

Glacial Nutrient Distribution and Diatom Productivity

Ying Ye, Peter Köhler, Martin Butzin and Christoph Völker

Motivation

Changes in the marine silicon cycle across glacial-interglacial transitions, and their influence on the biological carbon pump and atmospheric CO₂, remain debated. Proposed mechanisms include enhanced silicic acid leakage from the Southern Ocean, stimulating low-latitude diatom productivity either during the Last Glacial Maximum (LGM) or at the onset of deglaciation, as well as the deglacial redistribution of silicic acid from the abyssal ocean to surface waters. Here, we use the Earth system model AWI-ESM2, which explicitly represents diatom stoichiometry (cellular C:N:Si ratios), to investigate how glacial conditions affected nutrient supply and utilization, and marine biological productivity, as reflected in simulated carbon export and sedimentary opal fluxes.

Results

1. Enhanced glacial dust deposition altered diatom Si:N uptake ratio

Reconstructions indicate up to a 25-fold increase in dust deposition over the Southern Ocean (SO) during the LGM relative to the preindustrial (PI), reducing diatom Si:N uptake ratios (Fig.1a) and contributing to surface Si excess (Fig.1b), together with lower diatom growth (Fig.2) due to cooling and expanded sea-ice cover.

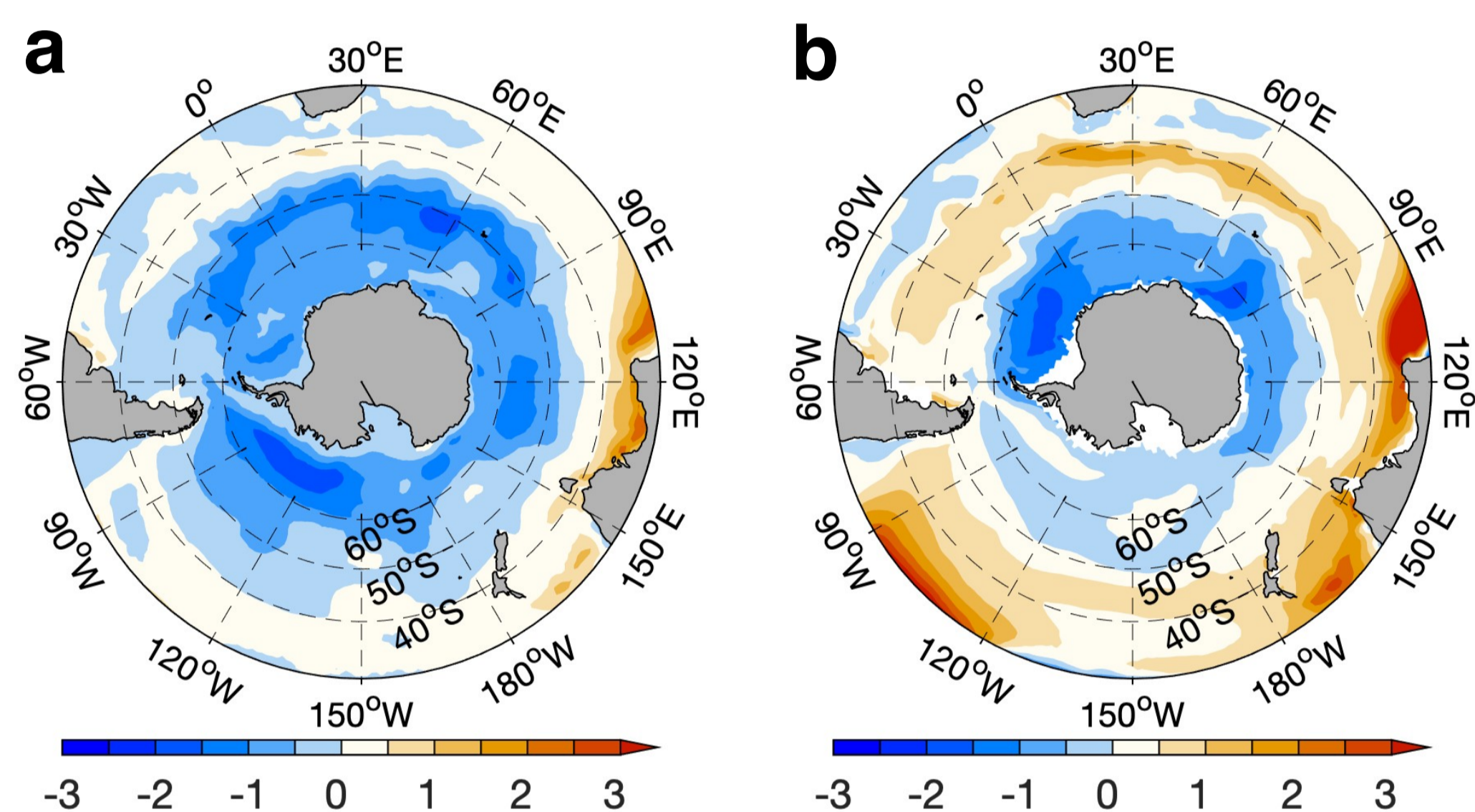


Fig1: Si:N anomaly south of 30°S in (a) diatoms and (b) surface seawater (molSi:molN).

2. Nutrient transport via intermediate waters

Simulated Si:N ratios are elevated in glacial intermediate waters while weakened formation of these water masses hampers exchange with deeper water layers and transport of high Si:N signals to low latitudes (Fig.3), resulting in only limited enhancement of low-latitude diatom growth (Fig.2).

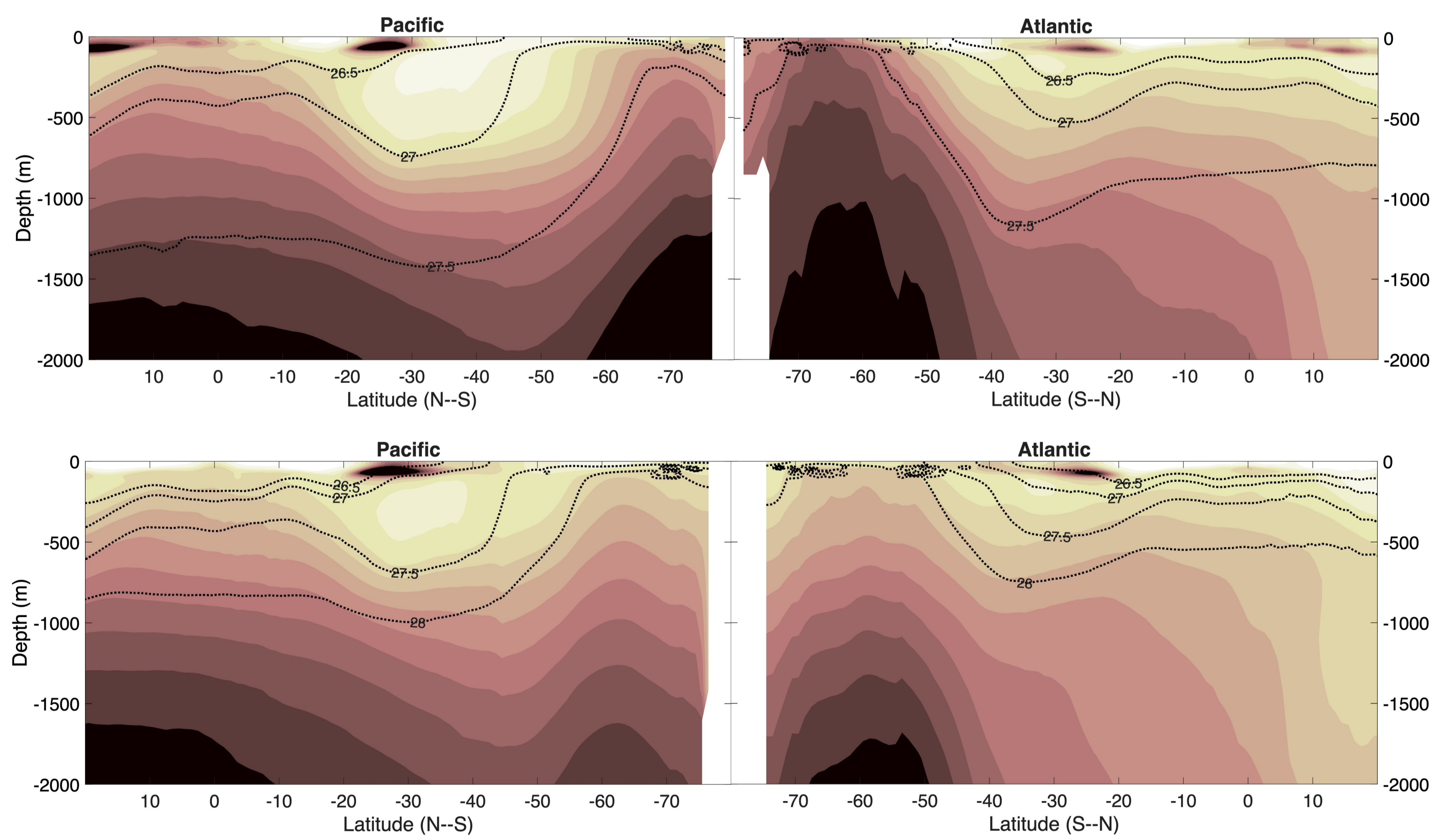


Fig3: Zonal averages of simulated Si:N ratios (molSi:molN) in the Pacific and Atlantic Ocean under LGM (upper) and PI (lower) climate conditions. Isopycnals around the intermediate waters are shown as black dotted lines.

Future work

Further model-data comparisons incorporating additional reconstructions of Southern Ocean physical and biogeochemical processes are needed to better understand their sensitivity to glacial-interglacial climate variability.

References

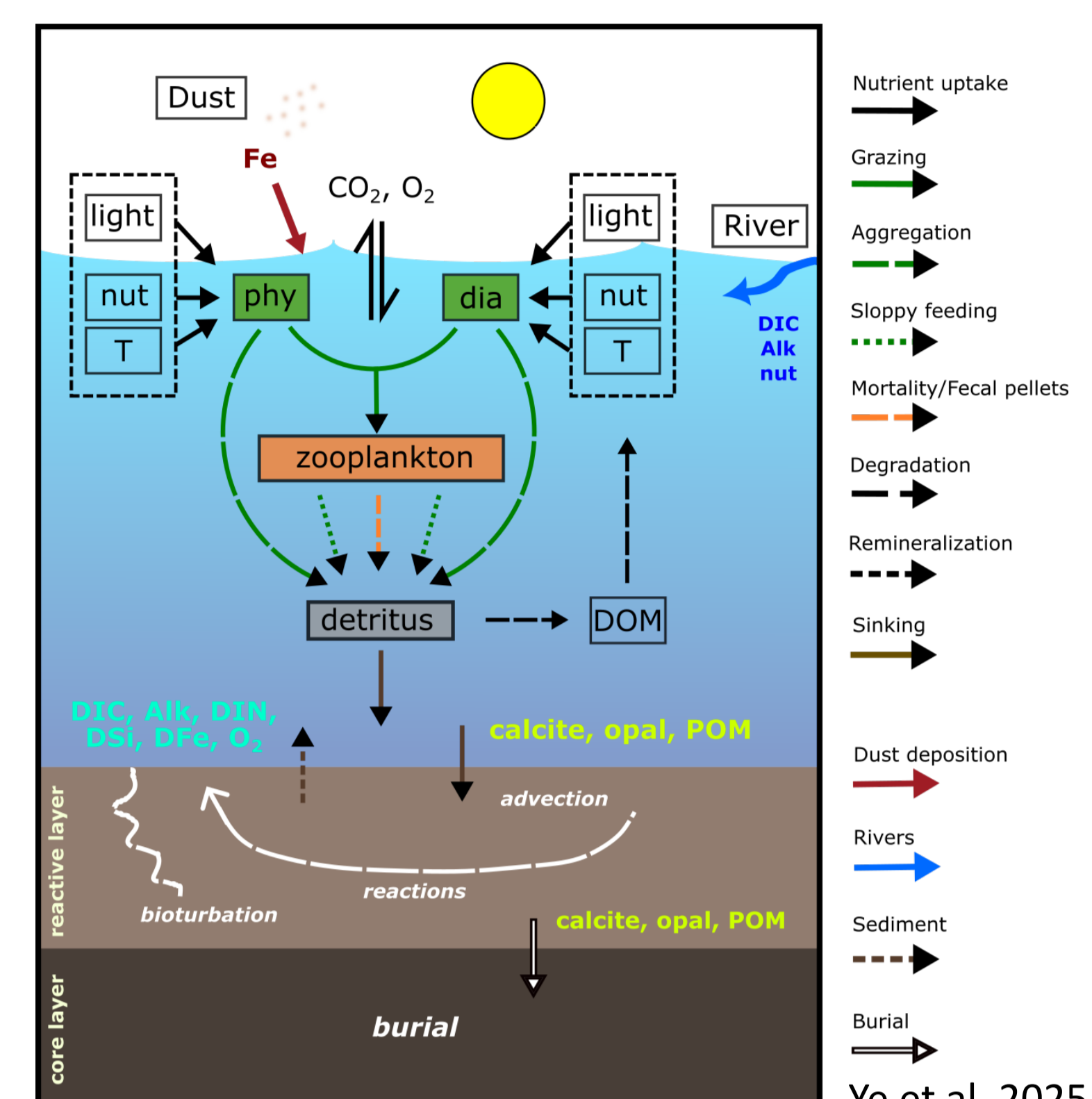
Ye, Y. et al (2025): <https://doi.org/10.5194/gmd-18-977-2025>.

Kohfeld, K. et al. (2013): <https://doi.org/10.1016/j.quascirev.2013.01.017>.

Fig.1, 2, 4 and 5: Ye, Y. et al. (under review): Silicon redistribution and promoted low-latitude diatom growth after Atlantic circulation recovered from deglacial meltwater discharge.

Model and simulations

Regulated Ecosystem Model with a variable diatom Si:N ratio regulated by iron supply
PI and LGM simulations following PMIP4 protocol



Ye et al. 2025

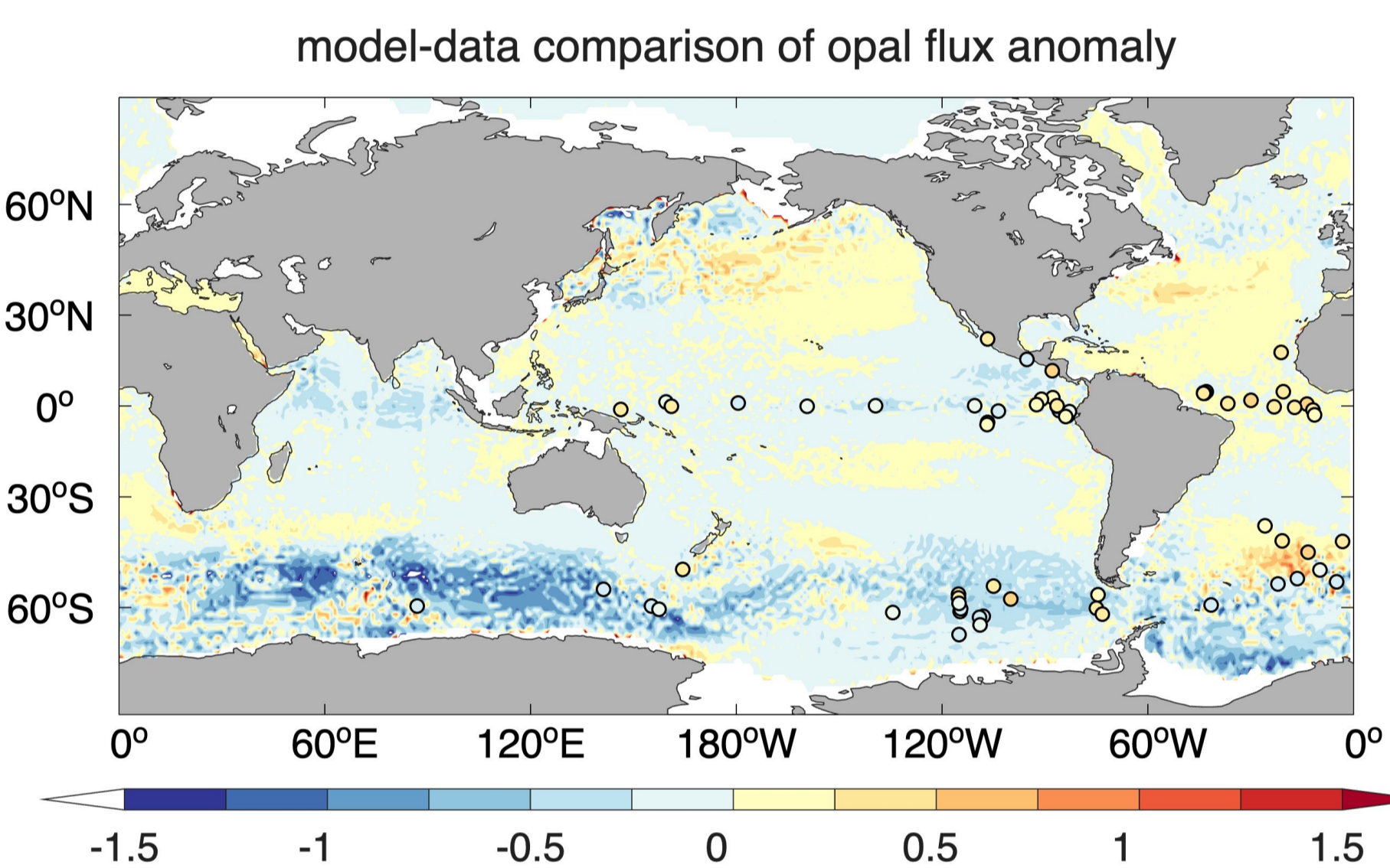


Fig2: Simulated opal flux (mmol Si m⁻² d⁻¹) anomaly (LGM-PI) compared qualitative estimates based on sediment core data.

3. Nutrient limitation and C export

Diatom growth is less limited at high latitudes and more limited at low latitudes during the LGM, driven by stronger stratification and alleviated Fe limitation, with some regions shifting from Fe to Si limitation.

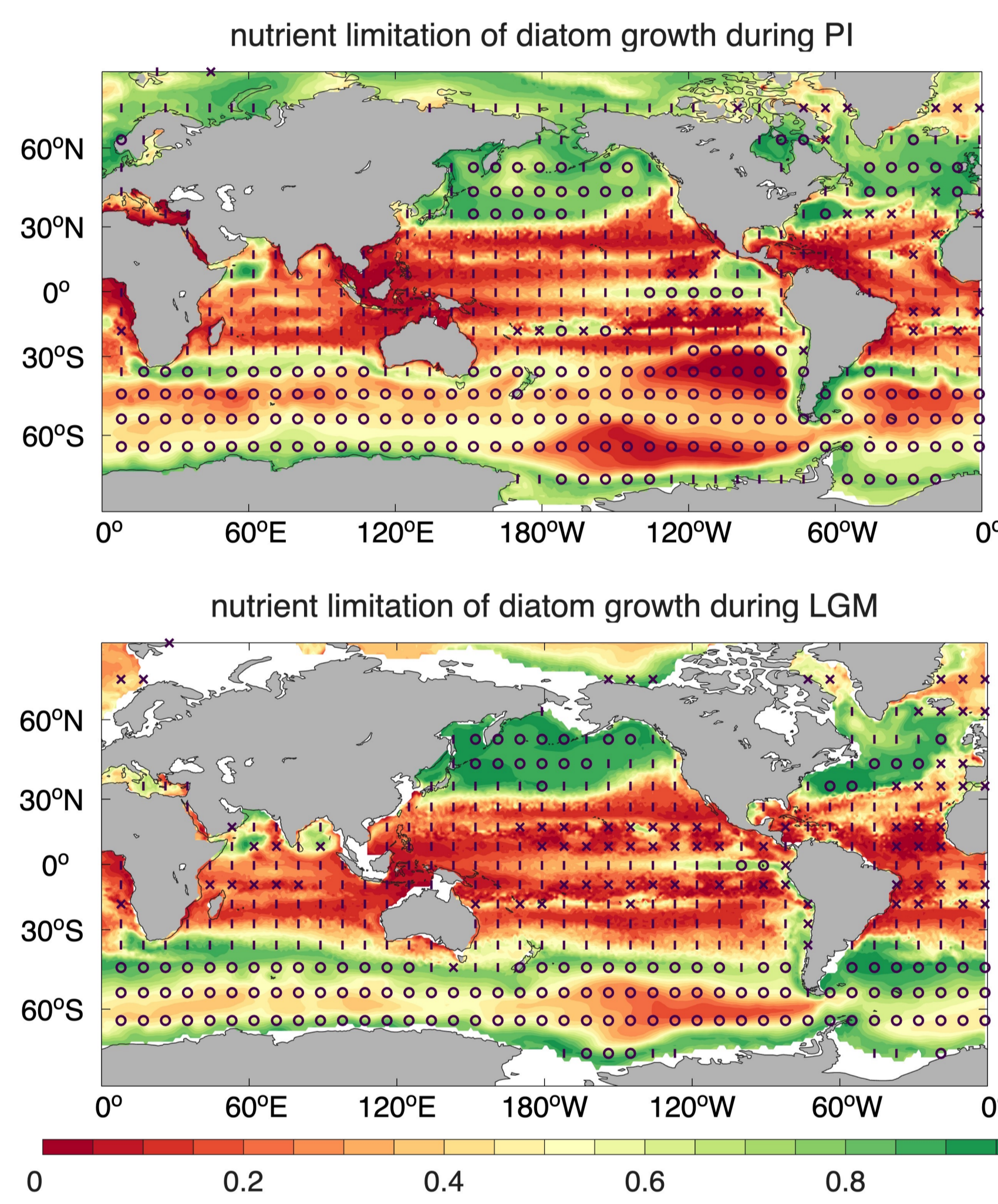


Fig.4 : Nutrient limitation factors for diatom, 0: strongly limited, 1: unlimited.

Together with the small phytoplankton group, simulated glacial-interglacial variability of C export agrees well with reconstructions, showing a bimodal shift across the Antarctic Polar Front (Fig.5).

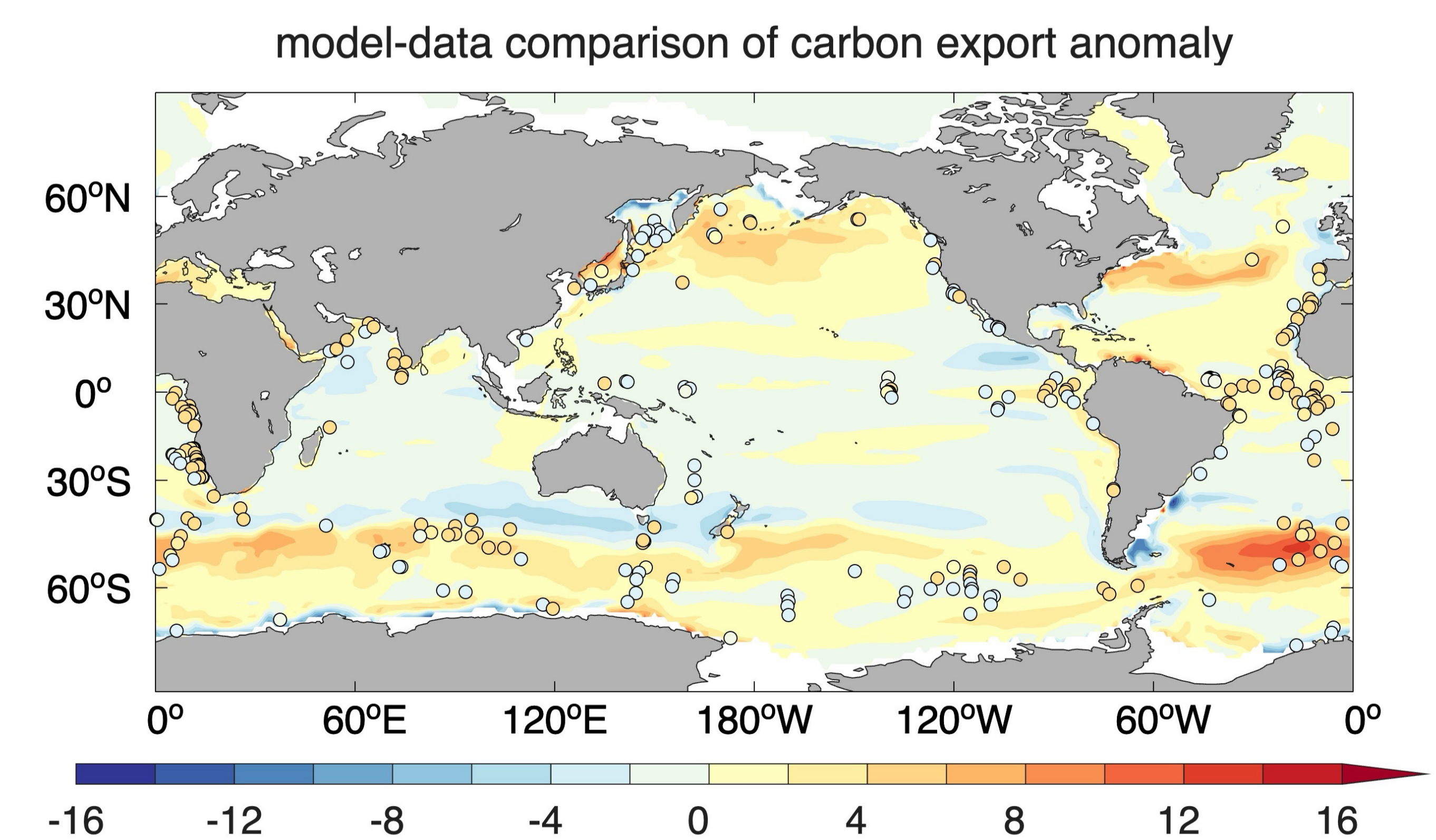


Fig5: Simulated POC export (mmol C m⁻² d⁻¹) anomaly (LGM-PI) compared with qualitative estimates of Kohfeld et al. (2013).