Insight into contributions of different iron sources to the ocean from a model of the Fe stable isotopes

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Motivation
It has been widely accepted that iron is an essential micronutrient for ocean biota, and its distribution strongly affects the magnitude of phytoplankton primary productivity and thus the carbon uptake in the ocean. Yet there is still no consensus on the mechanisms behind the distribution of iron and especially on the relative role of different external iron sources to the ocean. In recent years, the analysis of the stable isotopic composition of dissolved iron in sea water has been increasingly used to constrain the relative role of different iron sources. In a global biogeochemical model, we aim to take into account processes in the ocean interior to fractionate between iron isotopes and physical processes to mix water masses with different isotopic compositions.

References
Hauck et al. (2013) has been extended with an explicit representation of isotopic effects (ReCoM-Felsoi). The current model version considers (Fig. 1): δFe in dissolved iron (DFe), in all organic iron pools (phytoplankton, zooplankton and detritus), and in scavenged iron. Three external iron sources, i.e. dust, hydrothermal vents and sediment, bring DFe into the ocean with different isotopic composition. δFe from different sources is transported in the dissolved form, mixed between water masses, taken up by phytoplankton and goes through the biological cycle. To compare with observations, we calculate D[Fe](‰) with:

\[
\delta^{56}Fe = \left[ \frac{^{56}Fe}{^{54}Fe} \right]_{\text{sample}} - 1 \times 1000
\]

Sensitivity runs with varying source signals
At the first step we wanted to understand the effect of physical mixing on the isotopic composition of DFe and conducted first simulations without chemical and biological fractionation. δ[Fe](‰) values for dust, hydrothermal and sedimentary source were from literature and a set of sensitivity runs was conducted in order to illustrate how variations in source signals affect the end-member isotopic composition of DFe (Tab. 1).

<table>
<thead>
<tr>
<th>Run</th>
<th>dust</th>
<th>hydrothermal</th>
<th>sediment</th>
</tr>
</thead>
<tbody>
<tr>
<td>R₀</td>
<td>+0.10</td>
<td>-0.50</td>
<td>-3.00</td>
</tr>
<tr>
<td>R₀ non-red</td>
<td>+0.10</td>
<td>-0.50</td>
<td>+0.30</td>
</tr>
<tr>
<td>R₀ high</td>
<td>+0.10</td>
<td>-0.50</td>
<td>-1.00</td>
</tr>
<tr>
<td>R₀ low</td>
<td>+0.10</td>
<td>-0.50</td>
<td>-5.00</td>
</tr>
<tr>
<td>R₀ high hydro</td>
<td>+0.10</td>
<td>-0.30</td>
<td>-3.00</td>
</tr>
<tr>
<td>R₀ high dust</td>
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</tr>
</tbody>
</table>

Effect of the source signals on global distribution of δFe in DFe
The pattern of δ[Fe](‰) distribution in the model is determined by physical transport and mixing of three sources through circulation, and vertical transport of iron from the surface to the ocean interior by biological uptake, sinking and remineralisation of organic particles.

Slightly positive values of δFe in R₀ (Fig.2) are found in regions receiving much dust input of iron, e.g. the subtropical North Atlantic, eastern North Pacific affected by the Asian dust events and Indian Ocean. In HNLC regions, the main source of DFe is sediment input and upwelling. Both are isotopically light and result in more negative δFe. In the subtropical Pacific gyres, δFe is close to 0, due to lack of any external source and intensive biological activities. In all ocean basins and throughout the water column (Fig.4 top), values in R₀ produced are much lower than observed.

With enhanced δFe in the individual sources, R₀ high-, R₀ low- and R₀ high-dust show just slightly higher δFe in the deep and surface ocean, respectively. From R₀ non-red via R₀ to R₀ high-dust sediment supplies DFe with an increasing but still negative δFe. Modelled δFe in DFe increased correspondingly, but even in R₀ high-dust, δFe in the surface and mesopelagic waters is still lower than observation (Fig.4 middle). The positive signals in the deep ocean which is in agreement with observation, can not be explained by the negative signal from sediments but by transport of iron deposited at the surface.

ReCoM-Felho Model
A global biogeochemical model including iron (ReCoM, Hauck et al. 2013) has been extended with an explicit representation of isotopic effects (ReCoM-Felsoi). The current model version considers (Fig. 1): δFe in dissolved iron (DFe), in all organic iron pools (phytoplankton, zooplankton and detritus), and in scavenged iron. Three external iron sources, i.e. dust, hydrothermal vents and sediment, bring DFe into the ocean with different isotopic composition. δFe from different sources is transported in the dissolved form, mixed between water masses, taken up by phytoplankton and goes through the biological cycle. To compare with observations, we calculate D[Fe](‰) with:

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