PAL MOD GERMAN CLIMATE MODELING INITIATIVE

Southern Ocean Si:N drawdown ratio in the glacial ocean and its biogeochemical consequences in low latitudes

Ying Ye, Christoph Völker, Martin Butzin, Peter Köhler

Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research

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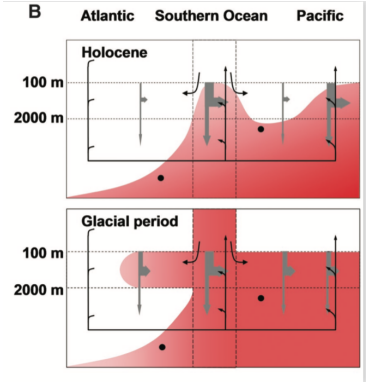
DLR Project Management Agency

Silicic acid leakage hypothesis (SALH)

- higher Si:N uptake ratio by diatoms under Fe-limitation
- higher dust deposition during glacial periods
  $\rightarrow$ relaxation of Fe-limitation in Southern Ocean
  $\rightarrow$ Si excess transported northward in low latitudes
- explain the glacial atmospheric CO_2 drawdown:
  diatom production in low latitudes $\uparrow$ + carbonate pump $\downarrow$
  (Matsumoto et al. 2002, 2008)

Requirements for models to test SALH:

- flexible stoichiometry (Si:N)
- dependence of Si uptake on Fe-limitation
- LGM conditions (climate, aeolian input of iron)



Ellwood et al. 2010

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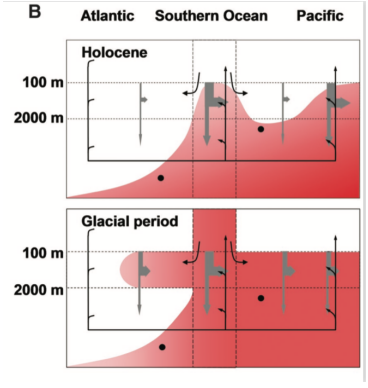

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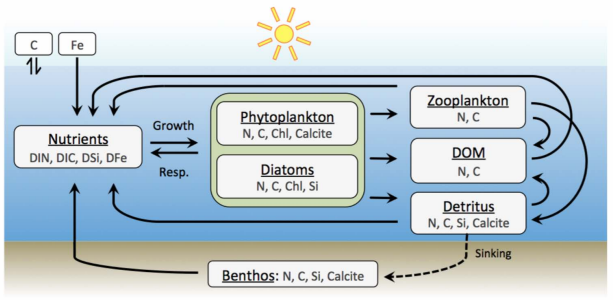
Regulated Ecosystem Model (REcoM)



Schourup-Kristensen et al. 2014

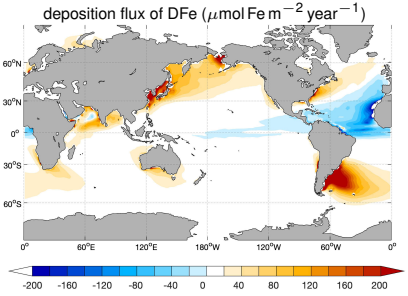
- coupled to MITgcm and FESOM
- indirect effect of Fe limitation on Si uptake:
  just depending on the Si availability and intracellular Si:C ratio
- physiological basis: down-regulation of N uptake by nutrient limitation (Claquin et al. 2002)

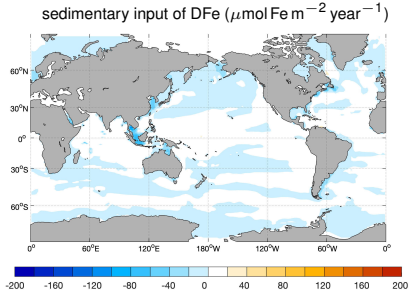
Model set up and experiments

forcing and initial field	PI	LGM
atmospheric	CORE	output from coupled COSMOS
pCO_2	284.3 or variable (initialised with 284.3)	190 or variable (initialised with 284.3)
dust	Albani 2014	Albani 2014
sea level	0	-116m
DIC and alkalinity	GLODAPv2	same amount as PI distributed over LGM volume
DIN and DSi	WOA	same method as for DIC
DFe	output from PICES	same method as for DIC

- physical spin-up 3000 years;
- biogeochemistry 1000 years and last 10 years for analysis;
- with constant atmospheric CO_2 and atmospheric CO_2 box

Change in iron supply by dust deposition and sediments





- Deposition flux: strongly enhanced in North Pacific and South Atlantic (doubled)
  reduced in the trop./subtrop. North Atlantic and eastern equat. Pacific
- sedimentary flux: one order of magnitude smaller than dust
  decreased to 1/4 in LGM, but not compensating dust increase

Step-by-step questions to examine SALH

1. if diatom Si:N decreased in Southern Ocean
2. if totally less Si compared to N utilised in Southern Ocean
3. if more DSi or higher Si:N remained in surface Southern Ocean
4. if Si-enriched waters transported northward to low latitudes
5. if diatom production in low latitudes increased and
6. if non-diatom production in low latitudes decreased

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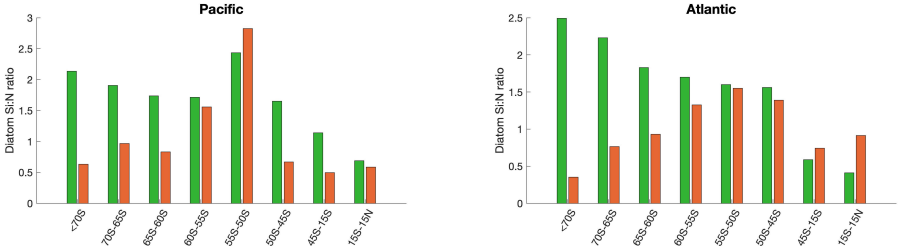
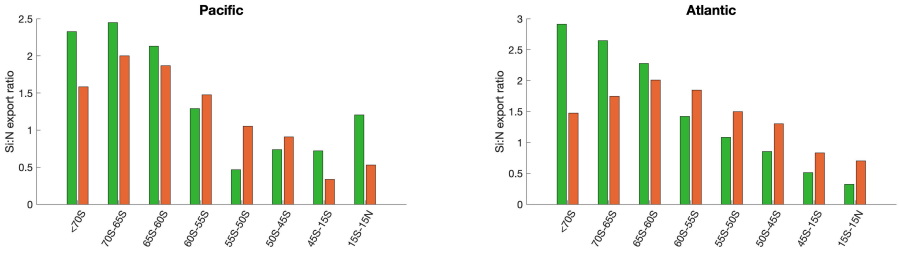
Diatom Si:N ratio



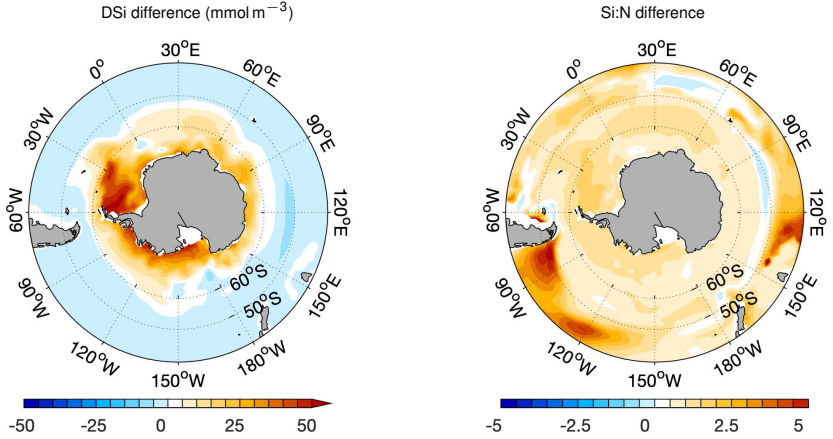
- south of 60°S: diatom Si:N is lowered during LGM
- northward shifted belt: growth limited by Fe $\rightarrow$ high Si:N
- higher Si:N in Pacific 50–55°S: strong increase of non-diatom
- Question 1: if diatom Si:N decreased in SO $\rightarrow$ Yes!

Total Si:N utilisation: Si:N in export



- decreased > 60°S and increased in the northward shifted belt
- decreased strongly in equatorial Pacific and increased in equatorial Atlantic
- Question 2: if less Si compared to N utilised in SO → Yes!

DSi and Si:N in SO seawater

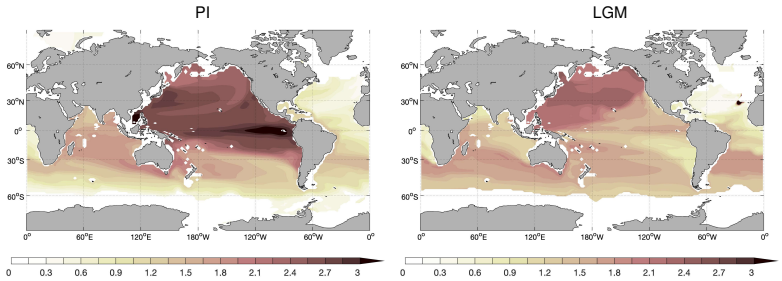


- Question 3: if more DSi or higher Si:N remains in surface SO $\rightarrow$ Yes!

Northward transport of Si-enriched water

Si:N along AAIW

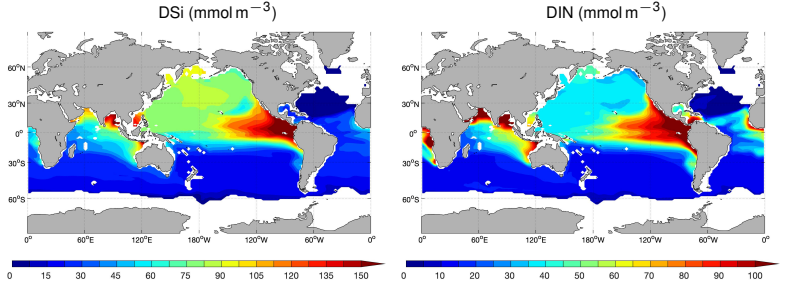
(σ=27.3)



- Si-enriched water transported along AAIW northward to subtropics/tropics
- Si:N in eastern South Pacific: LGM < PI; and in Atlantic: LGM $\geq$ PI
- Question 4: if Si-enriched waters transported northward to low latitudes
  $\rightarrow$ AAIW loses Si excess on the way to tropics

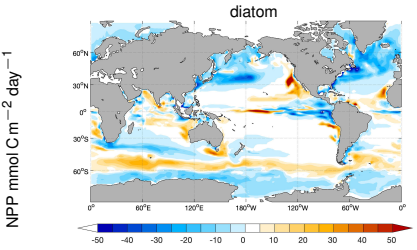
Northward transport of Si-enriched water

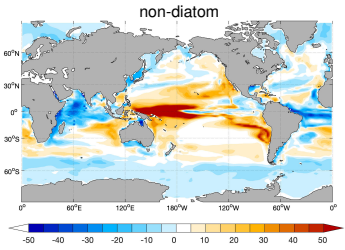
along AAIW (σ=27.3)



- DSi along AAIW slightly higher in eastern South Pacific
- DIN clearly increased:
  - higher dust input $\rightarrow$ strong increase of non-diatom growth
  - more DIN released by remineralisation

Biological production in low latitudes





- ↓ in east. and ↑ in central equat. Pac.
- ↓ in equat. Atl. but clearly ↑ in tropics
- Question 5: if dia. prod. in low latitudes ↑ → Yes for Atl. and No for Pac.!

- strongly ↓ in Atl.
- ↓ in east. equat. Pac. but clearly ↑ in west and subtropics
- Question 6: if non-diatom prod. in low latitudes ↓ → Yes for Atl. and No for Pac.!

Carbon uptake and storage

	PI			LGM		
	total	diatom	non-diatom	total	diatom	non-diatom
NPP (Pg C year^{-1})	36.8	13.5	23.3	41.6 (↑)	12.4 (↓)	29.2 (↑)
POC export (Pg C year^{-1})	8.9	-	-	8.0 (↓)	-	-
opal export (Tmol SiO_2 year^{-1})	-	107.2	-	-	72.8 (↓)	-
$CaCO_3$ export (Pg C year^{-1})	0.6	-	-	0.7 (↑)	-	-
$CaCO_3$: POC	0.067	-	-	0.089 (↑)	-	-

- NPP increased caused by increase of non-diatom
- non-diatom better recycled and not contributed much to export
- production of inorganic C increased compared to organic C: carbonate pump not reduced
- atmospheric pCO_2 decreased by 50 ppm
- more Si stored in the ocean interior during glacial time: Silicic Acid Ventilation Hypothesis?

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Thanks for your attention!