AV The Carbon Cycle from Fossil Fuels*

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Abstract

The burning of fossil fuels is injecting CO_2 into the biosphere (atmosphere/ocean/biomass) at rates that may meet or exceed any that have occurred in Earth history. There is no doubt that this is a significant perturbation to the carbon cycle. The carbon cycle has already responded: about half of the carbon emitted has been taken up by the ocean (demonstrably driving down ocean pH and carbonate saturation states) and terrestrial biota. Projections into the future demonstrate that the ability of these sinks to accommodate fossil fuel CO_2 will be reduced, leading to an increase in the airborne fraction of CO_2.

Fossil-fuel burning is an external forcing of the carbon cycle. In contrast, the carbon cycle variations on, for example, glacial/interglacial timescales are internal responses (feedbacks) to externally driven variations in insolation (Milankovitch cycles). In feedback loops, cause and effect become meaningless: causes become effects and vice versa. Thus, the search for leads and lags between temperature and CO_2 in ice-core records is of limited utility in determining the extent to which CO_2 is a "climate driver." More promising is the investigation of the Paleocene-Eocene Thermal Maximum (PETM) "supergreenhouse" event 55 million years ago. The combination of a sizeable negative carbon isotope excursion, marked global warming with polar amplification, and extensive seafloor carbonate dissolution provides a strong constraint on the source, magnitude, and rate of carbon addition that drove this climate perturbation. Based on numerical modeling results using an Earth system model of intermediate complexity, the source was fossil carbon, emitted over a few thousand years, with a total magnitude of ~7000 Pg. In other words, the rate of CO_2 emission was somewhat slower, but the magnitude somewhat larger, than the projected rate of fossil-fuel burning under "business-as-usual" scenarios. Sensitivity analysis reveals that the rate of addition is critical to the oceanic response: slow additions (less than 1 Pg carbon per year) lead to deep-ocean acidification, but surface waters remain supersaturated with respect to $CaCO_3$. Faster additions (including current and projected fossil-fuel burning rates) lead to surface-water acidification as well. Thus, the rather muted biotic response to the PETM (benthic foraminiferal extinctions, ecosystem migrations on land) may underestimate the biotic response to future fossil-fuel burning, both on land and in the ocean.

References

Doney, Scott C., 2006, The dangers of ocean acidification: Scientific American (March), p. 58-65.

Kleypas, J.A., R.A. Feely, V.J. Fabry, C. Langdon, C.L. Sabine, and L.L. Robbins, 2006, Impacts of ocean acidification on coral reefs and other marine calcifiers. A guide for future research: Report of a workshop sponsored by NSF, NOAA, and USGS.

Kleypas, J.A. and C. Langdon, (in press), Coral reefs and changing seawater chemistry (chapter), *in* J. Phinney, O. Hoegh-Guldberg, J. Kleypas, W. Skirving, eds., Coral Reefs and Climate Change: AGU Monograph Series.

Mann, Michael E., and Lee R. Kump, 2008, Dire Predictions: Understanding Global Warming. The illustrated guide of the findings of the intergovernment panel on climate change: DK Publishing, Inc., New York, 208 p.

Panchuk, K.M., A. Ridgwell, and L.R. Kump, 2008, Sedimentary response to Paleocene-Eocene Thermal Maximum carbon release: A model-data comparison. Geology, v. 36, p. 315-318.

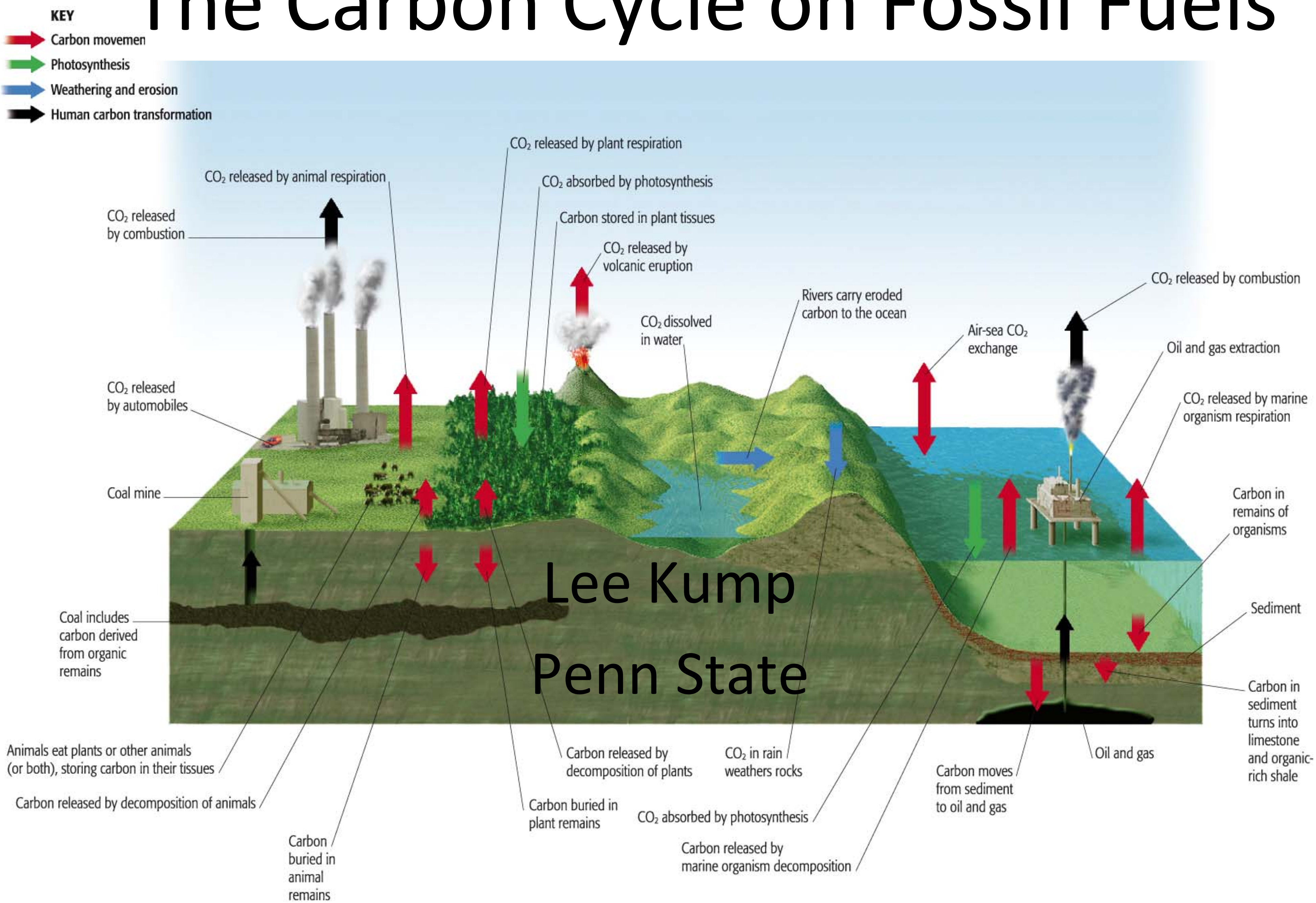
Ridgwell, A., Panchuk, K., and Kump, L., 2007, Application of Earth system models to understanding catastrophic changes in global carbon cycling at the PETM, EUG, Vienna, 2007.

Siegenthaler, Urs, Thomas F. Stocker, Eric Monnin, Dieter Lüthi, Jakob Schwander, Bernhard Stauffer, Dominique Raynaud, Jean-Marc Barnola, Hubertus Fischer, Valérie Masson-Delmotte, and Jean Jouzel, 2005, Stable carbon cycle–Climate relationship during the late Pleistocene, Science, v. 310, p. 1313-1317.

James Zachos, Mark Pagani, Lisa Sloan, Ellen Thomas, and Katharina Billups, 2001, Trends, rhythms, and aberrations in global climate 65 Ma to Present: Science, v. 292/5517, p. 686-693.

Zachos, James C., Ursula Röhl, Stephen A. Schellenberg, Appy Sluijs, David A. Hodell, Daniel C. Kelly, Ellen Thomas, Micah Nicolo, Isabella Raffi, Lucas J. Lourens, Heather McCarren, and Dick Kroon, 2005, Rapid acidification of the ocean during the Paleocene-Eocene Thermal Maximum: Science, v. 308/5728, p. 1611-1615.

The Carbon Cycle on Fossil Fuels

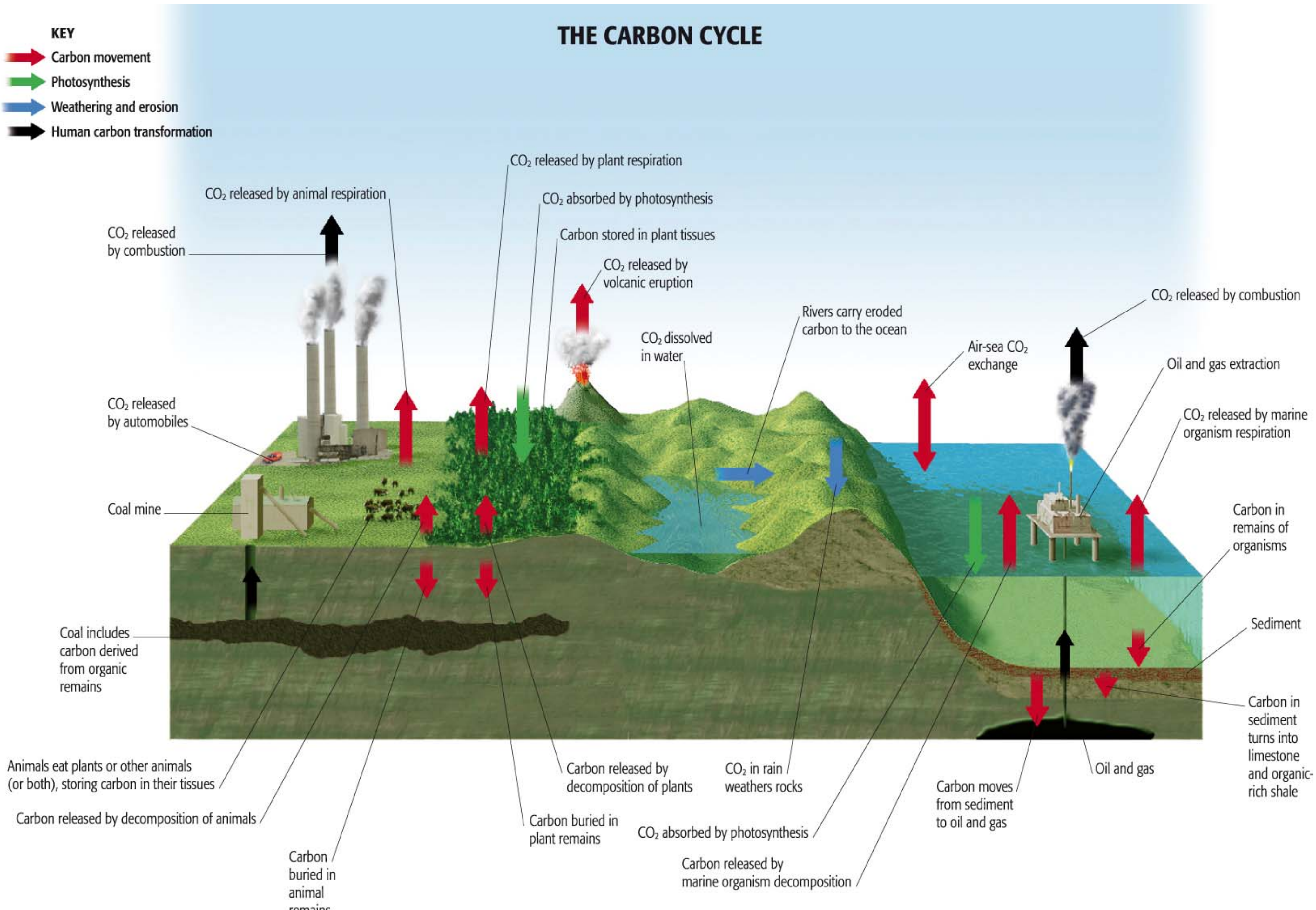


Lee Kump
Penn State

This is fossil fuels

This is the carbon cycle
on fossil fuels


Questions?
Partnership for a Carbon Free America

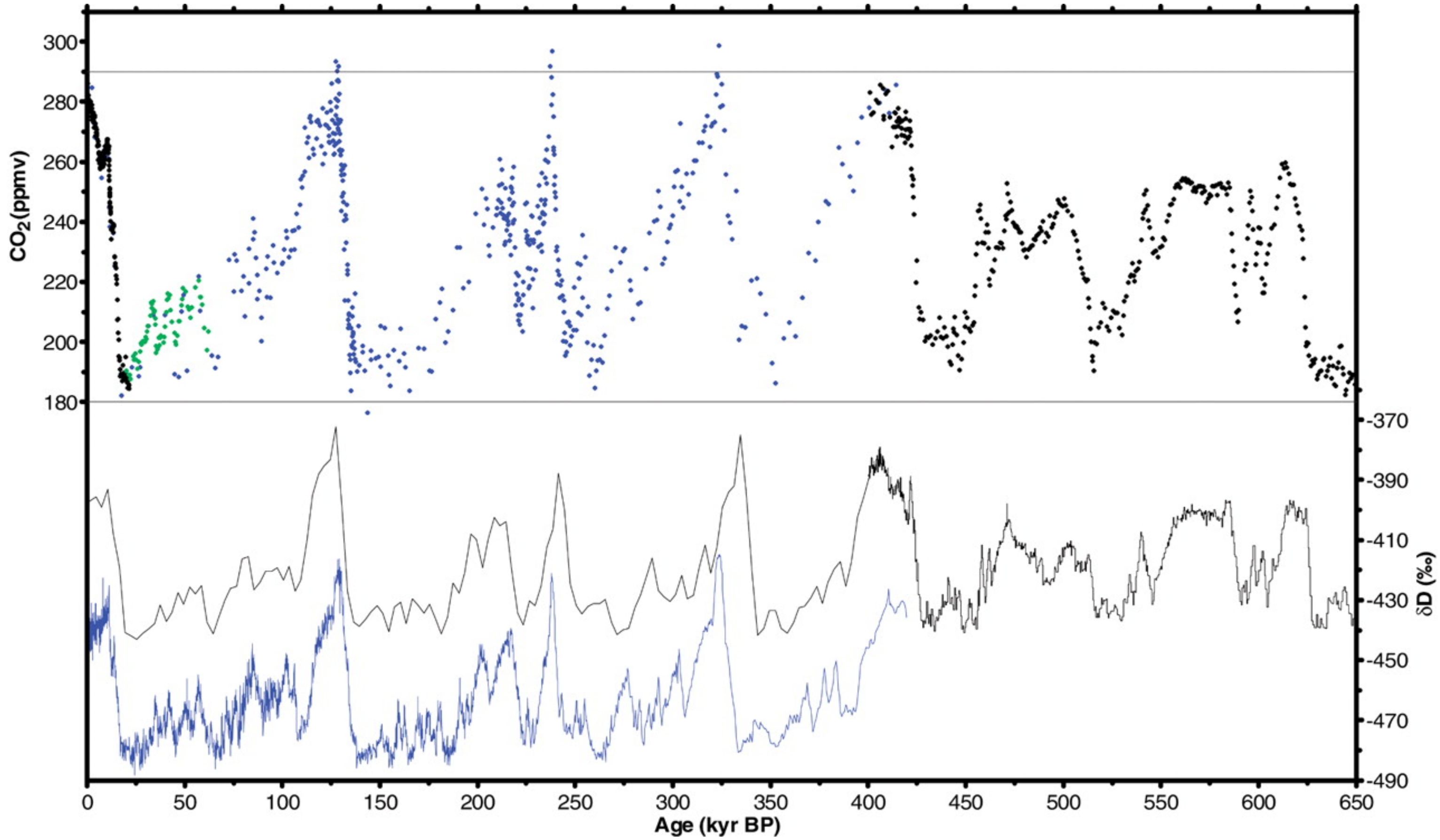


Mann and Kump (2008)

A composite CO_2 record over six and a half ice age cycles, back to 650,000 years B.P.

CO_2

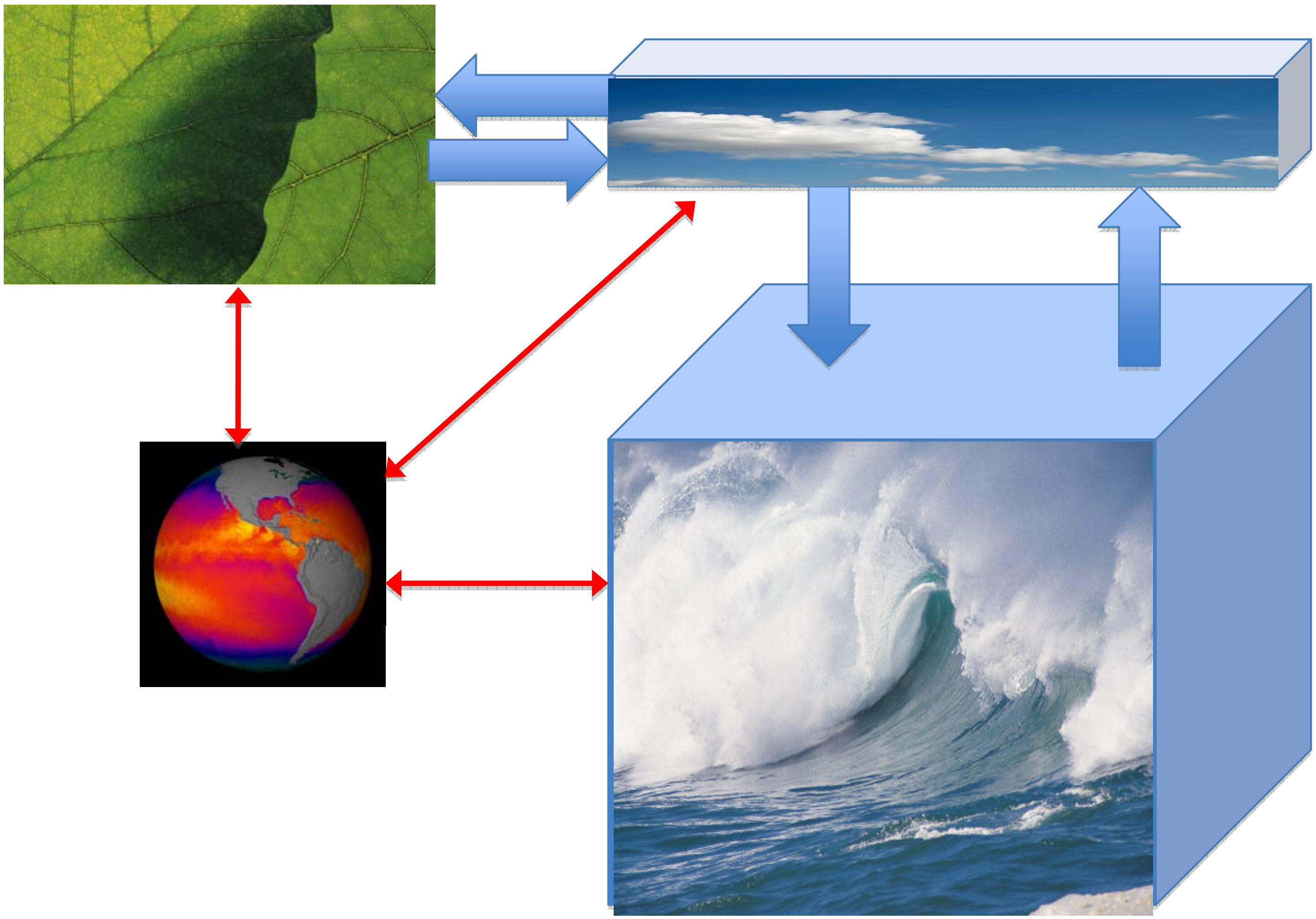
"temp"

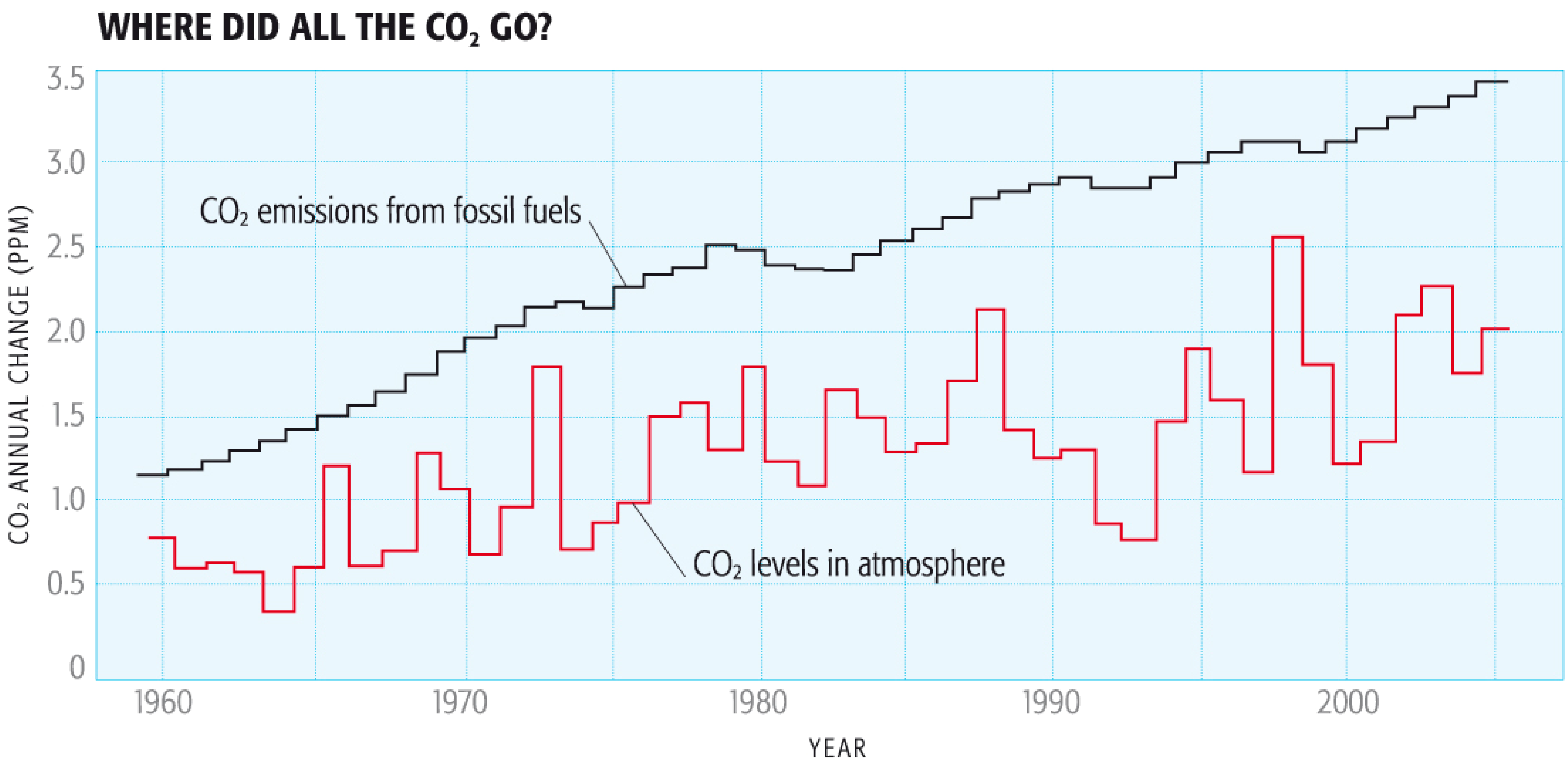


U. Siegenthaler et al., Science 310, 1313 -1317 (2005)

Published by AAAS

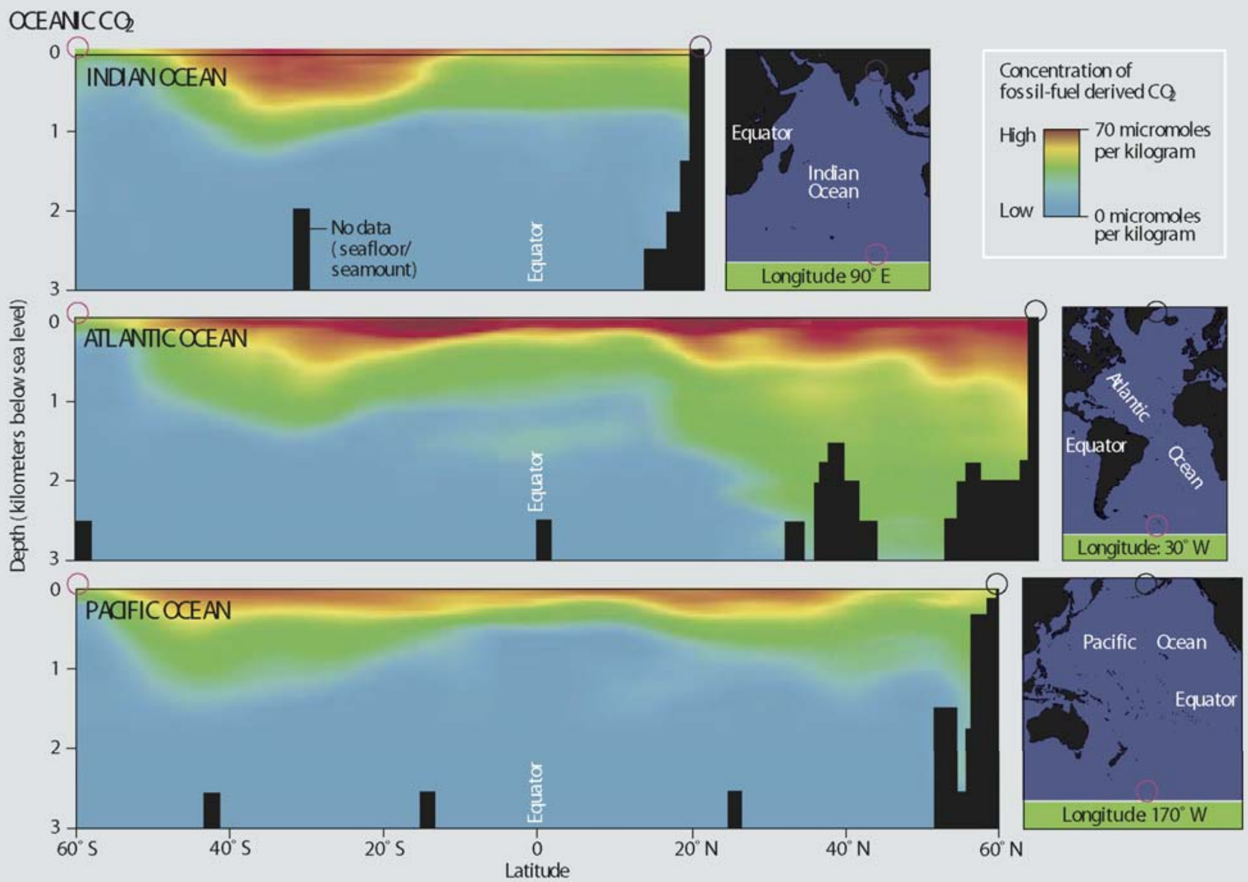
Carbon redistributed internally
in response to
climate feedbacks



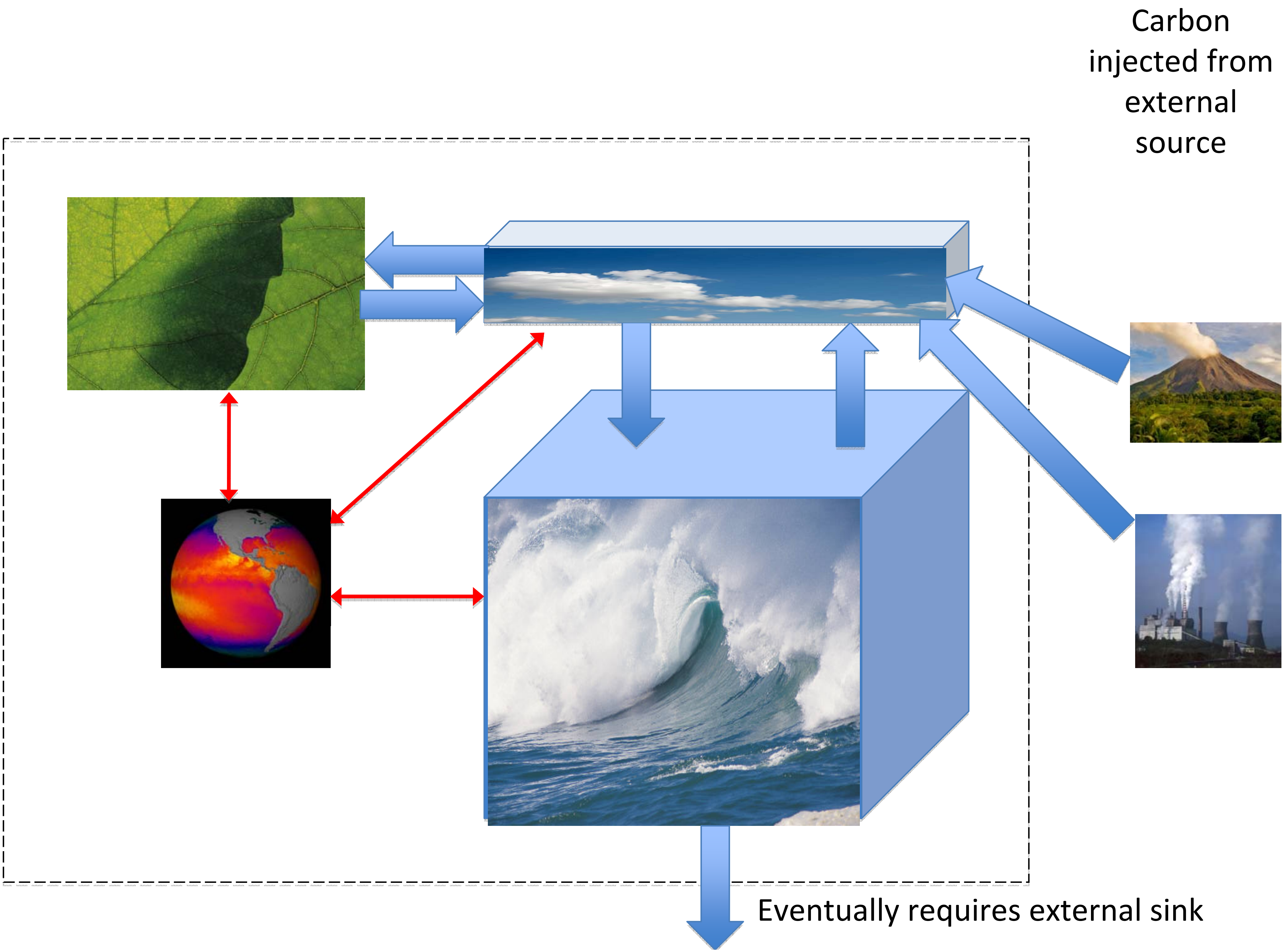


Mann and Kump (2008)

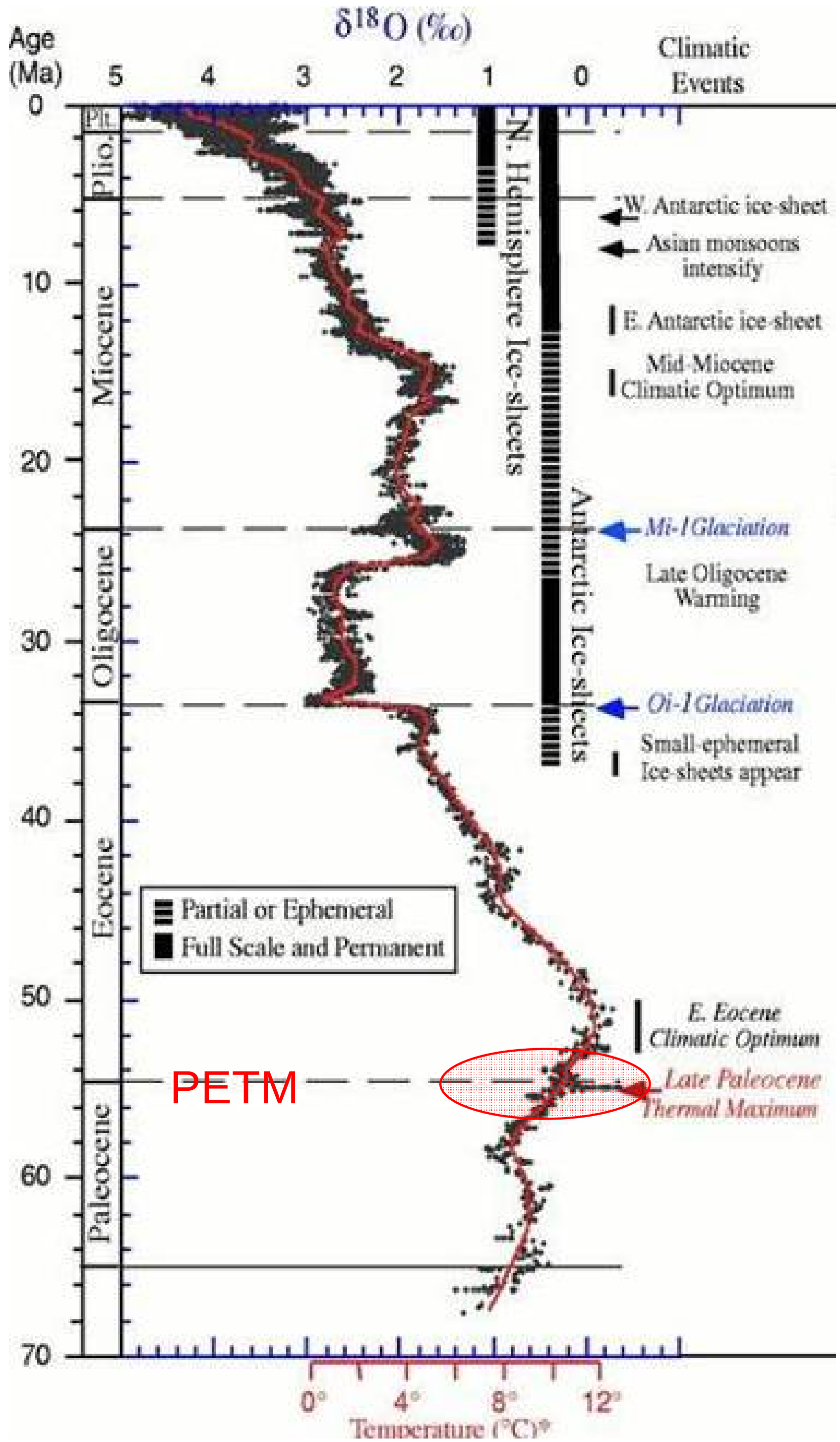
Fossil Fuel CO_2 Uptake by Ocean



Scientific American March 2006

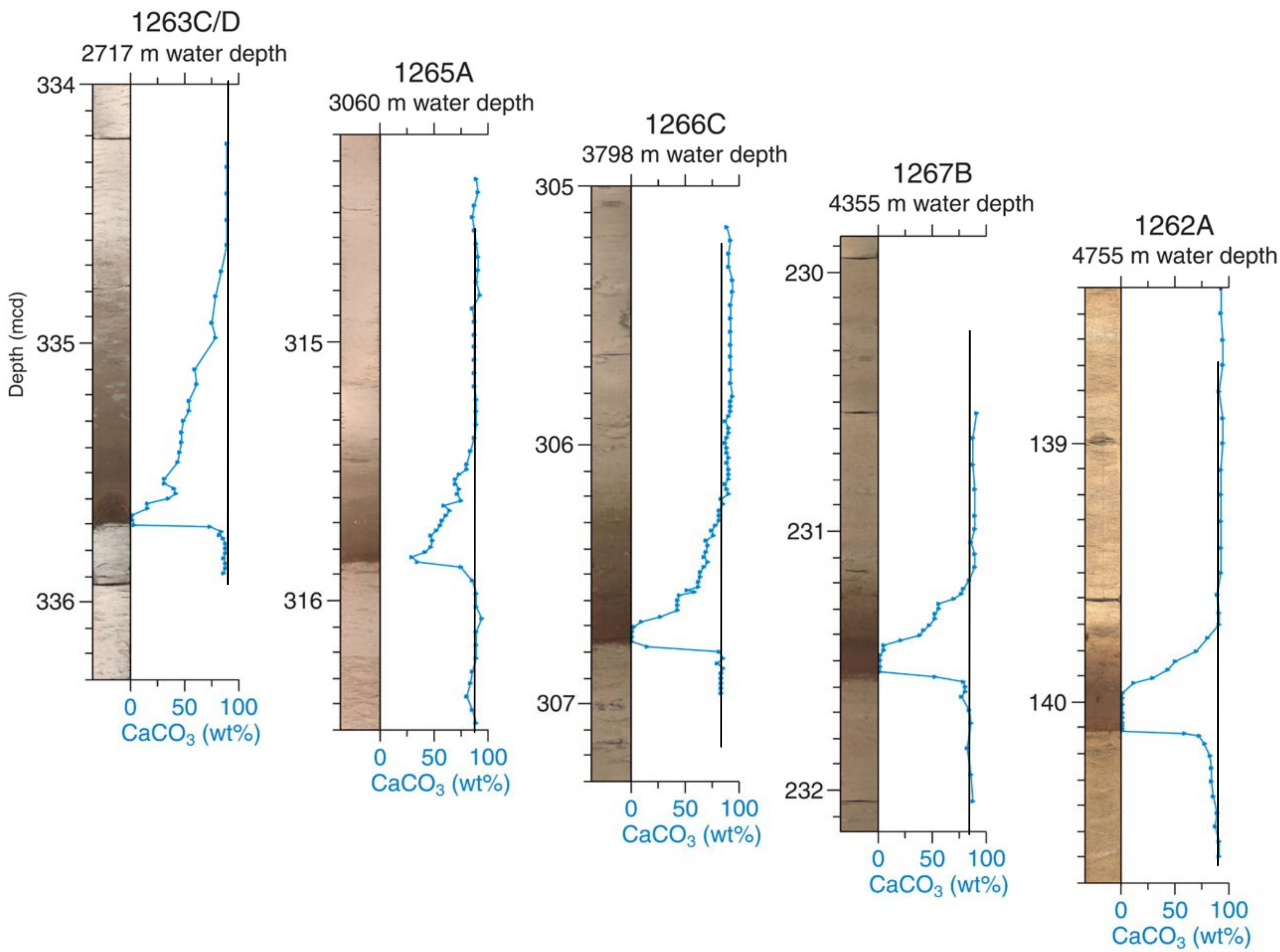

Carbon injected from external source
Eventually requires external sink

Polar temperatures for the last 65 million years



Zachos et al. (2001, *Science* 292: 686-693)

Digital core photos and weight % $CaCO_3$ content plotted versus meters of composite depth (MCD) across the PETM on Walvis Ridge



J. C. Zachos et al., Science 308, 1611 -1615 (2005)

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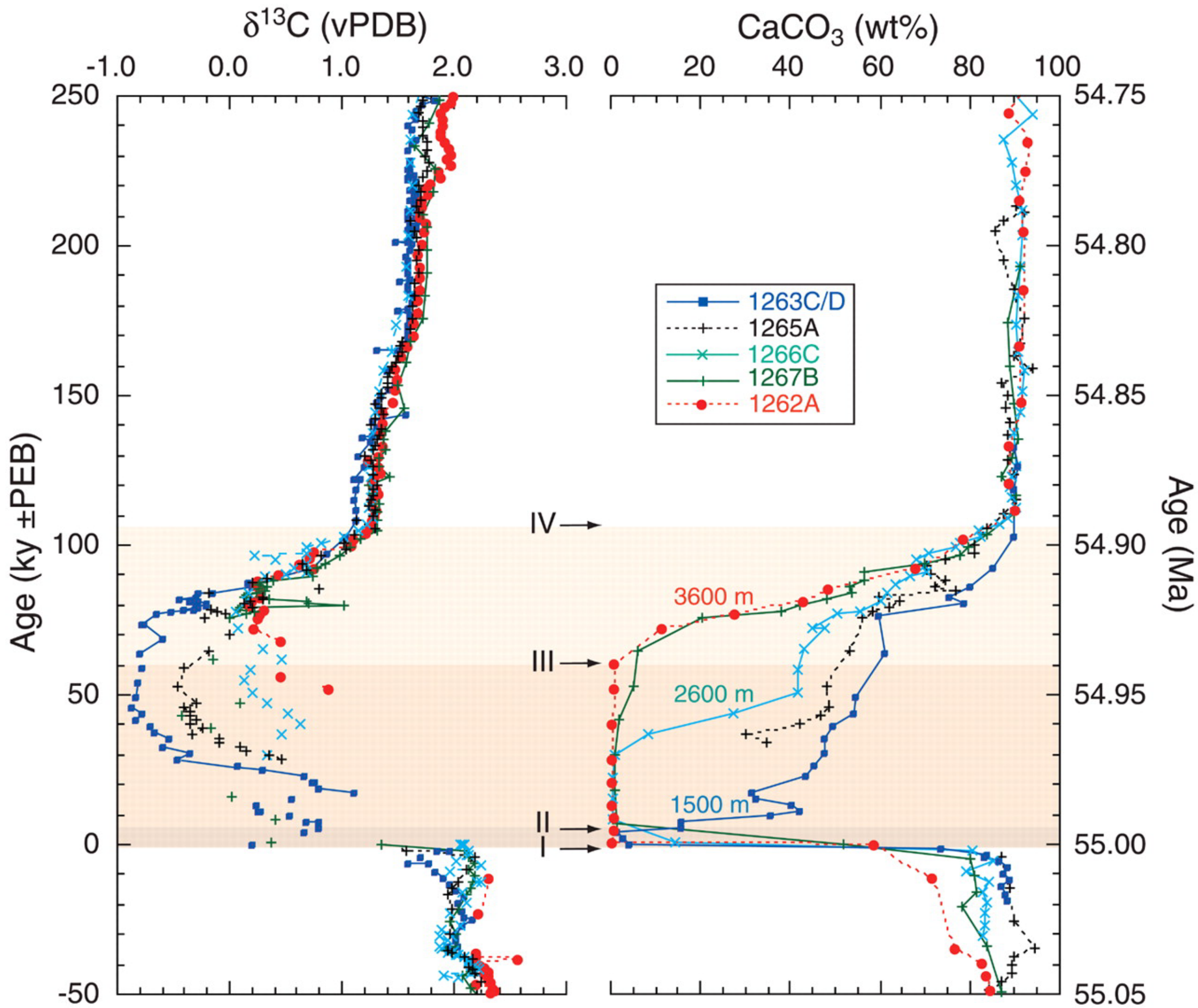
Bulk sediment δ13C and weight % carbonate content for ODP sites 1262, 1263, 1265, 1266, and 1267



J. C. Zachos et al., Science 308, 1611 -1615 (2005)

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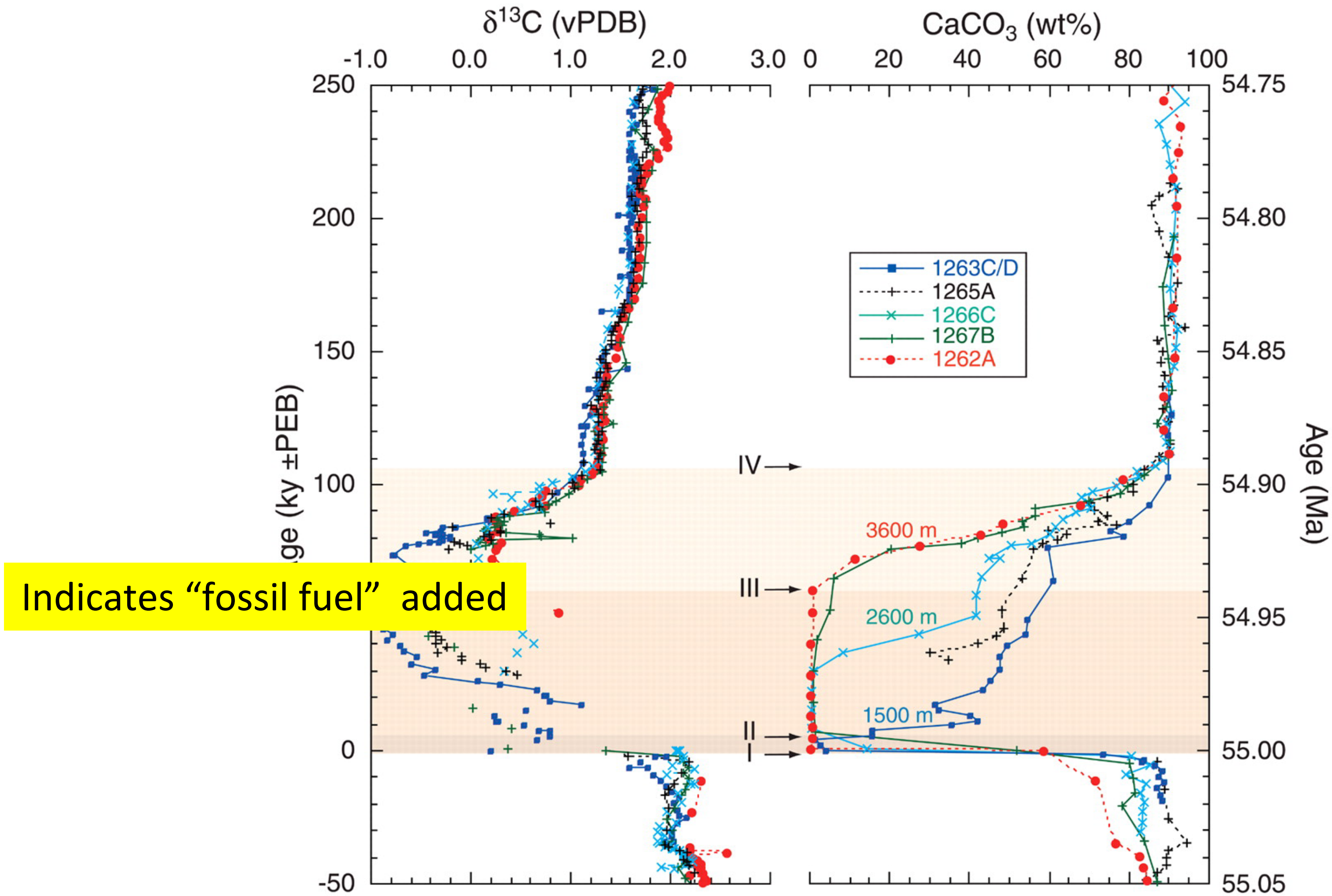
Bulk sediment δ¹³C and weight % carbonate content for ODP sites 1262, 1263, 1265, 1266, and 1267



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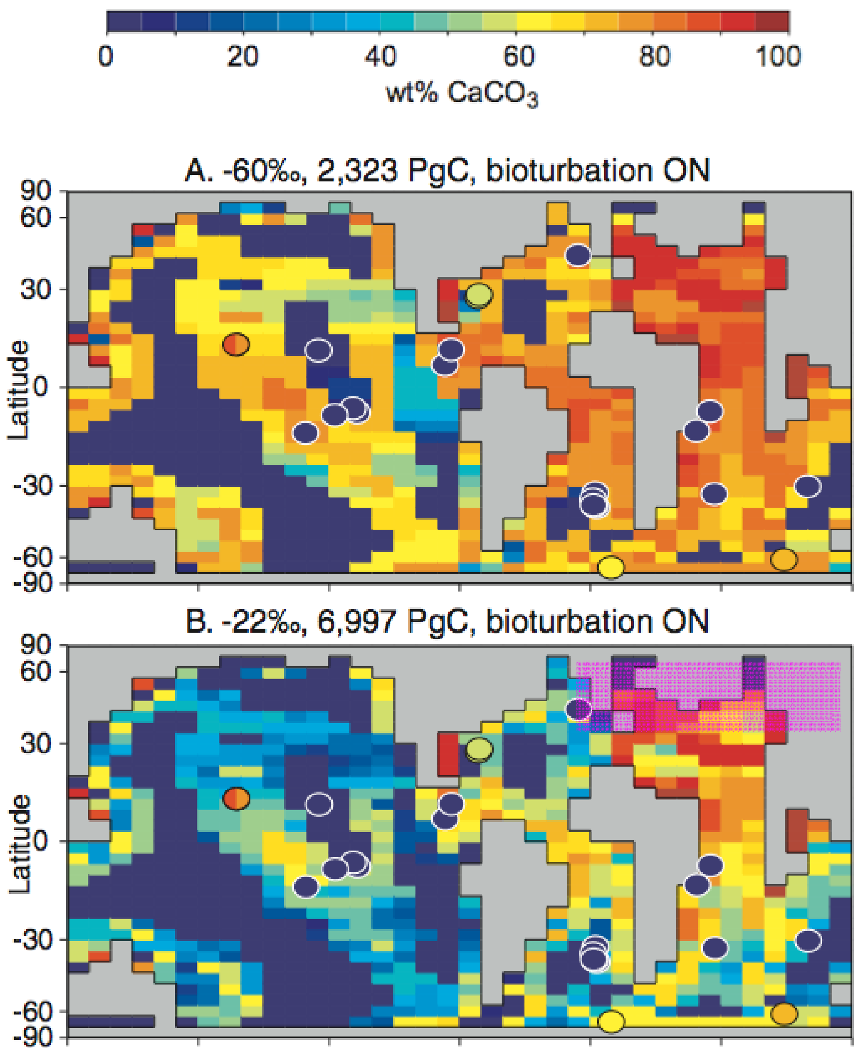
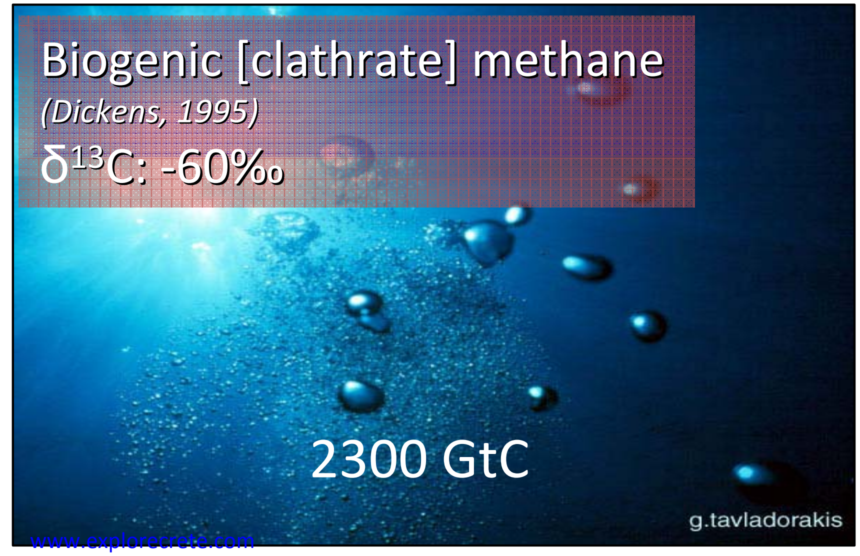
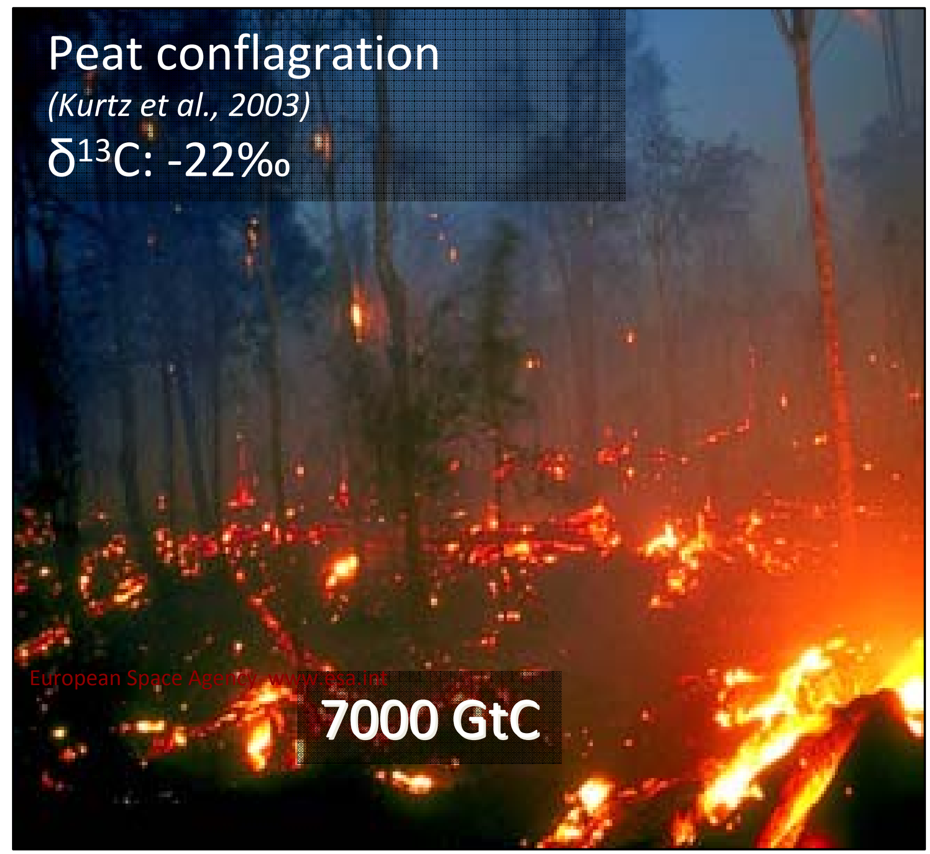
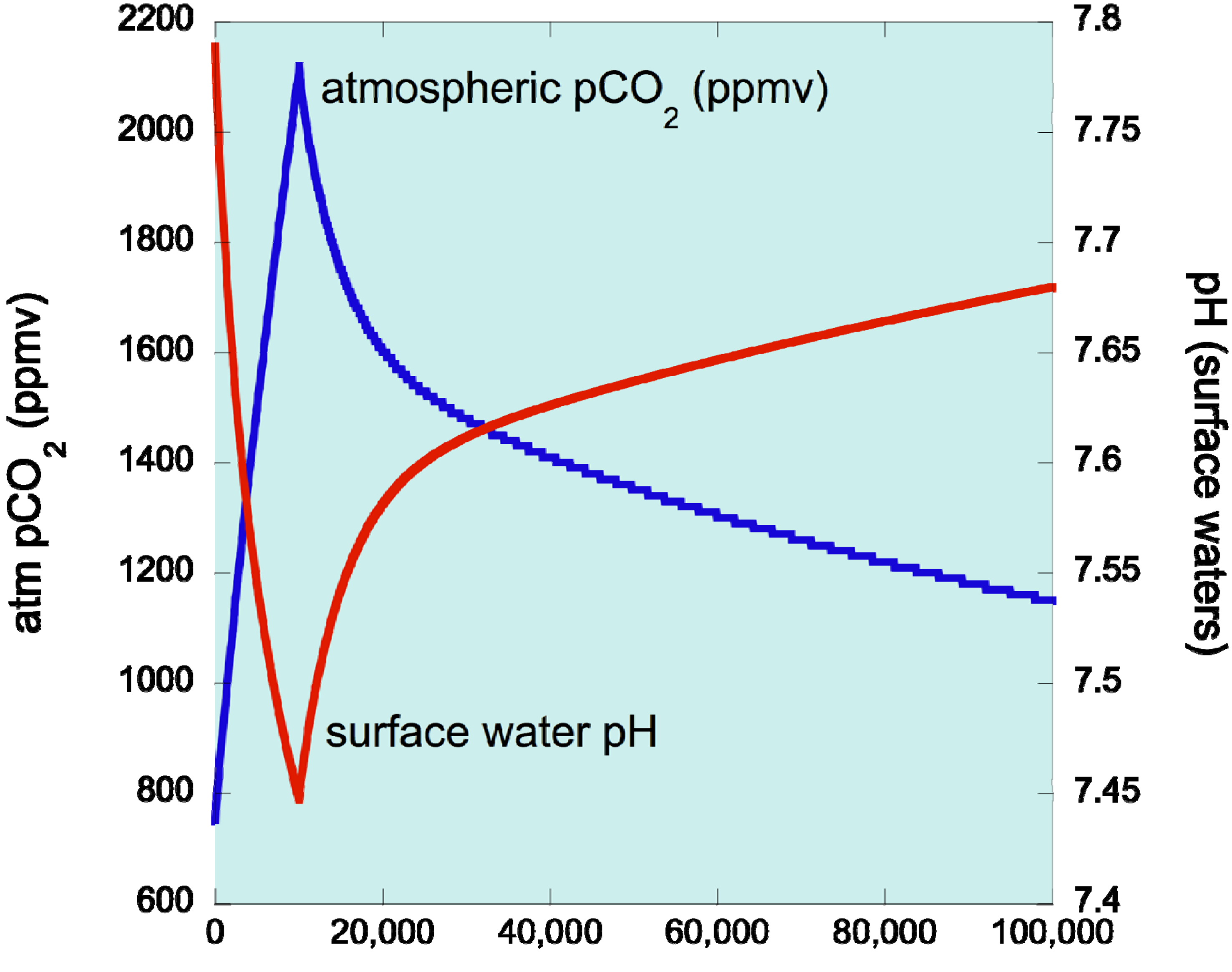
$CaCO_3$ wt% model vs. data (circles)



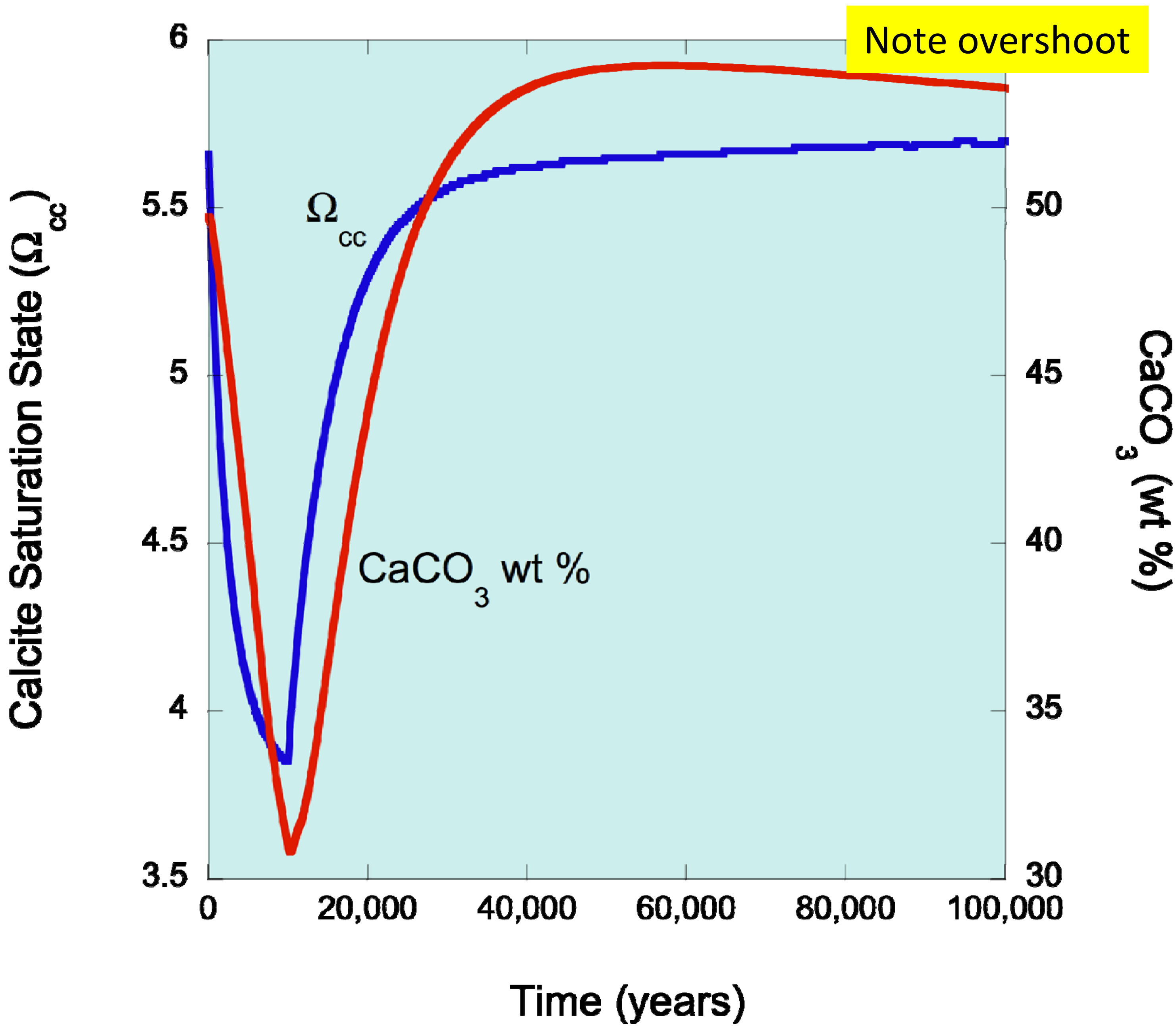


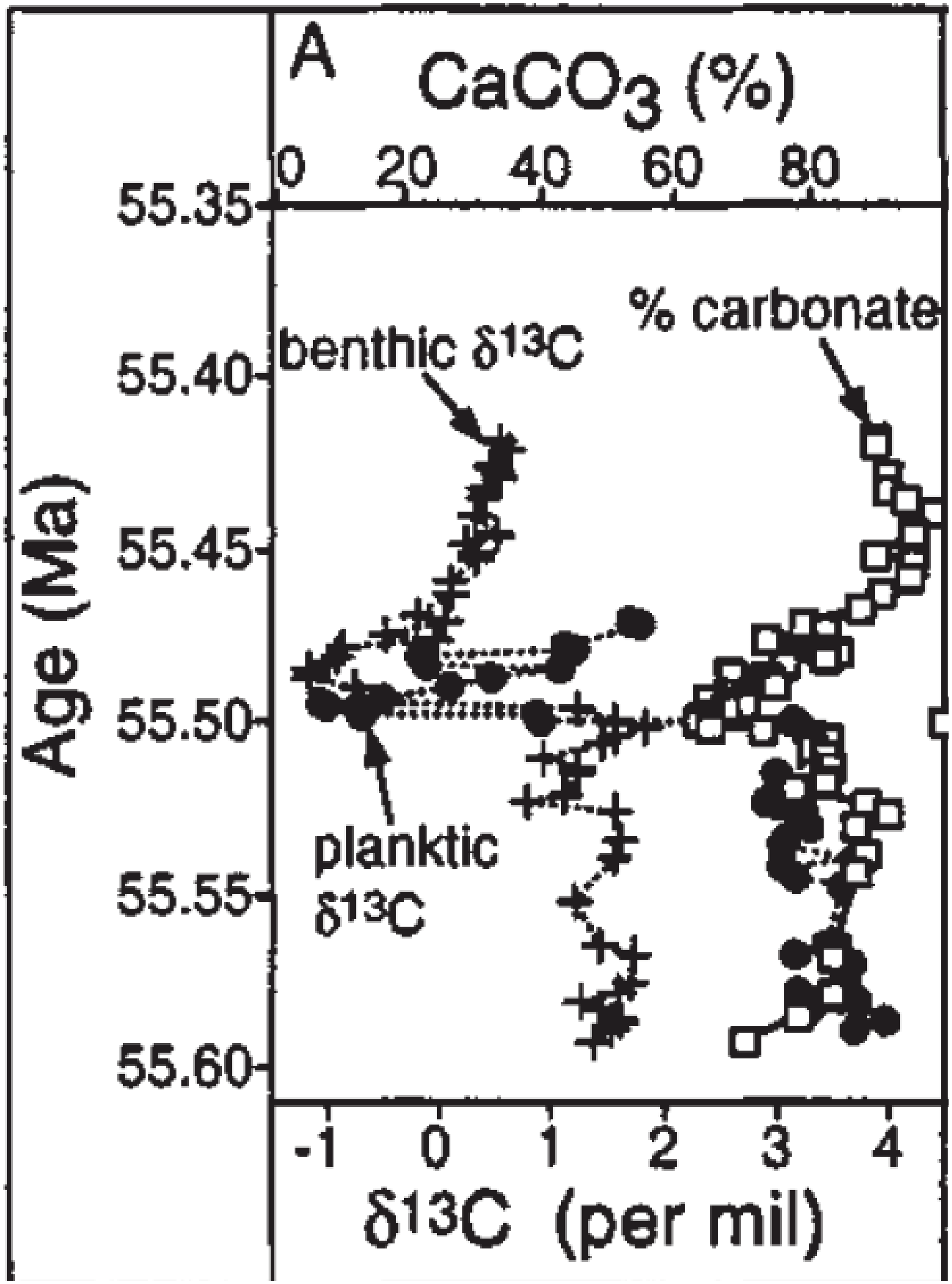


Panchuk et al. (2007)



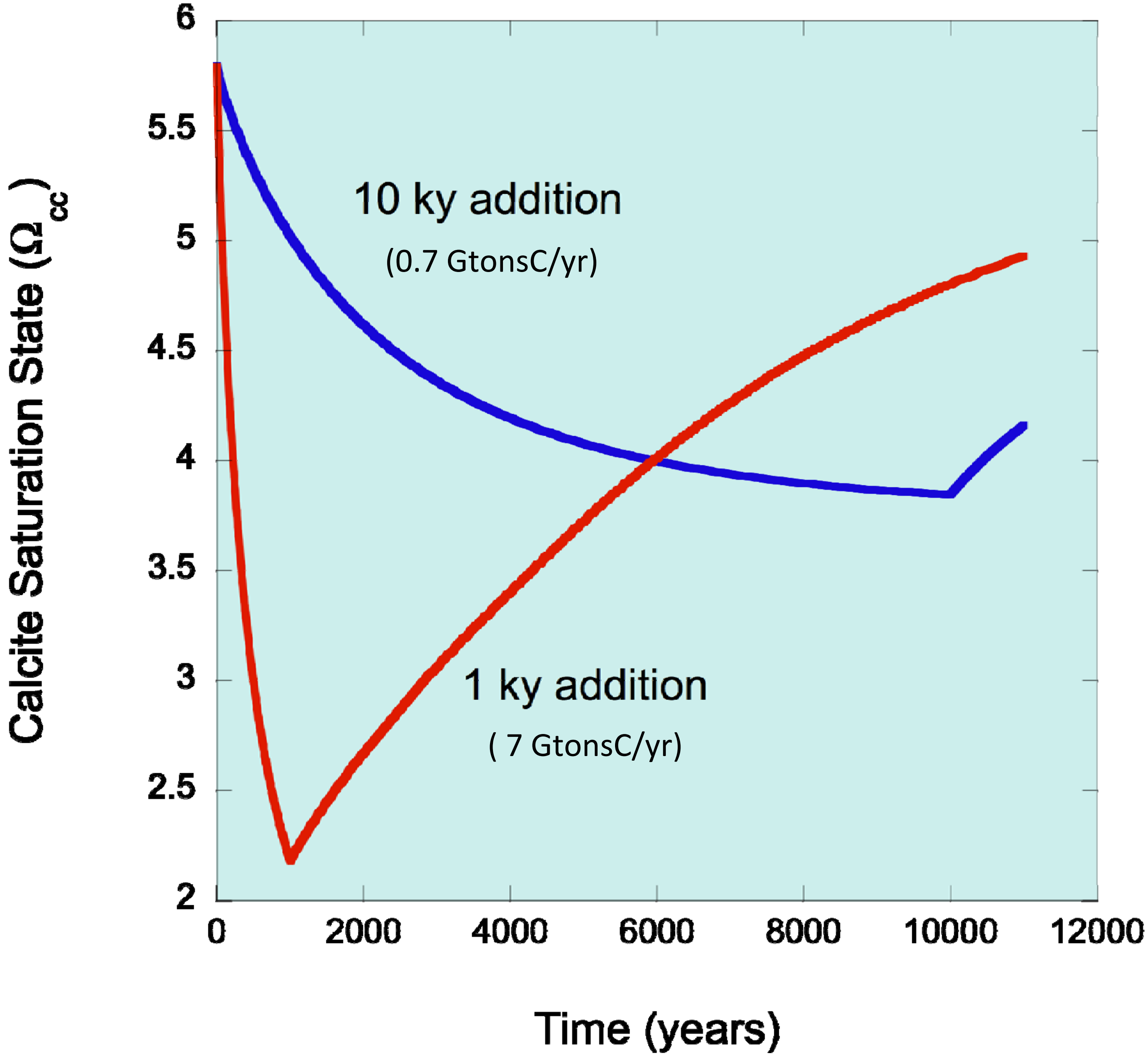
atmospheric pCO2 (ppmv)
surface water pH
2200
2000
1800
1600
1400
1200
1000
800
600
atm pCO2 (ppmv)
7.8
7.75
7.7
7.65
7.6
7.55
7.5
7.45
7.4
pH (surface waters)
0
20,000
40,000
60,000
80,000
100,000
Time (years)


Note overshoot
Calcite Saturation State (Ω_{cc})
Ω_{cc}
$CaCO_3$ wt %
$CaCO_3$ (wt %)
Time (years)
6
5.5
5
4.5
4
3.5
50
45
40
35
30
0
20,000
40,000
60,000
80,000
100,000



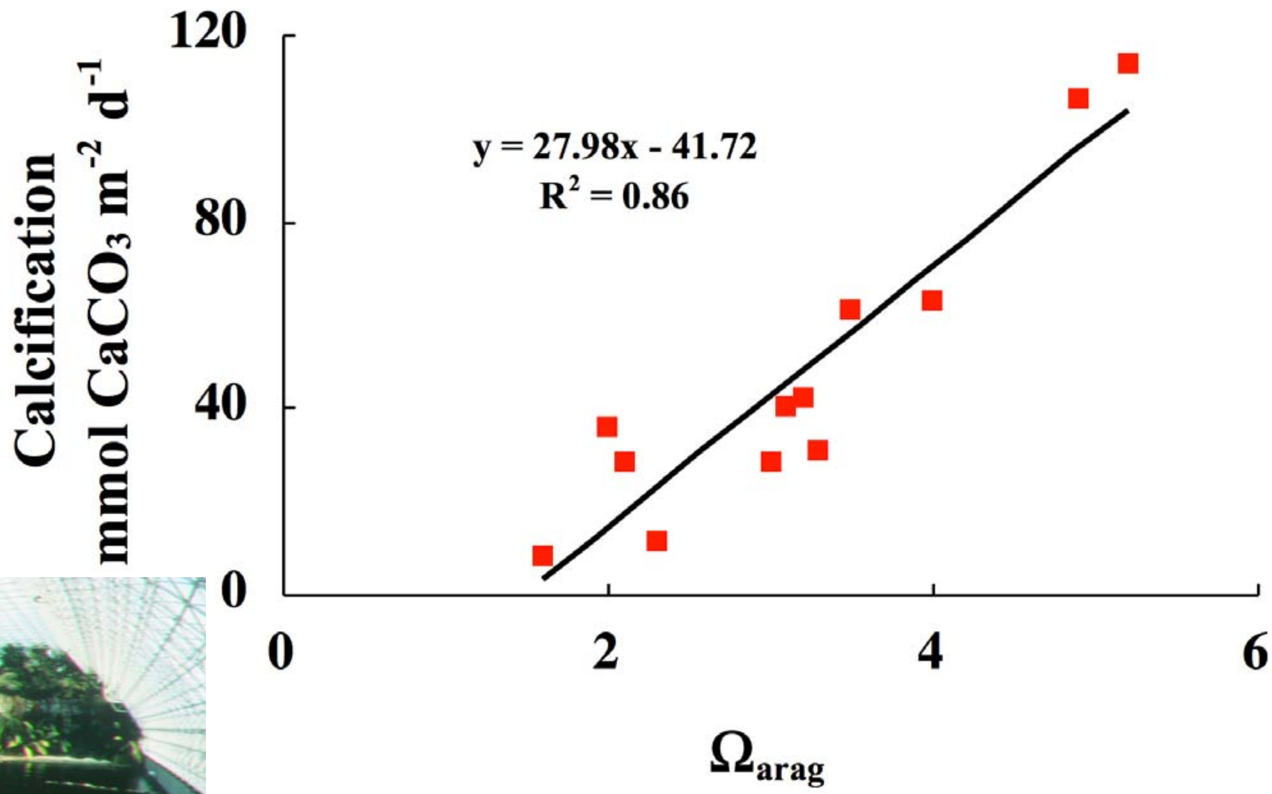
A
CaCO3 (%)
0 20 40 60 80
55.35
55.40
55.45
55.50
55.55
55.60
Age (Ma)
% carbonate
benthic δ13C
planktic
δ13C
-1 0 1 2 3 4
δ13C (per mil)

10 ky addition of 7000 Gtons C works for PETM, but slower than fossil fuel burning . . .



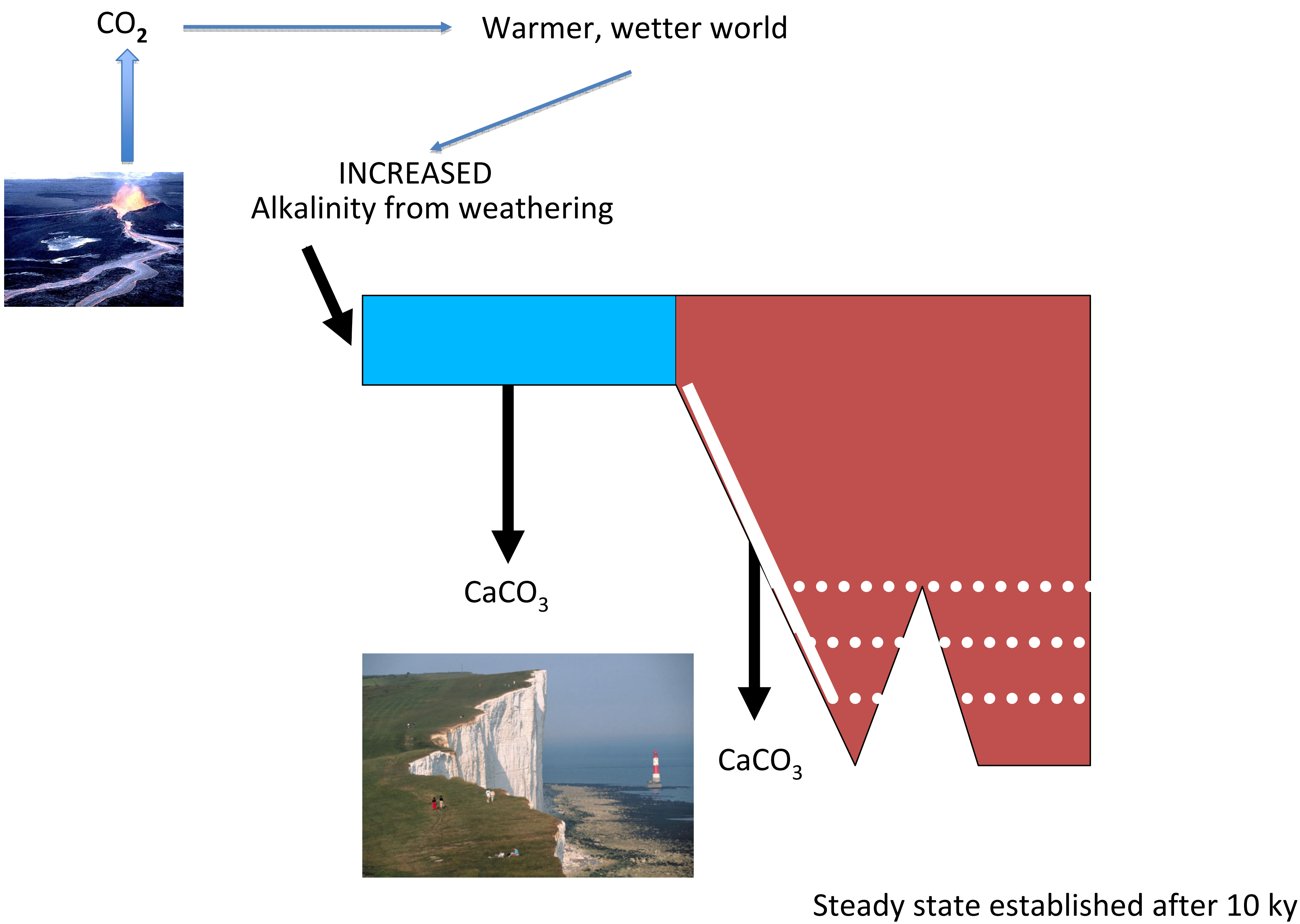
Corals and other calcifiers are wimps!

(Biosphere 2 Study)



C. Langdon

If life can't handle a little CO_2, how did we get the Cliffs of Dover?



CO_2
Warmer, wetter world
INCREASED
Alkalinity from weathering
$CaCO_3$
$CaCO_3$
Steady state established after 10 ky

Conclusions

- Glacial-interglacial atmospheric CO_2 fluctuations part of internal feedback system
- External forcing of carbon cycle (volcanoes, fossil fuel burning) leads to atmospheric CO_2 buildup, warming, "acidification"
- Rates matter!
- Cliffs of Dover confirm, rather than challenge, CO_2 – climate connection