Observationally Constrained Budget and Lifetime of Excess Atmospheric CO_2: In Praise of Simple Models

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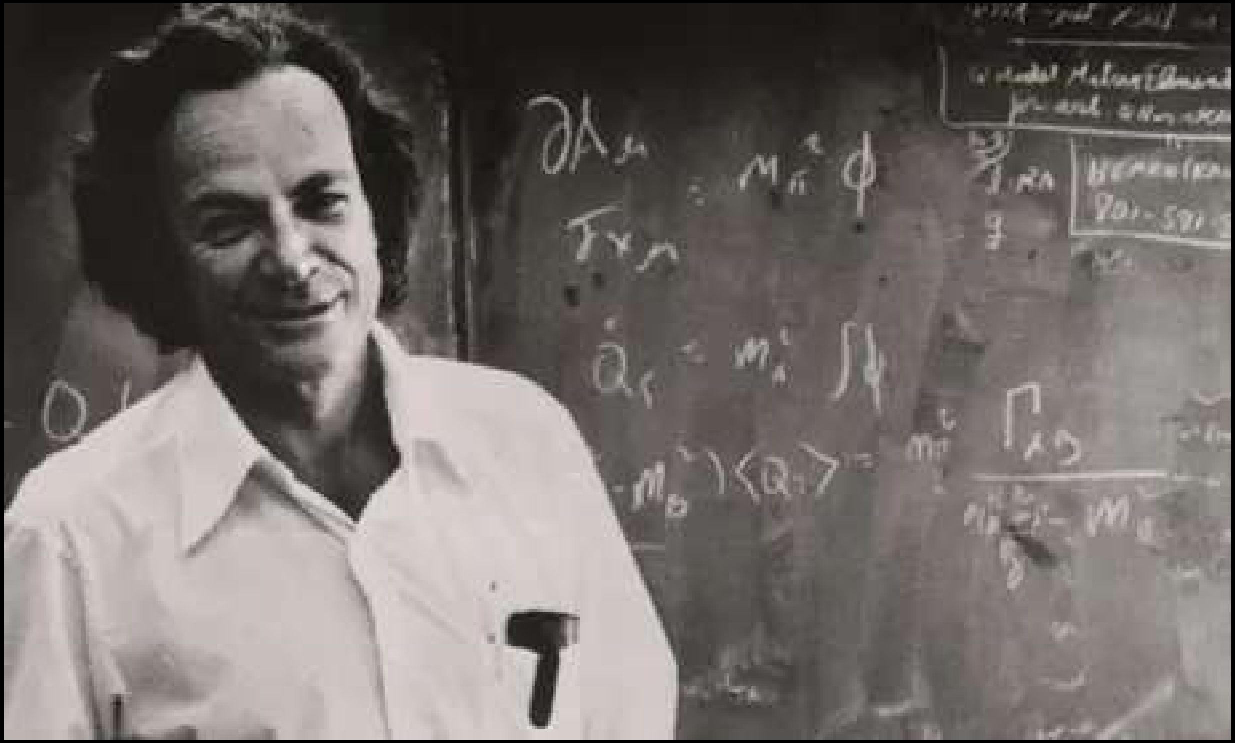

If you can’t explain something to a first year student, then you haven’t really understood it.

Richard Feynman

OUR COLLECTIVE ENERGY USE

Standard diet US adult: 2000 Calories (k cal) or 8400 kJ per day

Equivalent to 100 watts

OUR COLLECTIVE ENERGY USE

Standard diet US adult: 2000 Calories (k cal) or
8400 kJ per day

Equivalent to 100 watts

Per capita energy US use: 10,000 watts

100 100-watt light bulbs, 24 – 7

Equivalent to 100 people!

OUR COLLECTIVE ENERGY USE

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8400 kJ per day

Equivalent to 100 watts

Per capita energy US use: 10,000 watts
100 100-watt light bulbs, 24 – 7

Equivalent to 100 people!

And all these “people” are exhaling CO_2!

MOTIVATION

Why do we (or should we) care about the budget of excess atmospheric CO_2 and its rate of decay in the absence of anthropogenic emissions?

CO_2 is the major driving force of anthropogenic climate change.

How rapidly would atmospheric CO_2 respond to changes in emission (including net zero)?

What is the integrated climate forcing due to emission of CO_2 versus other greenhouse gases such as methane?

ZERO EMISSIONS COMMITMENT

Changes in CO_2 and global temperature after abrupt cessation of CO_2 emissions

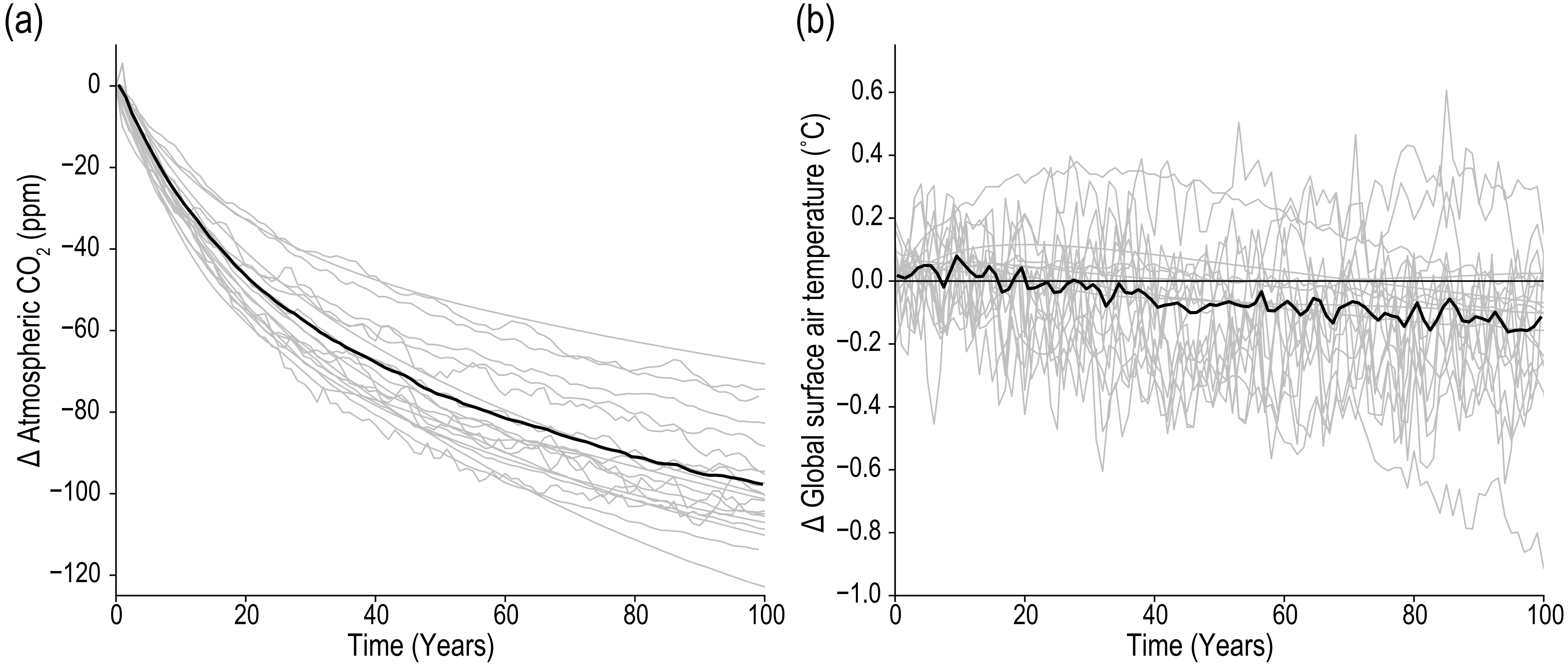
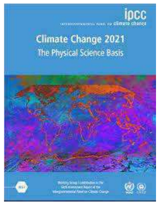
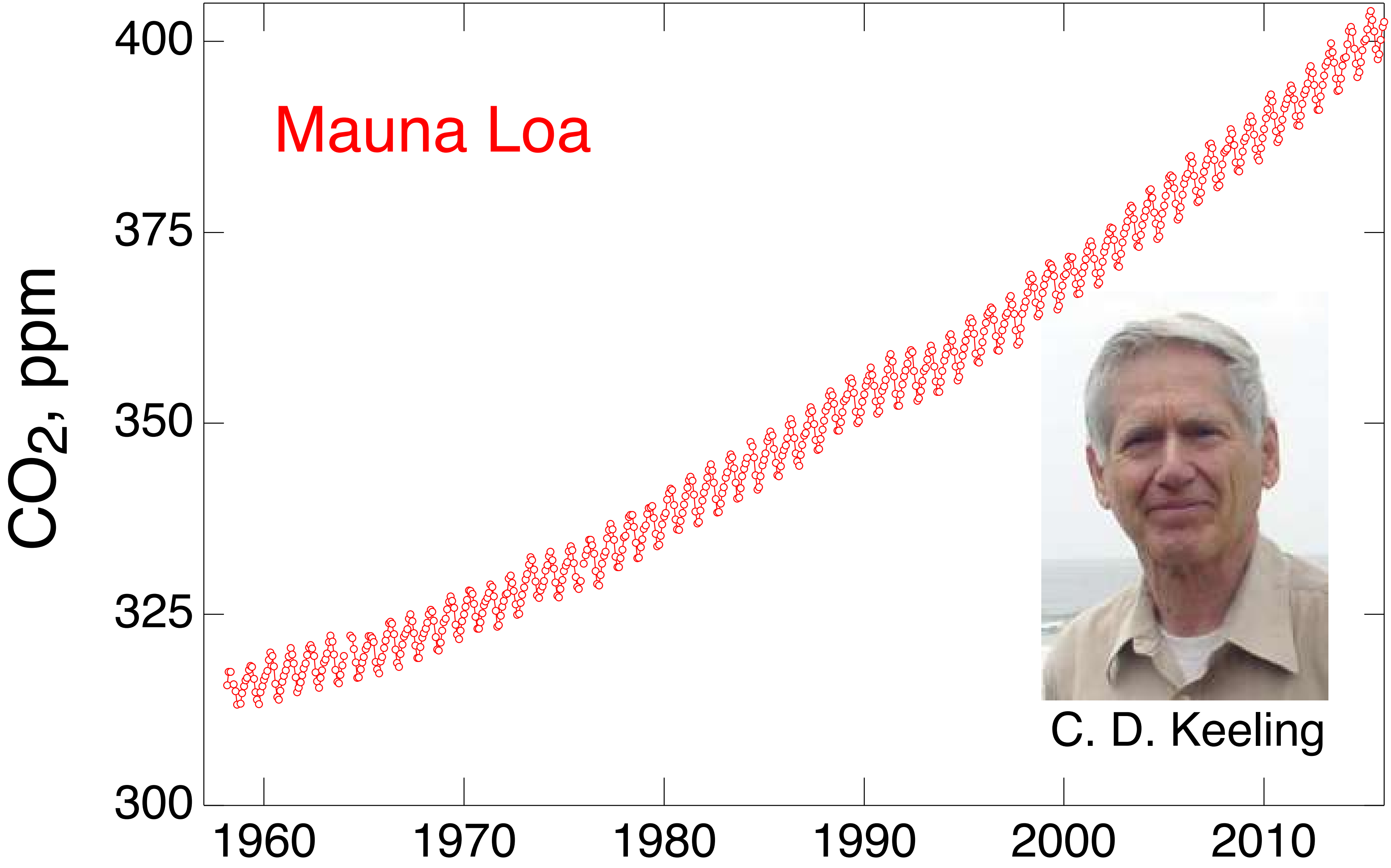


Figure 4.39 I Zero emissions commitment. Changes in (a) atmospheric CO2 concentration and (b) evolution of global surface air temperature (GSAT) following cessation of CO2 emissions (MacDougall et al., 2020). Multi-model mean is shown as thick black line, individual model simulations are in grey.



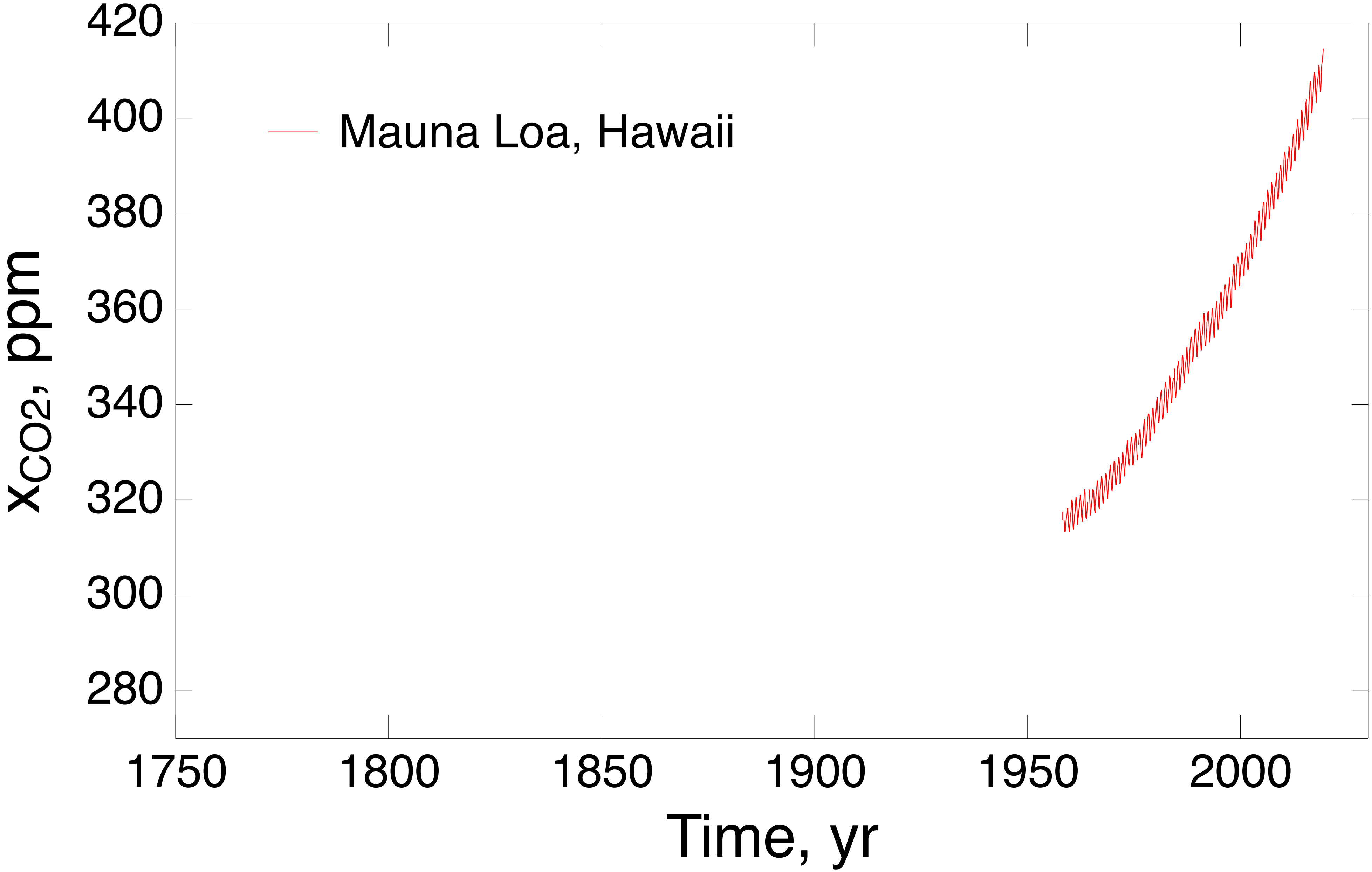
IPCC - AR6 - Fig 4.39, 2021

THE KEELING CURVE



Atmospheric CO_2 has increased substantially over this period.

Increasing CO$_2$ over the Anthropocene



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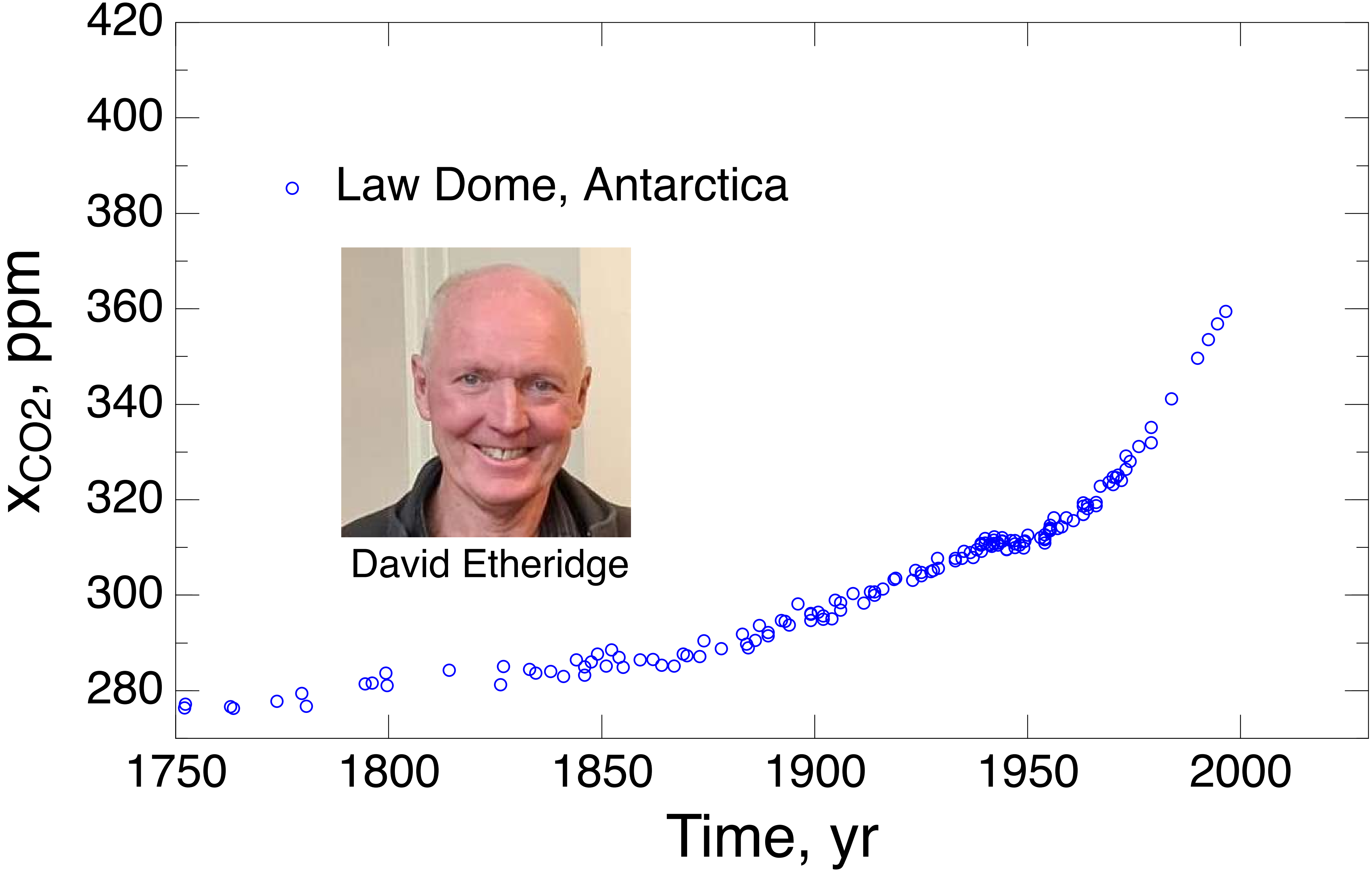

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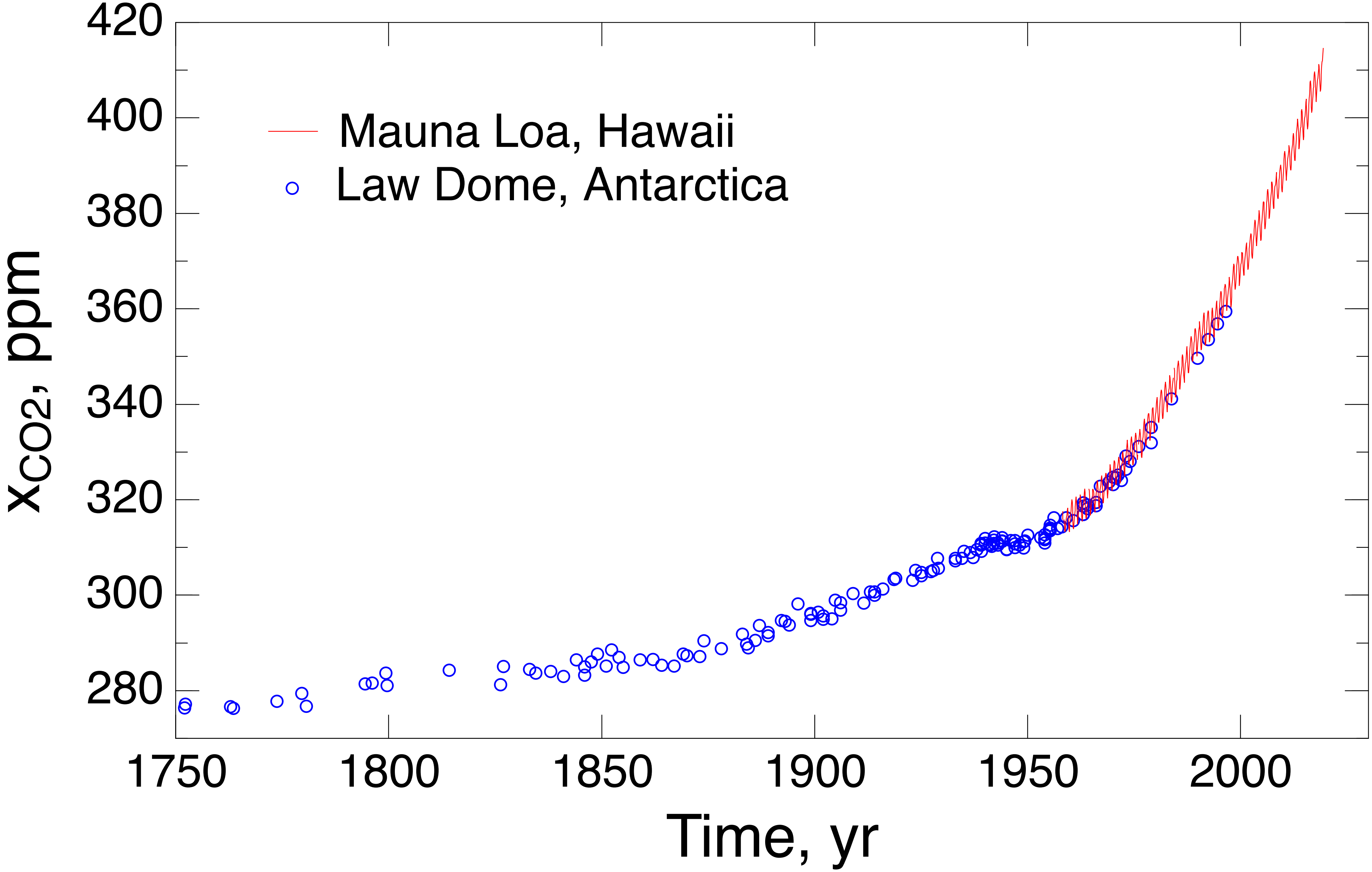
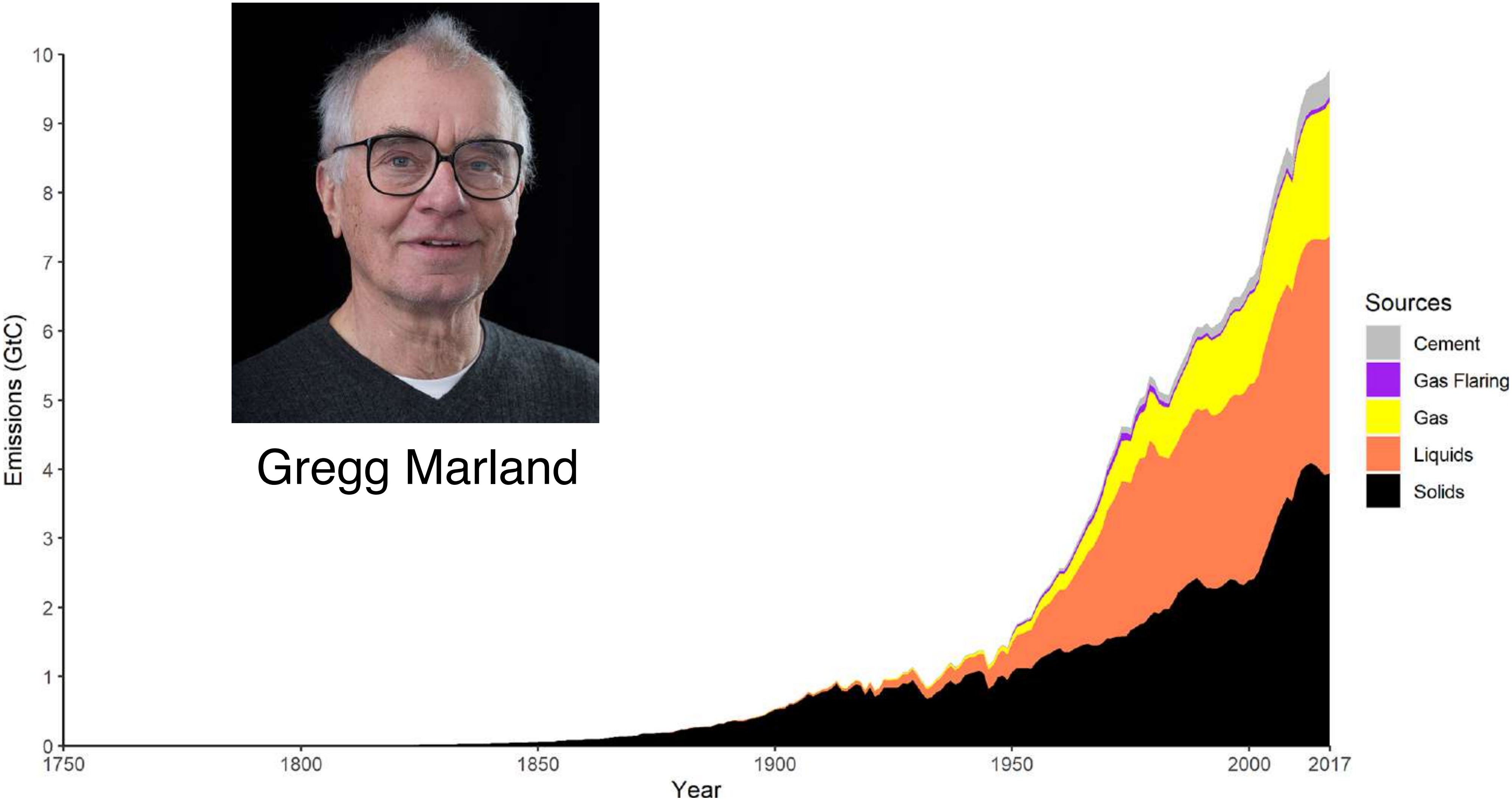


Fossil Fuel (and Cement) Emissions

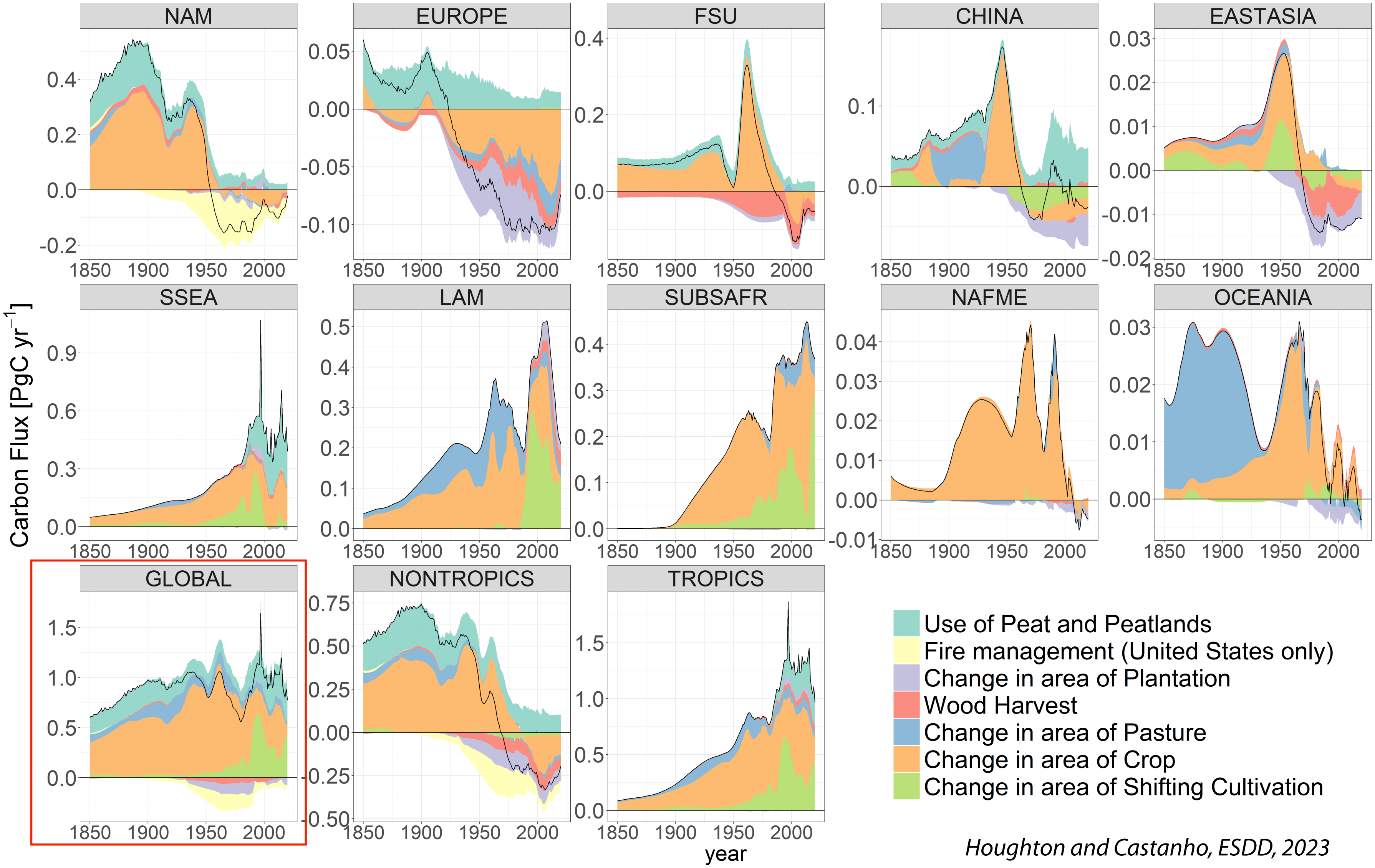


Gregg Marland

Gilfillan and G. Marland, ESSD, 2021

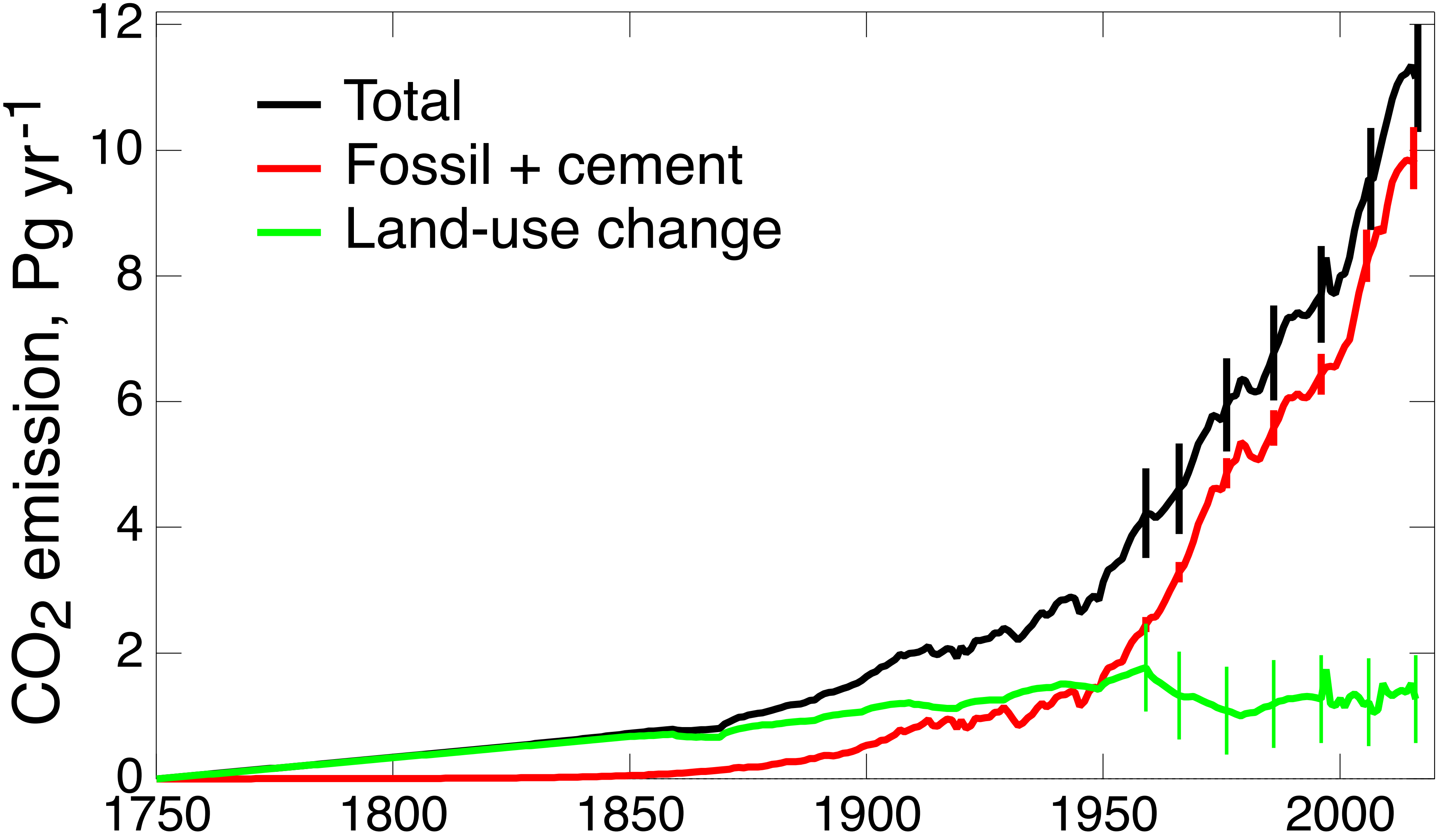
Richard Houghton

Net Land-Use Change Emissions



Houghton and Castanho, ESDD, 2023

ANTHROPOGENIC CARBON DIOXIDE EMISSIONS



Boden, Marland, Andres 2017

Houghton and Nassikas, 2017

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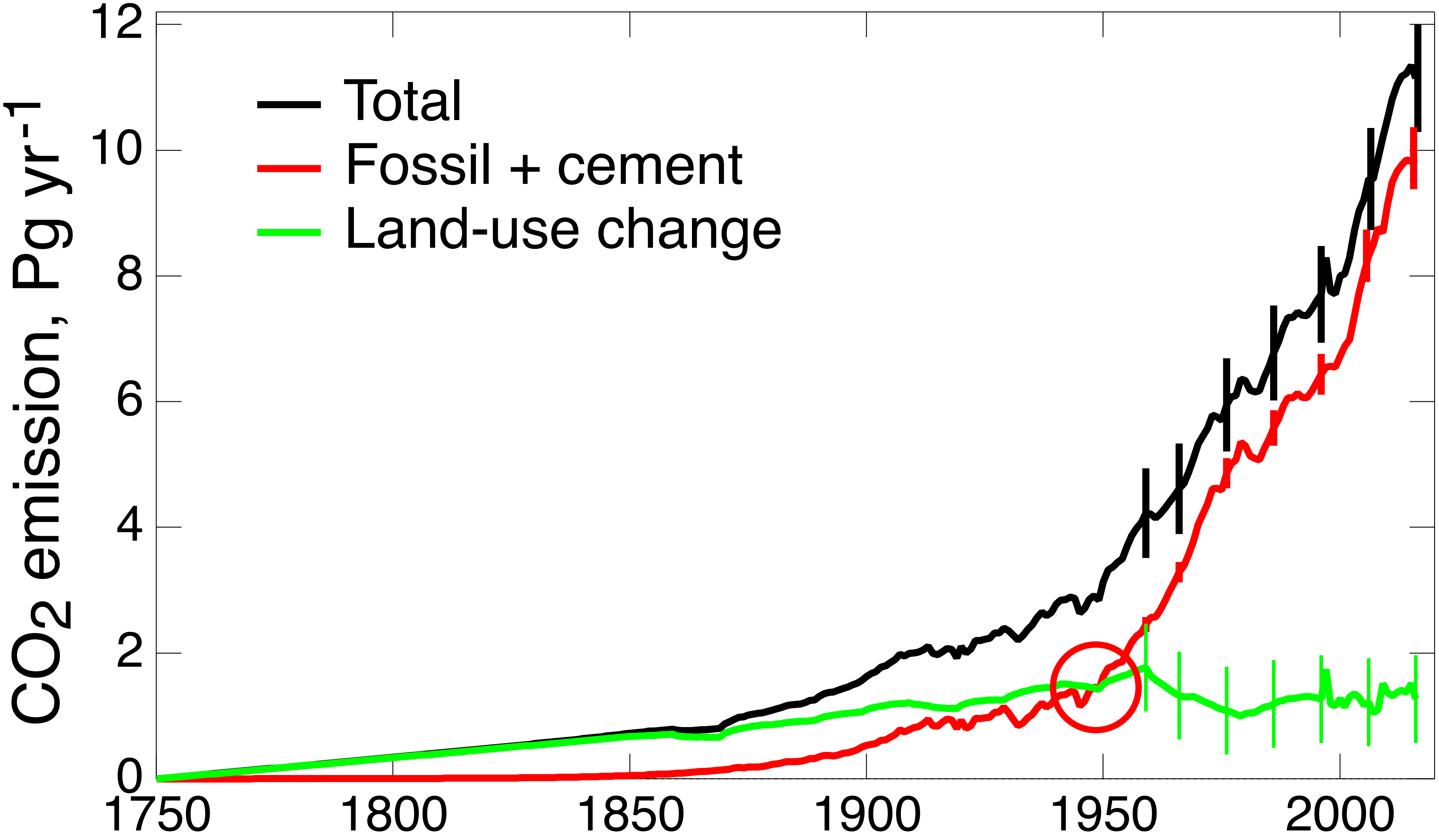
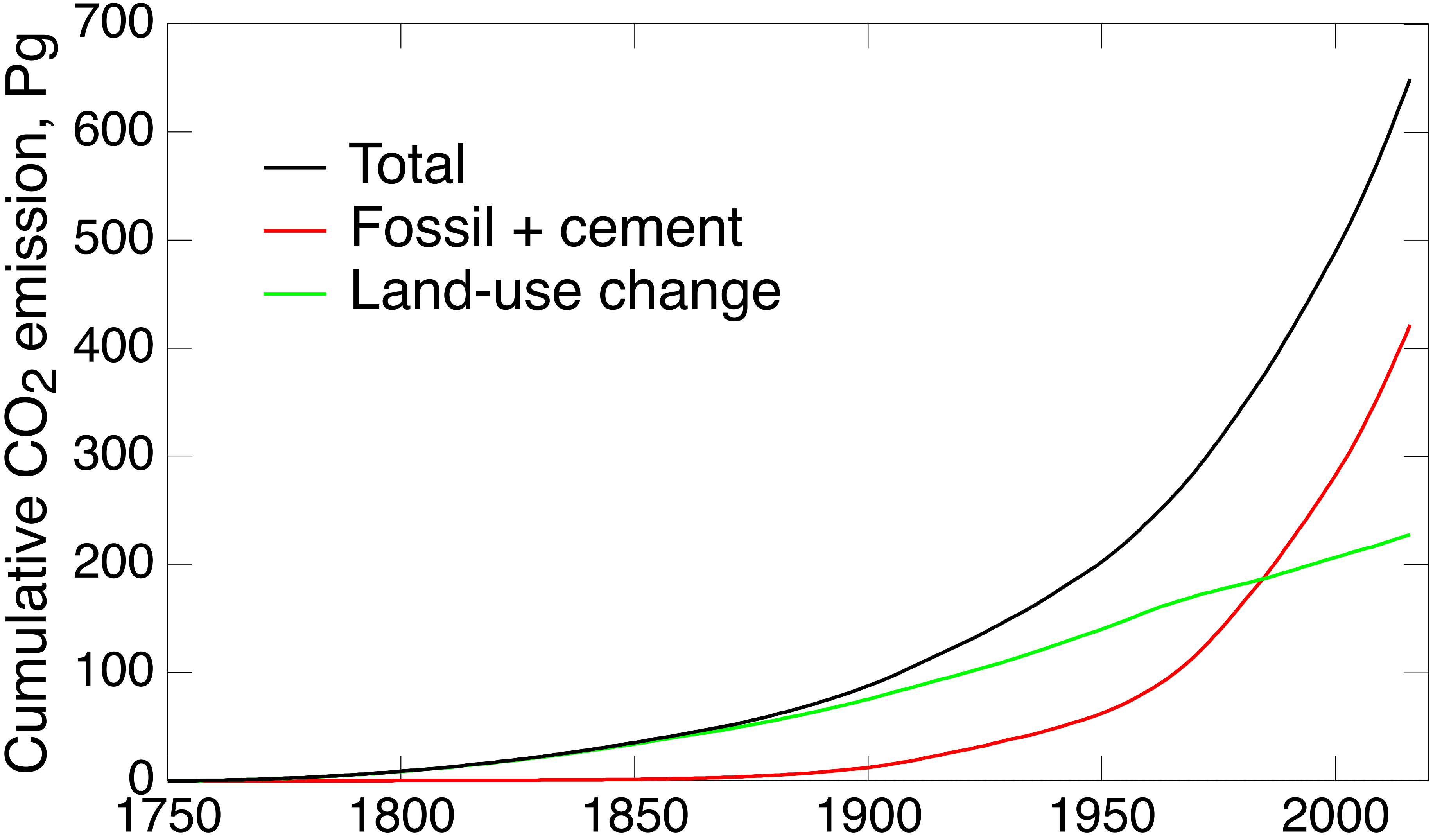


Boden, Marland, Andres 2017

Houghton and Nassikas, 2017

Fossil emissions don't exceed land-use emissions until about 1950.

CUMULATIVE ANTHROPOGENIC CO_2 EMISSIONS



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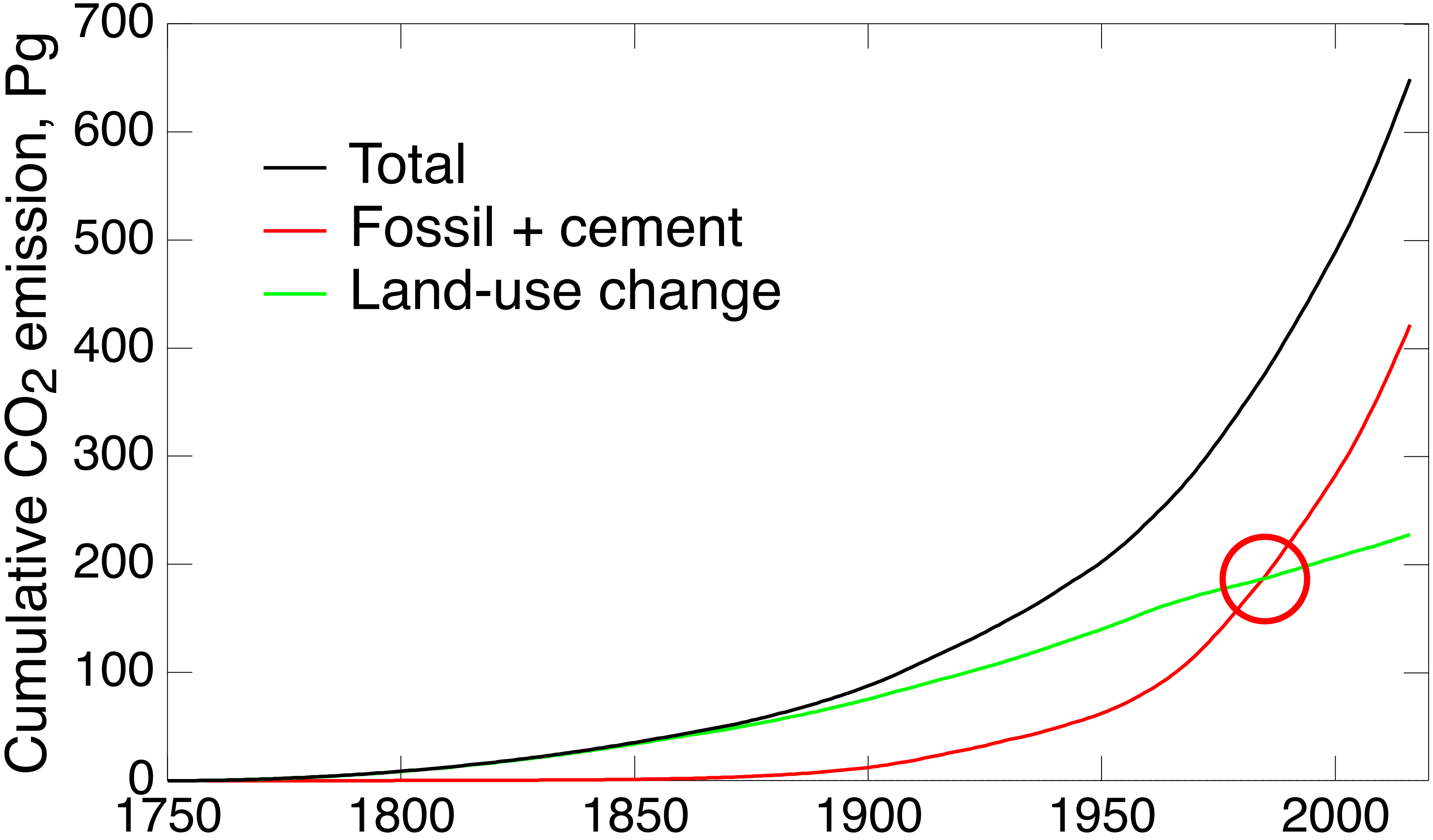
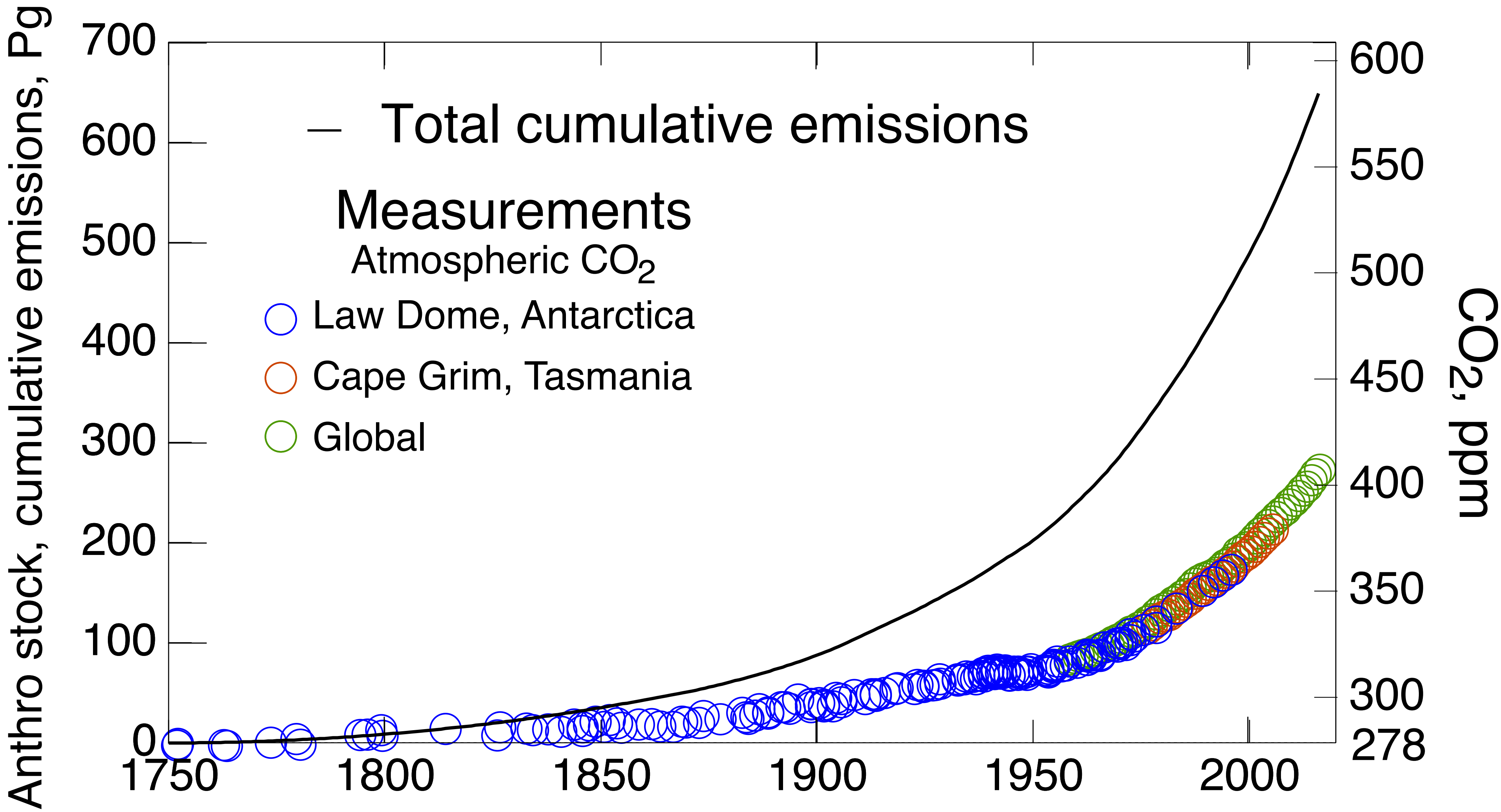


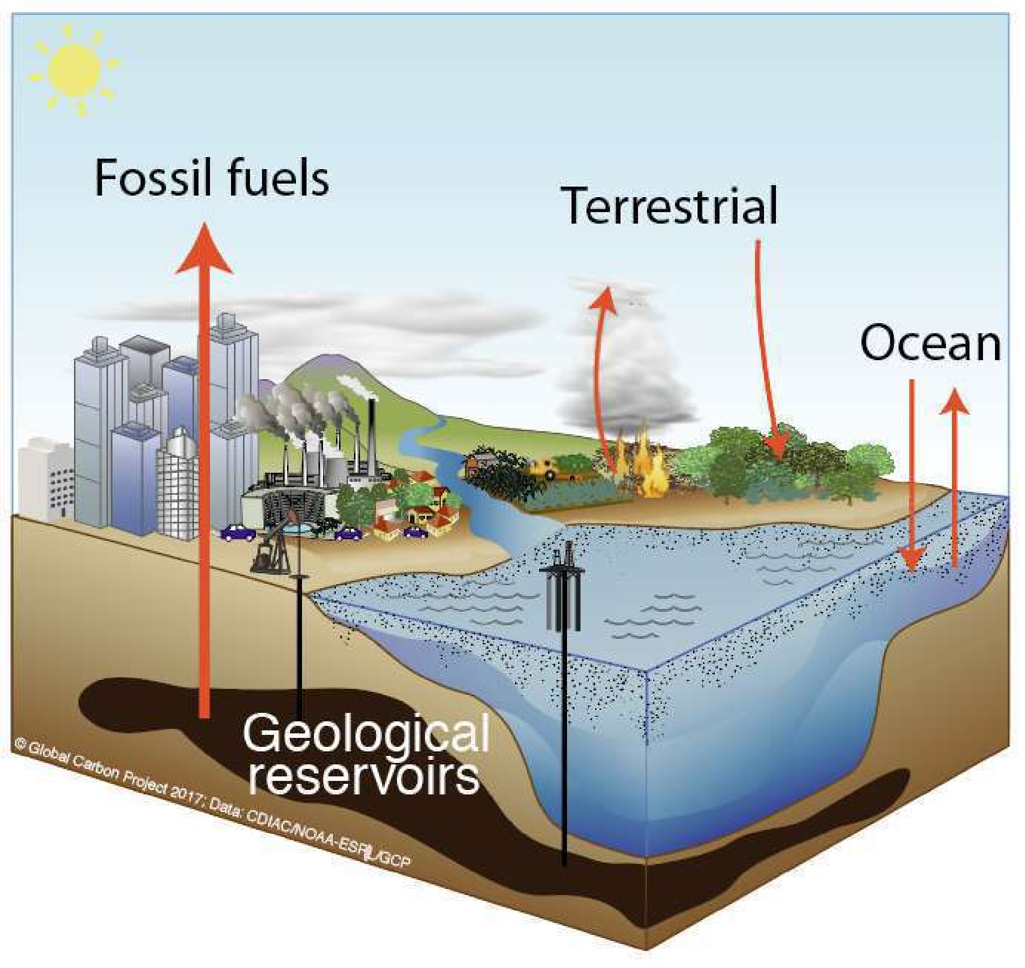
Cumulative fossil emissions don't exceed *cumulative* land-use emissions until about 1985.

CUMULATIVE ANTHROPOGENIC CO_2 EMISSIONS AND ANTHROPOGENIC ATMOSPHERIC STOCK



Nature’s “subsidy” of our carbon dioxide emissions.

THE GLOBAL CO_2 BUDGET



© Global Carbon Project 2017; Data: CDIAC/NOAA-ESRL/GCP

Annual Increment is Income minus Expenditures.

Net Worth = $\int$(Income - Expenditures) *dt.*

SINKS FOR ANTHROPOGENIC CARBON

Jorge L. Sarmiento and Nicolas Gruber

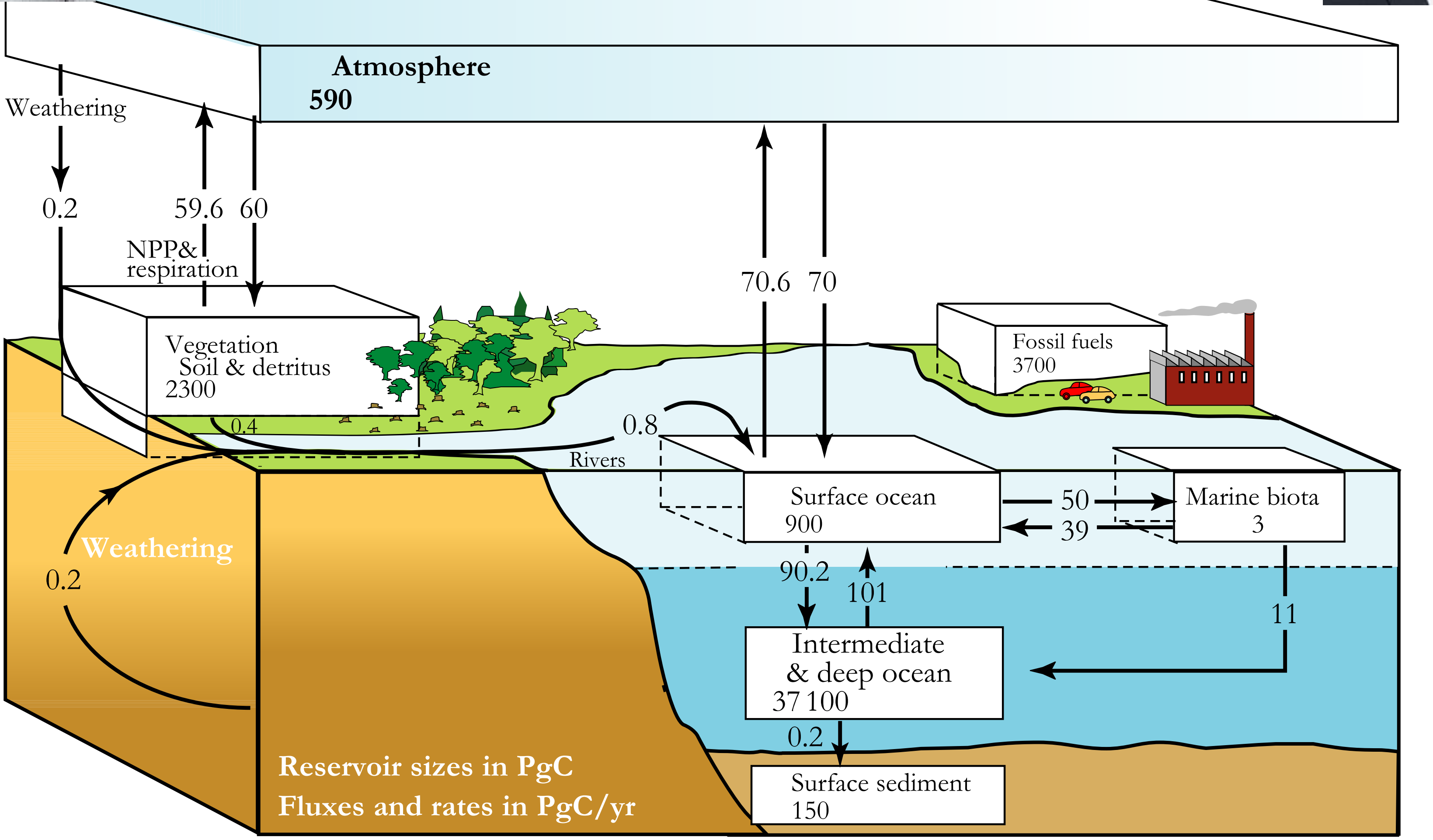
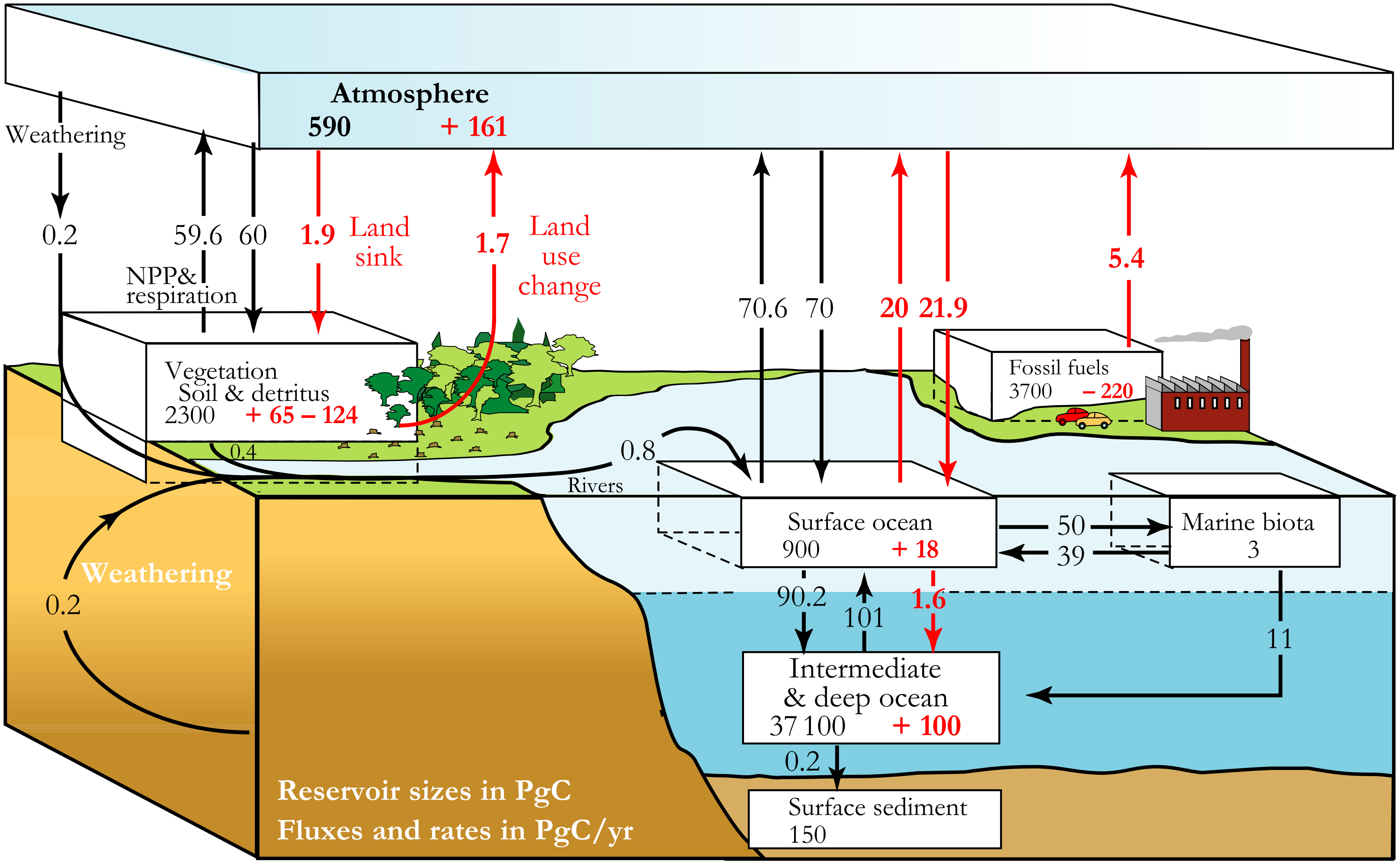


FIGURE 1. GLOBAL CARBON CYCLE. Arrows show the fluxes (in petagrams of carbon per year) between the atmosphere and its two primary sinks, the land and the ocean, averaged over the 1980s. Natural stocks and fluxes in black.

PHYSICS TODAY 2002

SINKS FOR ANTHROPOGENIC CARBON

Jorge L. Sarmiento and Nicolas Gruber



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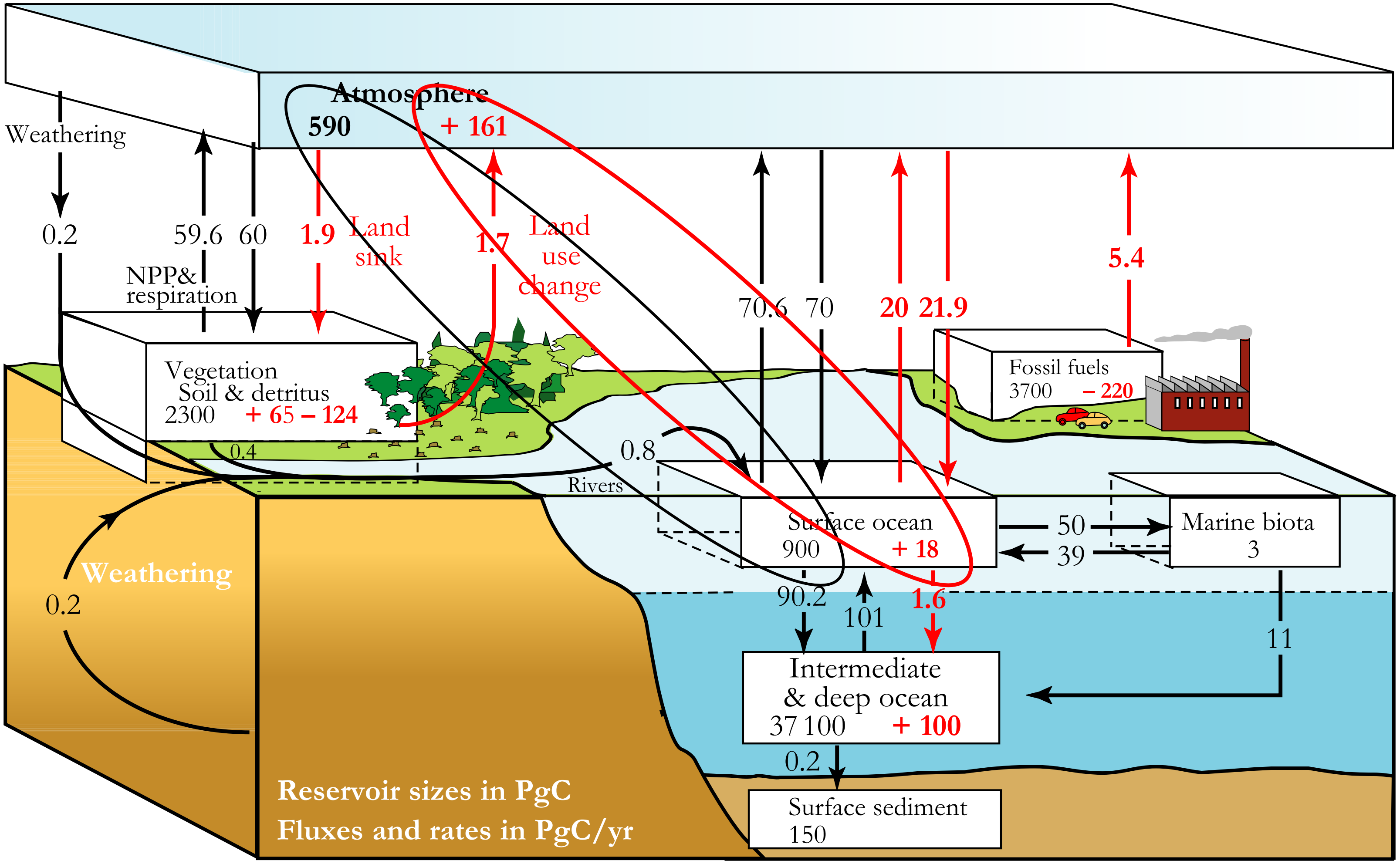

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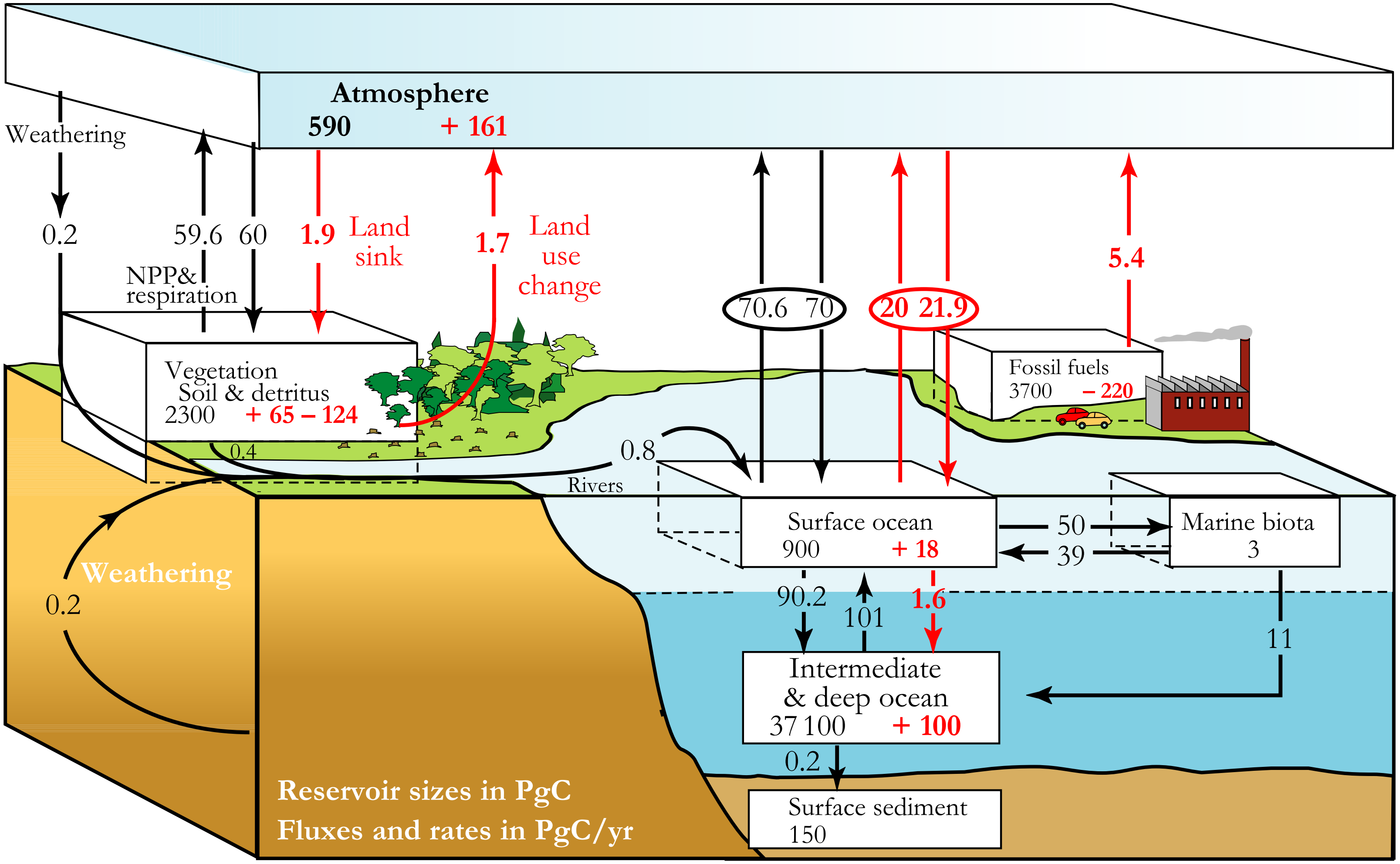
Sinks for Anthropogenic Carbon

Jorge L. Sarmiento and Nicolas Gruber



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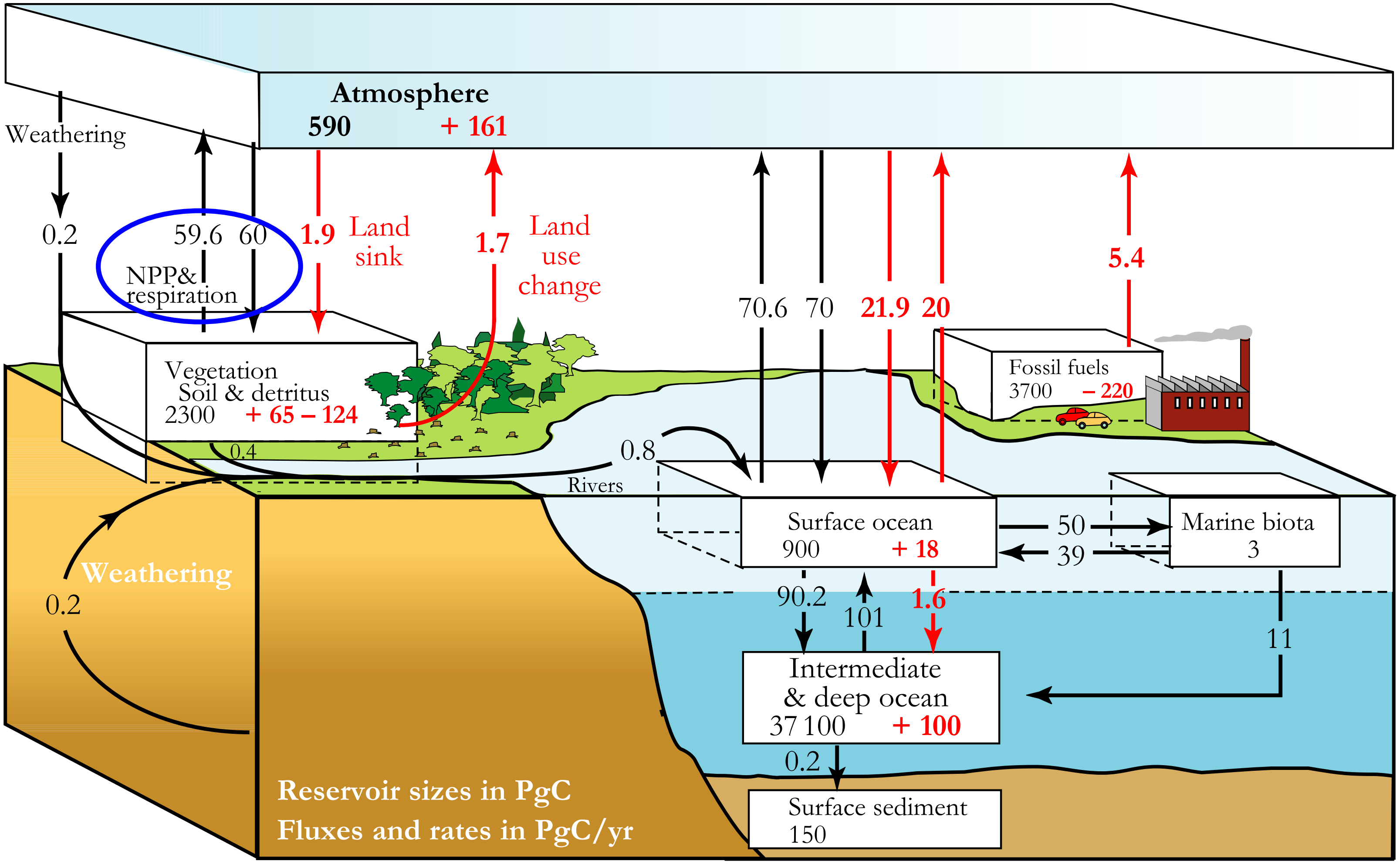

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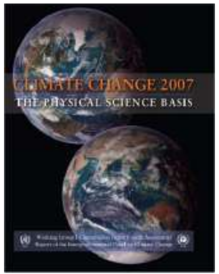
Climate Change 2007: The Physical Science Basis

AR4



Nobel Peace Prize

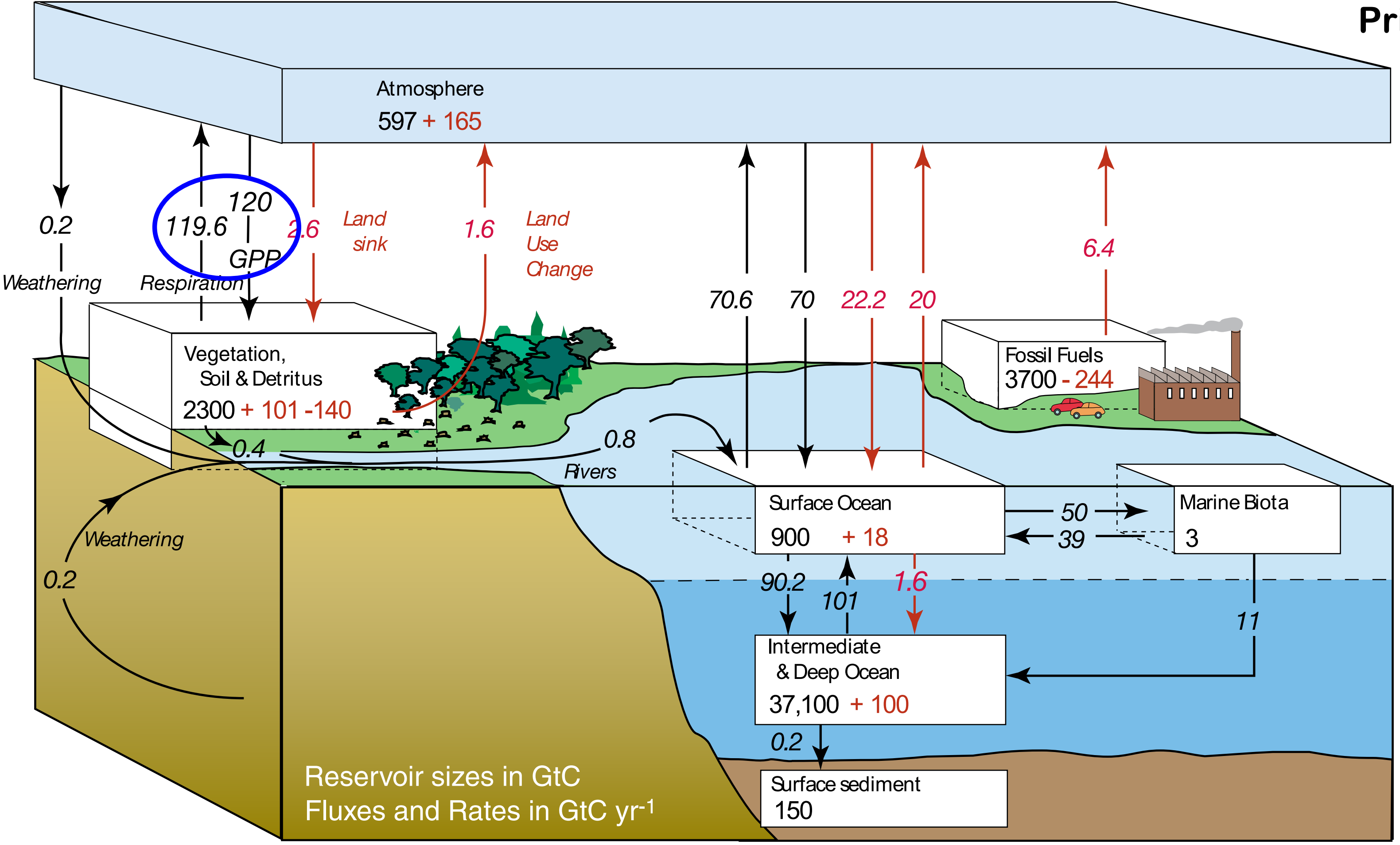


Figure 7.3. The global carbon cycle for the 1990s, showing the main annual fluxes in PgC yr–1: **pre-industrial 'natural' stocks and *fluxes* in black** and **'anthropogenic' stocks and *fluxes* in red**. Gross fluxes generally have uncertainties of more than ±20% but fractional amounts have been retained to achieve overall balance when including estimates in fractions of PgC yr–1. Atmospheric carbon content and all cumulative fluxes since 1750 are as of end 1994.

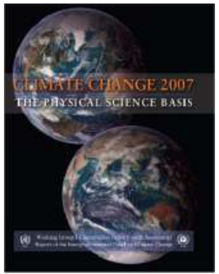
LAHERRÈRE'S LAW

Most of readers believe that a data with many decimals should be right. In the oil industry as accuracy on global data is around 10%, any author giving more than 3 significant digits shows that he is incompetent in assessing accuracy and in probability. ***Usually when more than 3 decimal digits are used, it is likely that the first digit is wrong****.*

Jean Laherrère

Climate Change 2007:
The Physical Science Basis

AR4



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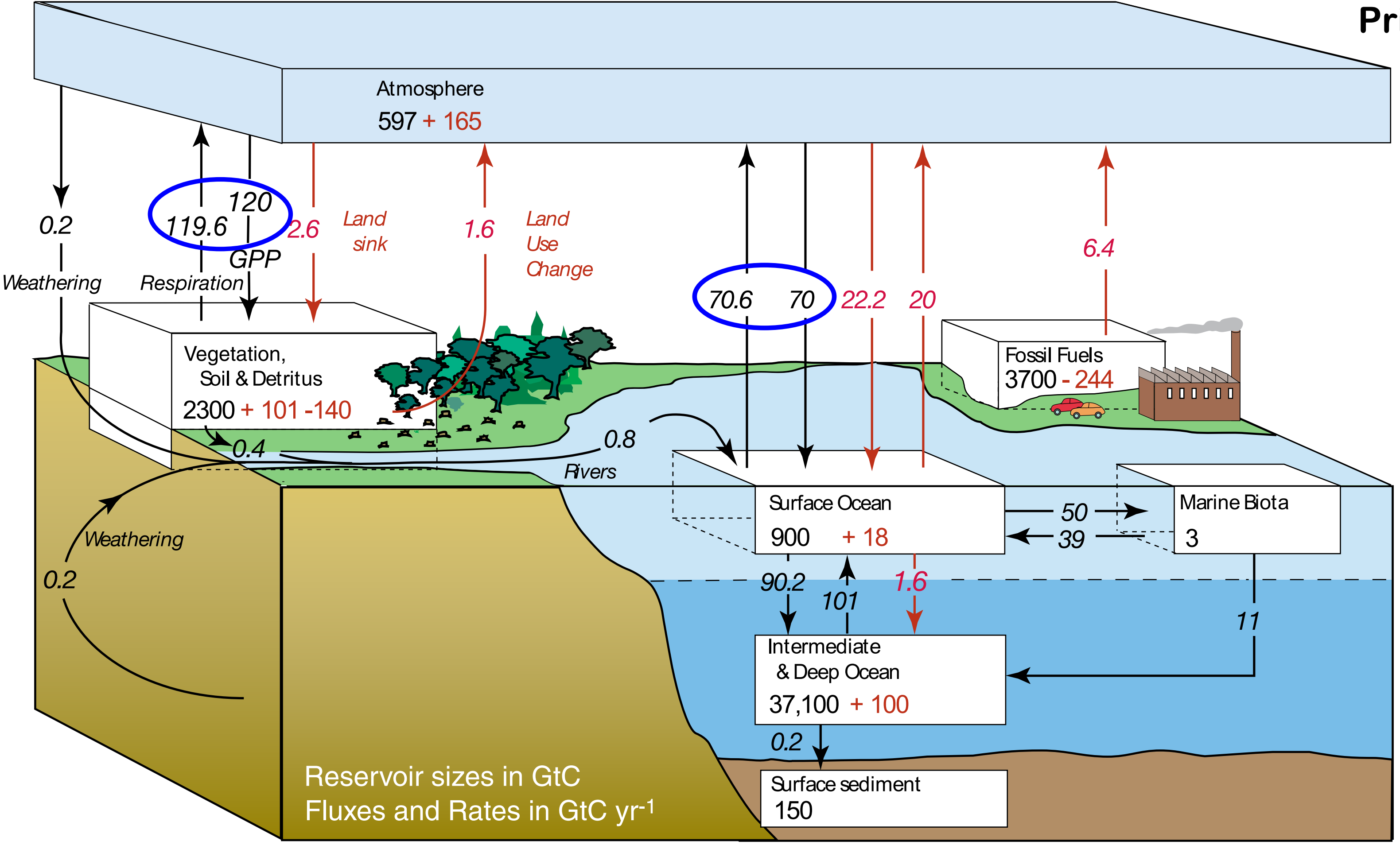

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Climate Change 2013
The Physical Science Basis

AR5

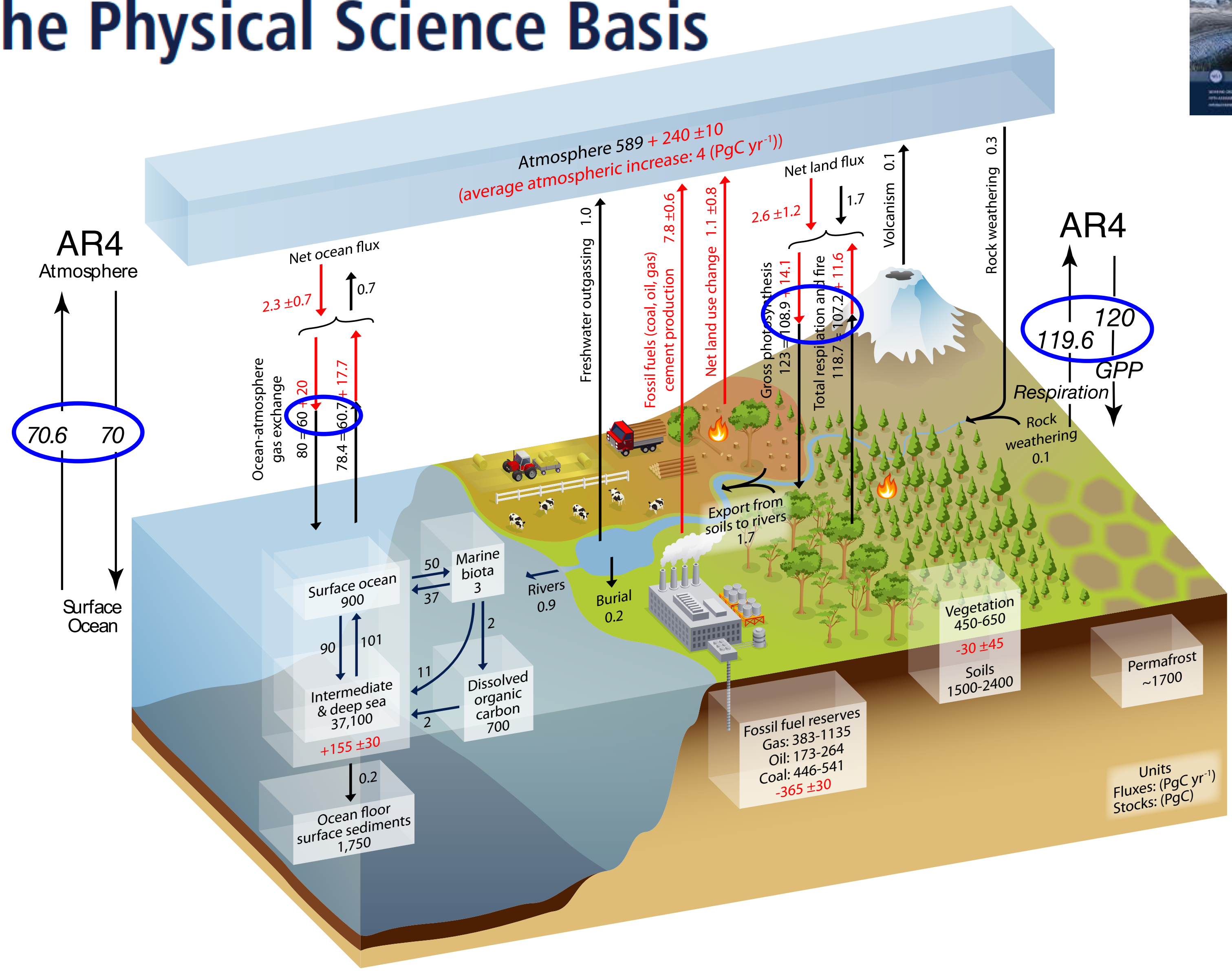


Figure 6.1. Simplified schematic of the global carbon cycle. The uptake of anthropogenic CO2 by the ocean and by terrestrial ecosystems, often called 'carbon sinks' are the red arrows part of Net land flux and Net ocean flux.

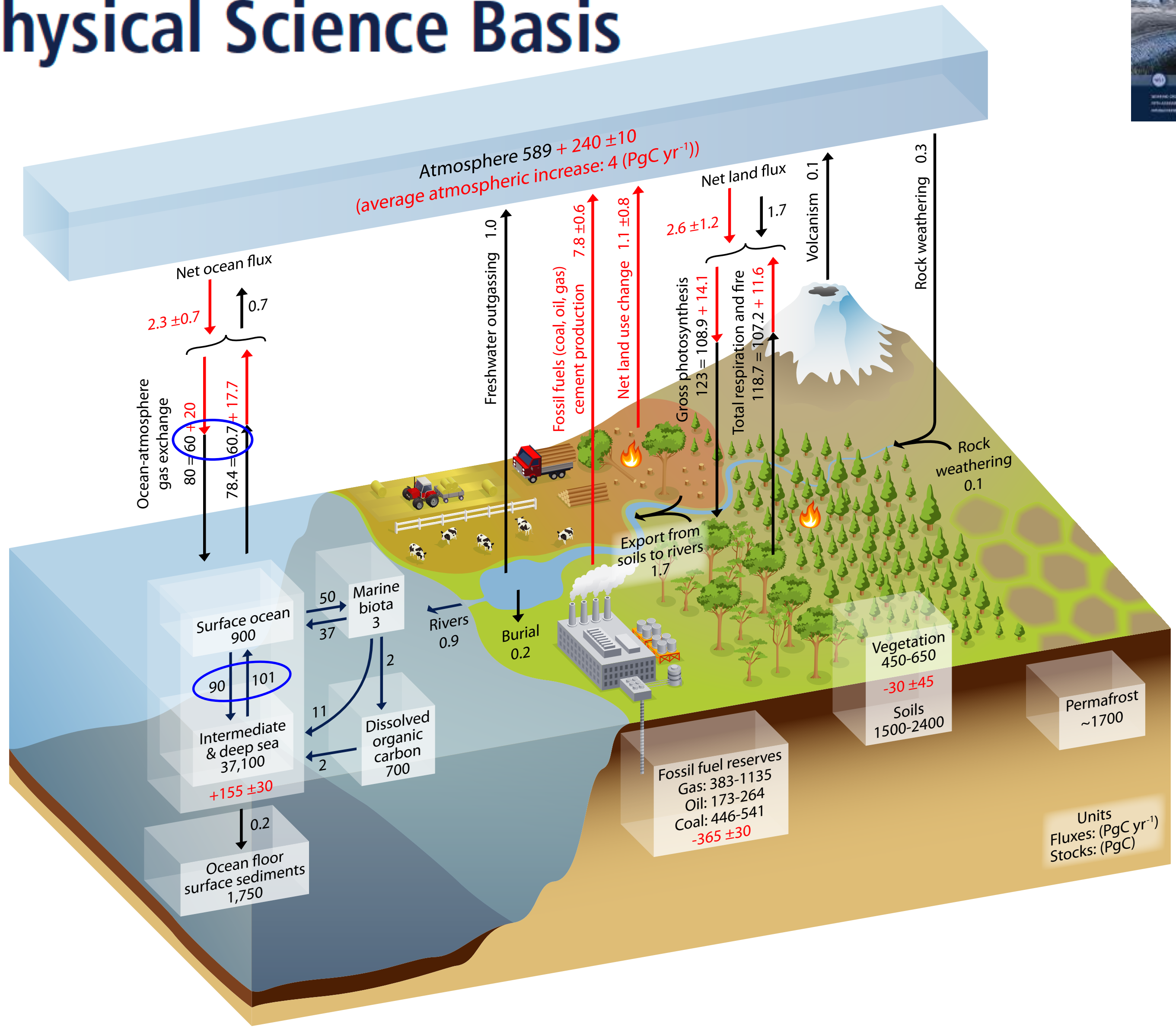
Climate Change 2013
The Physical Science Basis

AR5

ipcc

CLIMATE CHANGE 2013

The Physical Science Basis



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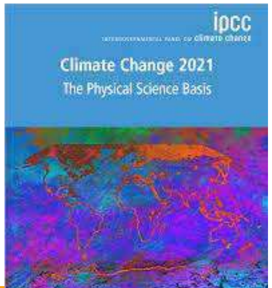
Climate Change 2021
The Physical Science Basis

AR6



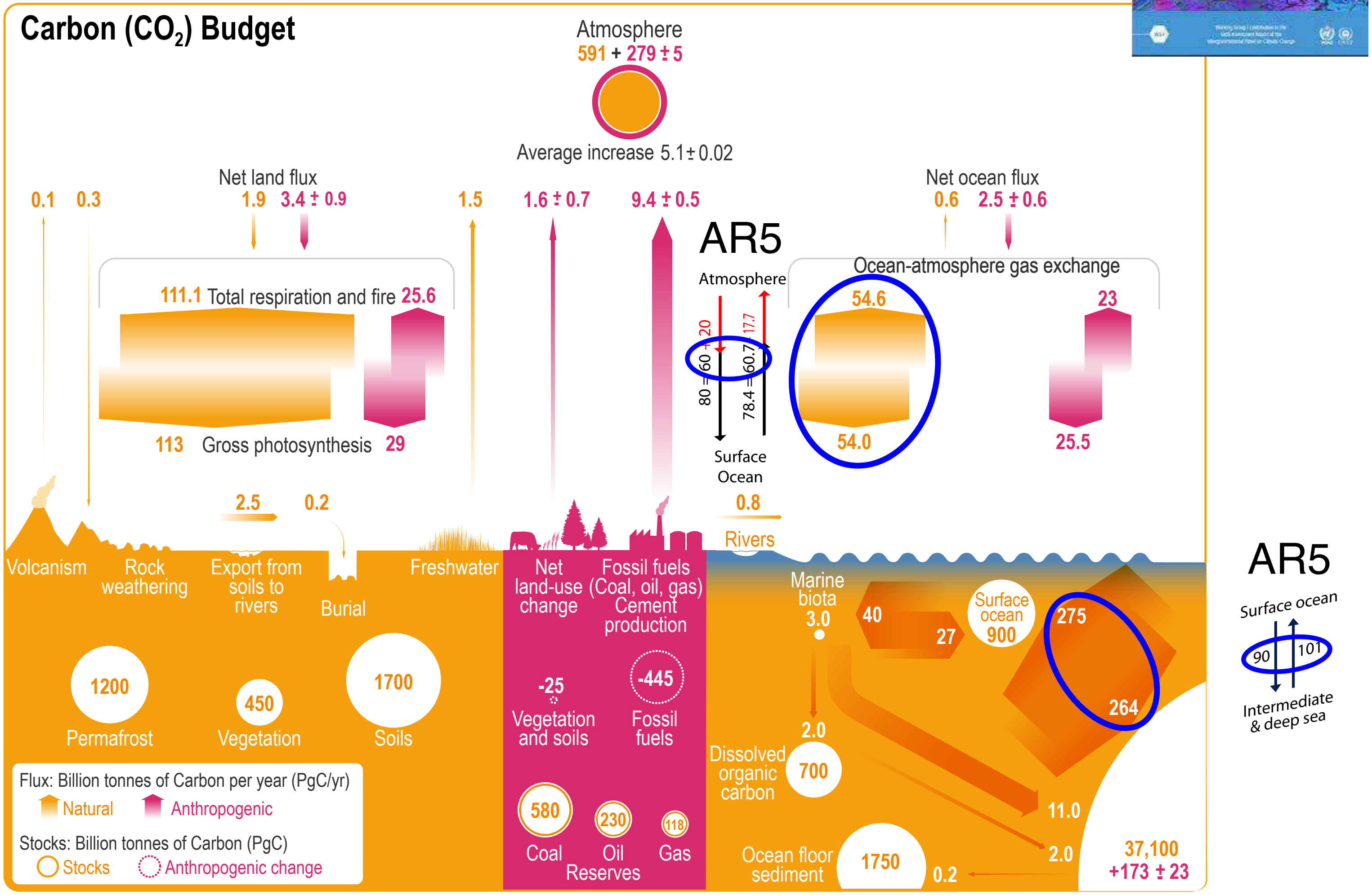


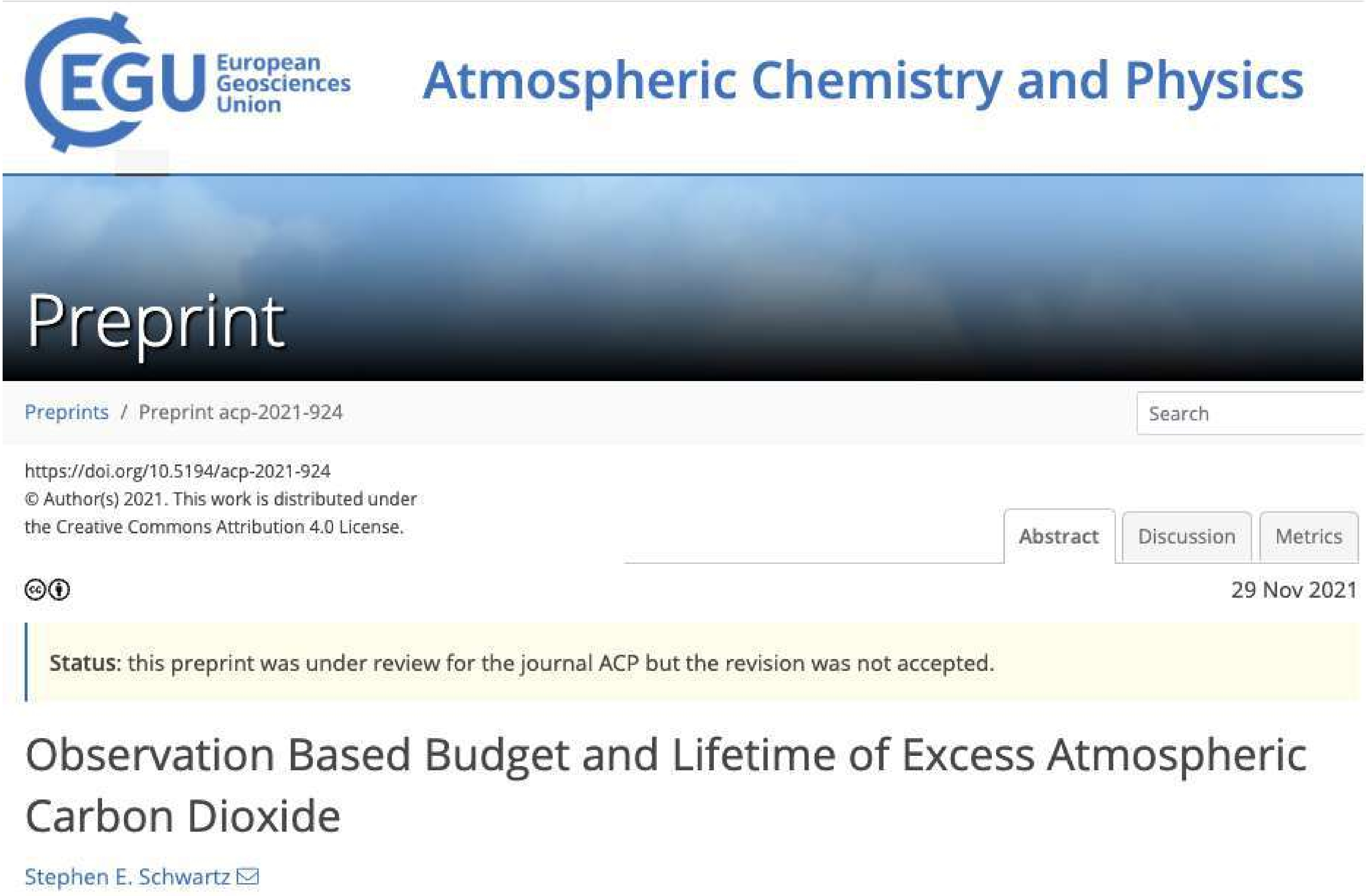
Figure 5.12 | Global carbon (CO$_2$) budget (2010–2019). Yellow arrows represent annual carbon fluxes (in PgC yr^{-1}) associated with the natural carbon cycle. Pink arrows represent anthropogenic fluxes averaged over the period 2010–2019. Circles with yellow numbers represent pre-industrial carbon stocks in PgC. Circles with pink numbers represent anthropogenic changes to these stocks (cumulative anthropogenic fluxes) since 1750.

WARNING

The manuscript reporting this work has been rejected by two highly regarded journals. Listen to the following at your own risk.

The manuscript and reviewer comments are available at

https://acp.copernicus.org/preprints/acp-2021-924/



Atmospheric Chemistry and Physics

Preprint

https://doi.org/10.5194/acp-2021-924

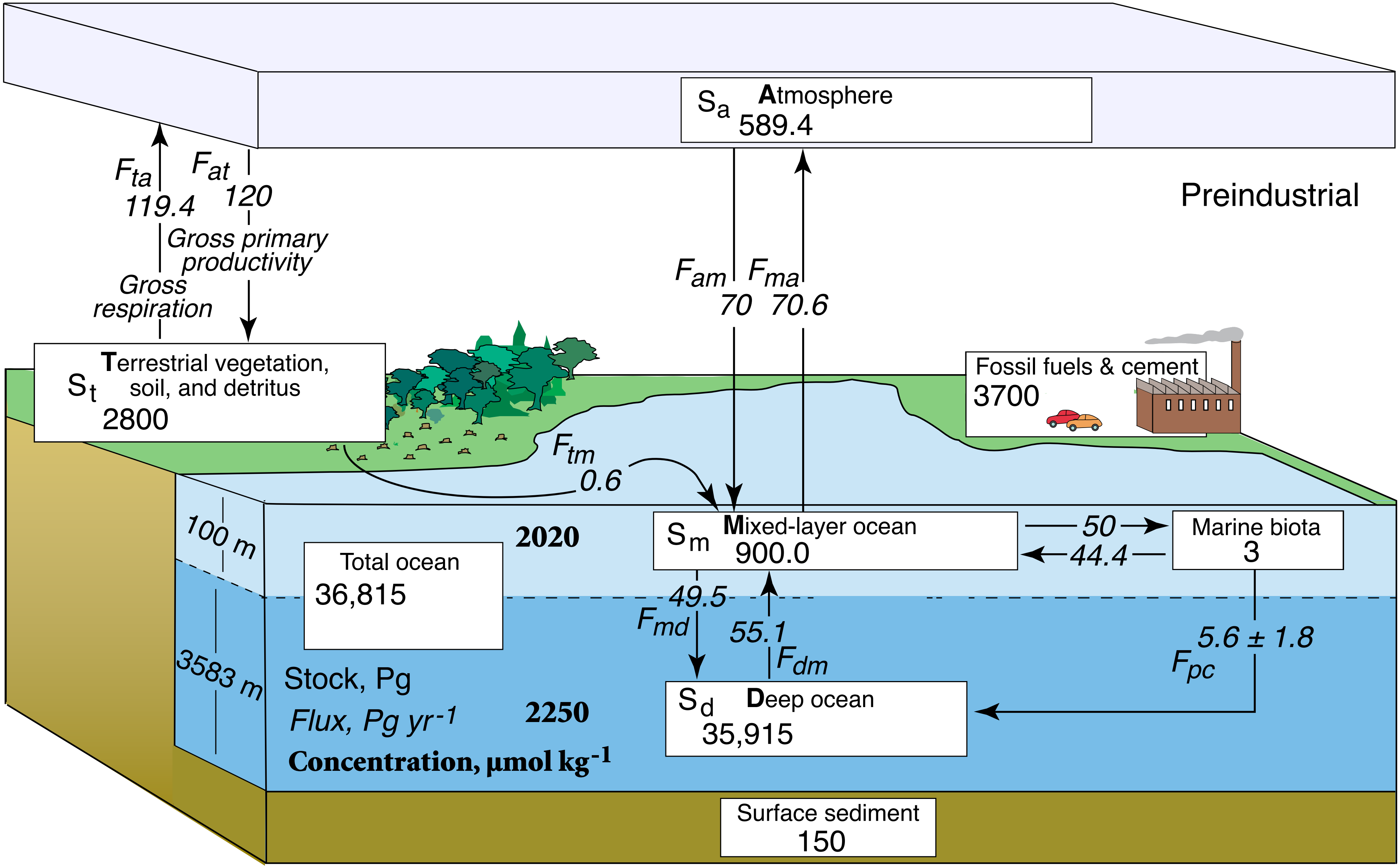
29 Nov 2021

Status: this preprint was under review for the journal ACP but the revision was not accepted.

Observation Based Budget and Lifetime of Excess Atmospheric Carbon Dioxide

Stephen E. Schwartz

CO_2 STOCKS, *FLUXES*



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modified (considerably) from AR4 (2007), Fig. 7.3
after Sarmiento & Gruber, Phys. Today (2002)

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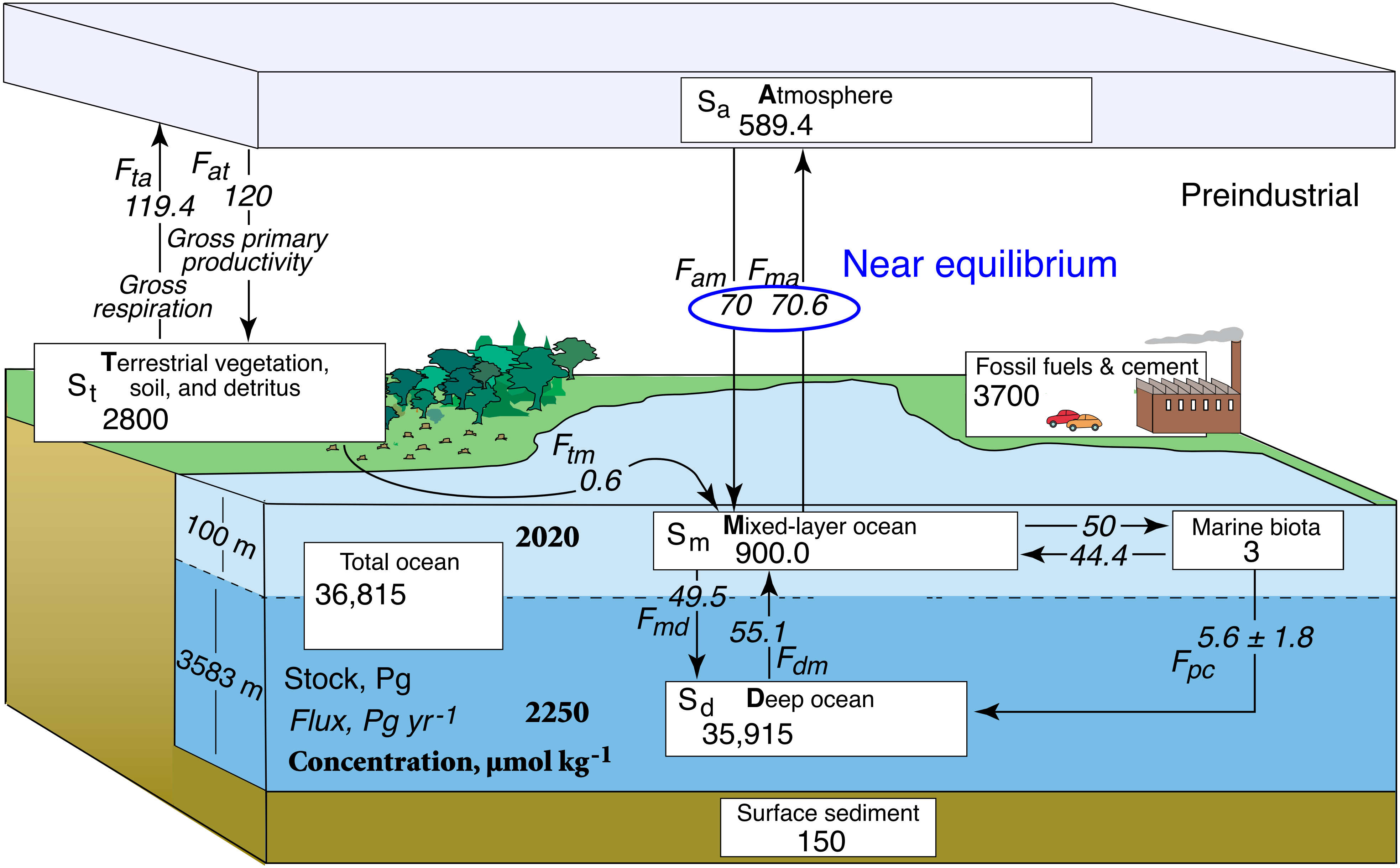

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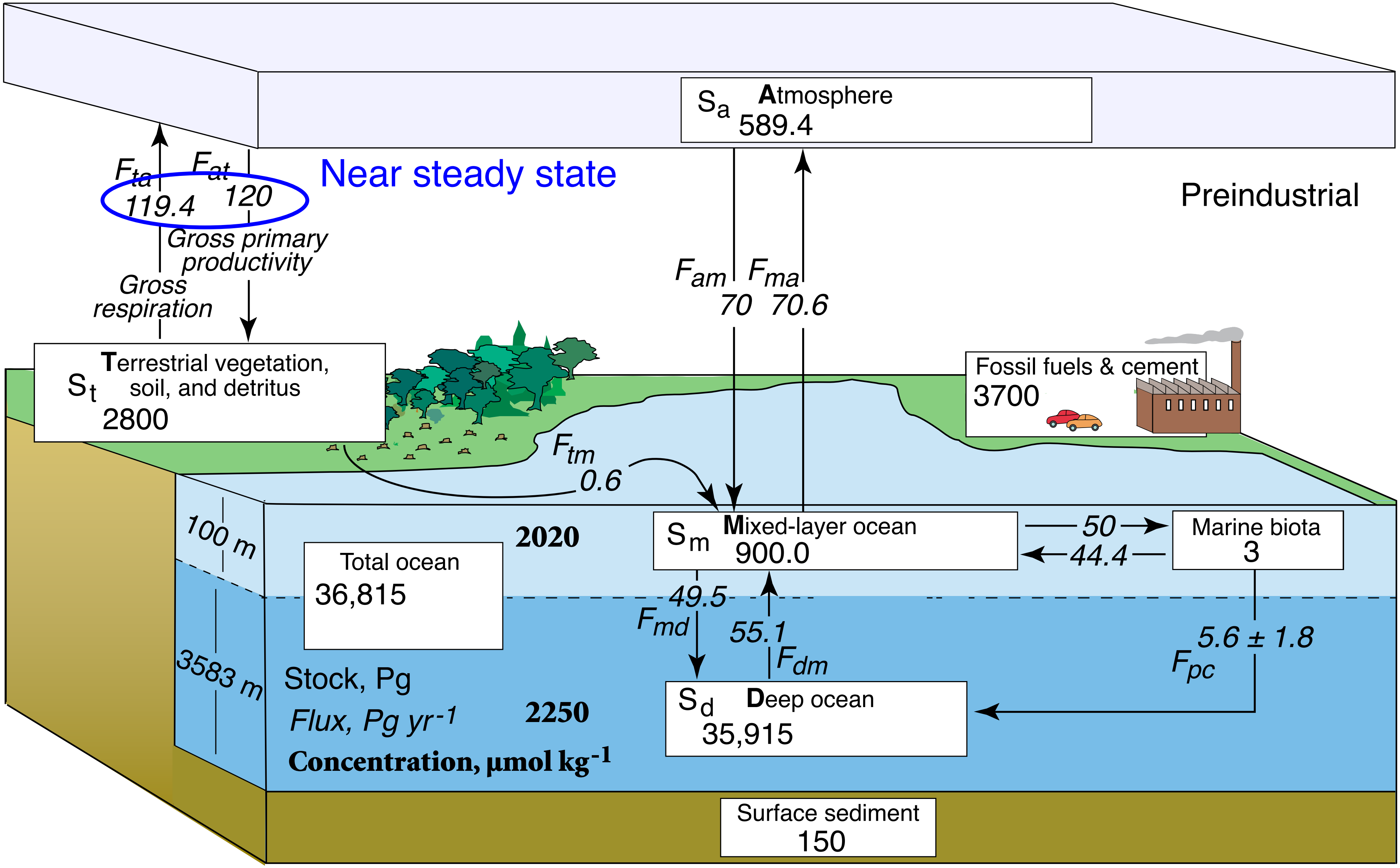

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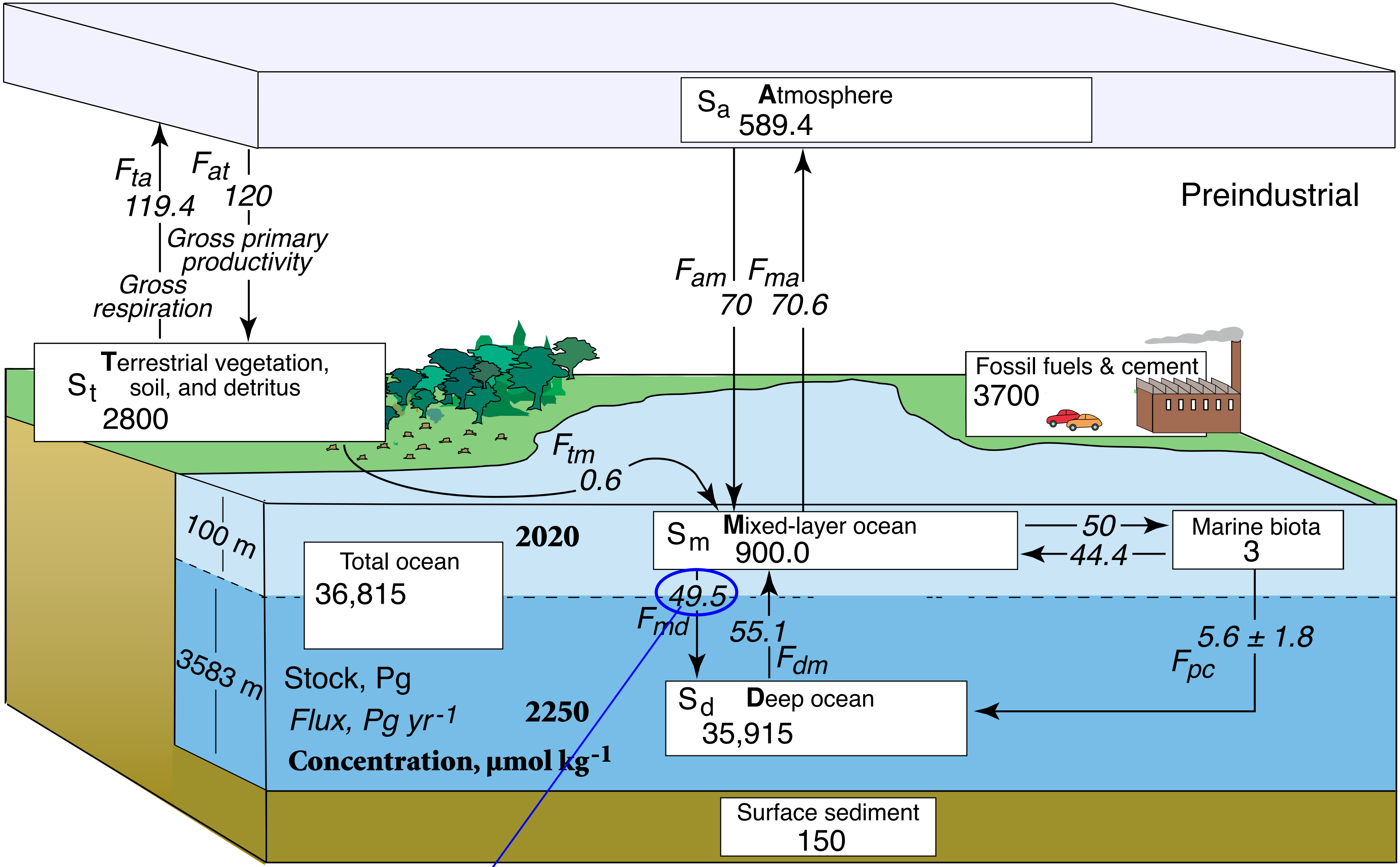

From global heat budget

k_{md} = 49.5/900 = 0.055 yr^{-1}
± 33%

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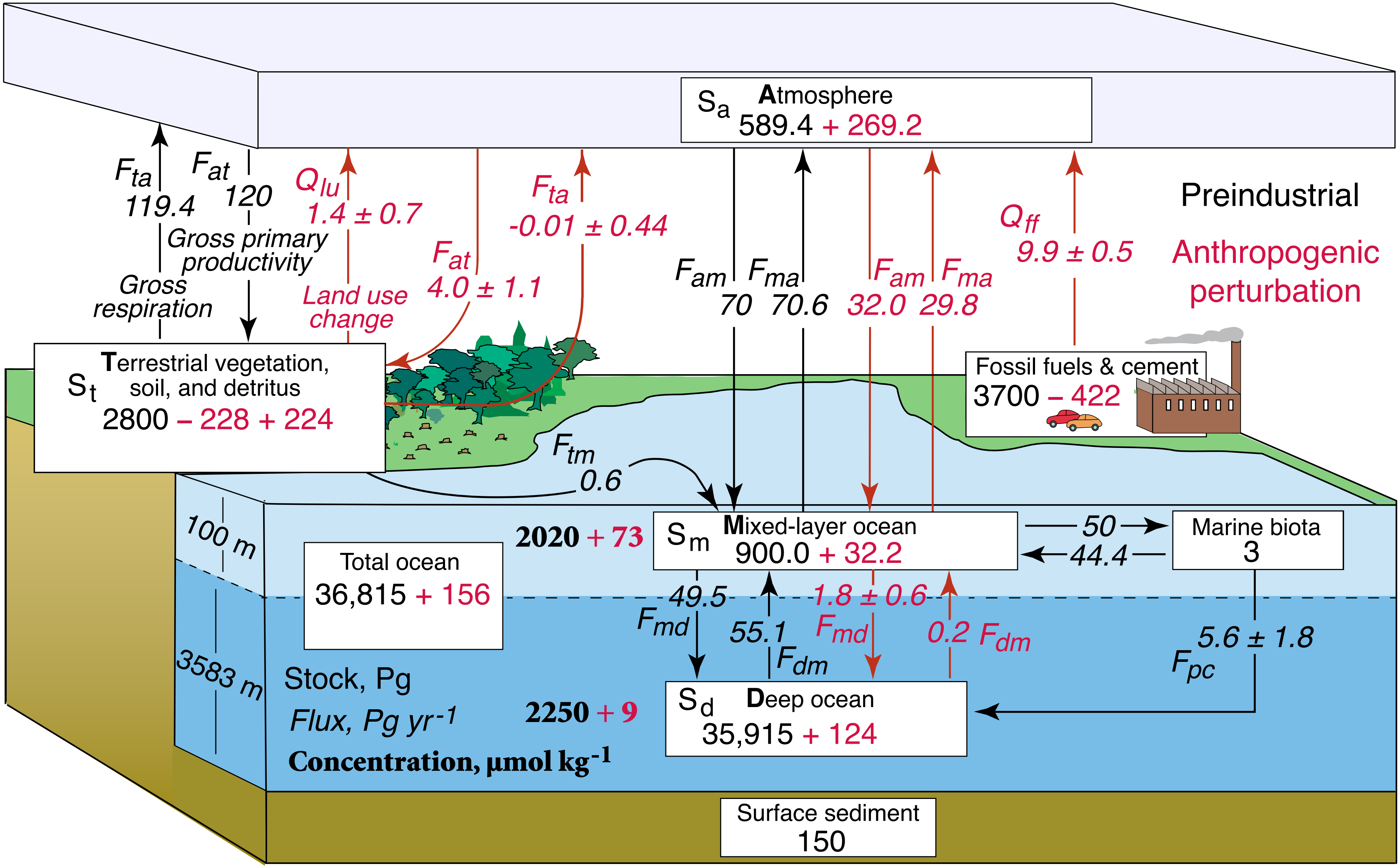

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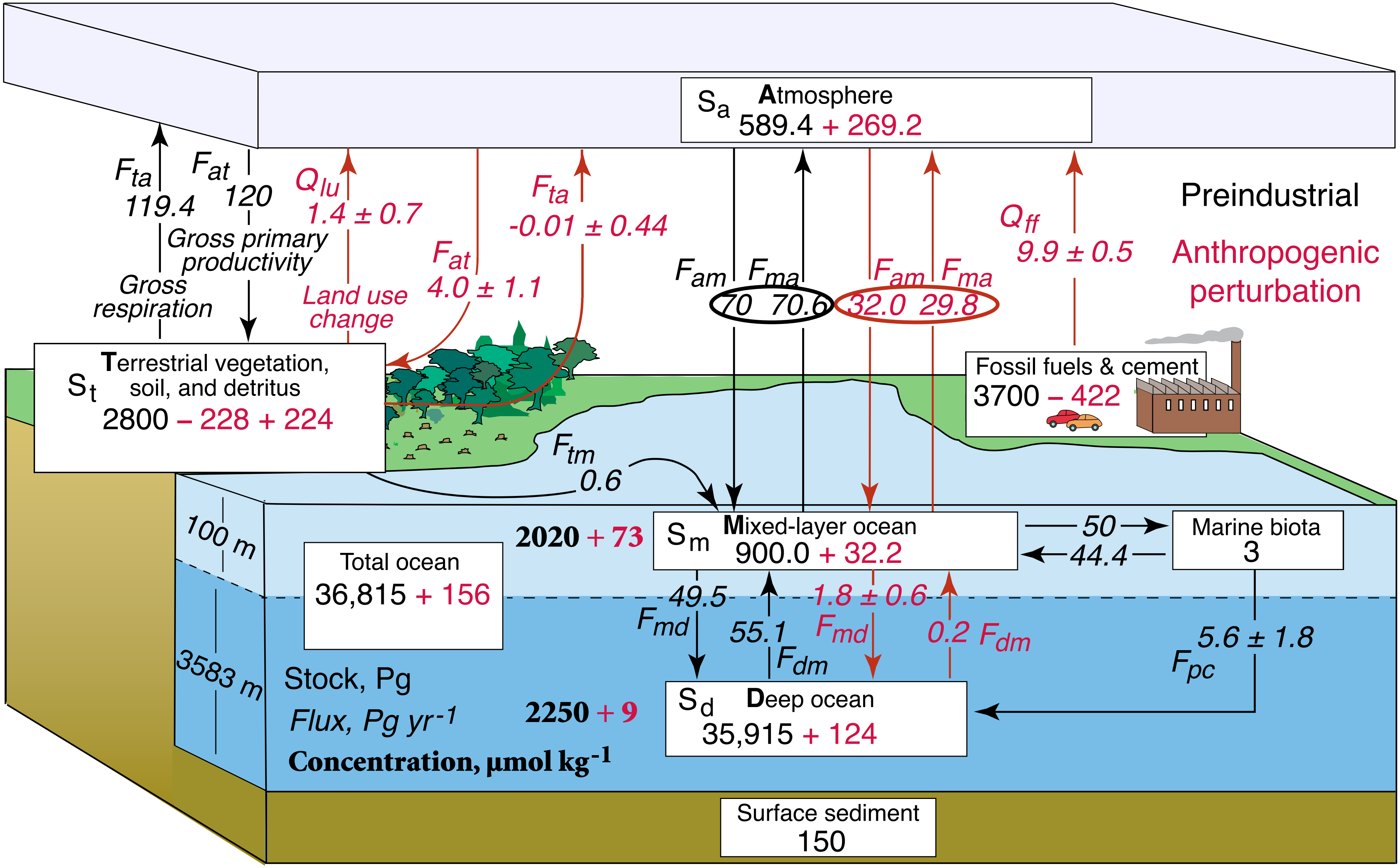

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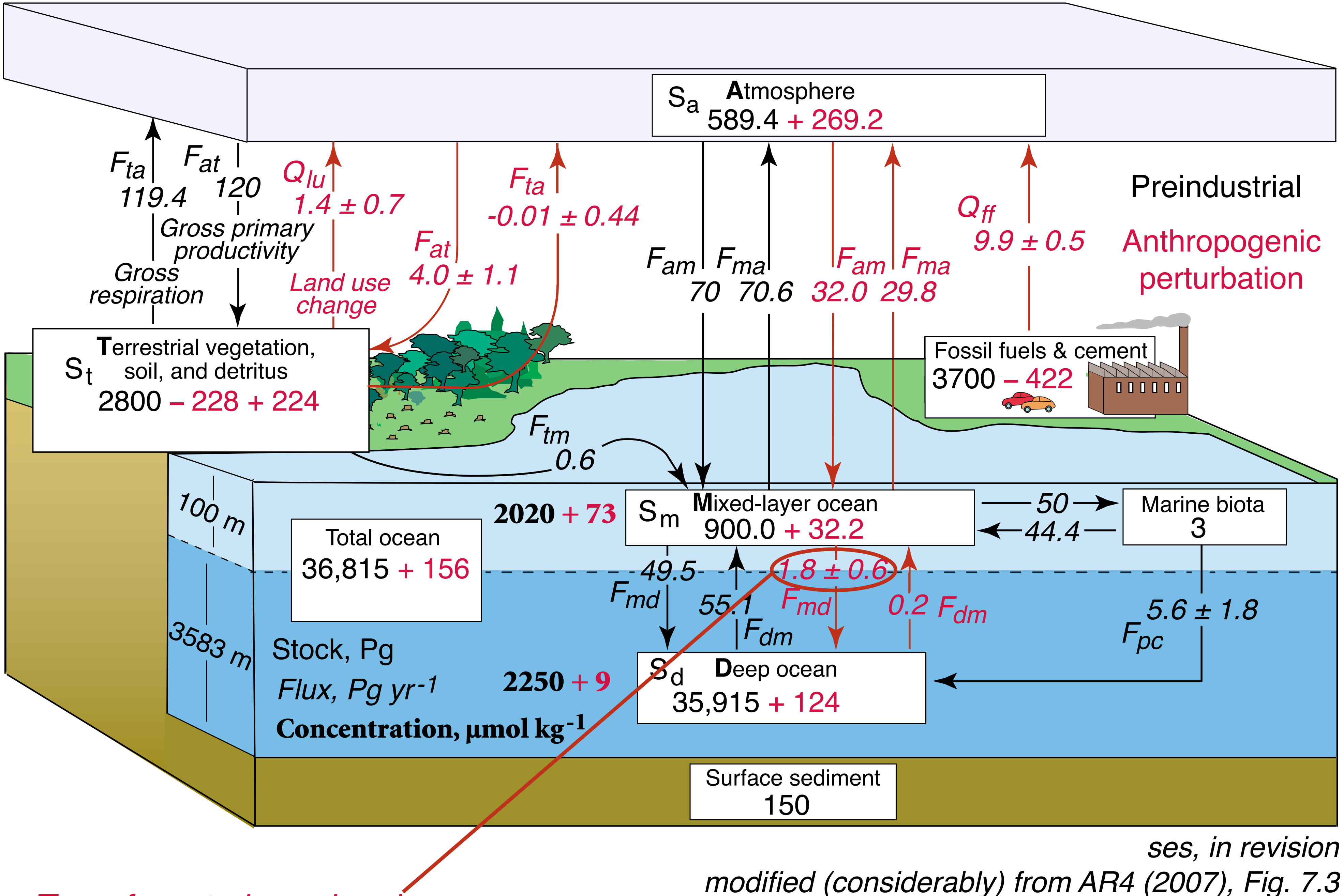

Preindustrial

Anthropogenic perturbation

Stock, Pg

Flux, Pg yr^{-1}

Concentration, μmol kg^{-1}

Transfer rate based on k_{md}

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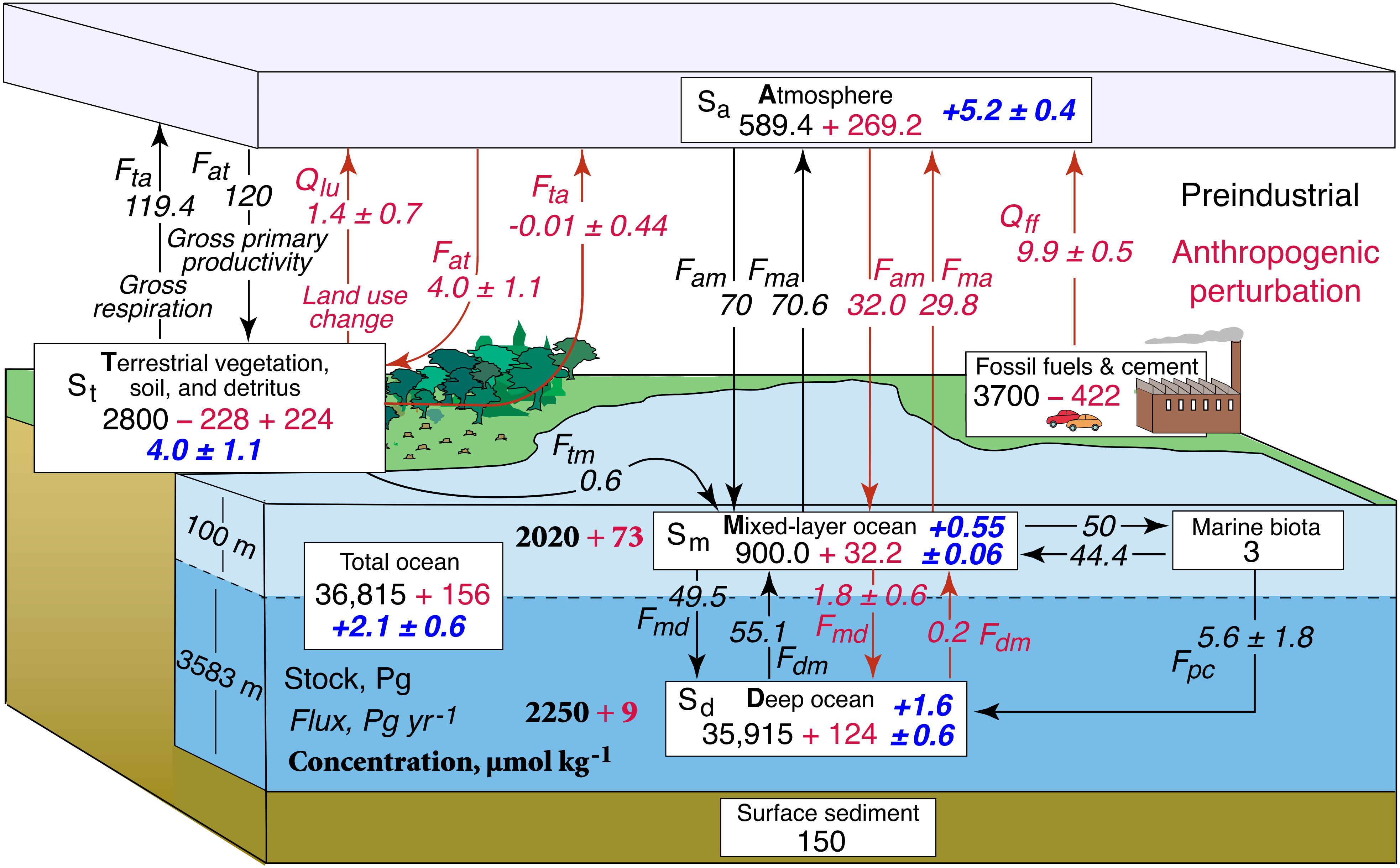
after Sarmiento & Gruber, Phys. Today (2002)

CO_2 STOCKS, *FLUXES*, AND ***ANNUAL GROWTH***



S_a **A**tmosphere
589.4 + 269.2
+5.2 ± 0.4

F_{ta} *119.4*
F_{at} *120*
Gross primary productivity
Gross respiration

Q_{lu} *1.4 ± 0.7*
Land use change

F_{at} *4.0 ± 1.1*

F_{ta} *-0.01 ± 0.44*

F_{am} *70*
F_{ma} *70.6*
F_{am} *32.0*
F_{ma} *29.8*

Q_{ff} *9.9 ± 0.5*

Preindustrial

Anthropogenic perturbation

S_t **T**errestrial vegetation, soil, and detritus
2800 – 228 + 224
4.0 ± 1.1

Fossil fuels & cement
3700 – 422

F_{tm} *0.6*

100 m

3583 m

Total ocean
36,815 + 156
+2.1 ± 0.6

2020 + 73

S_m **M**ixed-layer ocean
900.0 + 32.2
+0.55 ± 0.06

50
44.4

Marine biota
3

49.5 F_{md}
55.1 F_{dm}
1.8 ± 0.6 F_{md}
0.2 F_{dm}

5.6 ± 1.8 F_{pc}

Stock, Pg

Flux, Pg yr^{-1}

Concentration, μmol kg^{-1}

2250 + 9

S_d **D**eep ocean
35,915 + 124
+1.6 ± 0.6

Surface sediment
150

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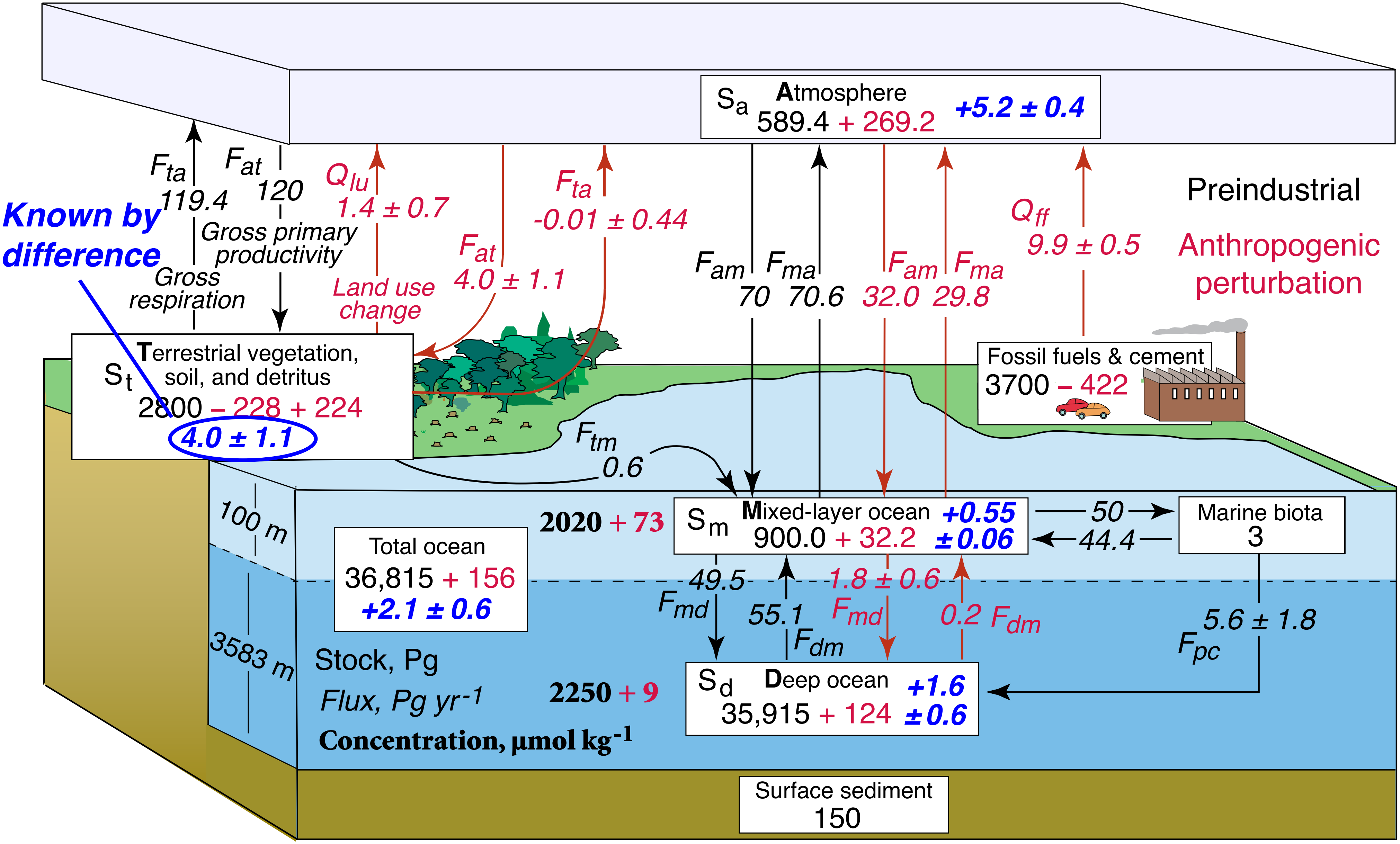
CO_2 STOCKS, *FLUXES*, AND ***ANNUAL GROWTH***



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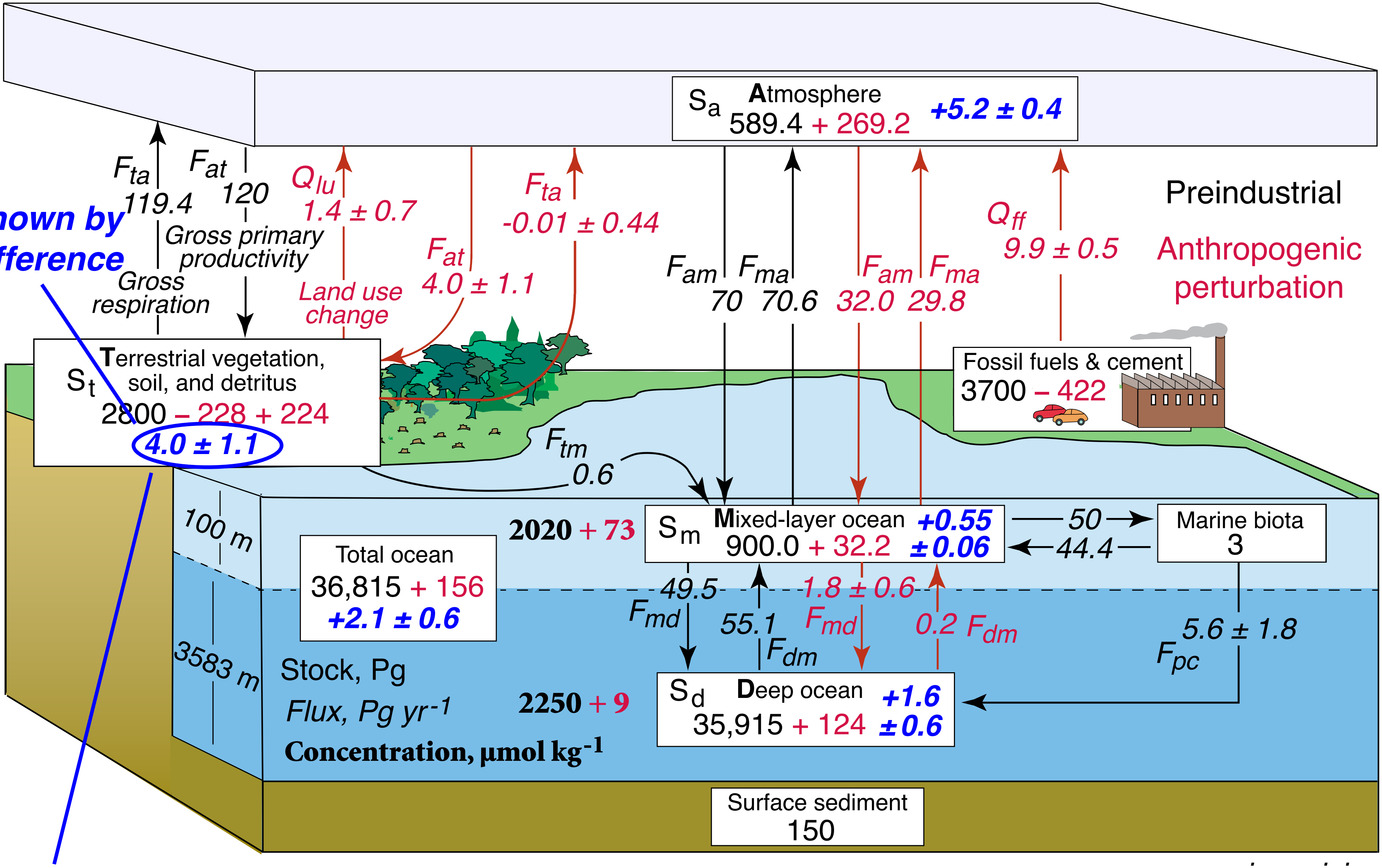


Known by difference

Need two compartments for terrestrial biosphere.
Short-lived (Labile) and long-lived (Obdurate).
Apportionment of uptake is not tightly constrained.
Requires two adjustable parameters.

ses, in revision
modified (considerably) from AR4 (2007), Fig. 7.3
after Sarmiento & Gruber, Phys. Today (2002)

OCCAM'S RAZOR

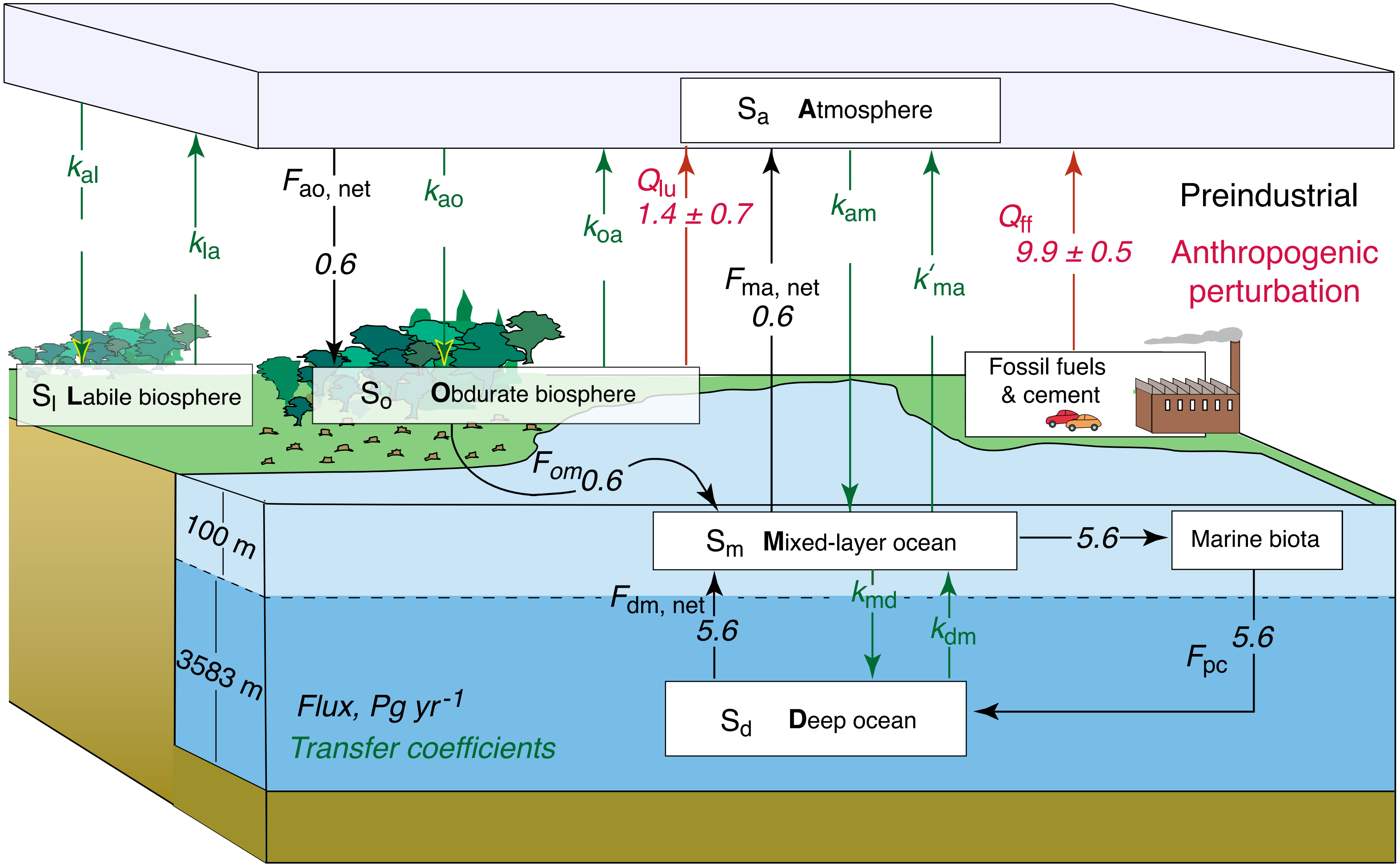
"Entia non sunt multiplicanda...

...praeter necessitatem."

MINIMALIST MODEL FOR CO_2

MINIMALIST MODEL

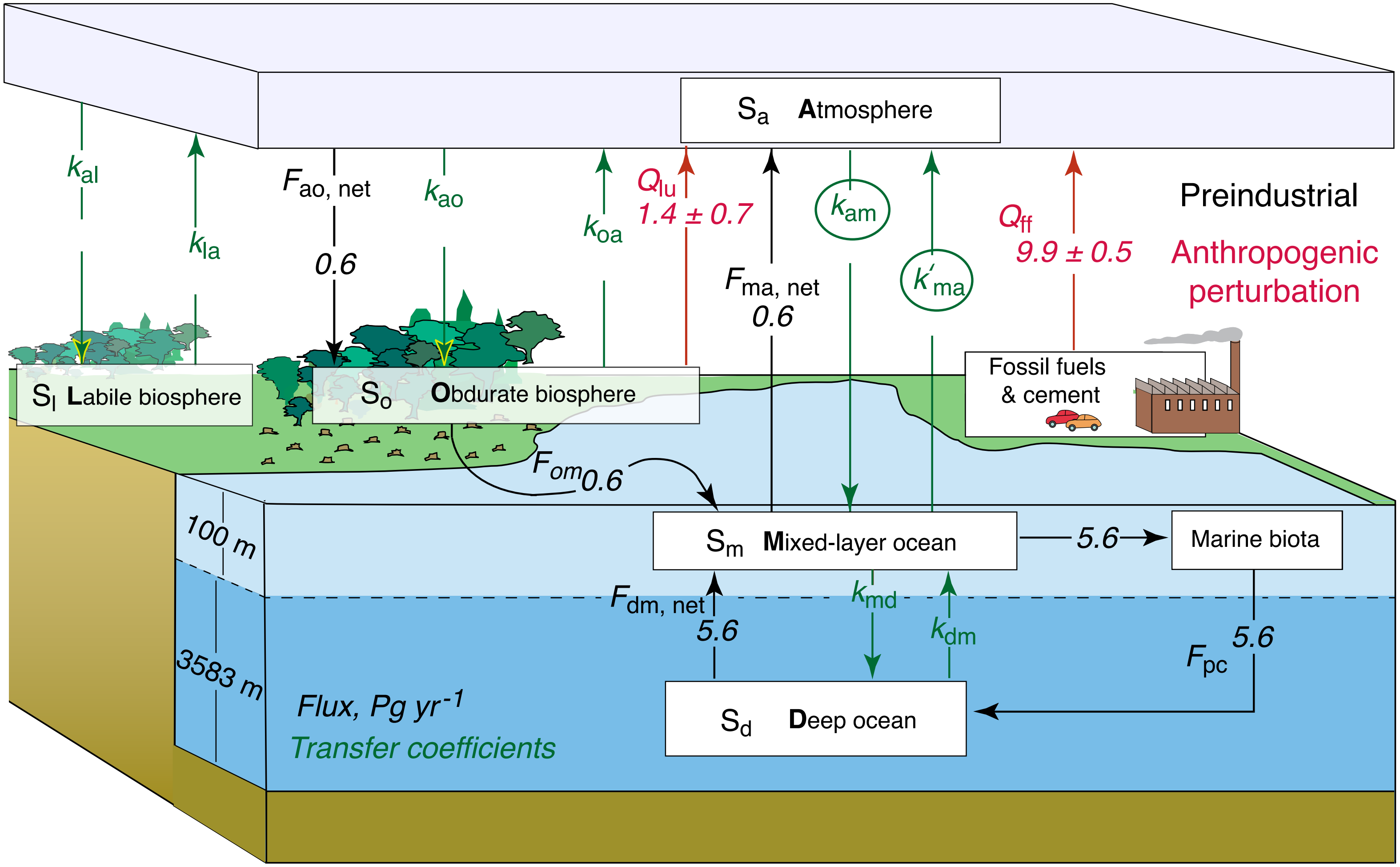
Five-compartment model with ***eight transfer coefficients***



Use observations and theory to constrain transfer coefficients

TRANSFER COEFFICIENTS FOR MODEL

Five-compartment model with ***eight transfer coefficients***

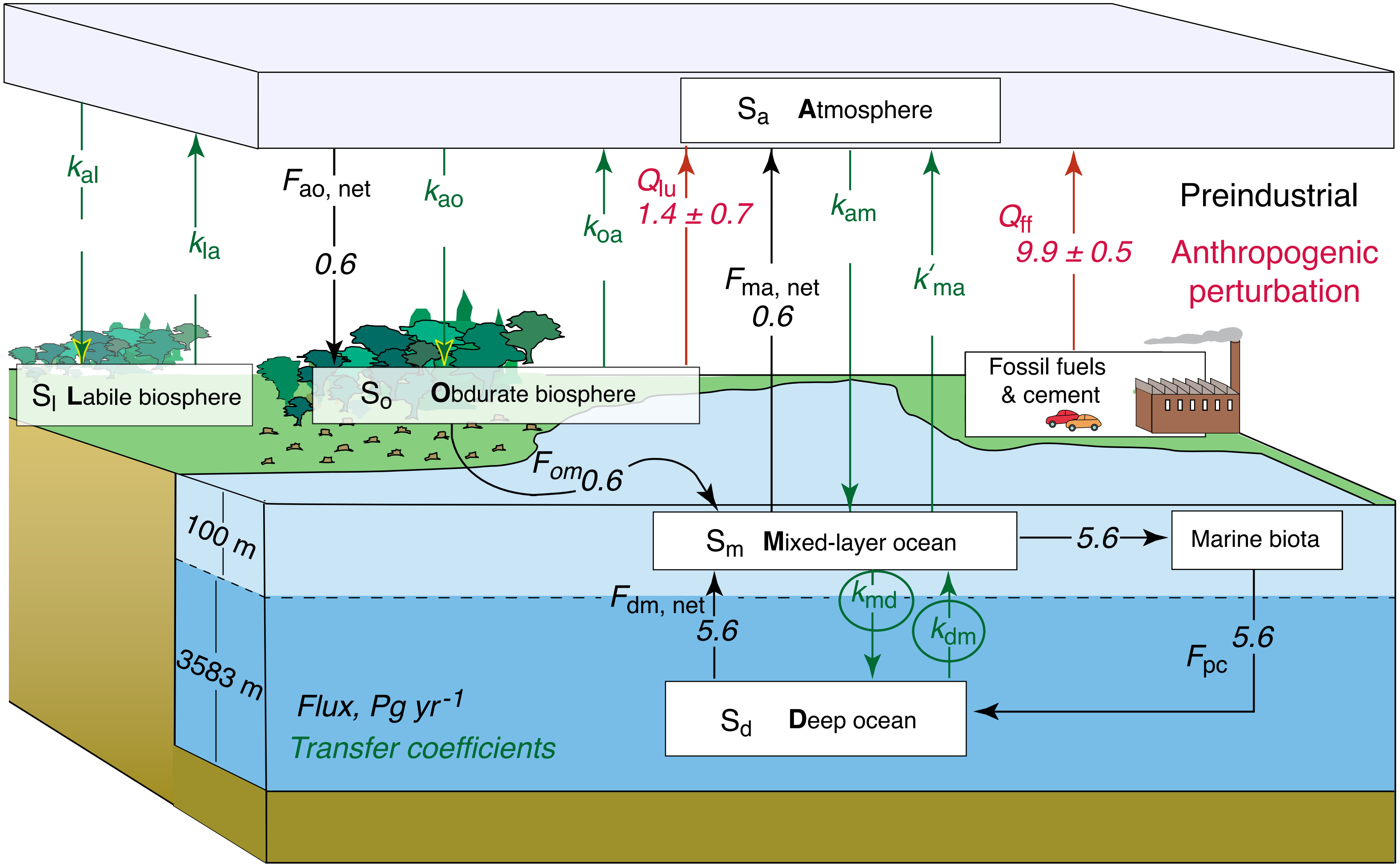


k_{am}: Universal deposition velocity applicable (with slight changes) to all weakly to moderately soluble gases

k'_{ma}: Related to k_{am} as $k'_{ma} = k_{am}/K_{am}$ (chemical equilibrium)

TRANSFER COEFFICIENTS FOR MODEL

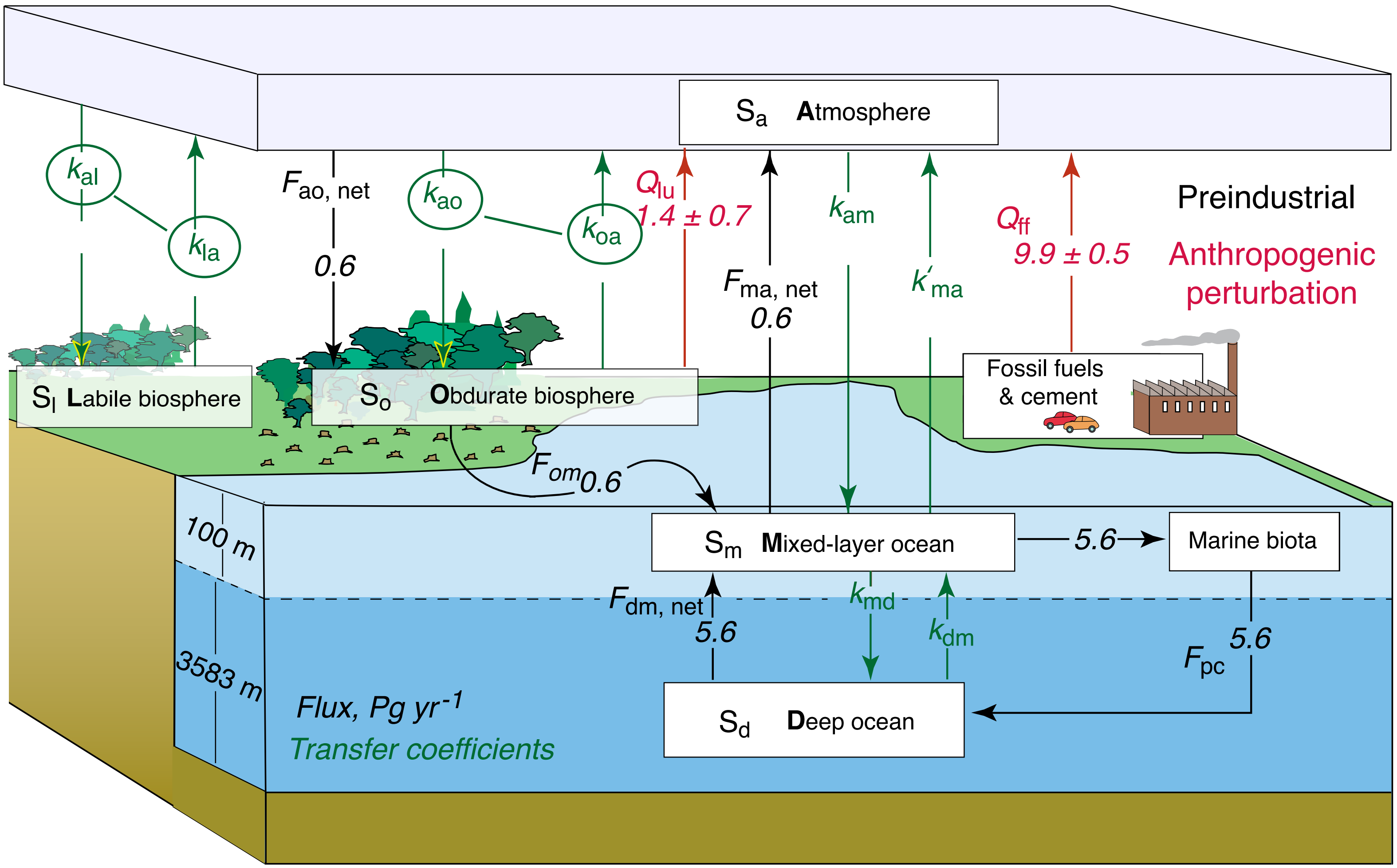
Five-compartment model with ***eight transfer coefficients***



k_{md}, k_{dm} related to piston velocity for heat transfer v_p as $v_p = k_{md} z_m = k_{dm} z_d$

TRANSFER COEFFICIENTS FOR MODEL

Five-compartment model with ***eight transfer coefficients***



k_{al}, k_{la} and k_{ao}, k_{oa} related by requirement of preindustrial steady state.

TWO ADJUSTABLE PARAMETERS

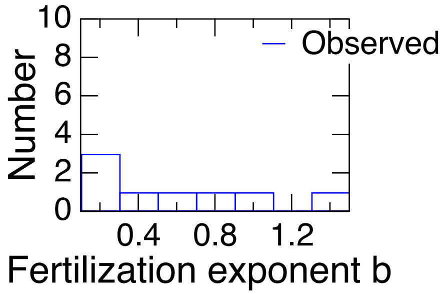
CO_2 fertilization exponent *b*

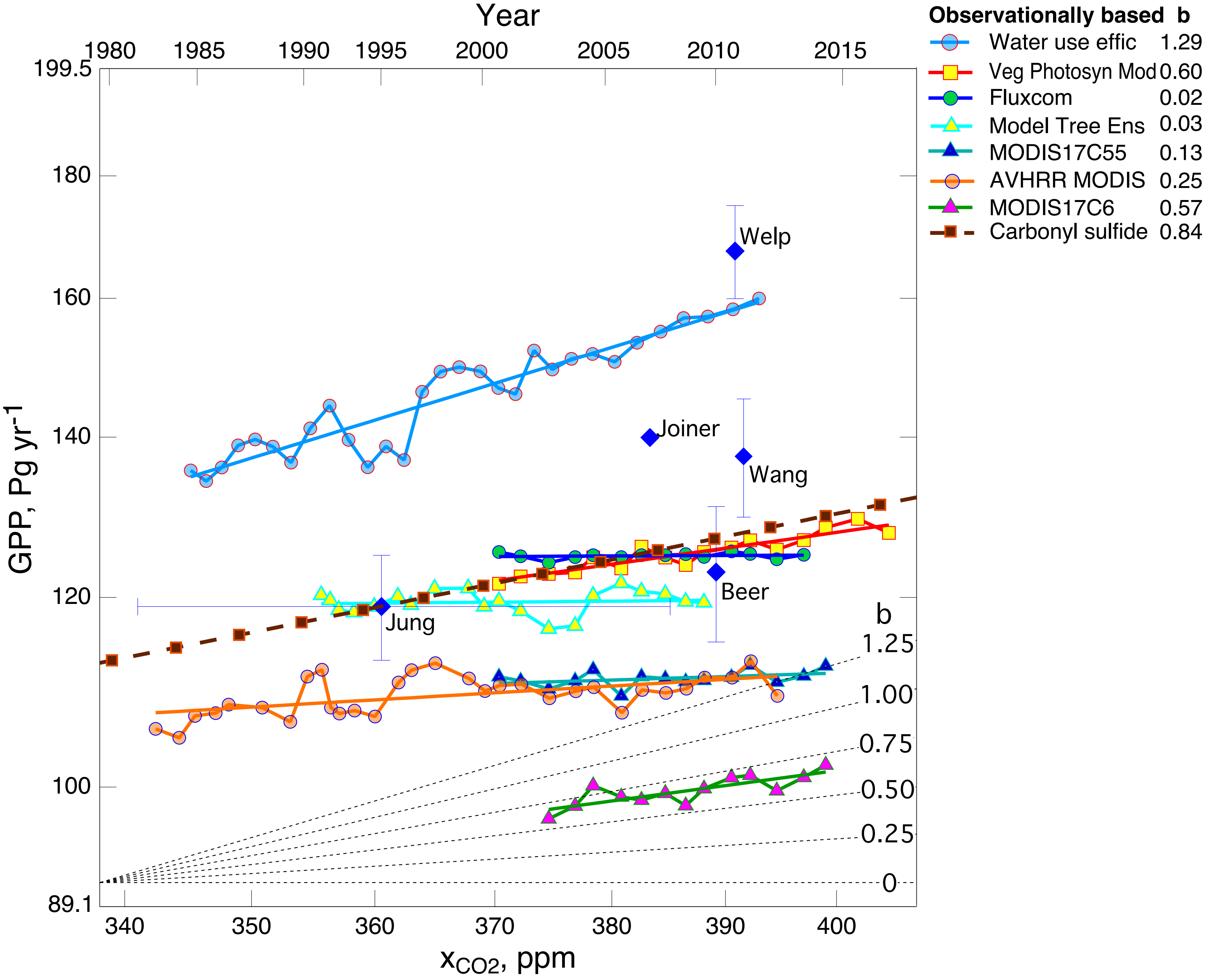
Preindustrial stock in labile biosphere S_l^{pi}

These parameters control the apportionment of CO_2 taken up by the labile biosphere vs. the obdurate biosphere.

CO_2 FERTILIZATION EFFECT

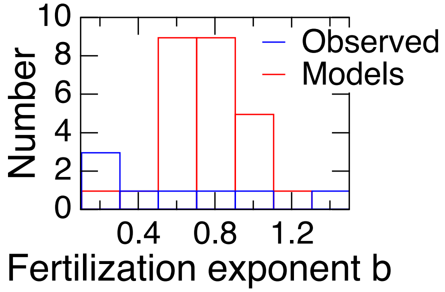
Compilation of recent observations

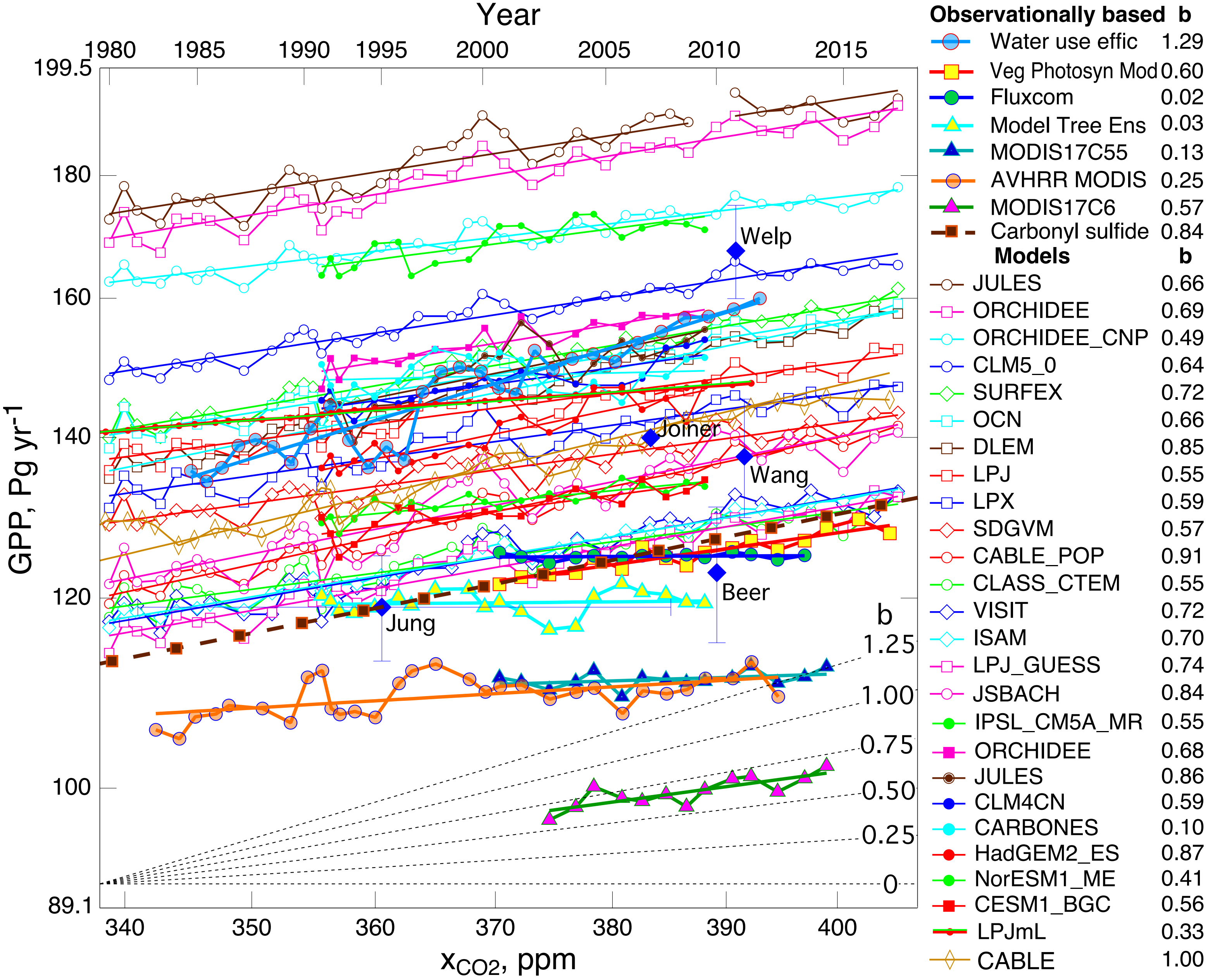




CO_2 FERTILIZATION EFFECT

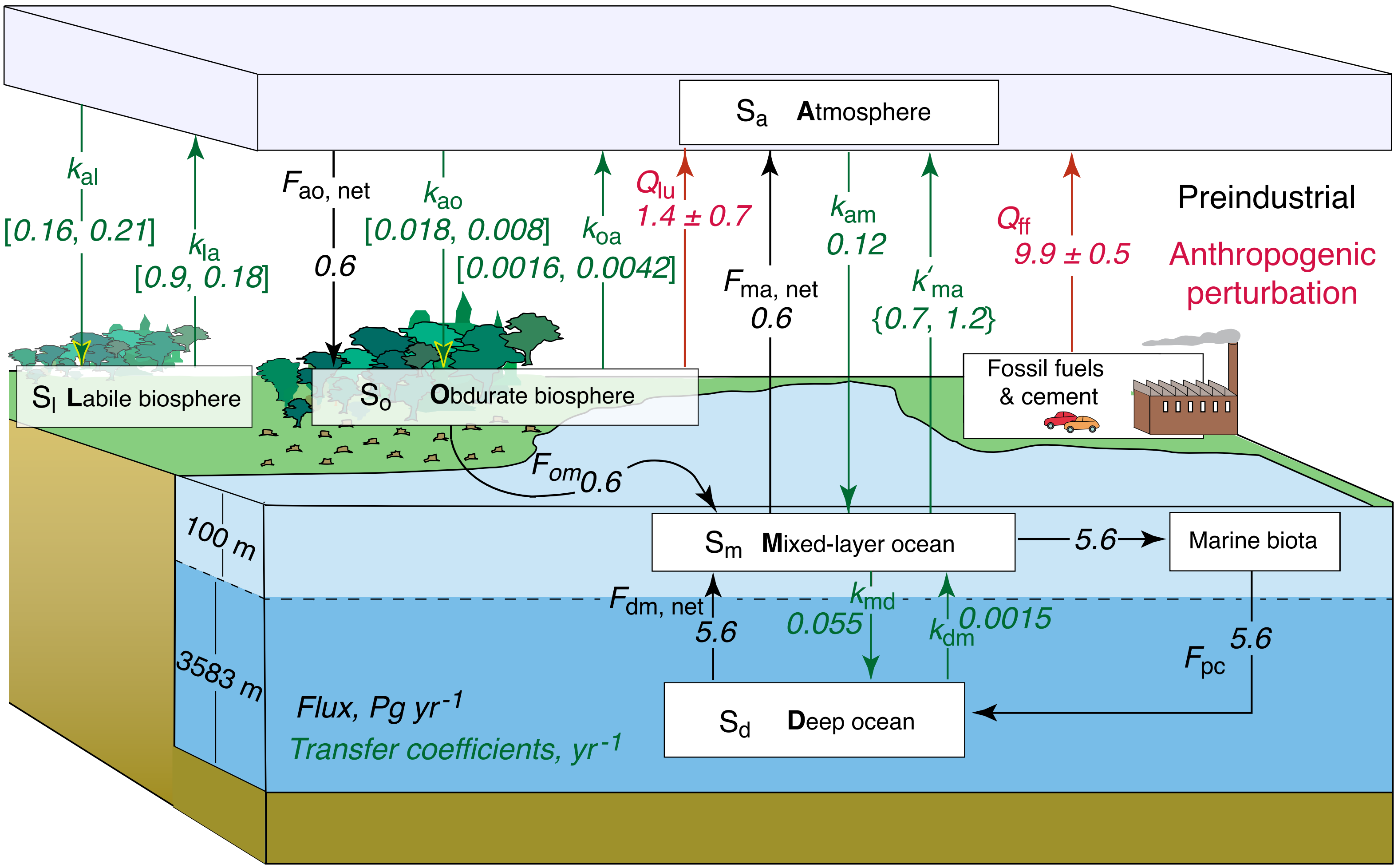
Compilation of recent observations and models





TRANSFER COEFFICIENTS FOR MODEL

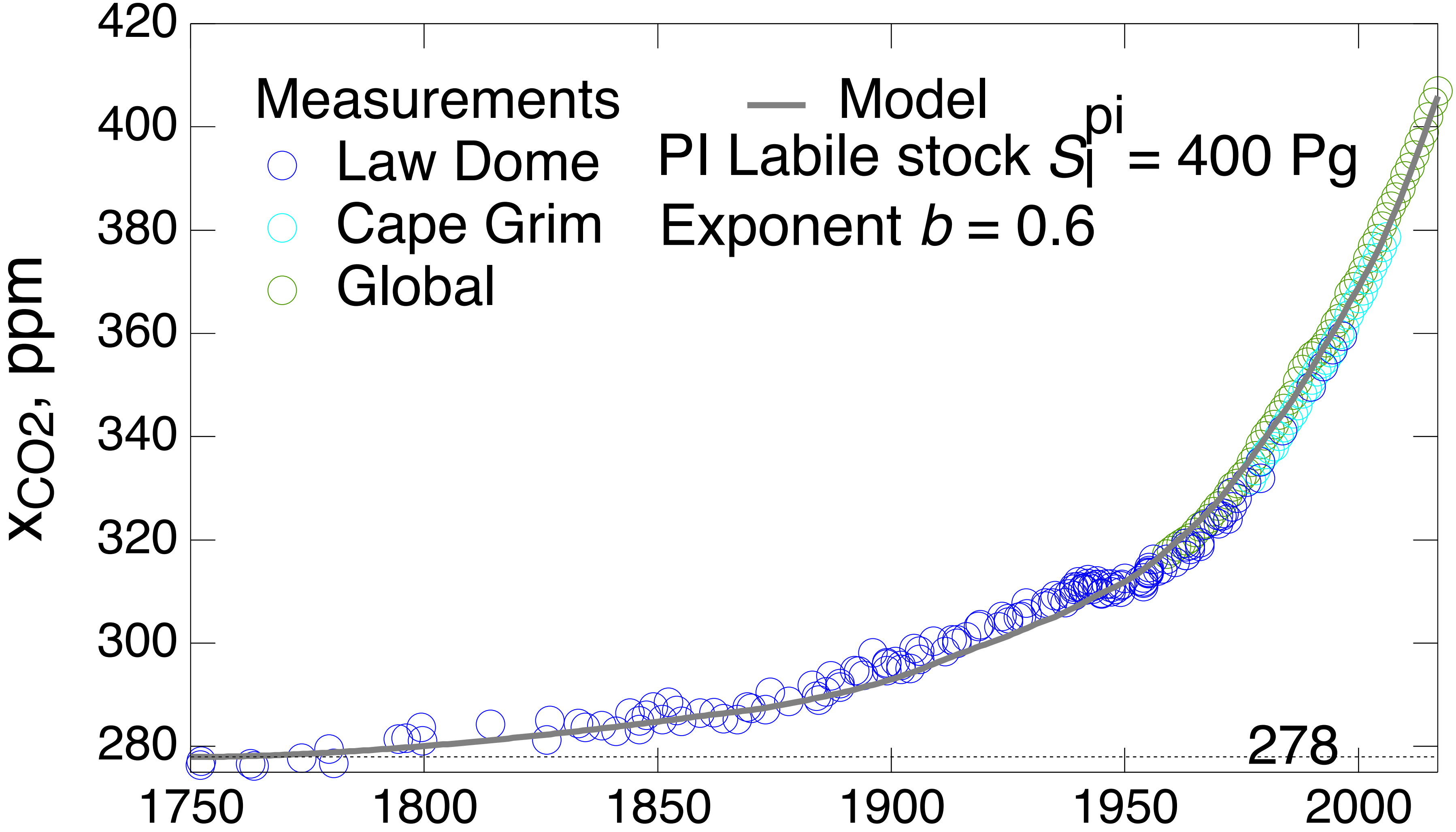
Evaluated from the observed budget



Range in coefficients denotes unconstrained parameters [ ] or dependence of equilibrium constant on dissolved inorganic carbon { }.

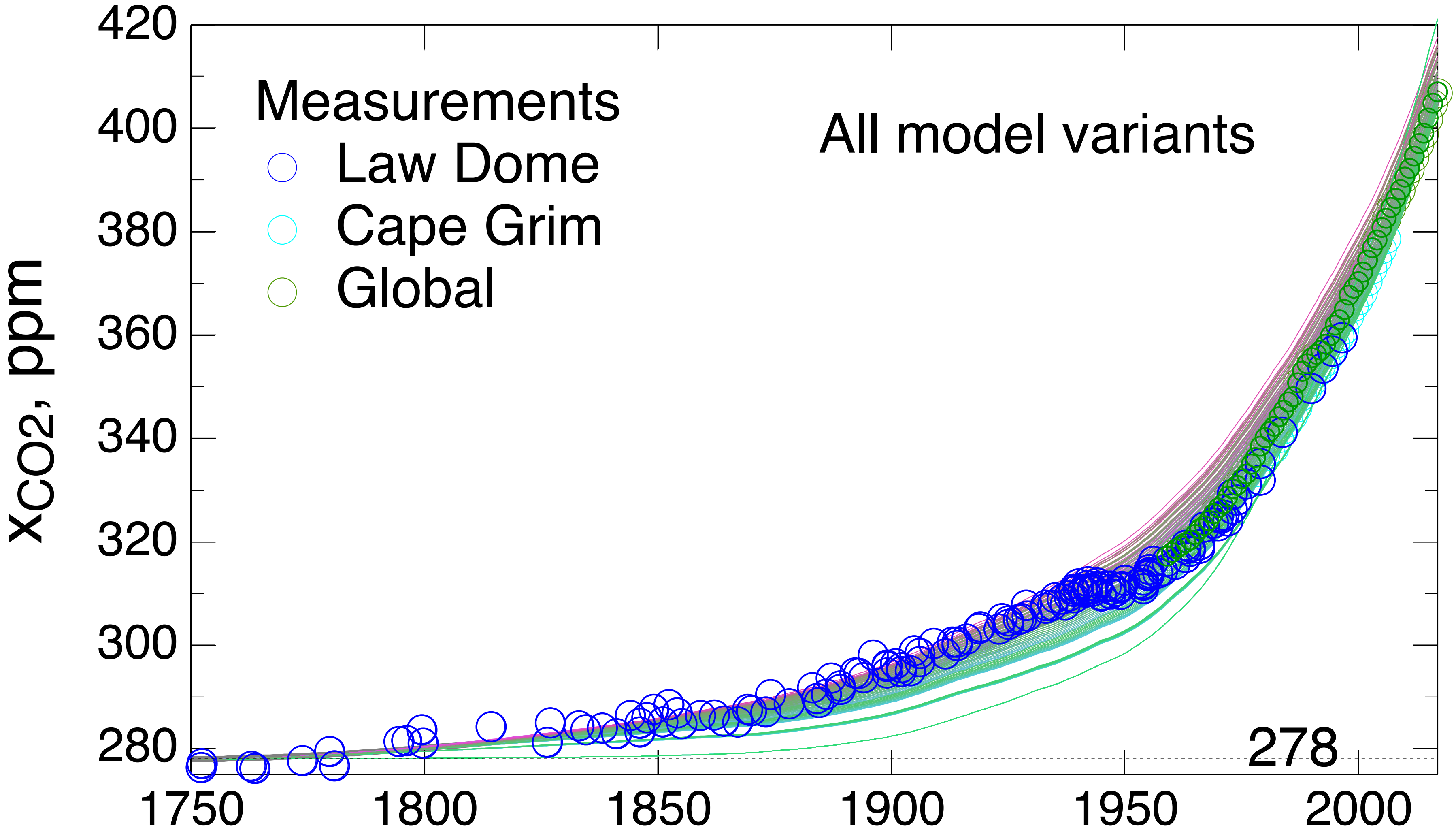
COMPARISON WITH OBSERVATIONS

Atmospheric CO_2



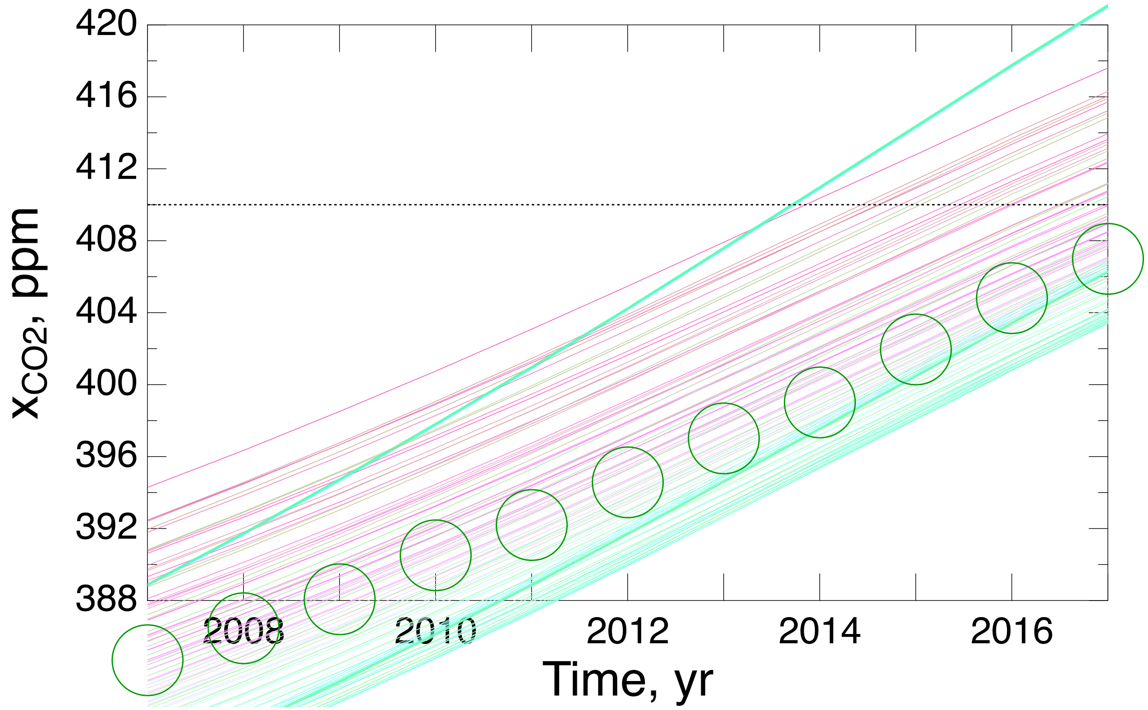
COMPARISON WITH OBSERVATIONS

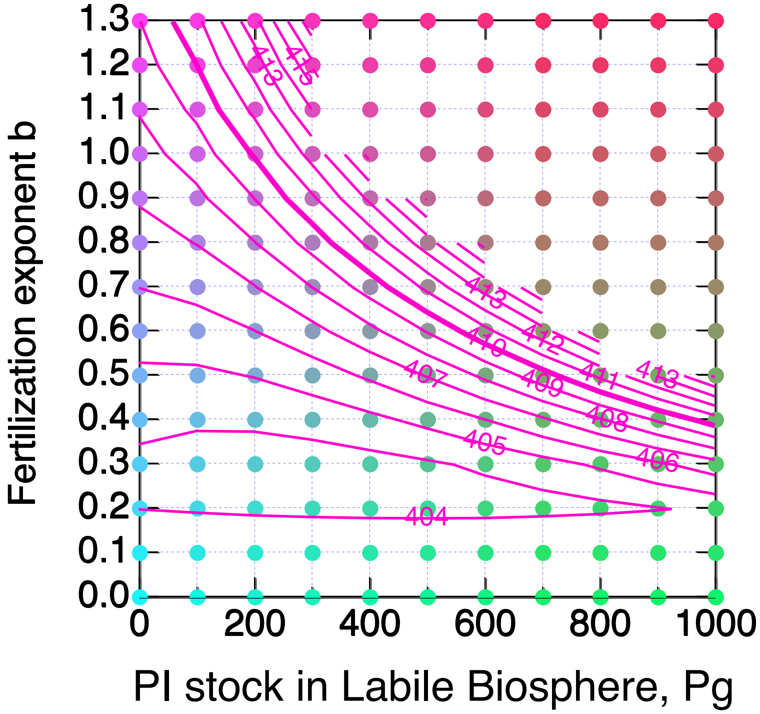
Atmospheric CO_2



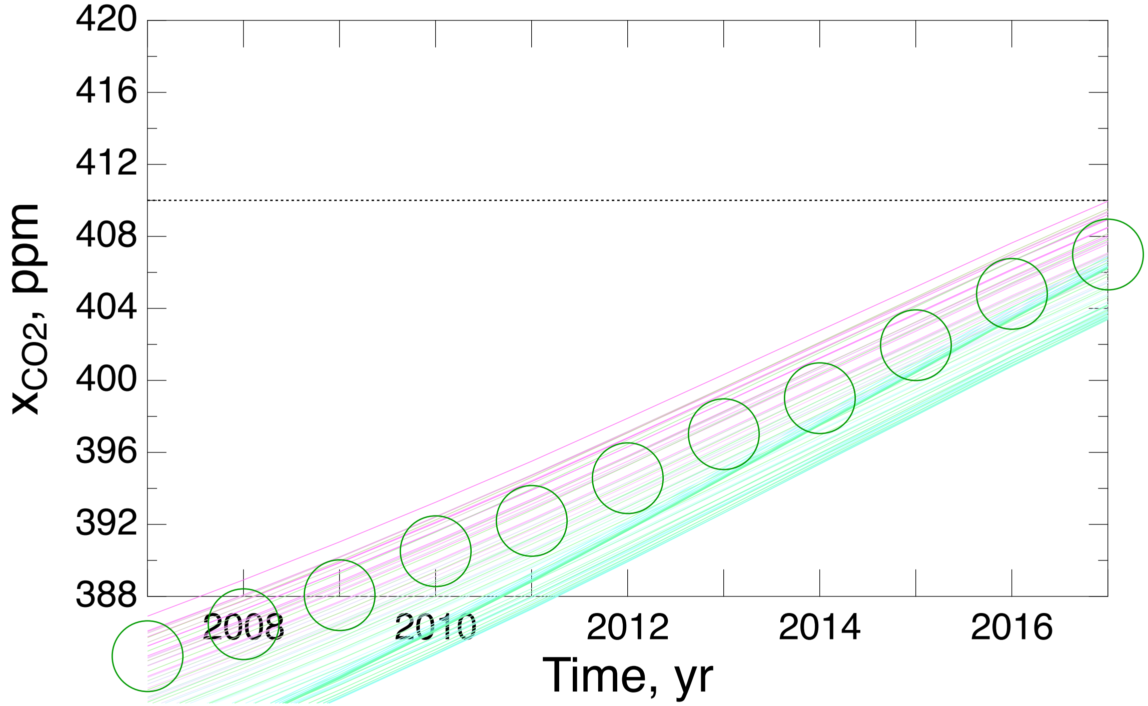
EXCLUDING MODEL VARIANTS THAT ARE INCONSISTENT WITH OBSERVATIONS

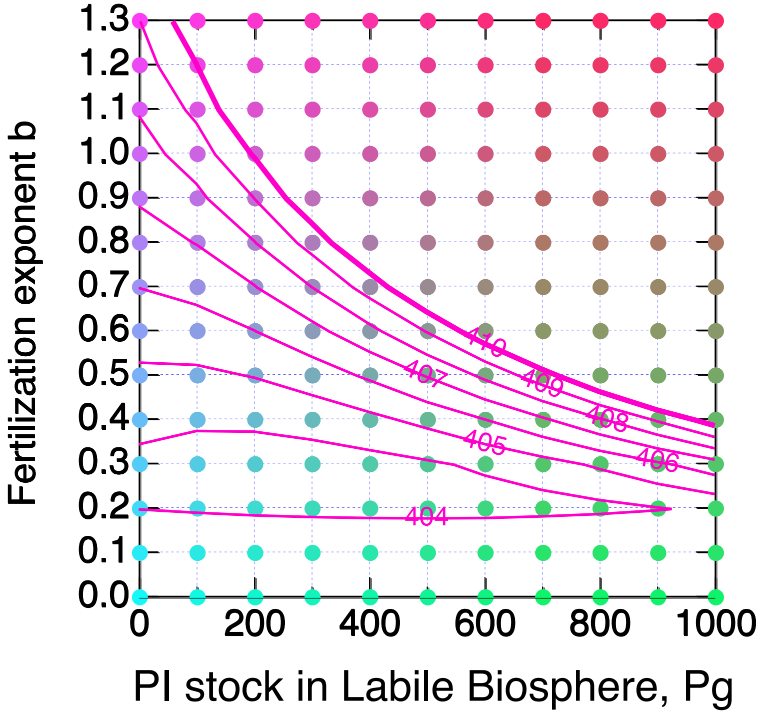
ATMOSPHERIC CO$_2$ (2017)



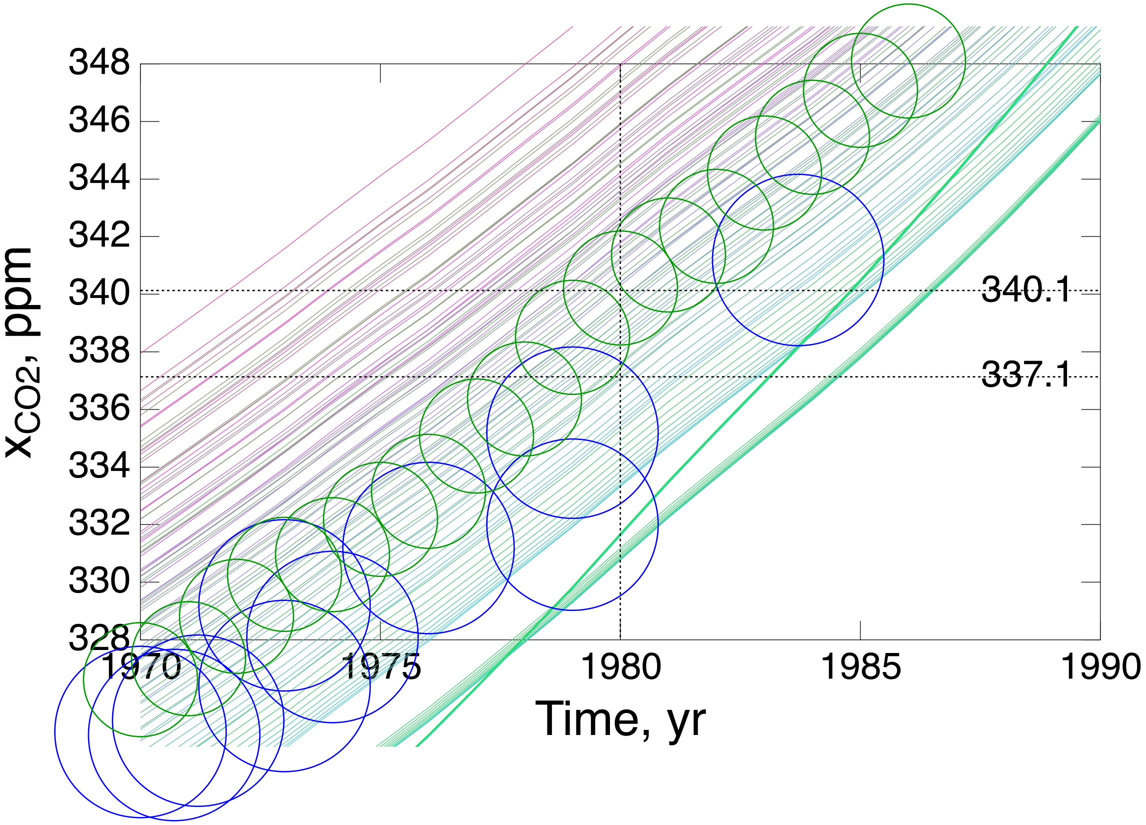


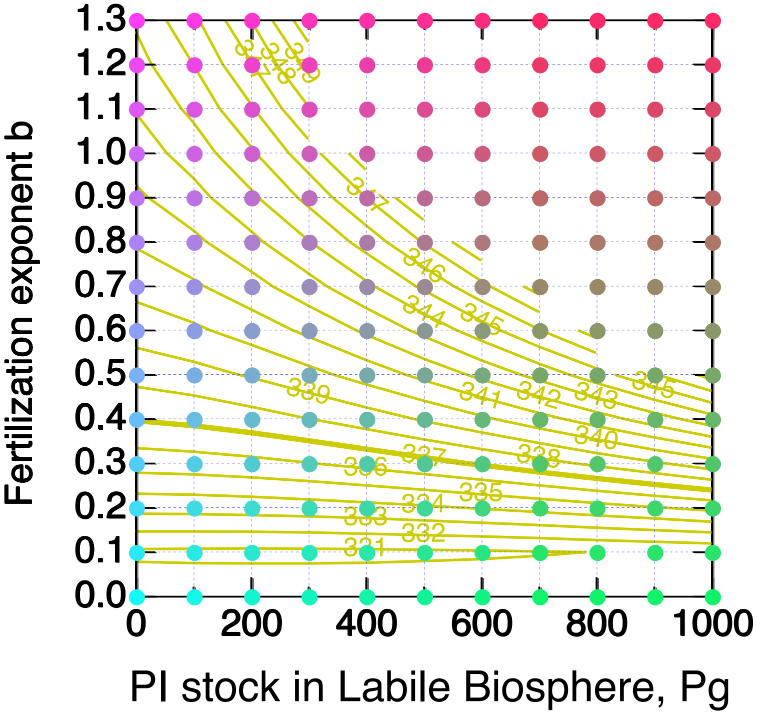
ATMOSPHERIC CO_2 (2017) < 410 ppm



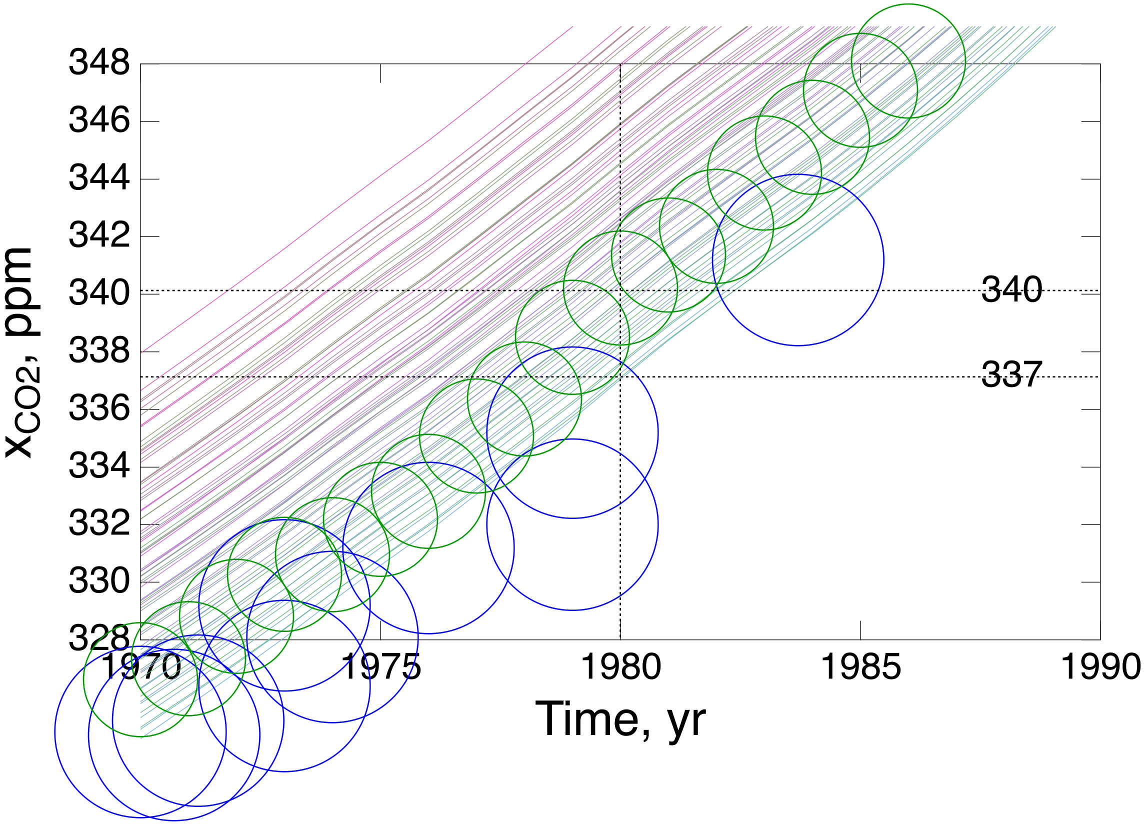


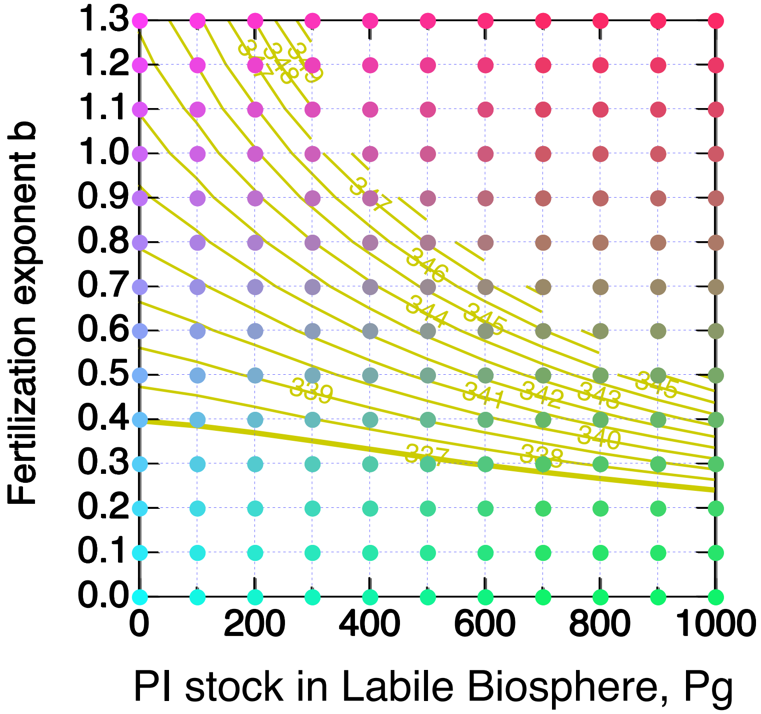
ATMOSPHERIC CO_2 (1980)



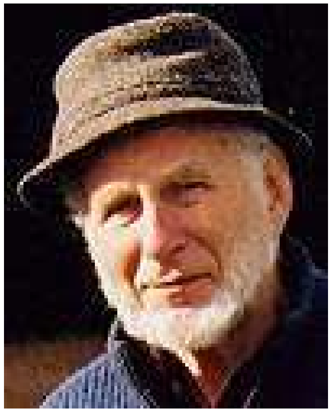


ATMOSPHERIC CO$_2$ (1980) > 337 ppm

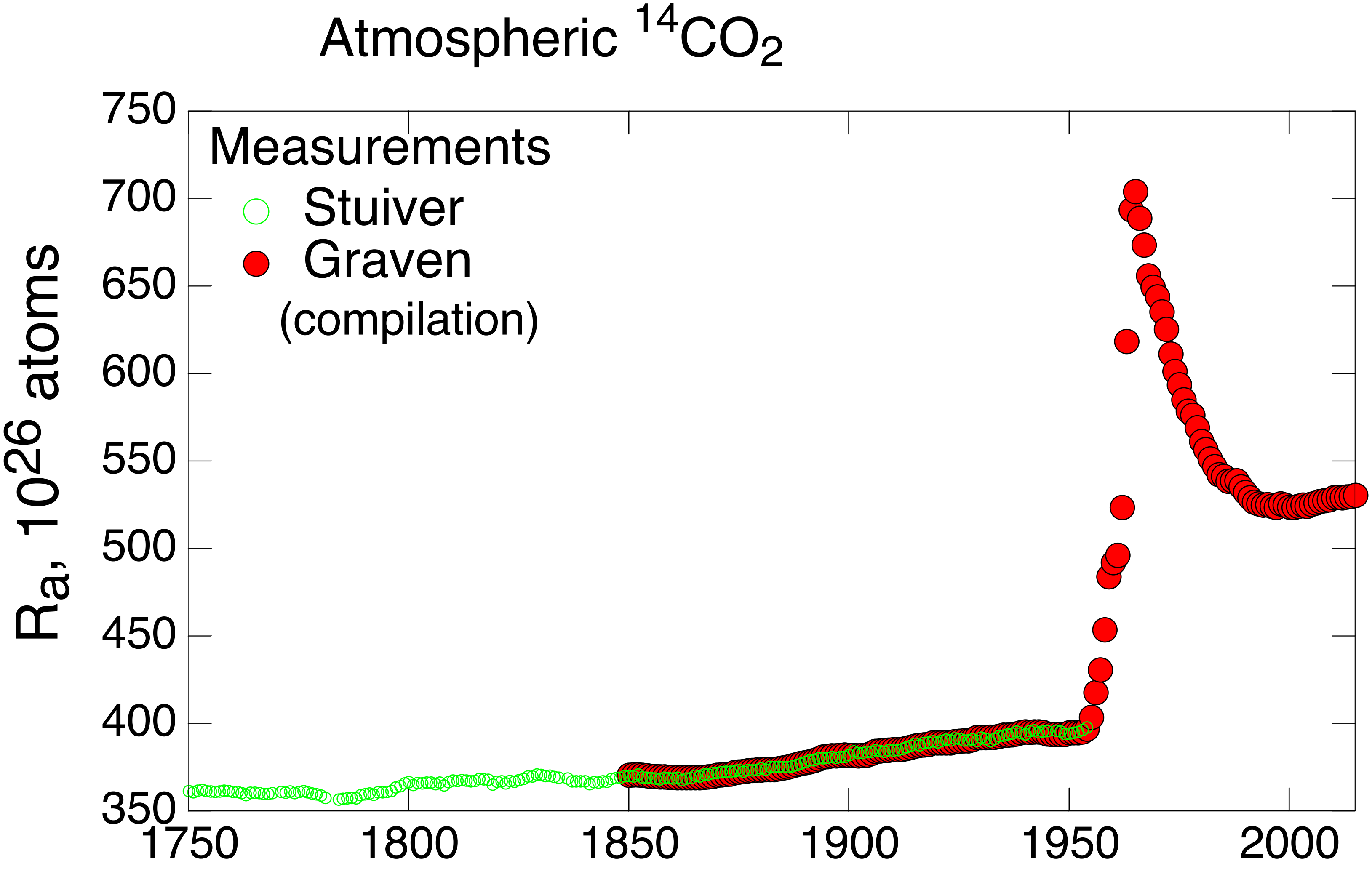




RADIOCARBON OBSERVATIONS FOR COMPARISON



Minze Stuiver



Gradual increase over anthropocene to 1950 due to increase in CO_2 from fossil fuels

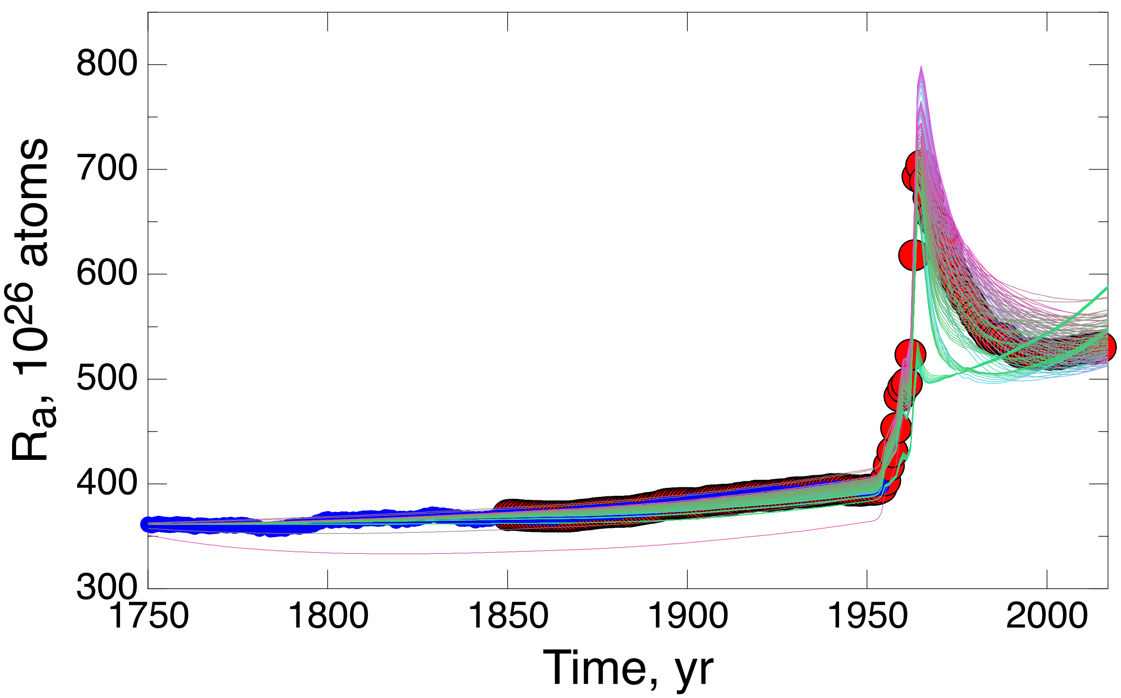
Abrupt increase due to atmospheric weapons testing.

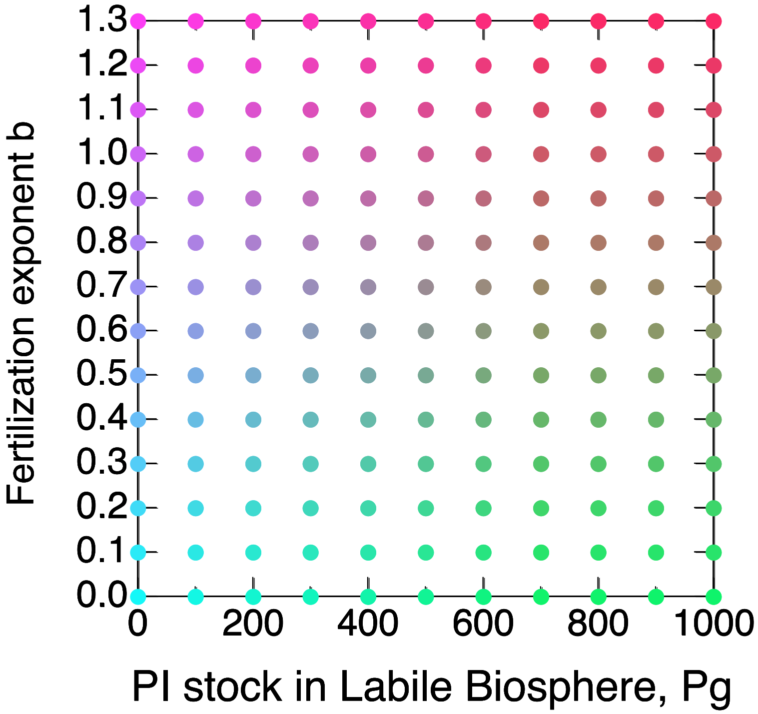
Gradual decrease after test ban treaty as $^{14}CO_2$ is taken up by oceans and terrestrial biosphere

Once again increasing in response to increasing atmospheric CO_2 from fossil fuels.

Atmospheric $^{14}CO_2$ as calculated by all model variants

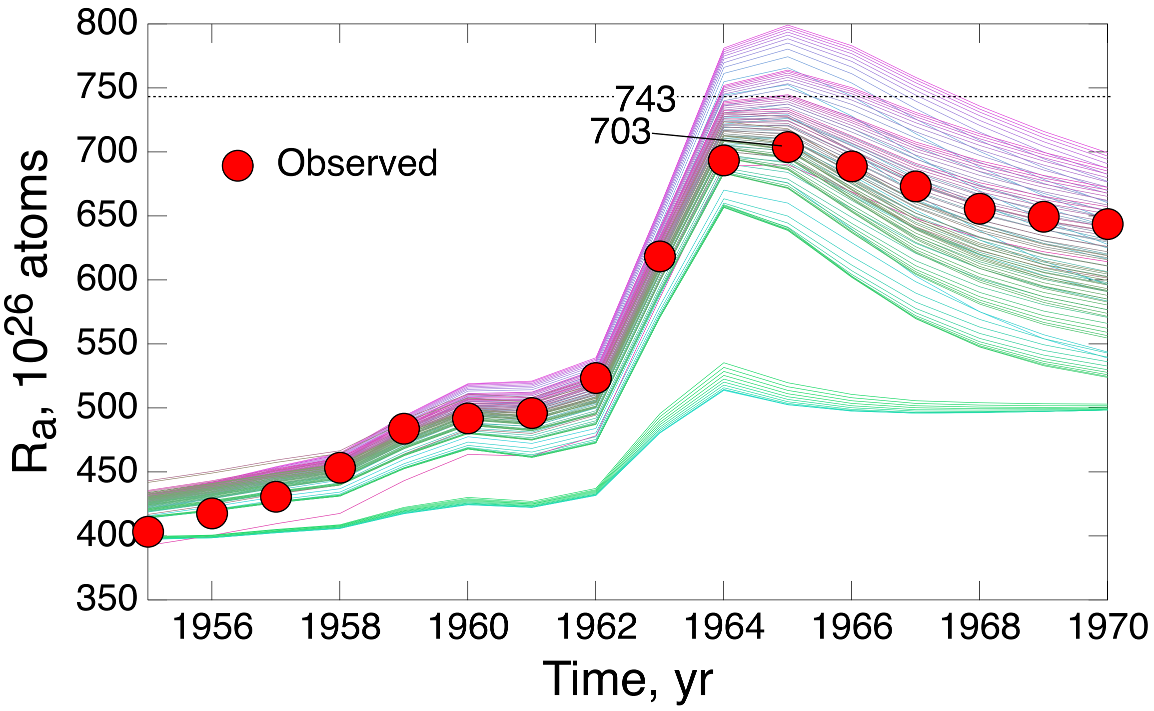
Color code denotes fertilization exponent b and preindustrial stock in labile biosphere

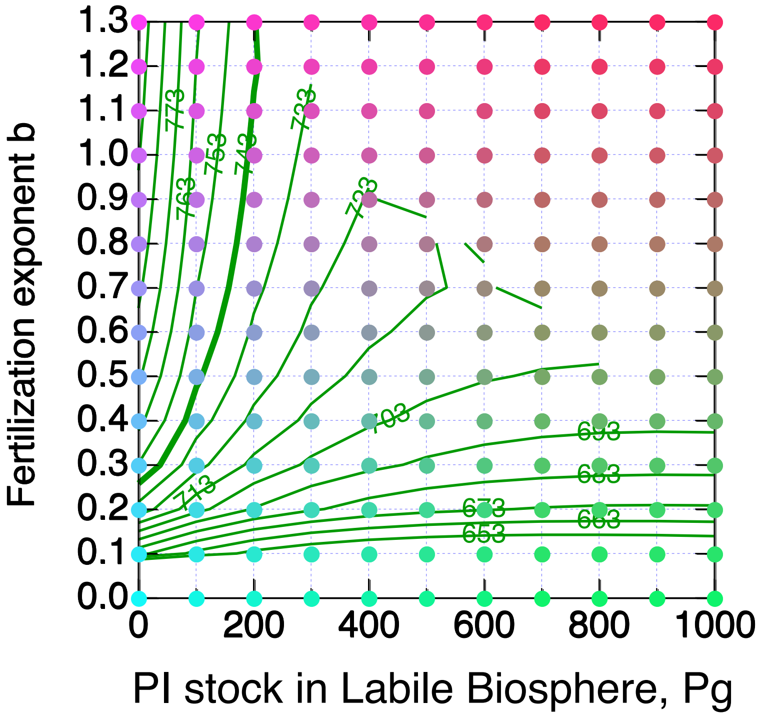




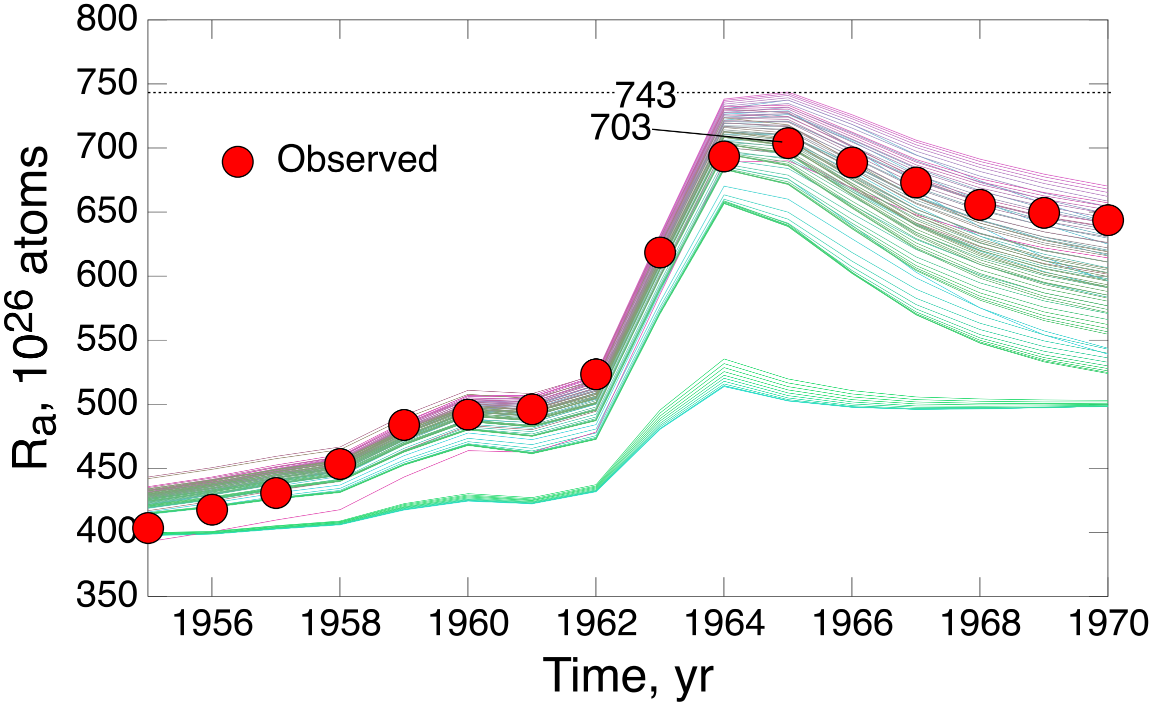
Model does a “pretty good” job but some departures that can be used to further constrain model variants.

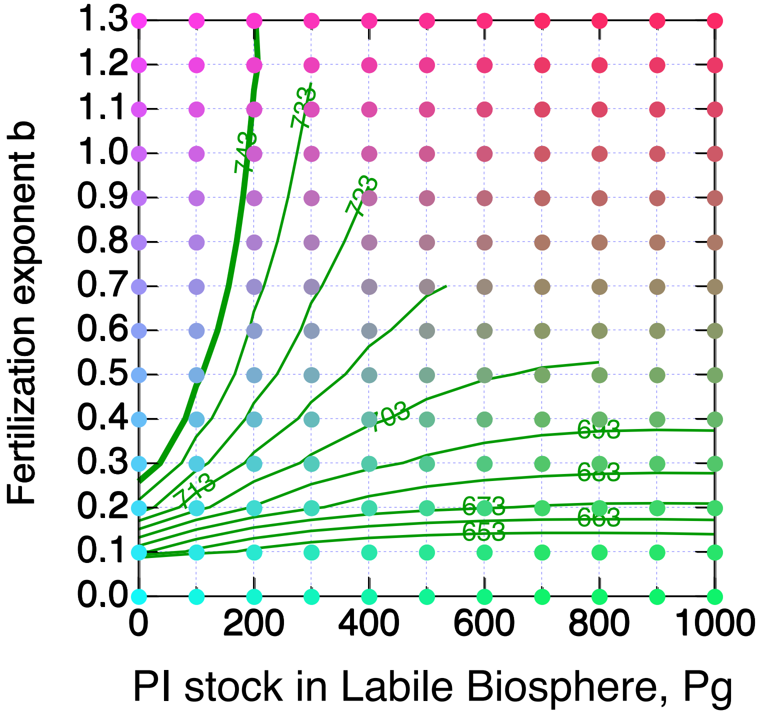
ATMOSPHERIC $^{14}CO_2$ (1965)





ATMOSPHERIC $^{14}CO_2$ (1965)

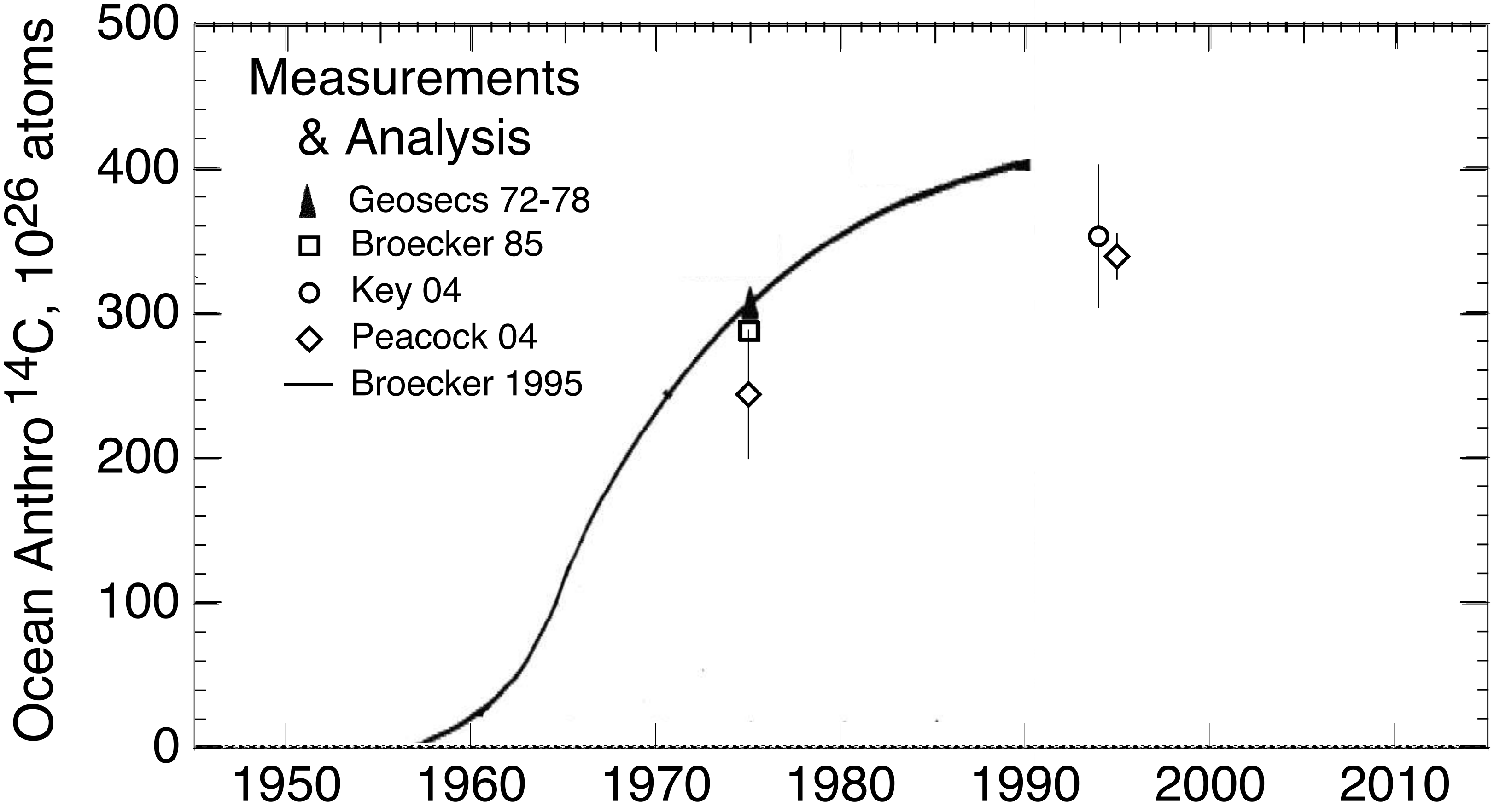




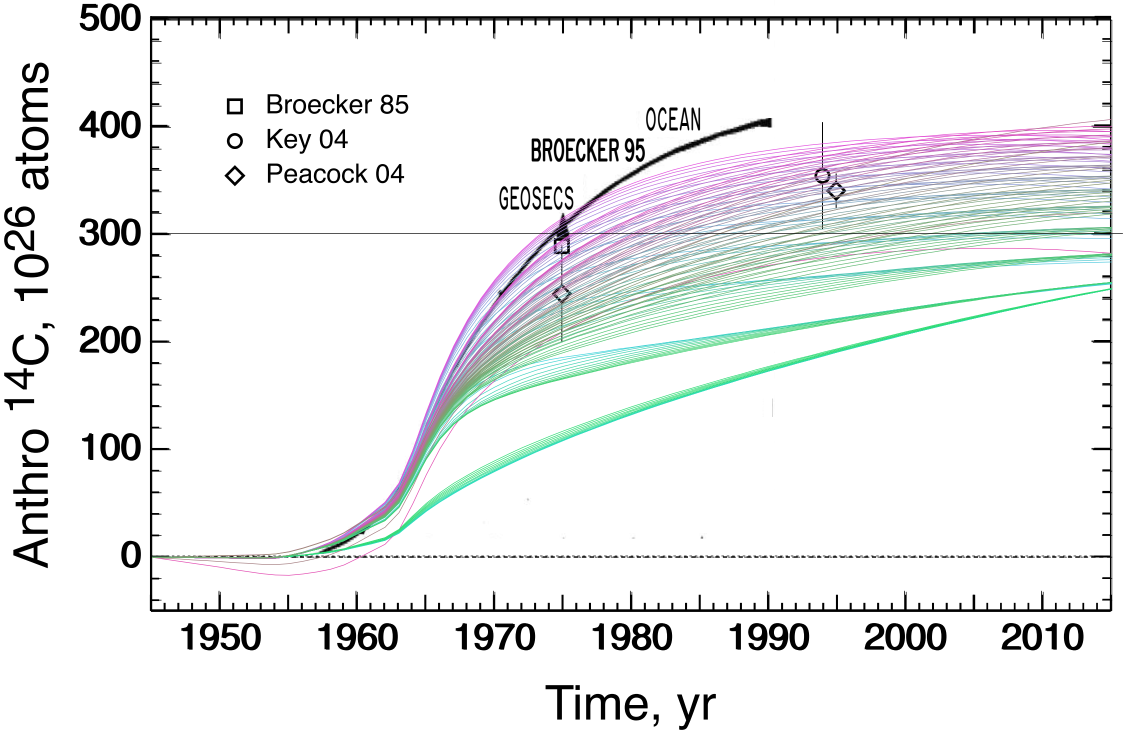
COMPARISON WITH RADIOCARBON OBSERVATIONS

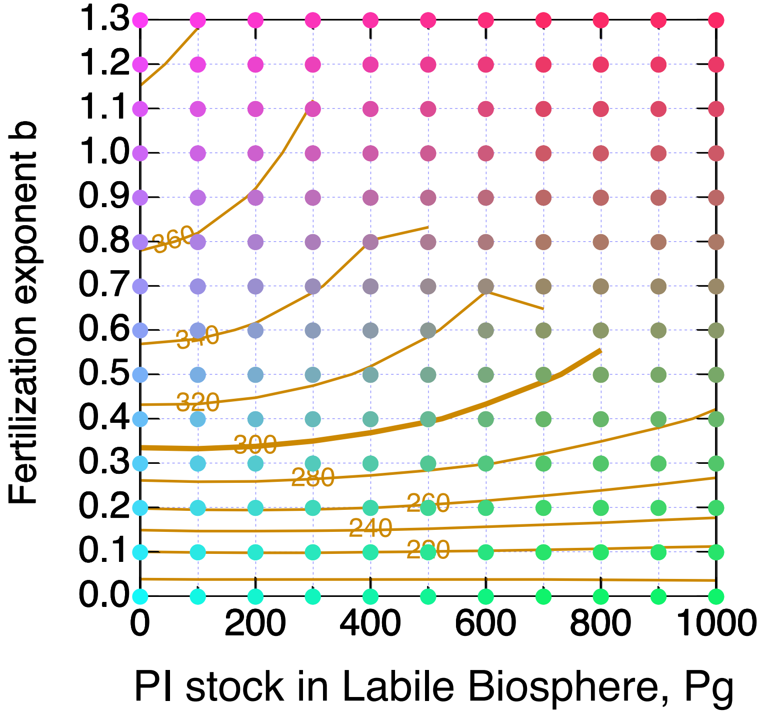
Wally Broecker

Oceanic $^{14}CO_2$



ANTHROPOGENIC RADIOCARBON IN WORLD OCEAN (1994)

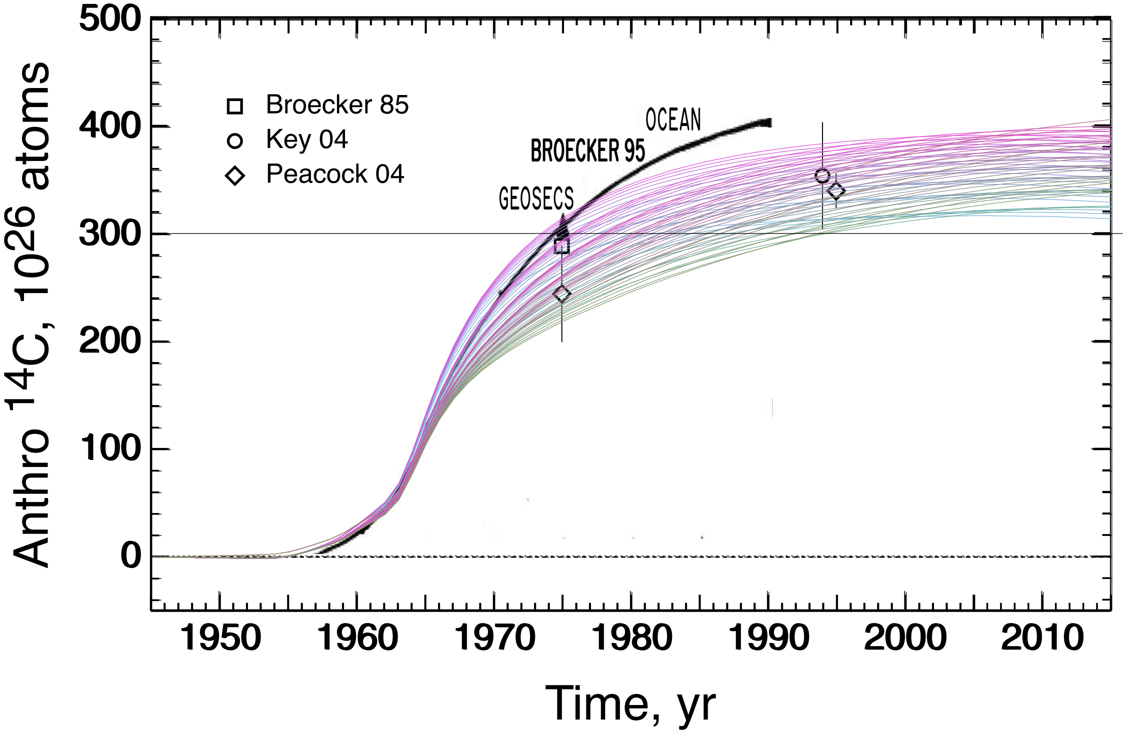


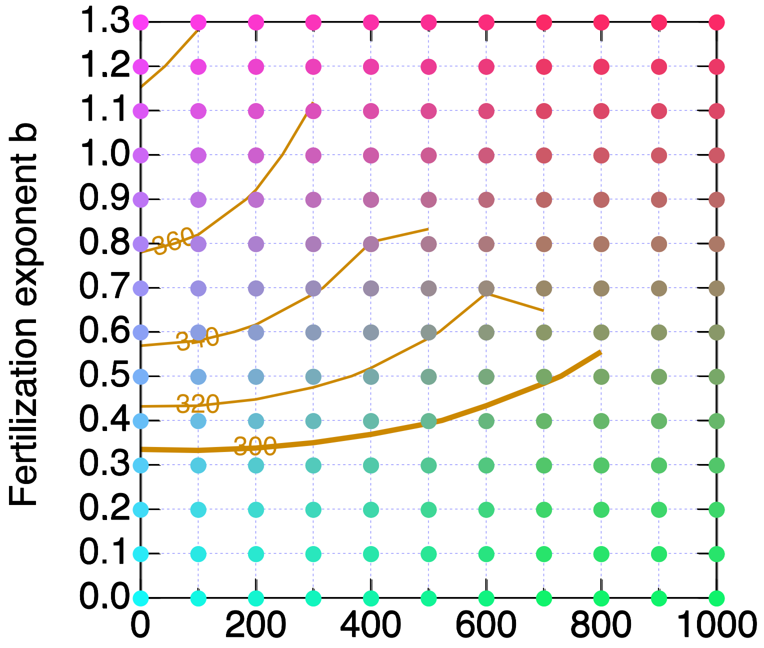


Model greatly underestimates ocean uptake of $^{26}CO_2$ for low fertilization exponent of terrestrial biosphere.

ANTHROPOGENIC RADIOCARBON IN WORLD OCEAN (1994)

Dependence on fertilization exponent b and preindustrial stock in labile biosphere

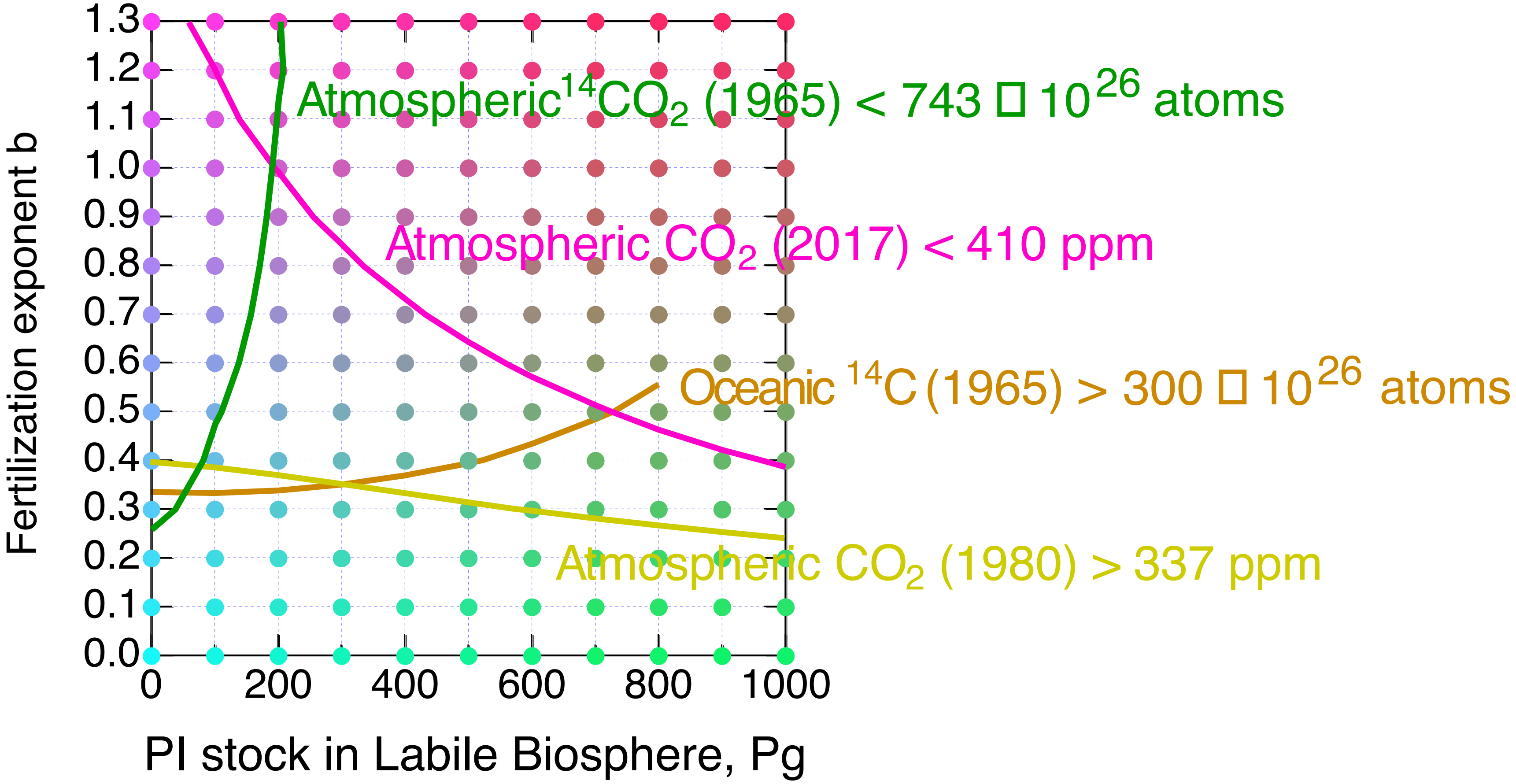




With removal of model variants for which anthropogenic stock at 1994 is less than 300 □ 10^{26} atoms

COMPARISON OF CONSTRAINED MODEL WITH OBSERVATIONS

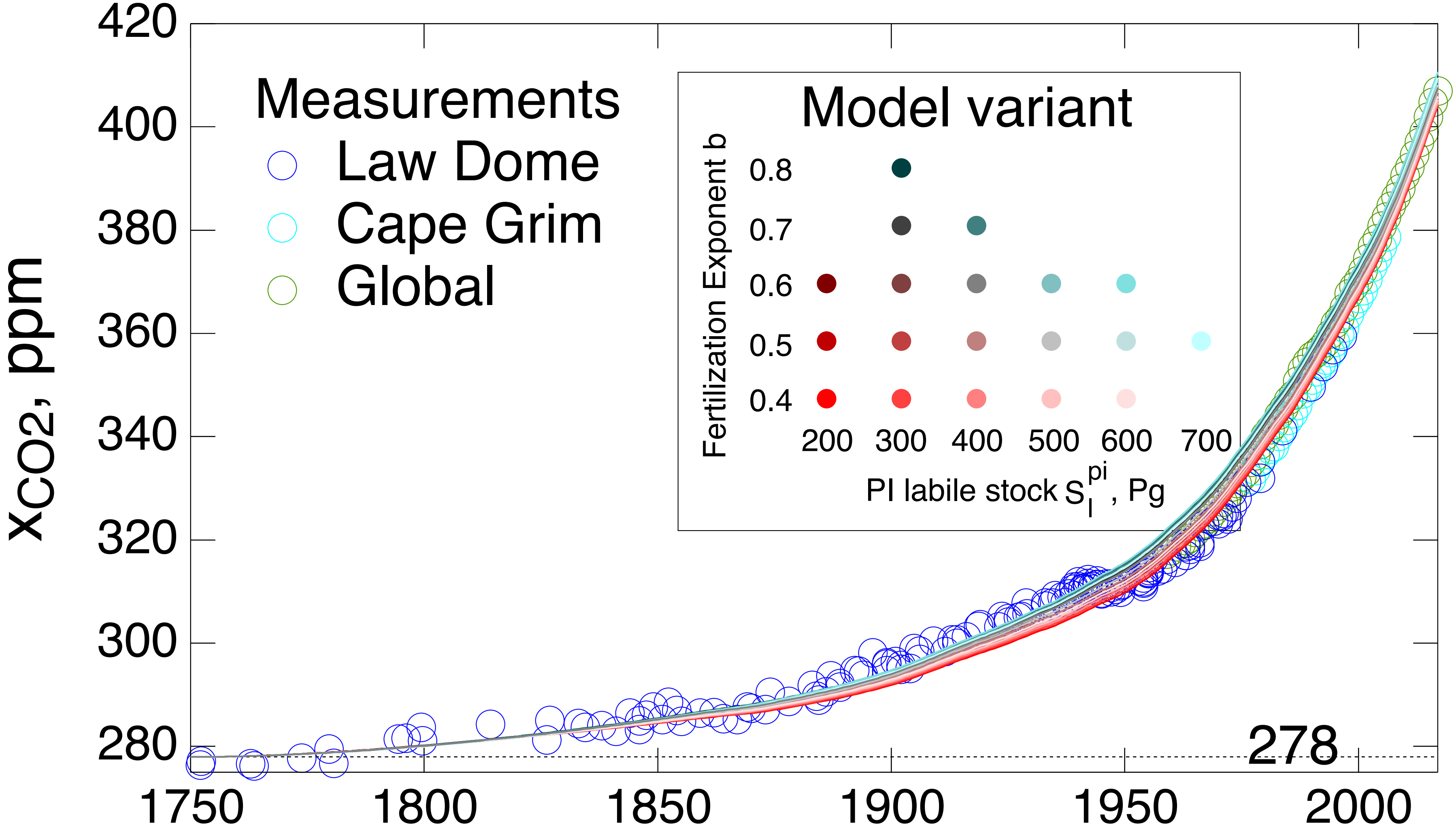
OBSERVATIONAL CONSTRAINTS ON ADJUSTABLE PARAMETERS



Parameter pairs must be within “quadrilateral” determined by comparison of model and observations.

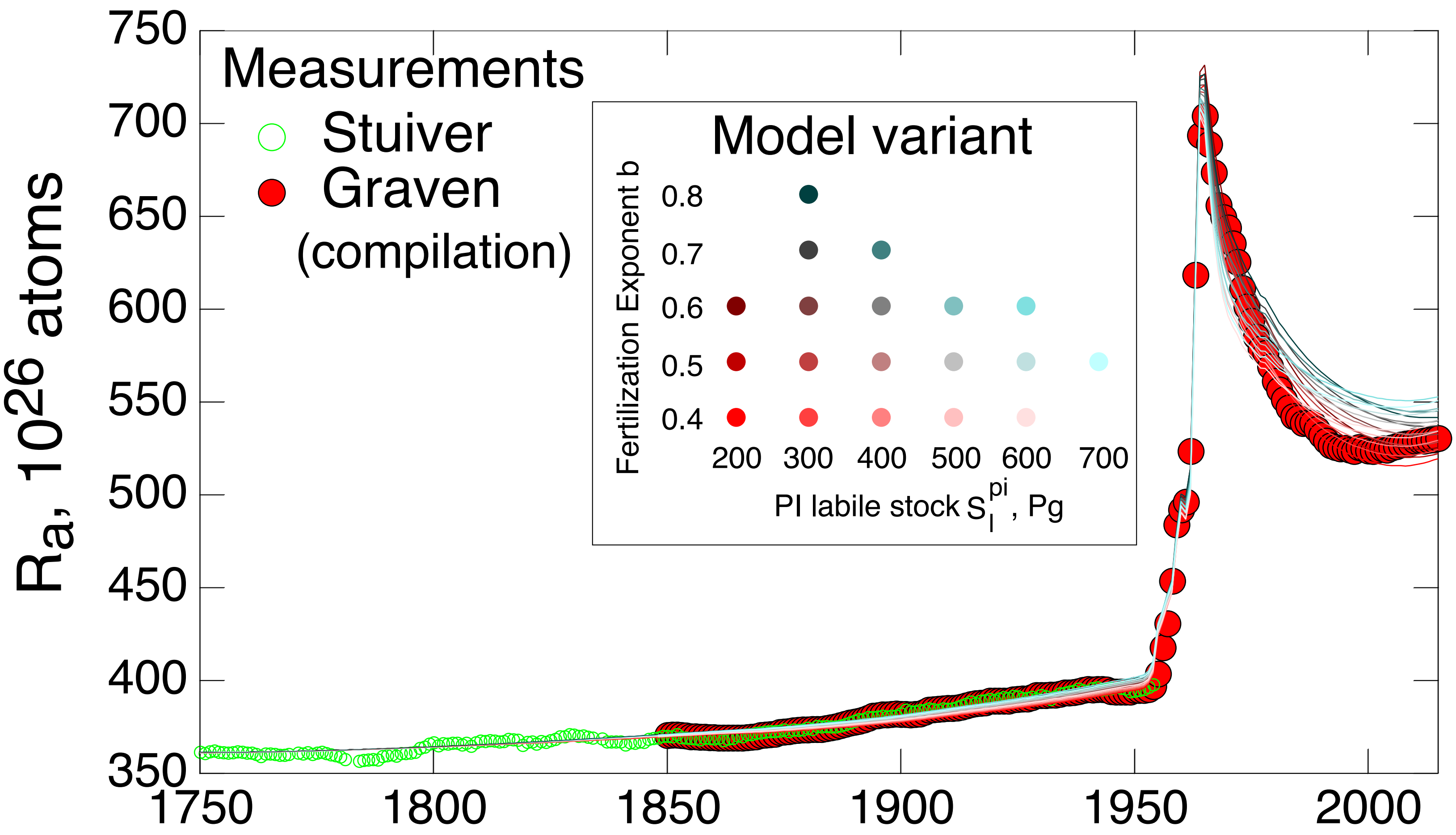
COMPARISON WITH OBSERVATIONS

Atmospheric CO_2



COMPARISON WITH RADIOCARBON OBSERVATIONS

Atmospheric $^{14}CO_2$



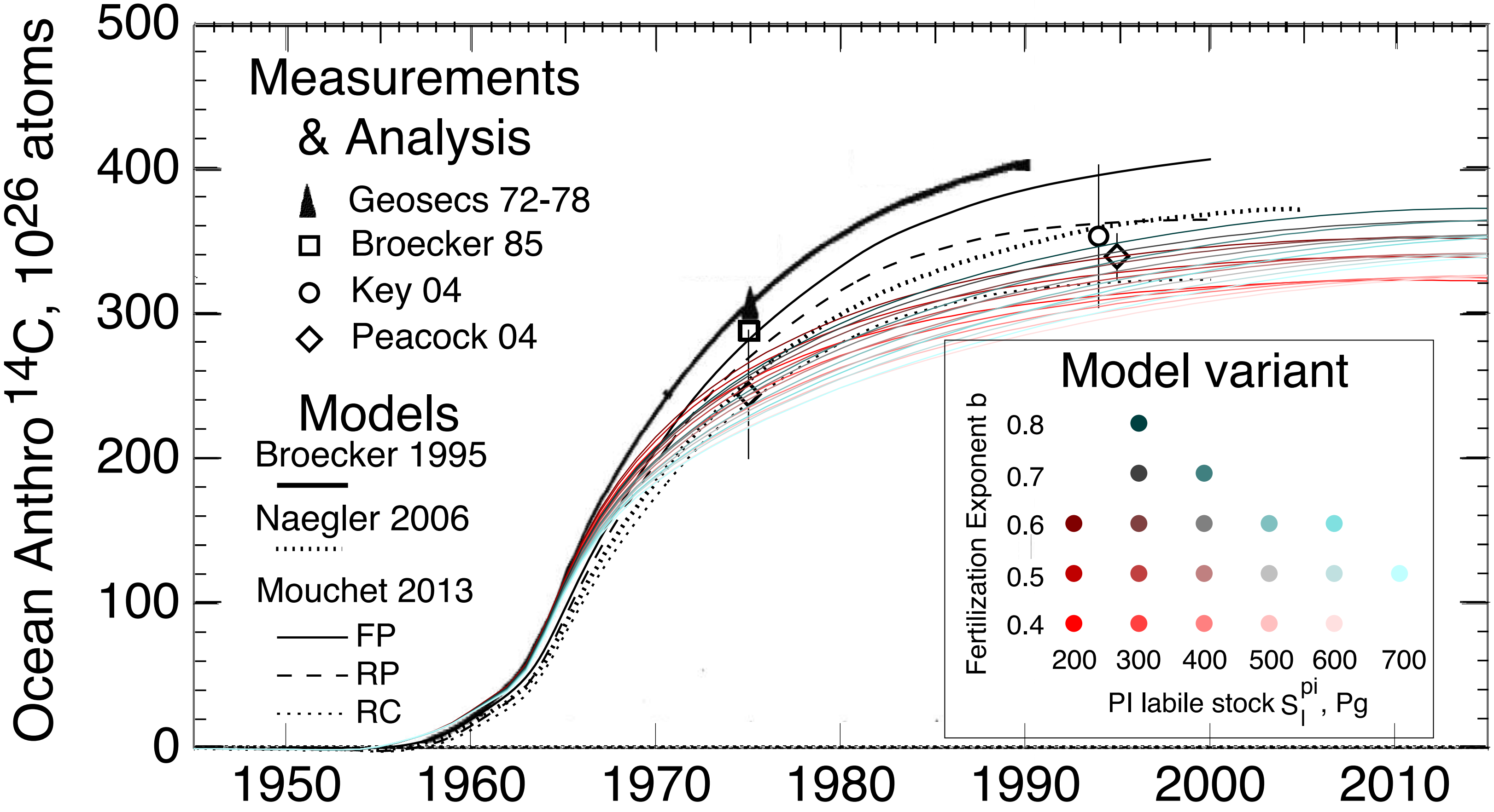
Excellent agreement with increase in $^{14}CO_2$ over pre-bomb era.

Good agreement in abrupt increase in $^{14}CO_2$ from atmospheric weapons testing.

Pretty good agreement in post-bomb era including increase after ~year 2000.

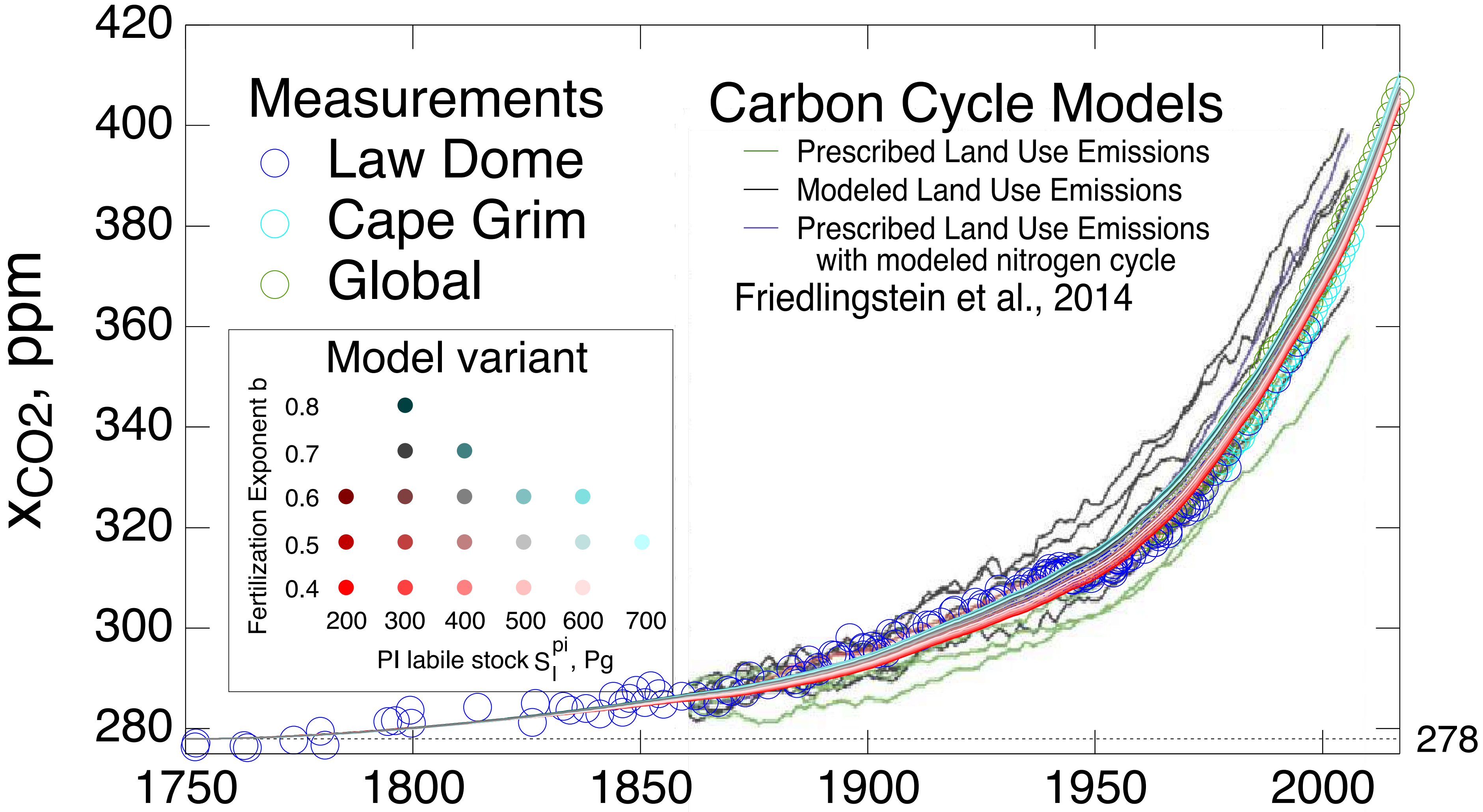
COMPARISON WITH RADIOCARBON OBSERVATIONS AND OTHER MODELS

Oceanic $^{14}CO_2$



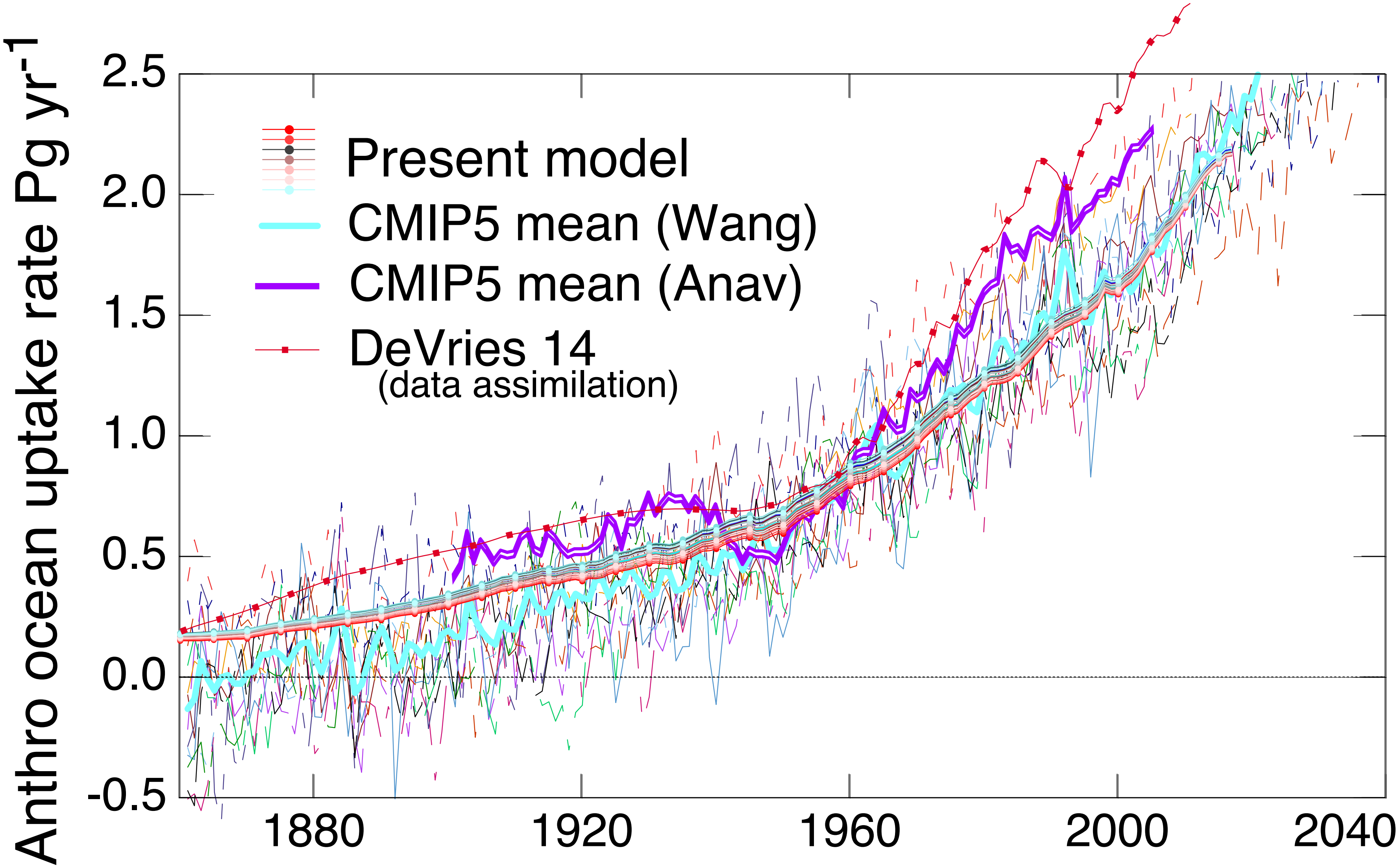
COMPARISON WITH OBSERVATIONS AND OTHER MODELS

Atmospheric CO_2 over the Anthropocene



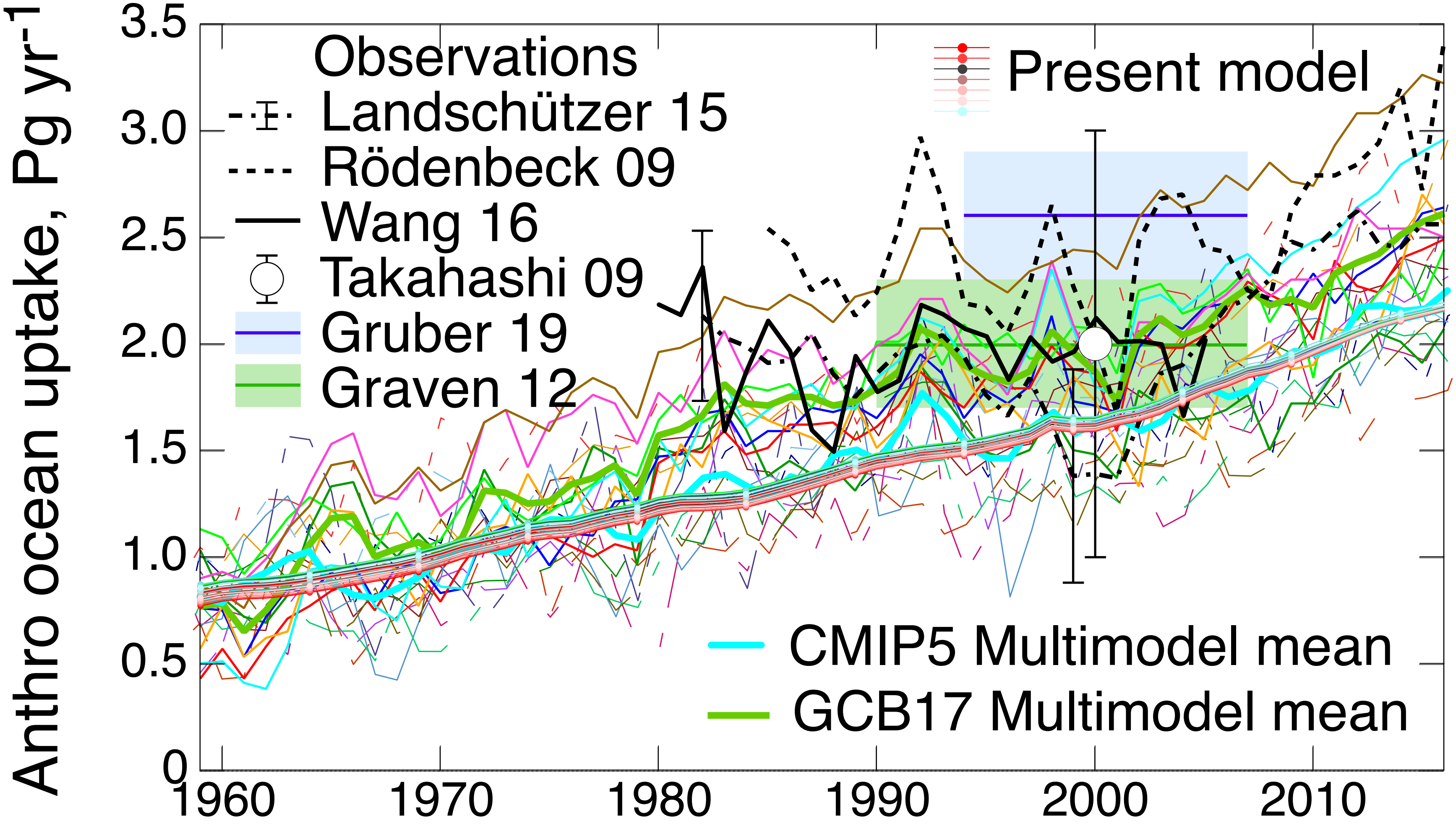
COMPARISON WITH OTHER MODELS AND DATA ASSIMILATION

Ocean Uptake Rate



COMPARISON WITH CARBON CYCLE MODELS AND OBSERVATIONS

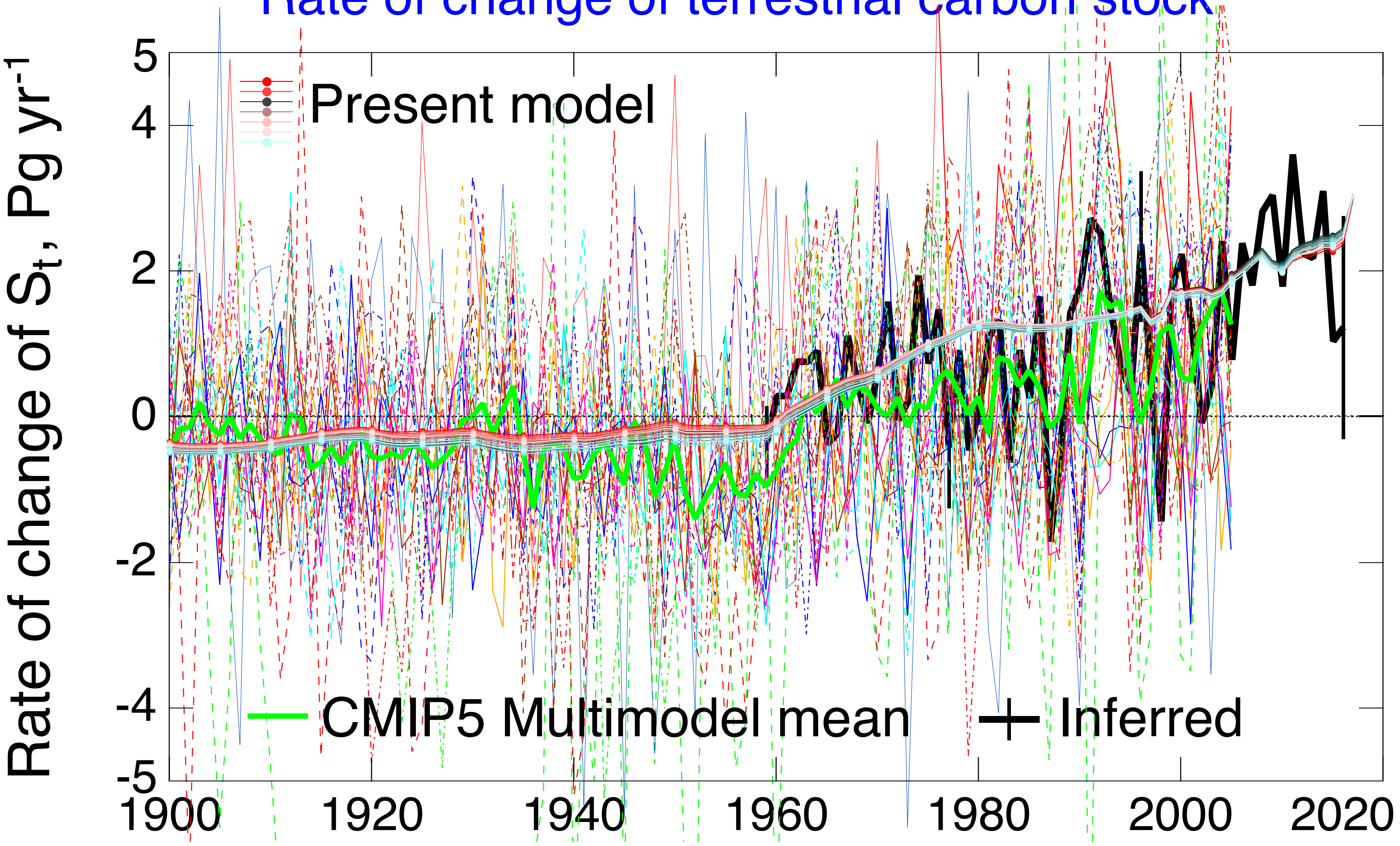
Ocean uptake rate of anthropogenic CO_2 over the Keeling era



Eight CC model calculations (thicker lines) and multimodel mean from Le Quéré, 2018
13 CC model calculations from CMIP5 (thinner lines), and multimodel mean from Wang, 2016

COMPARISON WITH CARBON CYCLE MODELS AND INFERRED FROM OBSERVATIONS

Rate of change of terrestrial carbon stock



Model results and multimodel mean from 18 CMIP5 models (Alessandro Anav).

Inferred is difference between fossil fuel and cement manufacture emissions minus observed atmospheric growth and modeled ocean uptake (multimodel mean, Le Quéré et al., (2018a).

USING THE MODEL

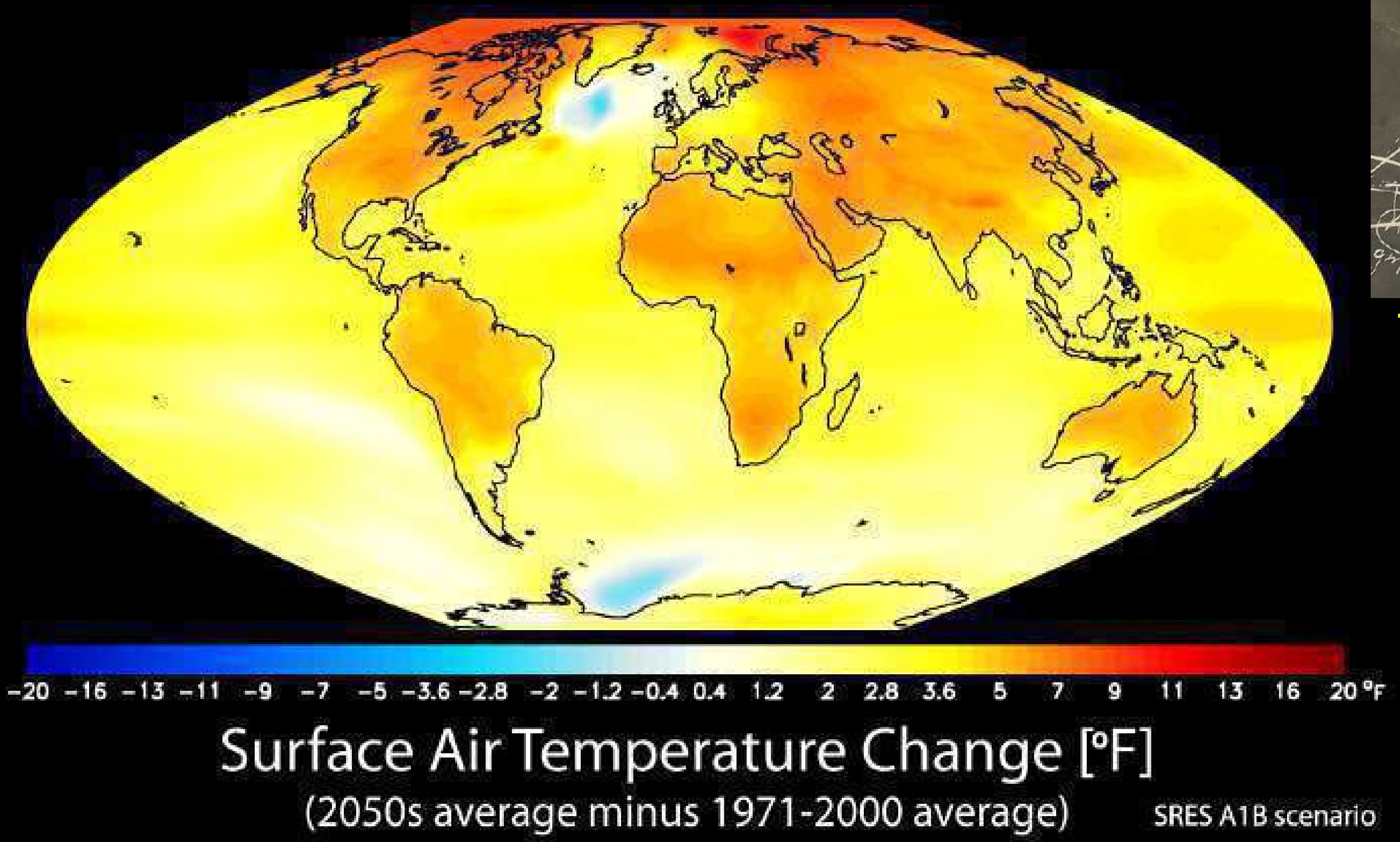
Use the model to answer societally relevant questions.

How rapidly would atmospheric CO_2 return to its preindustrial value in the absence of anthropogenic emissions?

MODELS VERSUS OBSERVATIONS

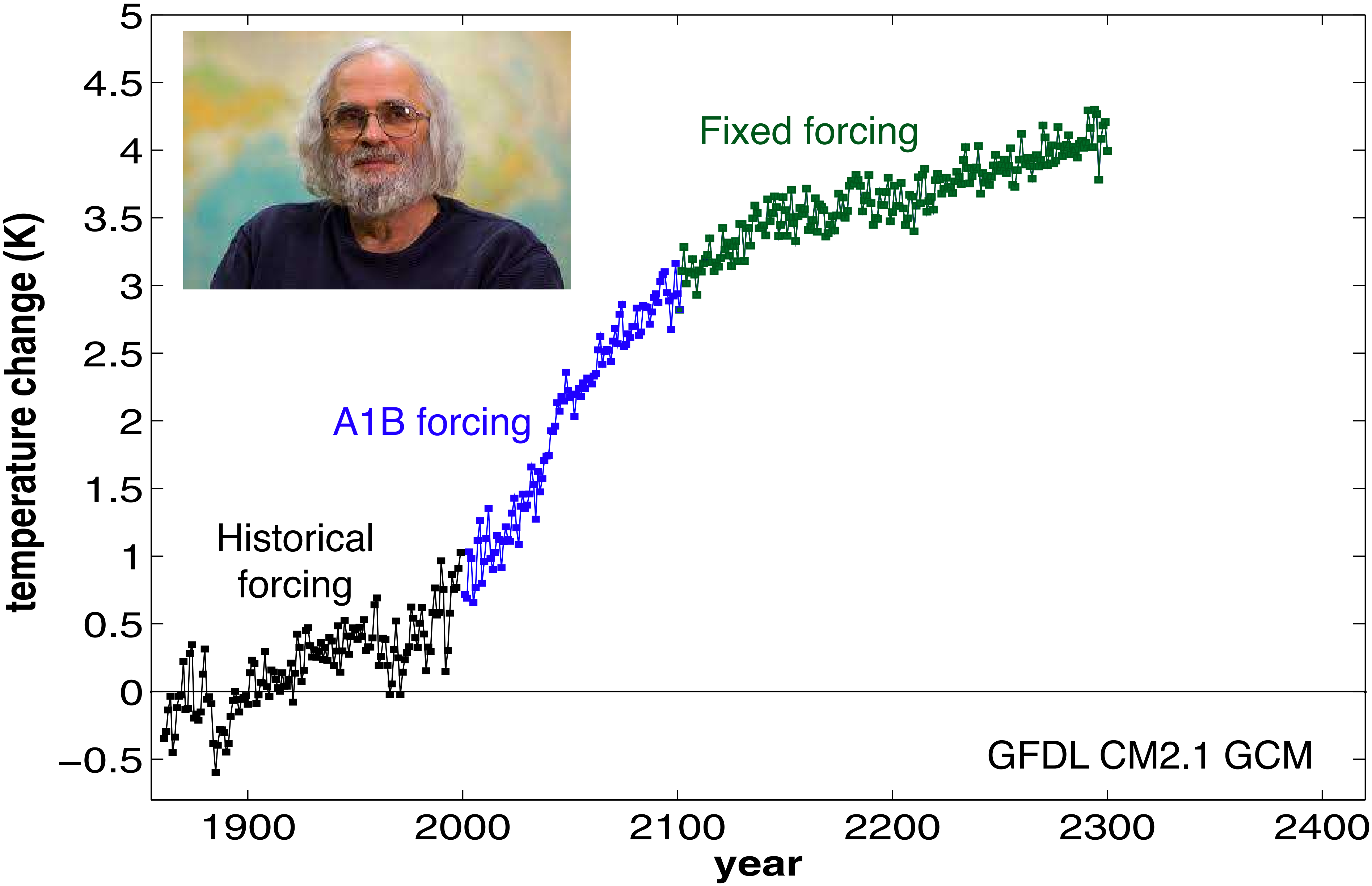
To the question “Should we trust models or observations?” we reply that if we had observations of the future, we obviously would trust them more than models, but unfortunately observations of the future are not available at this time.

Tom Knutson



J. Climate, 2005

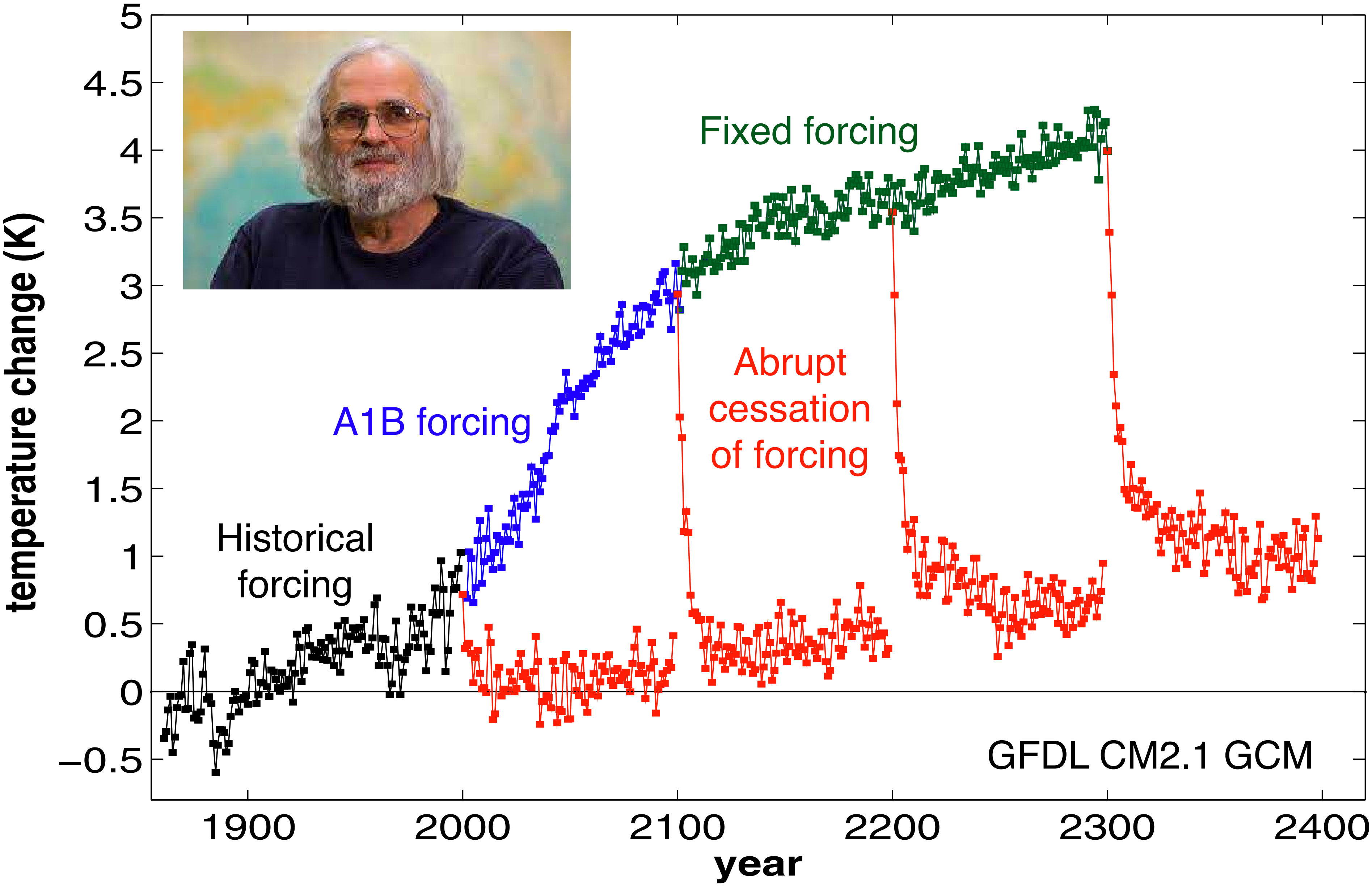
CLIMATE RESPONSE TO ABRUPT CESSATION OF FORCING



Held et al., *J. Clim.*, 2010

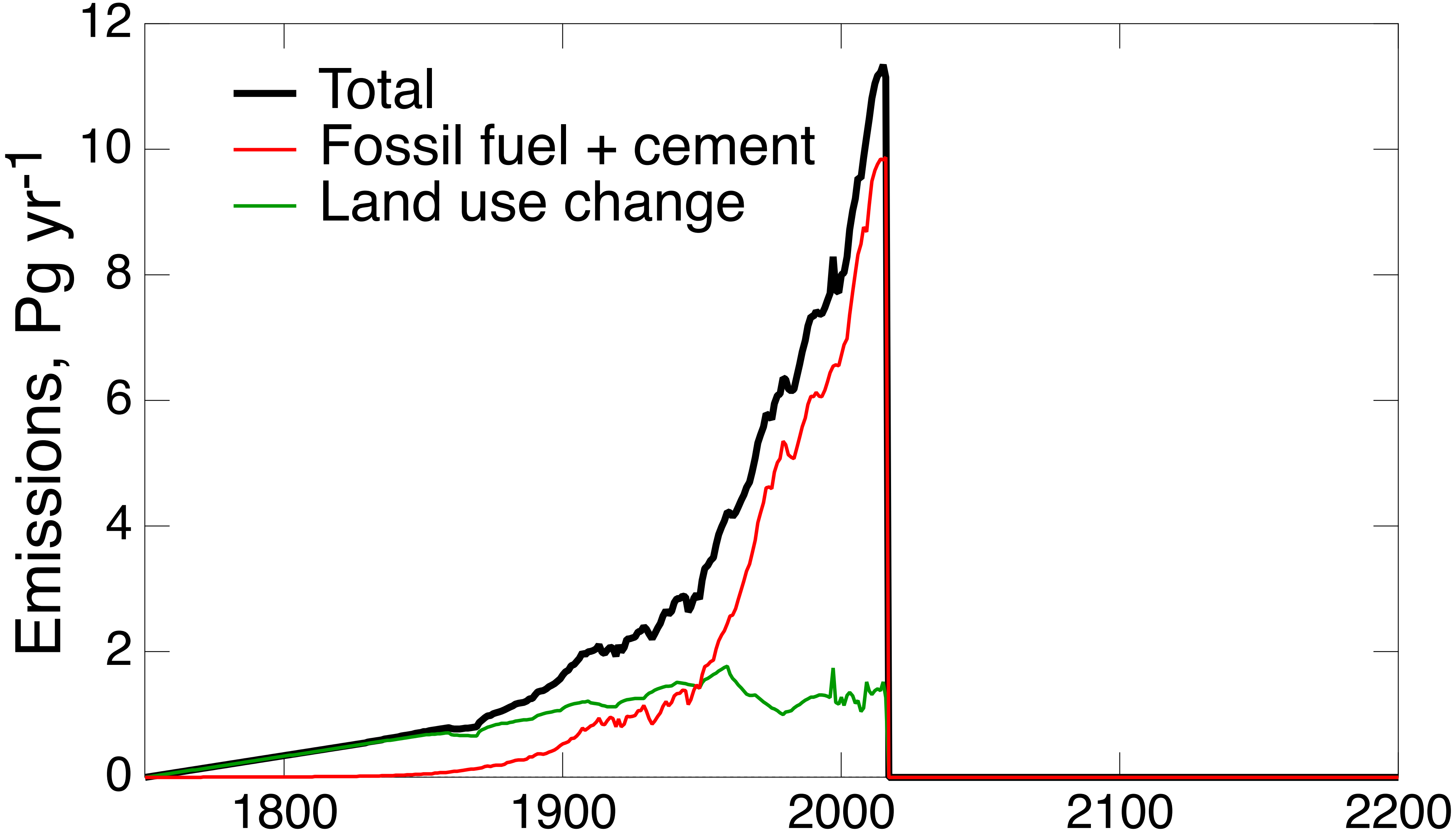
CLIMATE RESPONSE TO ABRUPT CESSATION OF FORCING

Global mean surface temperature responds substantially in 4-6 years



Held et al., *J. Clim.*, 2010

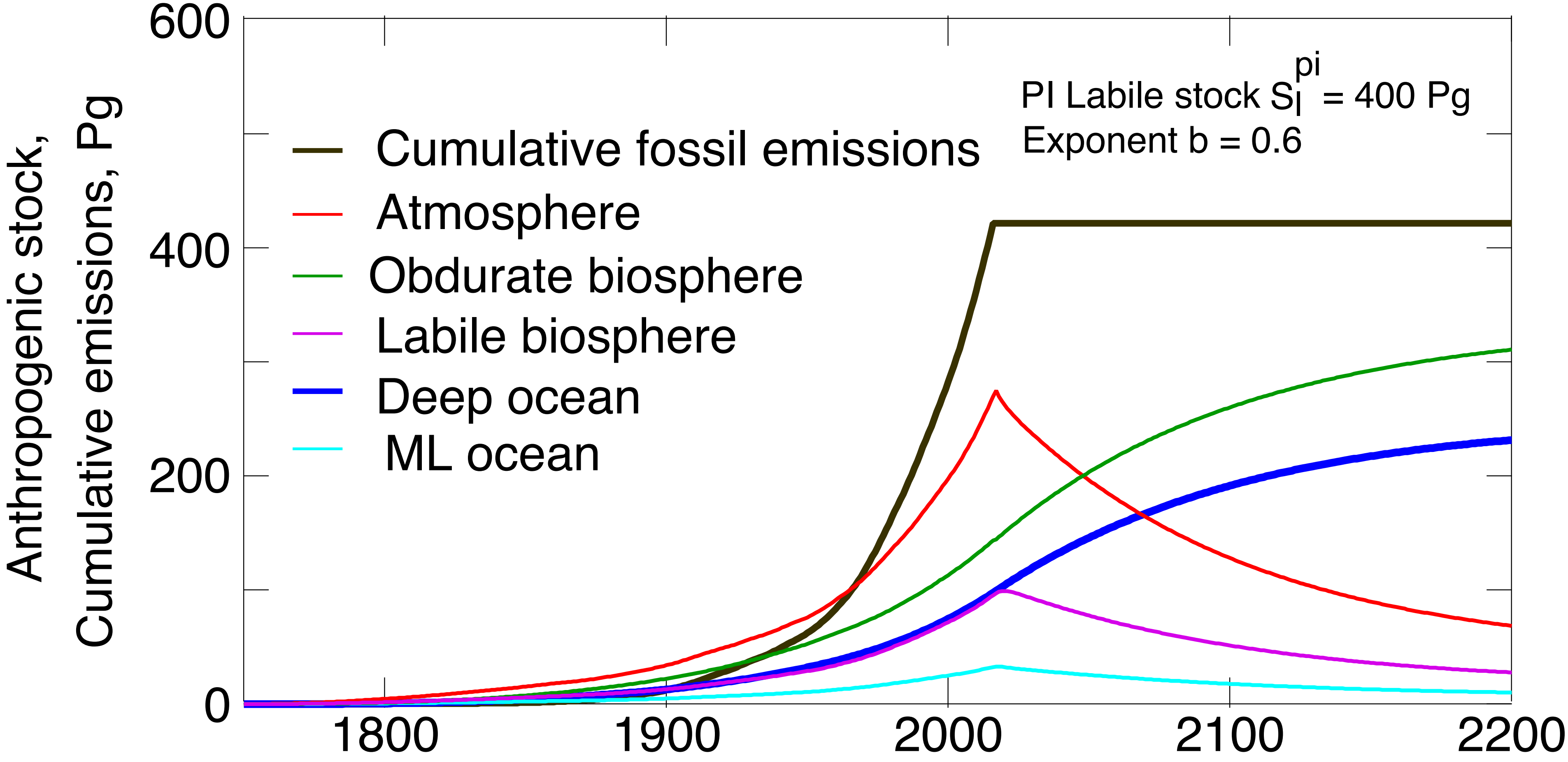
ABRUPT CESSATION OF ANTHROPOGENIC CO_2 EMISSIONS



Examine CO_2 response to abrupt cessation.

MODELED ANTHROPOGENIC STOCKS

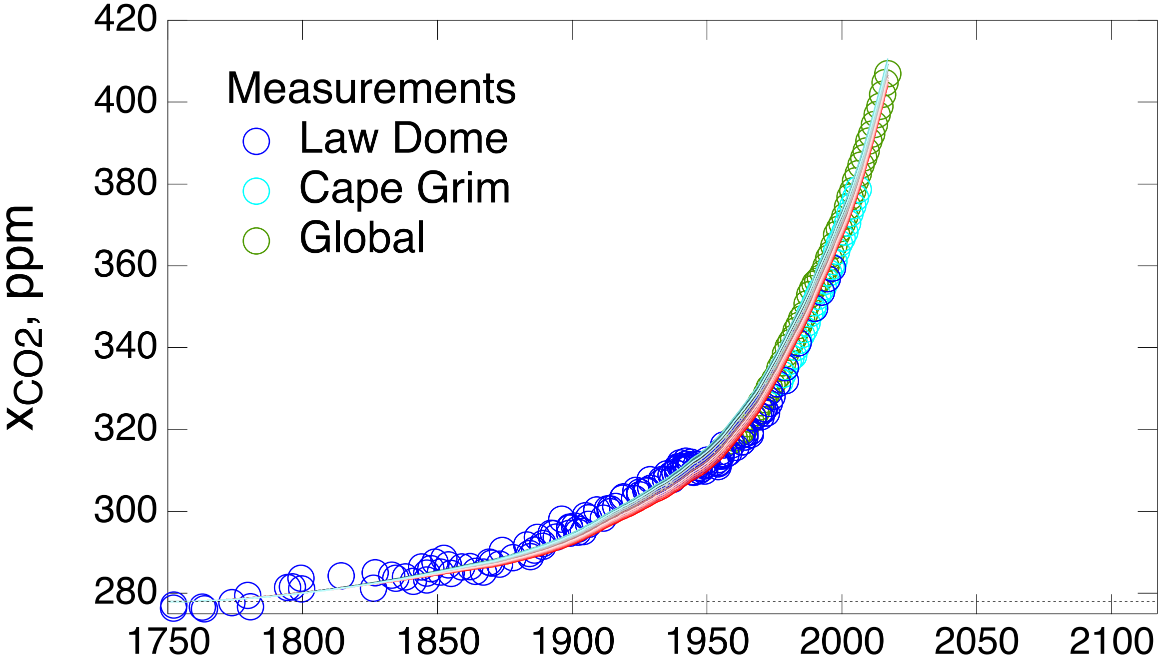
Before and after cessation of emissions



Upon cessation stocks in ML ocean and labile biosphere immediately start to decrease along with atmosphere.

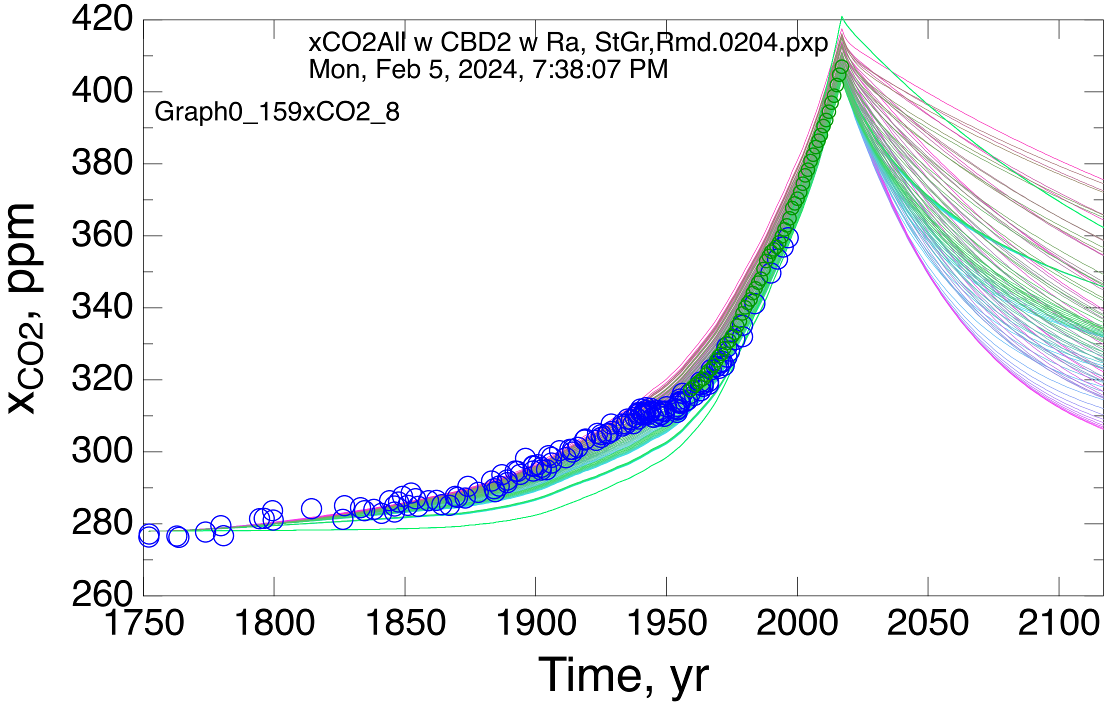
Stocks in deep ocean and obdurate biosphere continue to increase.

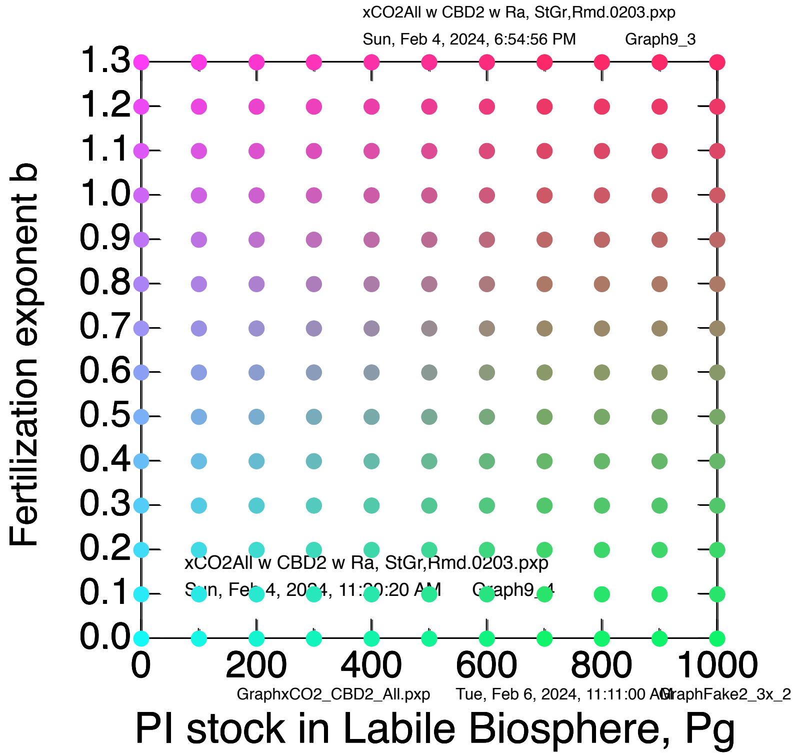
MODELING ATMOSPHERIC CO_2 OVER THE ANTHROPOCENE



Within the range of parameters the model closely approximates observations over the anthropocene.

MODELED CO_2 MIXING RATIO
For all model variants



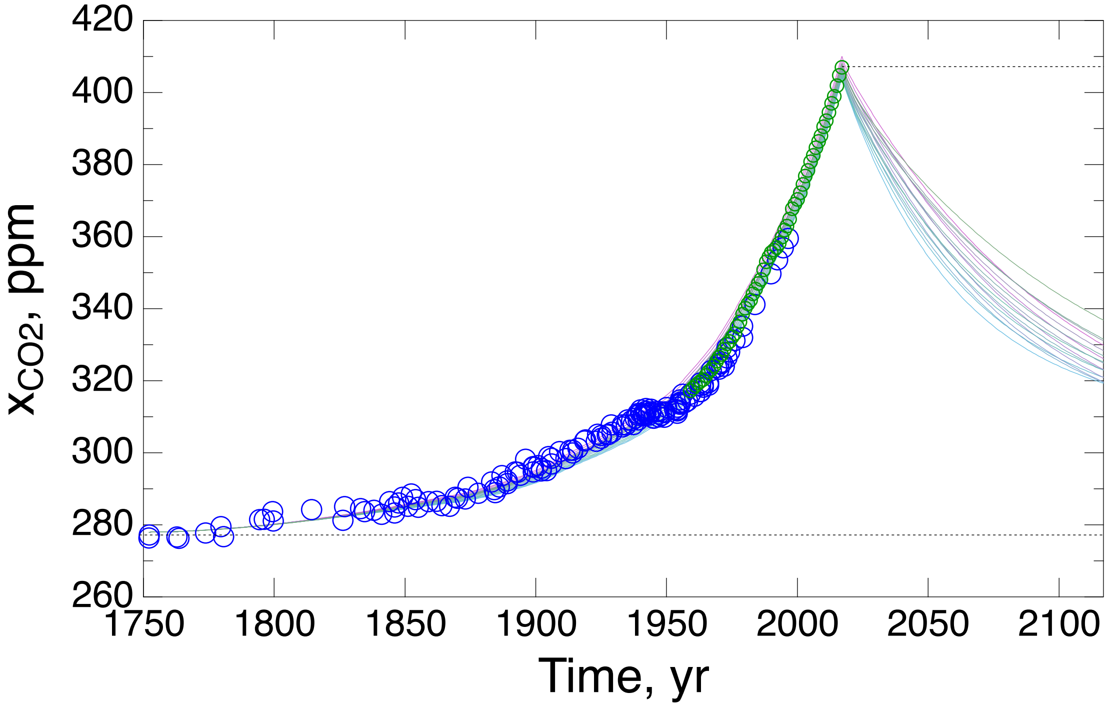


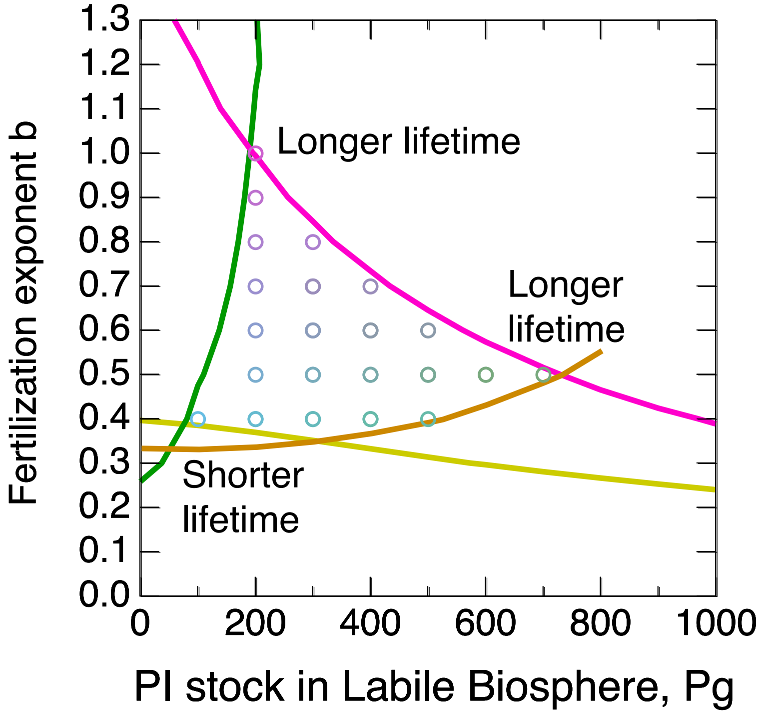
Model does a “pretty good” job of reproducing historical observations for all model variants.

Profiles of CO_2 subsequent to abrupt cessation of emissions diverge greatly.

MODELED CO_2 MIXING RATIO

As constrained by observations of atmospheric CO2 and atmospheric and oceanic radiocarbon

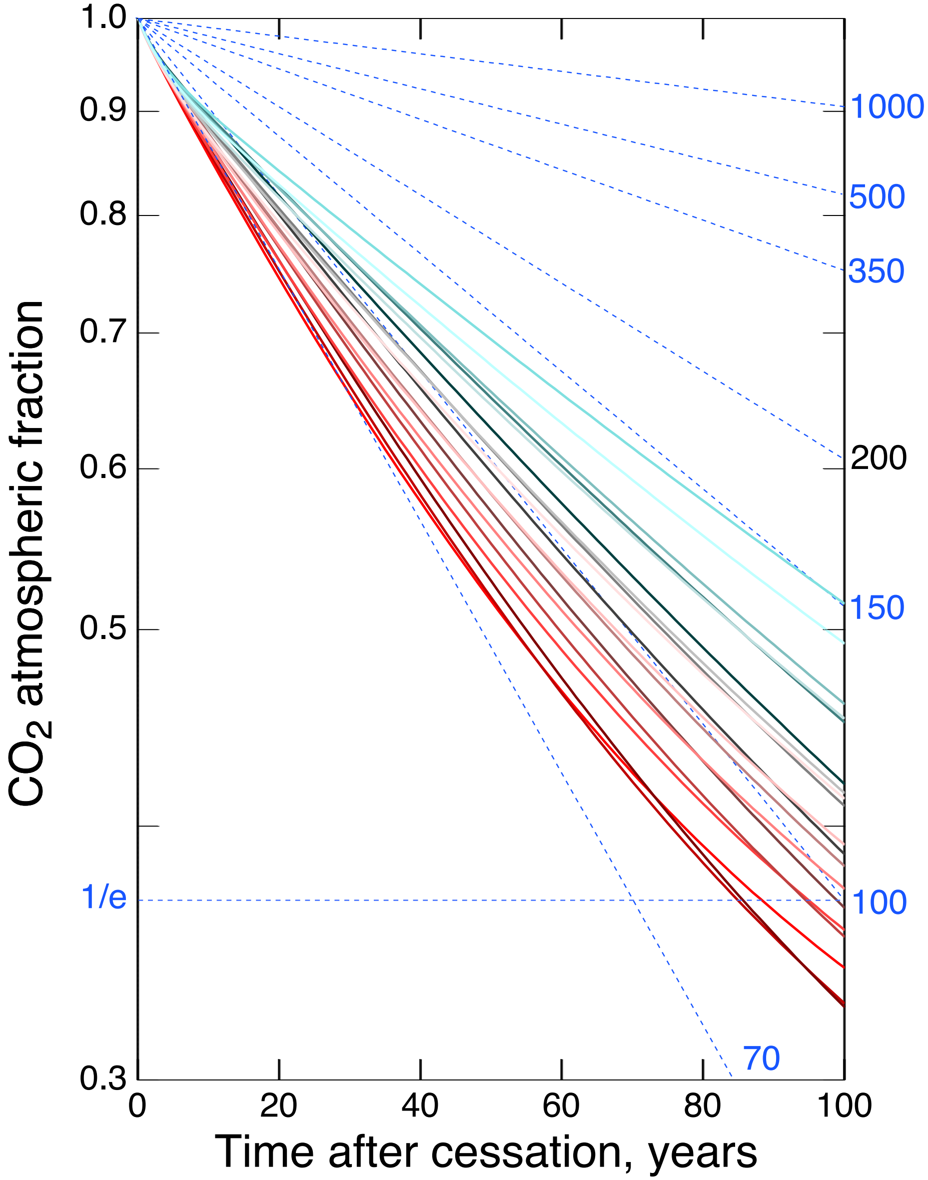


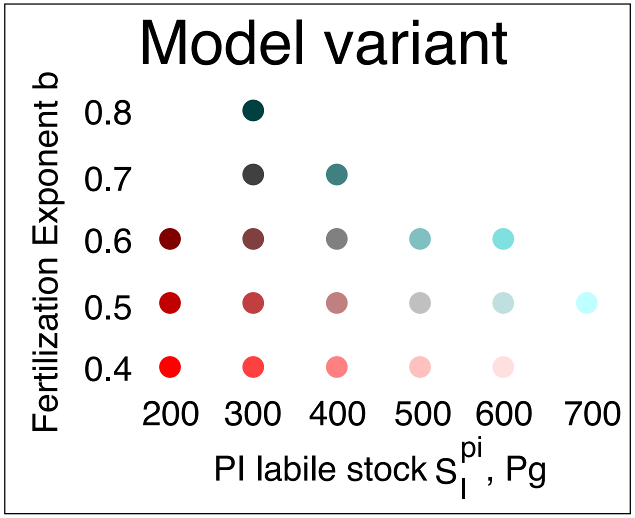


Model does a much better job of reproducing historical observations.

Profiles of CO_2 subsequent to abrupt cessation of emissions diverge much less.

DECAY OF EXCESS ATMOSPHERIC CO_2 AFTER ABRUPT CESSATION OF EMISSIONS





Following abrupt cessation of emissions, excess atmospheric CO_2 decreases toward zero (i.e., preindustrial value) approximately exponentially.

Time constants characterizing decrease, for variants of present model consistent with observations, range from about 85 to 150 years.

Fraction remaining at 100 yr = 0.40 ± 0.05 (1 s.d.)

ZERO EMISSIONS COMMITMENT

Changes in CO_2 and global temperature after abrupt cessation of CO_2 emissions

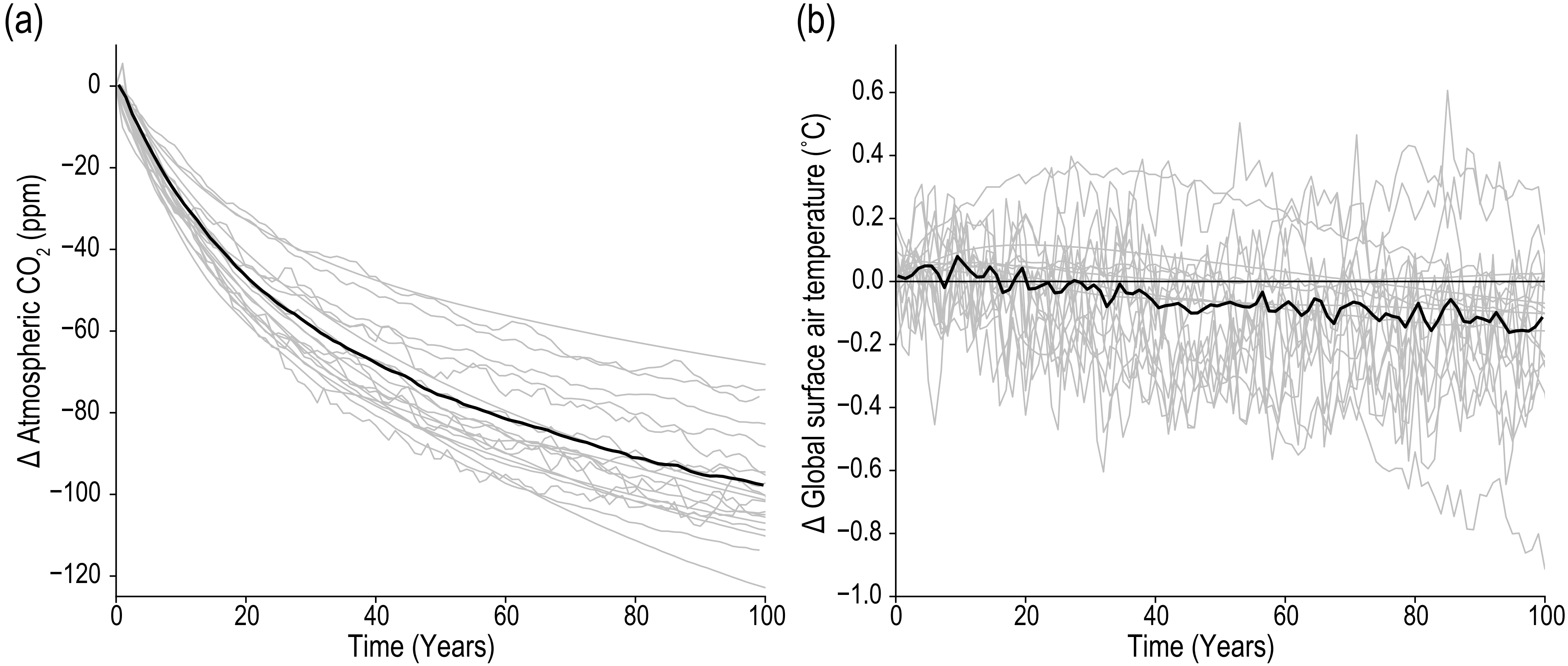
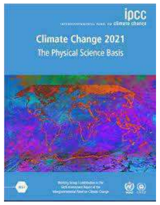


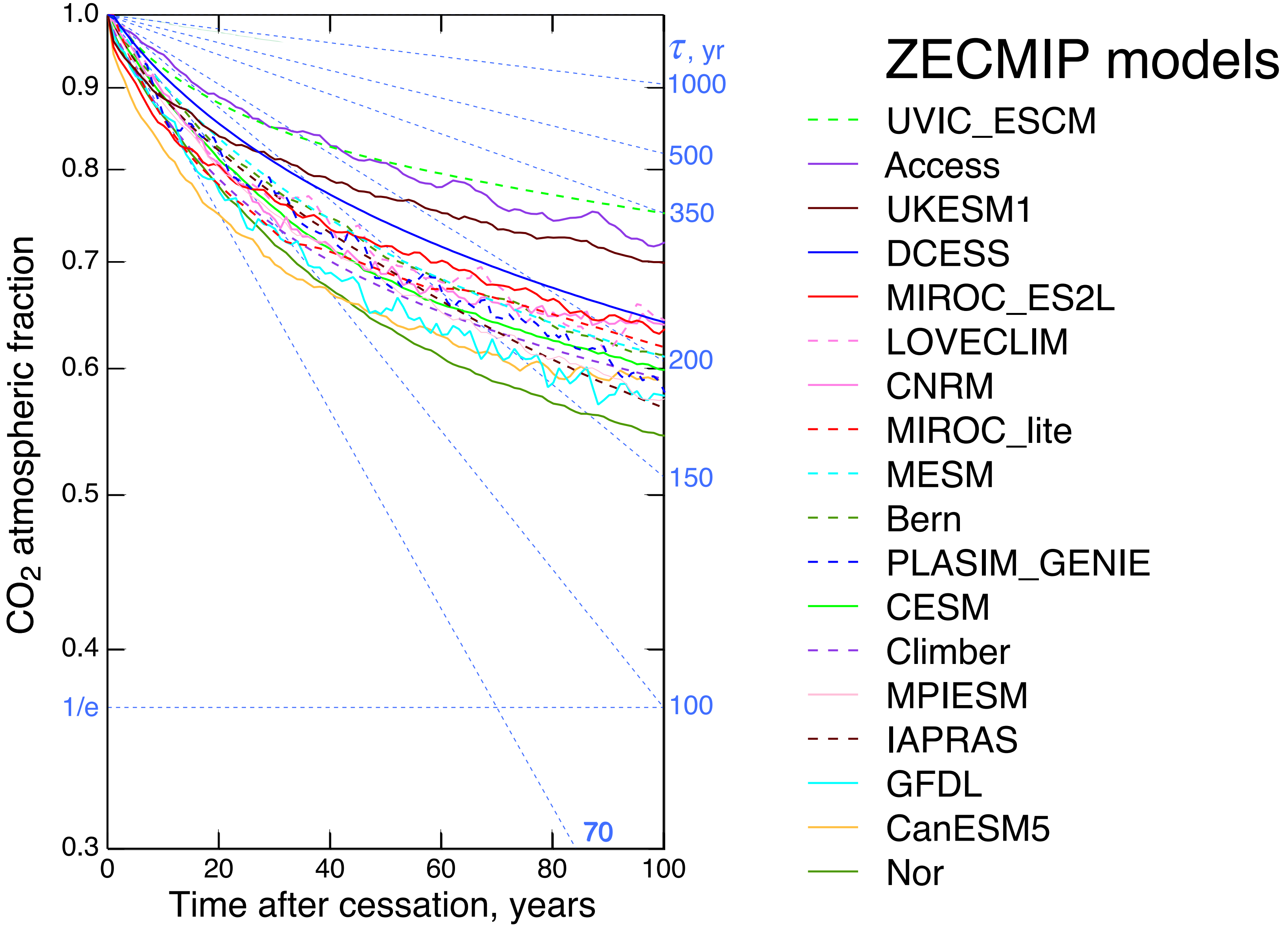
Figure 4.39 I Zero emissions commitment. Changes in (a) atmospheric CO2 concentration and (b) evolution of global surface air temperature (GSAT) following cessation of CO2 emissions (MacDougall et al., 2020). Multi-model mean is shown as thick black line, individual model simulations are in grey.



IPCC - AR6 - Fig 4.39, 2021

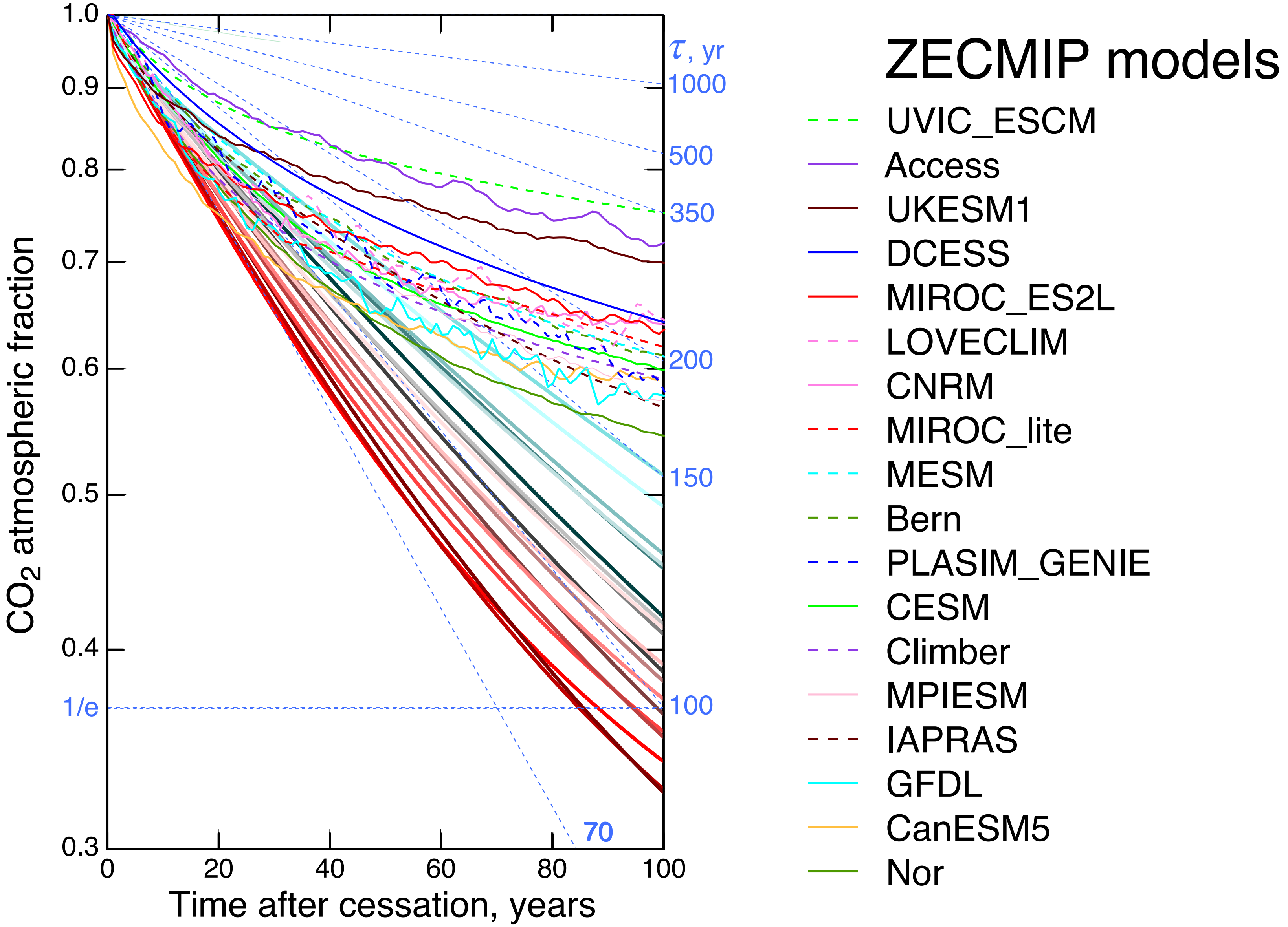
DECAY OF EXCESS ATMOSPHERIC CO
AFTER ABRUPT CESSATION OF EMISSIONS

Zero Emissions Commitment Intercomparison (MacDougall, 2020)



Fraction remaining at 100 yr = 0.73 ± 0.05 (1 s.d.)

DECAY OF EXCESS ATMOSPHERIC CO
AFTER ABRUPT CESSATION OF EMISSIONS
Zero Emissions Commitment Intercomparison (MacDougall, 2020)



Present results exhibit much faster decay than ZECMIP models.

MEASURES OF LIFETIME
(ADJUSTMENT TIME)

$f(t)$ is fraction of initial quantity remaining at time t after cessation of emissions

Instantaneous

$$\tau_{\mathrm{i}}(t) = -1 / d \ln f(t) / dt$$

Local in time

Requires taking derivative

Equivalent 1/*e* lifetime

$$\tau_{\mathrm{e}}(t) = -t / \ln(f(t))$$

$$\tau_{\mathrm{e}}(100\ \mathrm{yr}) = -100\ \mathrm{yr} / \ln(f(100\ \mathrm{yr}))$$

Measure of decrease over entire time *t* since cessation

Does not require taking derivative

Analogous to relation between half-life and 1/*e* lifetime

ADJUSTMENT TIMES

Comparison with previous studies

Equivalent 1/*e* lifetimes over initial
100 years subsequent to cessation

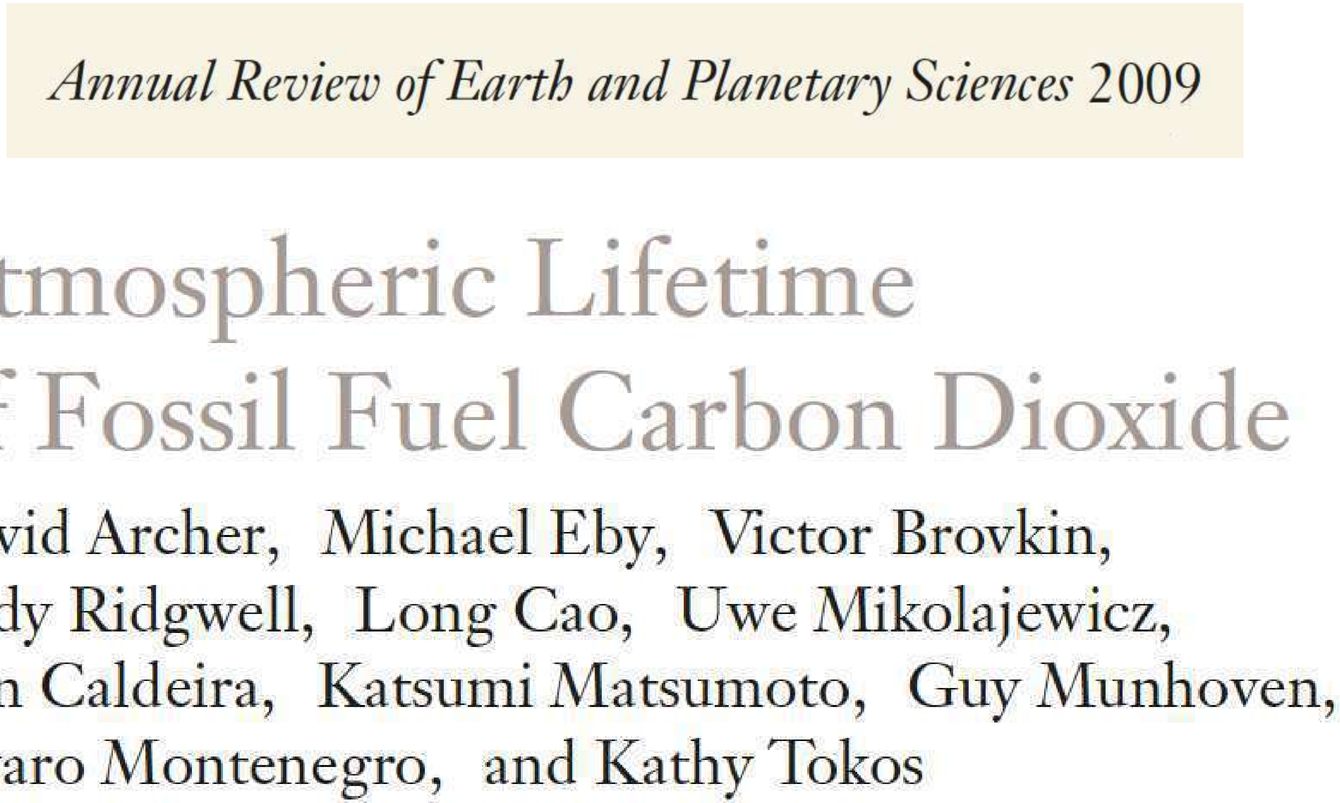
Mean ± standard deviation, yr

ZECMIP MODELS	Present model variants
337 ± 83	111 ± 17

Present model gives lifetime a factor of 3 shorter.

This would be good news, if correct!

LIFETIME – A PRACTICAL DEFINITION



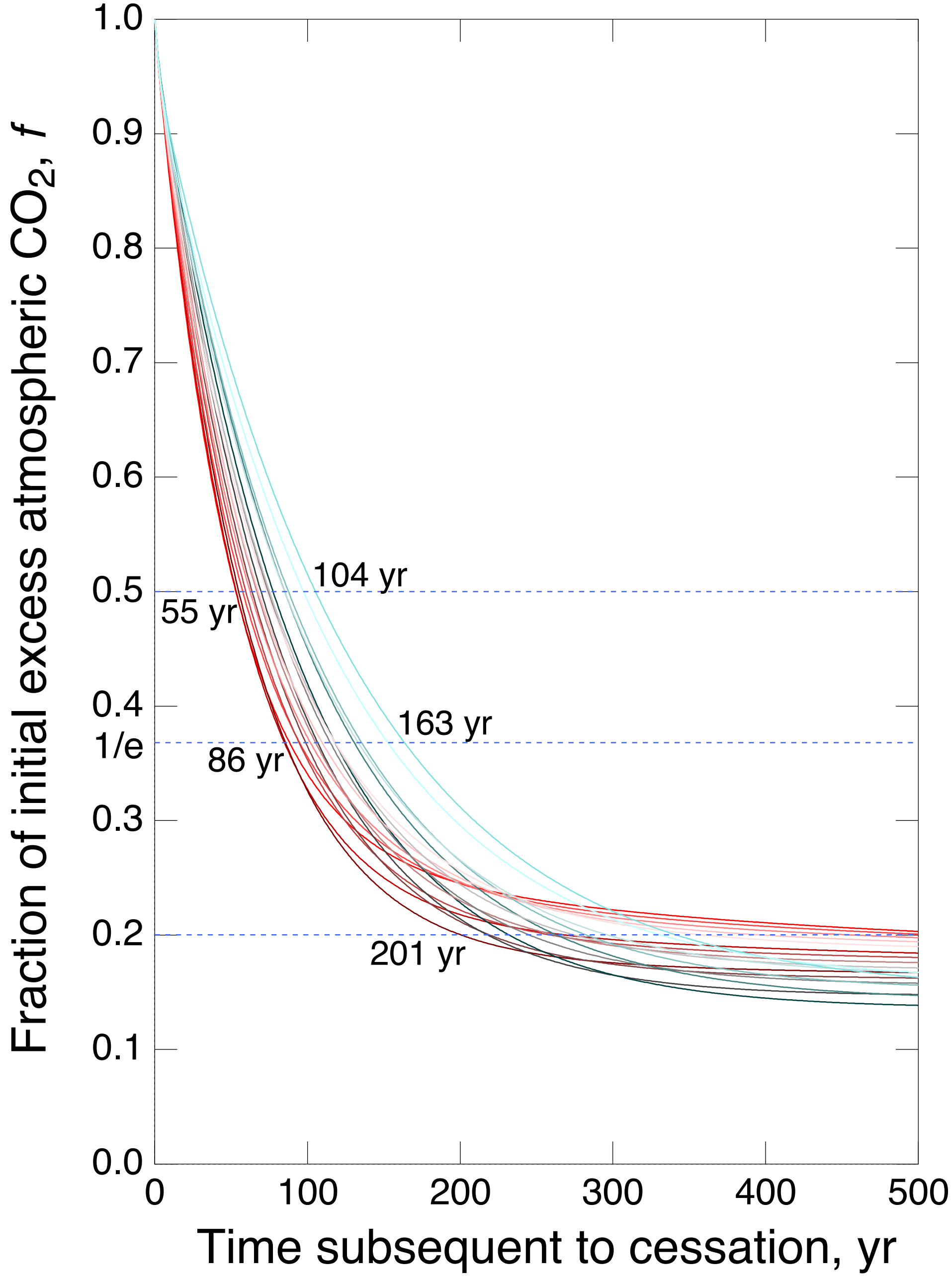
Annual Review of Earth and Planetary Sciences 2009

Atmospheric Lifetime
of Fossil Fuel Carbon Dioxide

David Archer, Michael Eby, Victor Brovkin,
Andy Ridgwell, Long Cao, Uwe Mikolajewicz,
Ken Caldeira, Katsumi Matsumoto, Guy Munhoven,
Alvaro Montenegro, and Kathy Tokos

The amount of time it [would take] until the CO_2 concentration in the air recovers substantially toward its original concentration [in the absence of emissions]

DECAY OF EXCESS ATMOSPHERIC CO_2 AT LONG TIME



CO_2 decays substantially on the 100 year time scale.

CO_2 does not decay to preindustrial but levels off at about 15 to 20% of value at cessation.

If this model is more or less correct that would be good news for strategies to reduce global warming by emissions reductions or cessation.

SUMMARY(1)

A 5-compartment budget for CO_2 is developed.

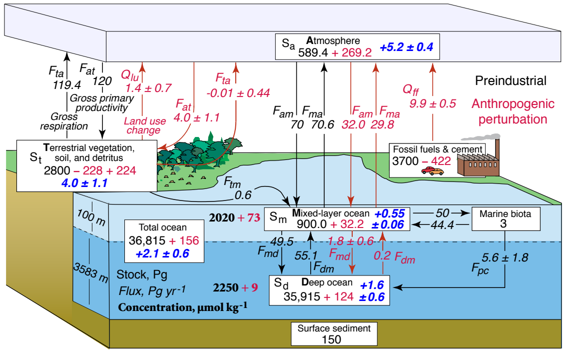
All stocks and fluxes are observationally determined except apportionment between the labile and obdurate biosphere.

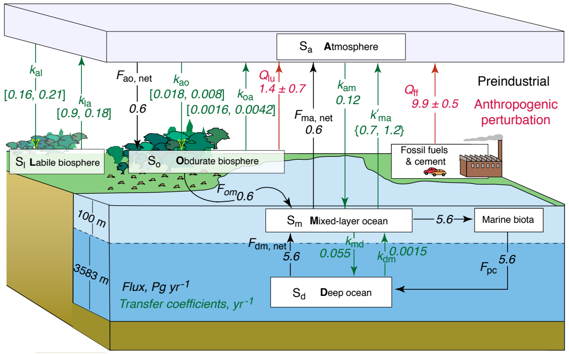
This budget is used to determine transfer coefficients.

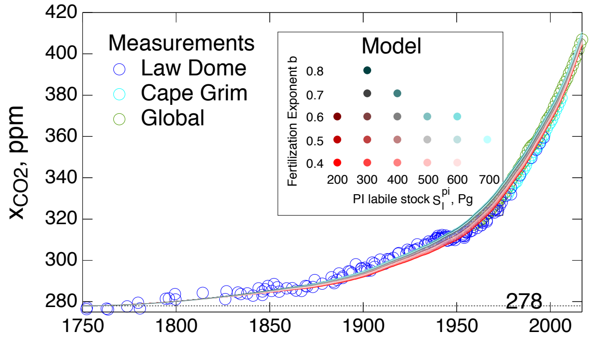
These transfer coefficients are used to evaluate the stocks of CO_2 (and radiocarbon) via a set of ordinary differental equations.

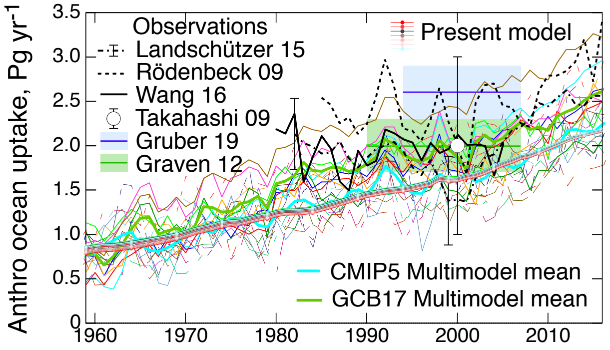
Modeled CO_2 agrees closely with observations. (No surprise). Also radiocarbon.

Modeled ocean uptake flux agrees well with observations.









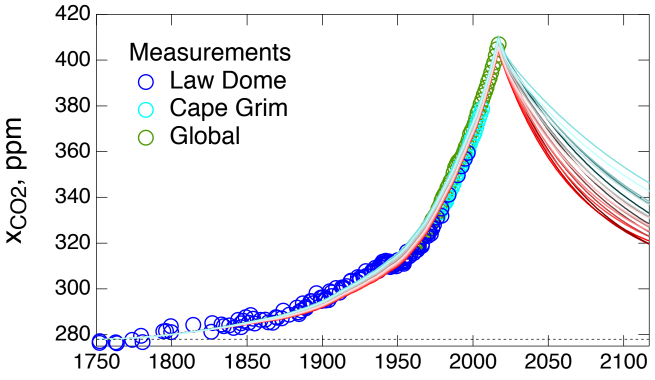
SUMMARY(2)

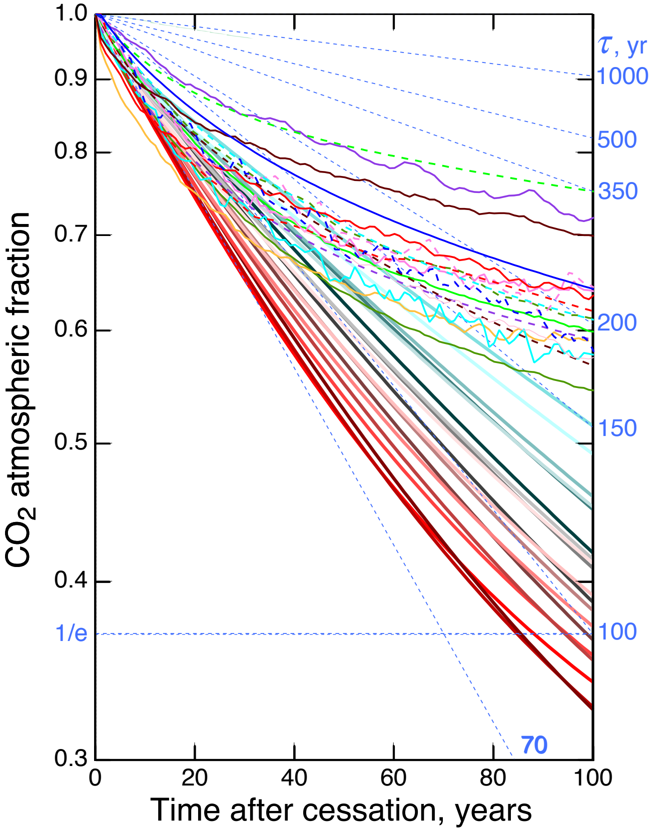
Model is used to examine the consequences of abrupt cessation of anthropogenic CO_2 emissions.

After cessation excess CO_2 decays approximately exponentially (lifetime ~120 ± 30 yr) to a floor of 15-25% of value at time of cessation.

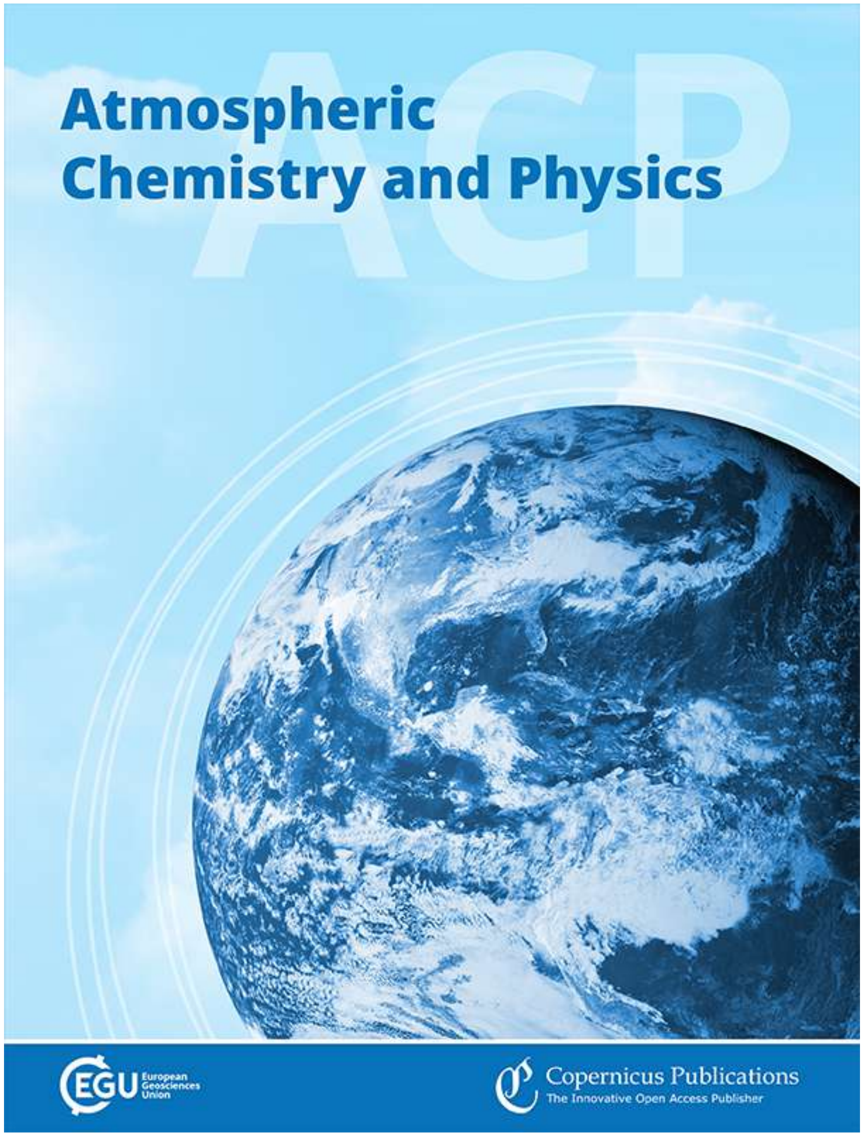
Decay is much more rapid than found with current models.

If this result is roughly correct it would mean that emissions reductions would be effective on the time scale of a human lifespan.





WHY WAS THIS PAPER REJECTED?



“Although many of your arguments are sound in principle, the fact remains that your results appear to overturn many other studies for reasons that have not been identified or quantified.

This is an astonishing result of high importance to policy, . . . so it needs to be explained rather than just reasoned.

I do see scope for a new submission. . . . Such a paper would need to address head on the question “Why is the lifetime of excess CO_2 much shorter than estimated by all current and previous models?”

To do this, one would have to understand and ***refute*** the results of other models rather than ***just providing reasoned arguments*** to believe the alternative model.”

[Emphasis added]

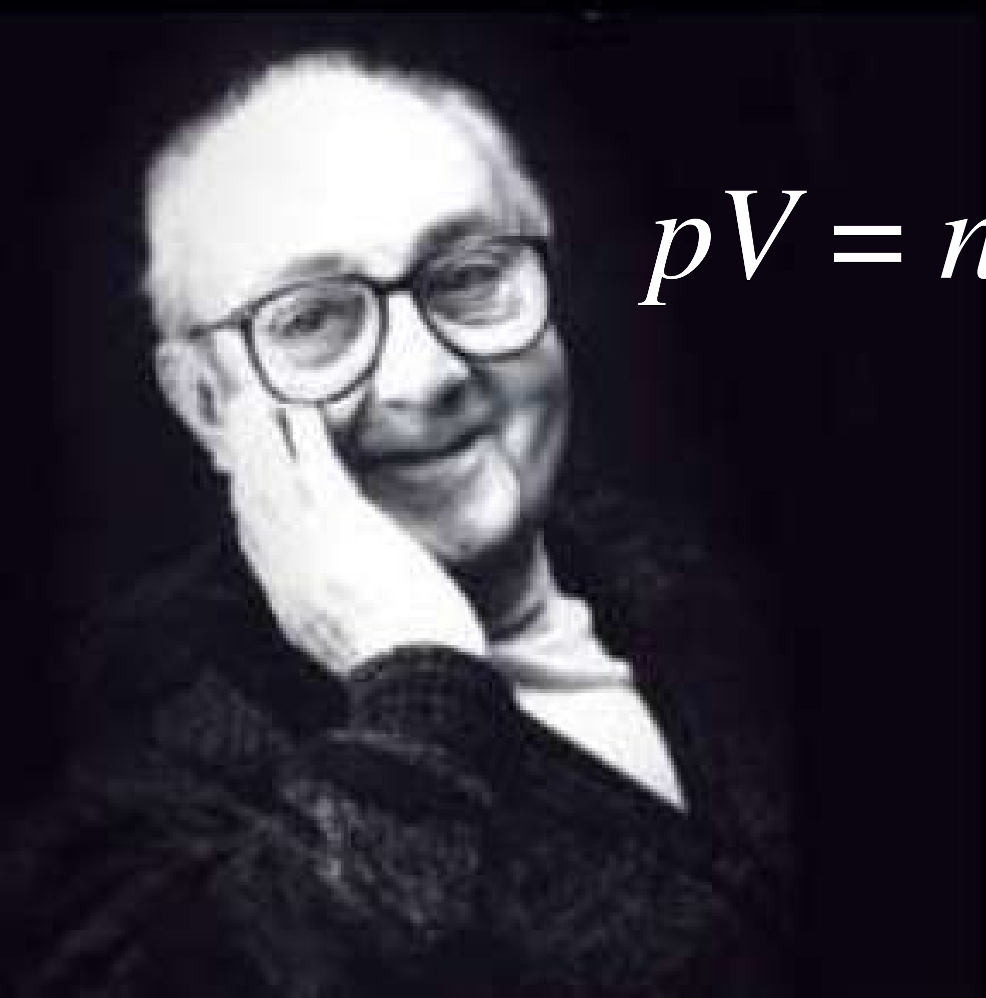
All models are wrong
but some are useful

George E.P. Box

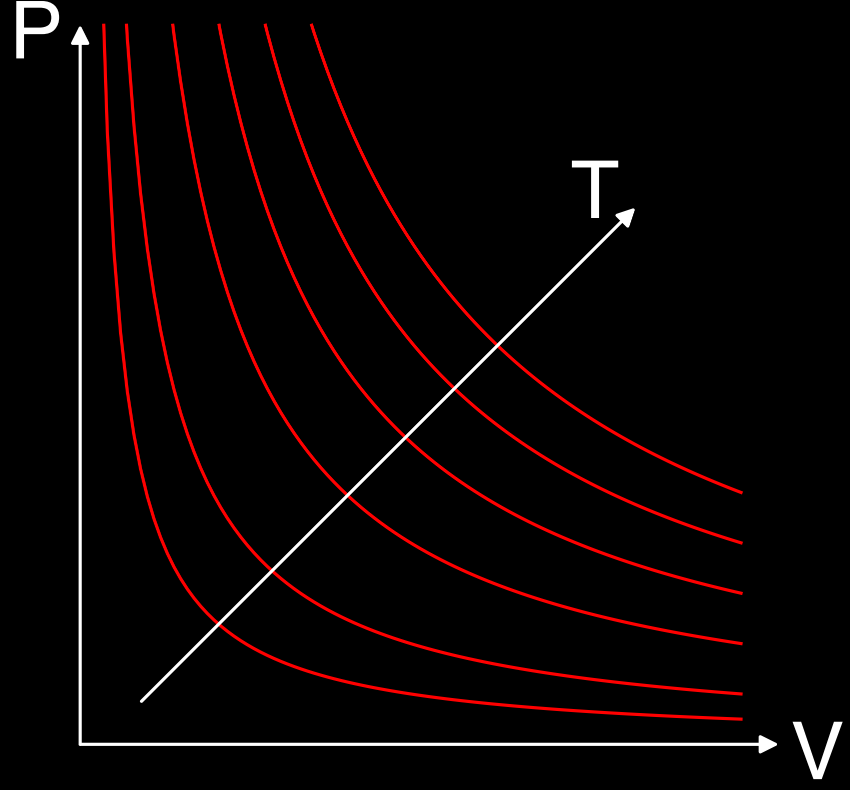
All models are wrong but some are useful

George E.P. Box

All models are wrong but some are useful



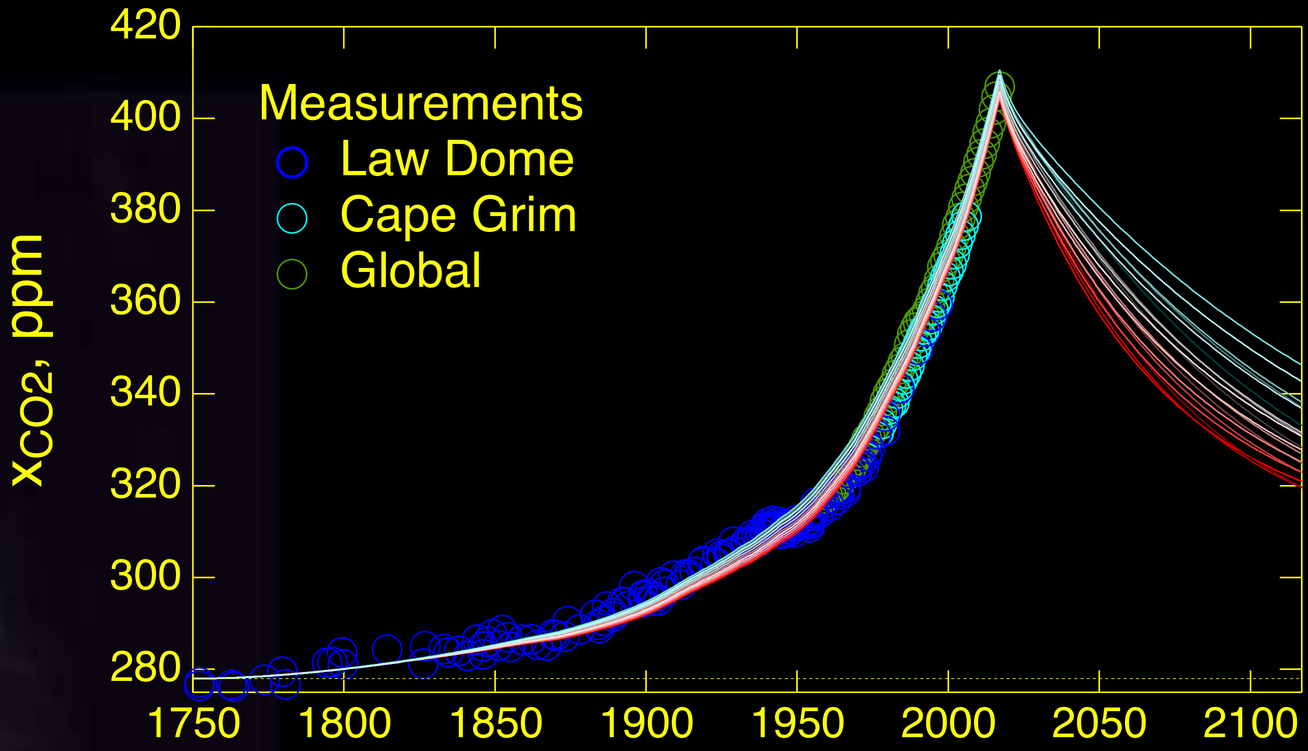
$$pV = nRT$$



George E.P. Box

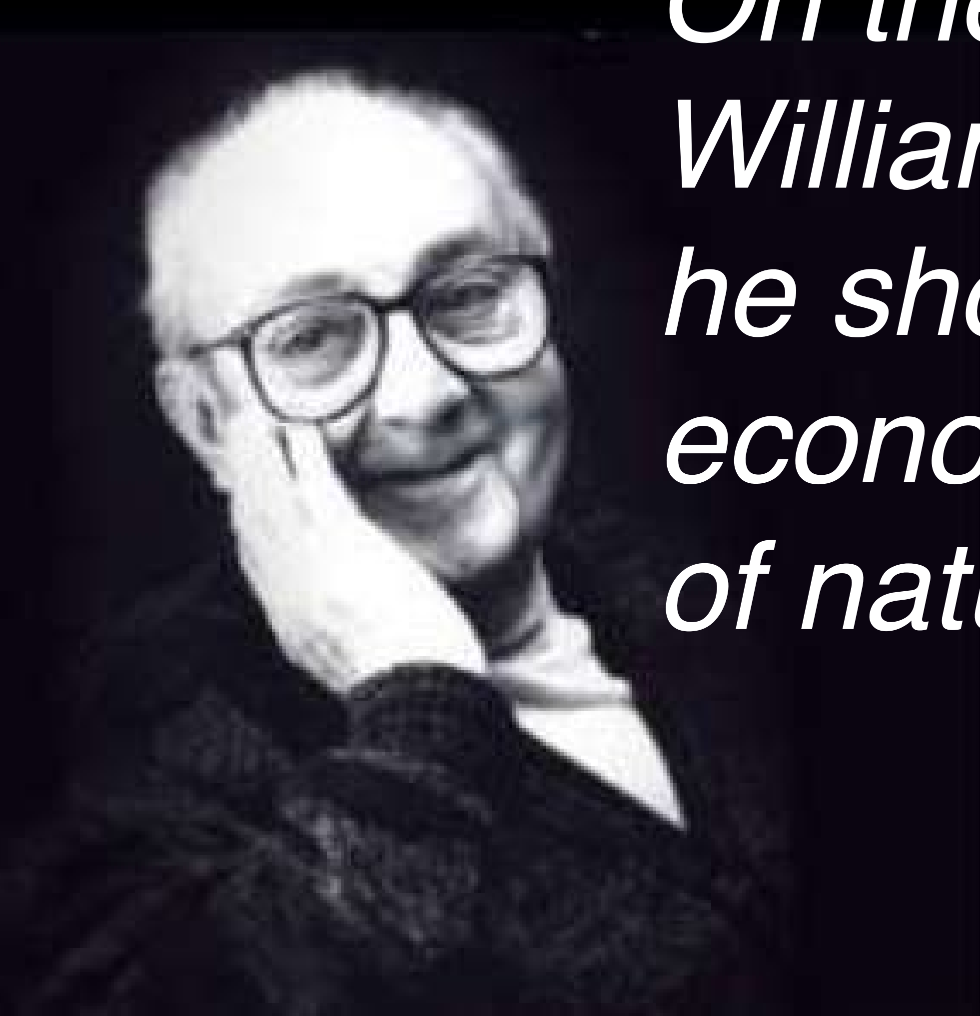
All models are wrong

but some are useful



George E.P. Box

Since all models are wrong, the scientist cannot obtain a "correct" one by excessive elaboration.



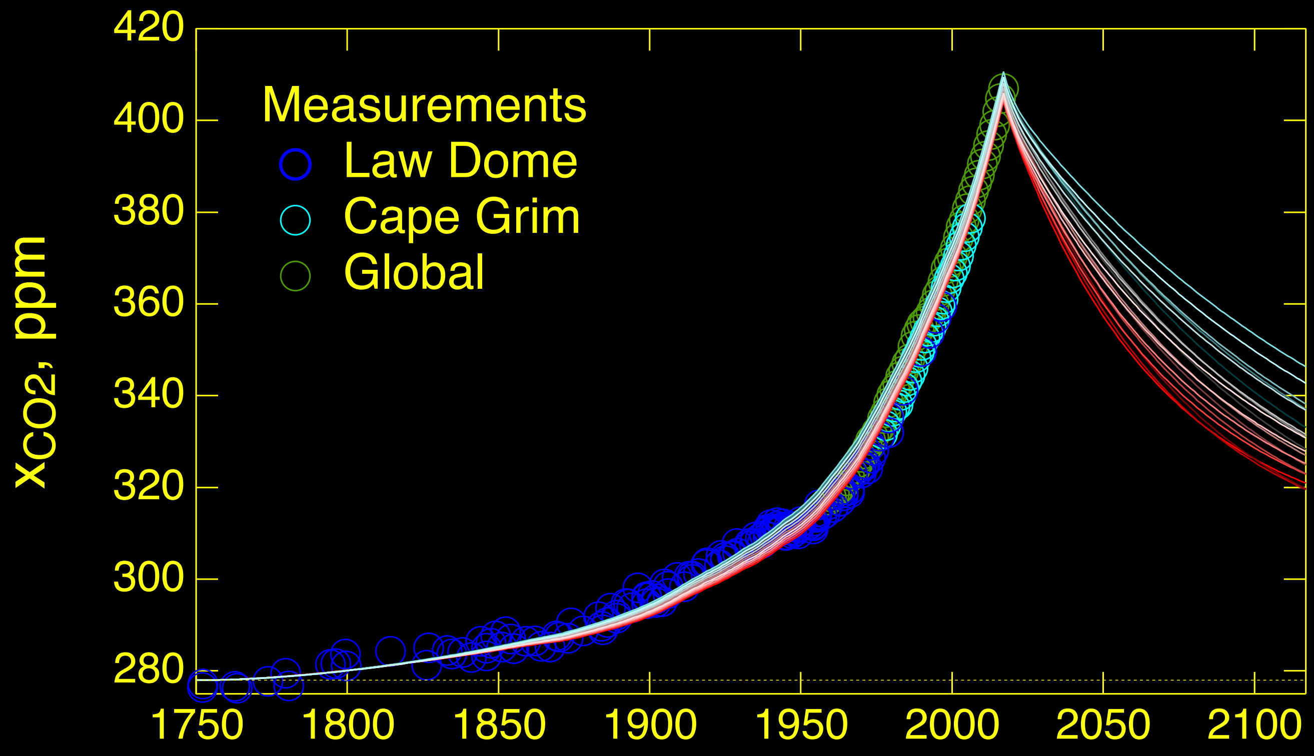
On the contrary, following William of Occam, he should seek an economical description of natural phenomena.

George E.P. Box

Just as the ability to devise simple but evocative models is the signature of the great scientist, so overelaboration and overparameterization is often the mark of mediocrity.

George E.P. Box

Thank you!


420
400
380
360
340
320
300
280
1750
1800
1850
1900
1950
2000
2050
2100
x_{CO2}, ppm
Measurements
○ Law Dome
○ Cape Grim
○ Global

Q & A

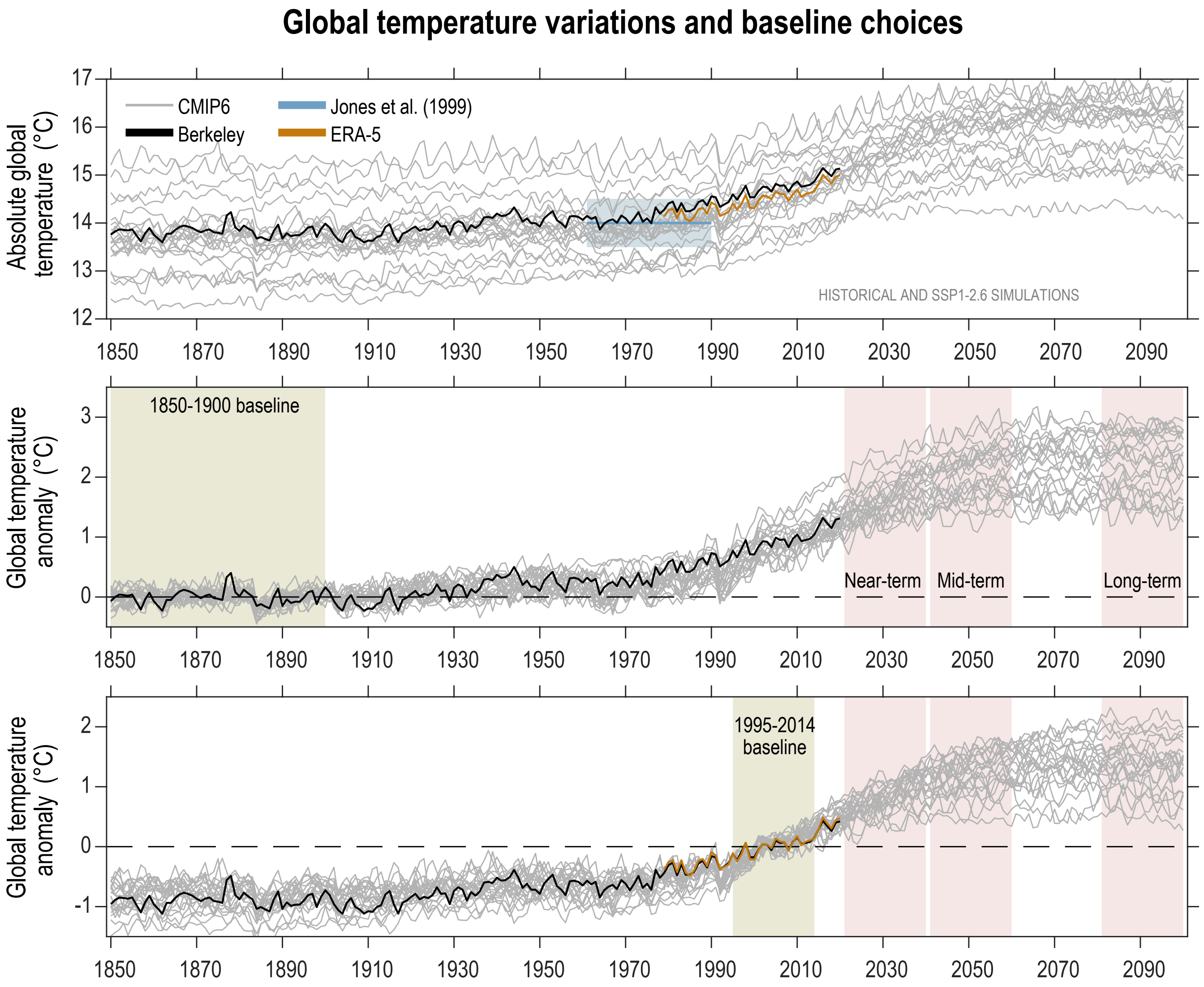
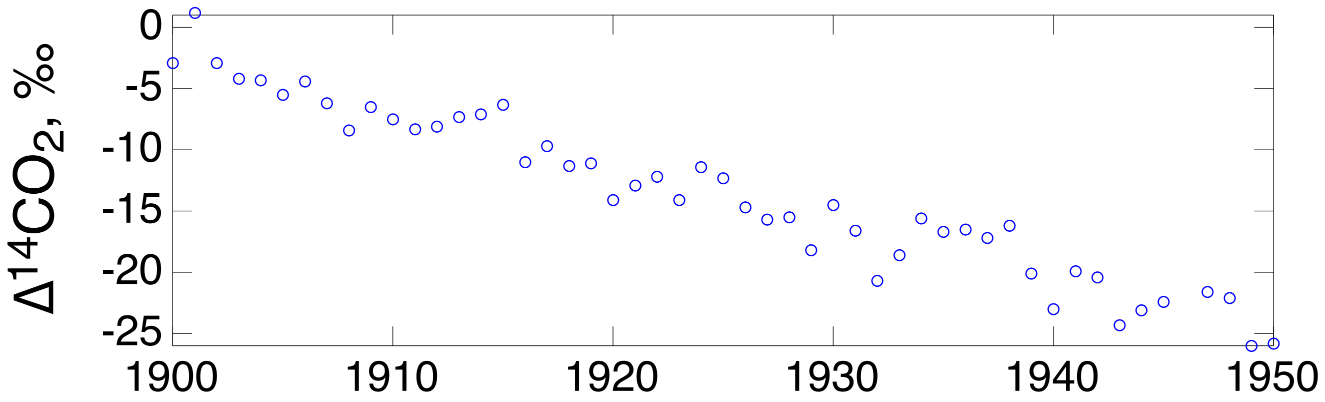
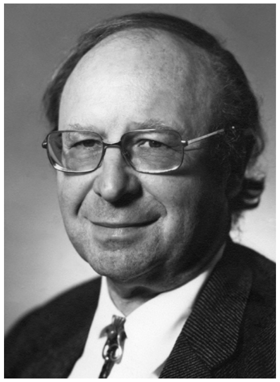


Figure 1.11 I Global mean surface air temperature (GSAT, grey) from a range of CMIP6 historical simulations (1850–2014; 25 models) and SSP1-2.6 (2015–2100) using absolute values (top) and anomalies relative to two different baselines: 1850–1900 (middle) and 1995–2014 (bottom). An estimate of GSAT from a reanalysis (ERA-5, orange, 1979–2020) and an observation-based estimate of global mean surface air temperature (GMST) (Berkeley Earth, black, 1850–2020) are shown.

THE SUESS EFFECT

The decrease in $\Delta^{14}C$ in atmospheric CO_2 due to emissions of fossil fuel CO_2

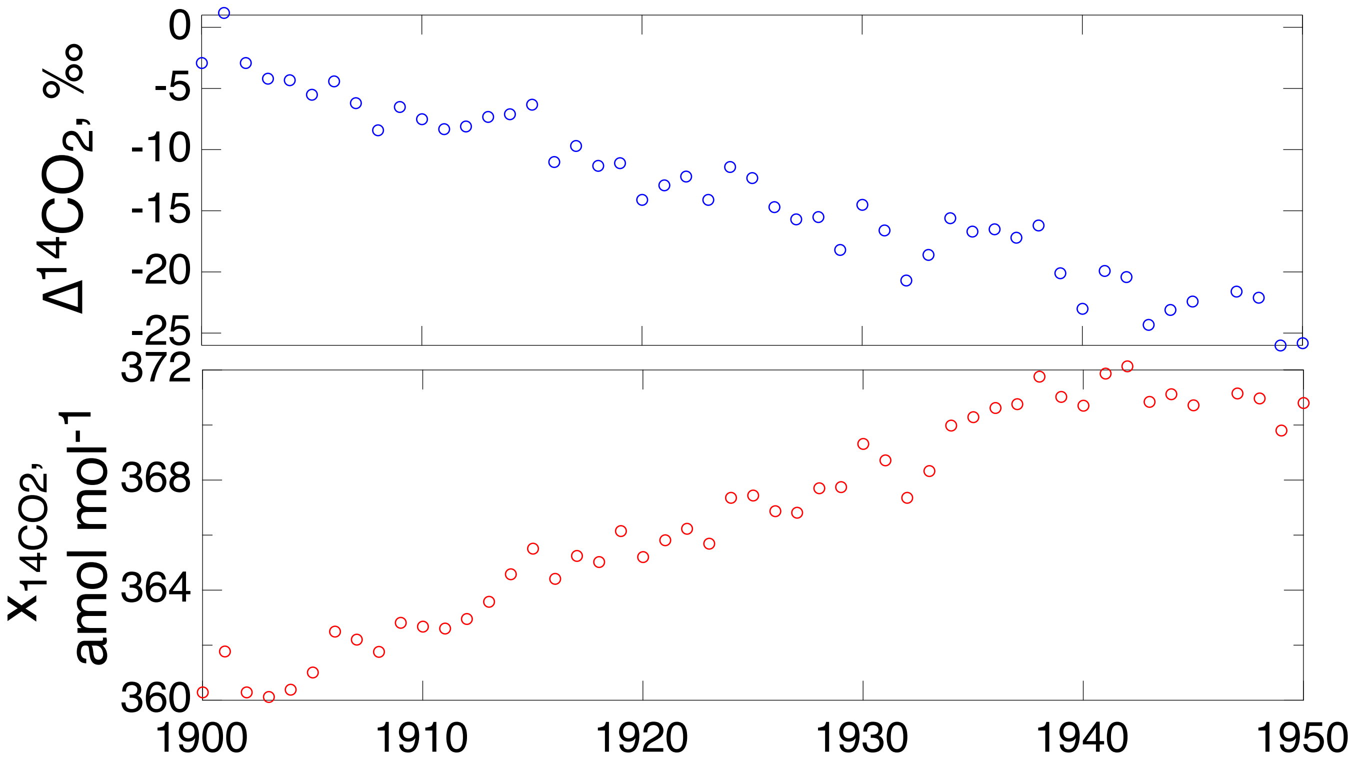


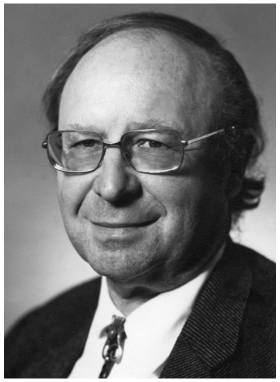


Hans Suess

THE SUESS EFFECT

The decrease in $\Delta^{14}C$ in atmospheric CO_2 due to emissions of fossil fuel CO_2



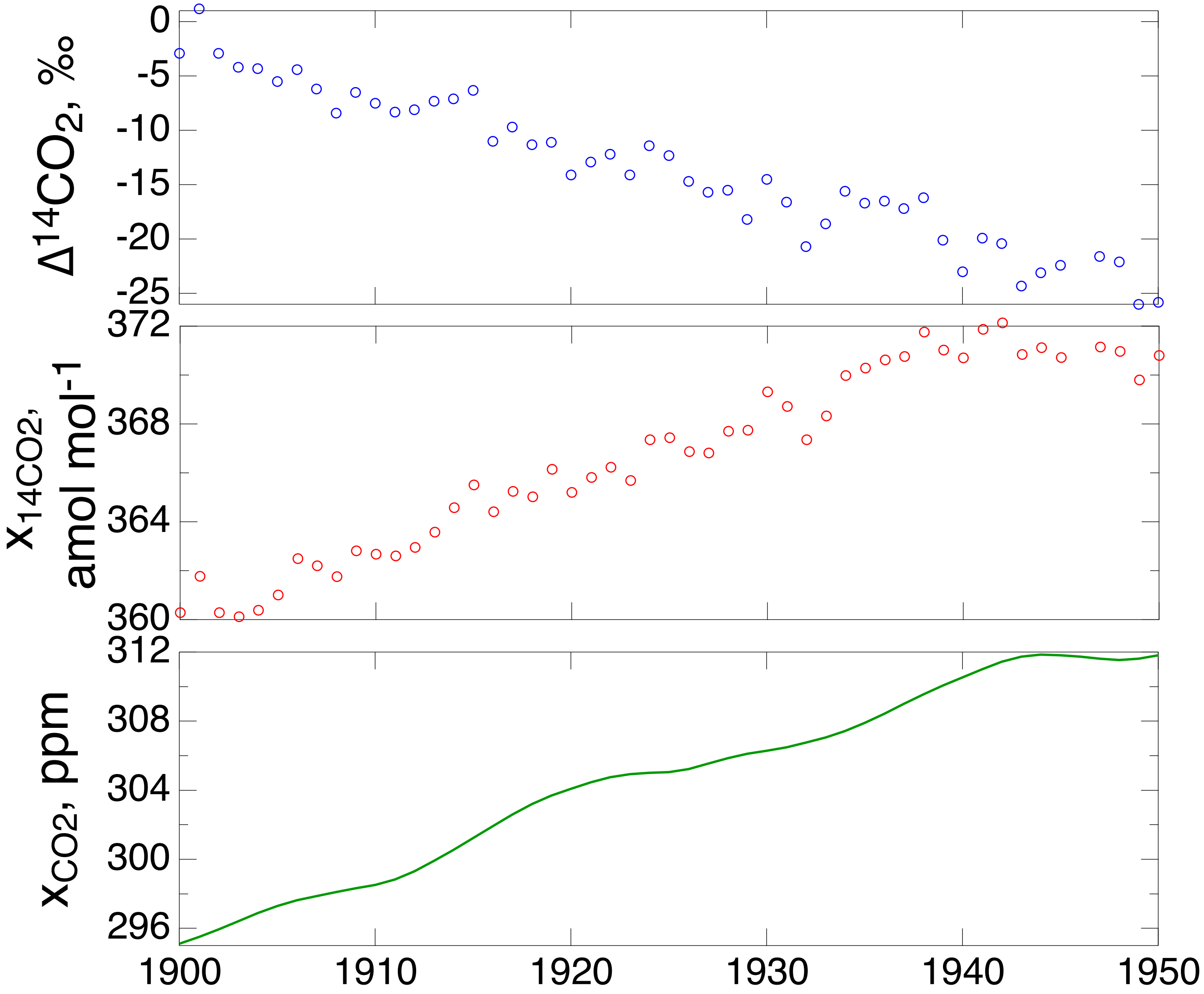


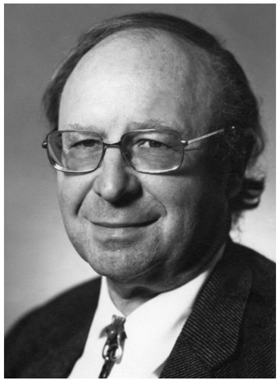
Hans Suess

But the amount of atmospheric CO_2 has actually been increasing. Why?

THE SUESS EFFECT

The decrease in $\Delta^{14}C$ in atmospheric CO_2 due to emissions of fossil fuel CO_2





Hans Suess

Because atmospheric CO_2 has been increasing faster than $\Delta^{14}C$ in atmospheric CO_2 has been decreasing

Schwartz, Hua, Andrews, R. Keeling, Lehman, Turnbull, Reimer, John B. Miller, Meijer, Radiocarbon, in press

SOME PREVIOUS STATEMENTS ABOUT THE LIFETIME OF ANTHROPOGENIC CO_2

Atmospheric Lifetime of Fossil Fuel Carbon Dioxide

David Archer,[1] Michael Eby,[2] Victor Brovkin,[3] Andy Ridgwell,[4] Long Cao,[5] Uwe Mikolajewicz,[3] Ken Caldeira,[5] Katsumi Matsumoto,[6] Guy Munhoven, Alvaro Montenegro,[2] and Kathy Tokos[6]

If we assume that 10% of the fossil fuel remains in the atmosphere until it is neutralized by silicate weathering on a time scale of 100,000 years, then the mean lifetime of fossil fuel CO2 is ~12–14 thousand years.

Ann. Rev. Earth Planet Sci, 2009

Lifetime of Anthropogenic Climate Change: Millennial Time Scales of Potential CO_2 and Surface Temperature Perturbations

M. EBY, K. ZICKFELD, AND A. MONTENEGRO
D. ARCHER K. J. MEISSNER AND A. J. WEAVER

For emissions of less than about 1500 Pg C, most of the CO2 will be absorbed within a few centuries.

J Climate, 2009

THE CO_2 LIFETIME CONCEPT SHOULD BE BANISHED

PIETER P. TANS

Climatic Change, 1997