Will climate change impact the biogeochemical cycles of essential micronutrients?

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Take home messages

Will climate change impact trace metals (Zn, Cu, Co and Mn) like other macronutrients (like P or N)?

➔ No

Why?

➔ Because TMs and P have very different

1) Distributions (R^2 between P and TM distributions <0.2)
2) Drivers
   - Uptake is an important driver of TM in the planktonic cells (and is itself driven by the flexible TM requirements of phytoplankton)
   - Scavenging is the main driver of TM particle inventory
3) Sources (Co and Mn have an important sedimentary source, which is dependent on $[O_2]$)

Introduction

- Trace metals (TM) are essential to life in the oceans
- TM are cofactors in important enzymes (Twining and Baines, 2013)

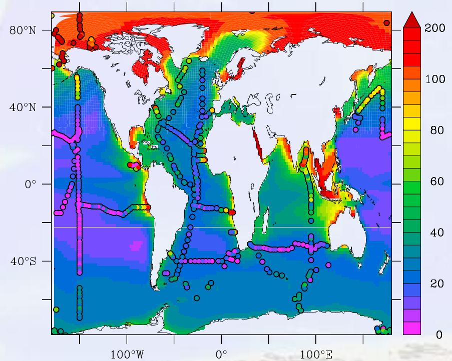
Examples of proteins with trace metal cofactors (from Twining and Baines, 2013)

Metal	Proteins
Cu	Plastocyanin, Cytochrome oxidase, Superoxide dismutase, …
Co	Vitamin B12
Zn	Carbonic anhydrase, alkaline phosphatase, superoxide dismutase, RNA polymerase, …
Mn	O_2-evolving enzyme, superoxide dismutase, arginase, …

Why are trace metals so special?

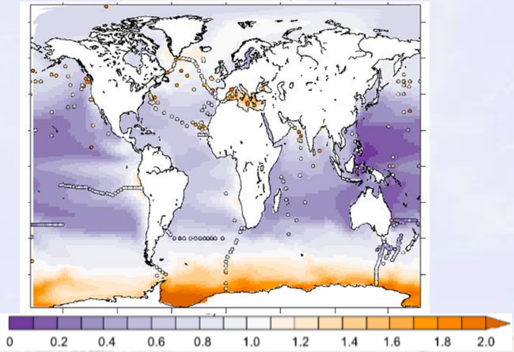
- TM are different than other macronutrients (like PO_4)
- PO_4 distribution is driven by biological interactions, circulation and external sources (Martiny et al. 2019).
- TM have low dissolved concentrations (nM or pM range), also impacted by biology, external sources and circulation
- Planktonic cells have very low and flexible requirements for TM, the flexible requirements impact TM uptake by phytoplankton
- TM are particle reactive (i.e. susceptible to scavenging), which is an important driver of particulate TM cycling

dCo surface concentration (nmol/m³)

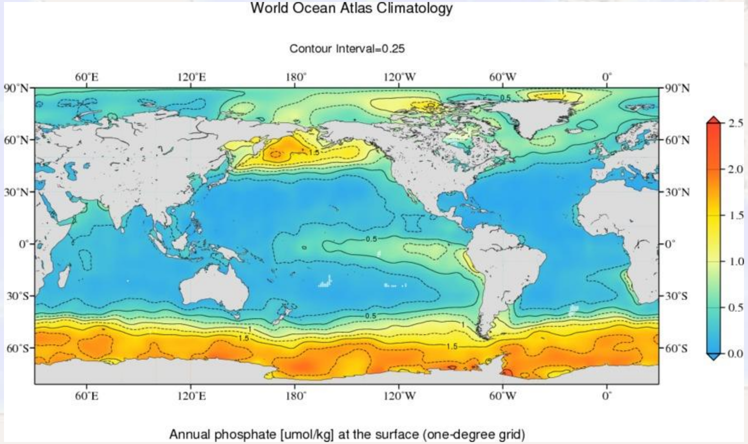


Tagliabue et al. (2018)

dCu surface concentration (µmol/m³)



Richon and Tagliabue (2019)



Introduction

As a result of the different drivers of macro and micronutrients biogeochemistry, climate change is expected to impact TMs differently than P.

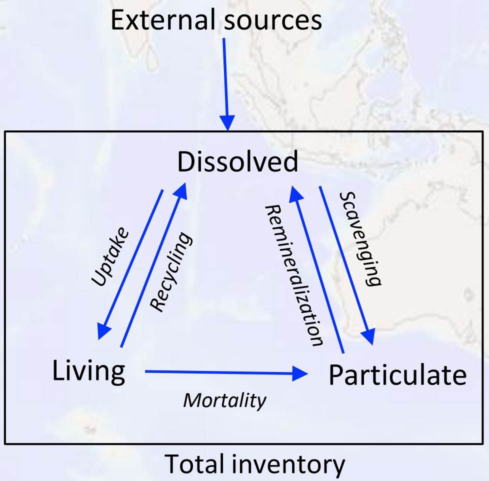
➔ We will focus the work on 3 questions relating to the specificities of upper ocean TM cycling:

1 – How important is phytoplankton TM uptake for their global inventory? What drives uptake and how is it going to evolve with climate change?

2 – How important is scavenging for particulate TM cycling? What are its drivers and how is it likely to change?

3 – Are variations in external sedimentary sources linked to changes in O_2 important for the changes in TM inventories?

Framework: components and fluxes driving the trace metal total inventories



We divide the global nutrient inventories in 3 components:

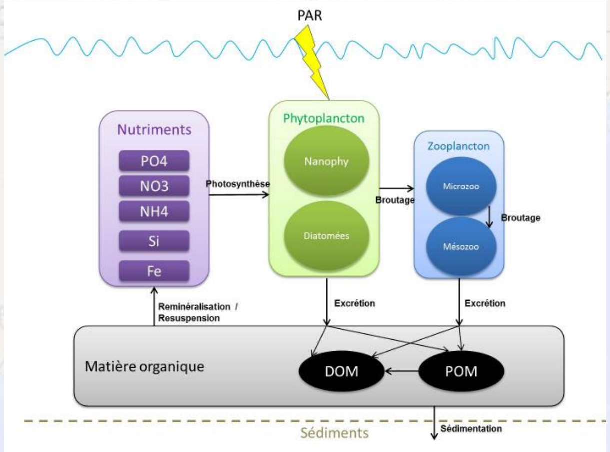
1) Living: Phytoplankton + zooplankton (+ living diatom frustule*)
2) Particulate: organic particles + scavenged (+ dead diatom frustule*)
3) Dissolved inventory

Total inventory: Living + Particulate + Dissolved

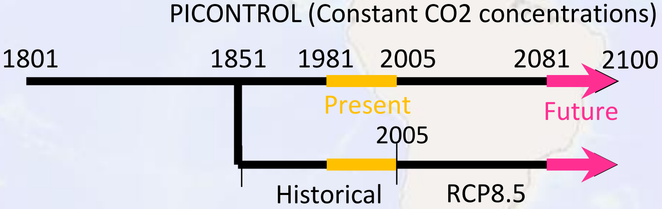
*for zinc

Methods

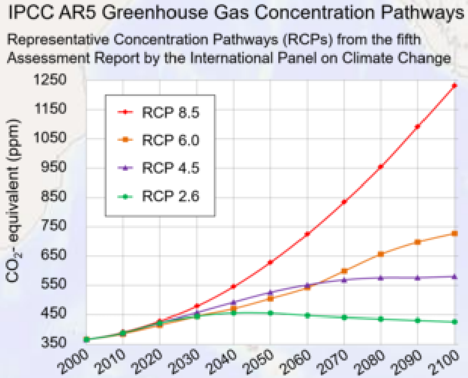
- We use a global coupled physical-biogeochemical model: NEMO/PISCES
- The model represents: - 4 macronutrients (PO_4, NO_3, NH_4, Si) + 1 micronutrient (Fe)
  - 2 phytoplankton groups (nano + diatoms) + 2 zooplankton size classes (micro + meso)
  - 4 new trace metals: Cu (7 tracers), Co (6 tracers), Zn (9 tracers), Mn (6 tracers)
- The impacts of TM on primary production are not represented in the model



- Simulations*:

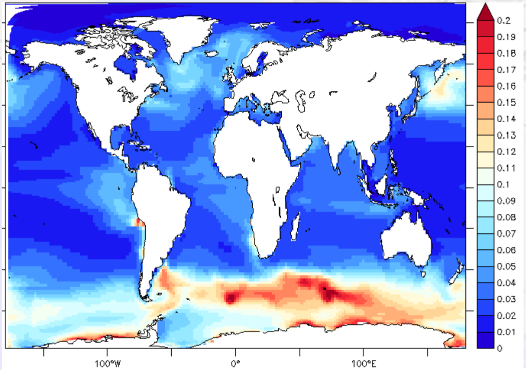


*IPSL-CM5

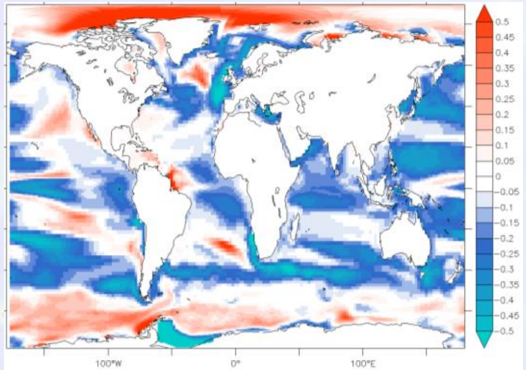


- No evolution of riverine, aerosol and hydrothermal sources of TM. But sedimentary sources of Co and Mn vary with O_2 concentrations in the water.

Results: Living component driven by uptake: the example of Zn



Zn in the living inventory in surface (0-100m), 1981-2005 average (µmolZn/m^3)



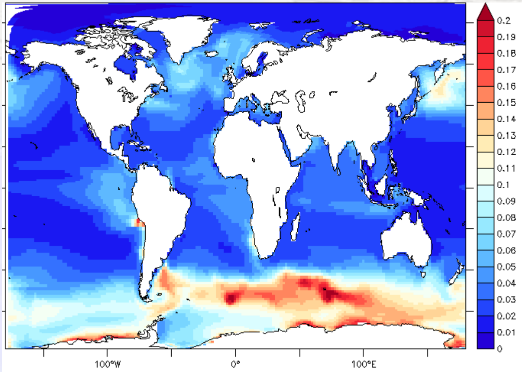
Changes in Zn living inventory between 2081-2100 and 1981-2005 (µmolZn/m^3)

Zn Living inventory = Phytoplankton + zooplankton + living diatom frustule

Zn living inventory represents up to 20 % of the total Zn inventory in the surface ocean.

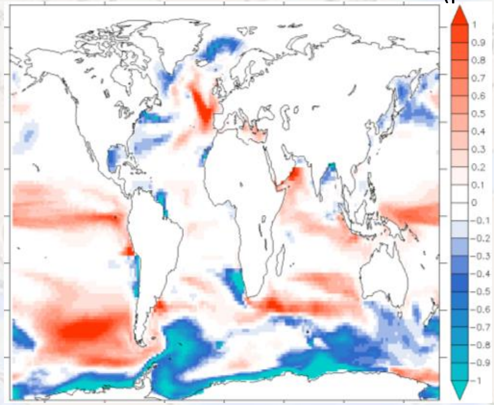
Zn living inventory decreases in the low latitudes and increases in high latitudes by the end of the century.

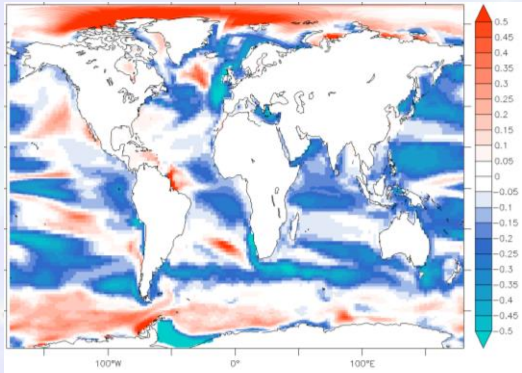
Results: Living component driven by uptake: the example the Zn



Zn in the living inventory in surface (0-100m), 1981-2005 average (µmolZn/m^3)

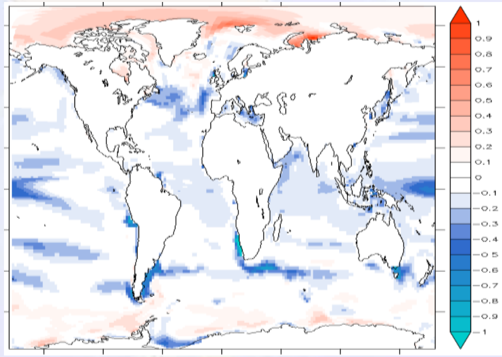
changes in phytoplankton Zn uptake between 1981-2005 and 2081-2100 (µmolZn/m^3/yr)





Changes in Zn living inventory between 2081-2100 and 1981-2005 (µmolZn/m^3)

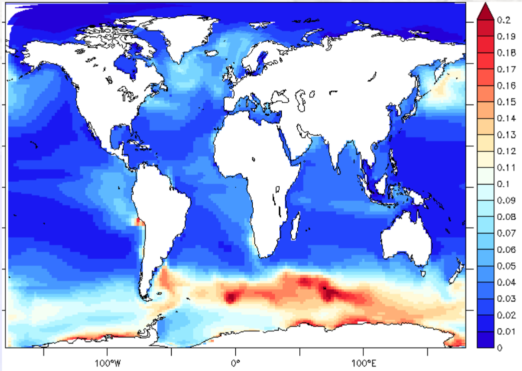
Changes in phytoplankton biomass (mmol/m^3) between 1981-2005 and 2081-2100



Changes in living inventory are related to both changes in phytoplankton Zn uptake and changes in phytoplankton biomass.

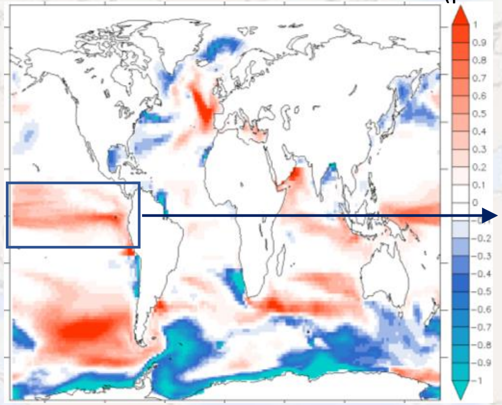
In high latitudes, increased living inventory seems to be explained by increased phytoplankton biomass.
In low latitudes, the regions where living Zn increases seem to correspond to regions where Zn uptake increases.

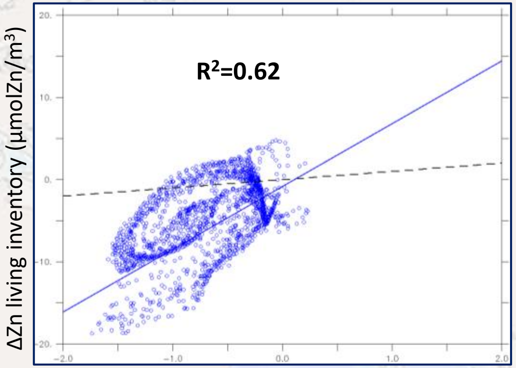
Results: Living component driven by uptake: the example of Zn

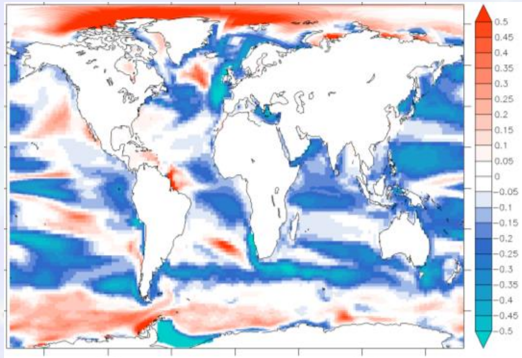


Zn in the living inventory in surface (0-100m), 1981-2005 average (µmolZn/m^3)

changes in phytoplankton Zn uptake between 1981-2005 and 2081-2100 (µmolZn/m^3/yr)

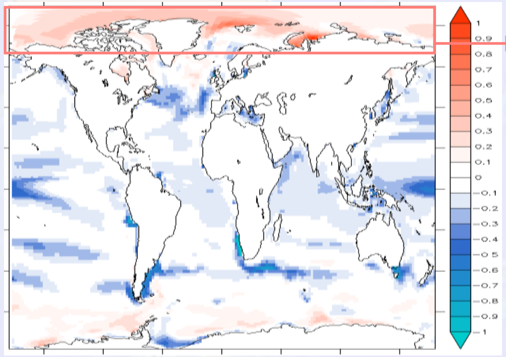


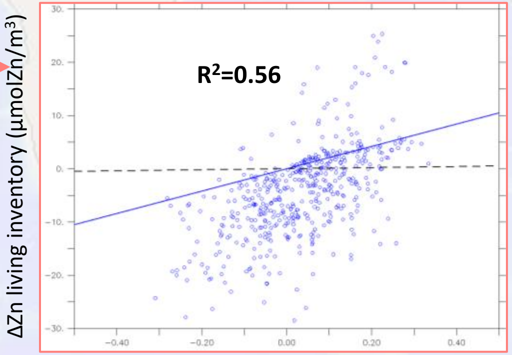




Changes in Zn living inventory between 2081-2100 and 1981-2005 (µmolZn/m^3)

Changes in phytoplankton biomass (mmol/m^3) between 1981-2005 and 2081-2100

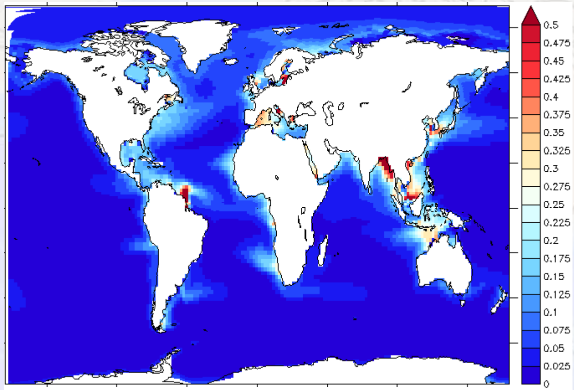




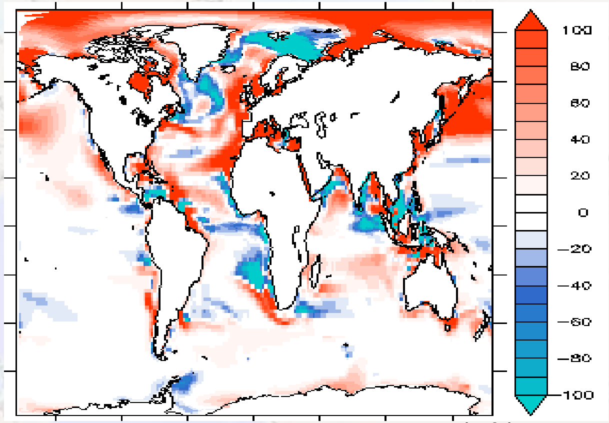
Good correlation between Zn living inventory and Zn uptake in the equatorial Pacific. In this region, the increase in uptake is due to an increase in phytoplankton Zn quotas.

In the Arctic, the increase in phytoplankton biomass correlates well with the increase in living Zn.

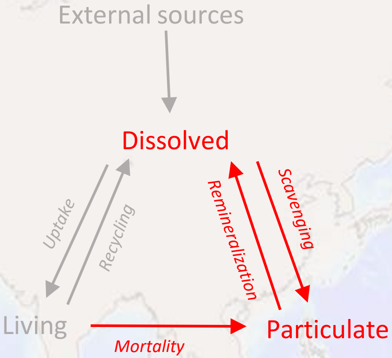
Results: Scavenging drives the particulate inventory: the example of Mn

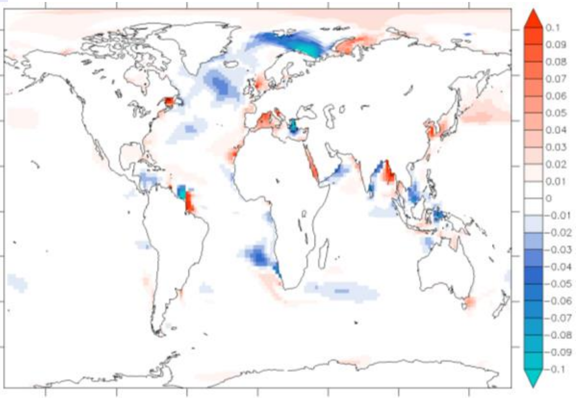


Mn in the particulate inventory in surface (0-100m), 1981-2005 average (nmolMn/m^3)



Changes in Mn scavenging (pmolMn/m^3/yr) between 1981-2005 and 2081-2100



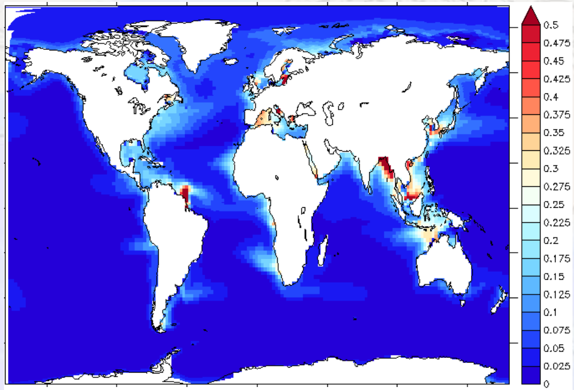


Changes in particulate Mn (nmolMn/m^3/yr) between 1981-2005 and 2081-2100

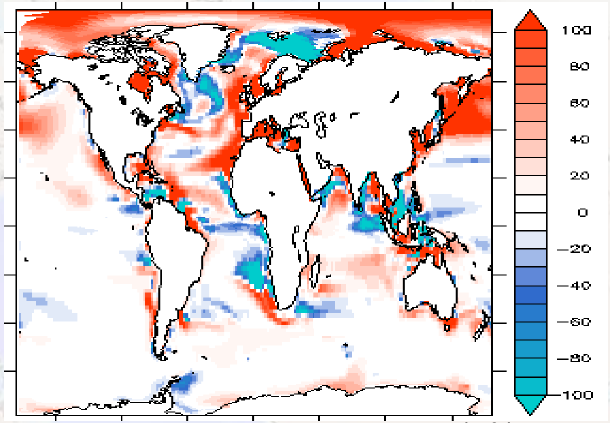
Particulate Mn represents 10 to 20% of the global Mn inventory in surface.

Changes in Mn particulate inventory seem to follow the changes in scavenging.

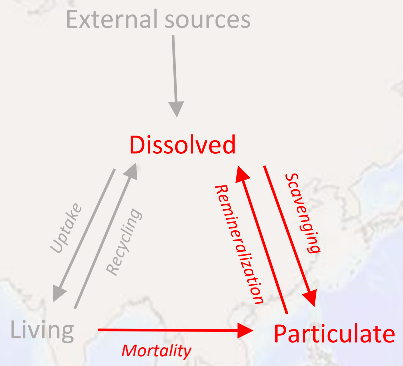
Results: Scavenging drives the particulate inventory: the example of Mn

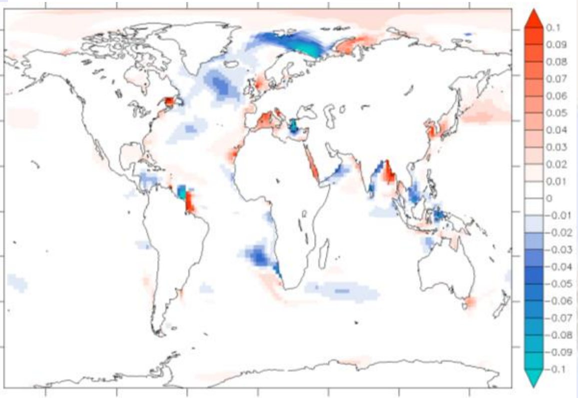


Mn in the particulate inventory in surface (0-100m), 1981-2005 average (nmolMn/m^3)

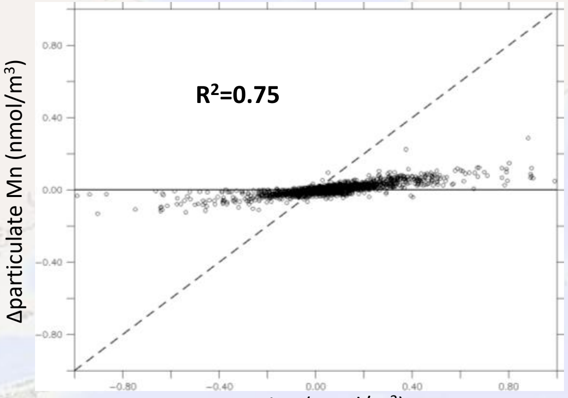


Changes in Mn scavenging (pmolMn/m^3/yr) between 1981-2005 and 2081-2100





Changes in particulate Mn (nmolMn/m^3/yr) between 1981-2005 and 2081-2100



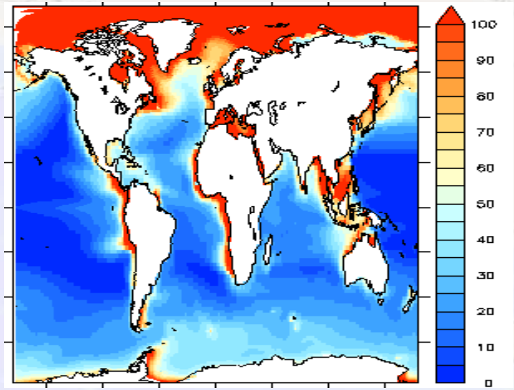
ΔMn scavenging (nmol/m^3)

The plot shows the global surface ocean changes in particulate Mn vs global changes in Mn scavenging.

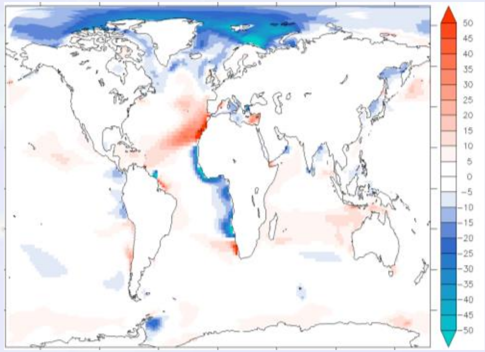
The good correlation indicates that Mn scavenging is an important driver of Mn particulate inventory changes during the century.

Results: Changes in external sources influence dissolved cobalt inventory

[dCo] (nmolCo/m^3) in surface 1981-2005 average



Changes in surface [dCo] (nmolCo/m^3) between 1981-2005 and 2081-2100



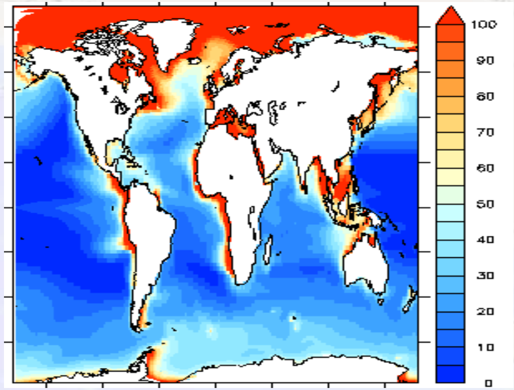
[dCo] is maximal in the Arctic and close to the coasts, because of strong sedimentary and riverine sources

Strong decrease in [dCo] in the Arctic by the end of the 21st century (associated with an increase in phytoplankton consumption and an increase in vertical transport).

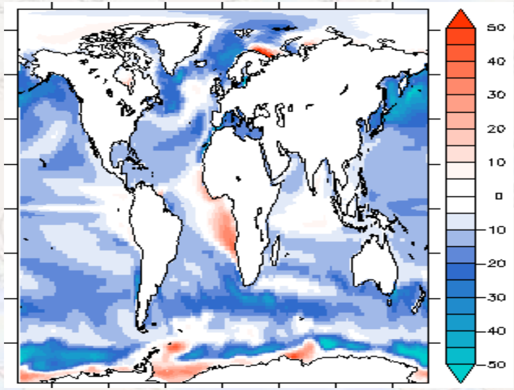
In the coastal subtropical areas, we note regions of strong decrease as well as regions of strong increase in [dCo].

Results: Changes in external sources influence dissolved cobalt inventory

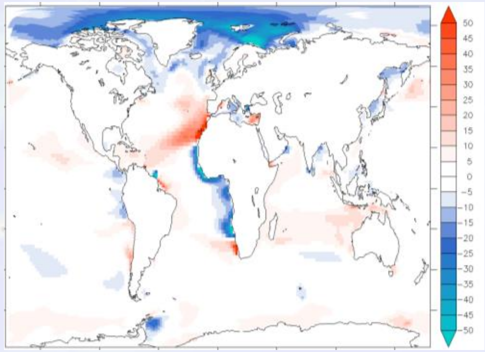
[dCo] (nmolCo/m³) in surface 1981-2005 average



Changes in surface [O_2] (mmol/m³) between 1981-2005 and 2081-2100



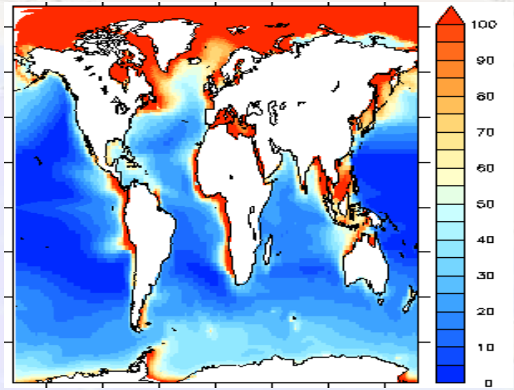
Changes in surface [dCo] (nmolCo/m³) between 1981-2005 and 2081-2100



O_2 impacts Co sedimentary source (low O_2 ➔ high dCo source)

Results: Changes in dissolved inventories are explained by multiple factors

[dCo] (nmolCo/m^3) in surface 1981-2005 average



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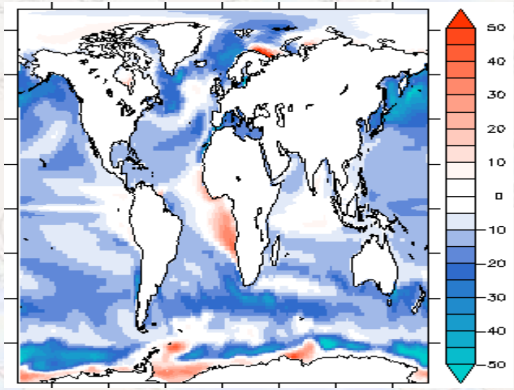
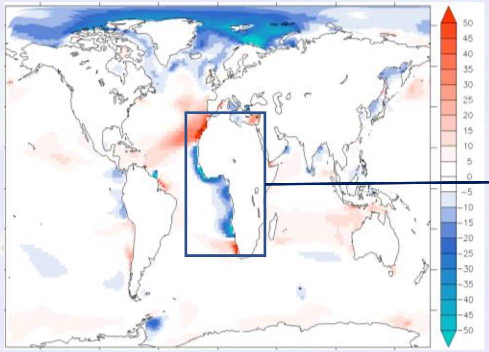
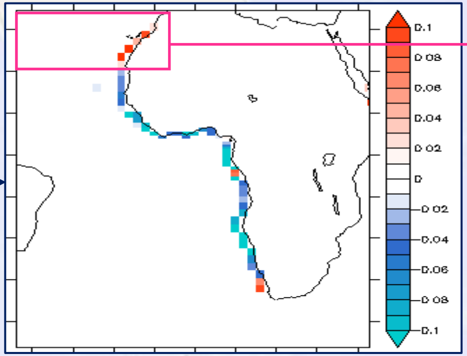


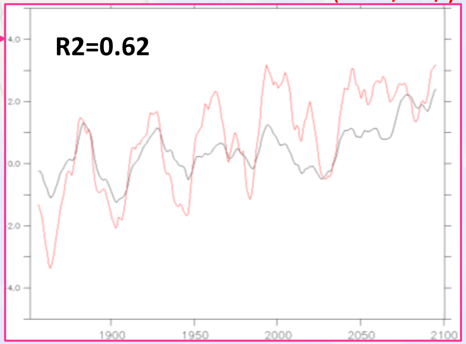
Changes in surface [dCo] (nmolCo/m^3) between 1981-2005 and 2081-2100



Changes in surface Co sedimentary source (pmolCo/m^3/yr) between 1981-2005 and 2081-2100



Time series of changes in average dCo (pmol/m^3) and Co flux from sediments (fmol/m^3/yr) in the equatorial Atlantic



Along the central African coast, the changes in [O_2] during the 21st century lead to a decrease in Co sedimentary source, leading to a decrease in [dCo].
In the North and South African coasts, the decrease in [O_2] leads to an increase in Co sedimentary source and an increase in [dCo] by the end of the century
Changes in external TM sources may significantly impact dissolved TM inventories.

Conclusion and perspectives

- Climate change impacts trace metal cycling differently than macronutrients
- Changes in TM living inventories are driven both by changes in phytoplankton biomass (i.e. increase in high latitudes, decrease in low latitudes) and uptake (which is itself driven by TM quotas in phytoplankton cells).
- The amount of TM in the particulate inventory is mainly driven by scavenging (because of the high particle reactivity of TMs)
- But dissolved TM inventories seem sensitive to changes in external sources.

➔ **We need scenarios for external sources evolution (integrated modelling with river runoff and aerosol scenarios)**

- Important mining of Co and Cu ➔ effects on surface inventories?

➔**We need constrains on anthropogenic sources**

- Kipp et al. 2018 showed that Ra sources in the Arctic increased in 10 years

➔**Need to revisit previously sampled areas?**

- Growth limitation by TM not included in the model

➔ **unknown feedbacks**

Questions/comments?
Ask in the chat, comment the presentation, or contact me at: crichon@liverpool.ac.uk