Ligand-associated feedbacks in global iron cycling, and their role for changes in export production

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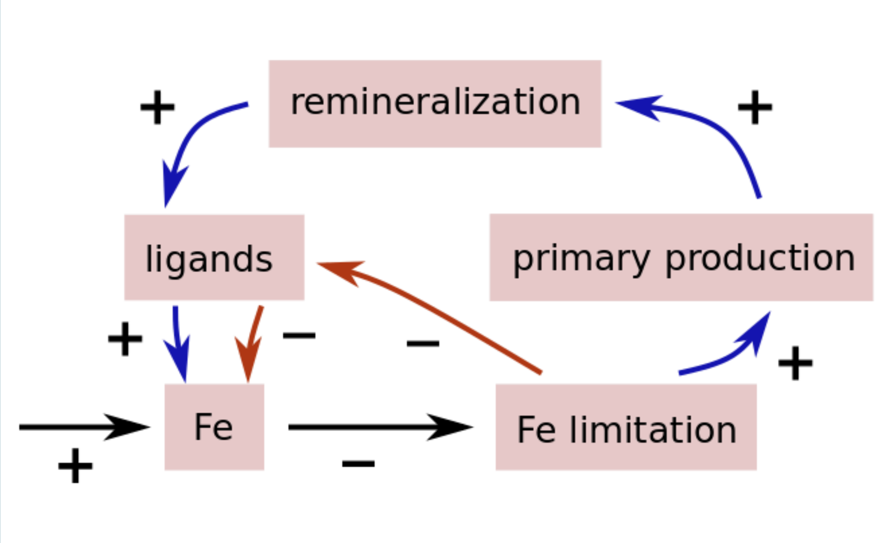
The Question

Organic ligands determine to a large extent the solubility of iron in seawater. On the other hand, organic ligands are a product or by-product of biological production themselves. This creates the possibility of feedbacks between biological production and the concentration of dissolved iron. Understanding the strength and direction of these feedbacks may therefore be important also for understanding how the system will react to external changes in the iron cycle, e.g. to the larger dust deposition or solubility under climate change.



Feedbacks in the system can be both positive (destabilising) and negative (stabilising), depending on how ligand production is linked to biological productivity:

- In the positive feedback scenario (blue arrows), ligands are predominantly a by-product of the remineralisation of particulate organic matter, such as pigments with porphyrin-like moieties that can bind iron.
- In the negative feedback scenario (red arrows), ligands are produced in response to iron limitation, to keep iron in solution and hence bioavailable. This would be a siderophore-centric scenario.

Both scenarios are probably realised in parallel in the ocean. We use a simple box model to assess:

- which description of the cycling of ligands is best able to capture the observed distributions of phosphate and dissolved iron in the ocean?
- what are the consequences for the strength and direction of the feedback, and how does that influence the change in ocean export production if the iron input from dust changes, as has been predicted under climate change and inferred for the glacial climate?

Acknowledgements

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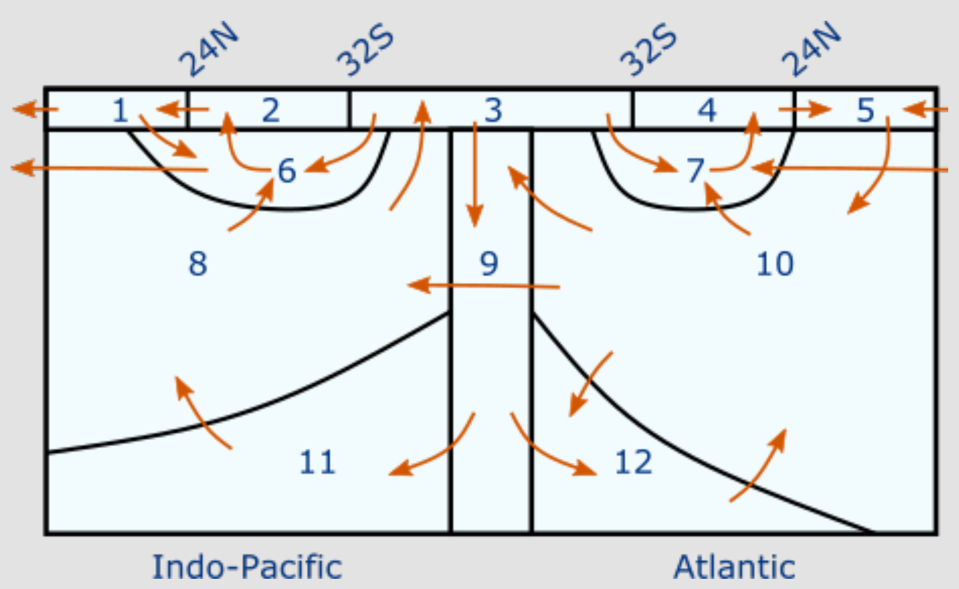
The Model



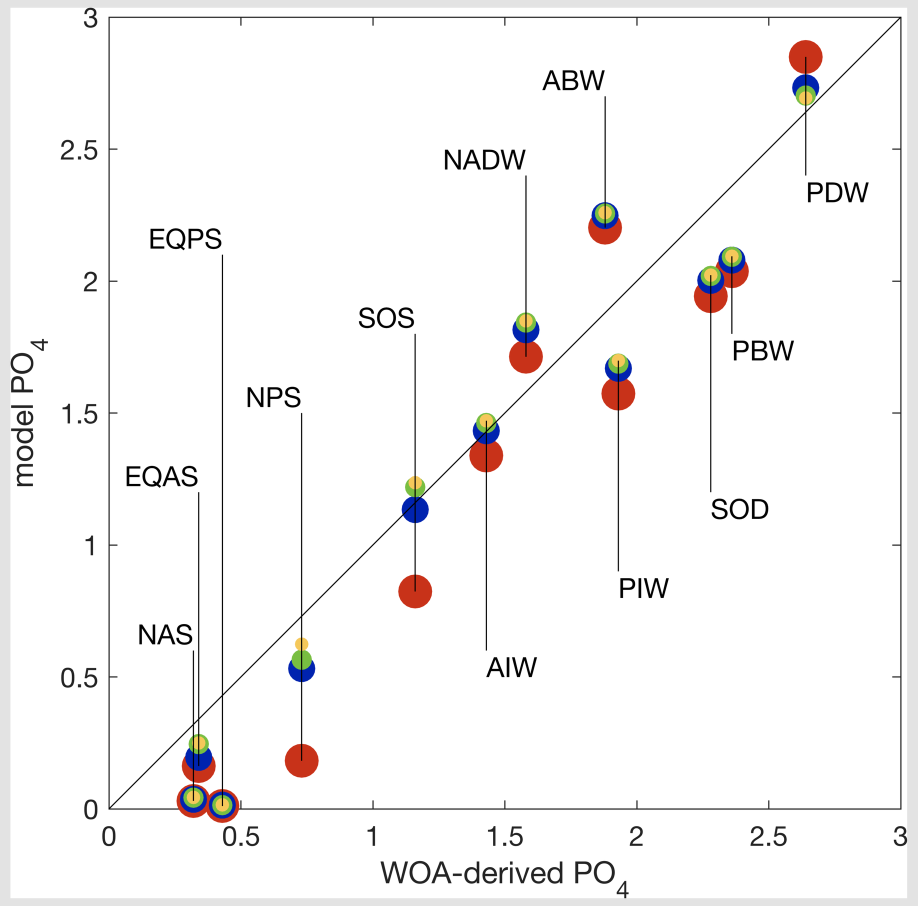
We use a simple box model to represent the ventilation of the global ocean; advective fluxes between the boxes are based on Talley et al. (2013). We solve equations for PO4, DOP, Fe, and one of several ligand representations:

- constant ligand, corresponding to what most biogeochemical models still do
- one long-lived DOC-like ligand, similar to Völker and Tagliabue 2015, and Lauderdale et al. 2020
- one DOC-like and one shorter-lived siderophore-like ligand with longer lifetime
- one DOC-like and one siderophore-like ligand with shorter lifetime

Conclusions

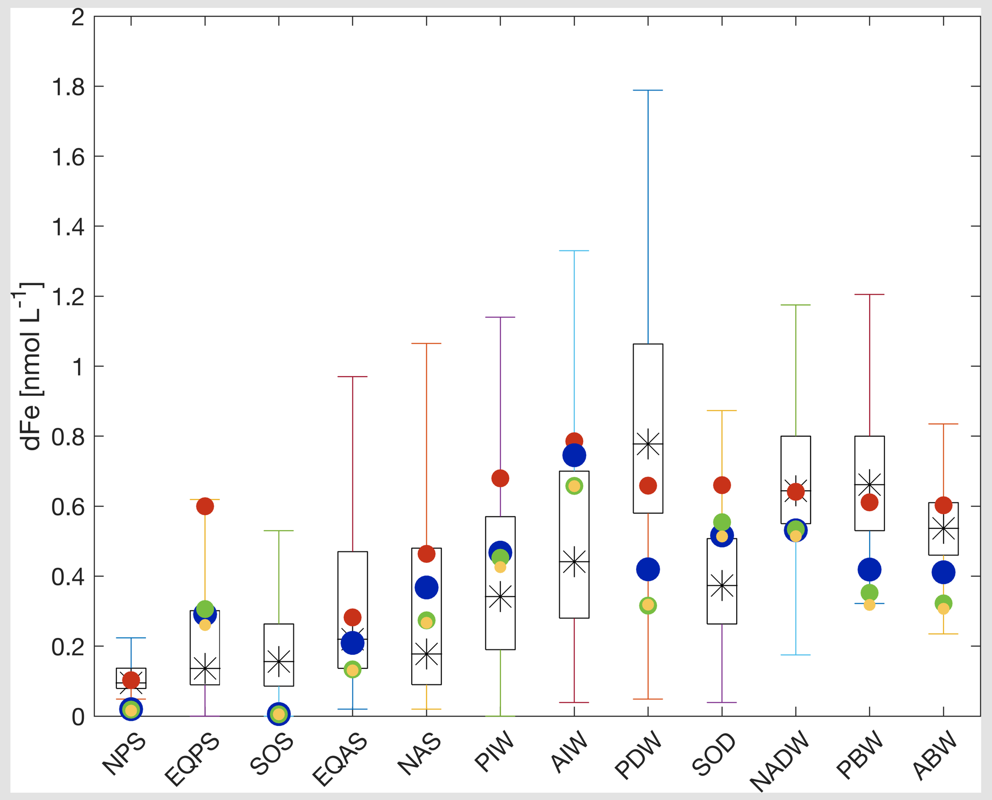
- Describing the ocean iron cycle with variable ligands gives a more realistic description of the nutrient (P, Fe) distribution than a model with constant ligand. More than one ligand is better than just one ligand.
- The ocean's reaction to changes in iron inputs into the ocean, e.g. by variations in dust iron input, is modified by variations in ligand concentration; these lead to feedbacks in the system.
- The direction and strength of the feedbacks depends of details of ligand cycling which are so far not well constrained.

Representation of PO4 and Fe by the different ligand models



Comparison of model-derived phosphate with the average World Ocean Atlas phosphate concentration in the individual model boxes.

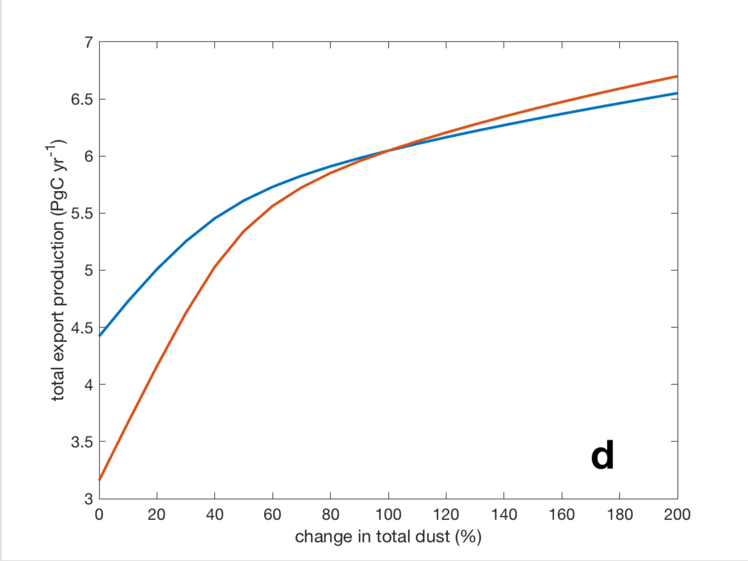
- Red dots: constant ligands
- Blue dots: one long-lived DOC-like ligand
- Green and yellow dots: one additional siderophore-like ligand. Green differs from yellow in the degradation rate of the ligand

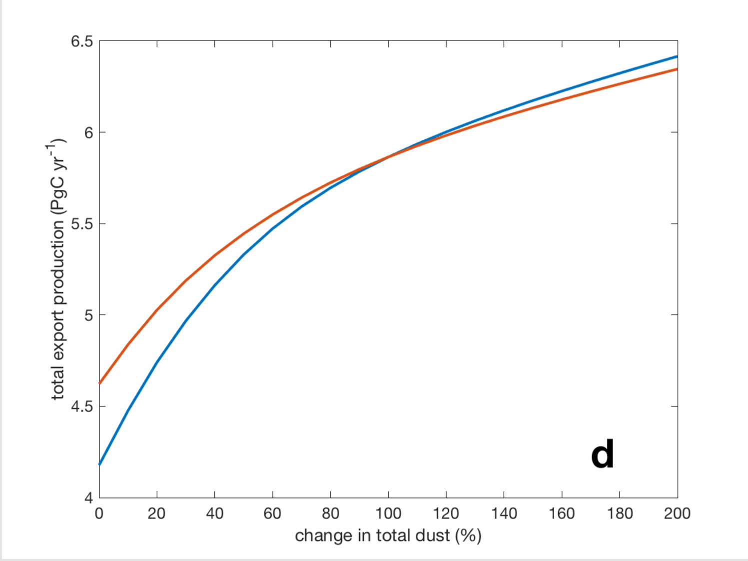


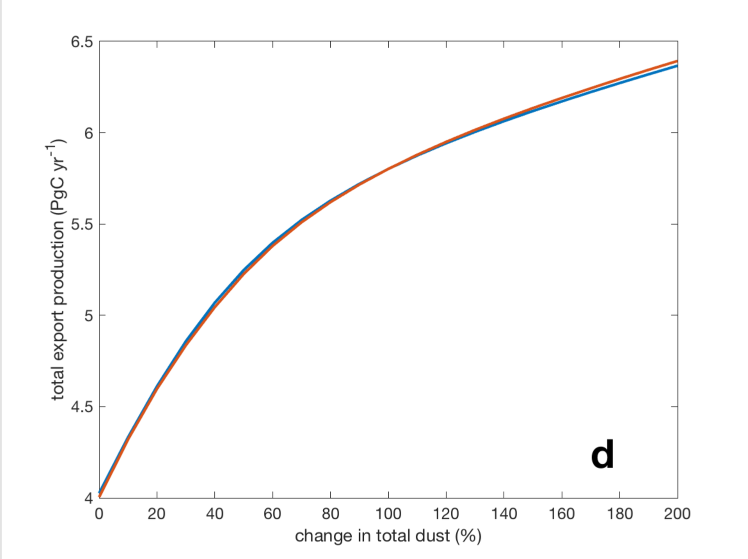
Comparison of model-derived dissolved iron with the median and quantiles of observed iron concentrations from the second GEOTRACES intermediate product for the individual model boxes.

- Red dots: constant ligands
- Blue dots: one long-lived DOC-like ligand
- Green and yellow dots: one additional siderophore-like ligand. Green differnrs from yellow in the degradation rate of the ligand

Feedbacks in export production for the different ligand models







Quantification of the strength of the feedback is done by varying the strength of the dust iron source from its normal value by a factor between zero and two and running the model into equilibrium.

In one set of simulations (blue lines), the concentration of ligands is held constant at the values obtained from the model at normal dust deposition. In the other set of simulations (red lines), the ligands are allowed to vary when dust iron inputs vary. A larger slope of the red, compared to the blue line indicated a net positive feedback, a smaller slope a negative feedback.

Feedbacks can be quantified for different target measeres; we show here global export production.

The strength and direction of the feedback depends on the representation of ligand cycling: With only a DOC-like siderophore (top figure), the overall feedback is positive, with one DOC like and a comparatively long-lived siderophore (middle figure), it is slightly negative, and with a DOC-like and a shorter-lived siderophore (lower figure) the two feedbacks almost cancel out for export production.