How does the 'organic carbon pump' determine the equilibrium CO_2 concentration in the atmosphere?

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Motivation: Ice Age cycles

Ice Age cycle is probably forced by variations in the orbit parameters of the Earth, but..

During Ice Ages, the atmospheric CO_2 concentration is about 200 ppm, during interglacials it is around 280 ppm.

Is there some positive feedback loop between climate and CO_2?

The ‘C $_2$-jump’ in the ocean

The carbon dioxide concentration in the atmosphere is approximately in equilibrium with the CO_2 concentration in the top layer of the ocean $\rightarrow$

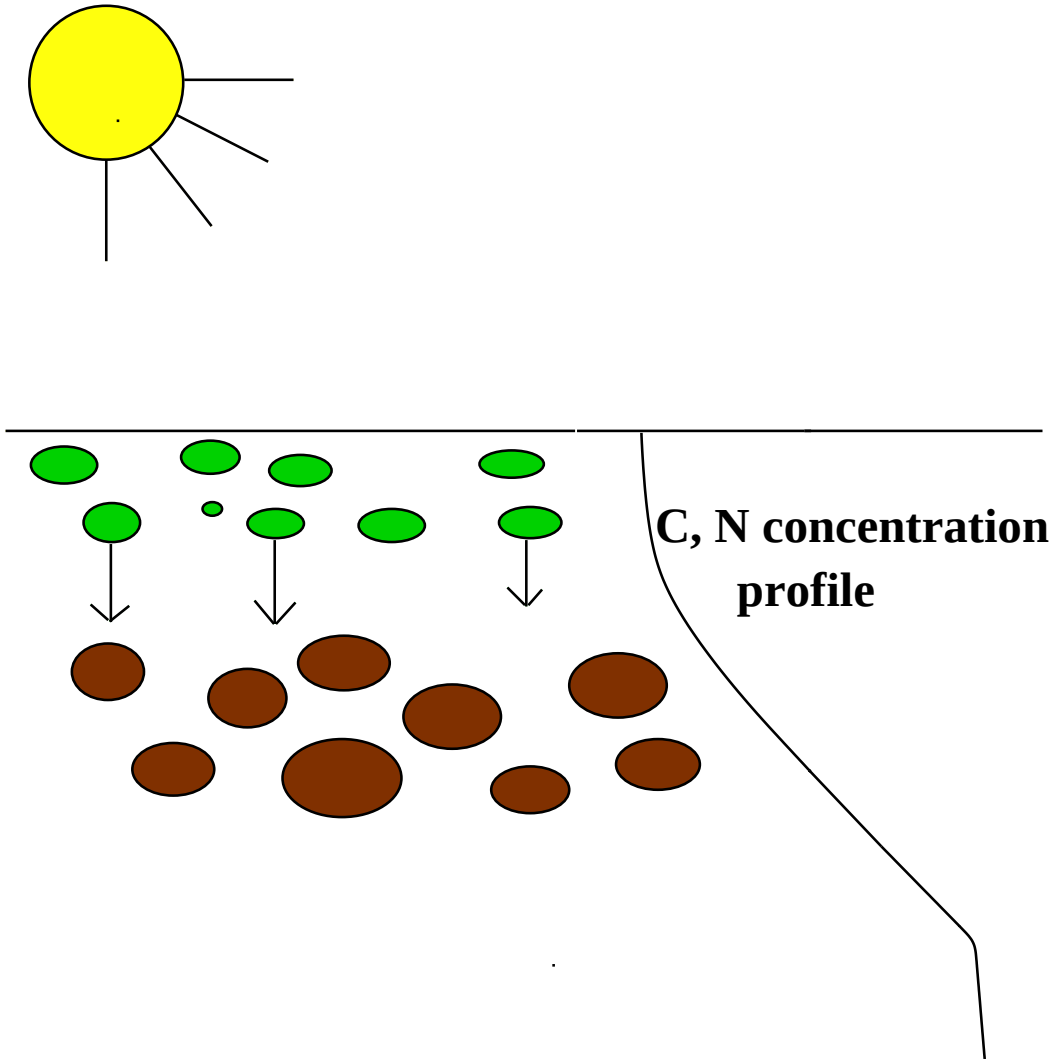
CO_2 concentration in the atmosphere follows from total amount of CO_2 in atmosphere plus ocean and from the seize of the CO_2-jump

What determines seize of C_2-jump?

CO_2-jump is caused by two 'pumps':

- Physical pump
- Biological pump

How does the biological carbon pump work?



Equilibrium: downward sinking of organic C and N is cancelled by upward flux of inorganic C and N

he impact of the biological carbon pump on the vertical carbon distribution

Biological carbon pump gives rise to a concentration difference ΔC between surface and deep sea equal to:

$$\Delta C = R \Delta N$$

with ΔN the N concentration difference between surface and deep sea and R the C:N ratio of the plankton

R very important for vertical distribution of carbon $\rightarrow$
Could there be a relationship between climatic conditions and R value?

Simulation setup

- 1000 m thick water column plus an 'atmosphere': an extra 150 m layer above the water exchanging CO_2 with the water
- no fluxes of nutrients and biomass components into or out of the water column
- no CO_2 flux across the lower boundary of the water column and the upper boundary of the 'atmosphere'
- Flexible-stoichiometry plankton model

Flexible vs fixed stoichiometry

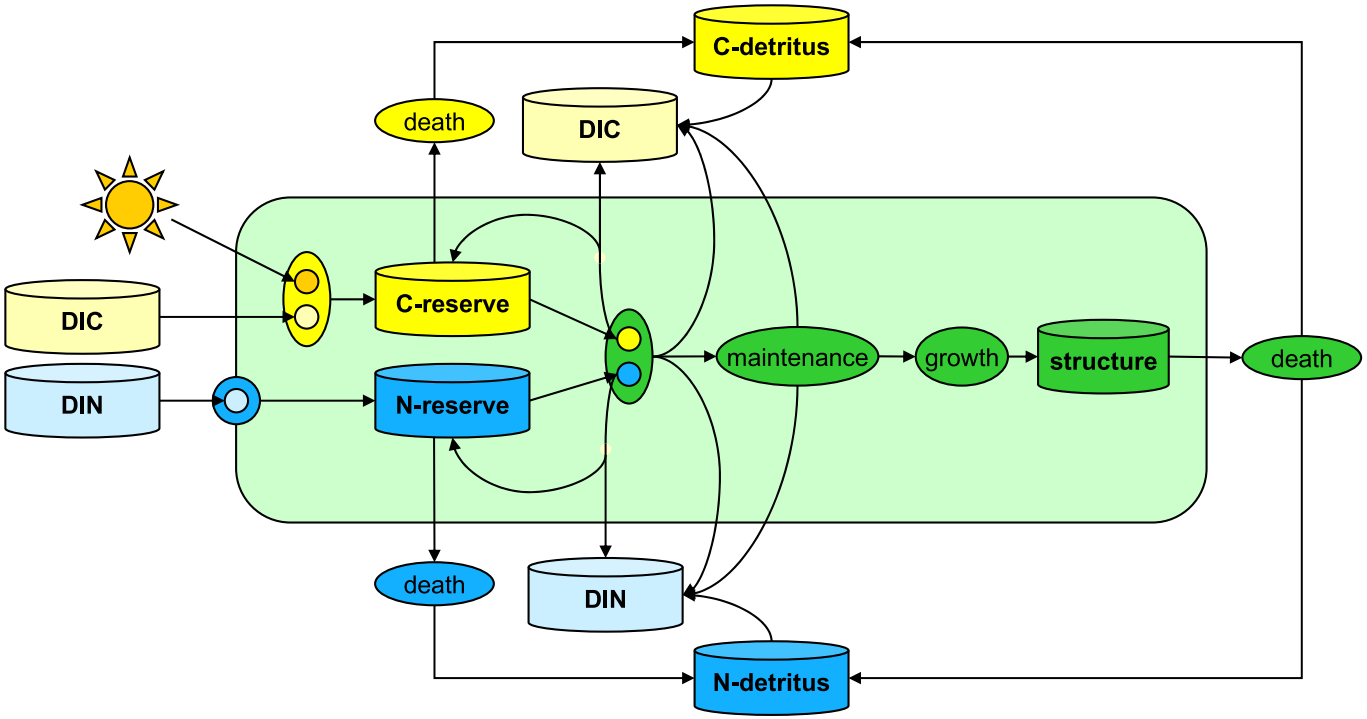
- C:N ratio of plankton determines effect of biological carbon pump and hence partitioning of carbon between atmosphere and ocean
- in many plankton models that are used in the Earth Sciences (e.g. the NPZD model), plankton has a fixed C:N ratio
- in the real world, the C:N ratio of plankton is not fixed but flexible because of 'luxury consumption' $\rightarrow$ we need a plankton model that includes a flexible C:N ratio

Flexible-stoichiometry plankton model

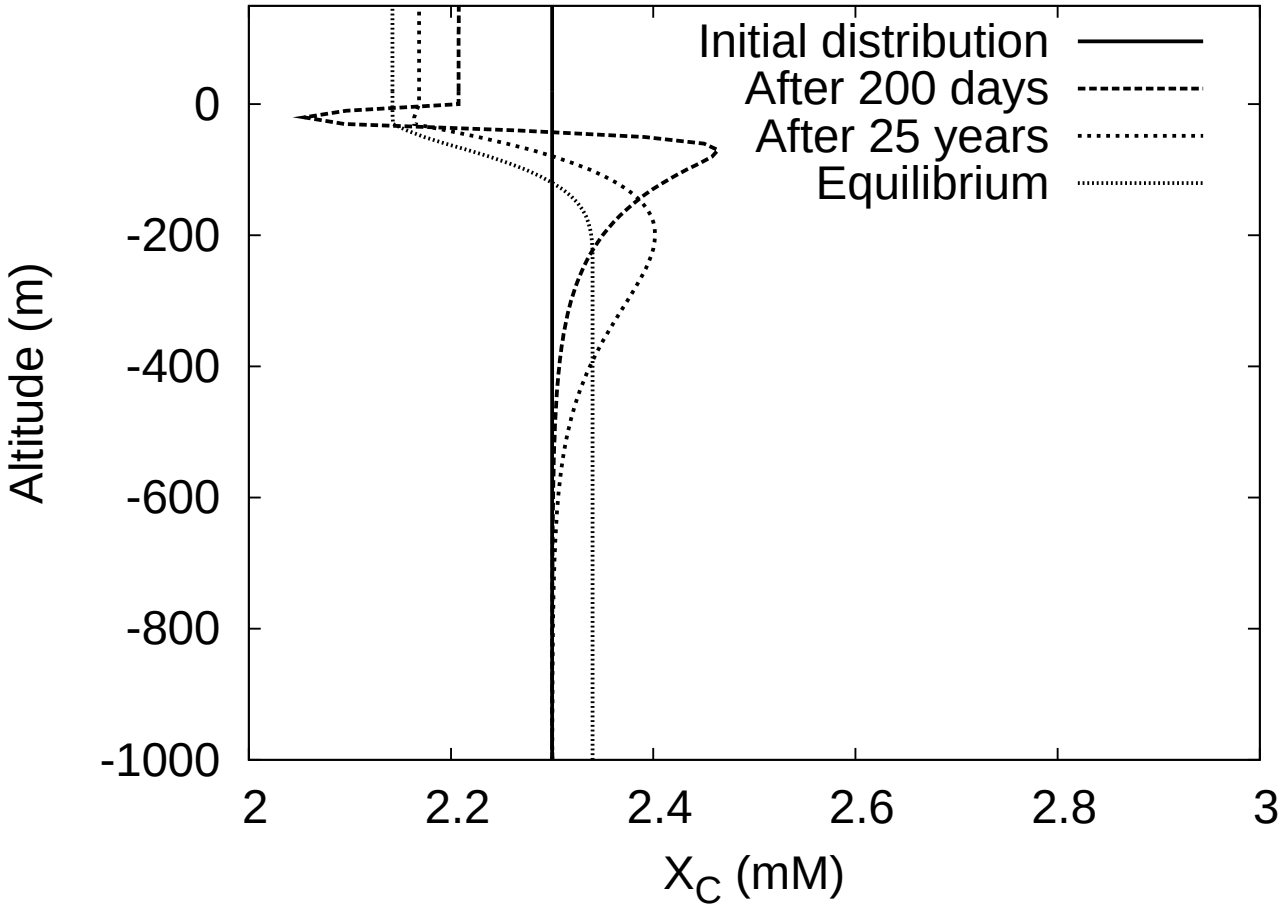
- model organisms consist of three components with different chemical compositions: structure (90% C, 10% N), C-reserve (100% C), and N-reserve (100% N)
- ratio of these three components determines the C:N ratio of the plankton

he model organism depicted

Phytoplankton 2 reserves + Det



Results: the emergence of a C_2-jump from a homogeneous carbon distribution

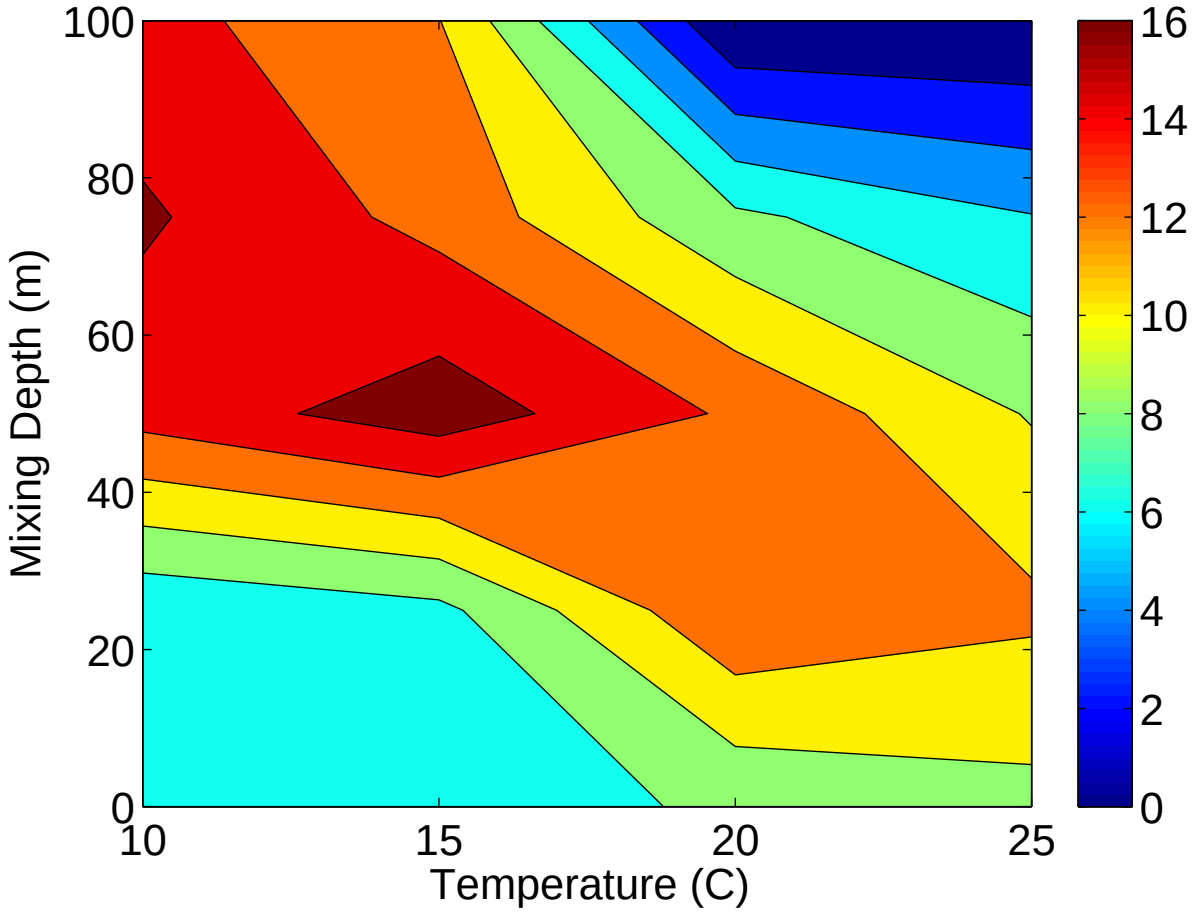


hat could determine the C:N ratio R?

The plankton stoichiometry might be influenced by many factors, e.g:

- mixed layer depth
- temperature
- exchange rate between mixed layer and deeper waters (e.g. sinking/diffusion rates)

Results: effect of mixed-layer depth and temperature on R



Discussion

Relationship between temperature and R may provide a positive feedback mechanism between temperature and atmospheric CO_2. However, there are some caveats:

- relationship between temperature and R relies on a subtle mechanism and hence somewhat speculative
- model takes physical environment constant: we only consider an equilibrium situation

utlook

- experimental test of relationship between temperature and R (unfortunately not in our ability)
- investigating effect of mesoscale eddies and other variations in physical environment on biological carbon pump