Si:N drawdown ratio in the glacial ocean and its biogeochemical impact

PALMOD GERMAN CLIMATE MODELING INITIATIVE

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Introduction / Motivation

Elevated Si:N drawdown and export ratios in the present-day Southern Ocean lead to a low Si:N ratio in the unused nutrients from the Southern Ocean. These nutrients are transported to low latitudes via mode and intermediate waters. It has been hypothesised that iron fertilisation of the Southern Ocean in the last glacial has led to a lower Si:N drawdown ratio there and hence changed stoichiometry of nutrients in low latitudes, with consequences for phytoplankton community structure and carbon cycling (**S**ilicic **A**cid **L**eakage **H**ypothesis). Here we investigate this hypothesis using a global biogeochemical model.

Model

We use a global set-up of the MITgcm global ocean circulation model (Marshall et al, 1997), coupled to the beigeochemical/ecosystem model REcoM (Hauck et al. 2013). REcoM is a flexible-quota model, based on Geider et al., 1998 and has been developed with the intention of reproducing changes in phytoplankton cellular stoichiometry.
The model is forced by atmospheric fields obtained from model output from the coupled climate model COSMOS (Zhang et al. 2013) for the last glacial maximum (LGM) and pre-industrial (PI) state. Dust deposition for the LGM is from Albani et al. 2014, for PI from Luo et al. 2003. In the LGM run, sea level is lowered by 116 m, and total ocean salinity and nutrient inventories are conserved.

Conclusion / Summary

As the SALH supposed, the Si-enriched Antarctic Intermediate Water in LGM supports higher diatom growth in low atitudes, contributing to higher C export there. The decrease in opal export in the eastern equatorial Pacific can be explained by lower Si:N uptake ratio when diatom is less limited by iron. The increase of C export in the western equatorial and tropical Pacific is mainly contributed by non-diatom production.
Using flexible cellular stoichiometry, we found out that opal flux is not necessarily proportional to diatom growth. Shifts in Si export agree with sediment cores, but resulting impact on C cycle is less straight forward than suggested in the SALH.

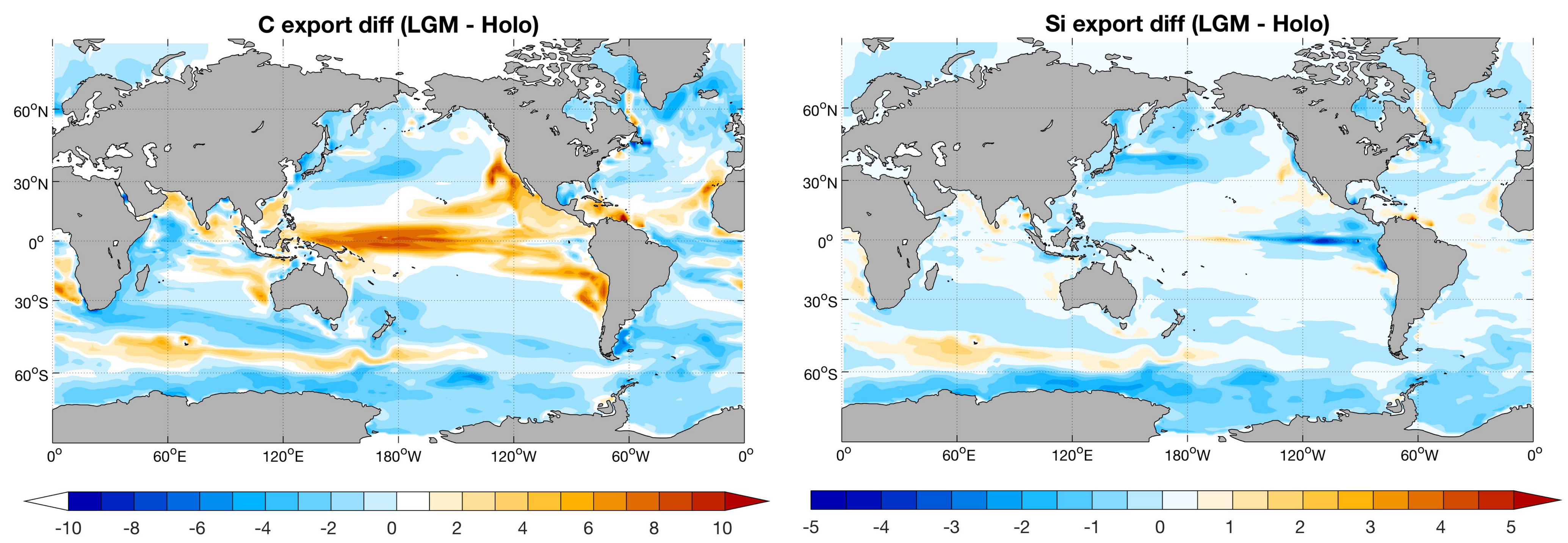


Fig. 1: Changes in biogenic carbon and opal export out of the euphotic zone, LGM minus PI. Fluxes are in mol Si/C m^{-2} yr^{-1}.

I. Changes in C and Si drawdown and export

The overall higher dust deposition in LGM leads to an increase of dissolved iron in most areas of the ocean, except in the tropical Atlantic. The changes in physical (sea ice, temperature) and nutrient (iron, silica) conditions results in a northward shift and overall decrease of Si and C export in the Southern Ocean. While C export increases overall in the low latitudes, Si export decreases in the eastern tropical Pacific and increases slightly in the tropical North Atlantic.
This seems to be at odds with the classical silicic acid leakage hypothesis, but agrees with findings from sediment cores in the tropical Pacific and Atlantic (Bradtmiller et al, 2006, 2007).

II. Changes in Si in AAIW and diatom production

Both the absolute Si concentration as well as the Si:N ratio increase overall in the density horizon of Antarctic Intermediate Water. This leads to higher diatom production in the equatorial and tropical ocean, where the Si-enriched intermediate water comes to the surface, supporting the SALH.

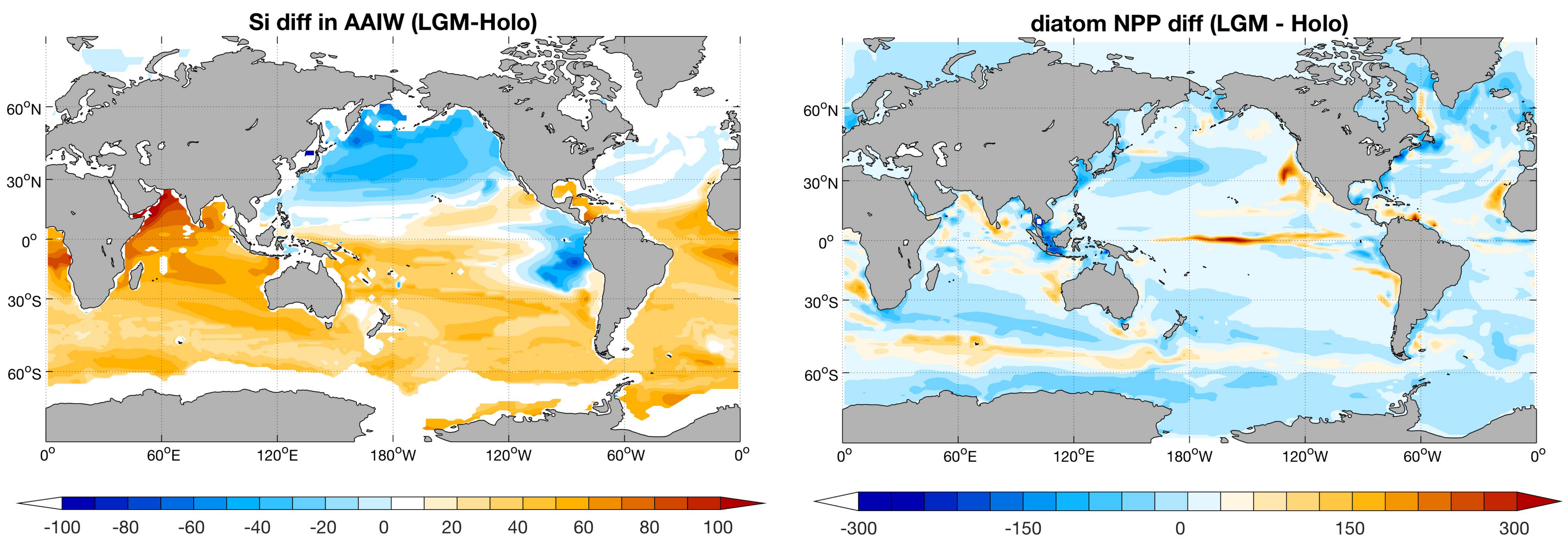
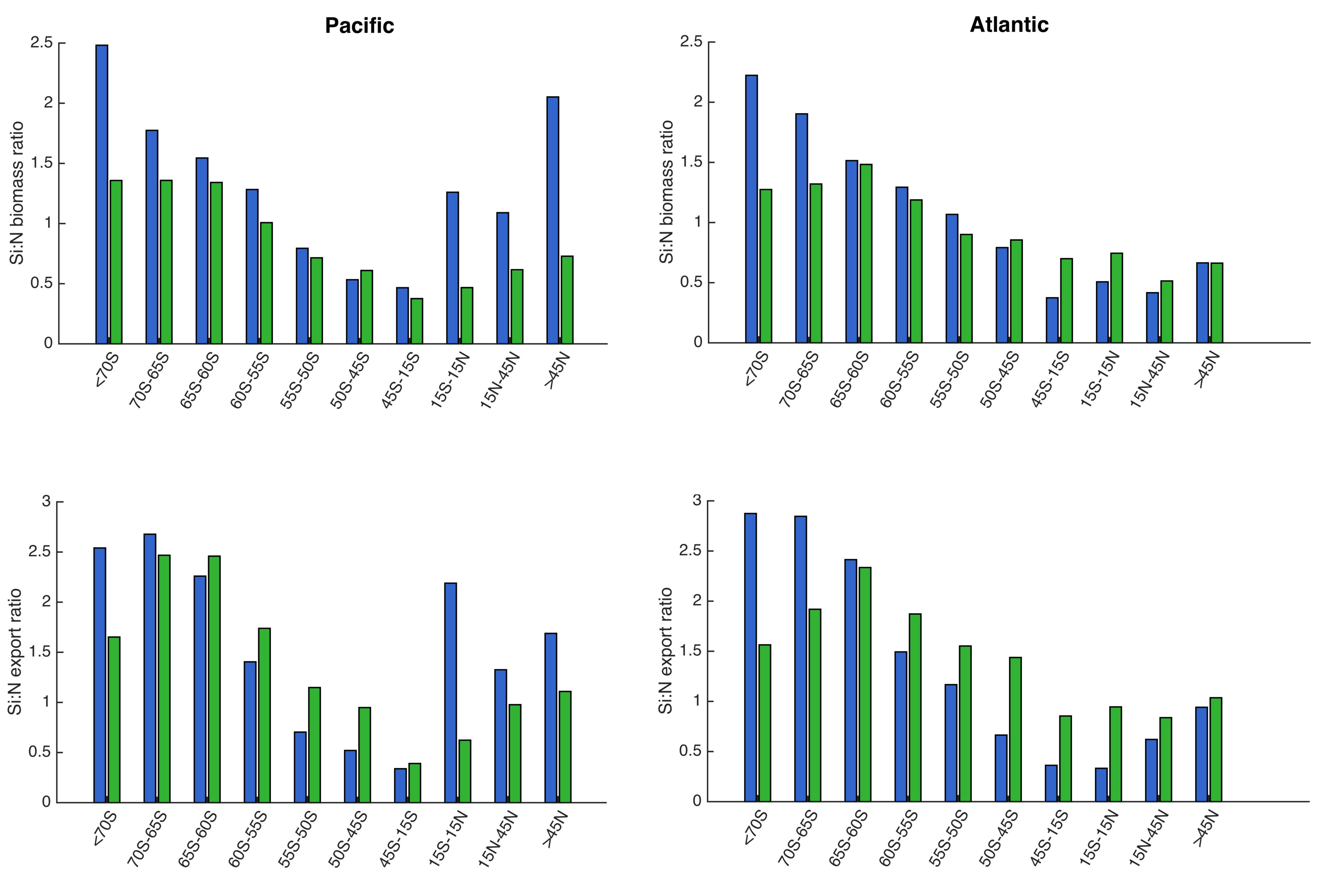


Fig. 2: Changes in dissolved Si on the depth of today's sigma=27.2 surface and diatom net primary production in mol C m^{-2} yr^{-1}, LGM minus PI.



III. Si:N ratio in diatom biomass and export

Diatom Si:N ratio significantly decreases in LGM in the Souther Ocean sector of both Pacific and Atlantic Ocean, due to the relaxation of Fe-limitation. The trend is also found in other HNLC regions like the tropical and North Pacific. In the rest of the Atlantic Ocean, the difference between LGM and present-day is relatively small.

The increase of Si:N in export between 60-45°S is caused by the northward shift of the diatom bloom. The higher diatom production is not accompanied by an increase of Si export in the tropical Pacific, because the Si:N drawdown ratio there is much lower compared to present-day. This decrease of Si:N drawdown ratio is explained by the relaxation of Fe-limitation for diatoms in LGM.

In total, the increase of C export in the tropical ocean can be partly explained by SALH. The contribution by diatom goes up to 100% in the eastern equatorial Pacific, whereas non-diatom phytoplankton dominates the larger increase of C export in the western equatorial and tropical Pacific. Diatom contributes most to the increase of C export in the tropical North Atlantic.

← Fig. 3 Si:N ratio in diatom biomass and export for PI (blue) and LGM (green), averaged over the latitude bands following Dunne et al. 2007.

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