Marine carbon cycle climate feedbacks – magnitudes and timescales

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What I will talk about

1. Feedback:
   Definition and main focus on
   marine fossil fuel CO_2 uptake kinetics
2. The feedback zoo
3. The role of biological vs. physical feedbacks

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1. What is a feedback ?

Feedback is a process whereby some proportion
- or in general, function –
of the output signal of a system
is passed (fed back) to the input.

Often this is done <u>intentionally</u>, in order to <u>control the dynamic behaviour of the system</u>.

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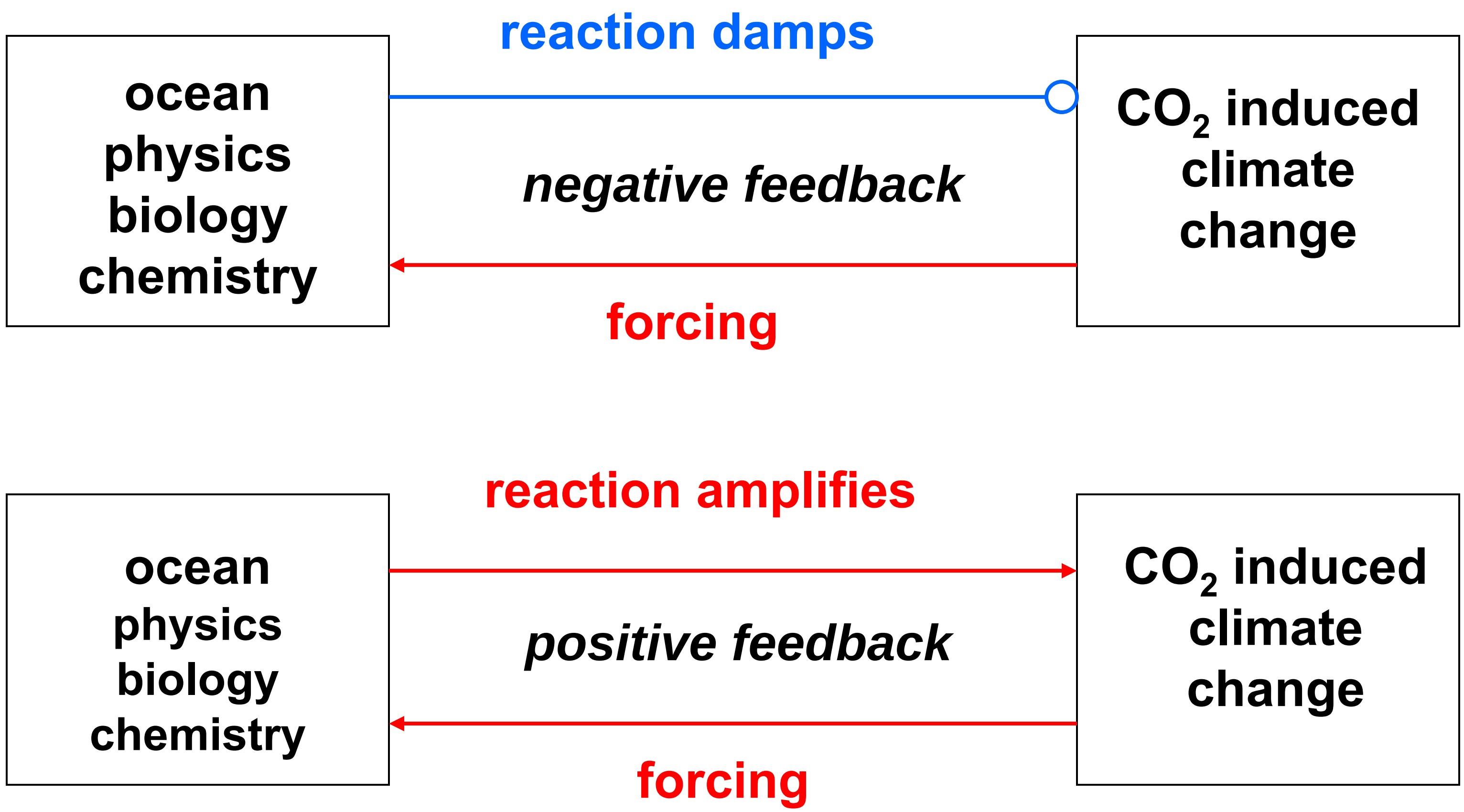
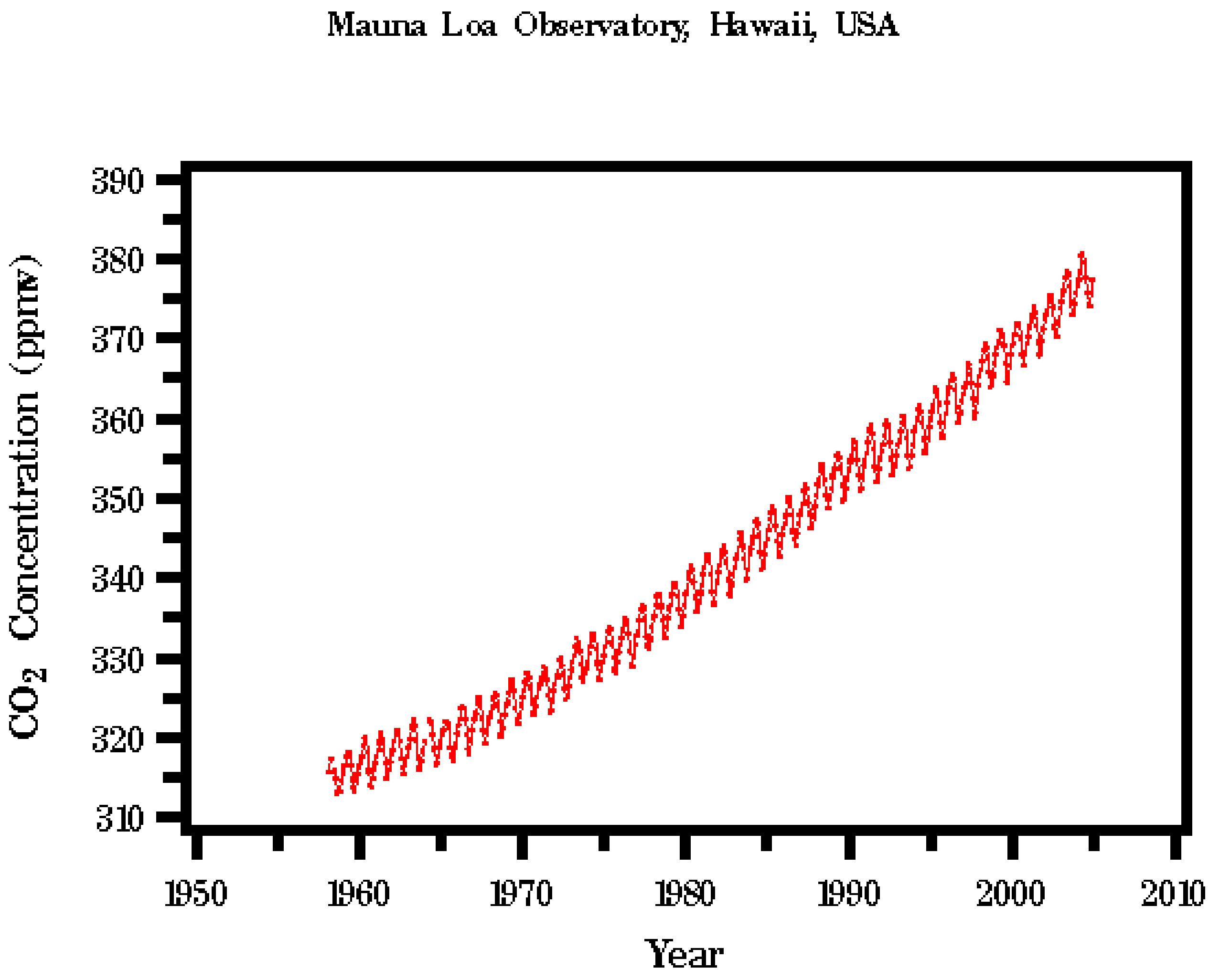
Feedback loops and stability



Fossil fuel CO_2 and the oceanic carbon sink: ”***<u>uptake kinetics</u>***” vs. ”***ultimate uptake capacity***”



Source: Dave Keeling and Tim Whorf (Scripps Institution of Oceanography)

Ultimate storage capacity of the ocean for anthropogenic CO_2:

CO_2 partitioning after re-equilibration.

11/12 of a perturbation in the atmospheric CO2 content will be taken up by the ocean.

1/12 will remain in the atmosphere.

(see e.g. Bolin and Eriksson, 1959)

Through repeated ocean mixing cycles and re-dissolution of $CaCO_3$ sediment from the ocean floor.

Given long enough time – i.e. after ca. 100,000 years. For mankind of limited interest!!!!!!!!!

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Uptake kinetics: important for mankind !

describes *how quickly* CO_2 is removed from the atmosphere by the ocean

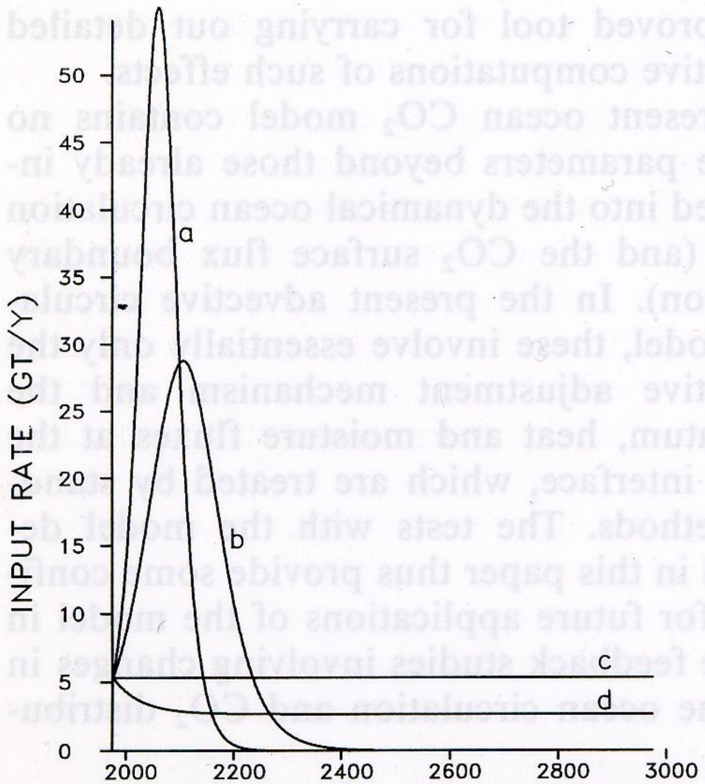

Fig. 24. Emission scenarios corresponding to logistic input functions with two different time scales *(curves a and b)*, a constant input at present-day levels *(curve c)* and an exponentially decreasing input up to the year 2018, succeeded by a constant input at half the present-day level *(curve d)*

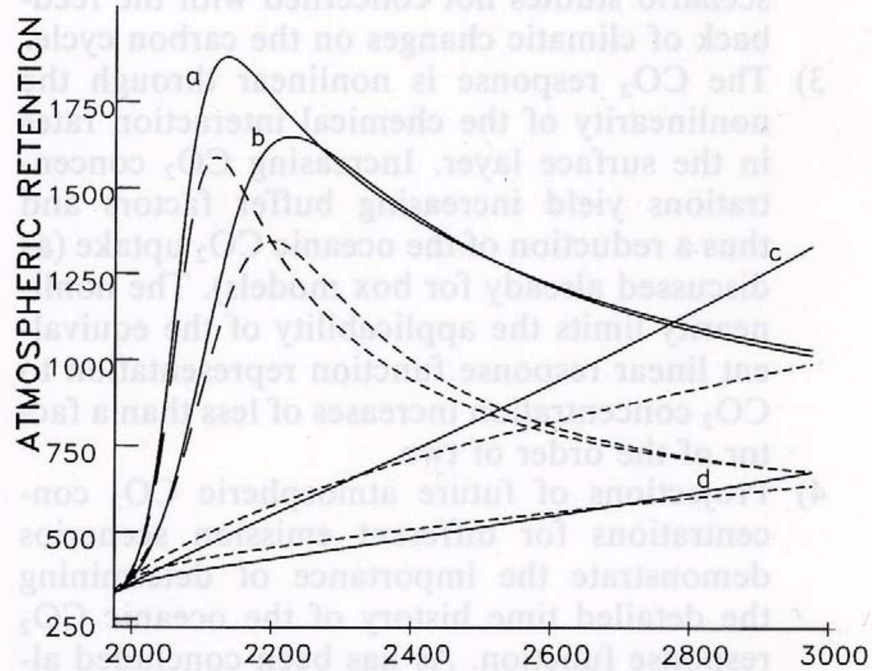

Fig. 25. Atmospheric CO_2 concentrations (ppm) for the four emission scenarios of Fig. 24 computed with the full model *(full curves)* and the equivalent linear input response function method *(dotted curves)*. The linear input response function is seen to underestimate the amplitude and time scale of the response for higher pCO_2 levels, but is a good approximation for small changes

Maier-Reimer and Hasselmann, 1987, Clim.Dyn., 2: 63-90 An abiotic model

The feedback zoo

Climate change induced forcings for the marine carbon cycle:

Warming of the ocean surface water

Freshening of the ocean surface

Rising CO_2 and acidification (pH lowering)

Changes in cloud cover, sea ice cover, and incoming solar radiation

Increasing stratification and reduction in large scale meridional overturning, shift of shelf regimes

Biogeochemical forcing (river loads, aoelian deposition, dust, micronutrients)

Destabilization of methane gas hydrates

Purposeful CO_2 storage in the ocean as an anthropogenic feedback to rising atmospheric pCO_2

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Process	Primary forcings
Change in CO_2 solubility and dissociation (buffer factor)	Warming, atmospheric pCO_2 increase
Biological export production of POC, DOC storage, particle flux mode	Warming, pCO_2 increase, runoff loads, dust deposition, slowing of ocean circulation, change in radiation
Biological export production of PIC ($CaCO_3$), particle flux mode	pCO_2 increase (pH decrease
Coral growth	Warming, atmospheric pCO_2 increase (pH decrease)
Dissolution of $CaCO_3$ sediments	pCO_2 increase (pH decrease)
DMS production, other secondary feedbacks	$CaCO_3$ production, dust flux
Destabilization of gas hydrates	Warming, pressure/circulation
Purposeful CO_2 storage	Human attempt to mitigate

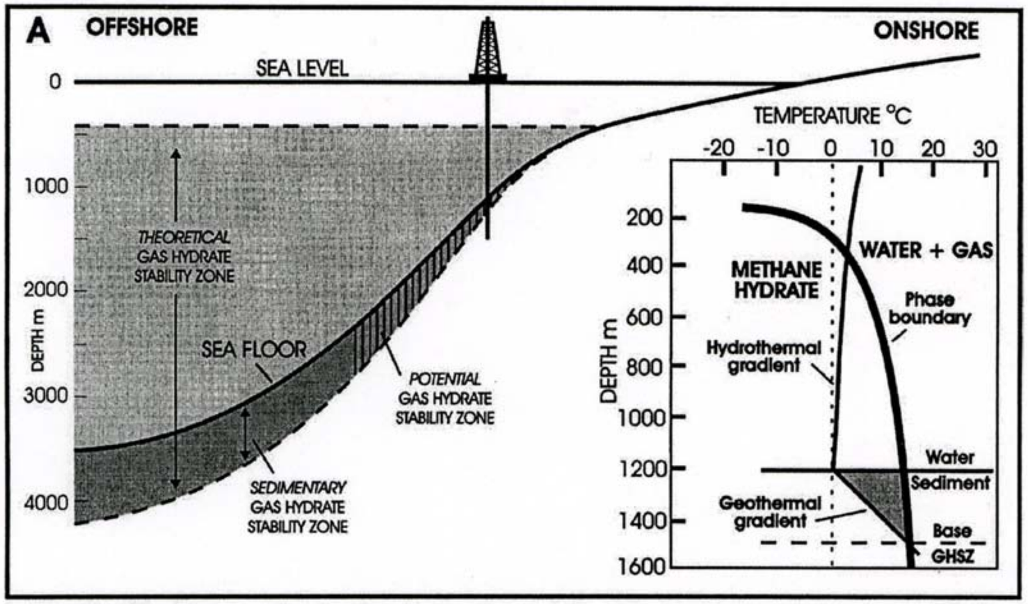
Process	Feedback
Change in CO_2 solubility and dissociation (buffer factor)	+
Biological export production of POC, DOC storage, particle flux mode	unknown
Biological export production of PIC ($CaCO_3$), particle flux mode	unknown
Coral growth	-
Dissolution of $CaCO_3$ sediments	-
DMS production, other secondary feedbacks	unknown
Destabilization of gas hydrates	+
Purposeful CO_2 storage	unknown

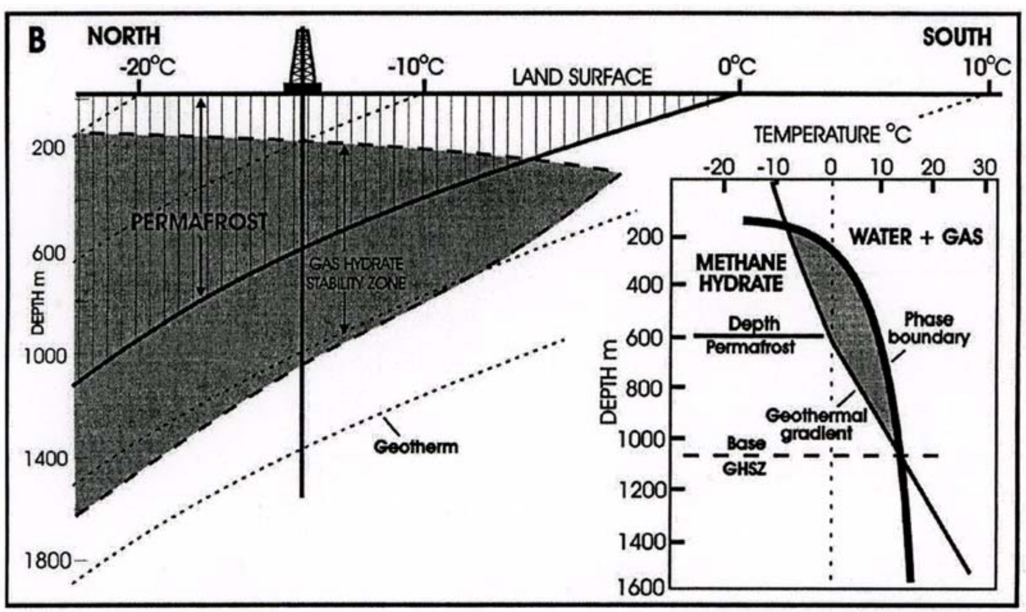
Process	Quantitative potential
Change in CO_2 solubility and dissociation (buffer factor)	high
Biological export production of POC, DOC storage, particle flux mode	unknown
Biological export production of PIC ($CaCO_3$), particle flux mode	unknown
Coral growth	unknown
Dissolution of $CaCO_3$ sediments	high
DMS production, other secondary feedbacks	unknown
Destabilization of gas hydrates	unknown
Purposeful CO_2 storage	unknown

Process	Reaction time scale
Change in CO_2 solubility and dissociation (buffer factor)	Immediate (-1000 yr)
Biological export production of POC, DOC storage, particle flux mode	0-1000 yr
Biological export production of PIC ($CaCO_3$), particle flux mode	0-1000 yr
Coral growth	0-100 yr
Dissolution of $CaCO_3$ sediments	1,000-100,000 yr
DMS production, other secondary feedbacks	0-1000 yr
Destabilization of gas hydrates	unknown
Purposeful CO_2 storage	unknown

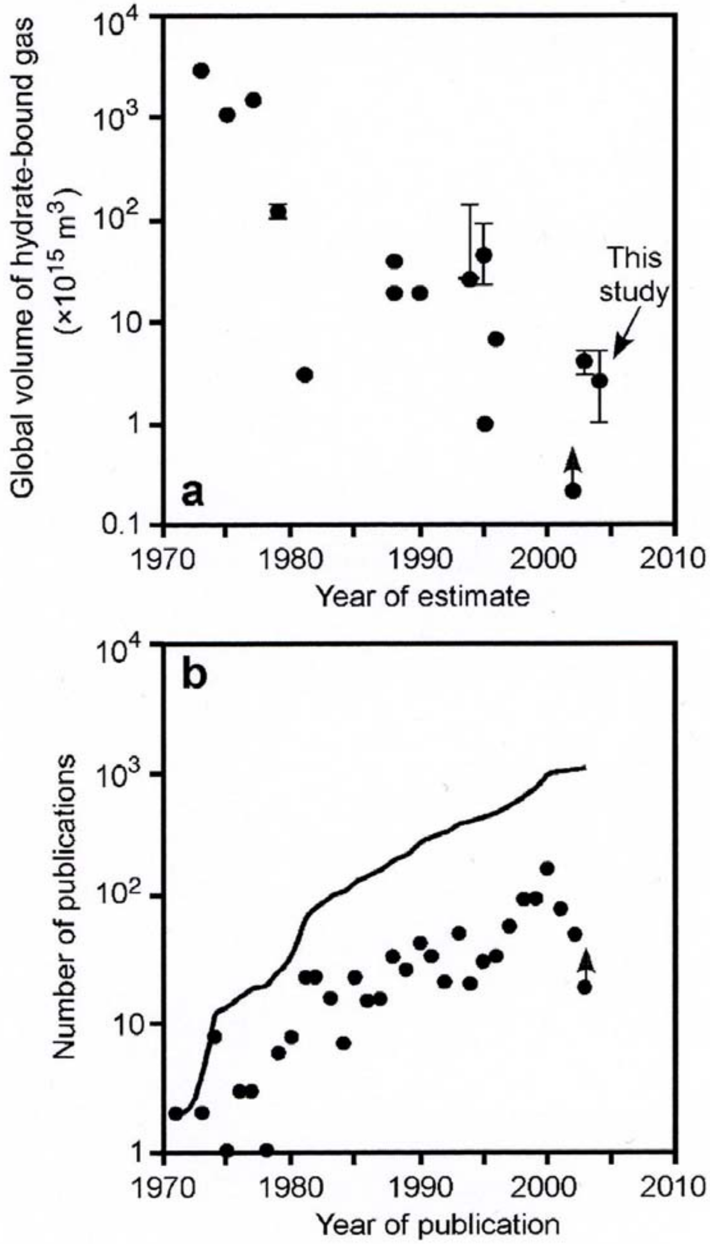
Process	Certainty
Change in CO_2 solubility and dissociation (buffer factor)	certainty
Biological export production of POC, DOC storage, particle flux mode	indication
Biological export production of PIC ($CaCO_3$), particle flux mode	indication
Coral growth	certainty
Dissolution of $CaCO_3$ sediments	certainty
DMS production, other secondary feedbacks	indication
Destabilization of gas hydrates	potential
Purposeful CO_2 storage	potential

Process	Certain + quantitatively important for C in atmosph. + now relevant
Change in CO_2 solubility and dissociation (buffer factor)	+
Biological export production of POC, DOC storage, particle flux mode	-
Biological export production of PIC ($CaCO_3$), particle flux mode	-
Coral growth	-
Dissolution of $CaCO_3$ sediments	-
DMS production, other secondary feedbacks	-
Destabilization of gas hydrates	-
Purposeful CO_2 storage	-

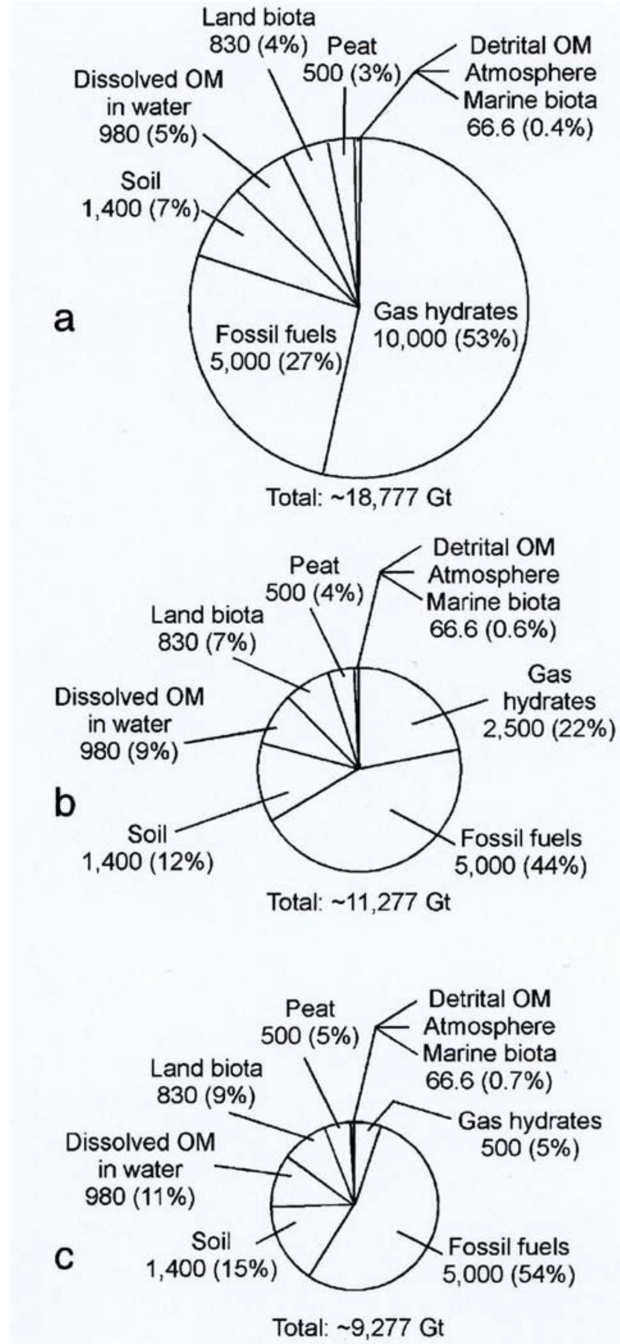




Beauchamp, 2004,
C.R. Geoscience



Milkov, 2004, *Earth Science Reviews*



The role of biological vs. physical feedbacks

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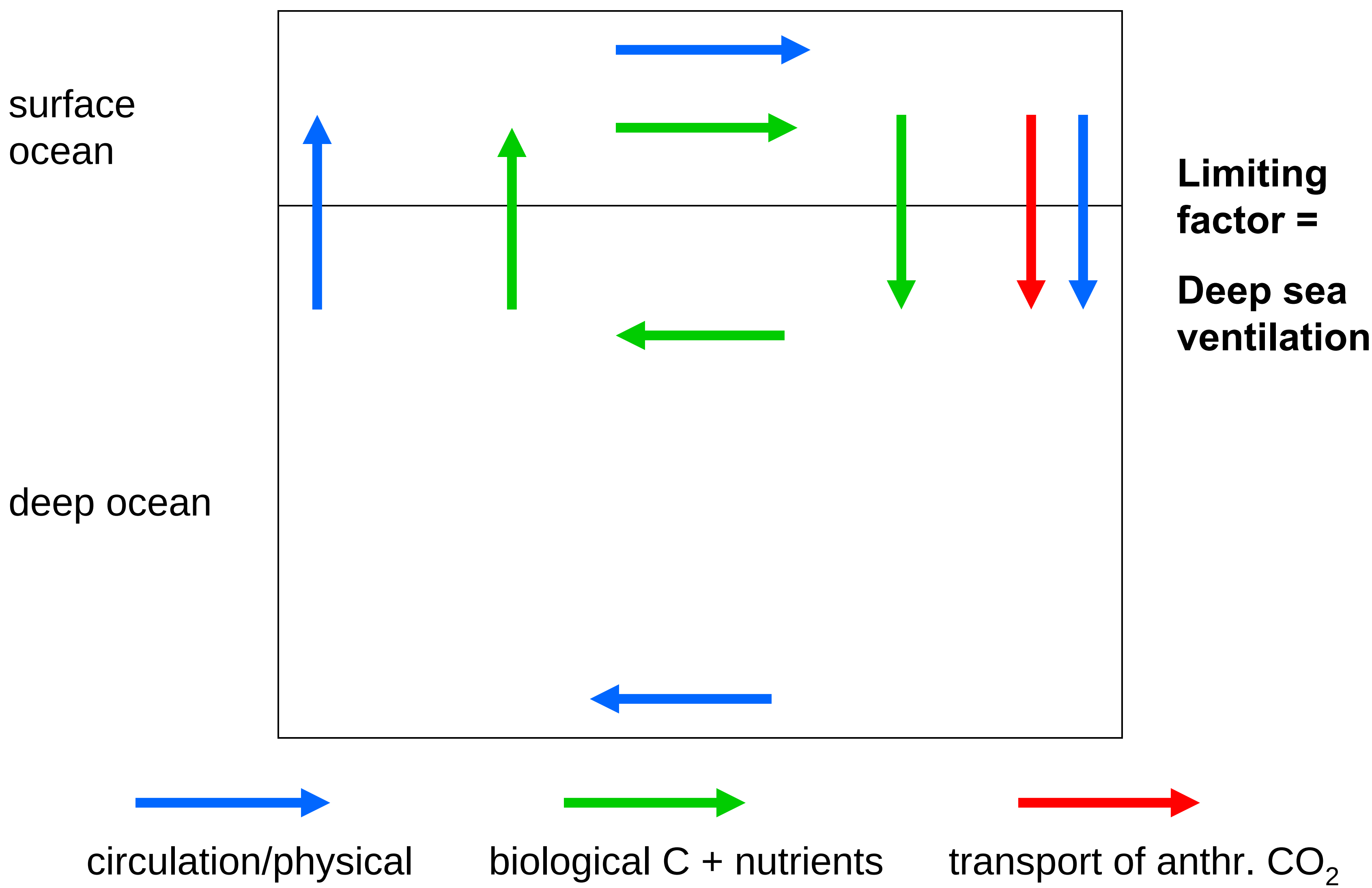
atmosphere

Anthropogenic CO_2 uptake:

assuming constant ocean circulation



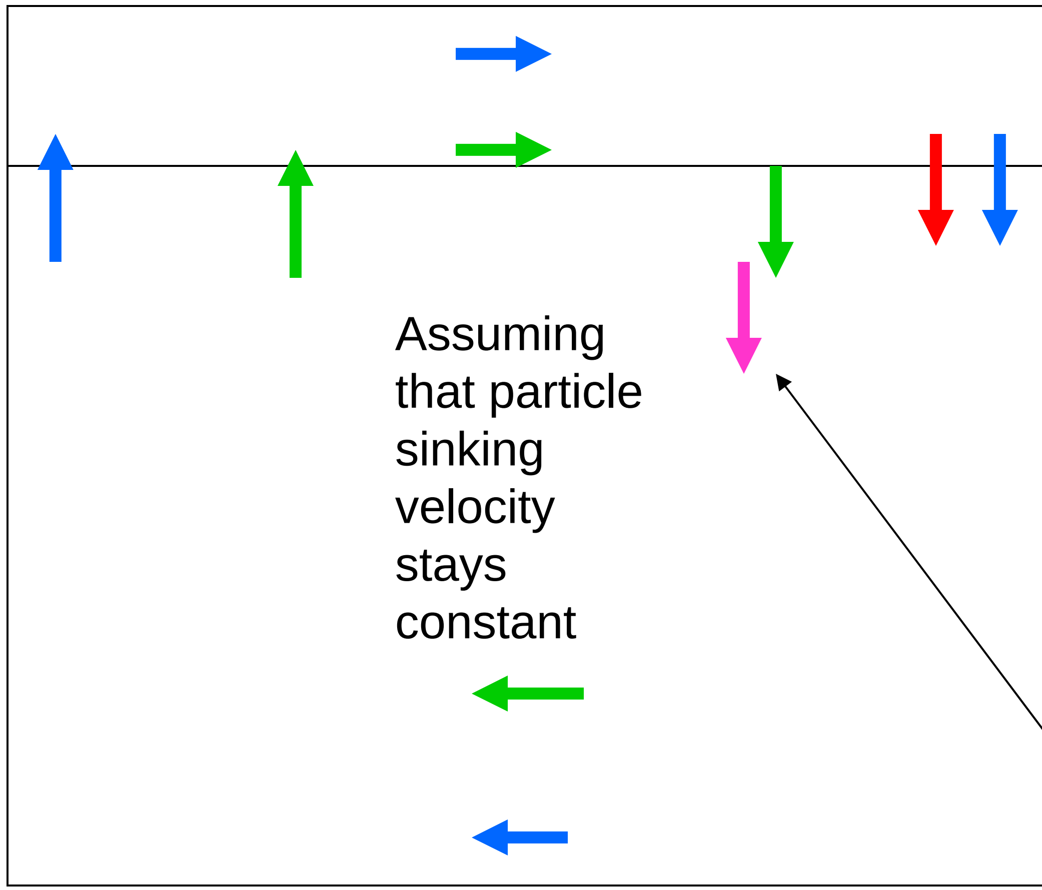
Anthropogenic CO_2 uptake:

slowing ocean circulation, increasing stratification

atmosphere

surface ocean

deep ocean



Limiting factor =

Deep sea ventilation

But: during slowing down vertical nutrient + C fractionation, ONLY DURING TRANSIENT!!

circulation/physical

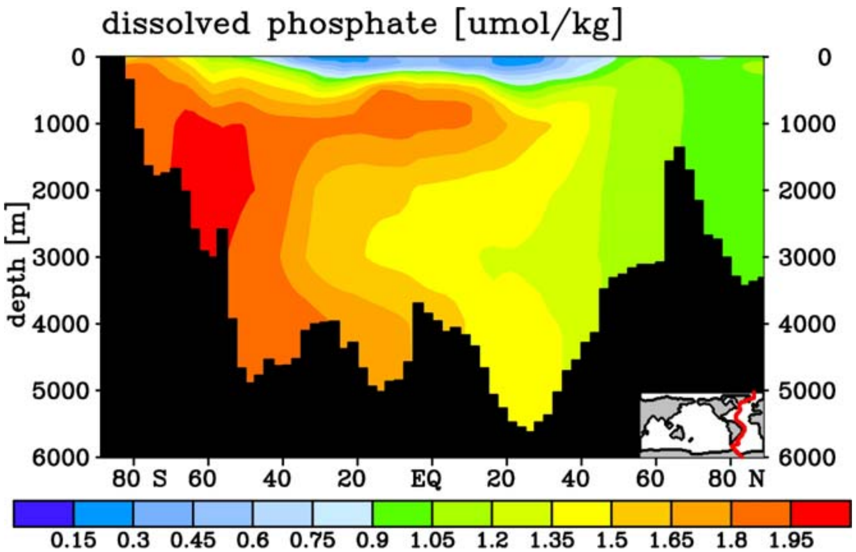
biological C + nutrients

transport of anthr. CO_2

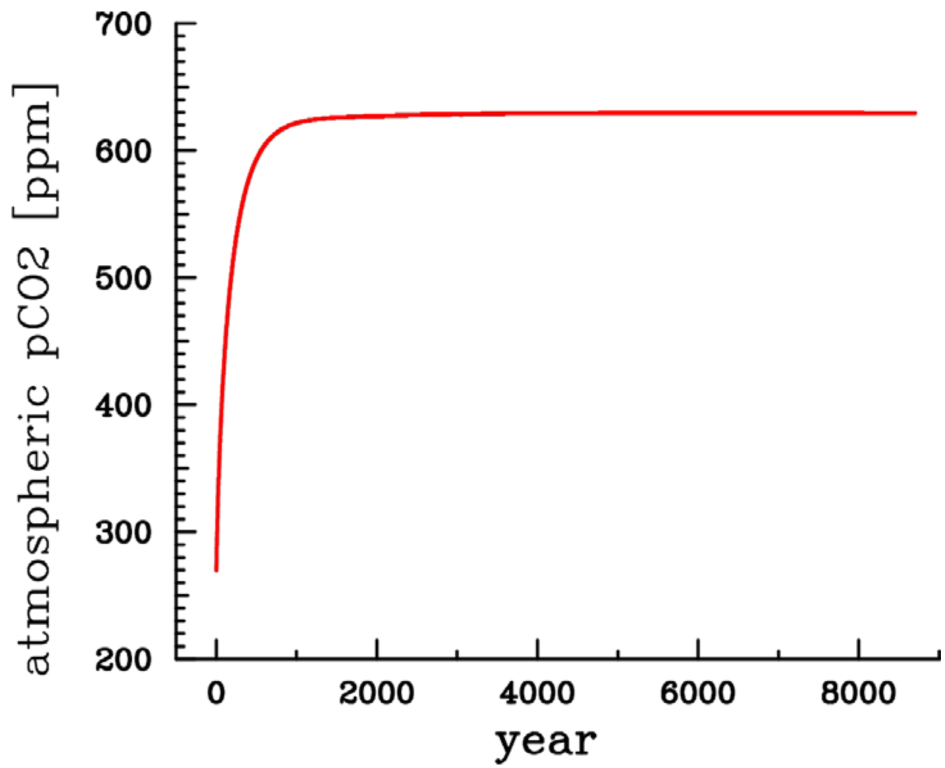
extreme scenarios (with the HAMOCC2 GCM)

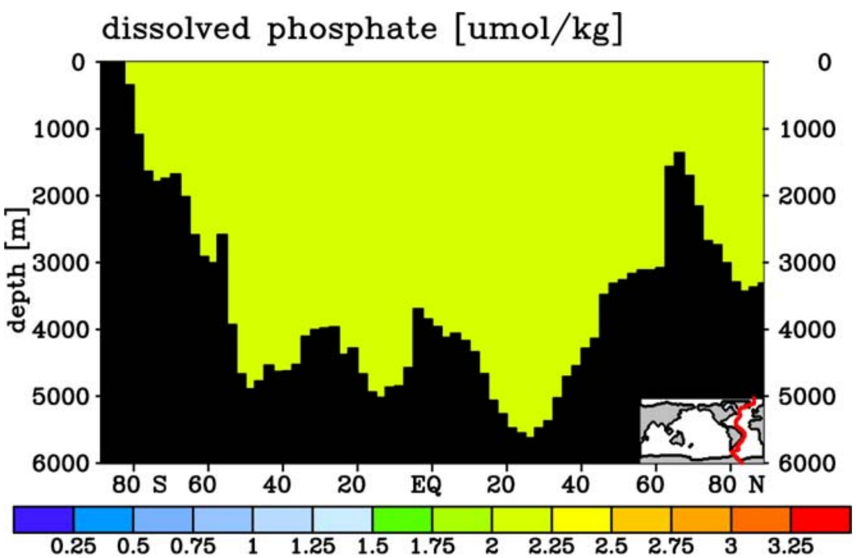
anthropogenic CO_2 + slowing down of ocean circulation

Extreme scenario 1: switching off biology



standard





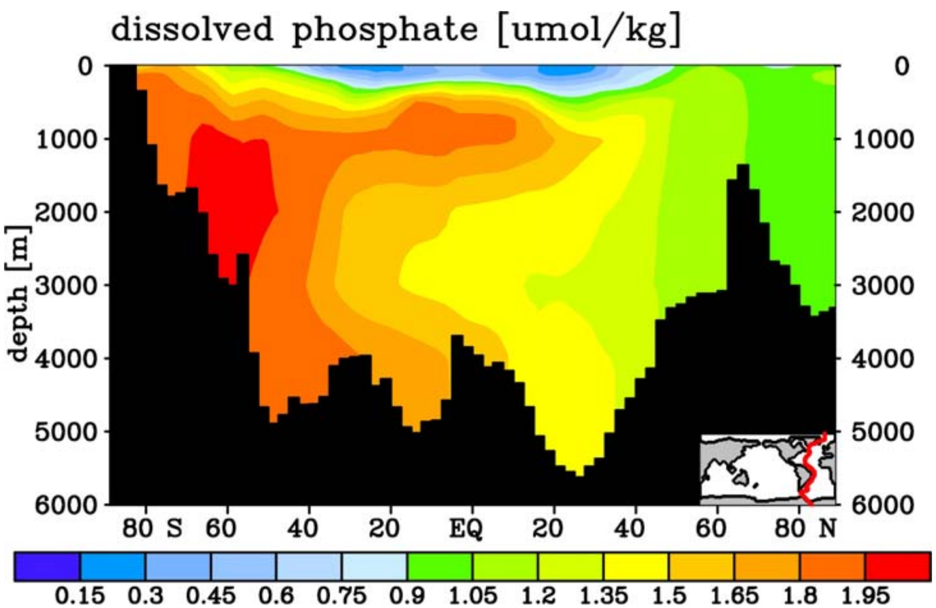
POC production=0, year 8700

Extreme scenario 2: "maximising biology"

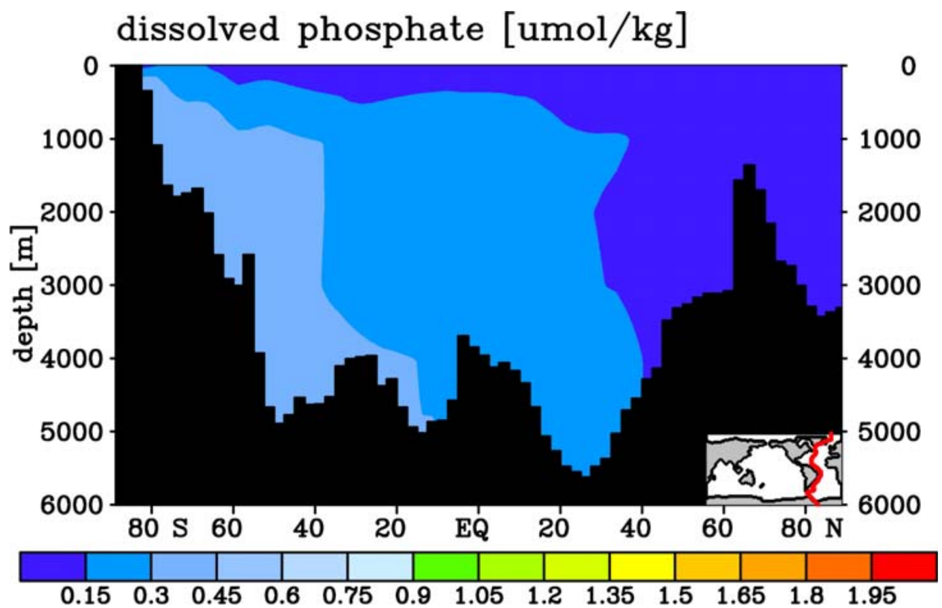
Circulation as in standard, but:

- no ice cover
- V_{max} x 10 (nutrient uptake velocity)
- particle sinking velocities x 10
- maximum rain ratio $CaCO_3$:POC / 10

standard



max. biology after 10,000 years



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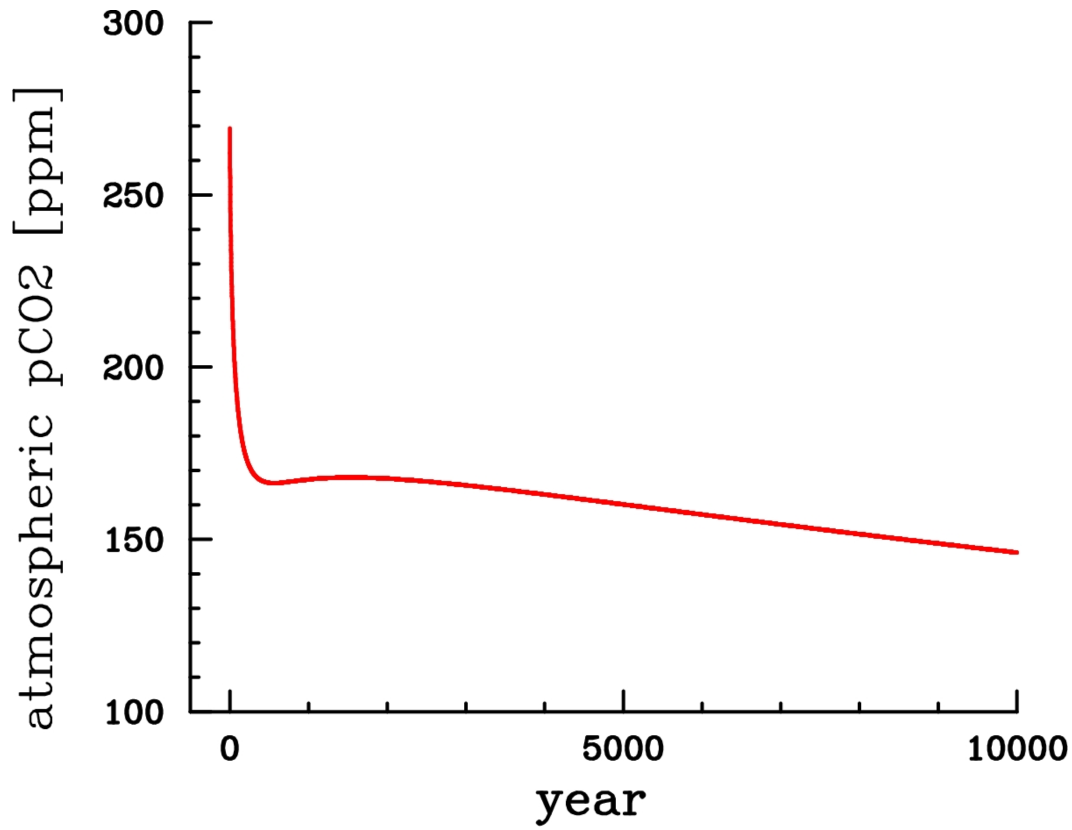
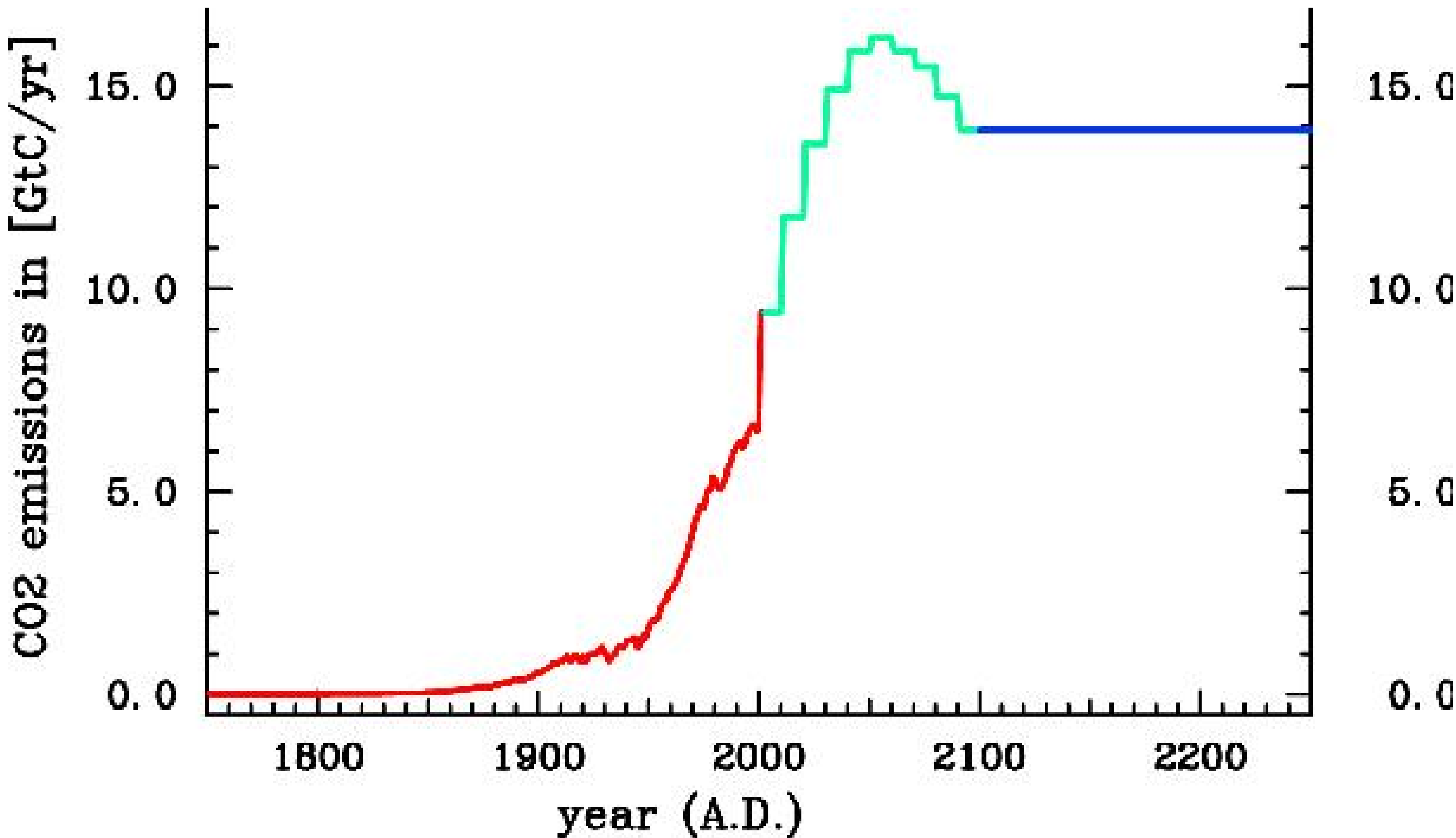


An anthropgenic CO_2 emission scenario:



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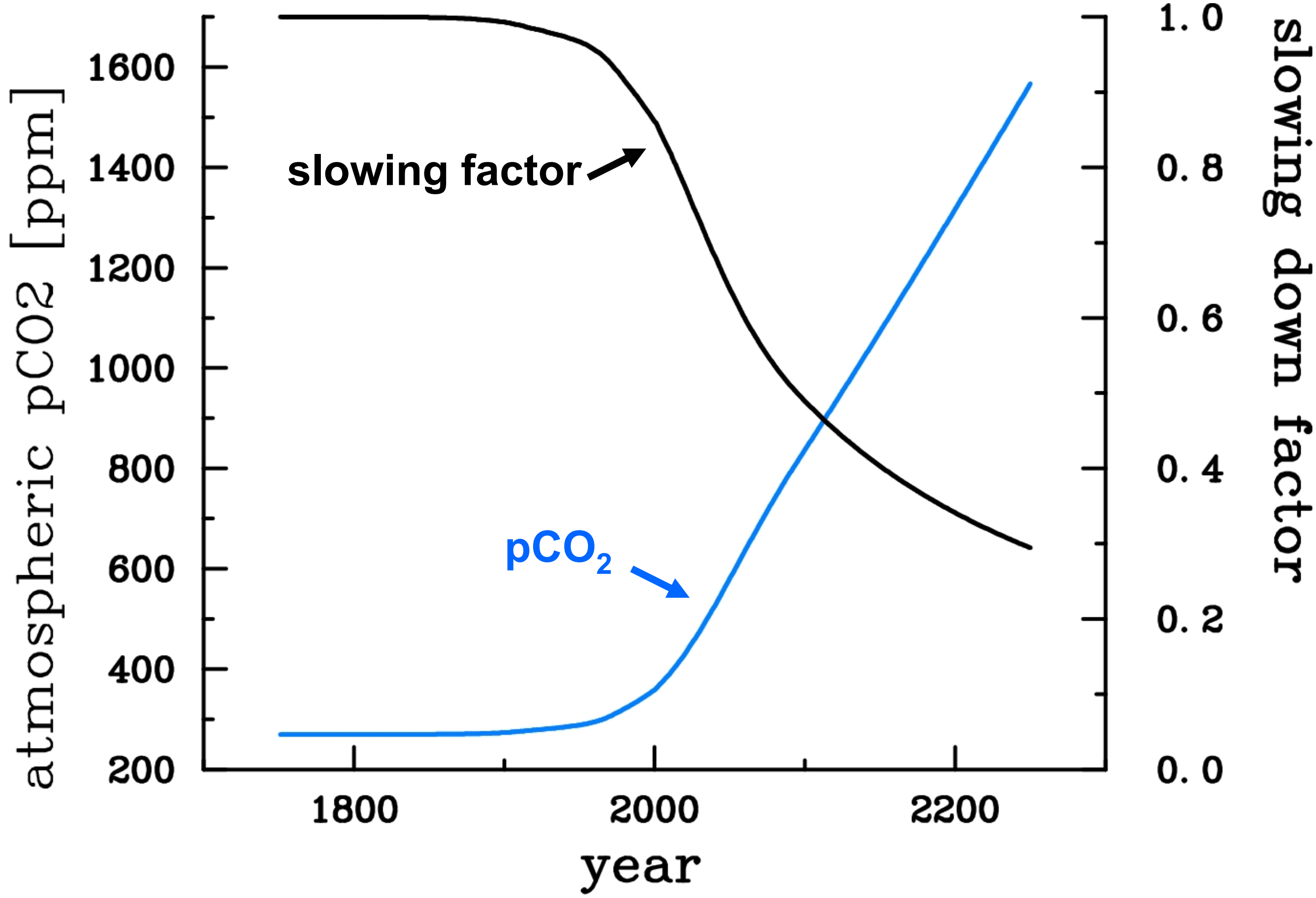
An anthropogenic CO_2 emission scenario:



Δ = [$pCO_2(t_1)$ - $pCO_2(t_0)$] x 0.5

slowing factor = $pCO_2(t_0)$ / [$pCO_2(t_0)$ + Δ]

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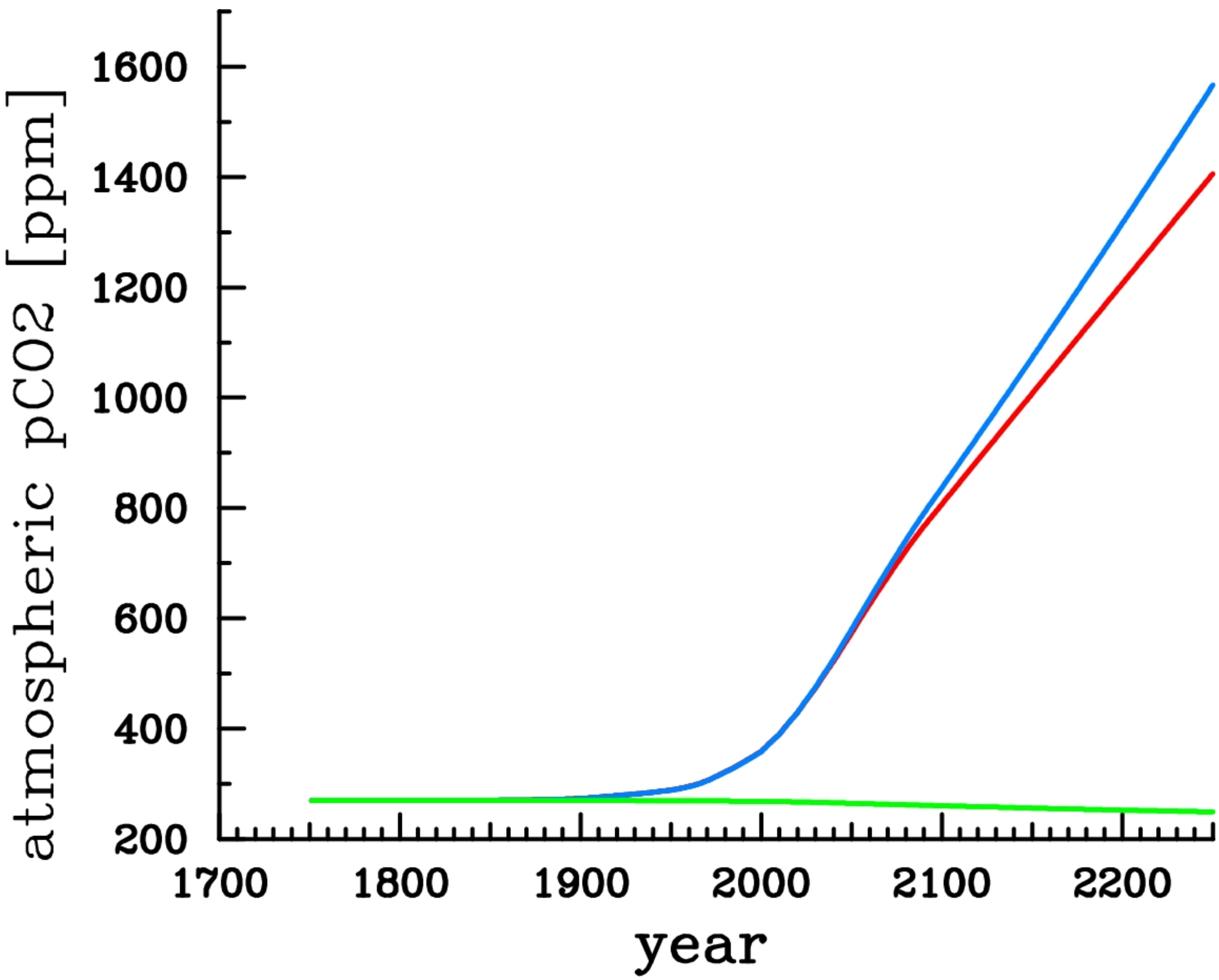
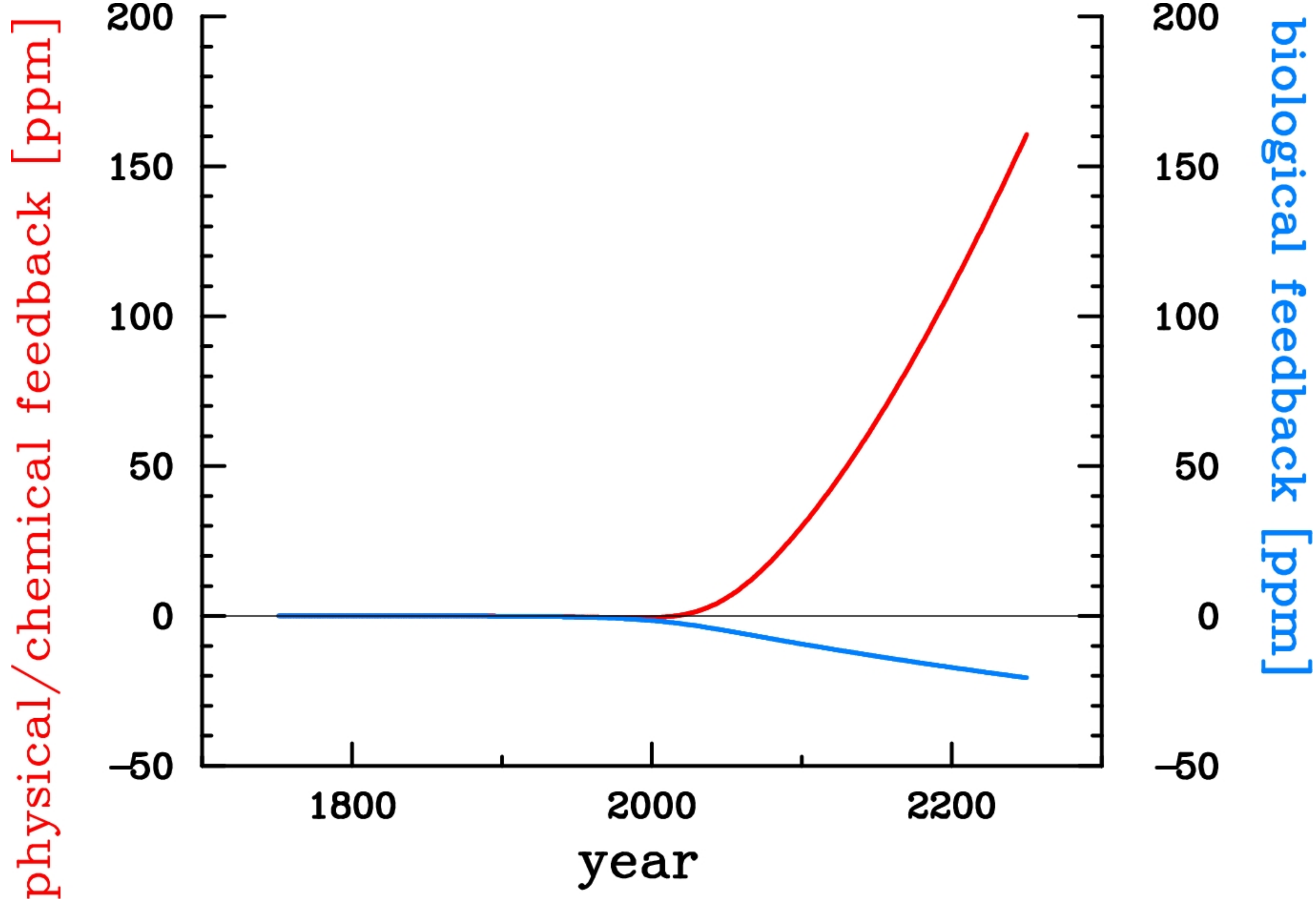
An anthropogenic CO_2 emission scenario:

case 1: circulation constant
case 2: circulation slowing
case 3: circulation slowing / no CO_2 emissions



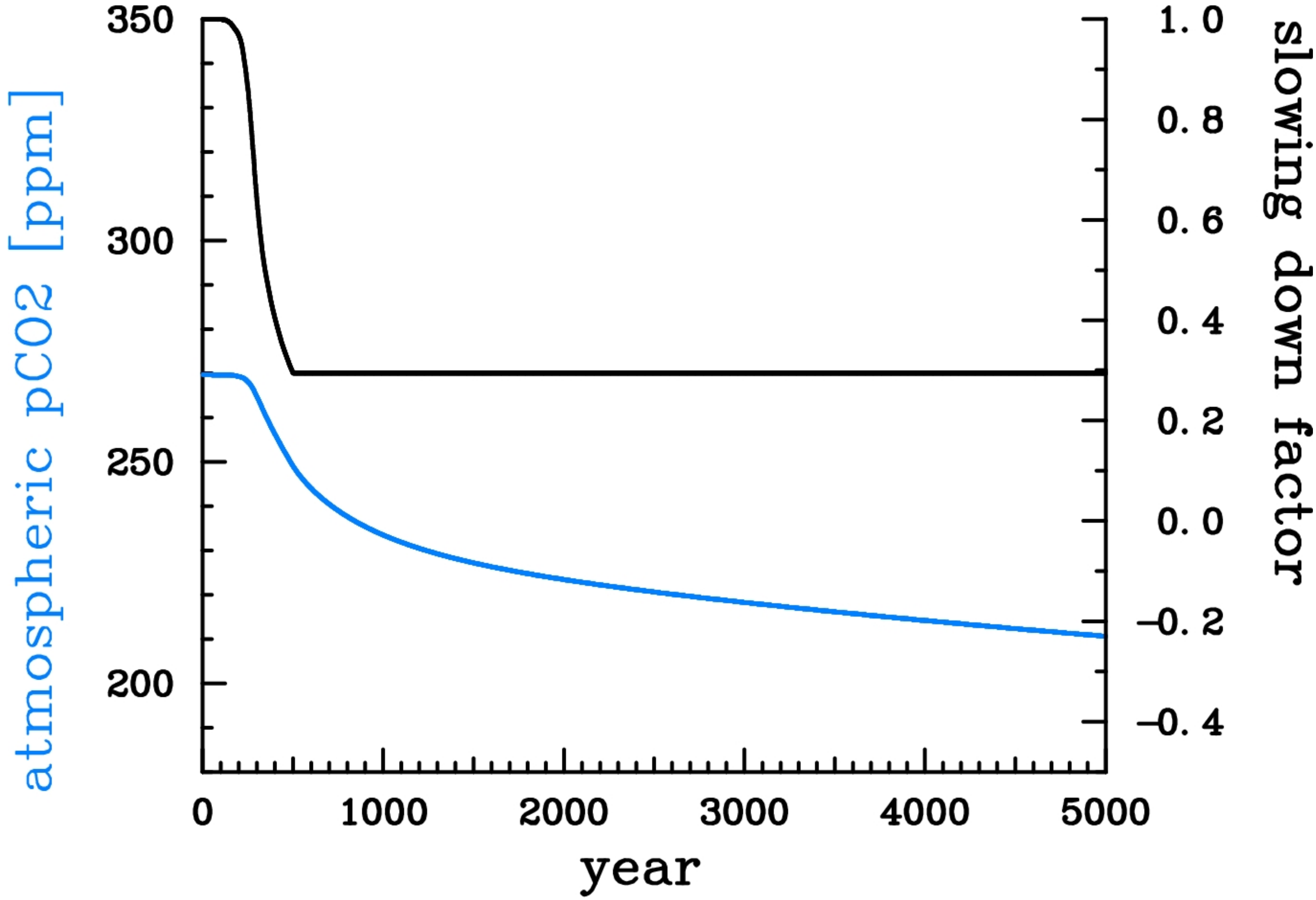
An anthropogenic CO_2 emission scenario:

Physical vs. biological feedback during rising pCO_2 and slowing circulation



An anthropogenic CO_2 emission scenario:

Biological feedback due to slowing circulation on long timescales



A preliminary conclusion:

The maximum effect of biological feedbacks on the kinetics of anthropogenic CO_2 uptake by the oceans is about

-200 to + 400 ppm

within 100-1000 years

But: for after all quite extreme and unrealistic scenarios.

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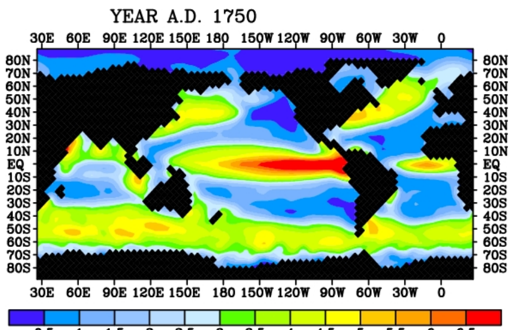
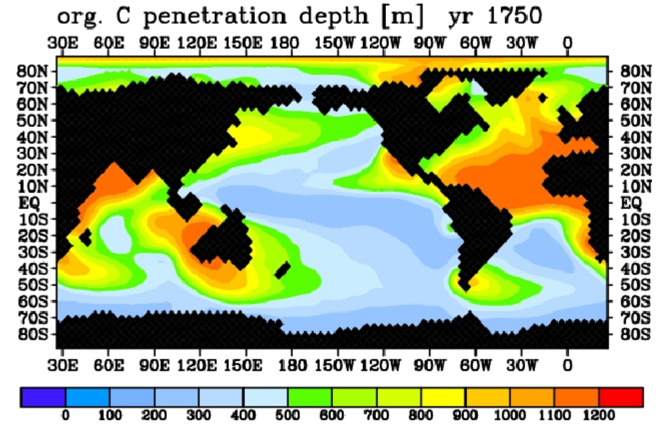
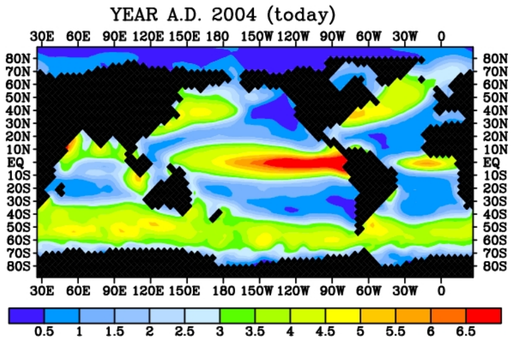


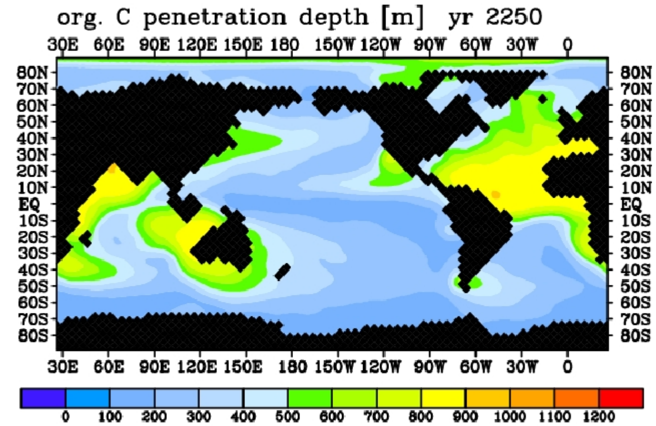
Riebesell/Zondervan

$CaCO_3$ feedback



Heinze *GRL* 2004



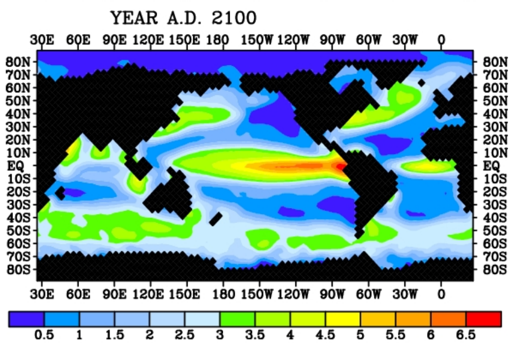


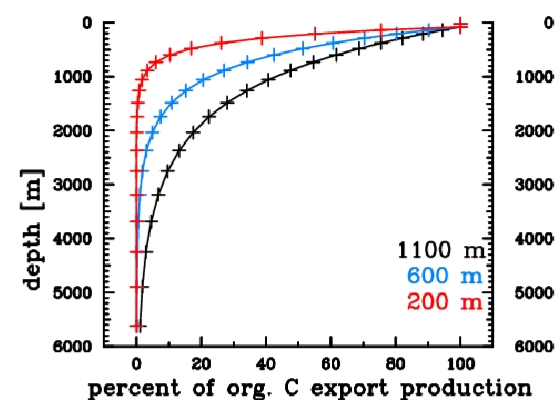
In year 2250:

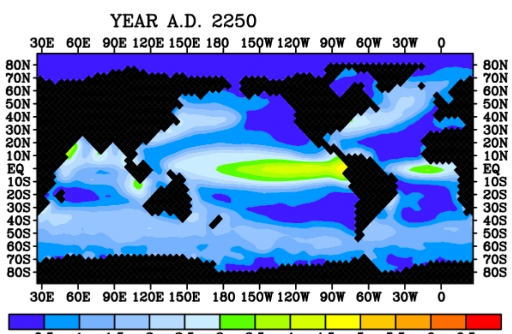
50% of pre-industrial CaCO3 production

-20 ppm without

-3 ppm with ballast effect







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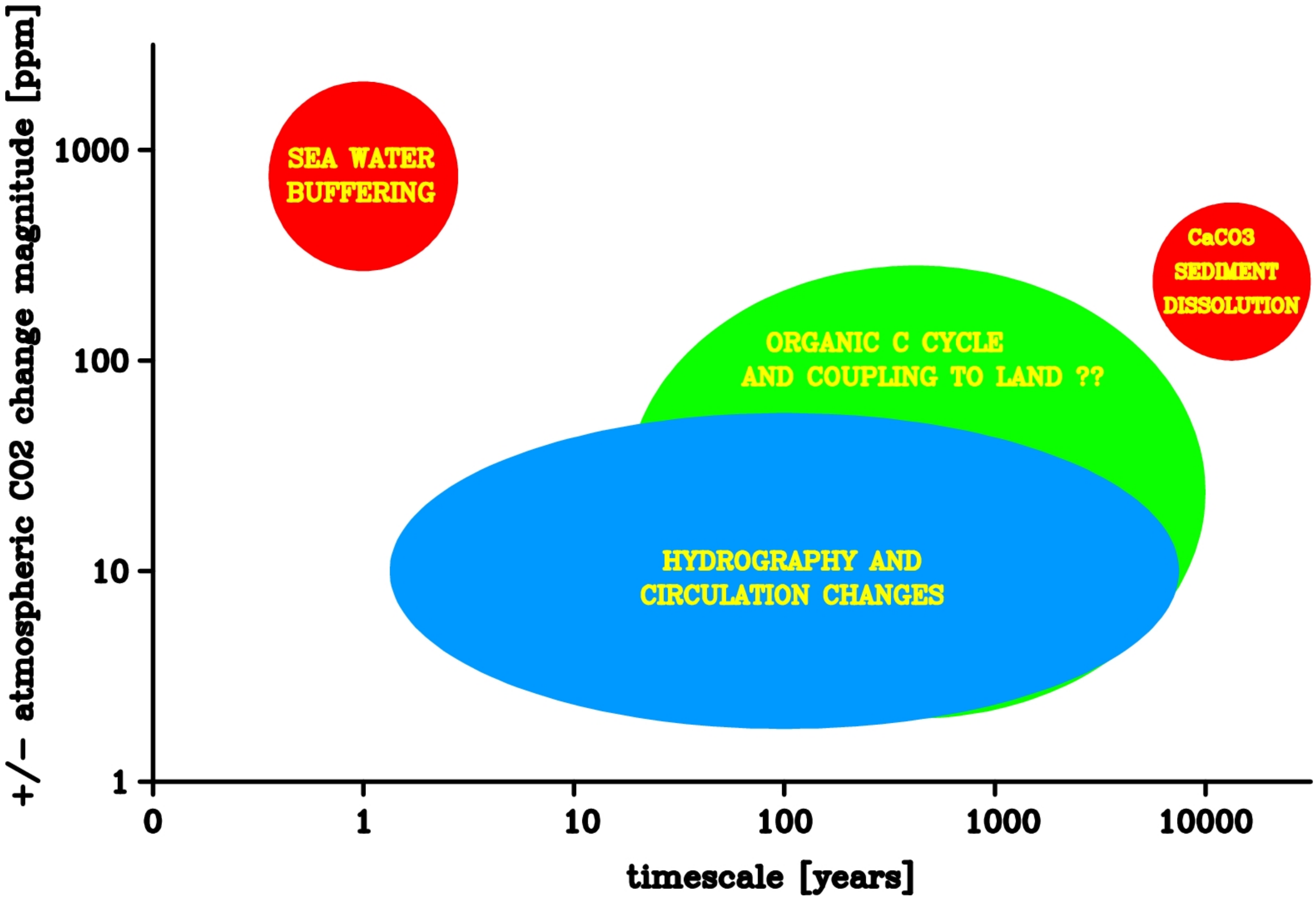

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