen

US AMOC meeting - Santa Fe, 24th May 2017

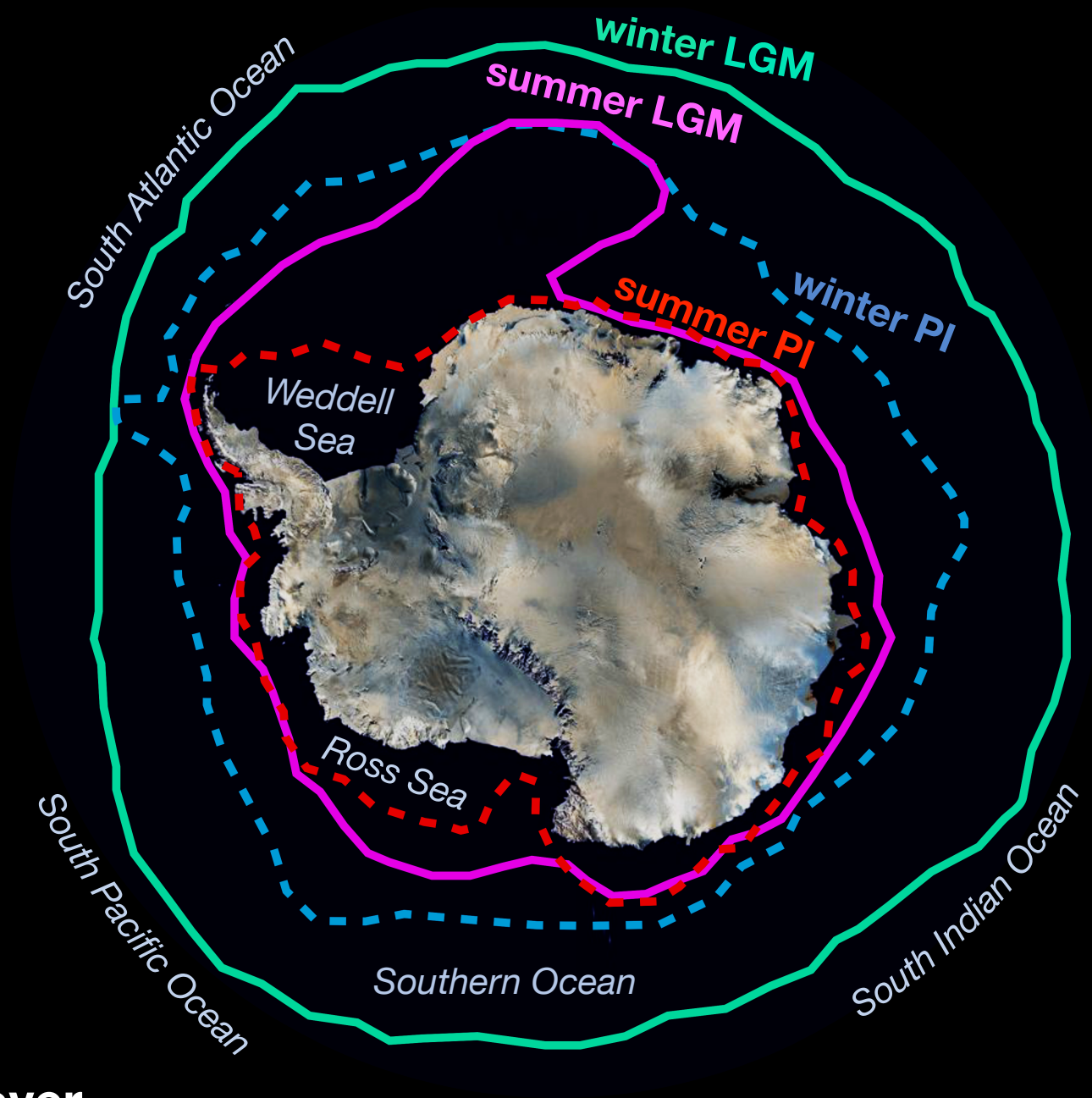
MOC: a Southern Ocean perspective



Last Glacial Maximum

~21k yrs ago
lower CO_2 (~190 ppm)
lower temperatures (~3-6 °C cooler)
lower sea level (~125 m less)
higher ocean salinity (~1 psu)
extensive ice sheets growth

Markwick (2003)

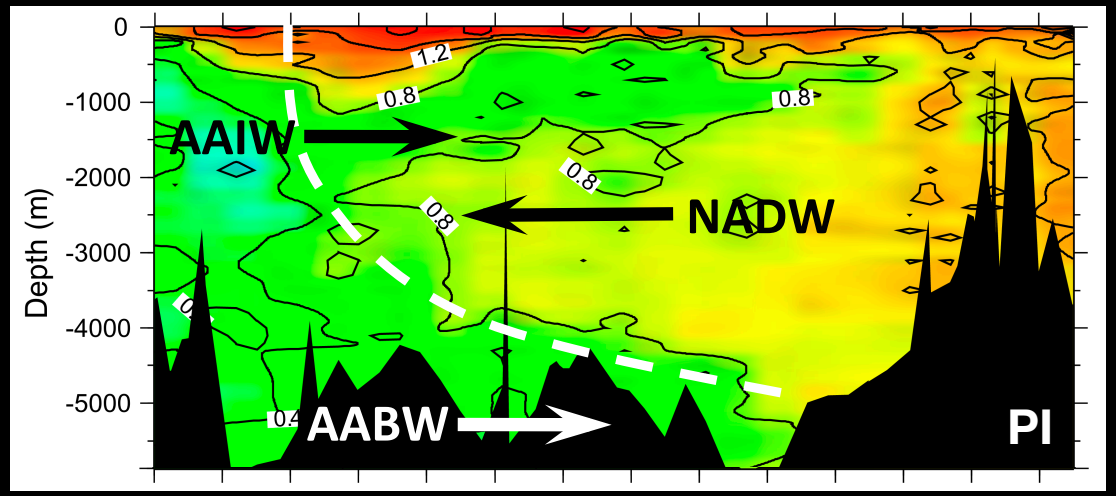


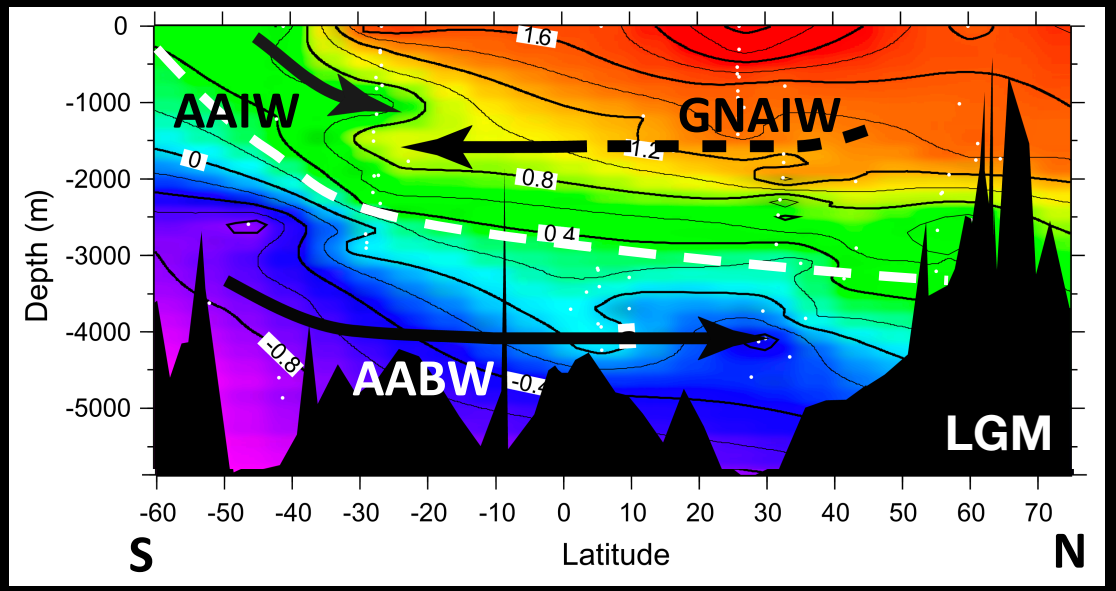
→ expanded Artic and Antarctic sea ice cover

compilation from Roche et al. (2012)

Modern vs LGM overturning circulation (Atlantic)

δC^{13} (Western Atlantic)

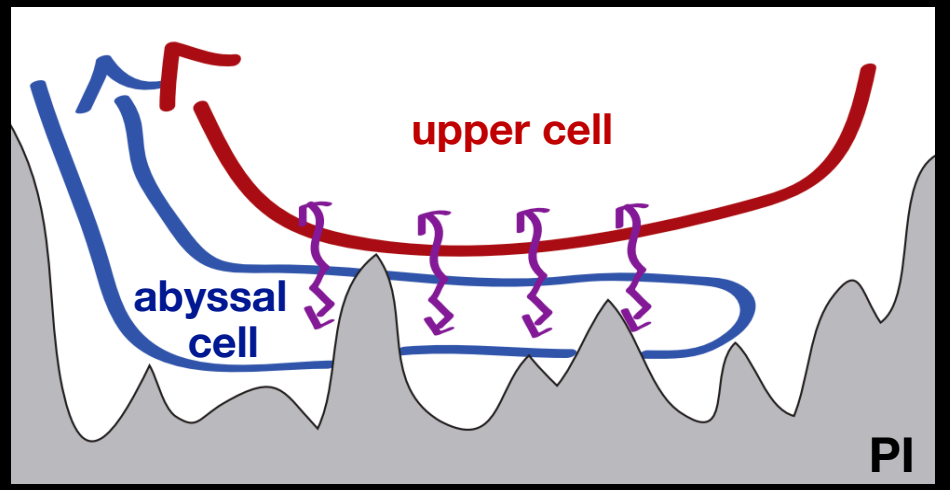


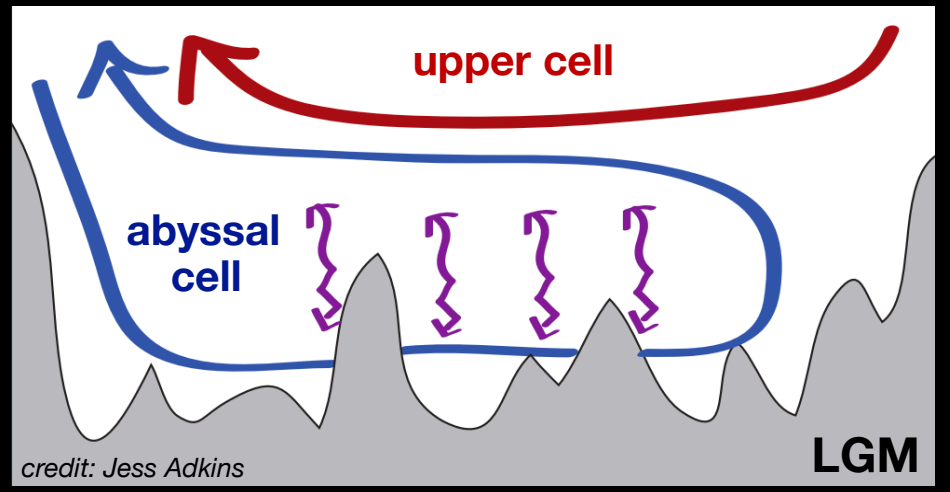


Curry and Oppo (2005)

shallower upper cell

expanded abyssal cell





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What caused the inferred changes in ocean circulation?

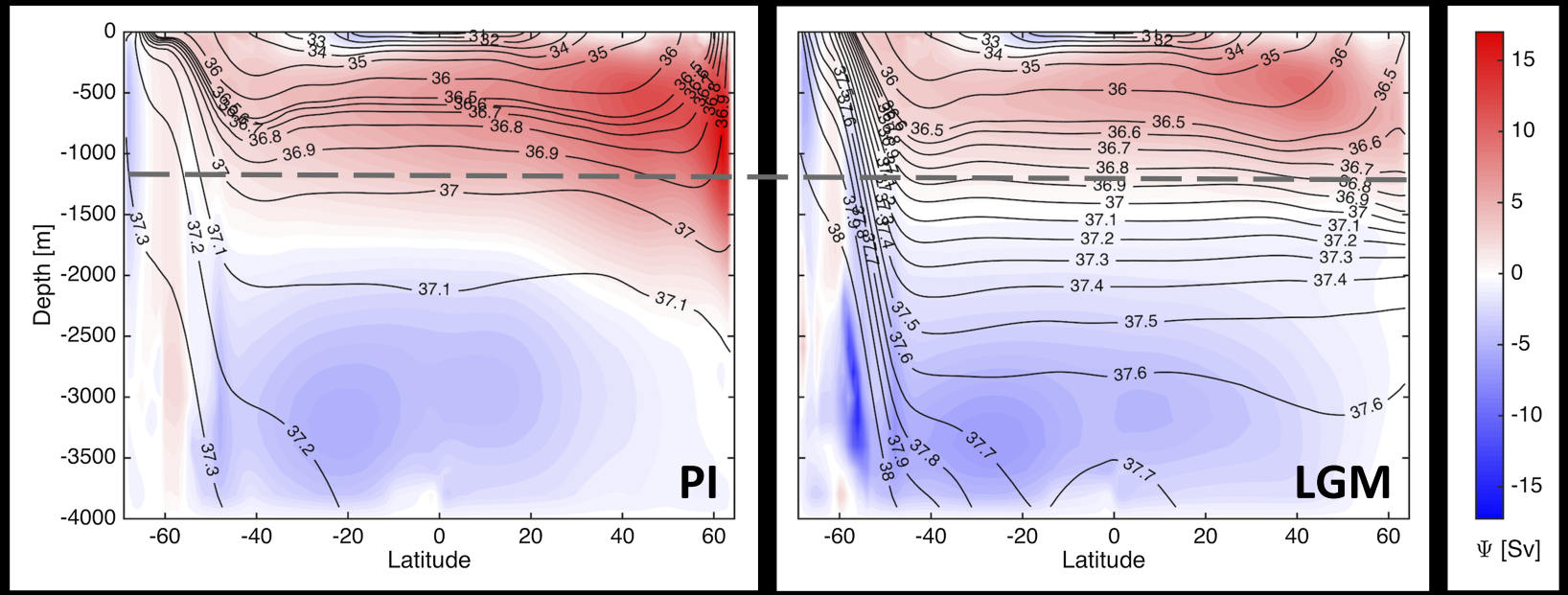
Mechanistic "chain of events" from idealized simulations:

LGM atmospheric cooling → increased Antarctic sea ice formation → increased buoyancy loss rates → increased abyssal stratification → upward shift of upper overturning cell (NADW)

overturning streamfunction

idealized ocean + sea ice model (single-basin)

Jansen (2017)



shallower upper cell

increased deep stratification

broadly consistent with proxies *(e.g. Adkins et al., 2002)*

Key: Antarctic sea ice/buoyancy loss. See also: Shin et al. (2003); Ferrari et al. (2014); Watson et al. (2015); Jansen & Nadeau (2016)

What caused the inferred changes in ocean circulation?

Mechanistic "chain of events" from idealized simulations:

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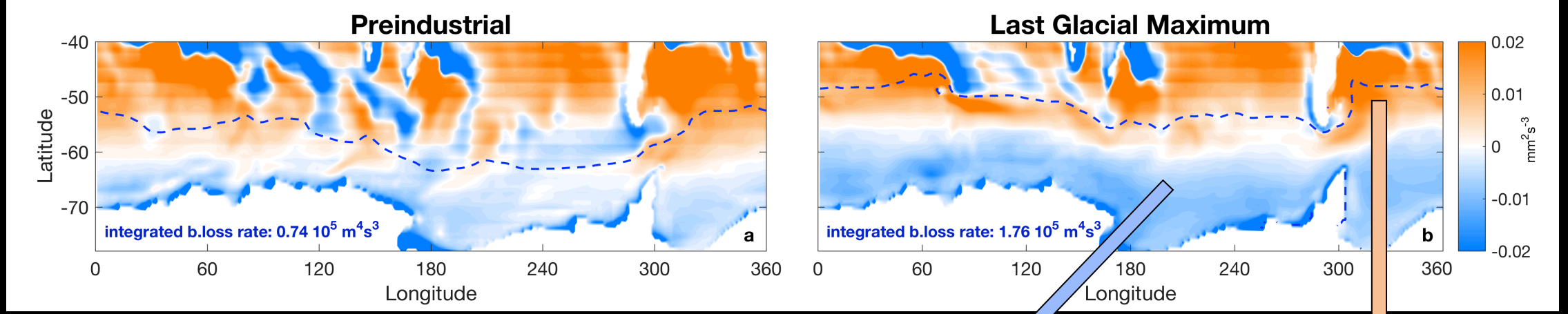
Can this mechanism be verified in fully-coupled simulations?

Paleoclimate Modelling Intercomparison Project (PMIP)

Marzocchi and Jansen (GRL – pending minor revisions)

CCSM3 (PMIP2)



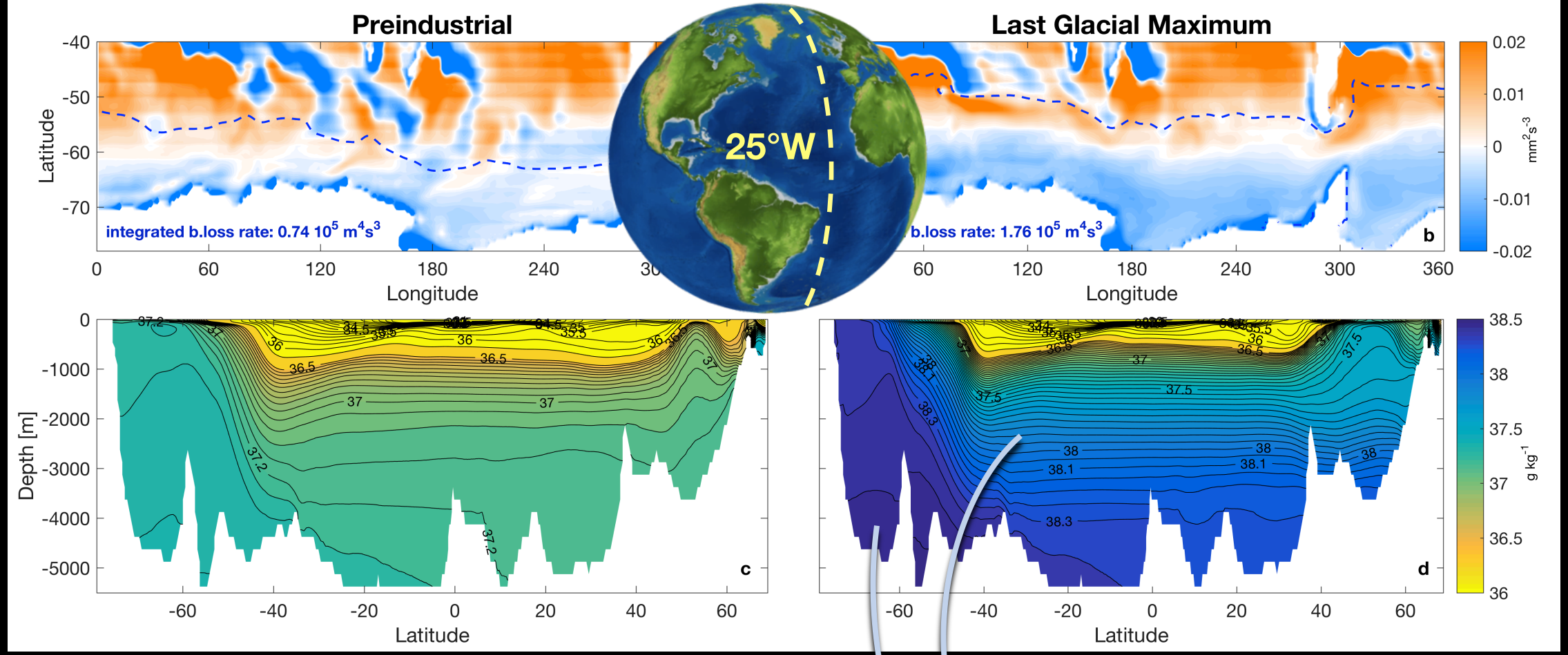
b. loss

NEGATIVE B:
atmospheric cooling
and brine rejection

POSITIVE B:
atmospheric heating
and precipitation

B: buoyancy fluxes = heat fluxes + freshwater fluxes

CCSM3 (PMIP2)



b. loss

density

increased LGM stratification

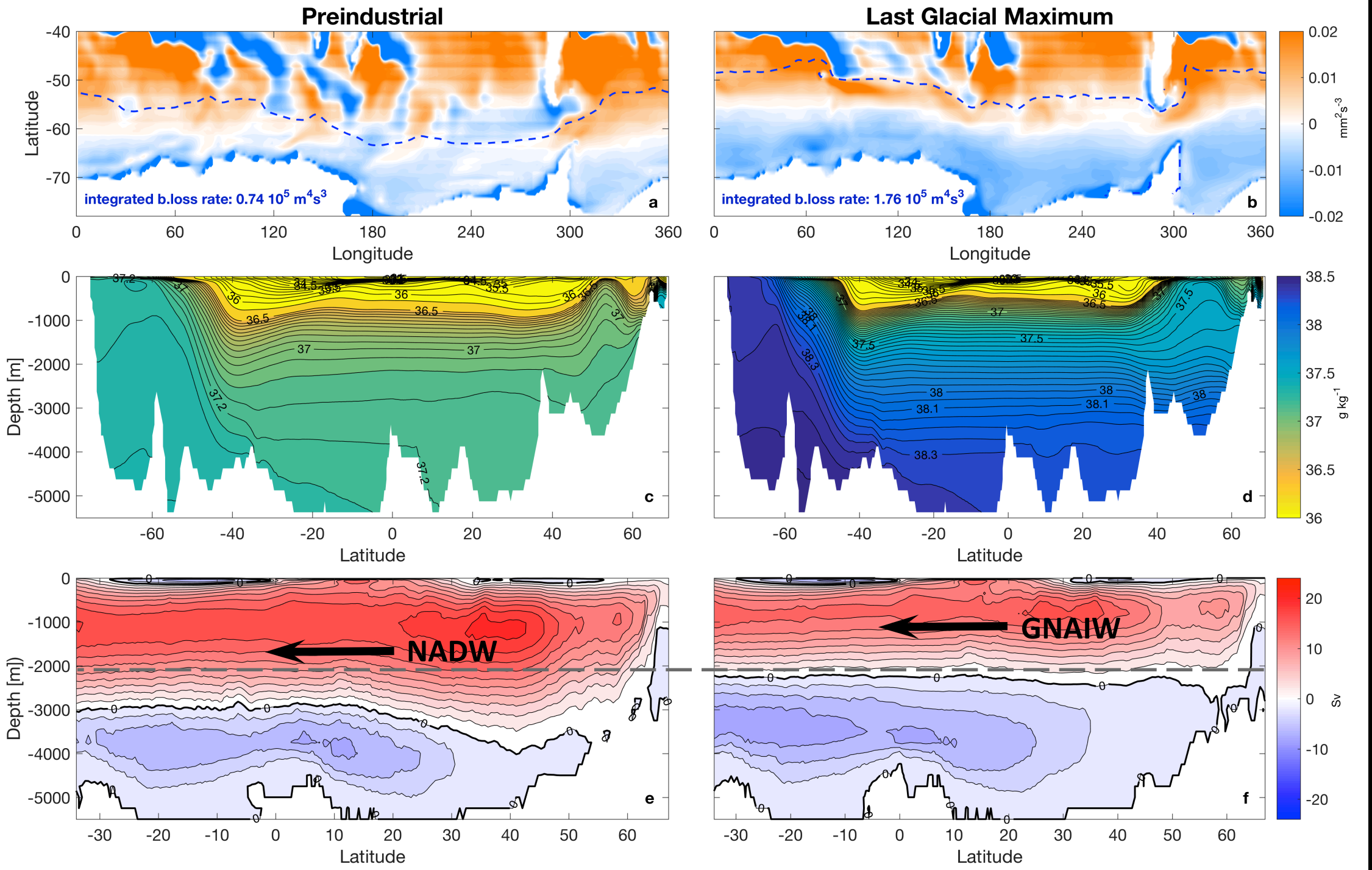
denser AABW formed

CCSM3 (PMIP2)

b. loss

density

AMOC

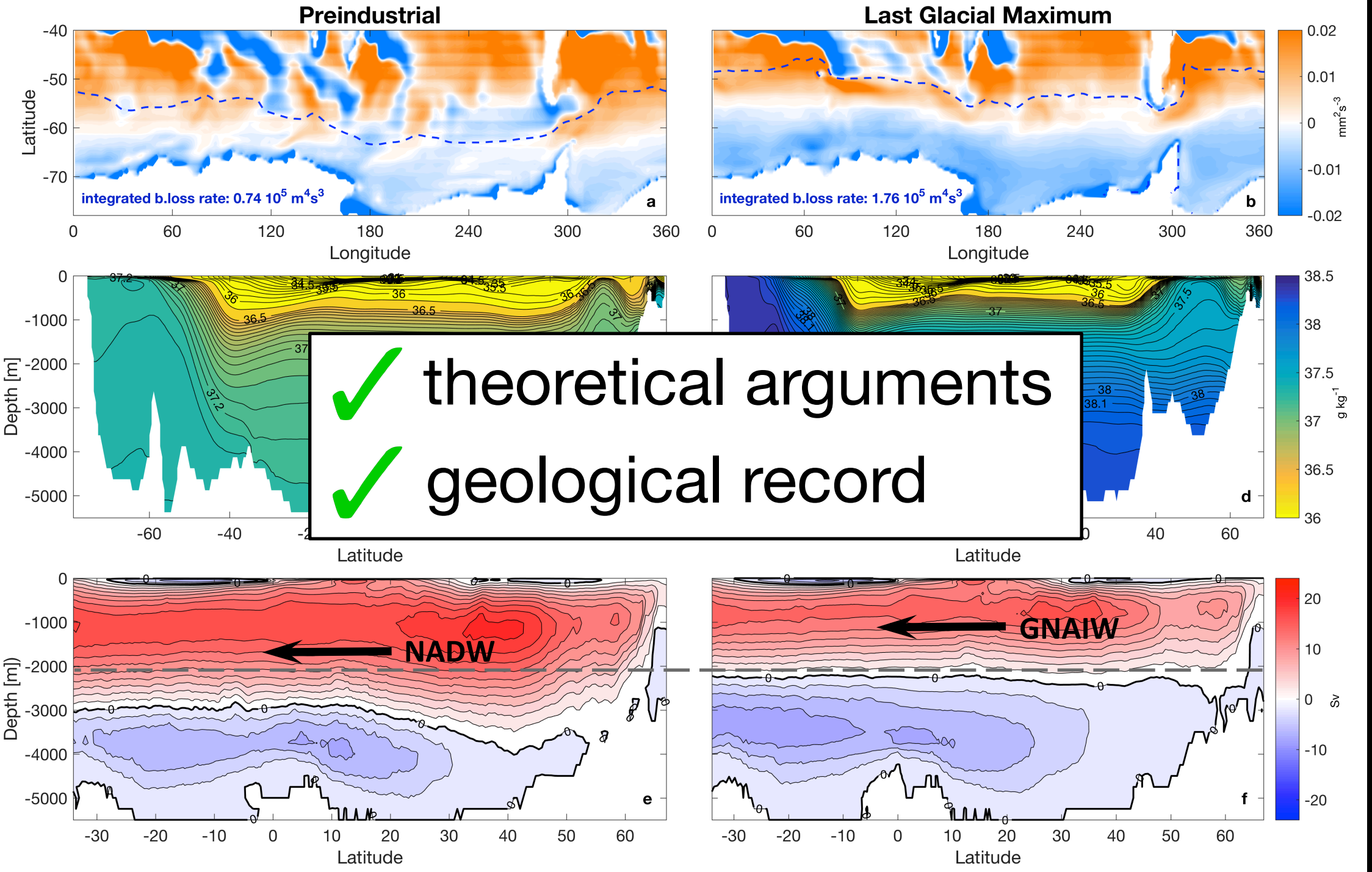


CCSM3 (PMIP2)

b. loss

density

AMOC



✓ theoretical arguments

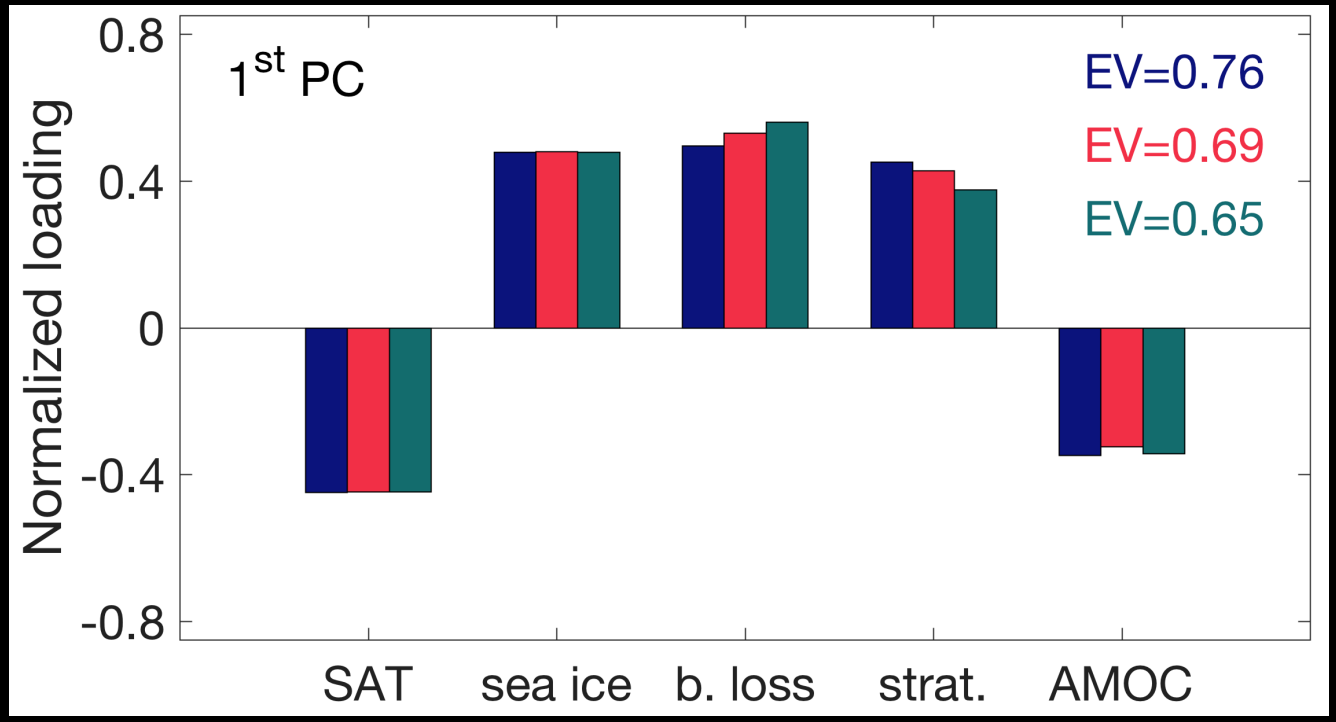
✓ geological record

What about other models?

(PMIP3/CMIP5)

Principal Component Analysis

"chain of events": surf. air temp. → sea ice extent → buoyancy loss rate → stratification → AMOC



Method #1: no missing data (CCSM3, CCSM4 and MRI)

Method #2: missing data for at most one of the five variables (CCSM3, CCSM4, MRI, FGOALS, MPI, MIROC, CNRM)

Method #3: all models (CCSM3, CCSM4, MRI, FGOALS, MPI, MIROC, CNRM, IPSL, GISS)

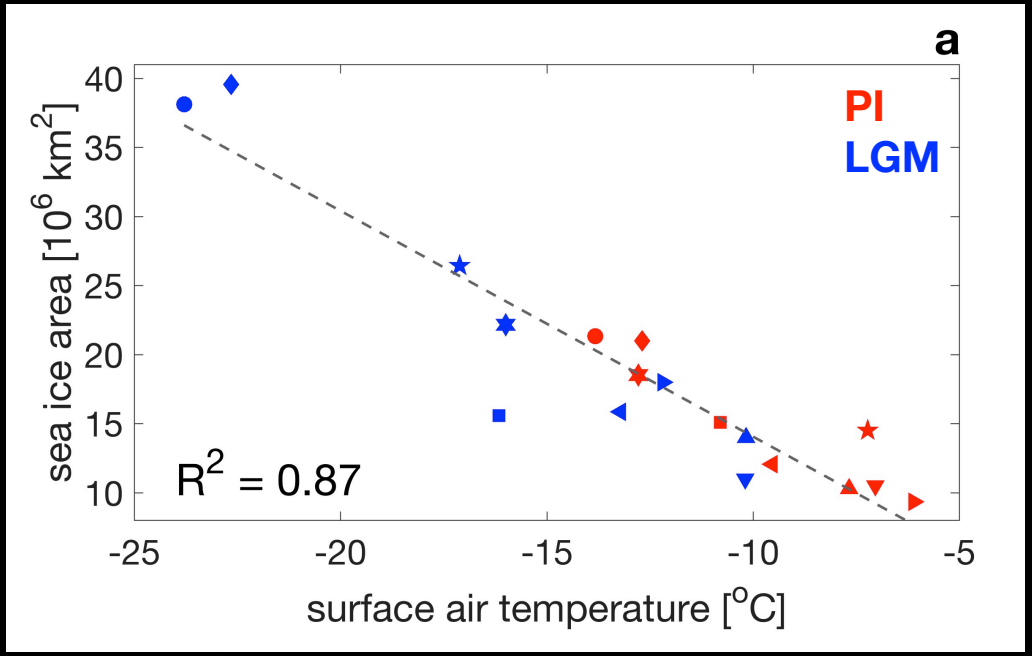
includes all PI and LGM simulations

PMIP3 models: mechanistic “chain of events”

surf. air temp.

⬇

sea ice conc.



PMIP2
- CCSM3
- CCSM4

PMIP3
- MRI
- FGOALS
- MIROC
- MPI
- IPSL
- CNRM
- GISS

PMIP3 models: mechanistic “chain of events”

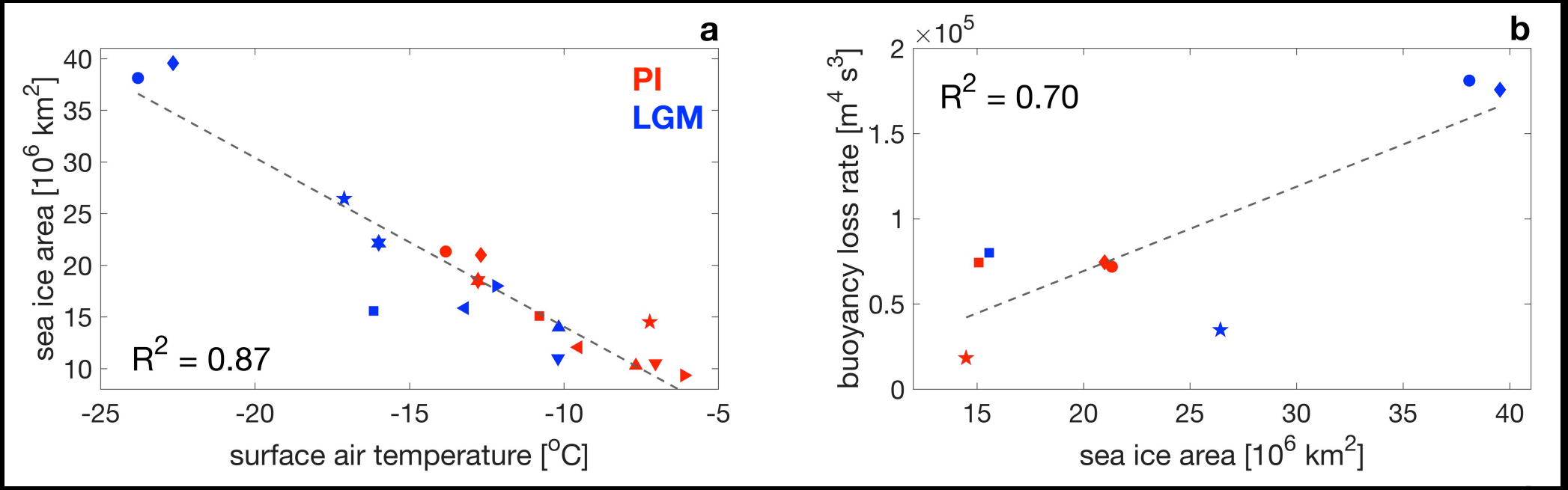
surf. air temp.

⬇

sea ice conc.

⬇

b. loss rate



- CCSM3
- CCSM4
- MRI
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- GISS

PMIP3 models: mechanistic “chain of events”

surf. air temp.

⬇

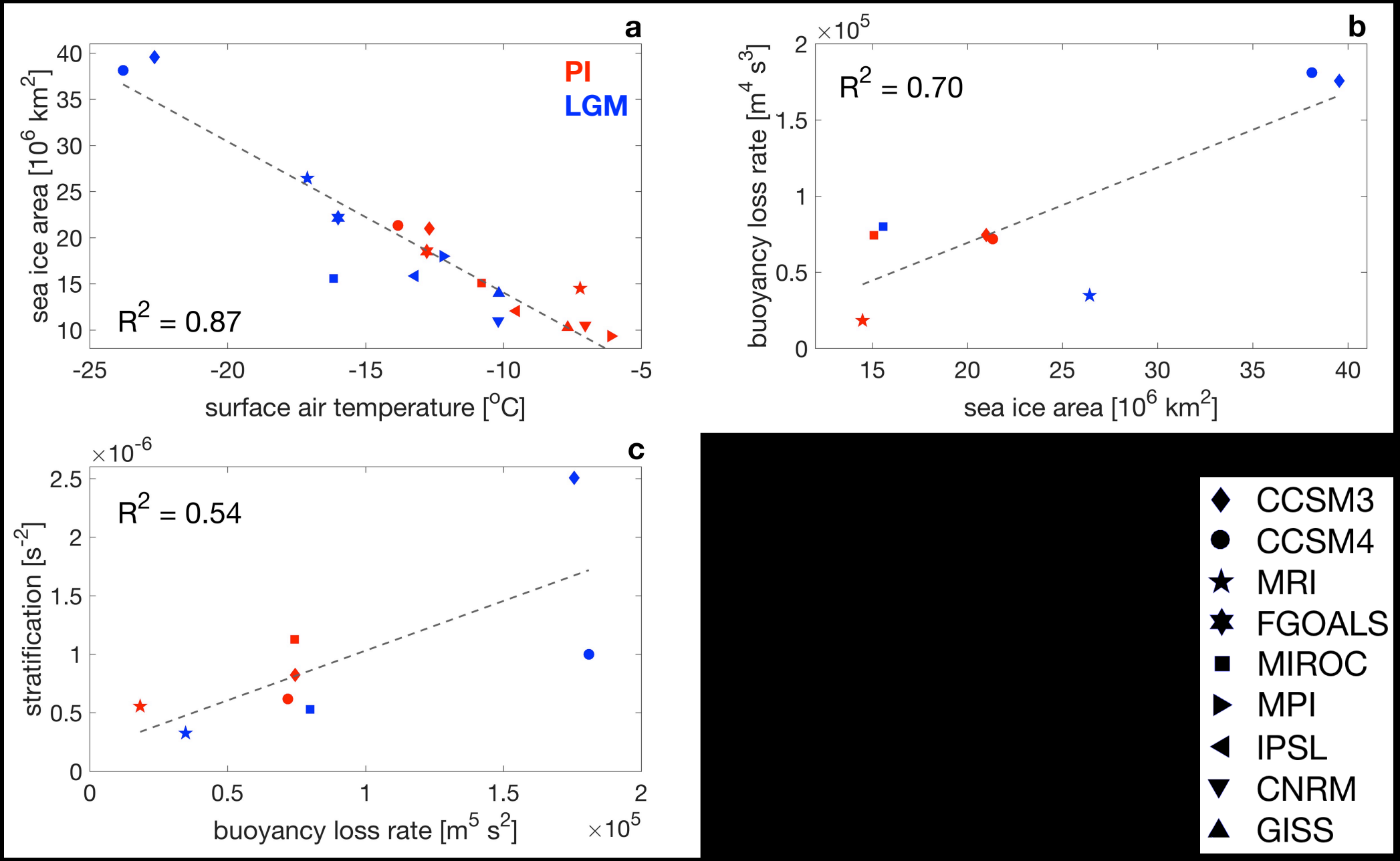
sea ice conc.

⬇

b. loss rate

⬇

stratif.



PMIP3 models: mechanistic “chain of events”

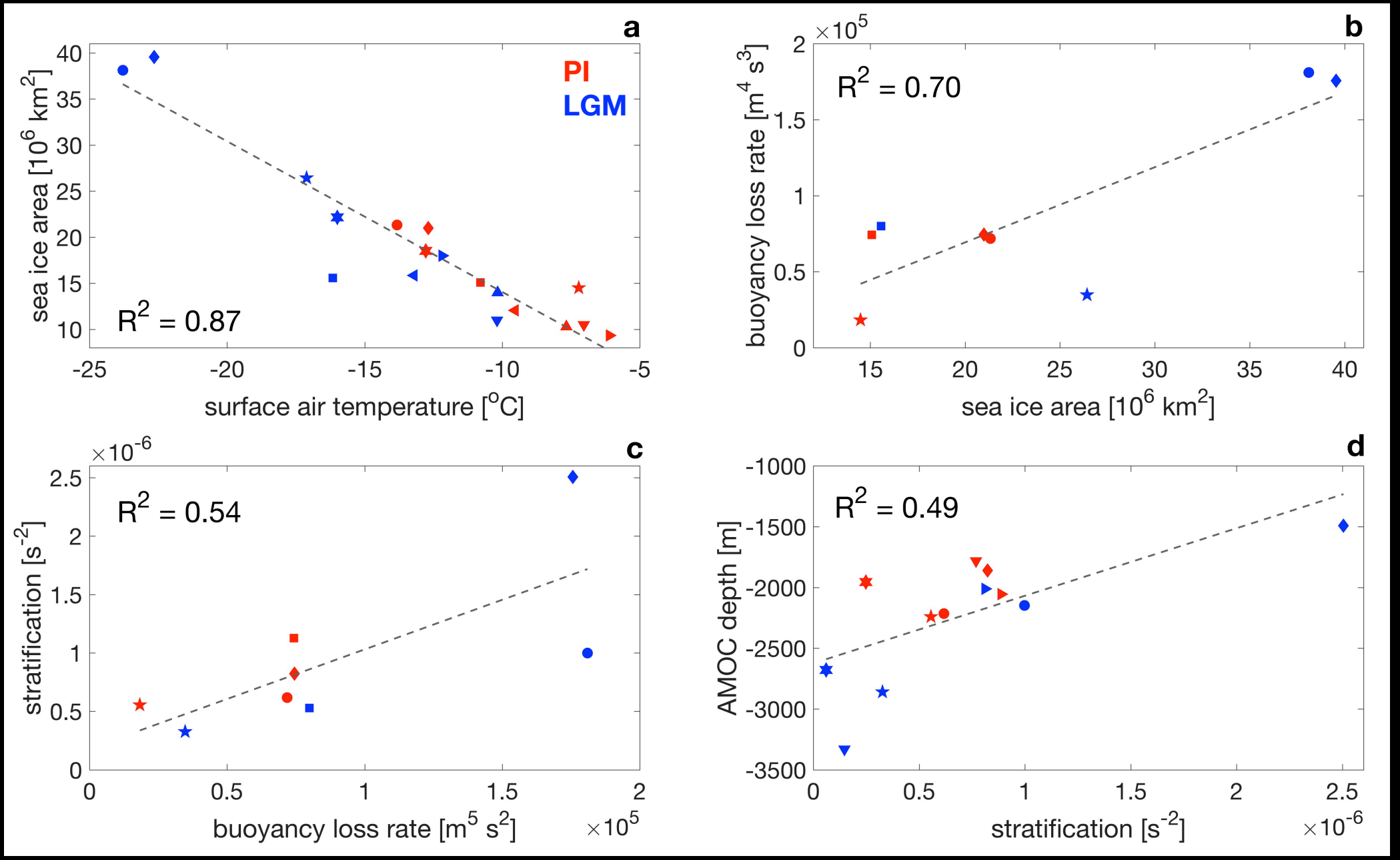
surf. air temp.

sea ice conc.

b. loss rate

stratif.

AMOC depth



PMIP3 models: mechanistic “chain of events”

surf. air temp.

⬇

sea ice conc.

⬇

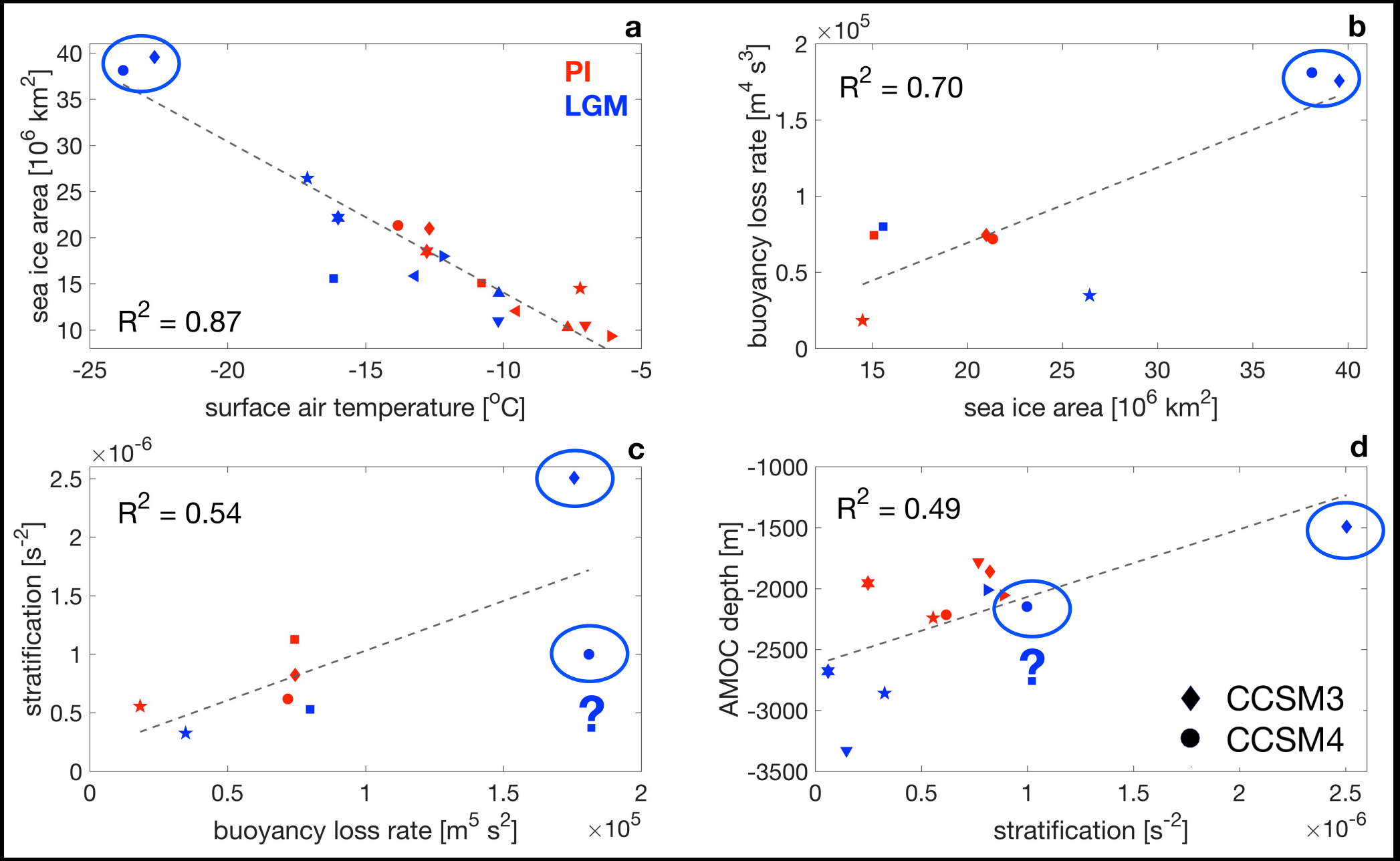
b. loss rate

⬇

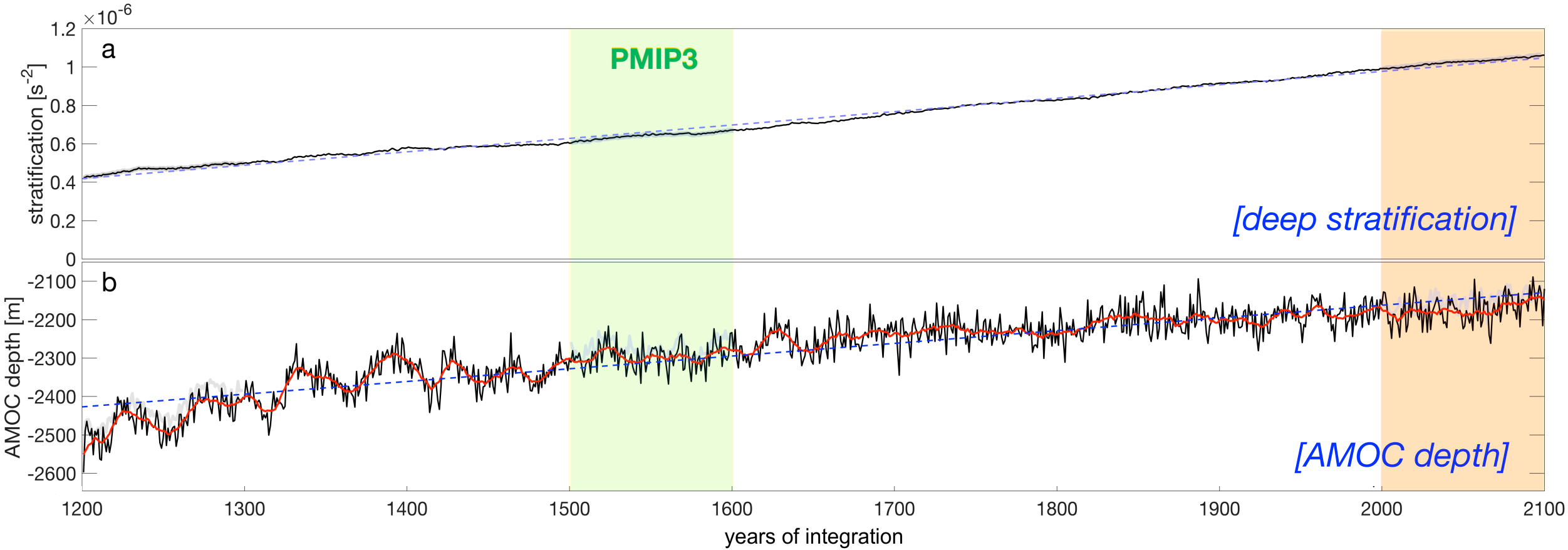
stratif.

⬇

AMOC depth

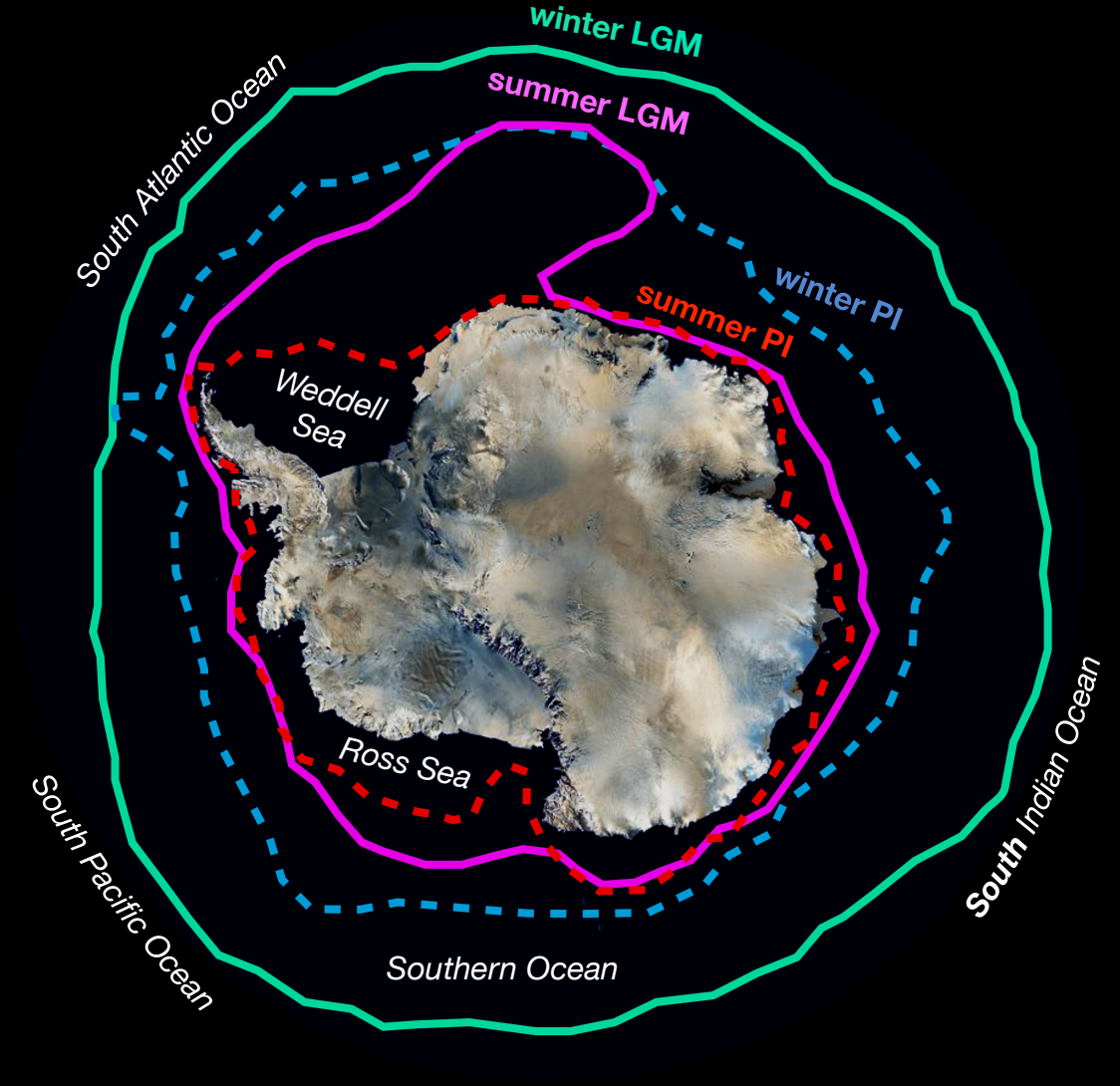


bias #1: lack of deep-ocean equilibration

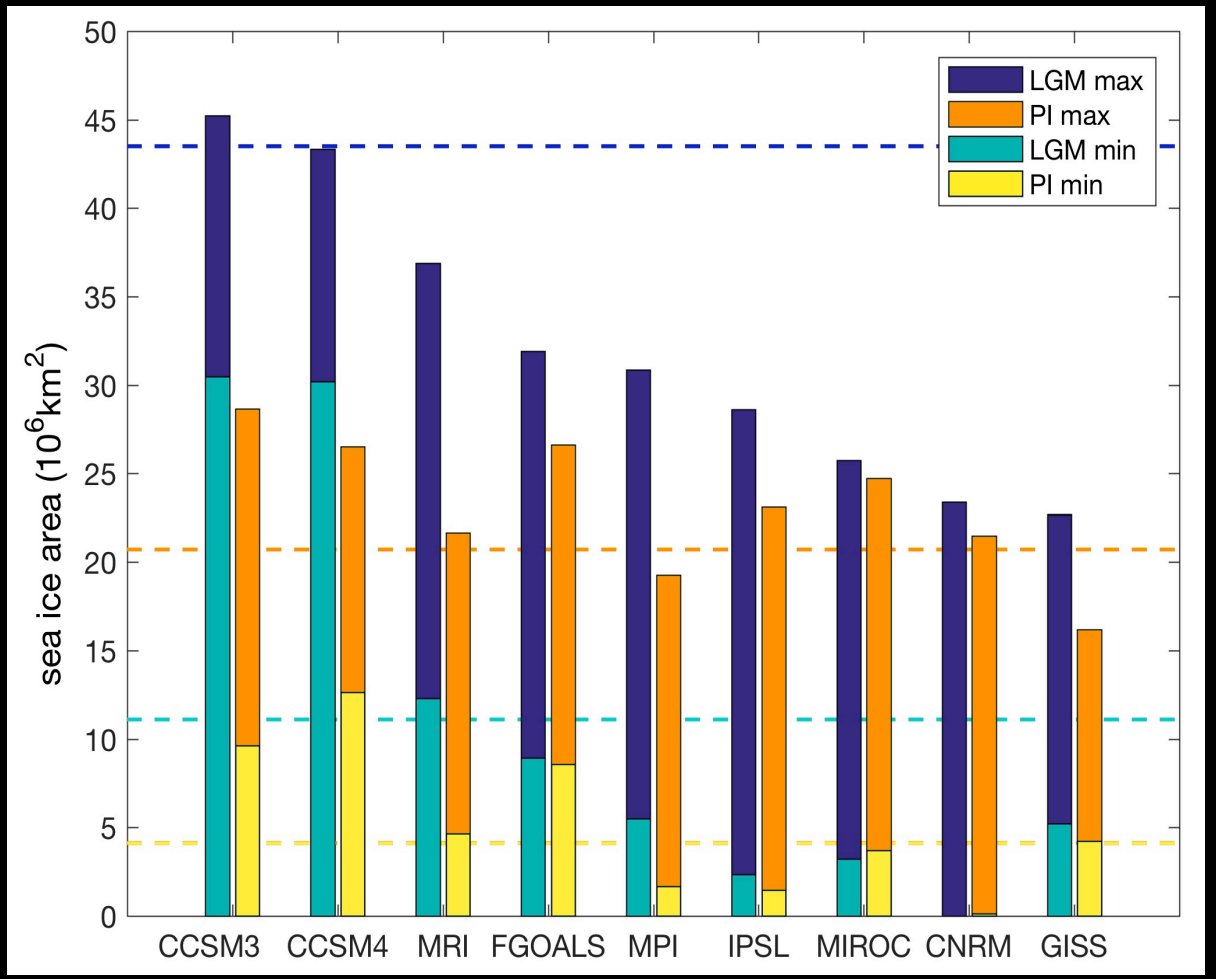


CCSM4 model, LGM simulation

bias #2: insufficient Antarctic sea ice formation/export



--- observations from Roche et al. (2012)



Observational compilation (Roche et al., 2012)

PIMIP2 **PIMIP3**

Take-home messages

- Importance of Antarctic sea ice (buoyancy loss) in setting deep-ocean stratification and AMOC strength/depth.

- Discrepancies between paleo-proxies and simulated LGM ocean circulation and between different PMIP models can largely be reconciled:

  #1: *biases due to different simulation of Antarctic sea ice formation/export*
  #2: *discrepancies amplified by short integration times (transient response)*
  #3: *effect of other compensating forcings (often model-specific)*

- Same models used for future projections → same issues! (PMIP4/CMIP6)

- **What about a warmer world?** Disappearance of Antarctic sea ice?
  → proposed mechanism would suggest AMOC strengthening/deepening
  BUT that is equilibrium response! Transient is likely AMOC weakening