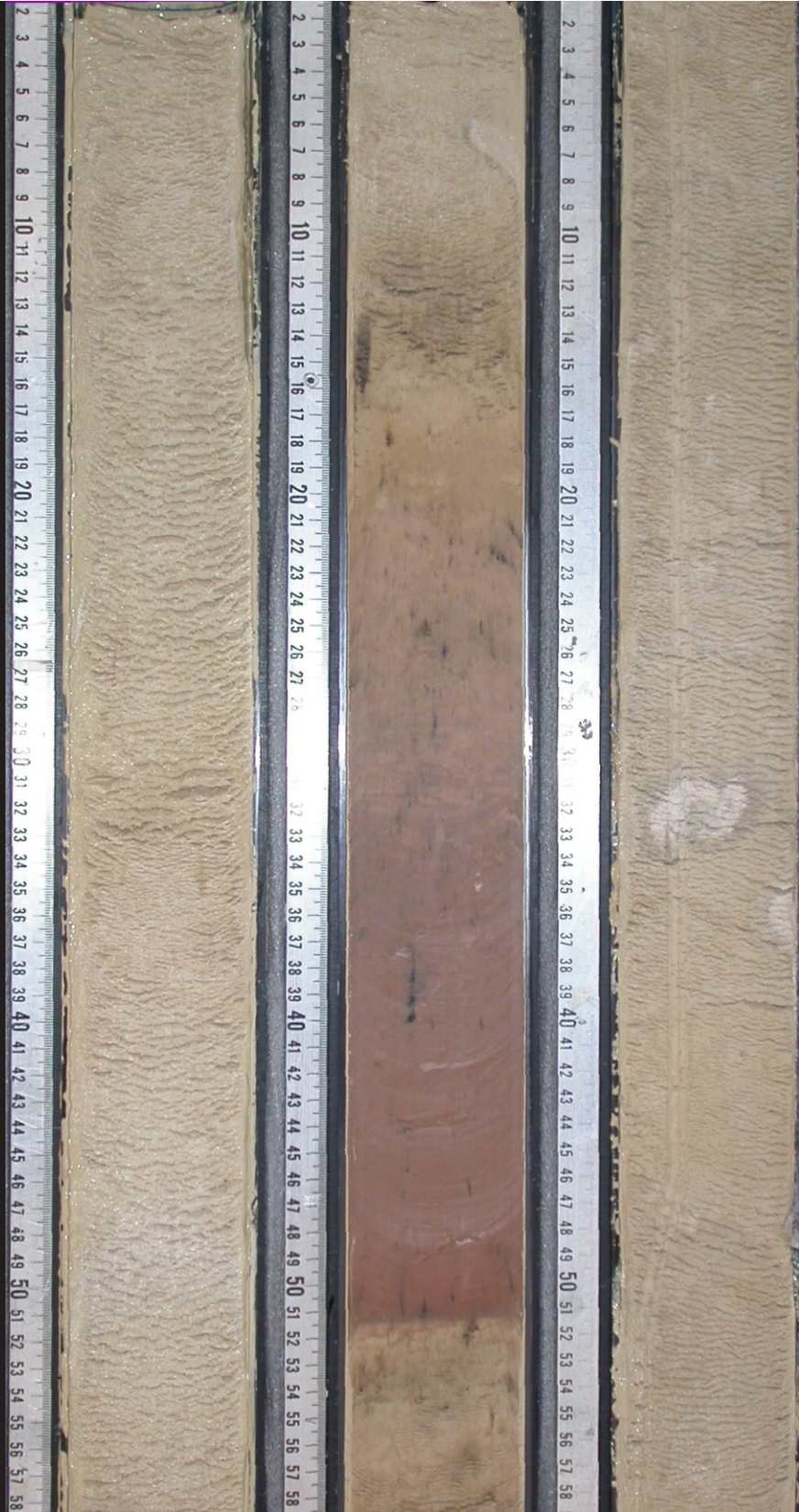
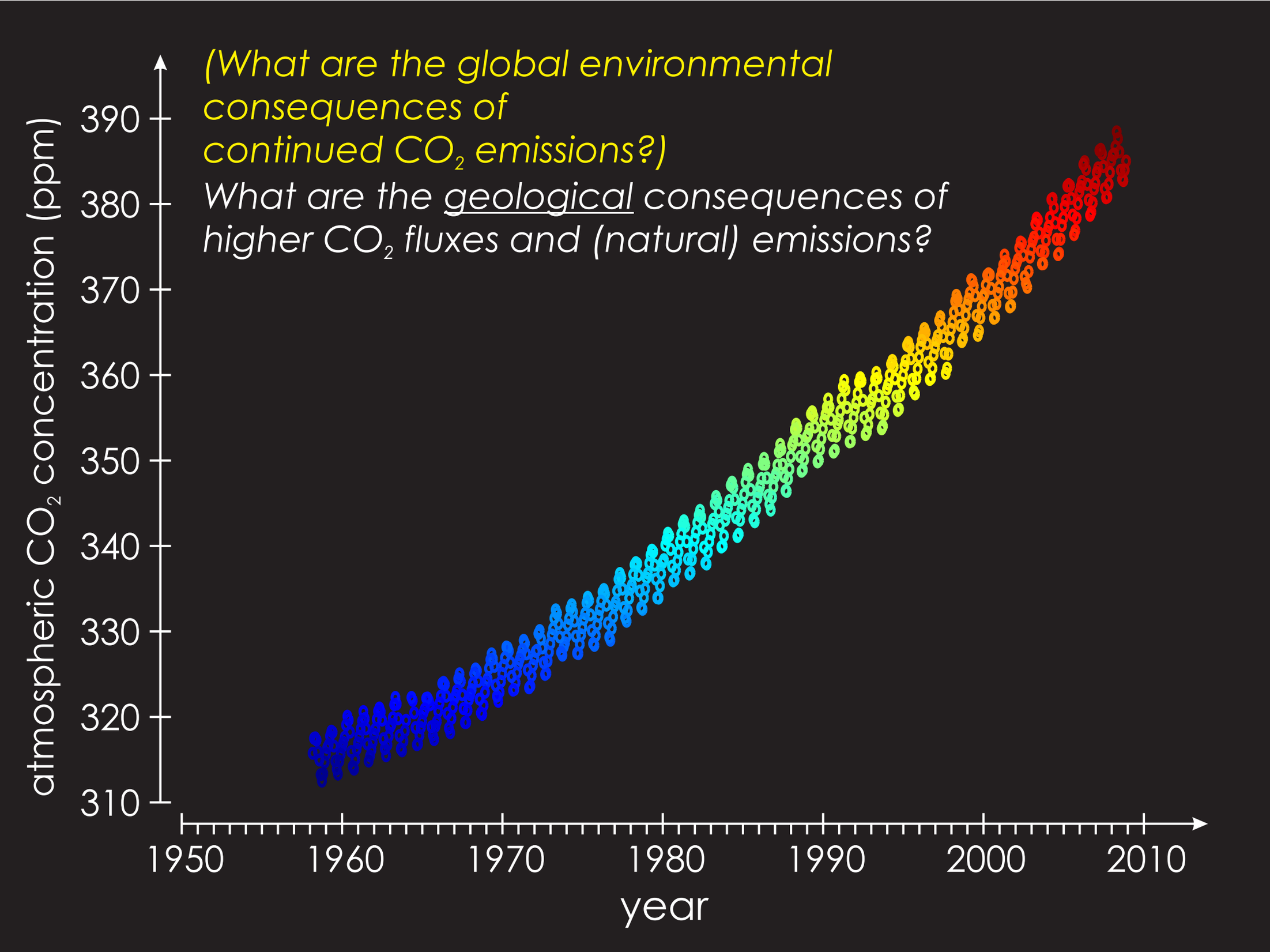
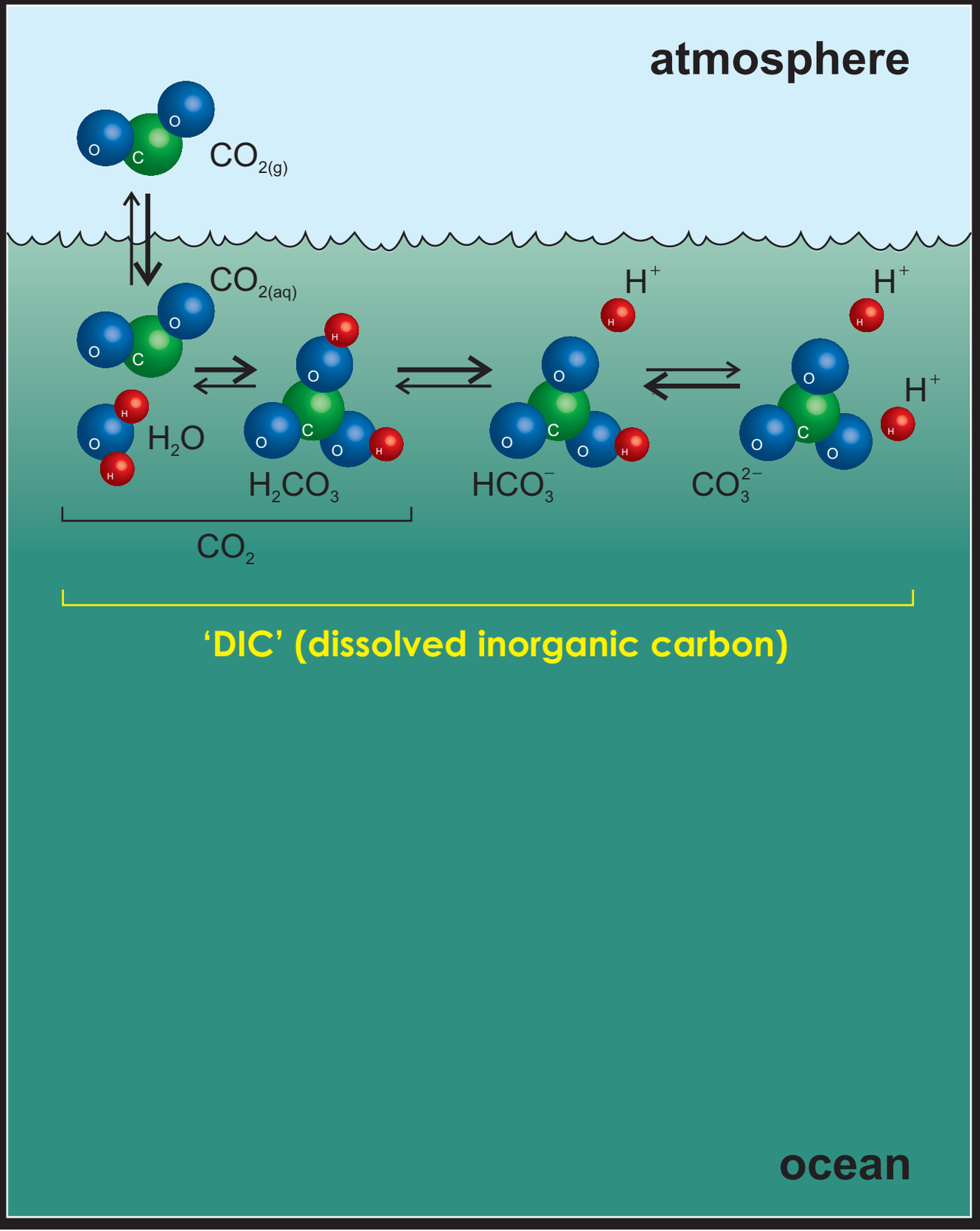
The Global carbon cycle pt. II – 'how long is forever?'

Andy Ridgwell



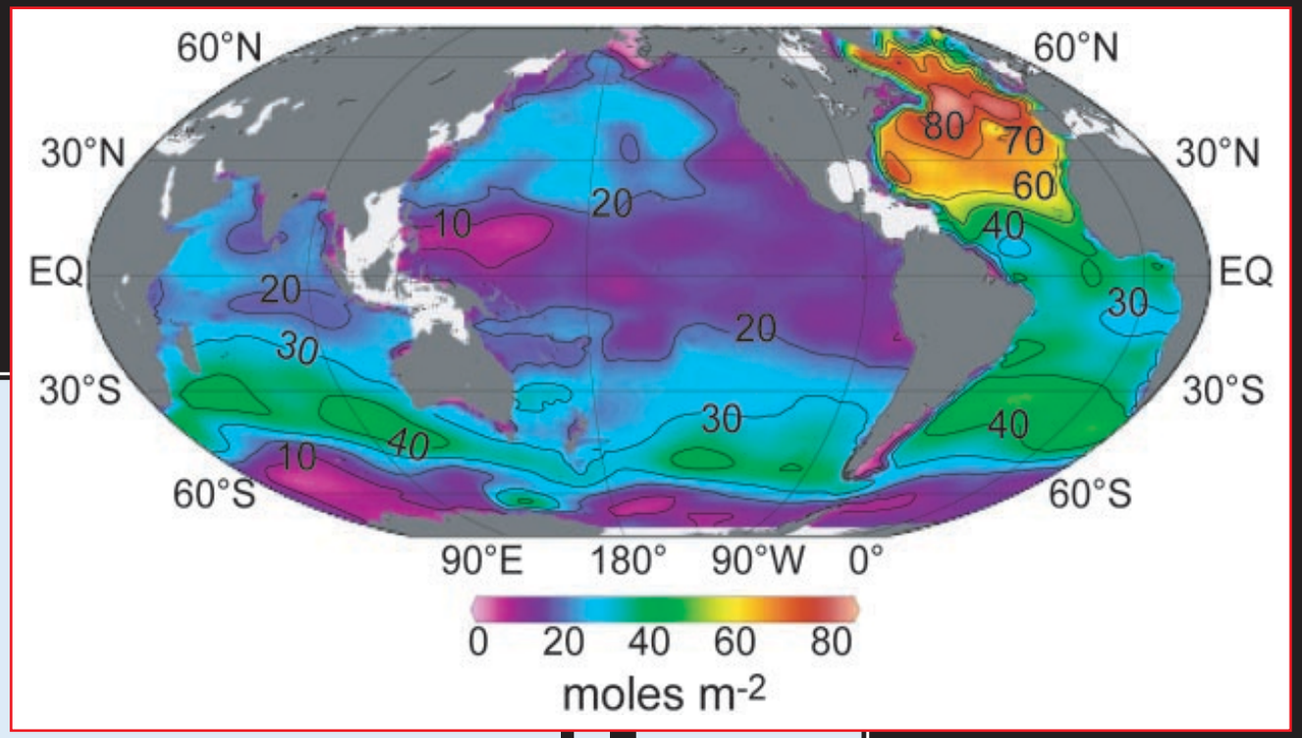

(What are the global environmental consequences of continued CO_2 emissions?)
What are the geological consequences of higher CO_2 fluxes and (natural) emissions?
atmospheric CO_2 concentration (ppm)
390
380
370
360
350
340
330
320
310
1950
1960
1970
1980
1990
2000
2010
year

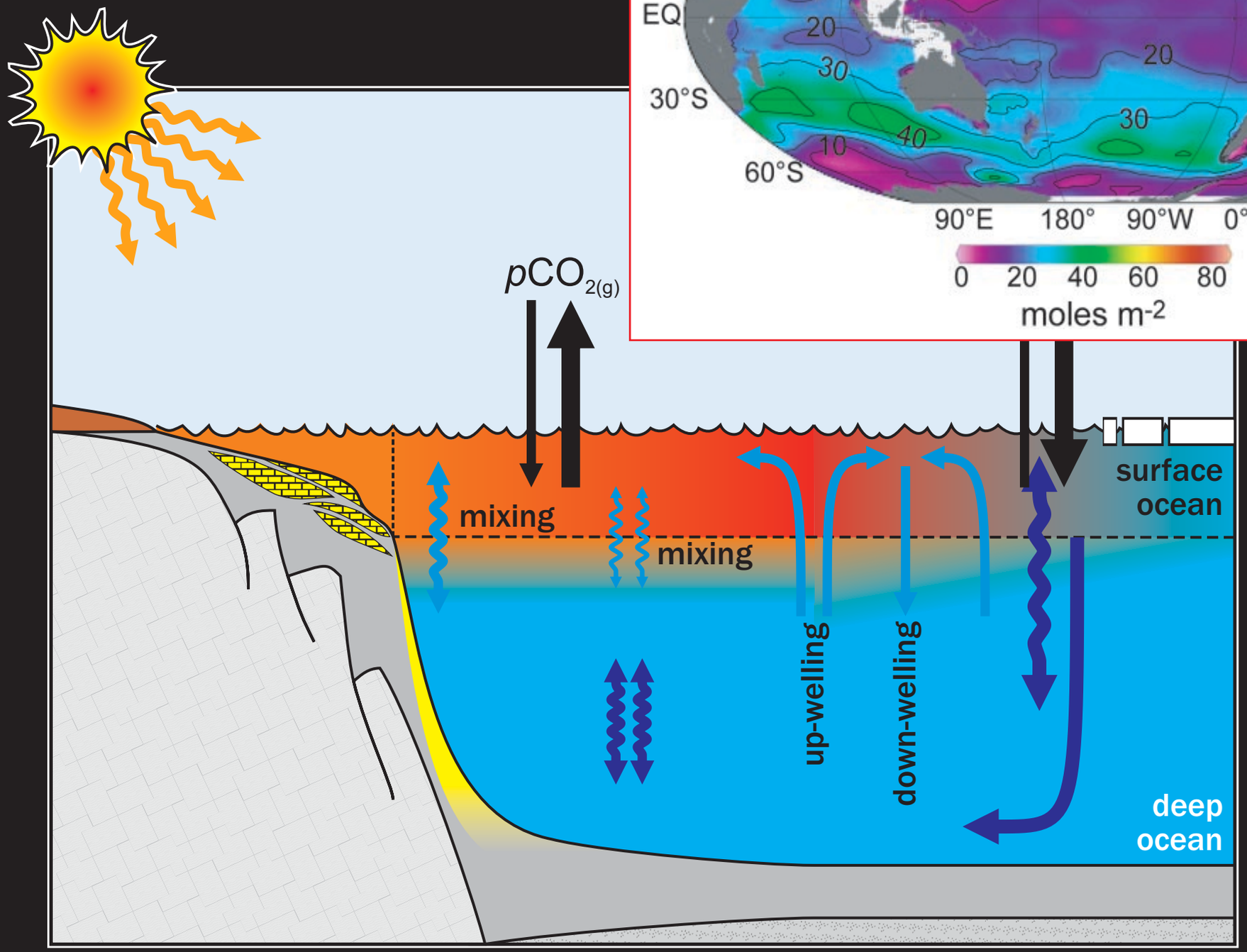
1. Dissolution in surface seawater

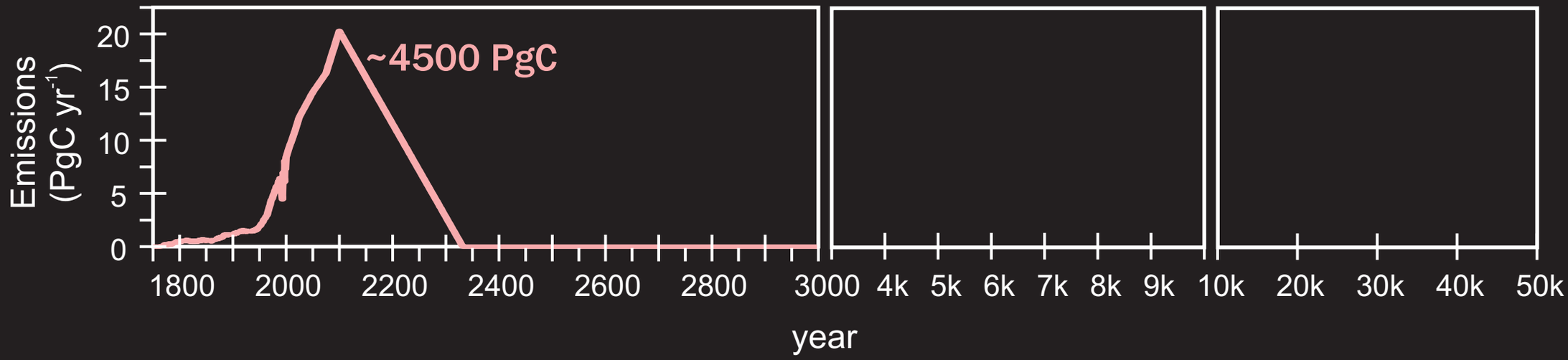


From: *Sabine et al.* [2004] (*Science* 305)

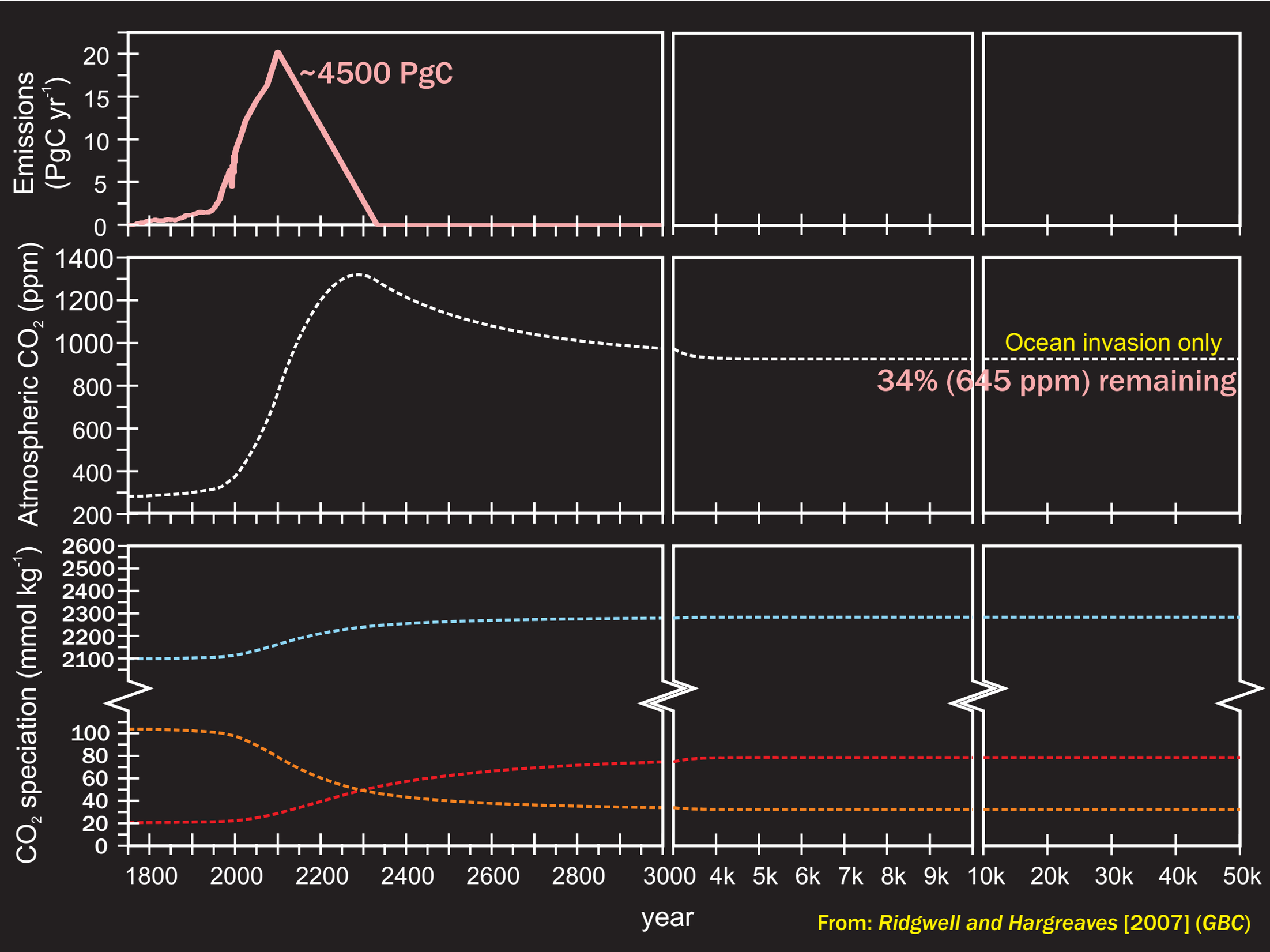
2. Ocean transport



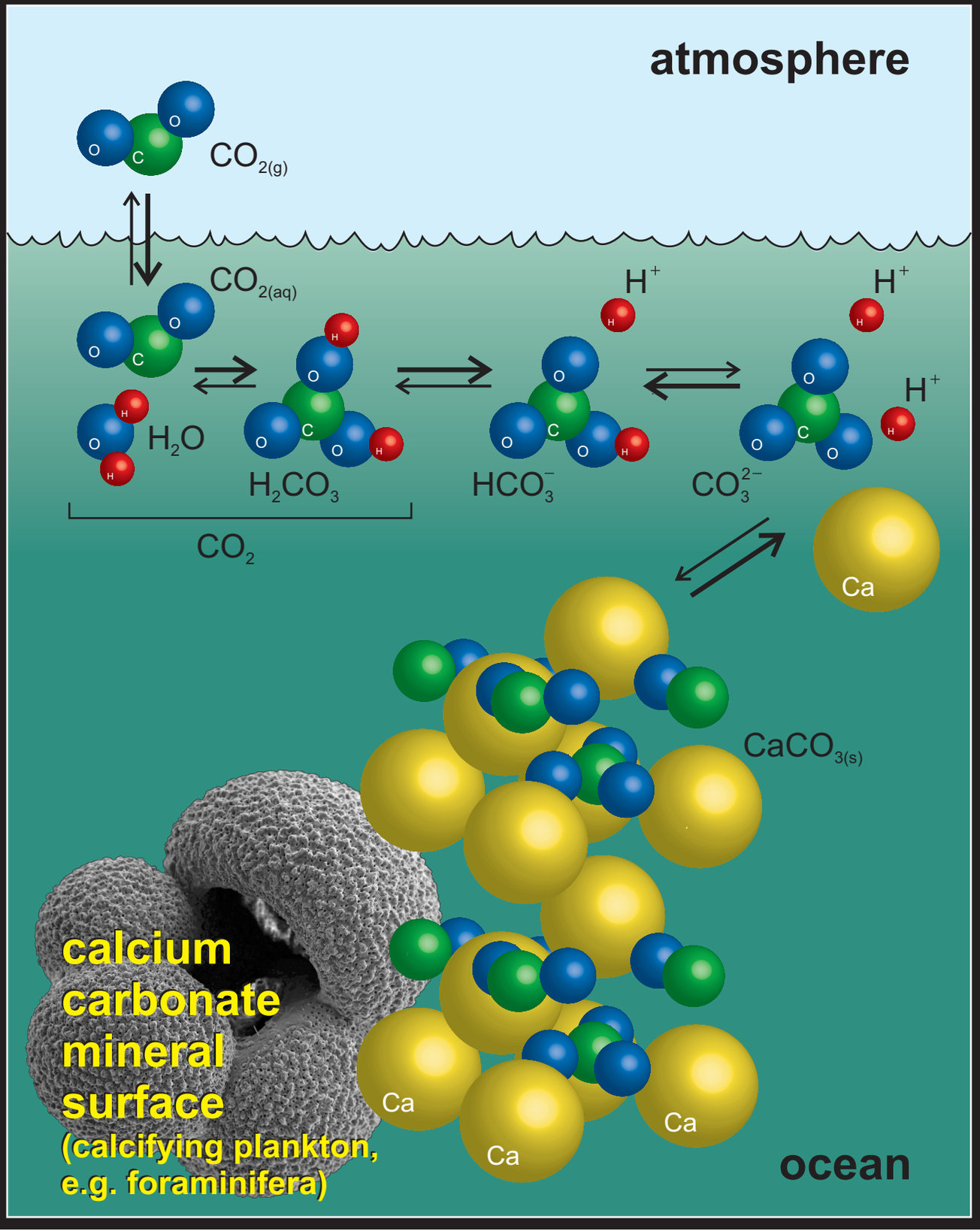




From: *Ridgwell and Hargreaves* [2007] (*GBC*)


Emissions (PgC yr-1)
20
15
10
5
0
~4500 PgC
Atmospheric CO2 (ppm)
1400
1200
1000
800
600
400
200
Ocean invasion only
34% (645 ppm) remaining
CO2 speciation (mmol kg-1)
2600
2500
2400
2300
2200
2100
100
80
60
40
20
0
1800
2000
2200
2400
2600
2800
3000
4k
5k
6k
7k
8k
9k
10k
20k
30k
40k
50k
year
From: Ridgwell and Hargreaves [2007] (GBC)

Biogenic $CaCO_3$ production



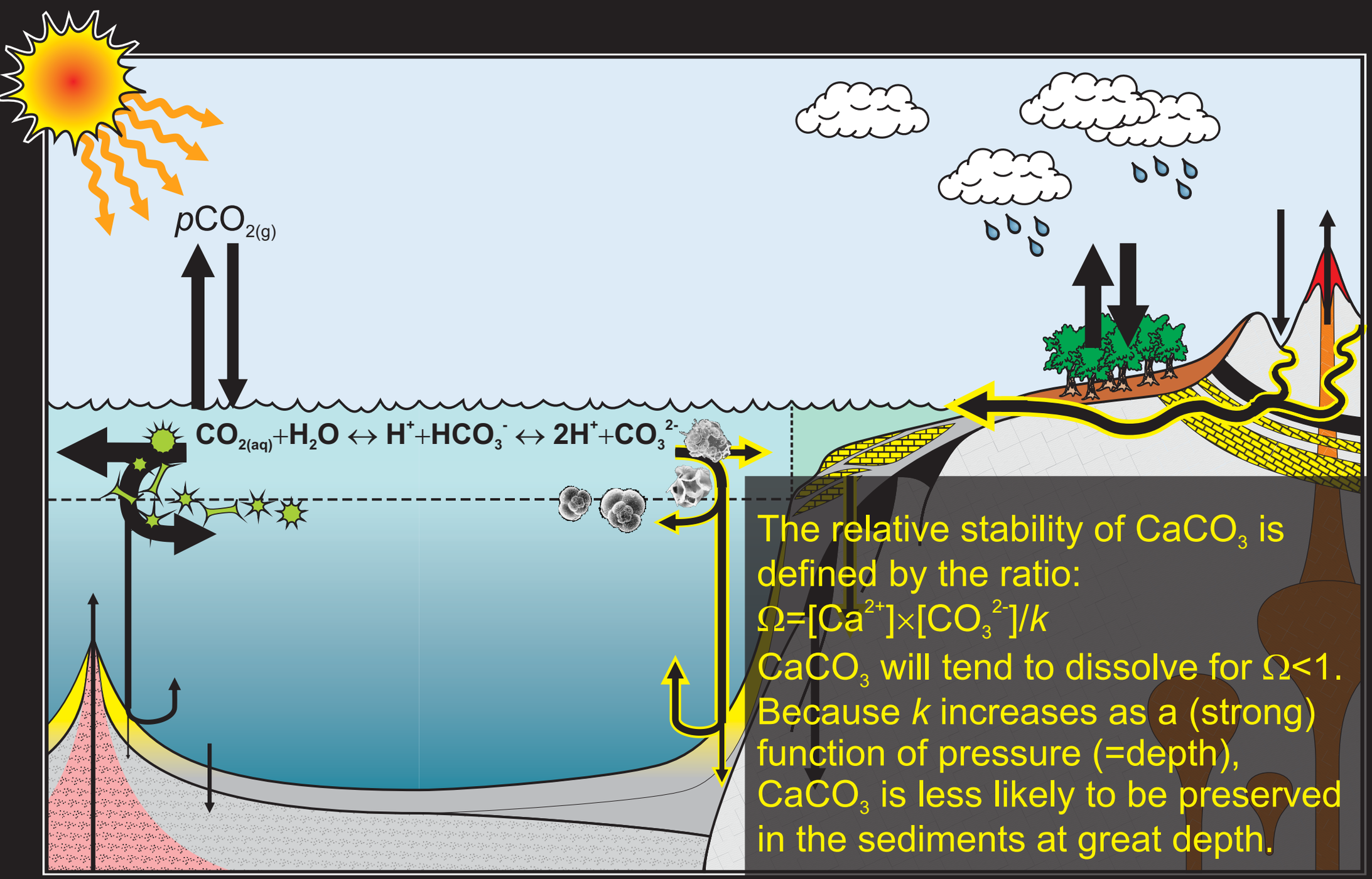
Aragonite

orthorhombic polymorph (e.g., many corals, pteropods)

Calcite

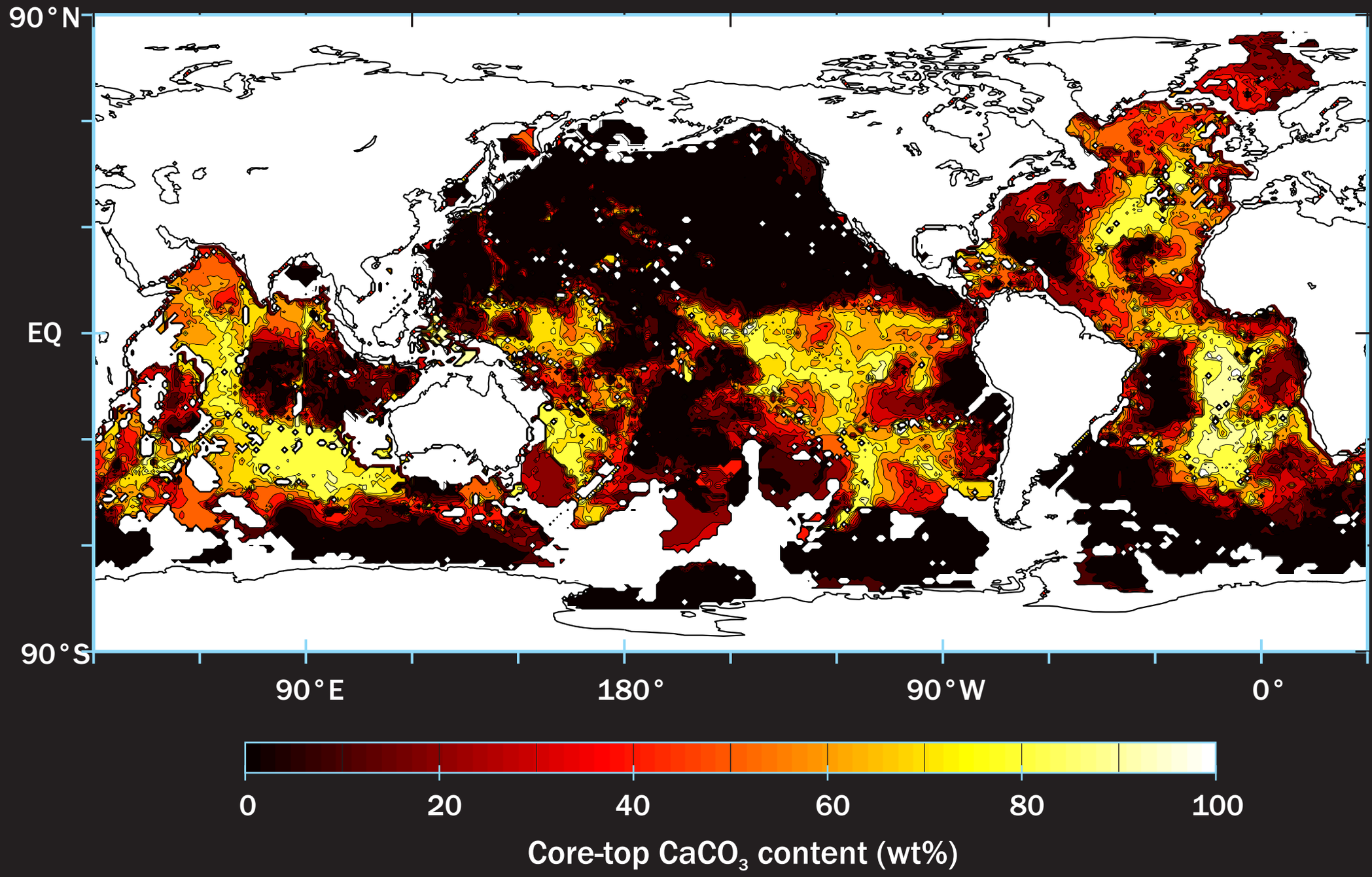
trigonal polymorph (e.g., coccolithophorides, foraminifera)

The marine carbon cycle - dynamics



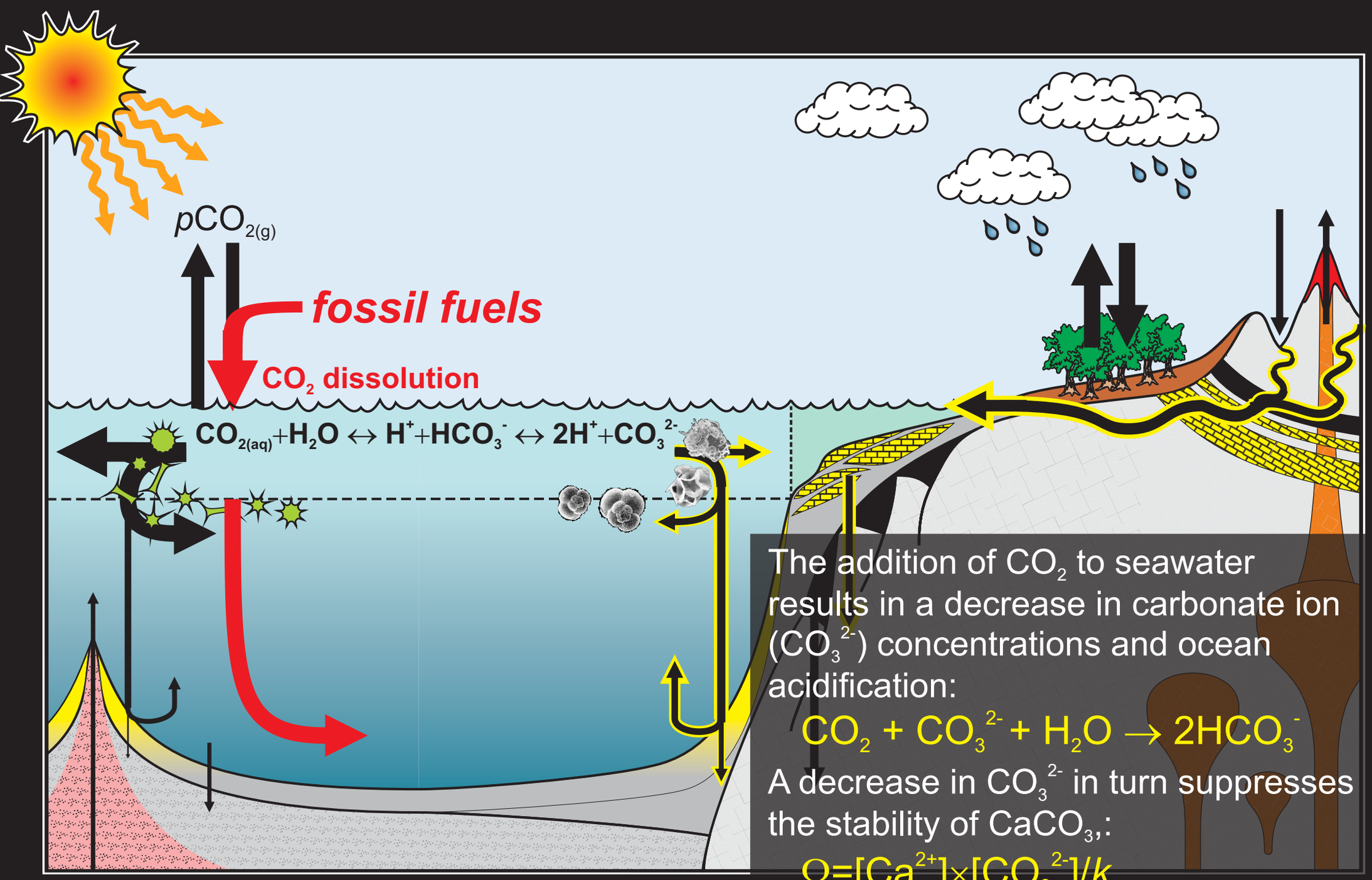
see; *Ridgwell and Zeebe* [2005] (*EPSL* 234) for a review of global carbonate cycling through Earth history

The marine carbon cycle - dynamics

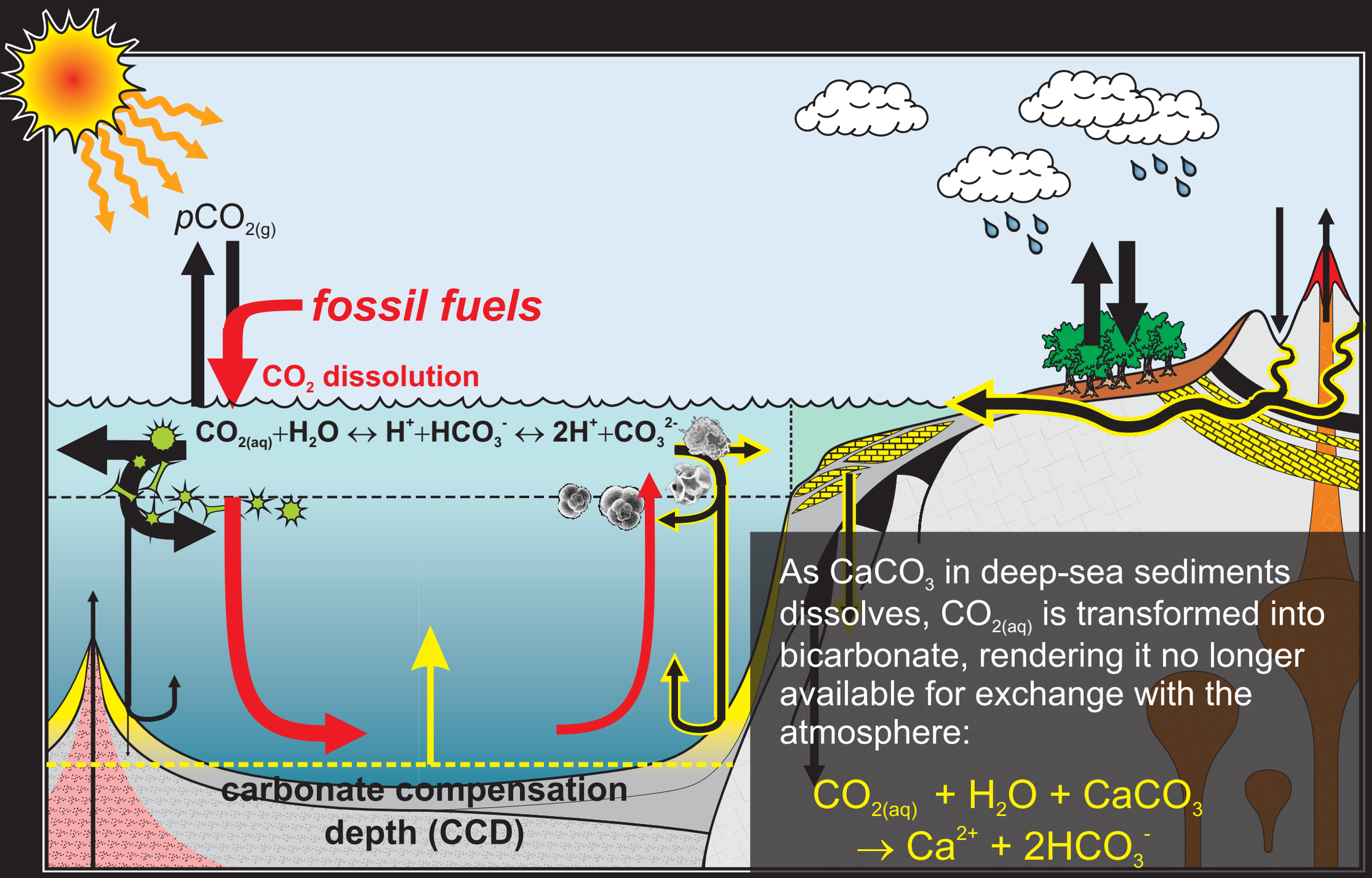


From: *Archer* [1996] (*GBC*)

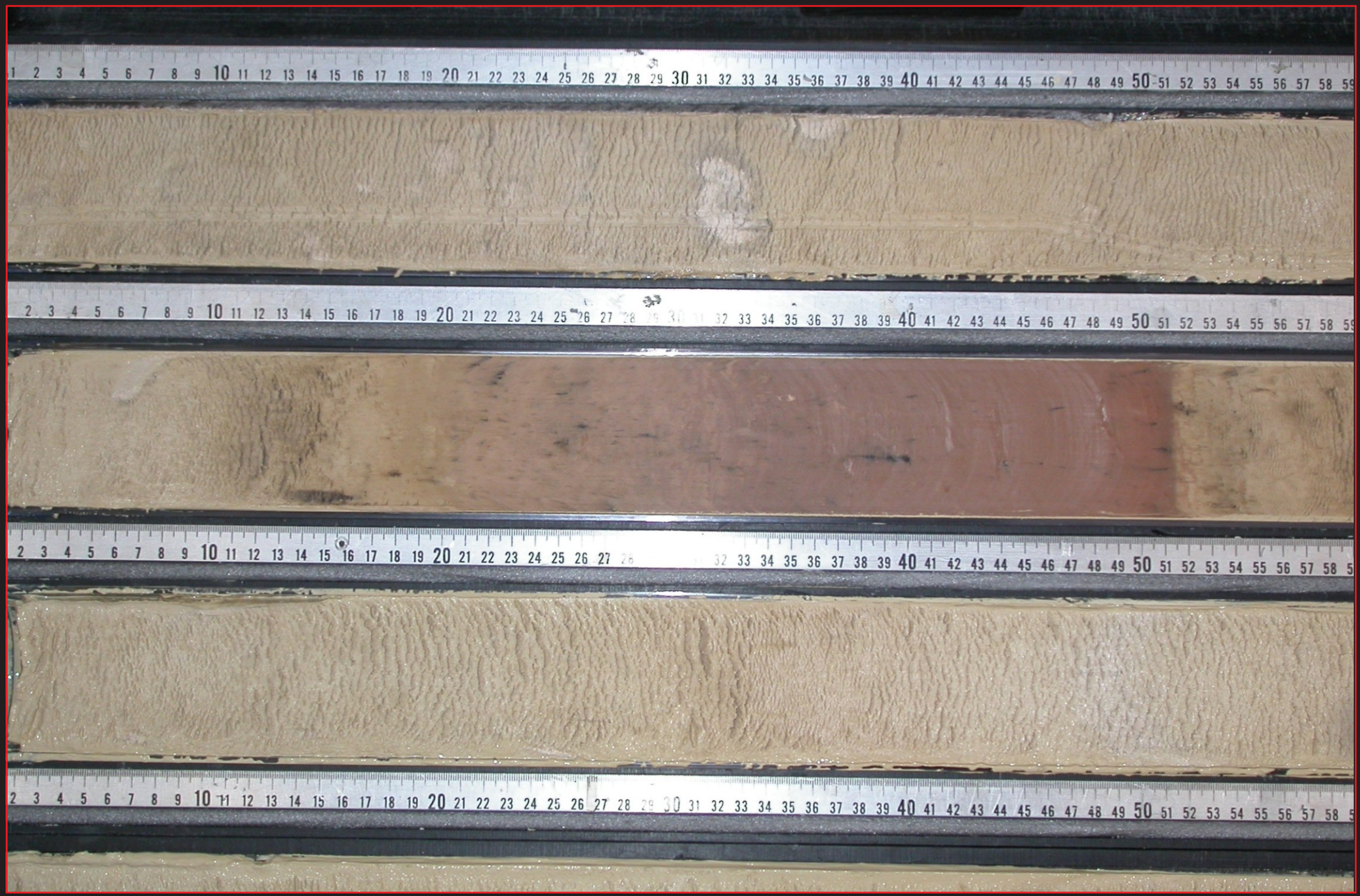
The marine carbon cycle - dynamics



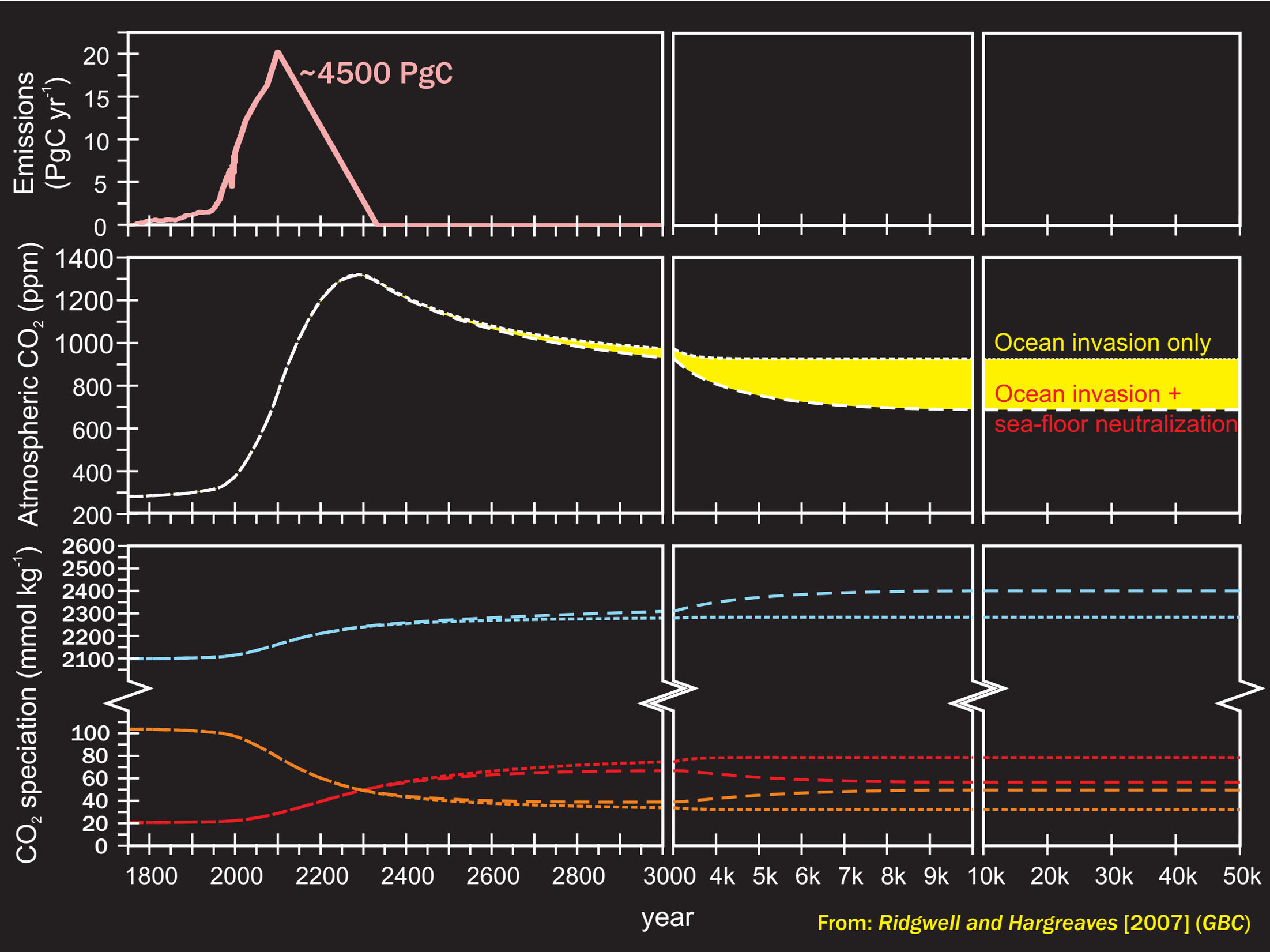
The marine carbon cycle - dynamics



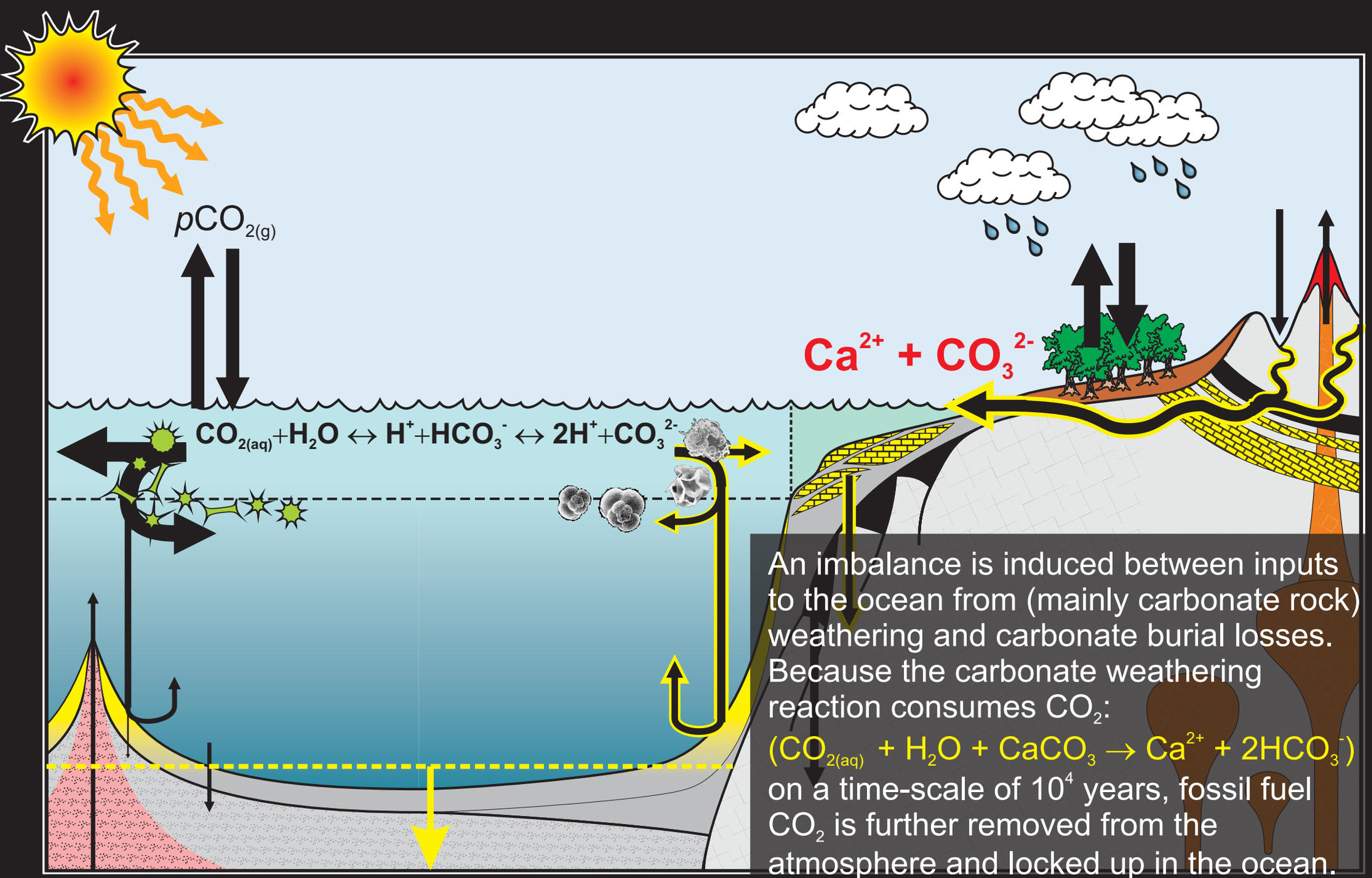
The marine carbon cycle - dynamics



Sediments spanning the Palaeocene-Eocene boundary recovered from ODP Leg 208 (Walvis Ridge)
Picture courtesy of Dani Schmidt (University of Bristol)


Emissions (PgC yr-1)
20
15
10
5
0
~4500 PgC
Atmospheric CO2 (ppm)
1400
1200
1000
800
600
400
200
Ocean invasion only
Ocean invasion +
sea-floor neutralization
CO2 speciation (mmol kg-1)
2600
2500
2400
2300
2200
2100
100
80
60
40
20
0
1800
2000
2200
2400
2600
2800
3000
4k
5k
6k
7k
8k
9k
10k
20k
30k
40k
50k
year
From: Ridgwell and Hargreaves [2007] (GBC)

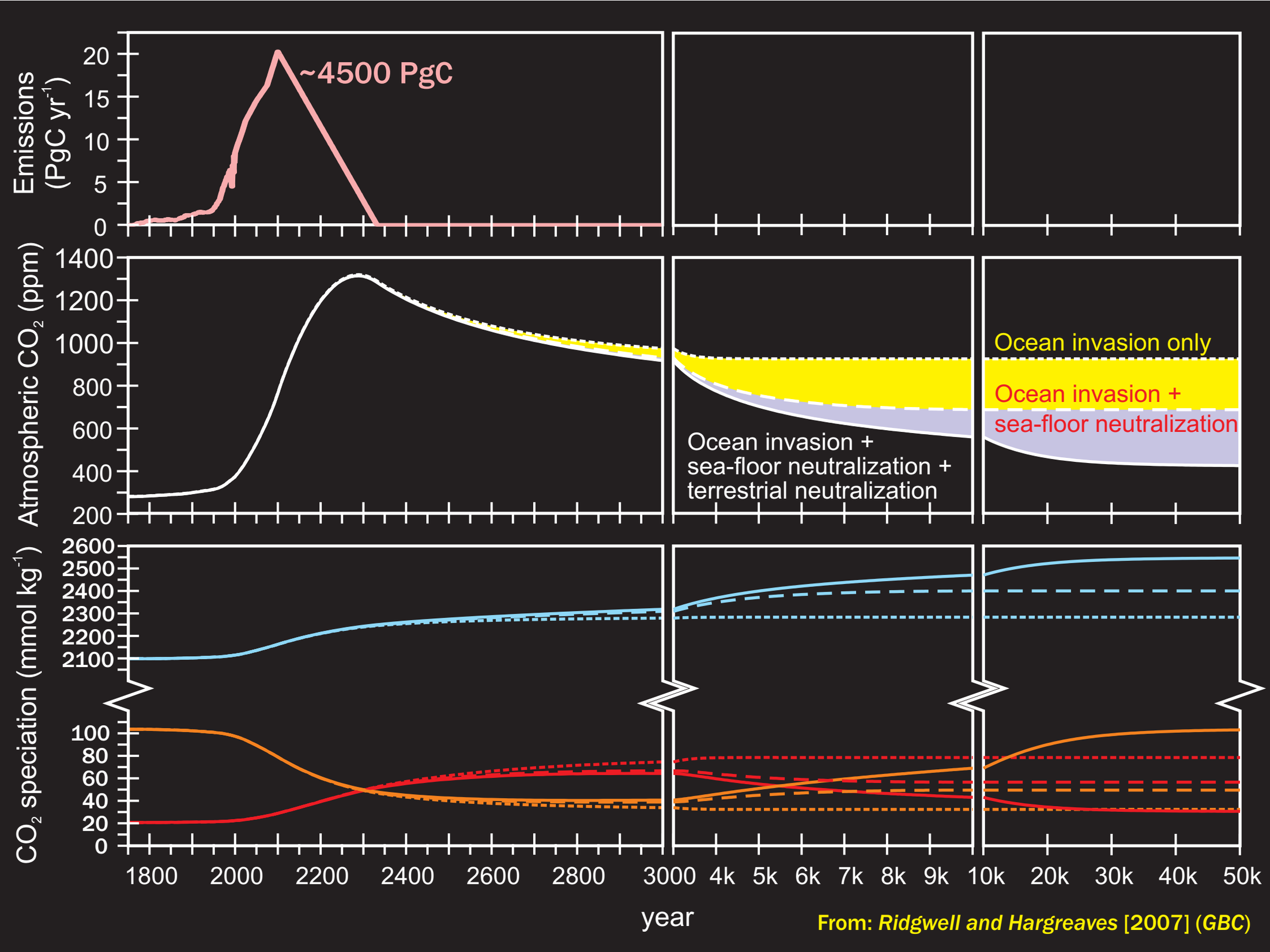
The marine carbon cycle - dynamics



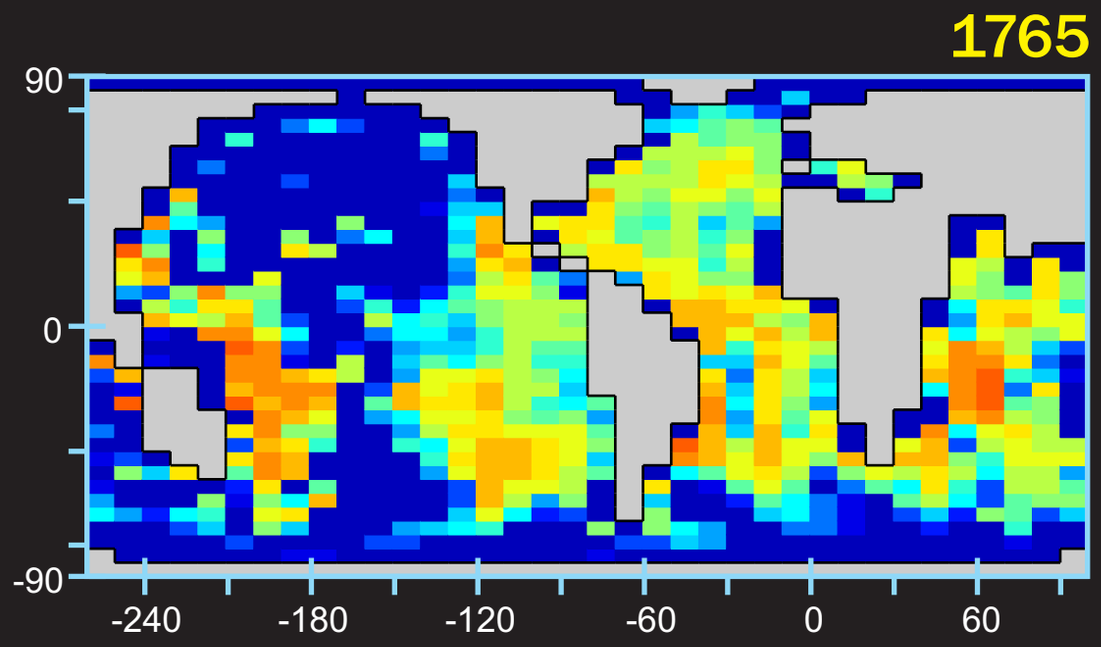
An imbalance is induced between inputs to the ocean from (mainly carbonate rock) weathering and carbonate burial losses. Because the carbonate weathering reaction consumes CO_2:

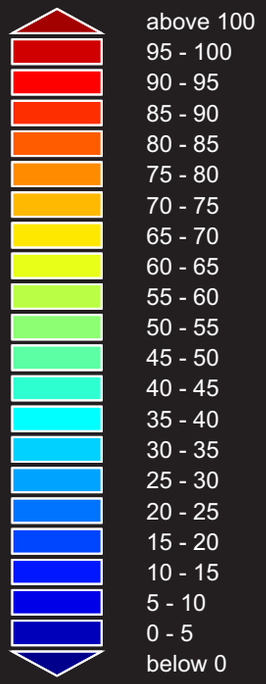
($CO_{2(aq)} + H_2O + CaCO_3 \rightarrow Ca^{2+} + 2HCO_3^-$)

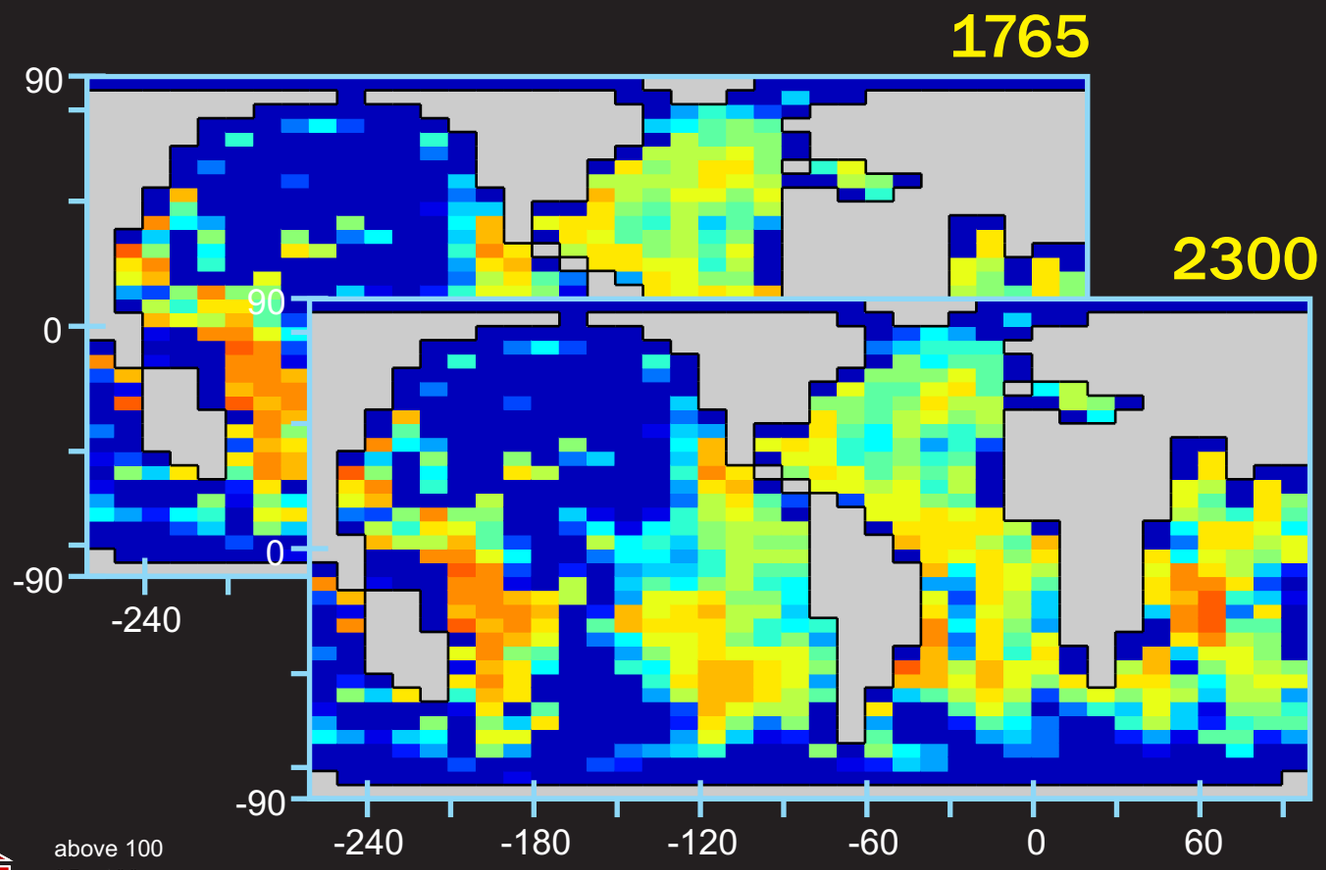
on a time-scale of 10^4 years, fossil fuel CO_2 is further removed from the atmosphere and locked up in the ocean.



From: *Ridgwell and Hargreaves* [2007] (*GBC*)

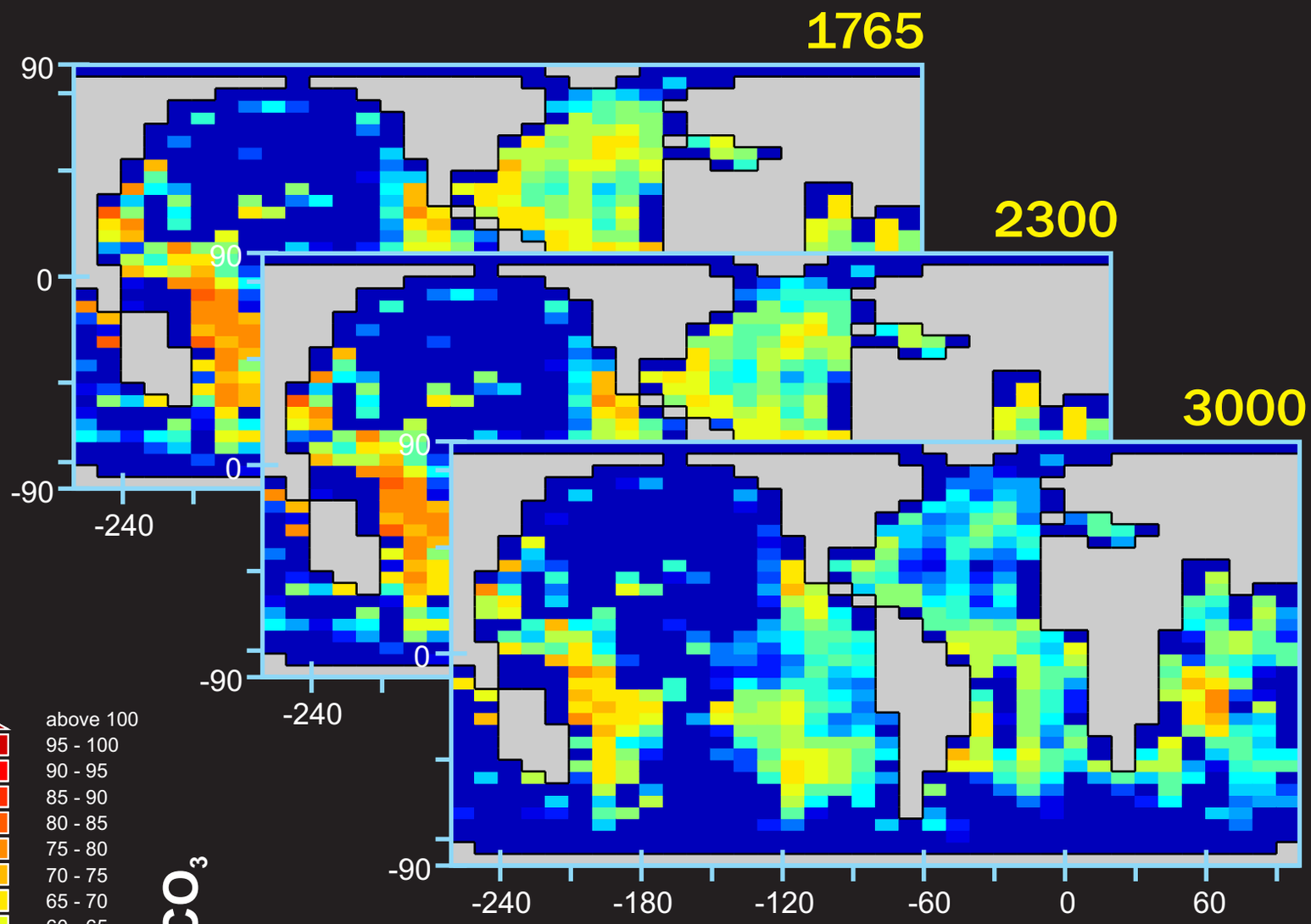

1765
90
0
-90
-240
-180
-120
-60
0
60


above 100
95 - 100
90 - 95
85 - 90
80 - 85
75 - 80
70 - 75
65 - 70
60 - 65
55 - 60
50 - 55
45 - 50
40 - 45
35 - 40
30 - 35
25 - 30
20 - 25
15 - 20
10 - 15
5 - 10
0 - 5
below 0
wt% CaCO3


1765
2300
90
0
-90
-240
-180
-120
-60
60


above 100
95 - 100
90 - 95
85 - 90
80 - 85
75 - 80
70 - 75
65 - 70
60 - 65
55 - 60
50 - 55
45 - 50
40 - 45
35 - 40
30 - 35
25 - 30
20 - 25
15 - 20
10 - 15
5 - 10
0 - 5
below 0

wt% $CaCO_3$


1765
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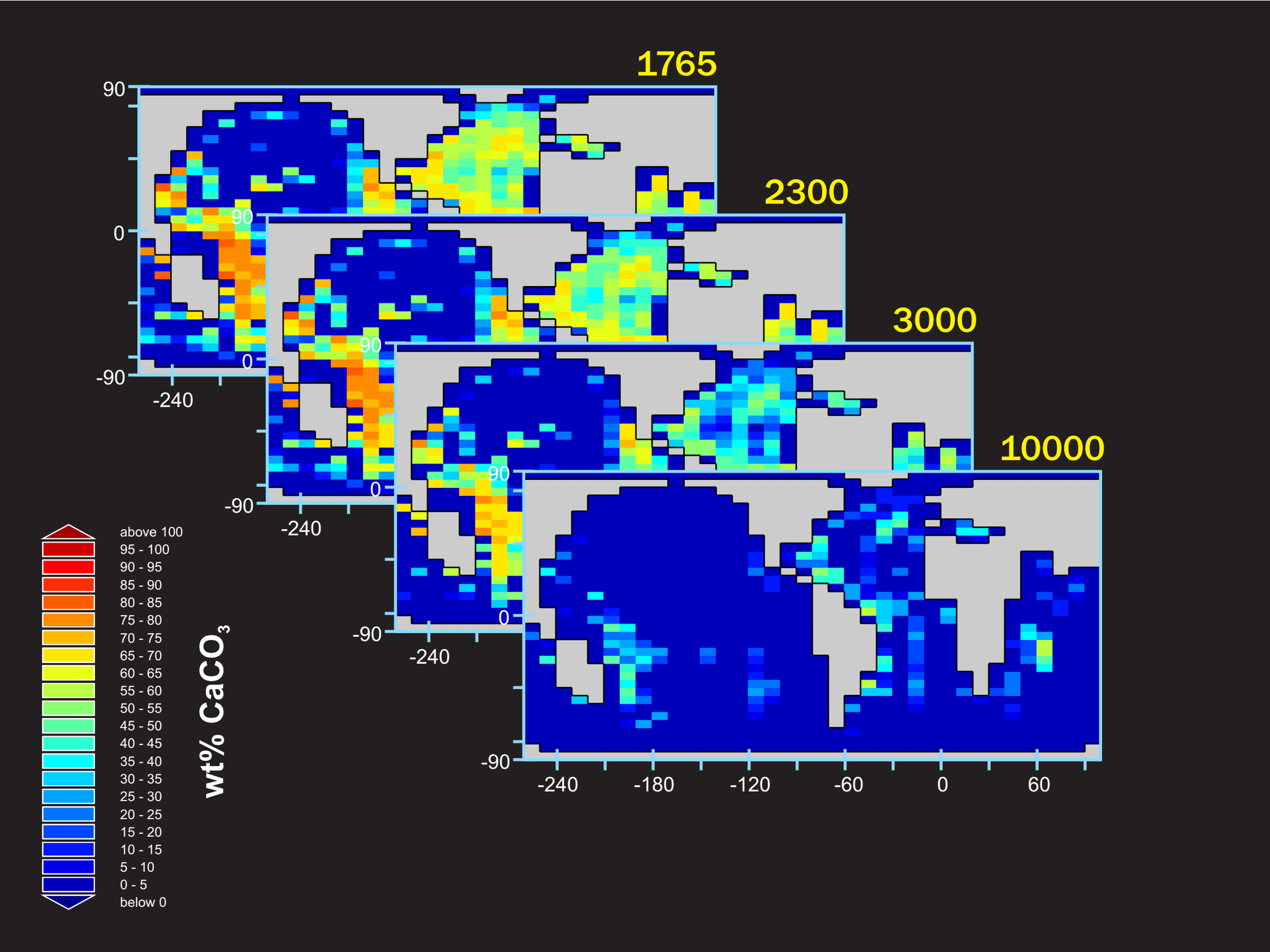
-240
-180
-120
-60
60
above 100
95 - 100
90 - 95
85 - 90
80 - 85
75 - 80
70 - 75
65 - 70
60 - 65
55 - 60
50 - 55
45 - 50
40 - 45
35 - 40
30 - 35
25 - 30
20 - 25
15 - 20
10 - 15
5 - 10
0 - 5
below 0
wt% CaCO3


1765
2300
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10000
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-90
-240
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-120
-60
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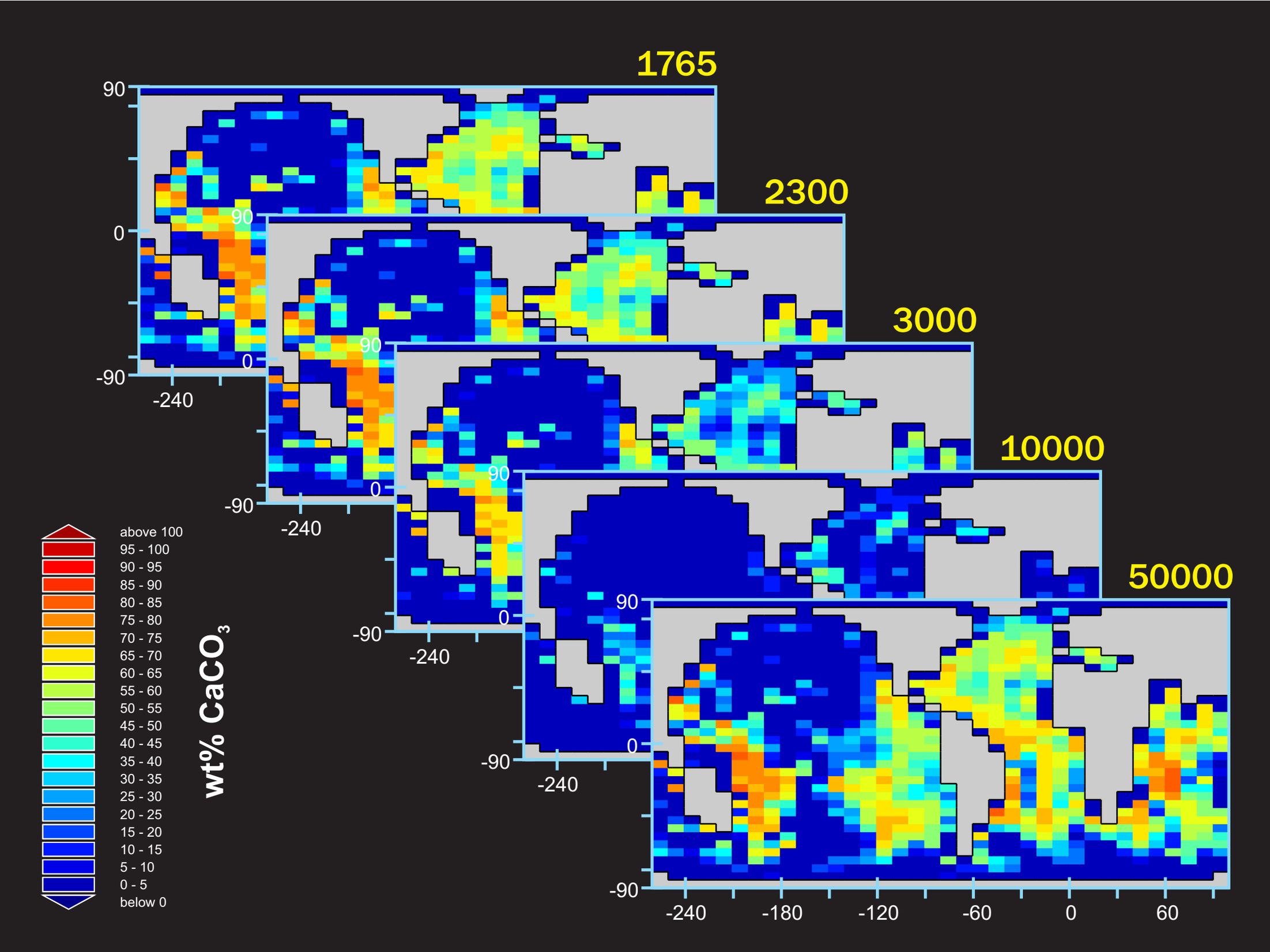
above 100
95 - 100
90 - 95
85 - 90
80 - 85
75 - 80
70 - 75
65 - 70
60 - 65
55 - 60
50 - 55
45 - 50
40 - 45
35 - 40
30 - 35
25 - 30
20 - 25
15 - 20
10 - 15
5 - 10
0 - 5
below 0
wt% CaCO3


1765
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0
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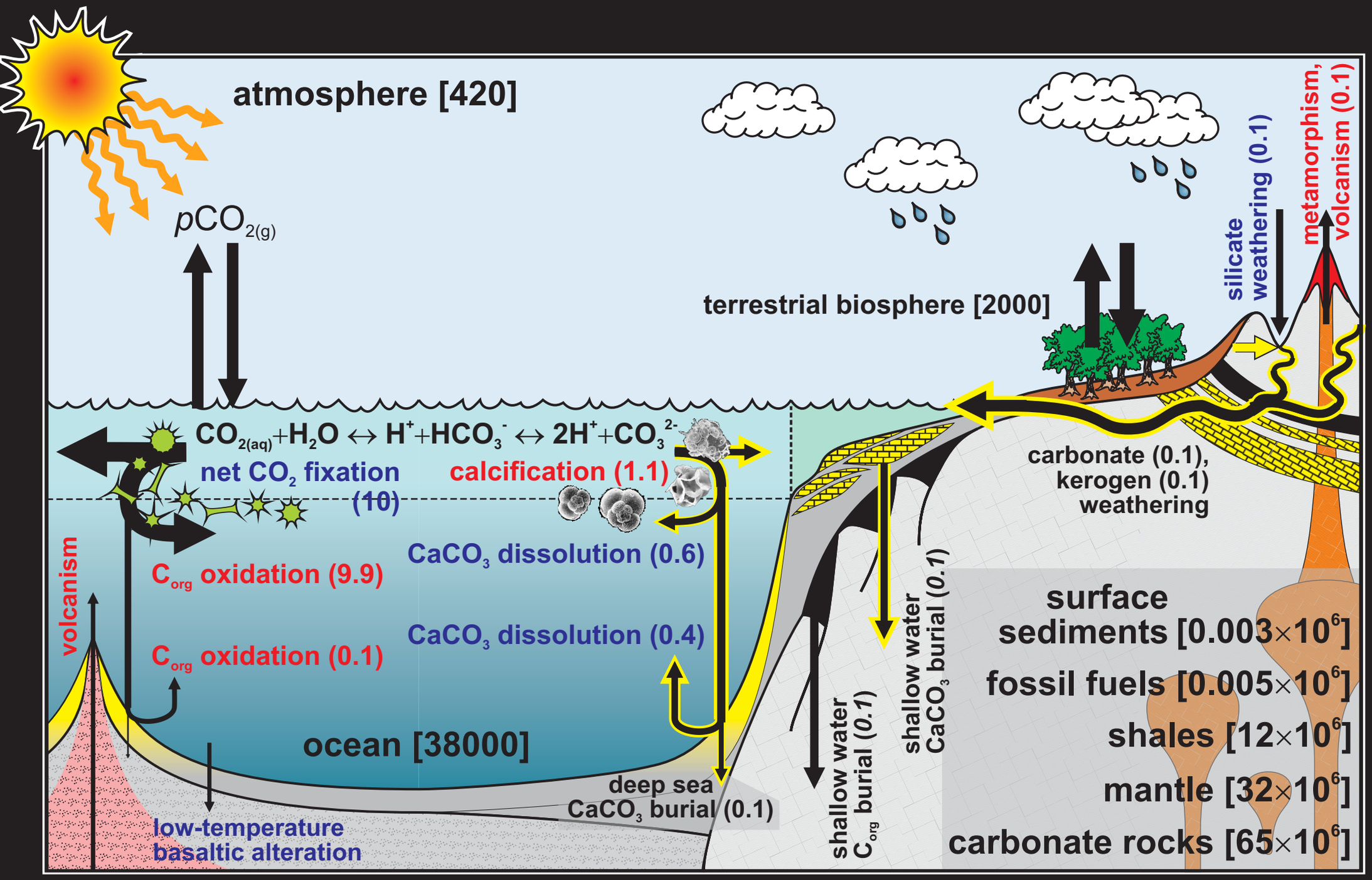
above 100
95 - 100
90 - 95
85 - 90
80 - 85
75 - 80
70 - 75
65 - 70
60 - 65
55 - 60
50 - 55
45 - 50
40 - 45
35 - 40
30 - 35
25 - 30
20 - 25
15 - 20
10 - 15
5 - 10
0 - 5
below 0
wt% CaCO3

Missing CO_2 regulation process?



The marine carbon cycle - dynamics

Terrestrial weathering can be (approximately equally) divided into carbonate ($CaCO_3$) and calcium-silicate ('$CaSiO_3$') weathering:

(1) $2CO_{2(aq)} + H_2O + CaSiO_3 \rightarrow Ca^{2+} + 2HCO_3^- + SiO_2$

(2) $CO_{2(aq)} + H_2O + CaCO_3 \rightarrow Ca^{2+} + 2HCO_3^-$

Ultimately, the (alkalinity: Ca^{2+}) weathering products must be removed through carbonate precipitation and burial in marine sediments:

(3) $Ca^{2+} + 2HCO_3^- \rightarrow CO_{2(aq)} + H_2O + CaCO_3$

It can be seen that in (2) + (3), that the CO_2 removed (from the atmosphere) during weathering, is returned upon carbonate precipitation (and burial). In (1) + (3) (silicate weathering) CO_2 is permanently removed to the geological reservoir. This CO_2 must be balanced by mantle (/volcanic) out-gassing on the very long term.

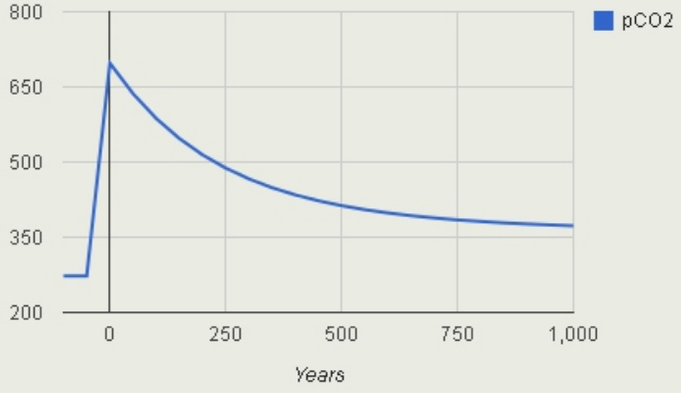
Silicate weathering is a ca. 100 kyr process. Hence, anthropogenic carbon 'pollution' and climate perturbation will persist for hundreds of thousands of years ...

> Bob Berner's 'GEOCARB' long-term carbon cycle box model + $CaCO^3$ burial additions by David Archer:
http://forecast.uchicago.edu/Projects/geocarb.html

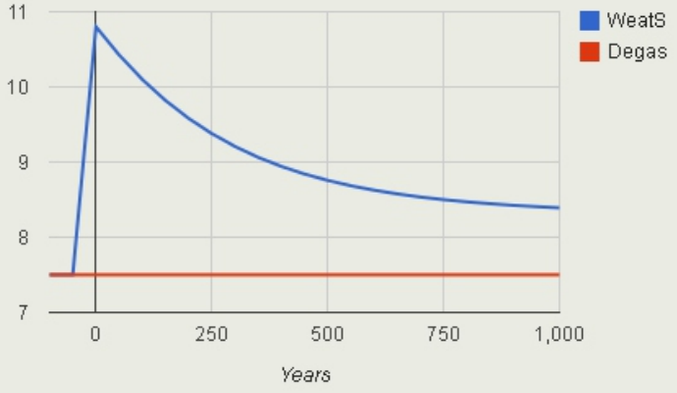
Geologic setting	0	million years ago
Mean latitude of continents	30	degrees absolute value
Delta T_{2x}	3	degrees per 2 x CO_2
Transition CO_2 Spike	1000	Gton C

	Spinup	Simulation
CO_2 degassing rate 10^{12} mol/yr	7.5	7.5
Plants	yes	yes
Land Area, Relative to today	1	1

pCO2



Silicate Thermostat



Save Model Run to Background

Show 1,000 years

Show Raw Model Output

> Bob Berner's 'GEOCARB' long-term carbon cycle box model + $CaCO^3$ burial additions by David Archer: **http://forecast.uchicago.edu/Projects/geocarb.html**

> First, explore the fate of (fossil) CO_2 without continental weathering:
(i) set land area (both Spinup and Simulation) to 0
(ii) set CO_2 degassing rate (both Spinup and Simulation) to 0
(iii) set to show more than 1000 years of simulation

Q. What is the apparent lifetime of CO_2? What fraction (estimate from how many ppm above 280 the atm concentration ends up converting with: 1 ppm ~= 2 PgC) of the initial emission remains in the atmosphere? Do either (lifetime, fraction) depend on the magnitude of emissions?

> Bob Berner's 'GEOCARB' long-term carbon cycle box model + $CaCO^3$ burial additions by David Archer: **http://forecast.uchicago.edu/Projects/geocarb.html**

> Reset parameter value with F5 (or Ctrl-F5). Run simulation and display 1,000,000 years.

Q. What is the time-scale of silicate weathering feedback?

> You could further explore e.g. geological flood basalt events by increasing CO_2 degassing in the Simulation (only).