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

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now at:
Glacial-interglacial transitions: ocean’s role?

Last Glacial Maximum (LGM) (~ 21,000 yrs ago)

CO₂ ~180-190 ppm
SAT ~ 2-6°C colder than present-day

Vostok ice core

data from Petit et al. (1999)
Observational and paleoclimate record

δ¹³C data from Western Atlantic

preindustrial

Last Glacial Maximum

Curry and Oppo (2005)
What drives glacial-interglacial water masses reorganization?

Key player: Antarctic sea ice
Glacial Antarctic sea-ice expansion

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. Gerson de et al., 2005; Benz et al., 2016)
Idealized ocean-sea-ice simulations

- Coupled to dynamic sea-ice model
- MITgcm
- Single basin with re-entrant channel
- $1^\circ \times 1^\circ$ horizontal resolution
- 29 vertical levels
- Prescribed P-E, winds and atm temperatures
Idealized ocean-sea-ice simulations

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

+++ sea ice expansion
+++ buoyancy loss

+++ stratification
--- AMOC depth
coupled climate model

CCSM3 simulation (Otto-Bliesner et al., 2006)
From ocean circulation to carbon storage

preindustrial

air-sea gas exchange

CO₂

dissolved carbon
From ocean circulation to carbon storage

Last Glacial Maximum

increased sea-ice extent

stronger stratification

mixing

sea-ice “lid”

dissolved carbon

CO₂
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)
DIC (dissolved inorganic carbon)

preindustrial

Last Glacial Maximum

DIC (dissolved inorganic carbon)

atmospheric pCO$_2$: 278 ppm

atmospheric pCO$_2$: 238 ppm

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

glacial-interglacial pCO$_2$ variations: 80-90 ppm

Sensitivity experiments

<table>
<thead>
<tr>
<th></th>
<th>CTRL</th>
<th>No sea ice</th>
<th>Seas. cycle</th>
<th>Efficient bio</th>
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<tr>
<td>PI</td>
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<td>270</td>
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<tr>
<td>LGM</td>
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From LGM reconstructions: 180-190 ppm
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

- spin-up (transient)
- equilibrium

reference/initial condition: preindustrial

forcing: 2-6°C atm

“glacial”

“hot house”

cooling warming

Jansen et al. (2018)