Simulating the distribution of stable silicon isotopes in the Last Glacial Maximum

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• changes in Southern Ocean Fe fertilization and Si drawdown are one hypothesized contribution to lower glacial $p$CO$_2$

• ultimate test: Si accumulation rates and $\delta^{30}$Si from sediment cores

• but these need interpretation: models can help to check assumptions, and extrapolate to carbon fluxes
biogeochemical model: HAMOCC 5.1, with ocean & sediment, weathering fluxes prescribed added to that: $^{30}$Si cycle, with constant fractionation by diatoms (Gao et al, 2016) forced by atmospheric fields from coupled climate model for LGM and pre-industrial (Zhang et al. 2013) integrated for 10000 years with climatological forcing LGM sea-level lowered by 116 m, ocean inventories of S and nutrients preserved stronger dust deposition in LGM
LGM OCEAN VS. PRE-INDUSTRIAL

Prominent changes:
- SO winter sea ice area ≈ 2 times larger
- Saltier AABW, filling a larger fraction of the ocean
- Weaker and somewhat shallower Atlantic meridional overturning

temperature and salinity in Atlantic for LGM and PI
DUST BRINGS IN MORE Fe IN LGM

- glacial increase in dust deposition drives higher dissolved iron concentrations
- increase is modest in Southern Ocean: despite large fractional change in dust deposition it still is small compared to upwelling
- caveat: The model only takes into account dust as iron source: changes in sedimentary iron fluxes are absent

change in sea surface dissolved iron, driven by changes in dust deposition
CHANGES IN EXPORT PRODUCTION

• equatorward shift in SO productivity in LGM, due to extended sea-ice cover

• increased productivity in most of the equatorial Pacific

• is this due to more diatom growth, driven by silicic acid leakage from the Southern Ocean, transported in SMPW and AAIW?
AND IN OPAL EXPORT

• general pattern is similar for opal export
• but: contrary to the expectations of the Silicic Acid Leakage Hypothesis, there is no increase but a decrease of diatom export in the eastern tropical Pacific!
• and an increase in the tropical Atlantic
• this agrees with sediment core findings by Bradtmiller et al. (2006, 2007)
**Si(OH)$_4$ DISTRIBUTION CHANGES**

- surface Si(OH)$_4$ is reduced throughout tropical and subtropical oceans, but most in eastern tropical Pacific

- Si(OH)$_4$ increases in Antarctic Intermediate and Subpolar Mode Waters, *except in the eastern tropical Pacific*

- basin shift in diatom productivity leads to decrease in deep Pacific Si(OH)$_4$, and to increase in deep Atlantic Si(OH)$_4$
A CAVEAT

A central element of the Silicic Acid Leakage Hypothesis is missing in the model: Si:N ratio in diatoms varies as a function of Fe limitation, leading to higher Si:N drawdown ratio in the Southern Ocean (e.g. Dunne et al. 2007)

But: very similar results also found in a model that includes this effect: See poster BN34A-1144:

Ye et al. “Modelled changes in the Southern Ocean Si:N drawdown ratio in the glacial ocean, and their biogeochemical consequences”
CHANGES IN $\delta^{30}\text{Si}$

- both in pre-industrial and in LGM, the distribution sea surface $\delta^{30}\text{Si}$ is consistent with fractionation models: low $\delta^{30}\text{S}$ in regions of abundant $\text{Si(OH)}_4$, high in $\text{Si(OH)}_4$-depleted regions
- but the change in $\delta^{30}\text{Si}$ is neither clearly related to changes in surface $\text{Si(OH)}_4$, nor to changes in diatom productivity
Many (not all) $\delta^{30}$Si glacial-interglacial records from marine sediment cores show lower glacial $\delta^{30}$Si, higher interglacial $\delta^{30}$Si.

The pattern is not the same as that in diatom productivity change!

Caveat: unchanged $\delta^{30}$S in weathering fluxes!
HOW TO INTERPRETE $\delta^{30}\text{Si}$?

- surface $\delta^{30}\text{Si}$ values show increased values at low $\ln(\text{Si(OH)}_4)$, consistent with Raleigh fractionation
- slope of $\delta^{30}\text{Si}$ vs. $\ln(\text{Si(OH)}_4)$ varies between ocean basins, despite constant diatom fractionation
- $\delta^{30}\text{Si}$ vs. $\ln(\text{Si(OH)}_4)$ relation is different in LGM and PI climate states!

blue: best fit for LGM state, red: best fit for PI state
CONCLUSIONS & THANK YOU FOR LISTENING!

- modeled LGM has less diatom production in eastern tropical Pacific, more in tropical Atlantic
- agrees with some sediment core reconstructions but not with SALH
- drives some shift of Si from deep Pacific to deep Atlantic
- glacial $\delta^{30}$Si at surface generally lower in LGM, except in tropical Pacific
- fractionation-like relation between $\delta^{30}$Si and Si differs between ocean basins and between climate states

Also go and see poster BN34A-1144: Ye et al. “Modelled changes in the Southern Ocean Si:N drawdown ratio in the glacial ocean, and their biogeochemical consequences”!