

What have I done in the past 5 months?

(numerical fun with the global weathering thermostat
and other climate control knobs)

Andy Ridgwell



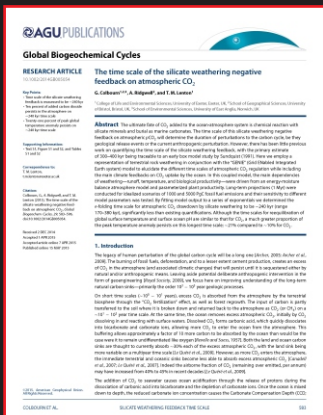
long-term
feedbacks on
atmospheric CO₂



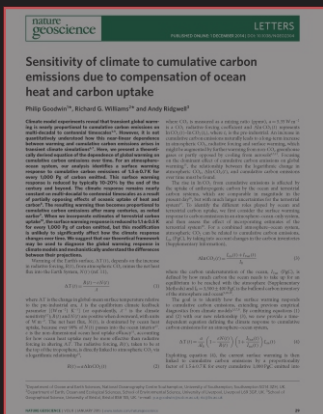


long-term feedbacks on atmospheric CO₂

Lord et al. [in press]



Colbourn et al. [2015]



Goodwin et al. [2015]



An impulse response function for the 'long tail' of excess atmospheric CO₂ in an Earth system model

N. S. Lord¹, A. Ridgway^{1,2}, M. C. Thomas¹ and J. Lunt^{1,3}

¹School of Geographical Sciences, University of Bristol, Bristol, UK;
²Climate Systems, University of Bristol, Bristol BS8 1UJ, UK;
³Department of Earth Sciences, University of California, Riverside, CA, USA

Modeling and Associates Limited, Harncliffe, Bishop Auckland, County Durham, UK

Corresponding author: N. S. Lord, School of Geographical Sciences, University of Bristol, University Road, Clifton, Bristol, BS8 1SS, UK. (Email: Lord@bristol.ac.uk)

Accepted Article

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process which may lead to differences between this version and the Version of Record. Please refer to this article at doi:10.1002/2015gl026194

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Lord et al. [in press]

AGU PUBLICATIONS

Global Biogeochemical Cycles

RESEARCH ARTICLE

The time scale of the silicate weathering negative feedback on atmospheric CO₂

S. Colburn¹, A. Ridgway^{1,2} and N. Lord¹

Abstract The silicate weathering negative feedback is a stabilizing mechanism for atmospheric CO₂ over geological timescales. However, the time scale of this feedback is poorly understood. We use a coupled climate-carbon cycle model to investigate the time scale of the silicate weathering negative feedback. We find that the time scale of the silicate weathering negative feedback is approximately 100,000 years, which is significantly longer than the time scale of the atmospheric CO₂ concentration response to a step change in CO₂ concentration. This result has implications for the interpretation of the geological CO₂ concentration record and for the design of Earth system models.

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Colburn et al. [2015]

nature geoscience

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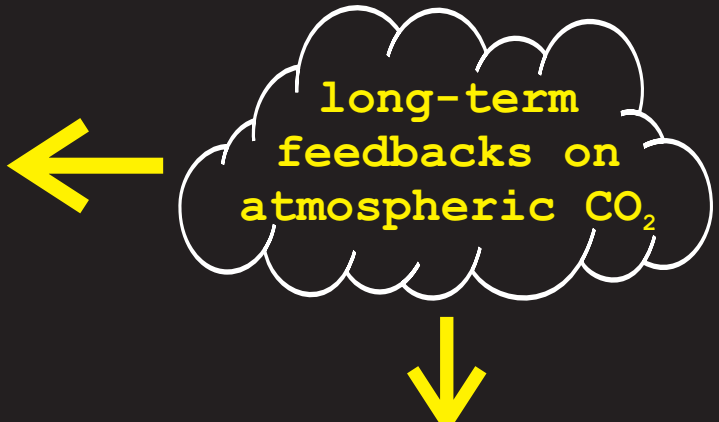
Sensitivity of climate to cumulative carbon emissions due to compensation of ocean heat and carbon uptake

Philip Goodwin¹, Richard G. Williams¹ and Andy Ridgway¹

Abstract The sensitivity of climate to cumulative carbon emissions is a key question in Earth system science. We use a coupled climate-carbon cycle model to investigate the sensitivity of climate to cumulative carbon emissions. We find that the sensitivity of climate to cumulative carbon emissions is significantly higher than the sensitivity of climate to annual carbon emissions. This result has implications for the interpretation of the geological CO₂ concentration record and for the design of Earth system models.

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Goodwin et al. [2015]



RESEARCH ARTICLE

CLIMATE CHANGE

Combustion of available fossil fuel resources sufficient to eliminate the Antarctic ice Sheet

K. Winkelman^{1,2}, A. Ridgway^{1,2}, J. Lunt^{1,2} and N. Lord^{1,2}

Abstract The Antarctic ice sheet is a major component of the Earth system. We use a coupled climate-carbon cycle model to investigate the impact of the combustion of available fossil fuel resources on the Antarctic ice sheet. We find that the combustion of available fossil fuel resources is sufficient to eliminate the Antarctic ice sheet. This result has implications for the interpretation of the geological CO₂ concentration record and for the design of Earth system models.

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Winkelman et al. [2015]

nature geoscience

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How warming and ice melt affect the carbon cycle

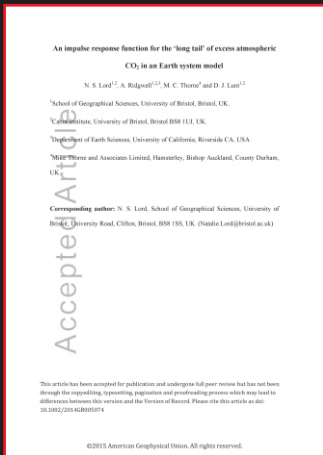
Richard G. Williams¹, Philip Goodwin¹ and Andy Ridgway¹

Abstract The carbon cycle is a key component of the Earth system. We use a coupled climate-carbon cycle model to investigate the impact of warming and ice melt on the carbon cycle. We find that warming and ice melt significantly affect the carbon cycle. This result has implications for the interpretation of the geological CO₂ concentration record and for the design of Earth system models.

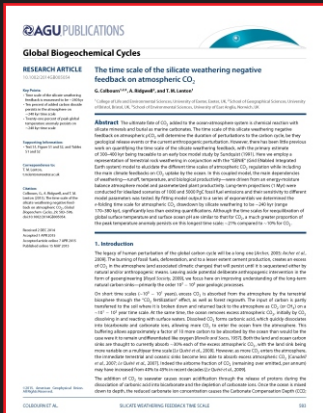
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Williams et al. [2012]

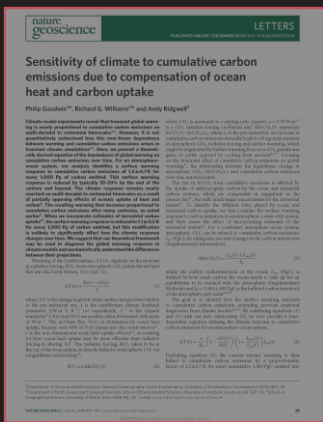




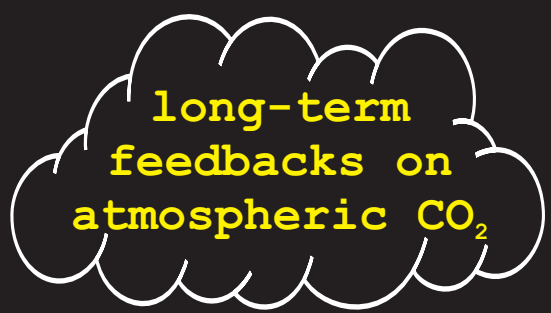
Lord et al. [in press]



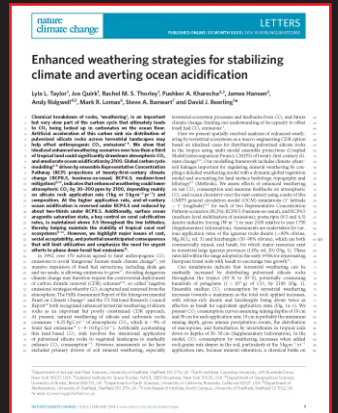
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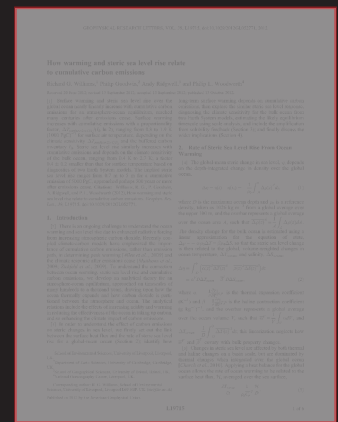
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Taylor et al. [in press]



Williams et al. [2012]

Talk outline: PALEO

GEO250.2015

Accepted Article

An impulse response function for the 'long tail' of excess atmospheric CO₂ in an Earth system model

N. S. Lord¹, A. Ridgway^{1,2}, M. C. Thomas¹ and J. Lunt^{1,2}

¹School of Geographical Sciences, University of Bristol, Bristol, UK.
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⁴McDermott and Associates Limited, Harnbury, Bobsy, Australia, County Durham, UK

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Lord et al. [in press]

AGU PUBLICATIONS

Global Biogeochemical Cycles

RESEARCH ARTICLE

The times scale of the silicate weathering negative feedback on atmospheric CO₂

S. Colburn¹, A. Ridgway^{1,2} and M. Lomas¹

Abstract The silicate weathering negative feedback on atmospheric CO₂ is a stabilizing mechanism that is essential to the long-term stability of Earth's climate. However, the timescale of this feedback is poorly understood. We use a coupled Earth system model to investigate the timescale of the silicate weathering negative feedback on atmospheric CO₂. We find that the timescale of the silicate weathering negative feedback is on the order of 10⁵ years, which is significantly longer than the timescale of the atmospheric CO₂ concentration response to a step change in CO₂ concentration. This implies that the silicate weathering negative feedback is a slow-acting mechanism that is essential to the long-term stability of Earth's climate.

10 November 2015

Colburn et al. [2015]

nature geoscience

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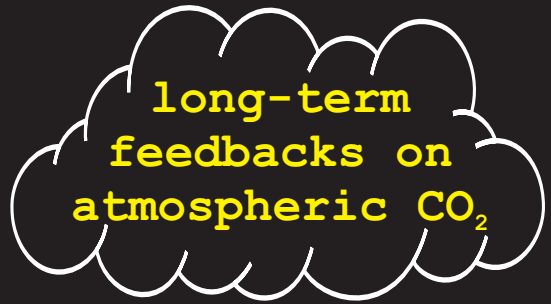
Sensitivity of climate to cumulative carbon emissions due to compensation of ocean heat and carbon uptake

Philip Goodwin¹, Richard G. Williams² and Andy Ridgway¹

Abstract The ocean heat capacity is a key factor in determining the sensitivity of climate to cumulative carbon emissions. However, it is not generally appreciated that the ocean heat capacity is also a function of the ocean's carbon content. We show that the ocean heat capacity is a function of the ocean's carbon content, and that this relationship is important for understanding the sensitivity of climate to cumulative carbon emissions. We find that the ocean heat capacity is a function of the ocean's carbon content, and that this relationship is important for understanding the sensitivity of climate to cumulative carbon emissions.

10 November 2015

Goodwin et al. [2015]



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Carbon-GENIE

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RESEARCH ARTICLE

CLIMATE CHANGE

Combustion of available fossil fuel resources sufficient to eliminate the Antarctic ice Sheet

K. Winkelman^{1,2}, A. Ridgway^{1,2}, M. Lomas¹ and J. Lunt^{1,2}

Abstract The Antarctic ice sheet is a major component of Earth's cryosphere. It is a major source of sea level rise, and its loss would have significant impacts on global climate. We use a coupled Earth system model to investigate the potential for the Antarctic ice sheet to be eliminated by the combustion of available fossil fuel resources. We find that the combustion of available fossil fuel resources is sufficient to eliminate the Antarctic ice sheet, and that this process would occur within the next 100 years.

10 November 2015

Winkelman et al. [2015]

nature geoscience

LETTERS

The warming and ice melt from the last interglacial period

Philip Goodwin¹, Richard G. Williams² and Andy Ridgway¹

Abstract The last interglacial period (LIG) was a period of high interannual variability in climate. We use a coupled Earth system model to investigate the warming and ice melt from the LIG. We find that the LIG was a period of high interannual variability in climate, and that this variability was driven by changes in the ocean's carbon content. We find that the LIG was a period of high interannual variability in climate, and that this variability was driven by changes in the ocean's carbon content.

10 November 2015

Williams et al. [2012]

nature climate change

LETTERS

Enhanced weathering strategies for stabilizing climate and averting ocean acidification

L. L. Taylor¹, J. S. Boyle¹, R. M. M. Thomas¹, P. H. Rothwell¹, A. Ridgway¹, J. Lunt¹, A. Ridgway^{1,2}, M. Lomas¹, S. B. Branson¹ and David J. Beerling¹

Abstract The ocean is a major sink for atmospheric CO₂, and its acidification is a major concern. We use a coupled Earth system model to investigate the potential for enhanced weathering strategies to stabilize climate and avert ocean acidification. We find that enhanced weathering strategies can stabilize climate and avert ocean acidification, and that this process would occur within the next 100 years.

10 November 2015

Taylor et al. [in press]

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Geophysical Research Letters

RESEARCH LETTER

Assessing the controllability of Arctic sea ice extent by sulfate aerosol geoengineering

L. A. Jackson¹, J. A. Coakley¹, A. S. Brown¹, M. L. Anderson¹, M. R. McManus¹, and M. R. Marshall¹

Abstract The Arctic region is a major component of Earth's cryosphere. It is a major source of sea level rise, and its loss would have significant impacts on global climate. We use a coupled Earth system model to investigate the potential for sulfate aerosol geoengineering to stabilize Arctic sea ice extent. We find that sulfate aerosol geoengineering can stabilize Arctic sea ice extent, and that this process would occur within the next 100 years.

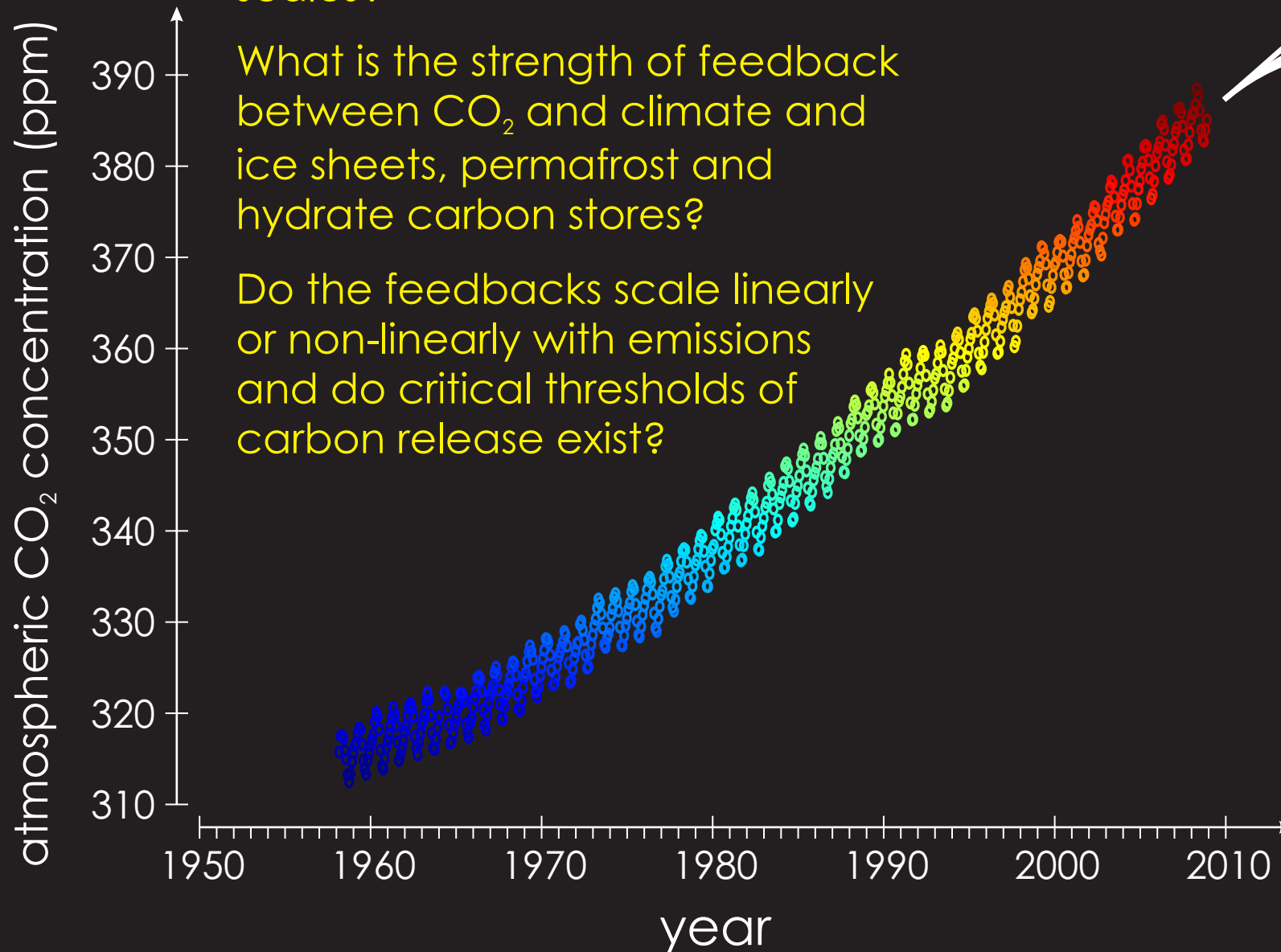
10 November 2015

Jackson et al. [2015]

What is the 'fate' of CO₂ emissions on hundred, thousand, and ten thousands of year time-scales?

What is the strength of feedback between CO₂ and climate and ice sheets, permafrost and hydrate carbon stores?

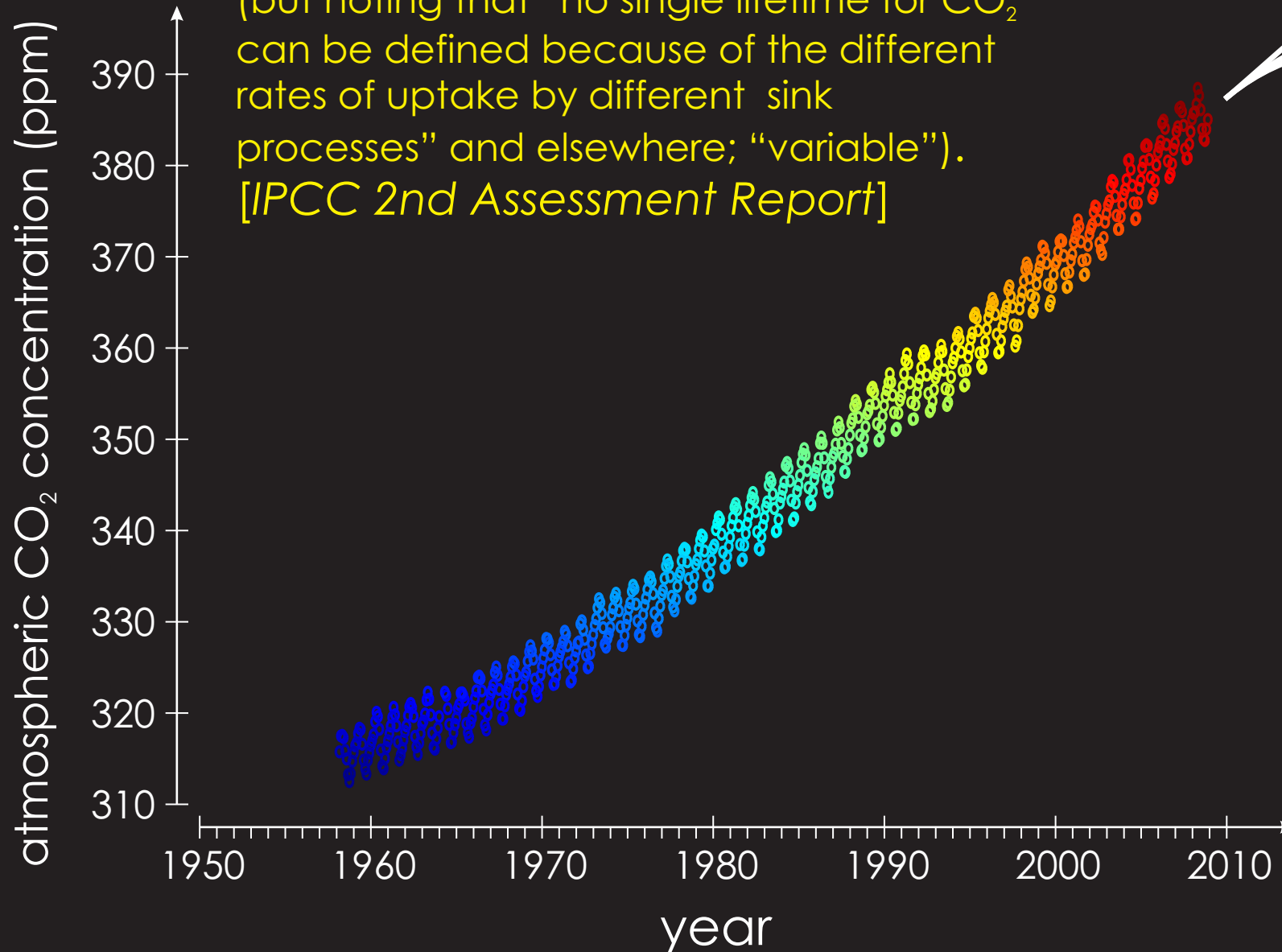
Do the feedbacks scale linearly or non-linearly with emissions and do critical thresholds of carbon release exist?

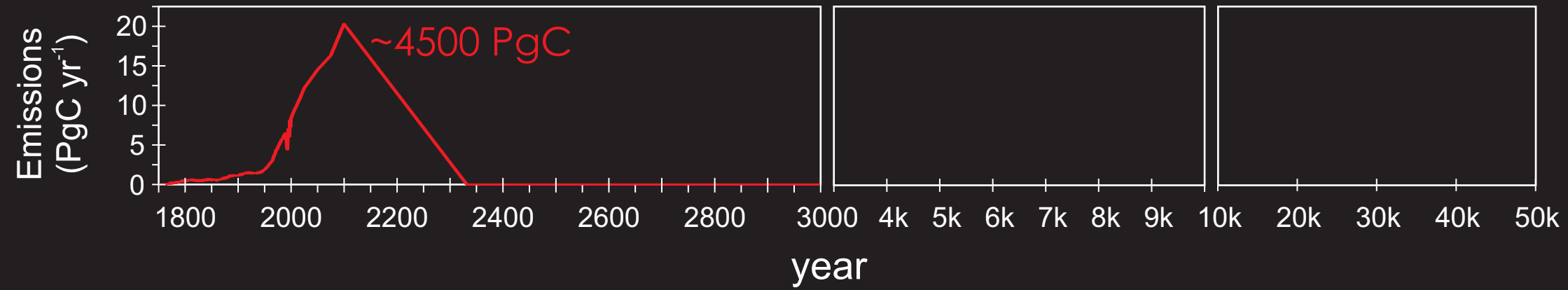


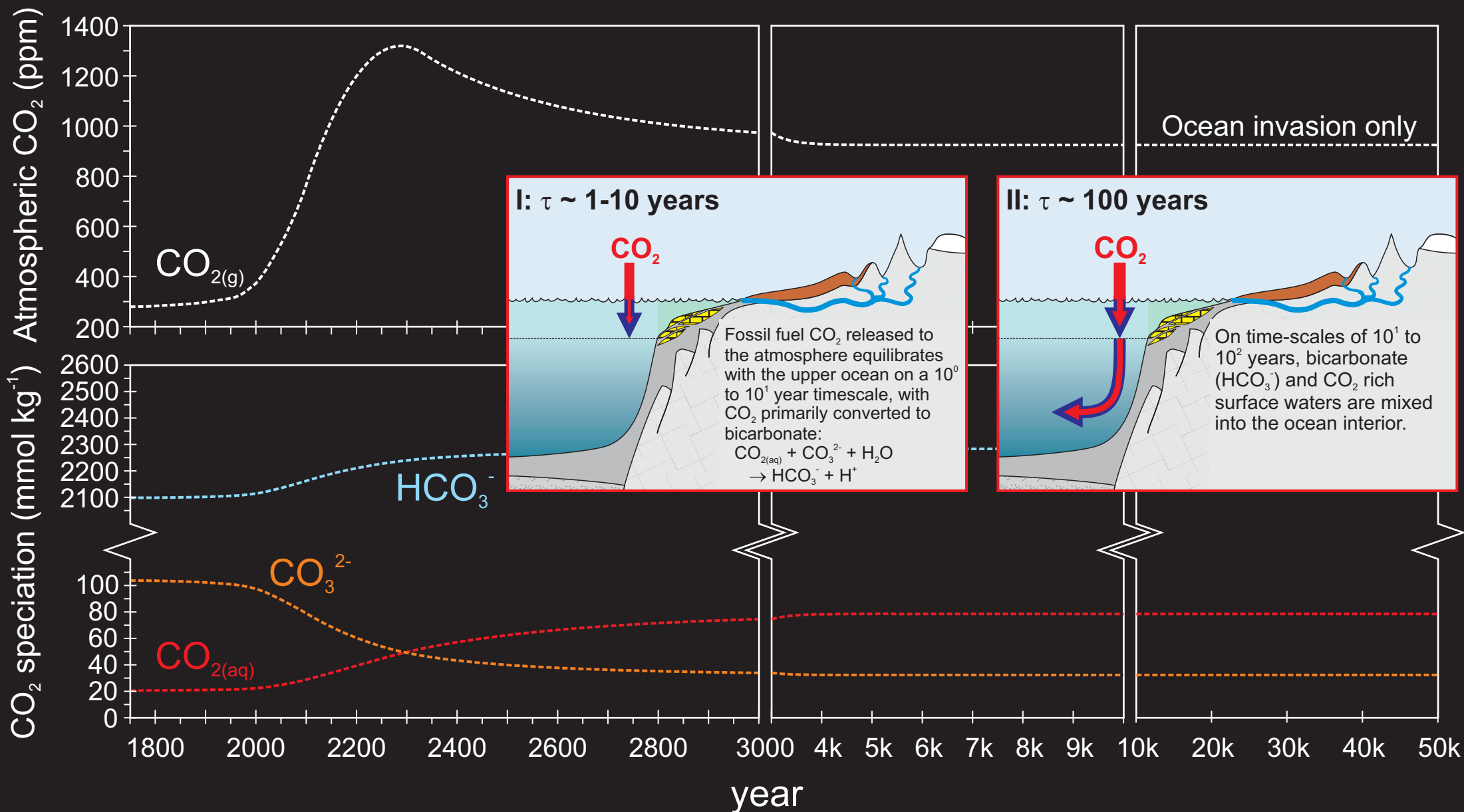
“CO₂ has an atmospheric lifetime of 50-200 years”

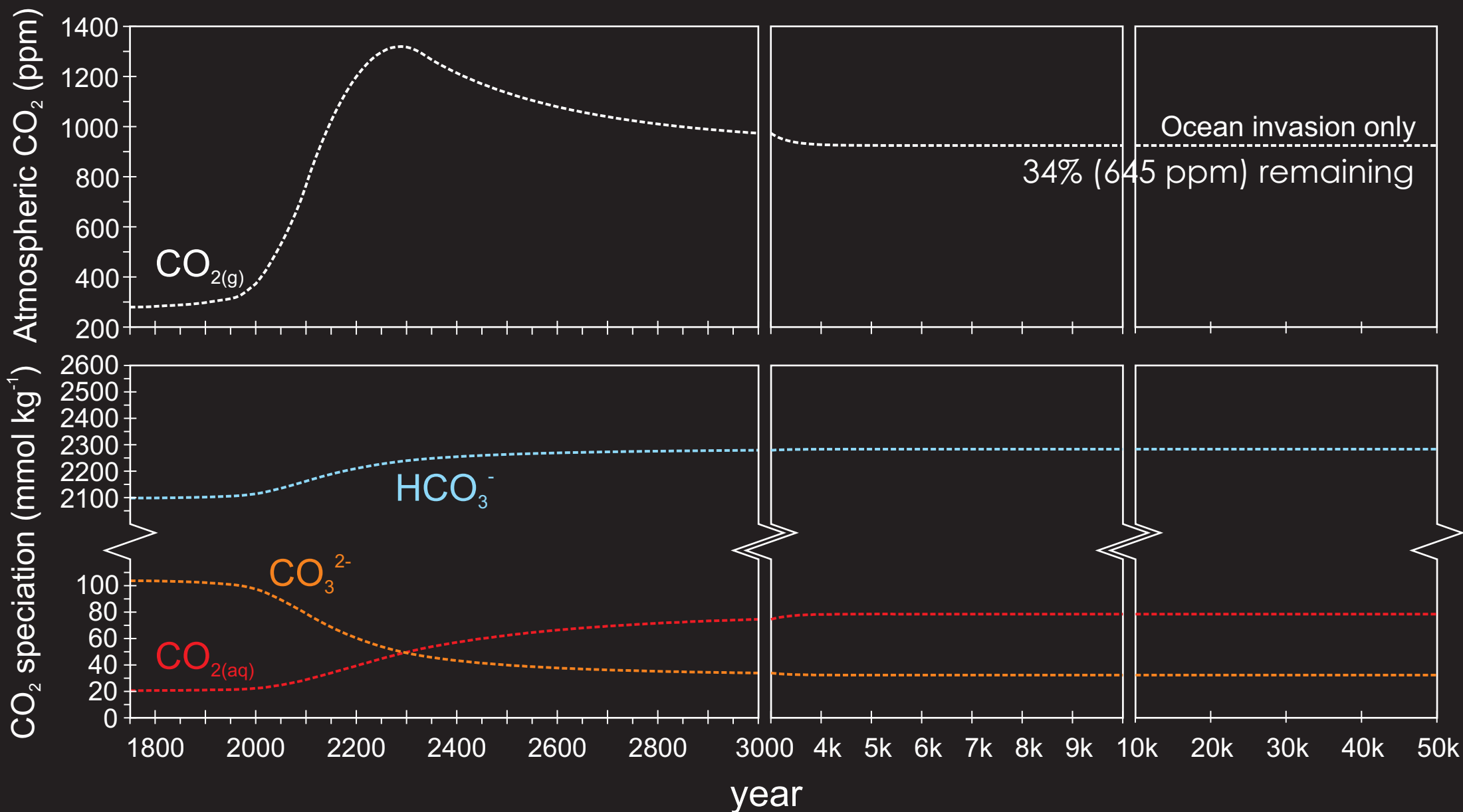
(but noting that “no single lifetime for CO₂ can be defined because of the different rates of uptake by different sink processes” and elsewhere; “variable”).

[IPCC 2nd Assessment Report]

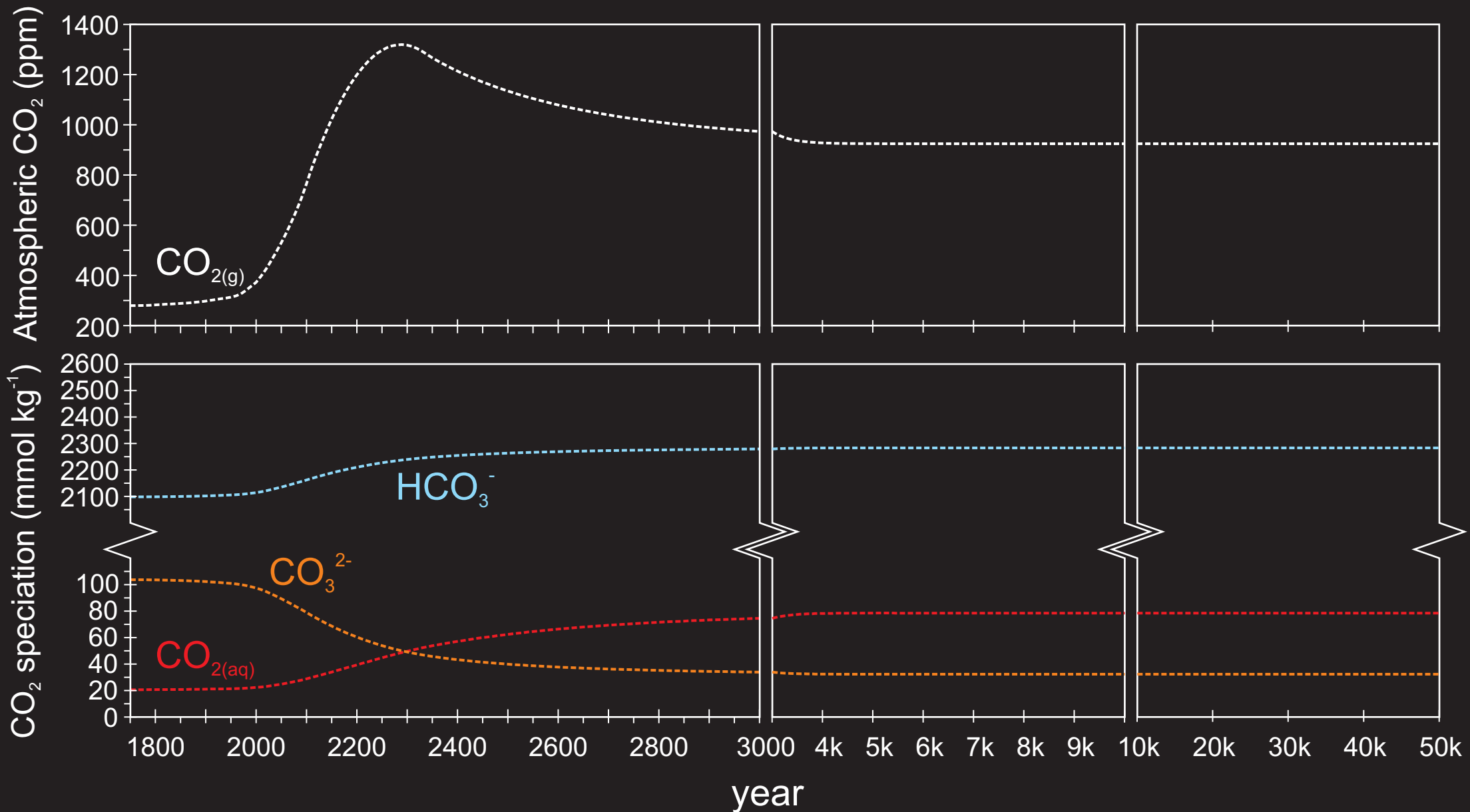




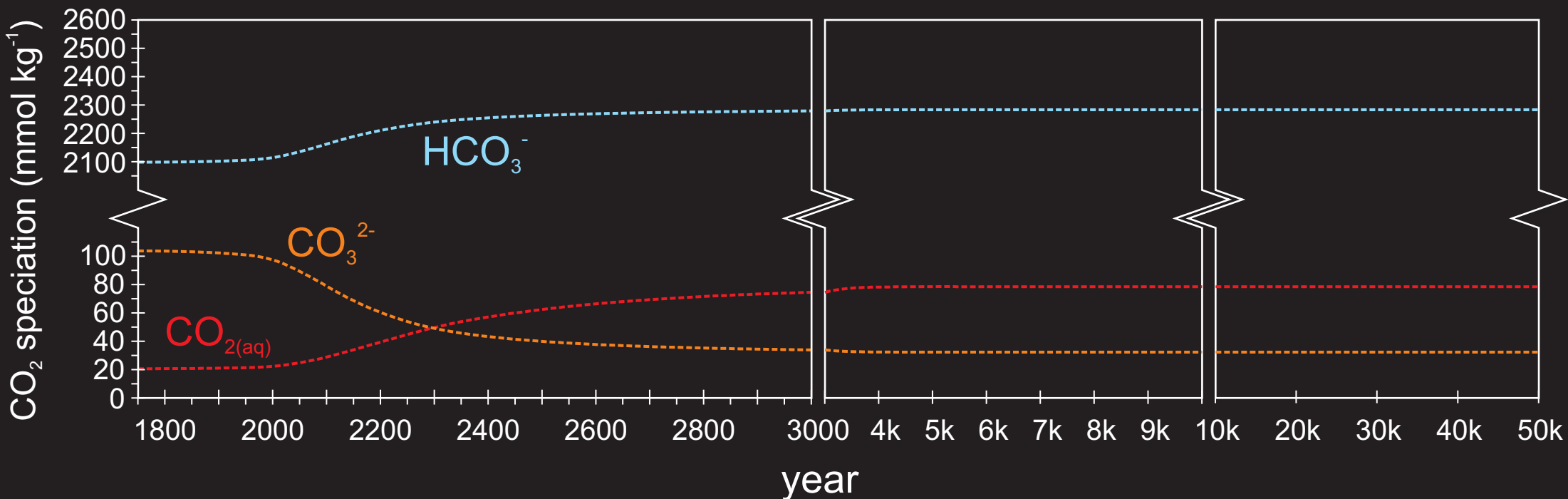
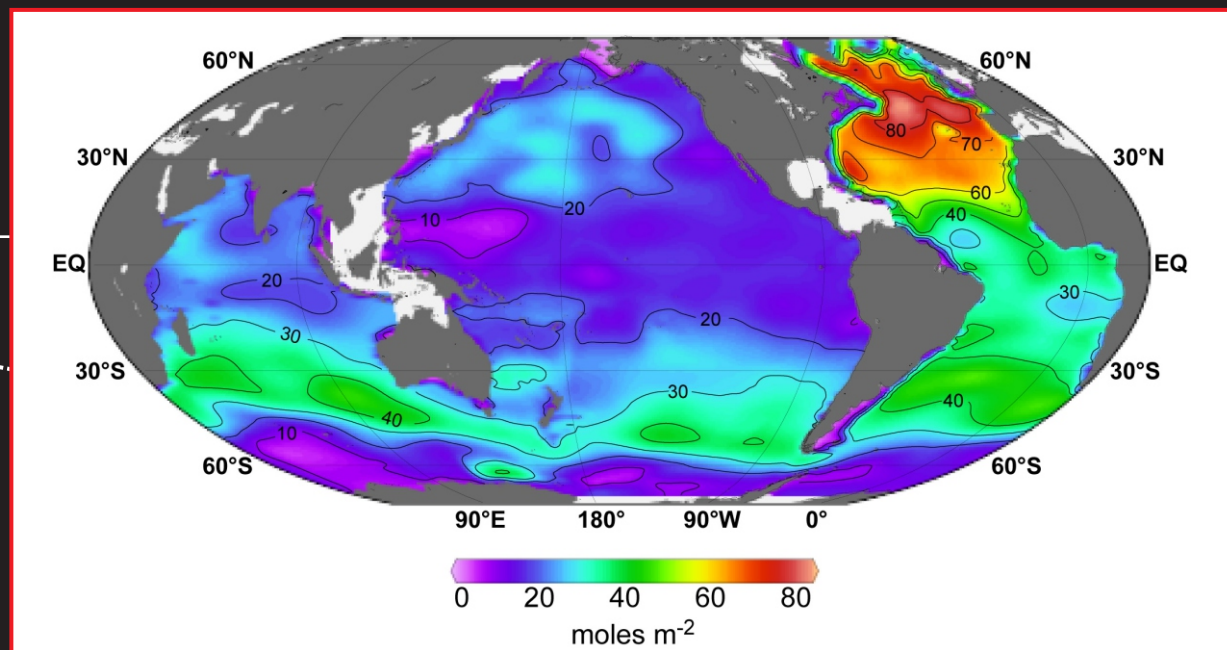
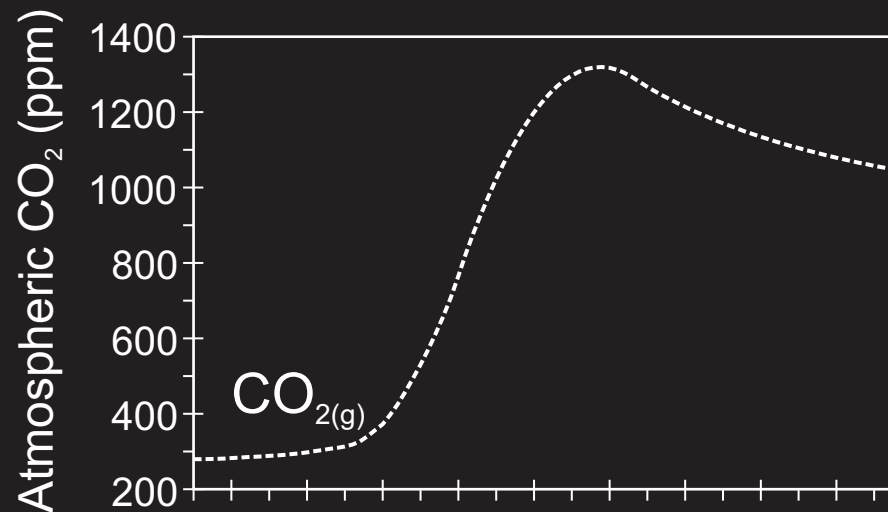




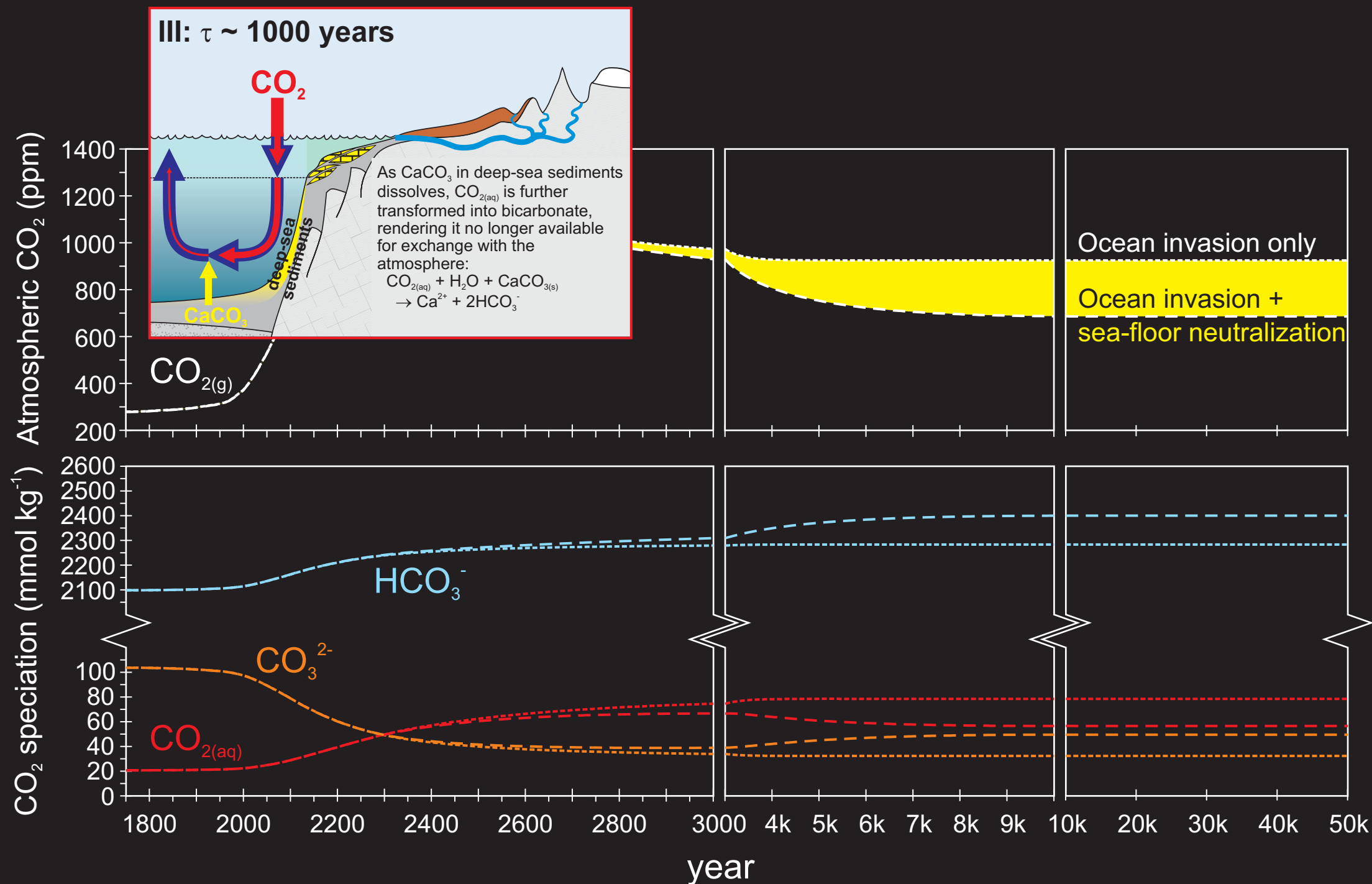
evidence?



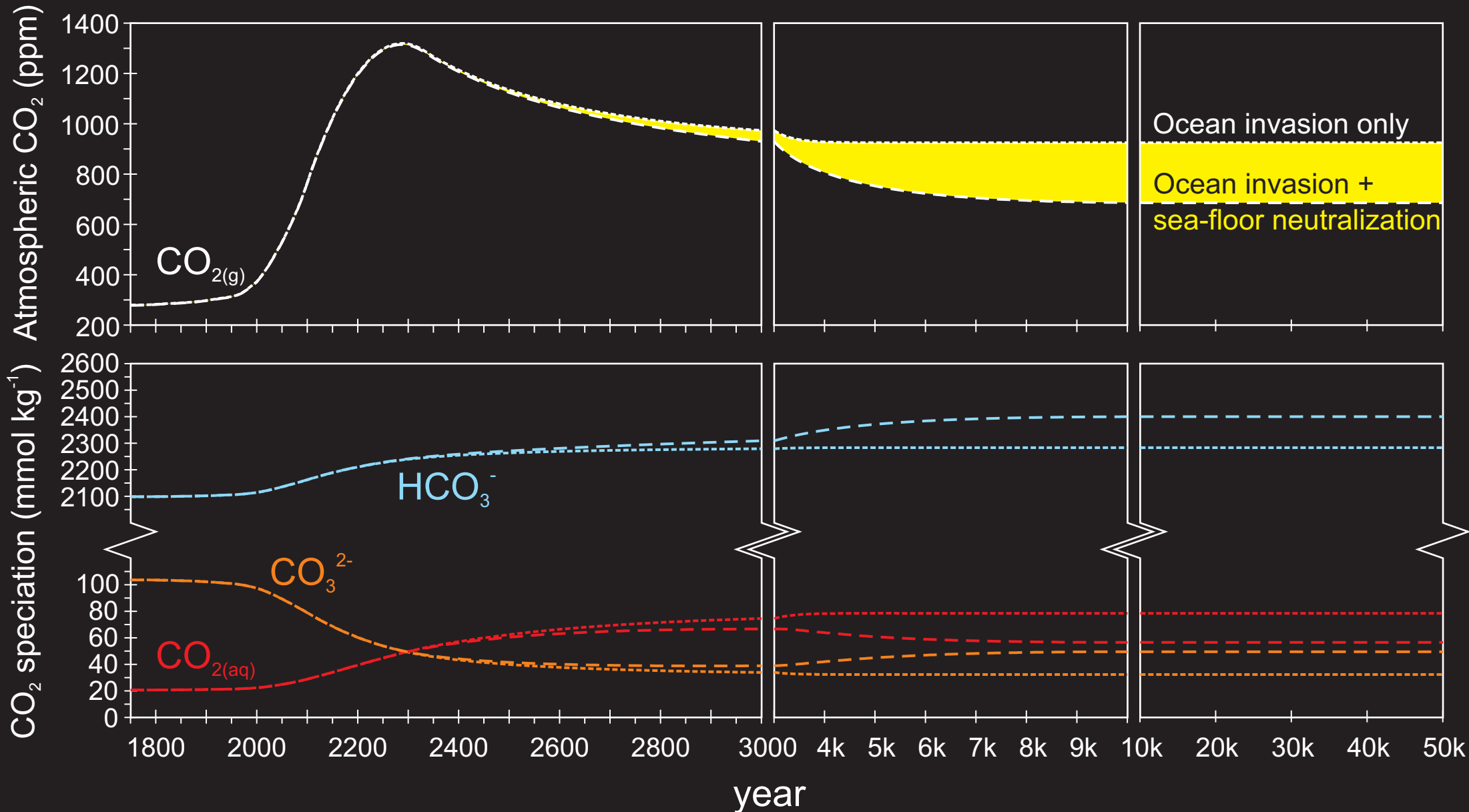
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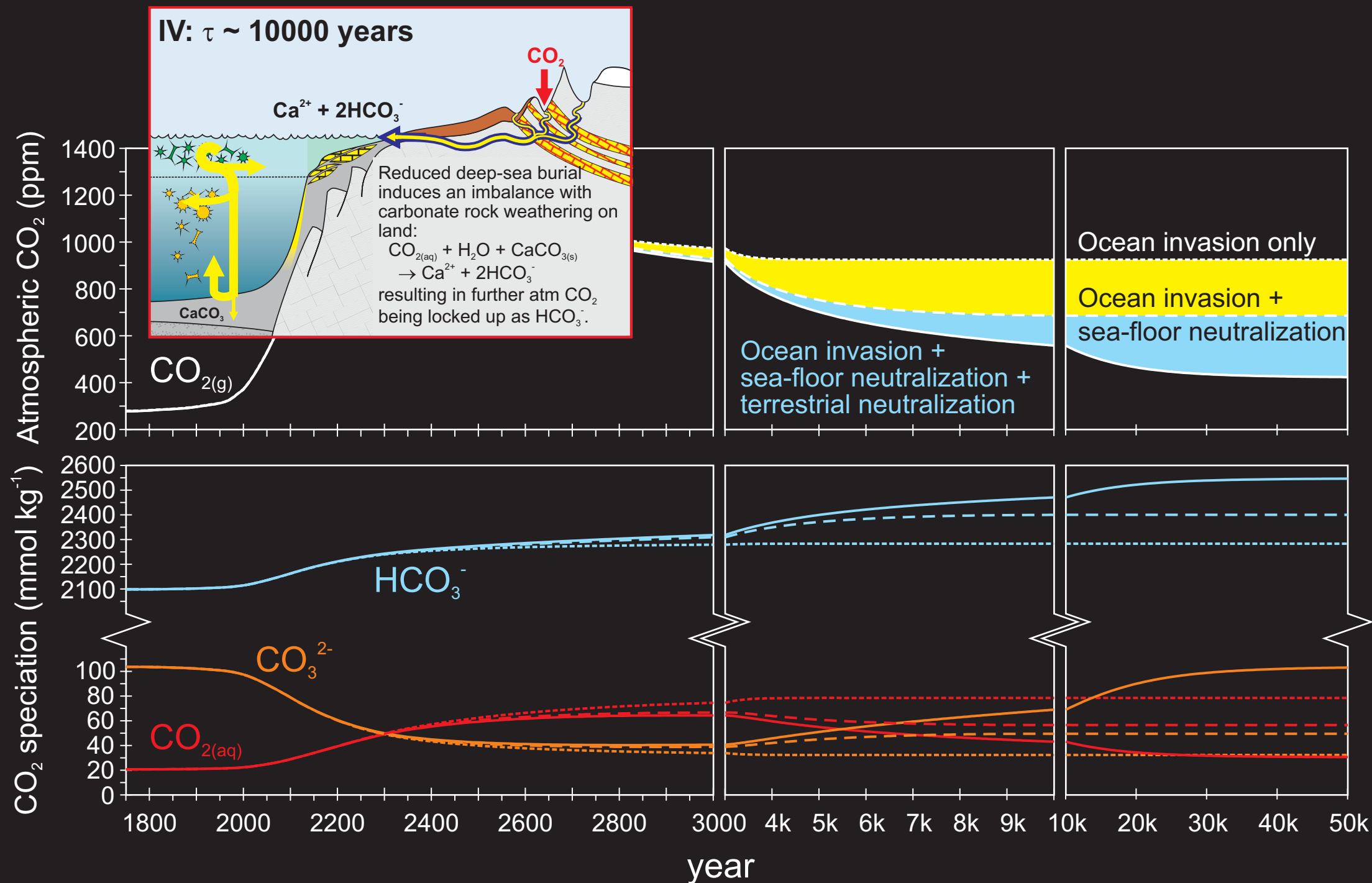


From: Sabine et al. [2004] (Science)

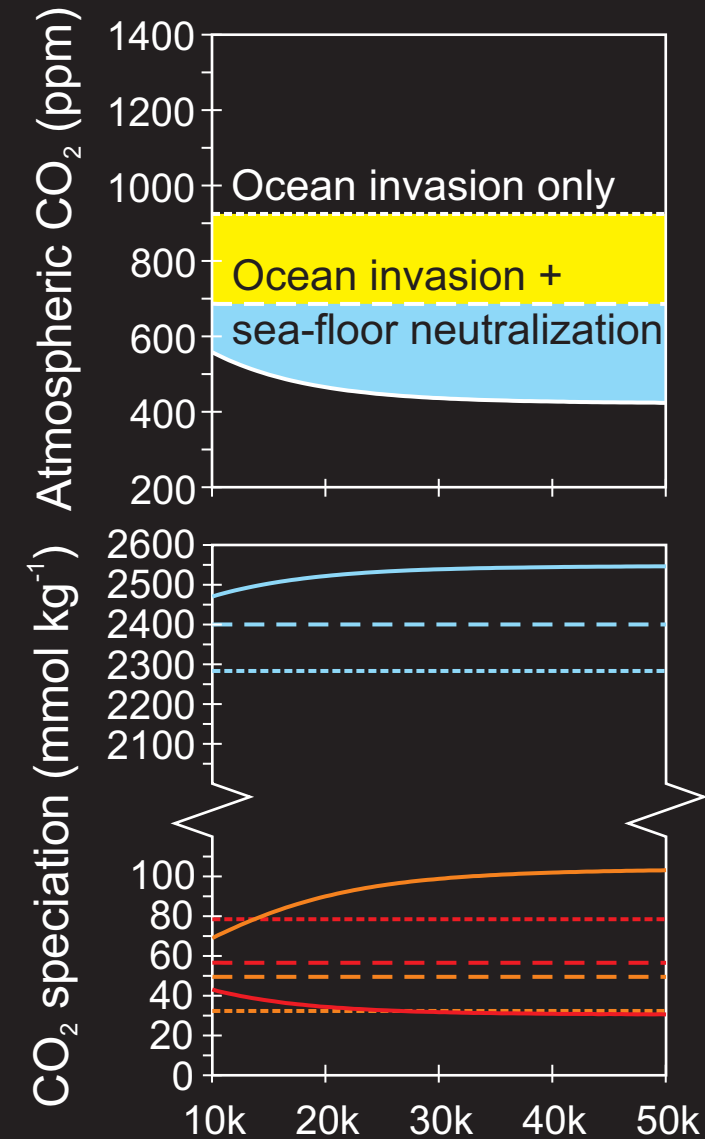


evidence?





Q. Is a residual fraction of CO₂ persisting for ever ... 'OK'?



Terrestrial weathering can be (approximately equally) divided into carbonate (CaCO₃) and calcium-silicate ('CaSiO₃') weathering:



Ultimately, the (alkalinity: Ca²⁺) weathering products must be removed through carbonate precipitation and burial in marine sediments:



It can be seen that in (2) + (3), that the CO₂ removed (from the atmosphere) during weathering, is returned upon carbonate precipitation (and burial). In (1) + (3) (silicate weathering) CO₂ is permanently removed to the geological reservoir. This CO₂ must be balanced by mantle (/volcanic) out-gassing on the very long term.

Furthermore, the rate of silicate weathering should scale with climate. Hence a ca. 100 kyr time-scale **silicate weathering feedback** is formed:

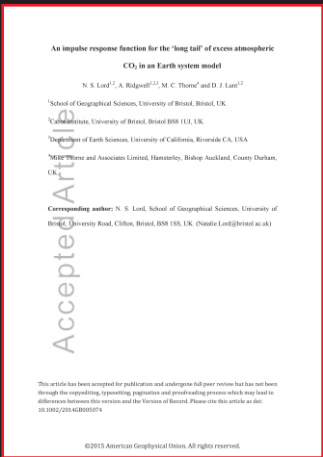
higher pCO₂ → higher temperatures (and rainfall) → higher weathering rates
→ lower pCO₂

(A regulating feedback system linking CO₂ and climate with ocean productivity and oxygenation, and organic carbon burial, can also be formulated but not discussed further here.)



(I) An impulse response function for the 'long tail' of CO_{2(excess)}

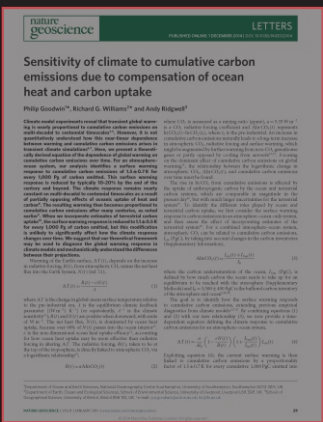
GEO250.2015



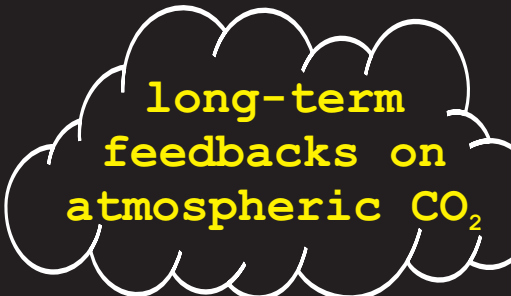
Lord et al. [in press]



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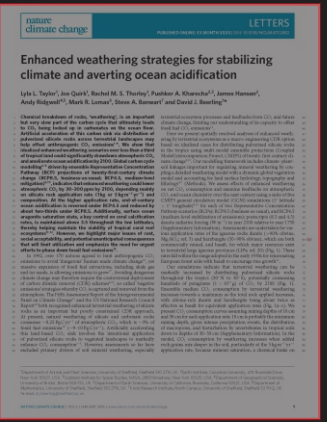
Goodwin et al. [2015]



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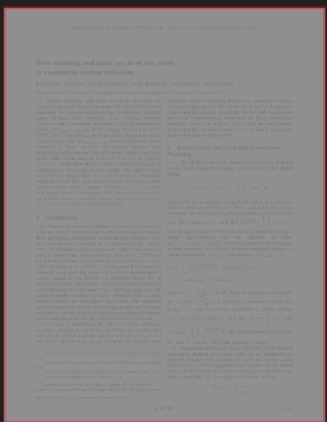
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Taylor et al. [in press]

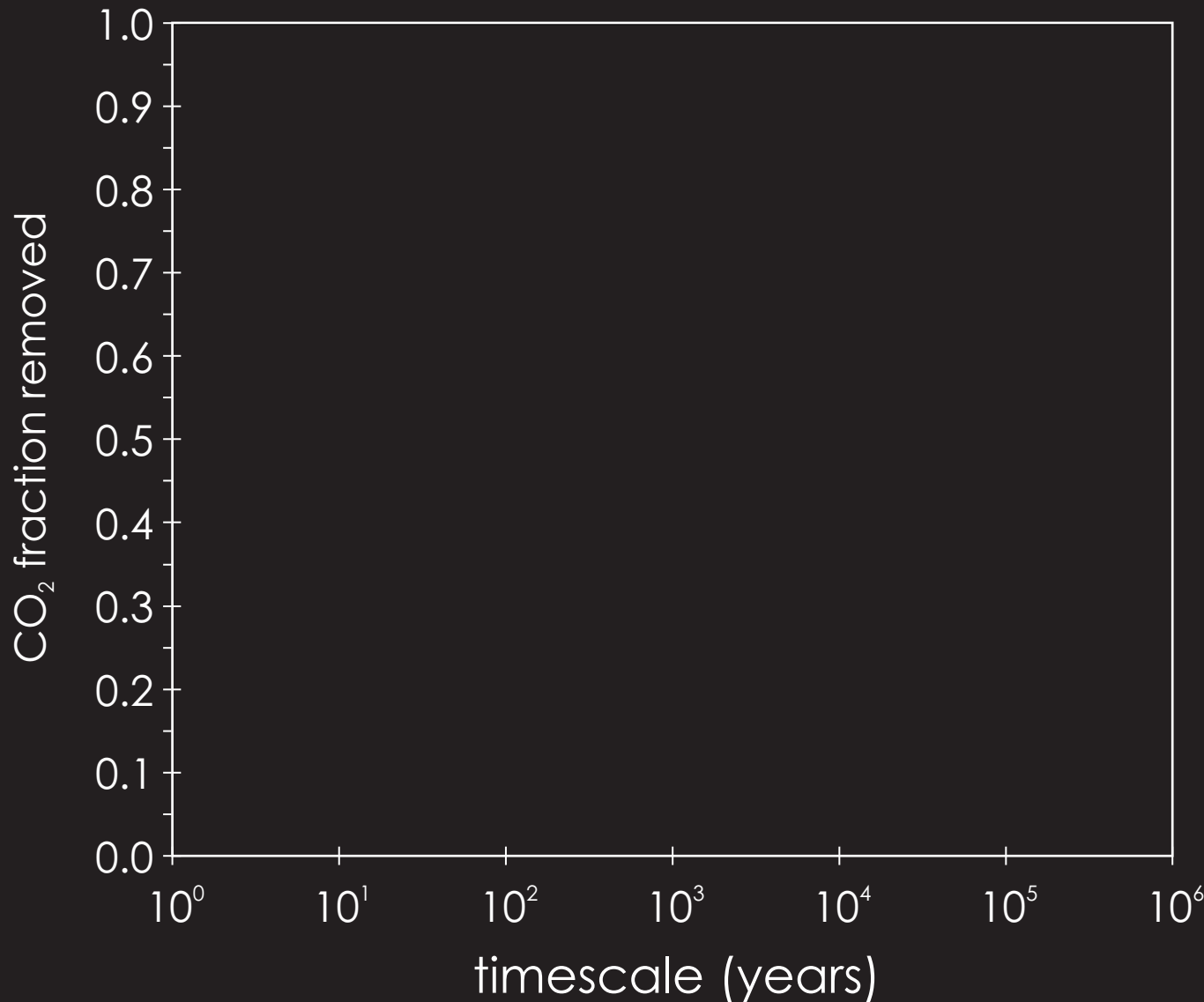


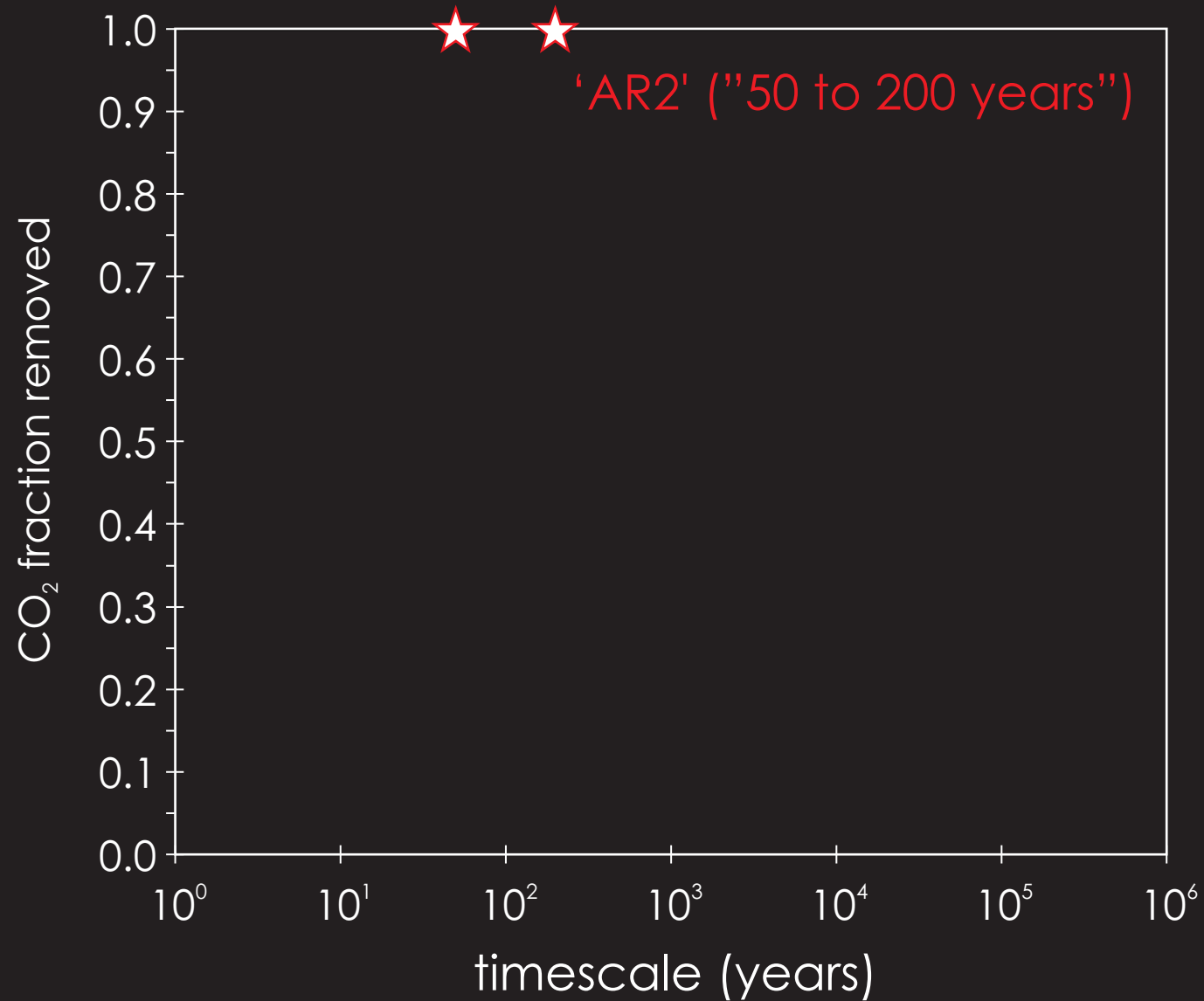
Jackson et al. [2015]



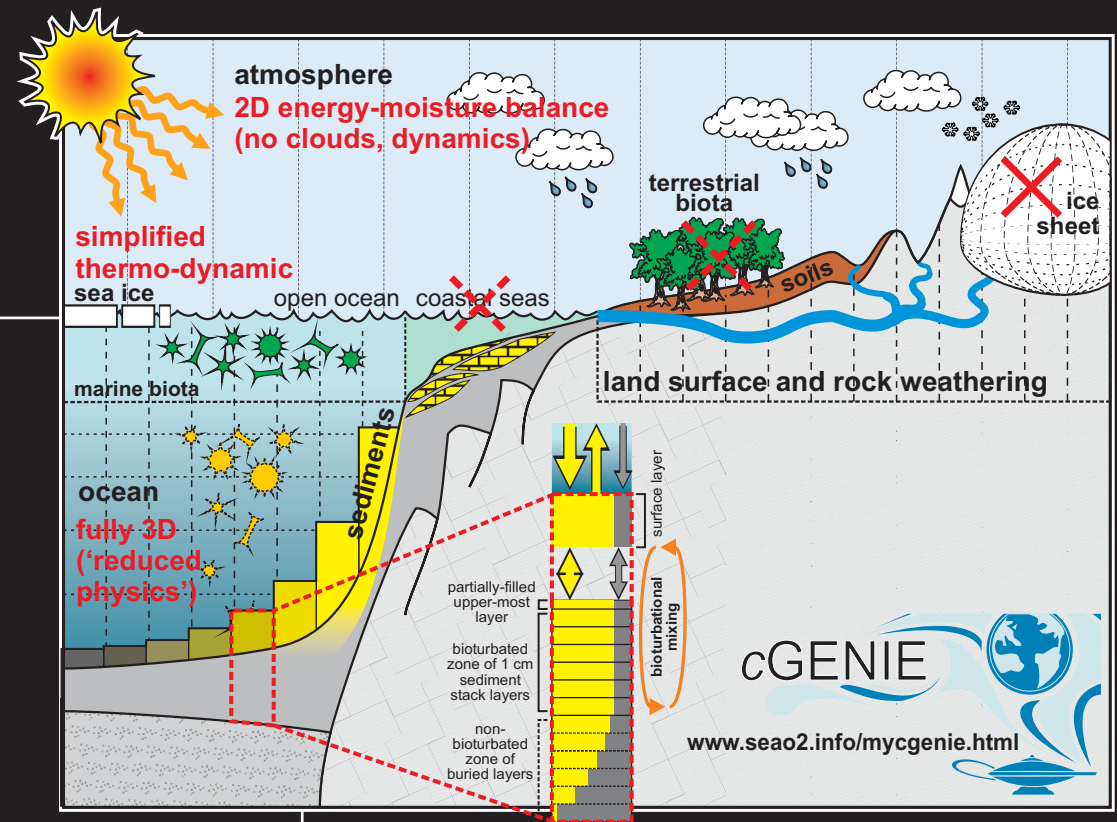
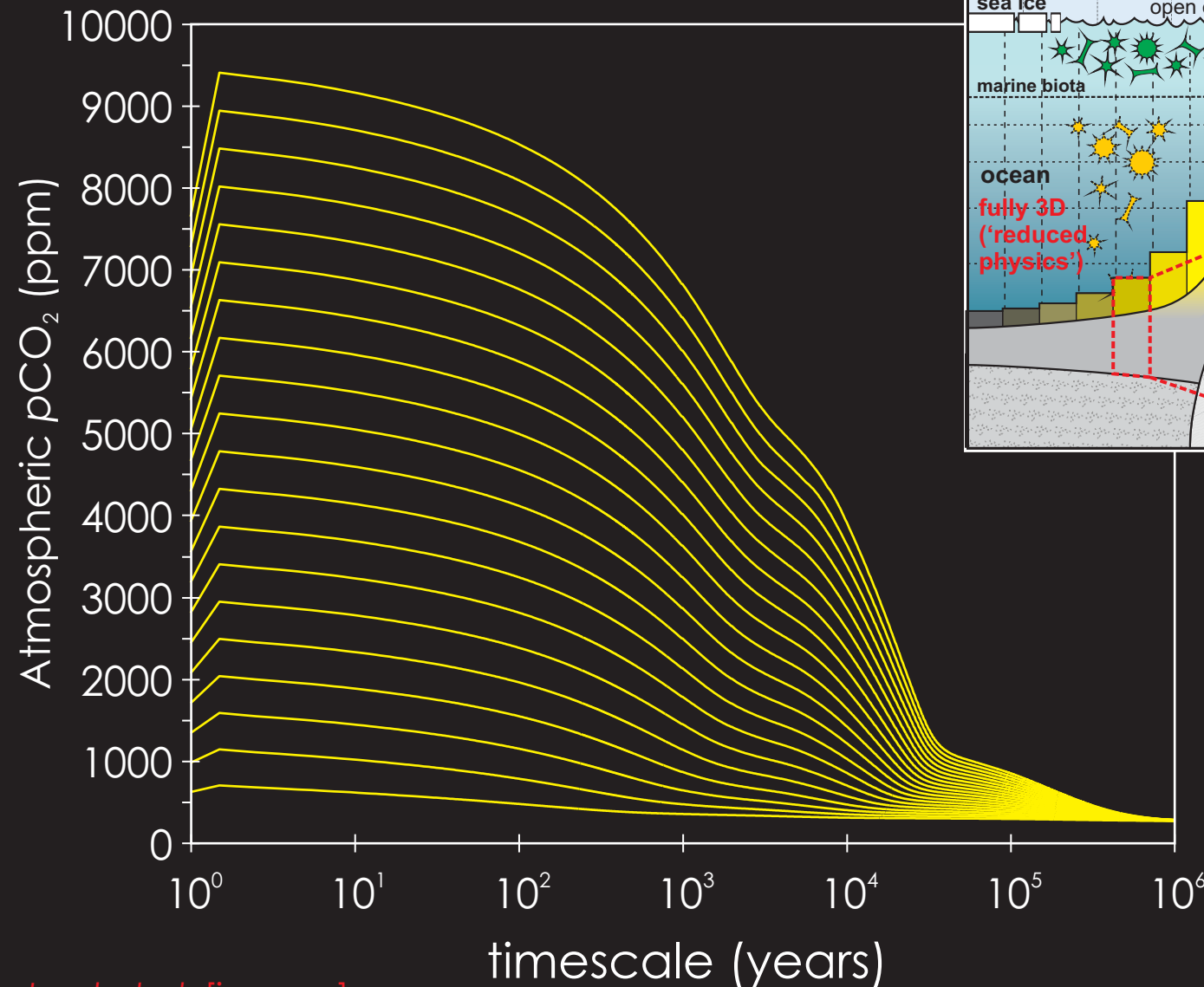
Williams et al. [2012]

Cross-plot of the fraction of total CO_2 emissions to the atmosphere removed by a particular process (carbon sink), vs. the characteristic (e-folding) time-scale of that process (\log_{10} scale).

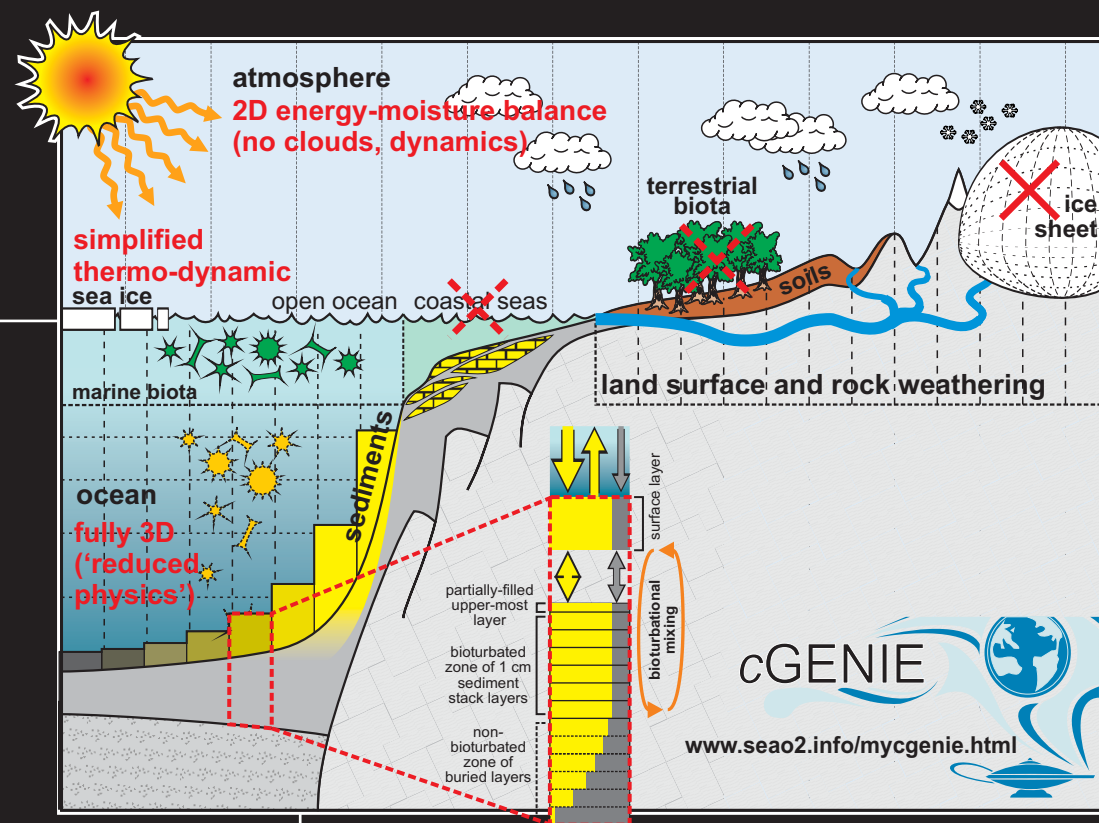
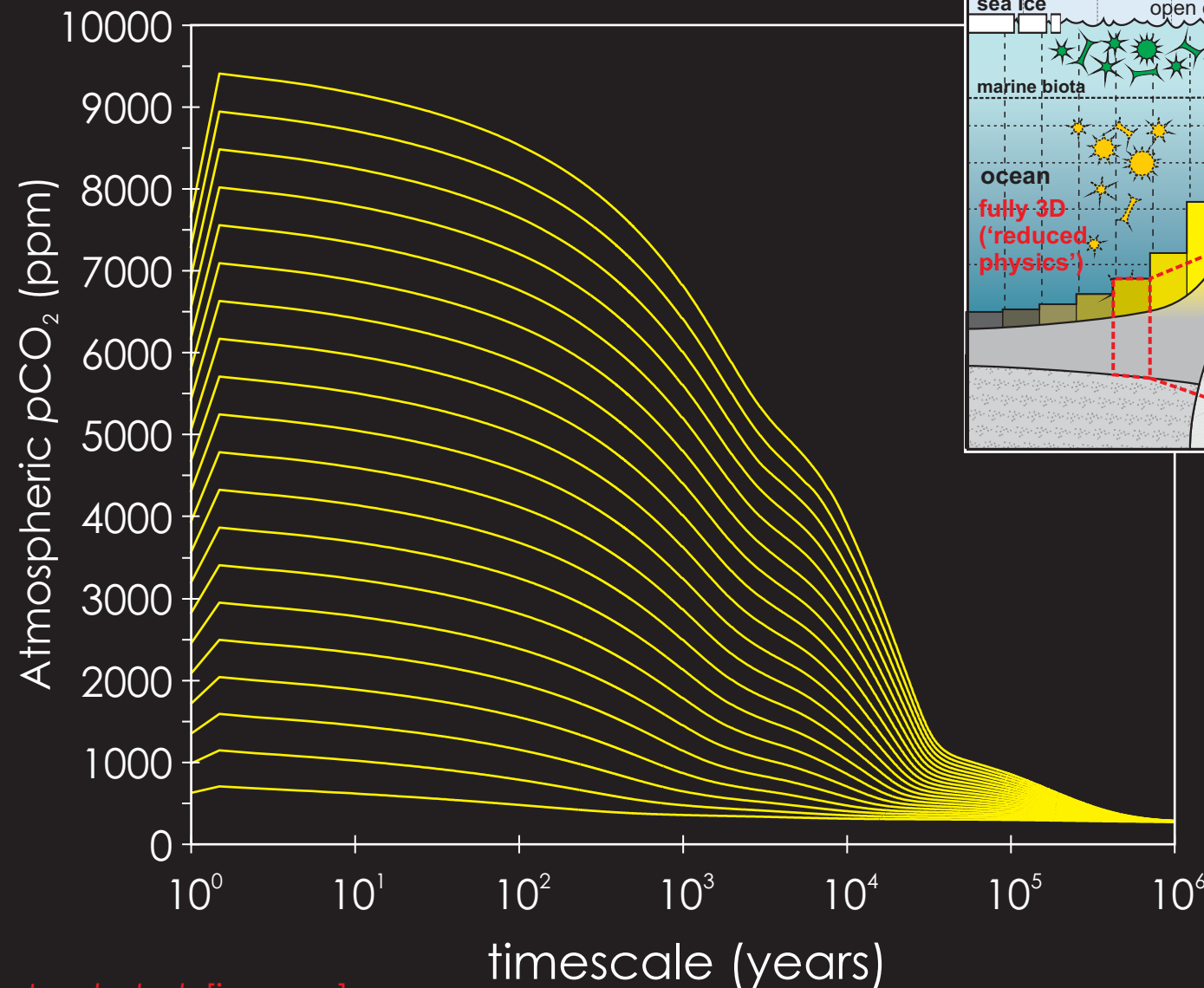




(1) Series of 1 Myr Earth system model experiments. CO_2 emissions from 1,000 to 20,000 PgC (GtC). Release interval: 1 yr.



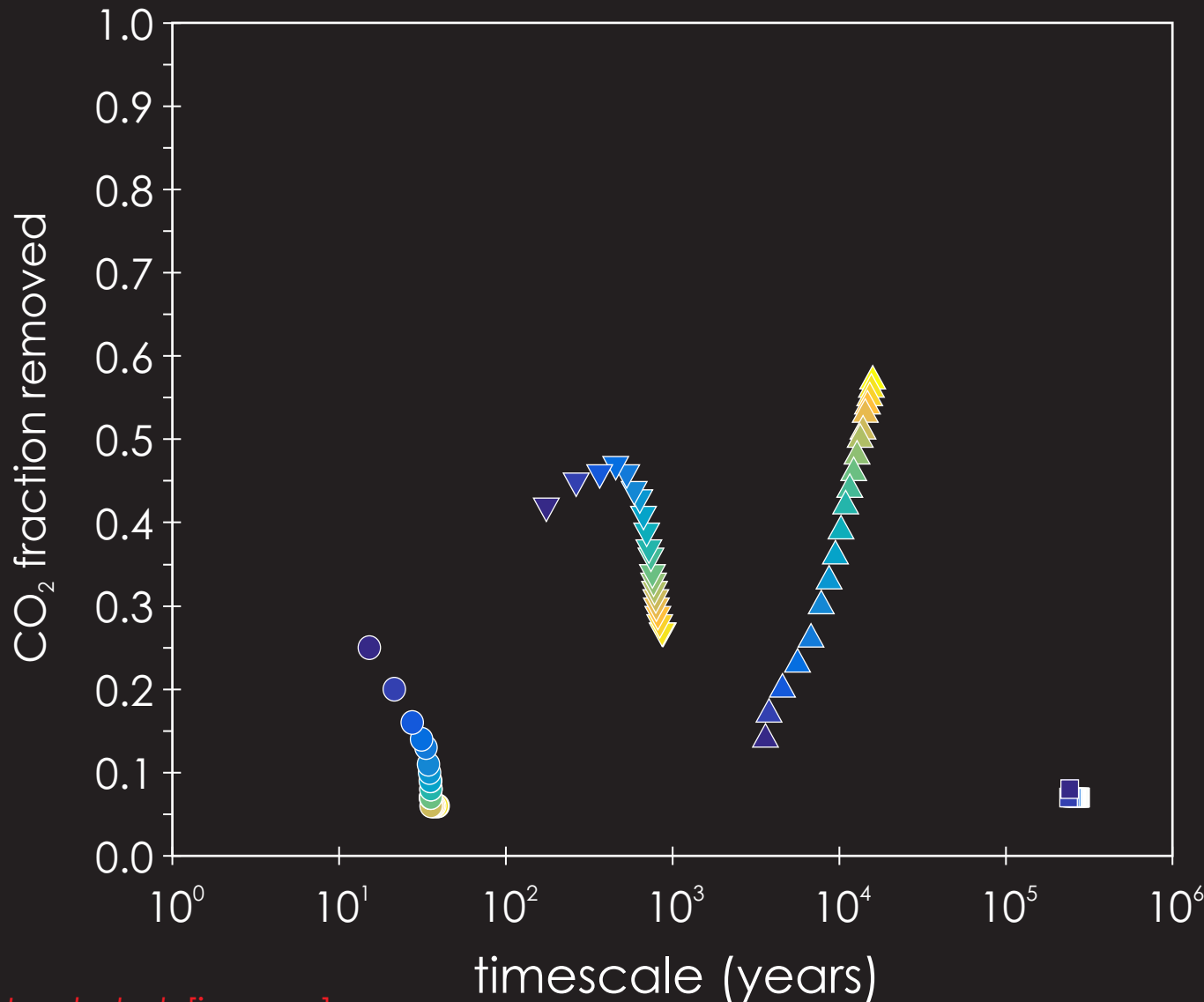
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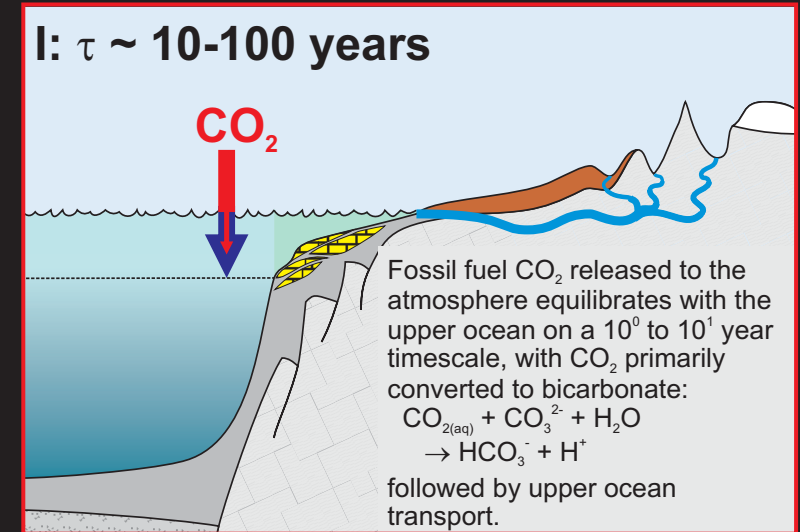
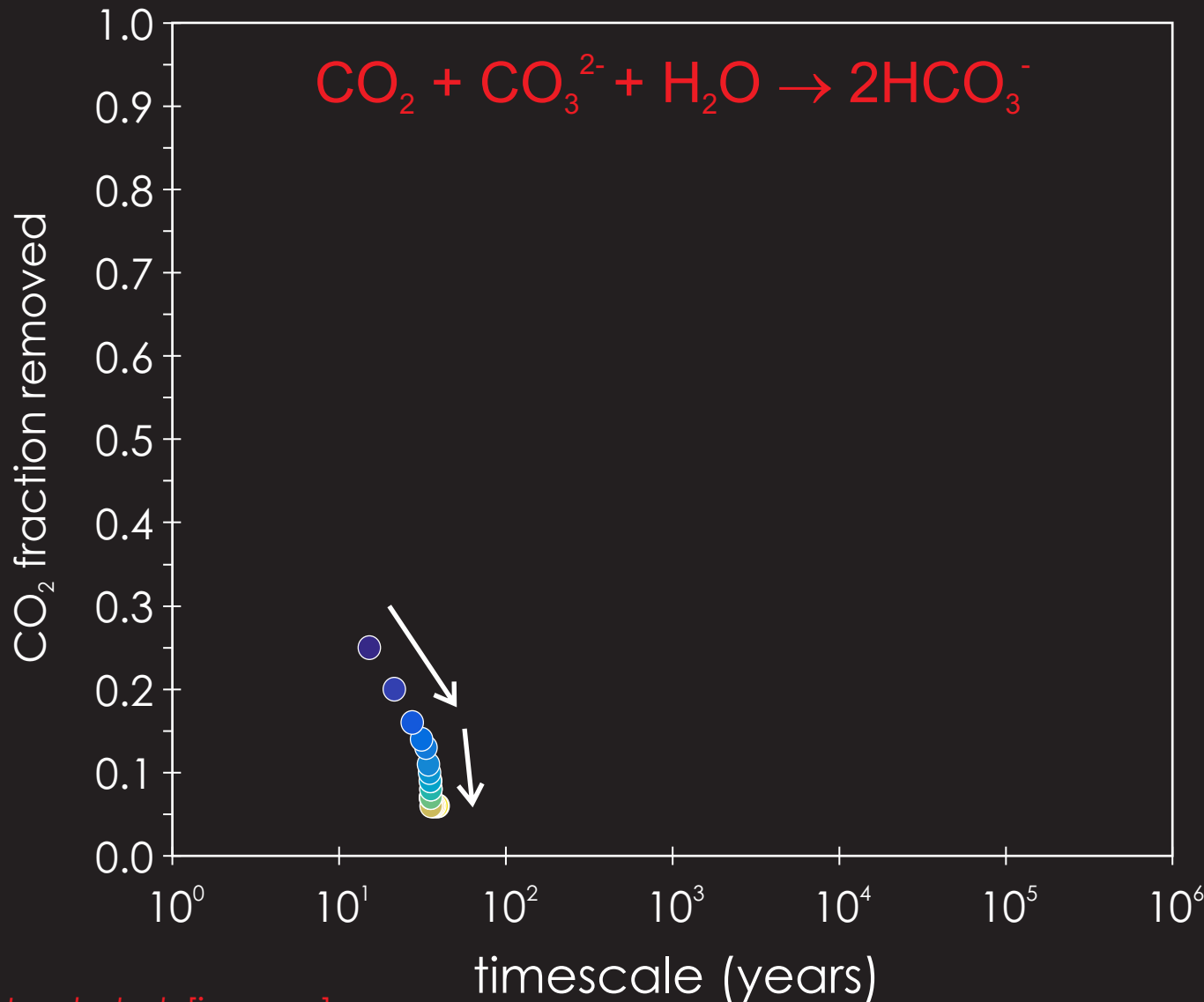
(2) Fit each CO_2 decay curve with a series (4 optimal) of exponentials. Extract the fraction of CO_2 and time-scale associated with each.

(The resulting empirical model can be used in place of a mechanistic model for projecting the long-term fate of carbon release.)

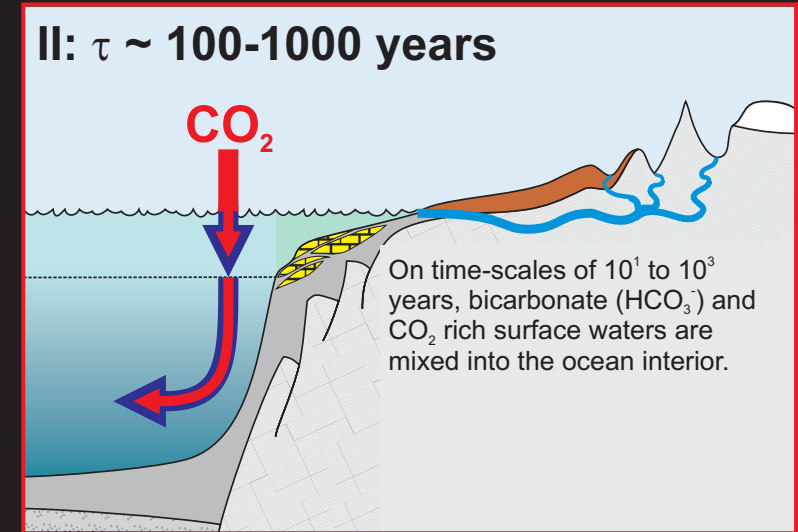
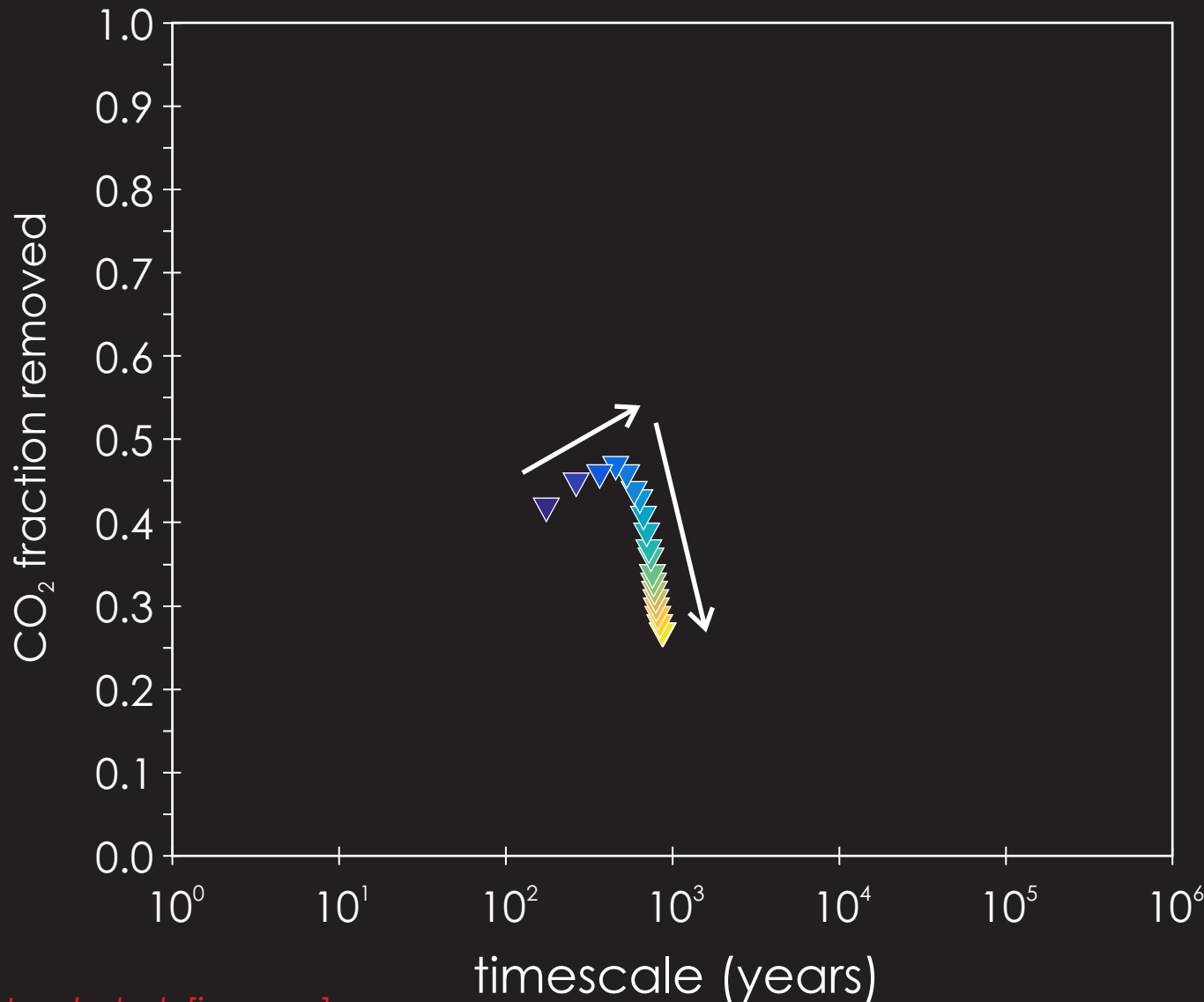
Response of fraction of CO_2 removed vs. the characteristic time-scale, as a function of total emissions, ranging from 1,000 PgC (dark blue) to 20,000 PgC (yellow).



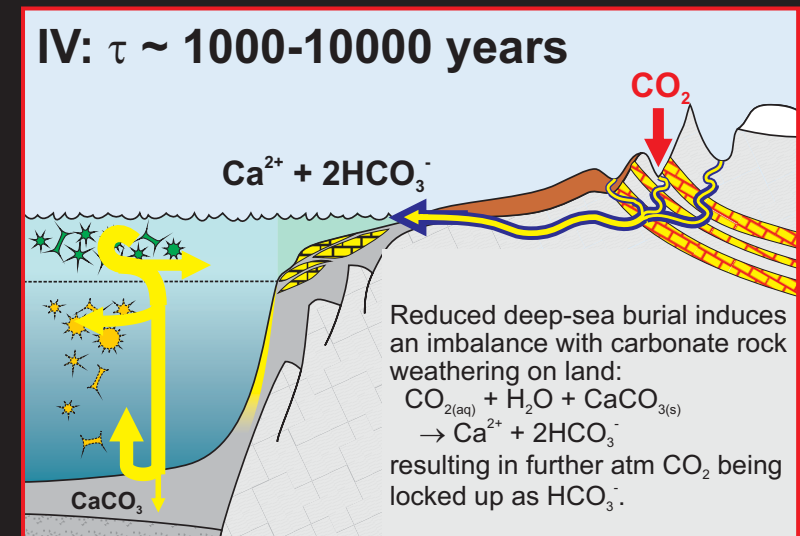
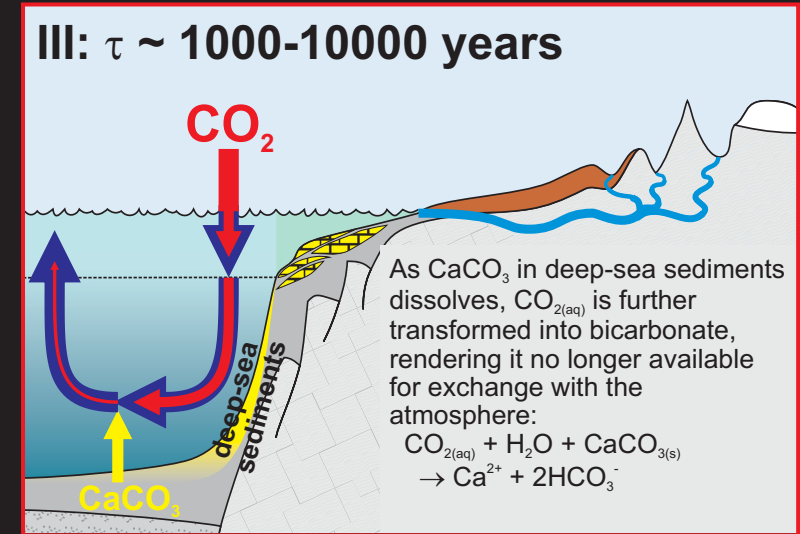
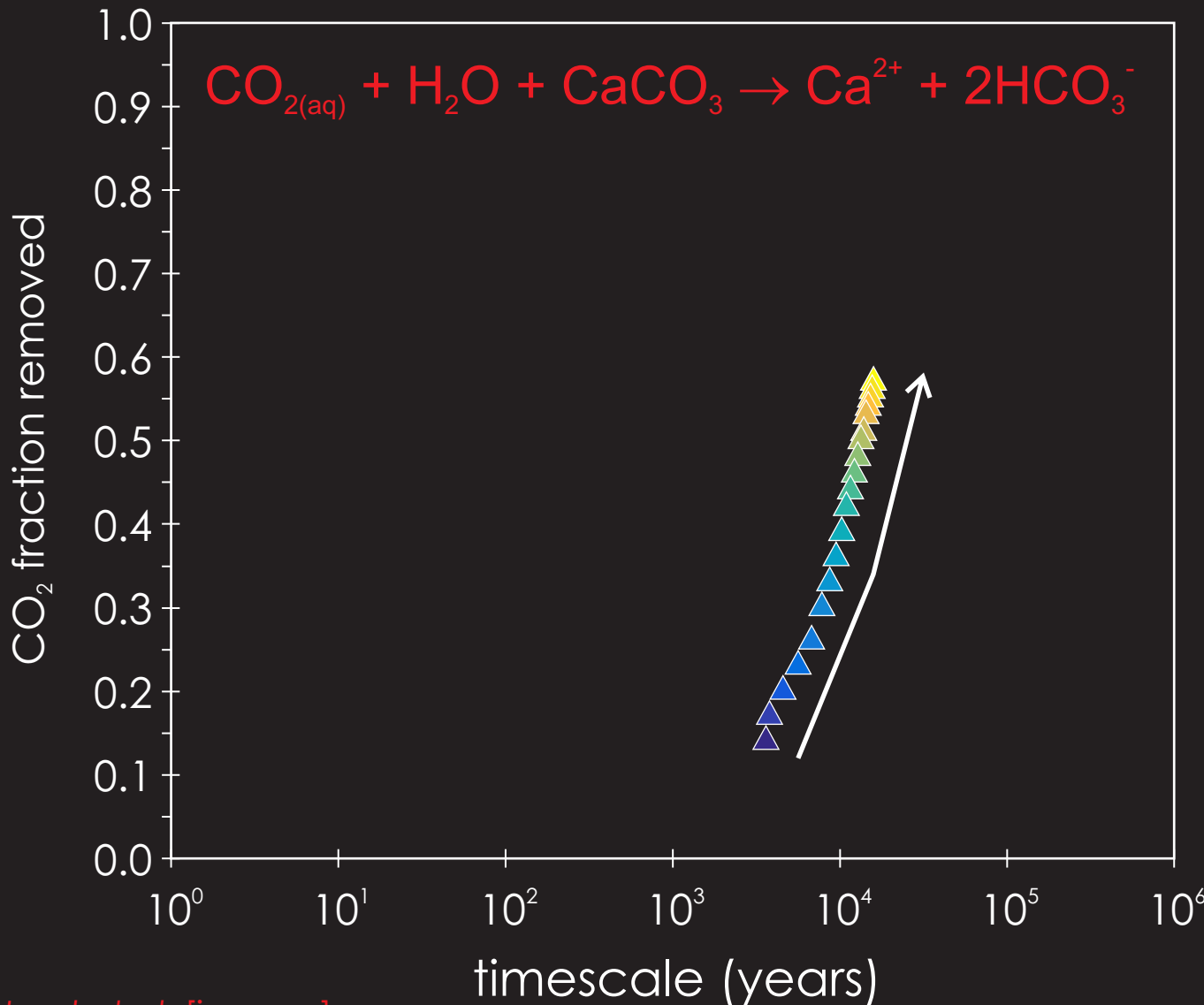
Depletion of mixed layer carbonate buffer;
ocean stratification and reduced surface
mixing. Warming and reduced CO_2 solubility.



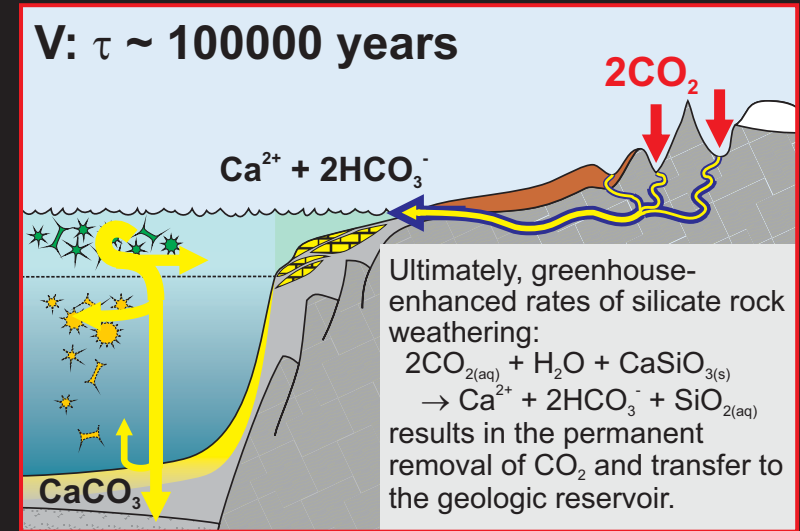
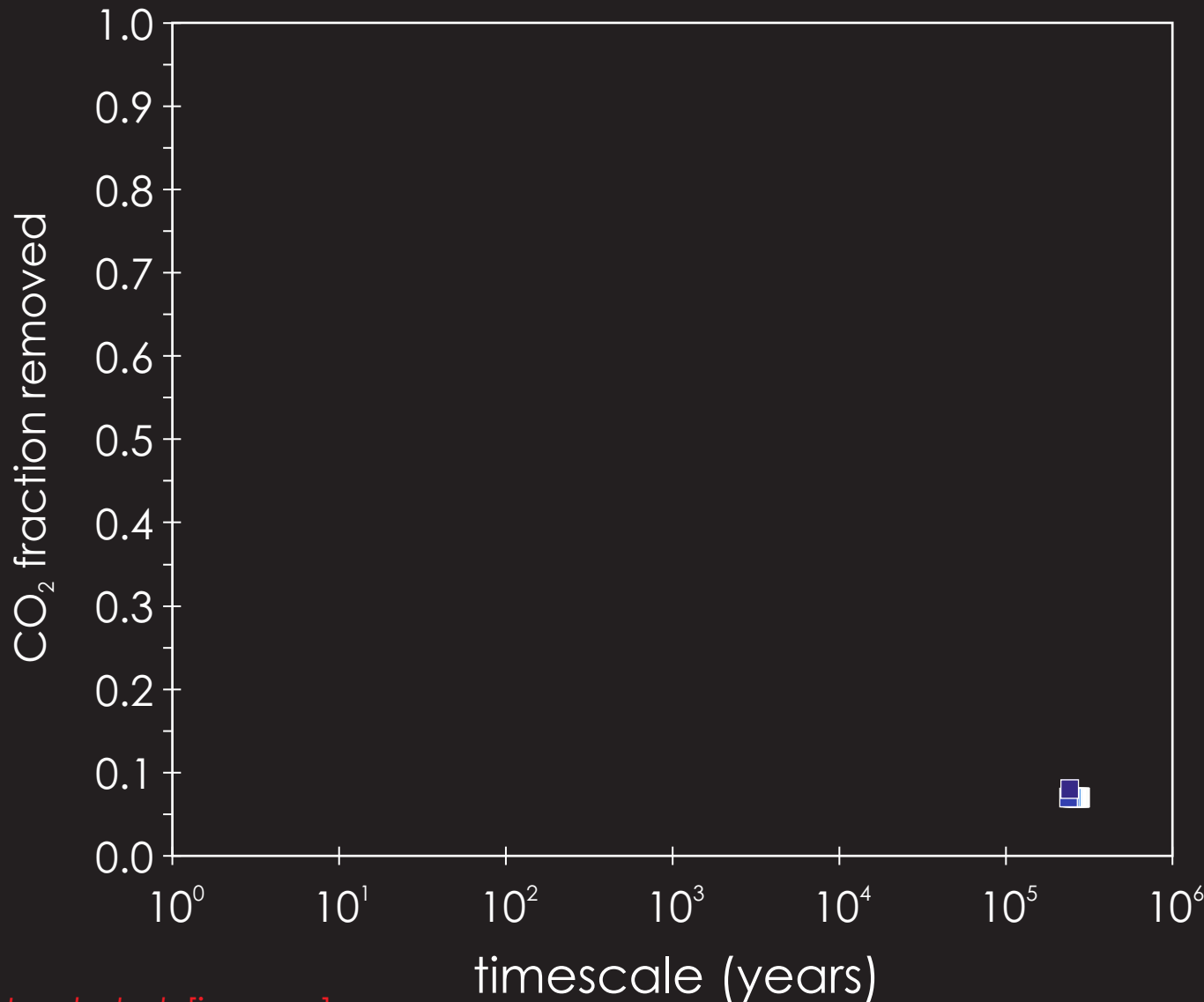
Ocean stratification and collapse of the AMOC
(in this particular model).
Threshold reached @ ~4000 PgC?

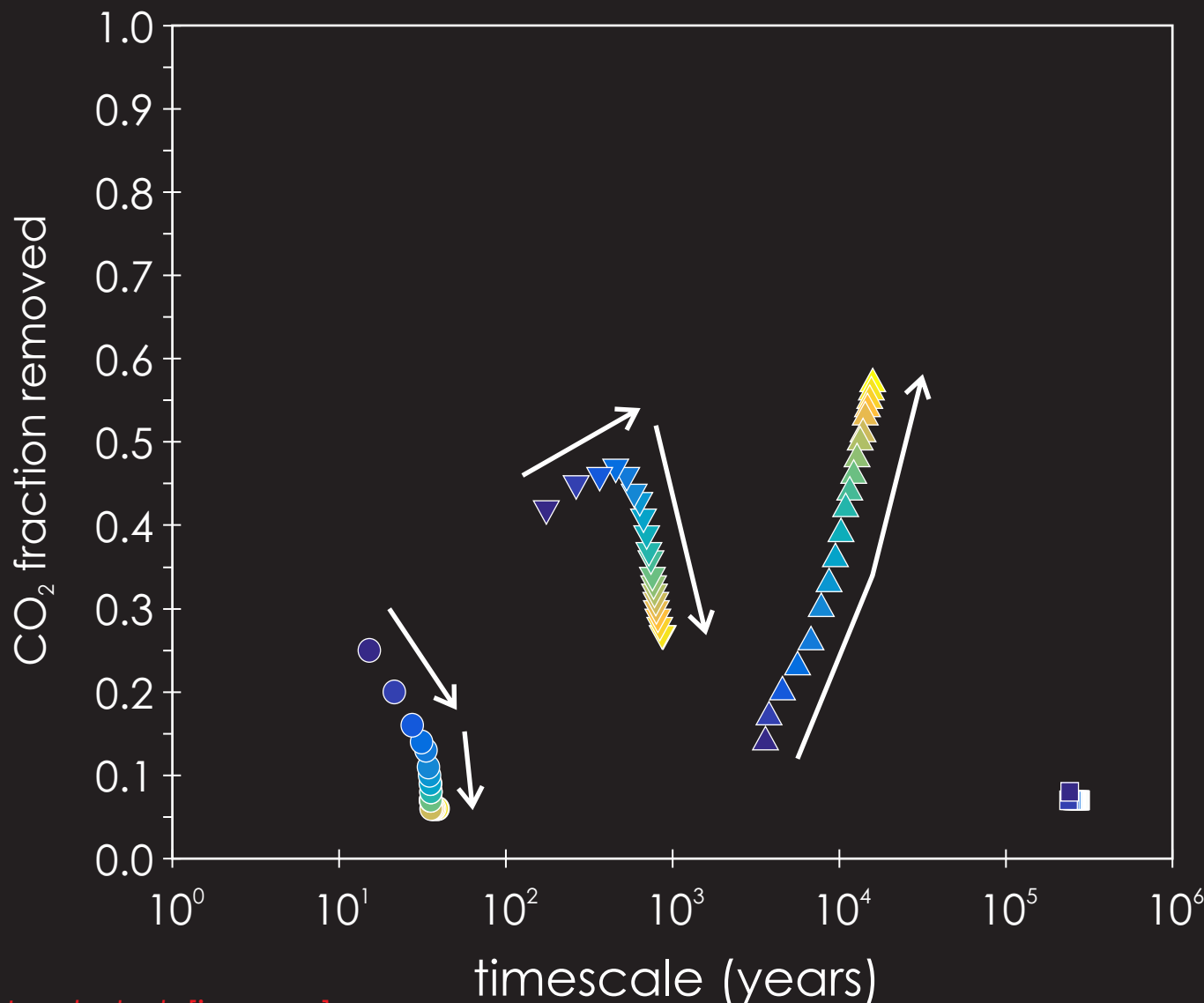


Geologic CO_2 removal via carbonate rocks and marine sediments – occurring on an increasing protracted time-scale.



Silicate weathering (no time-scale response!).

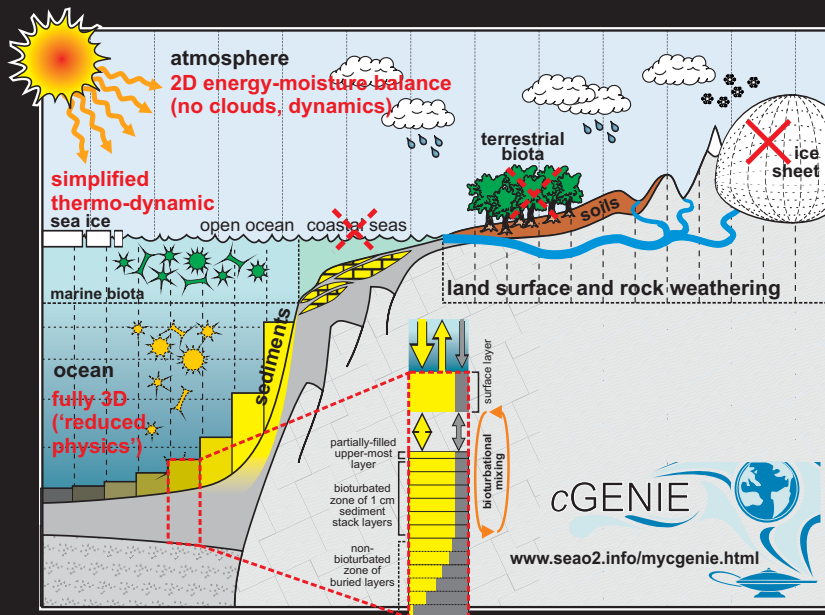




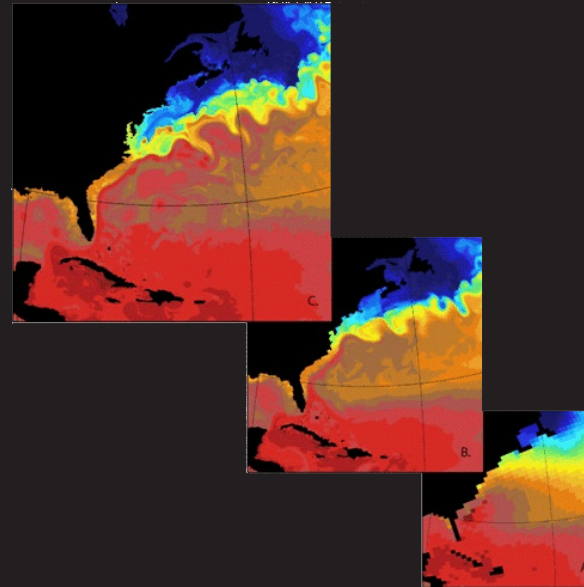
Summary:

With increasing total CO_2 emissions, the response time of all sinks (bar silicate weathering) lengthen, and the shorter time-scale two weaken at the expense of the $\sim 10,000$ year CaCO_3 burial process. Elevated atmospheric $p\text{CO}_2$ (and hence warming) will hence become more persistent as the main short-term CO_2 feedbacks weaken.

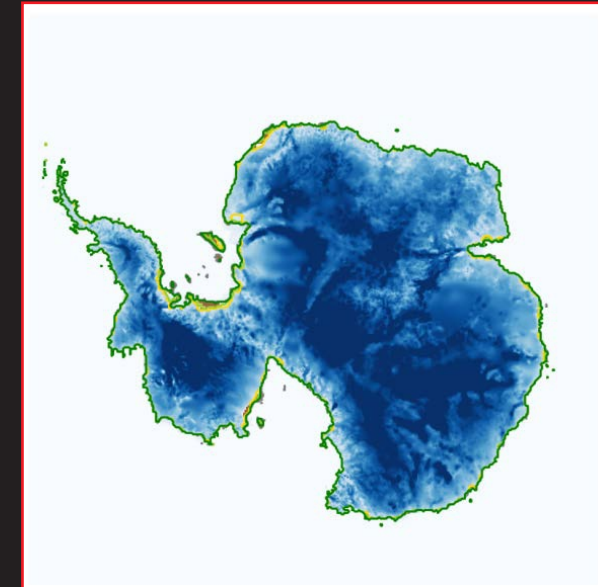
Only a (almost invariant) small fraction ($\sim 7\%$) of CO_2 is extremely persistent. BUT, the majority of carbon removal beyond $\sim 10,000$ PgC is removed only on time-scales exceeding 10,000 years.



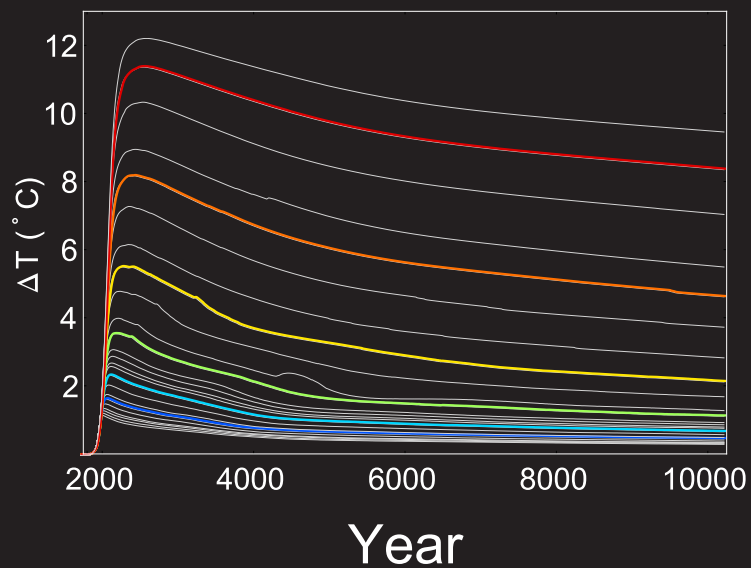
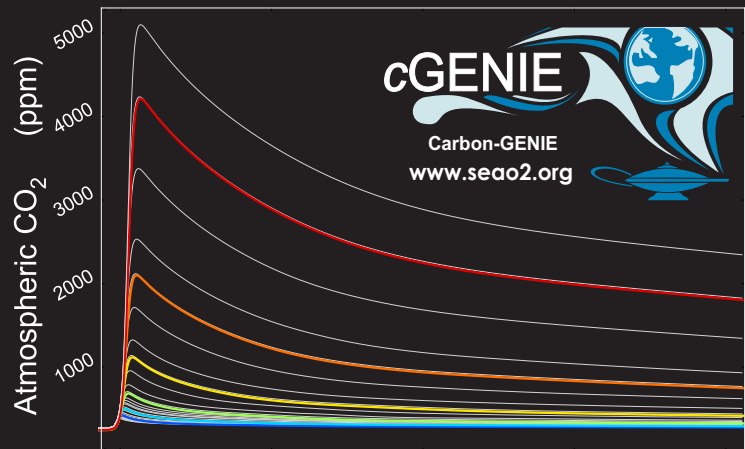
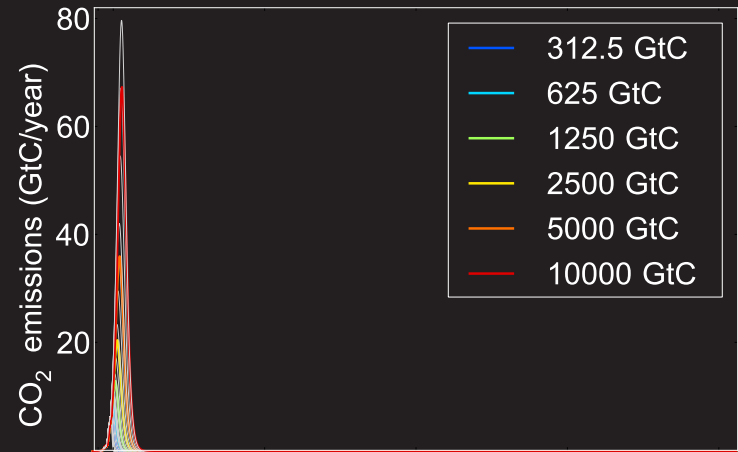
Earth system model
(CO₂ and mean SST trajectories)

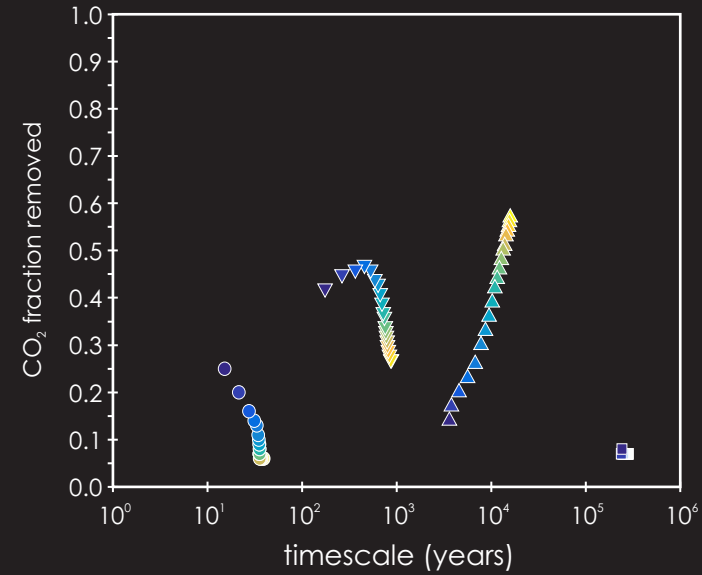
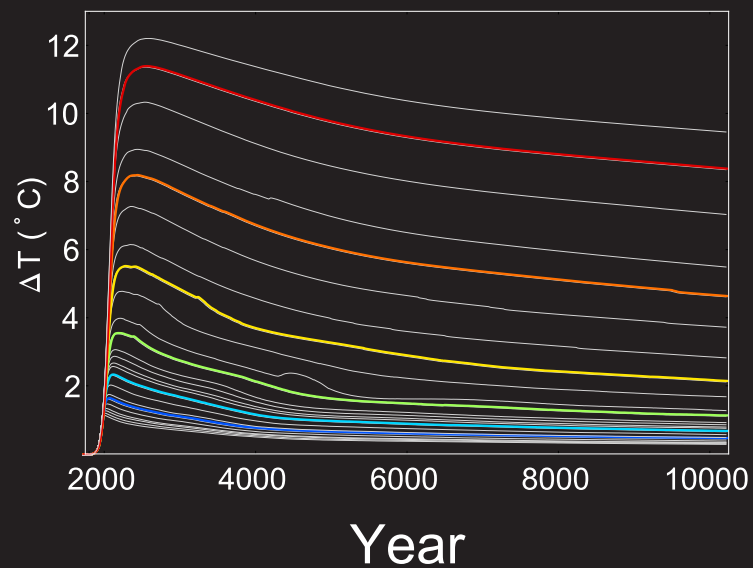
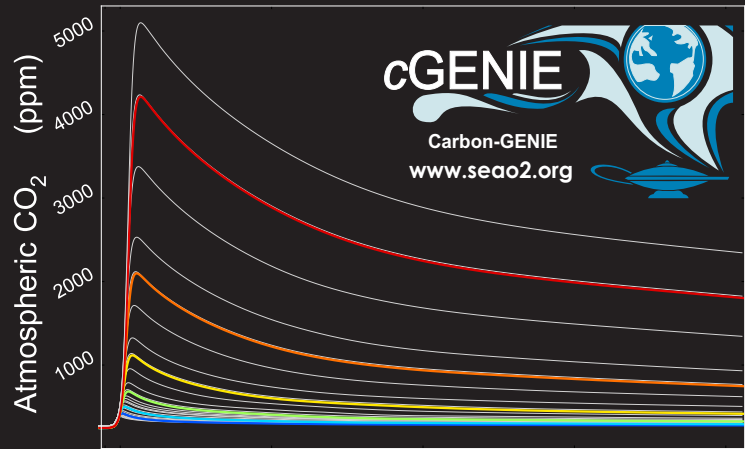
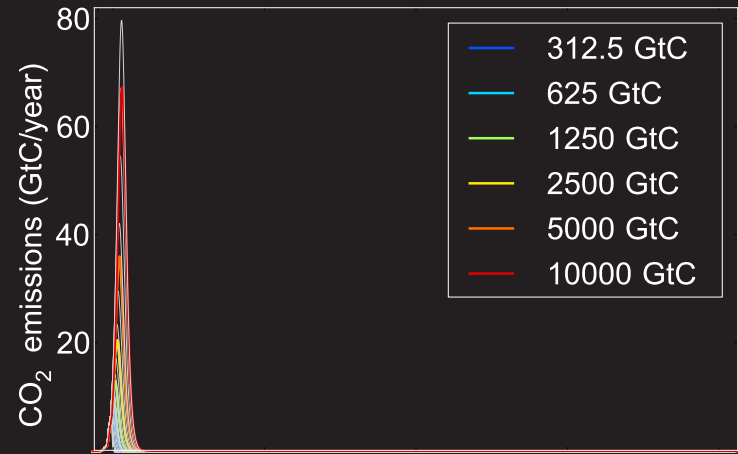


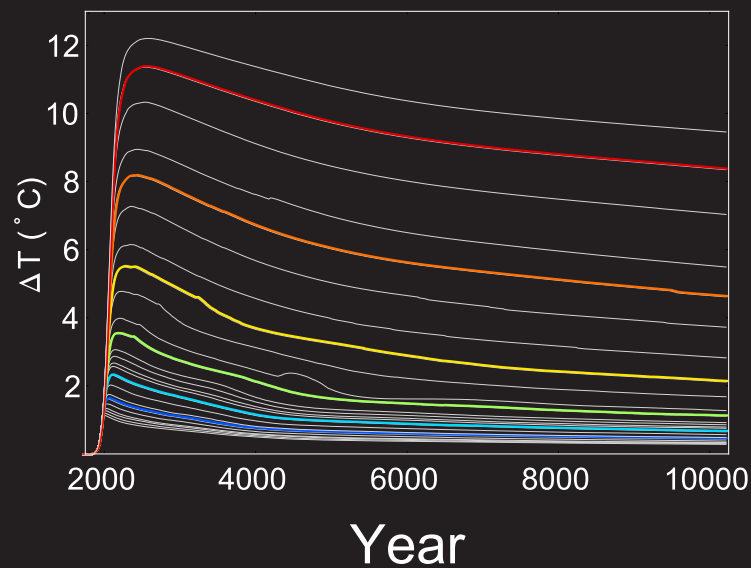
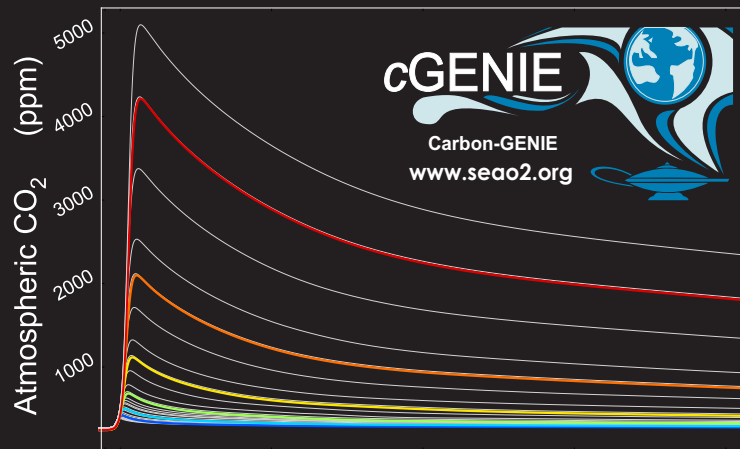
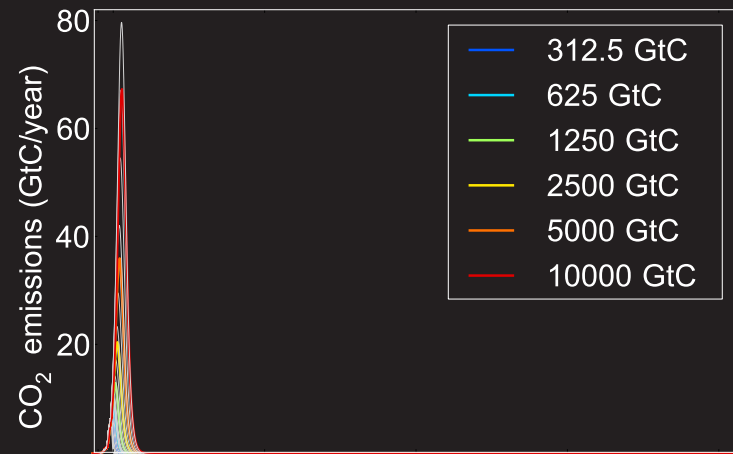
Downscaling
(50 SST and regional climate)



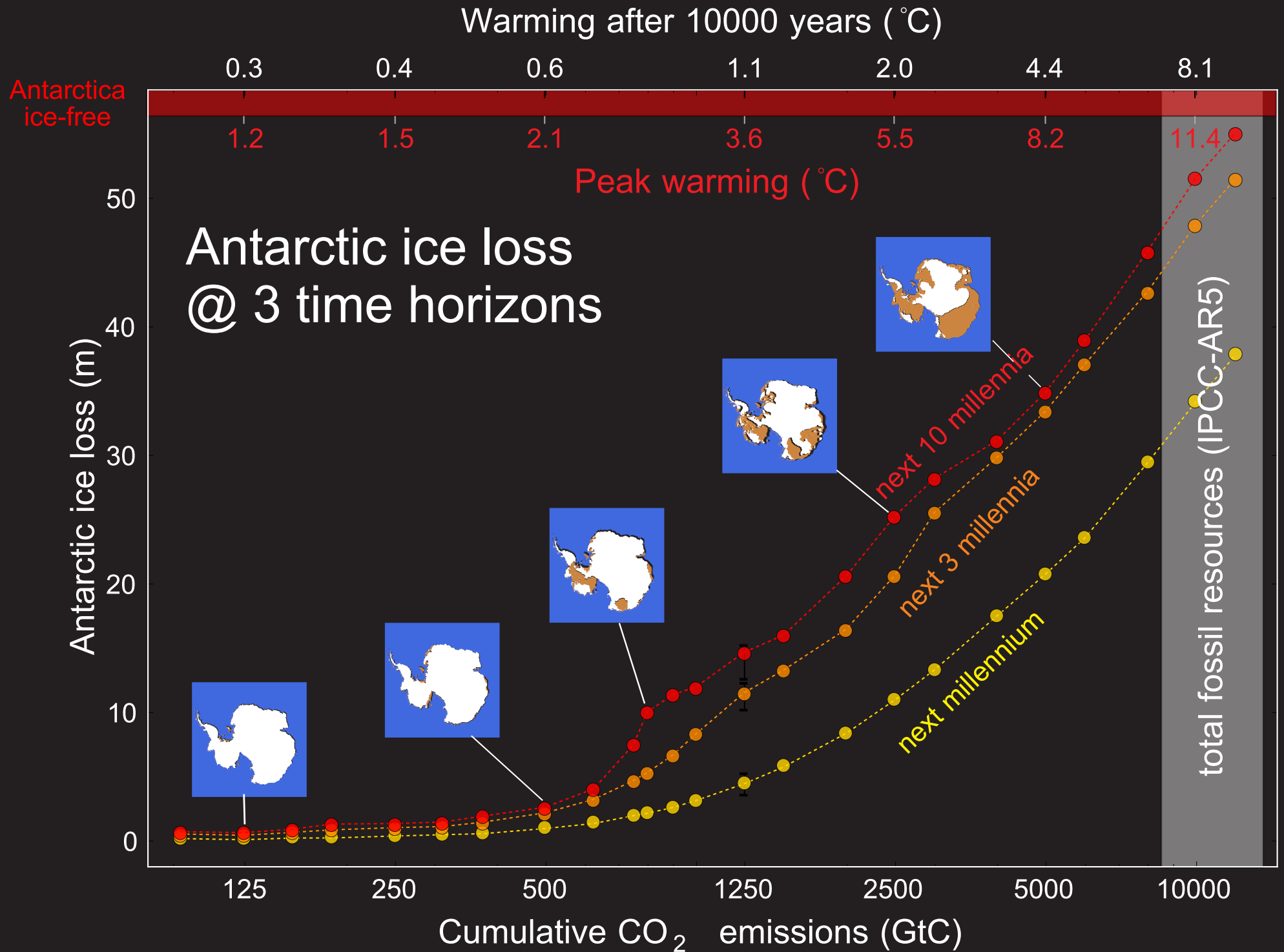
Ice sheet model



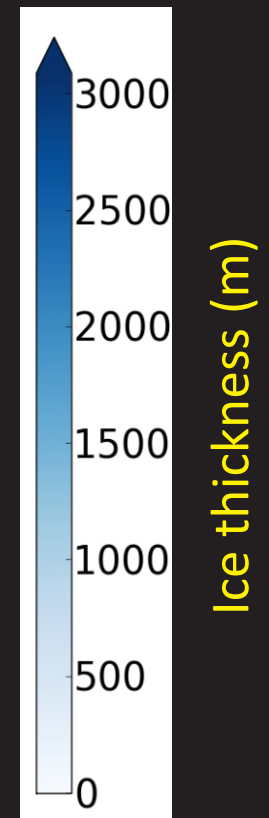
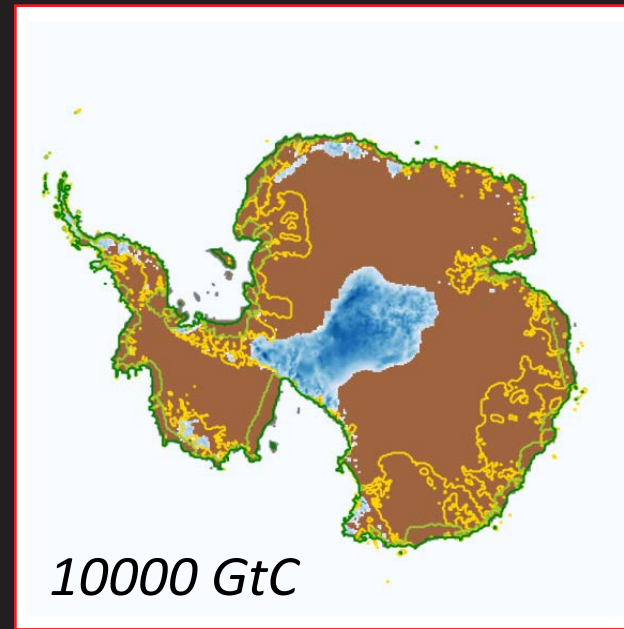
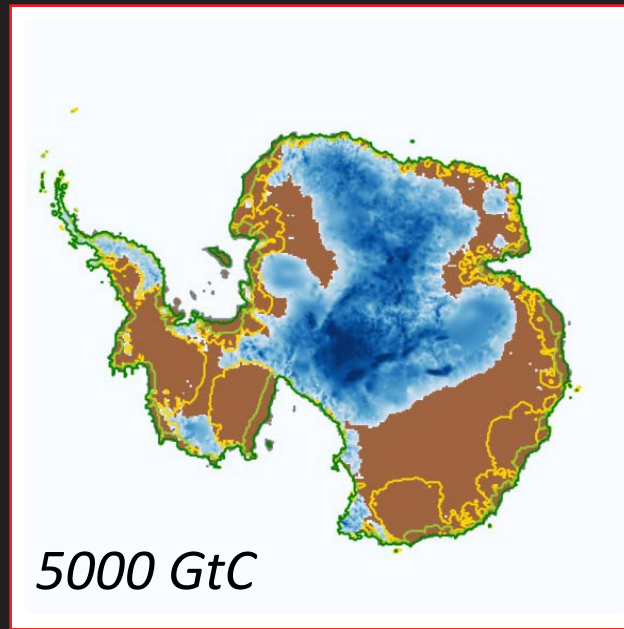
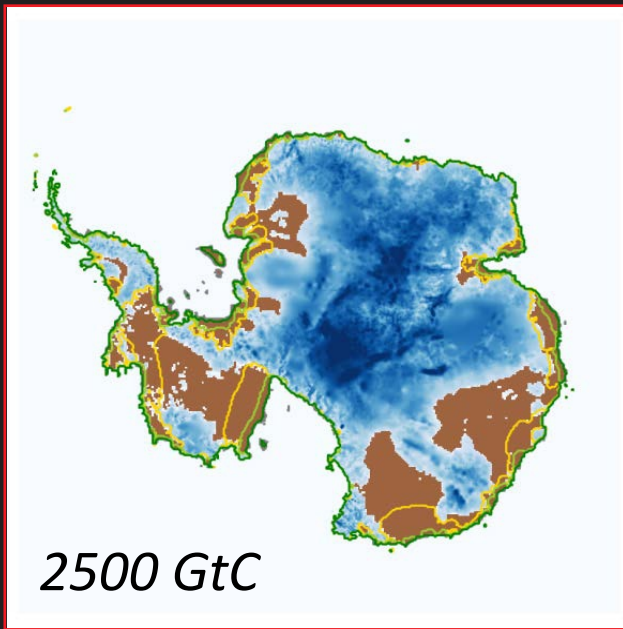
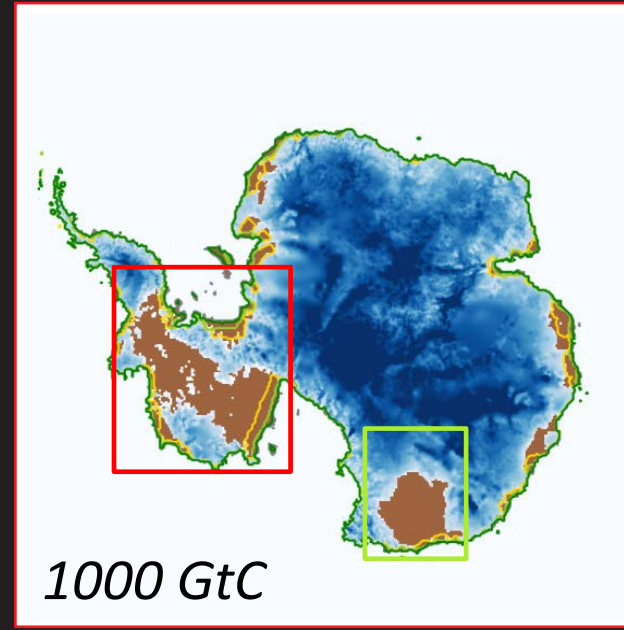
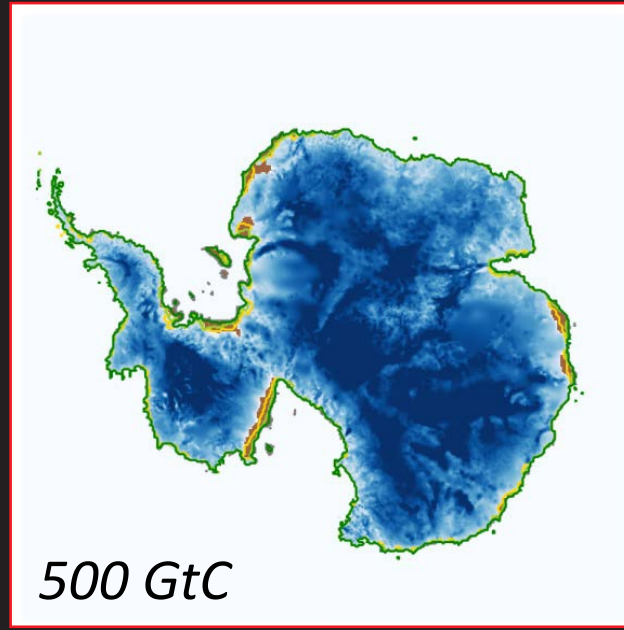
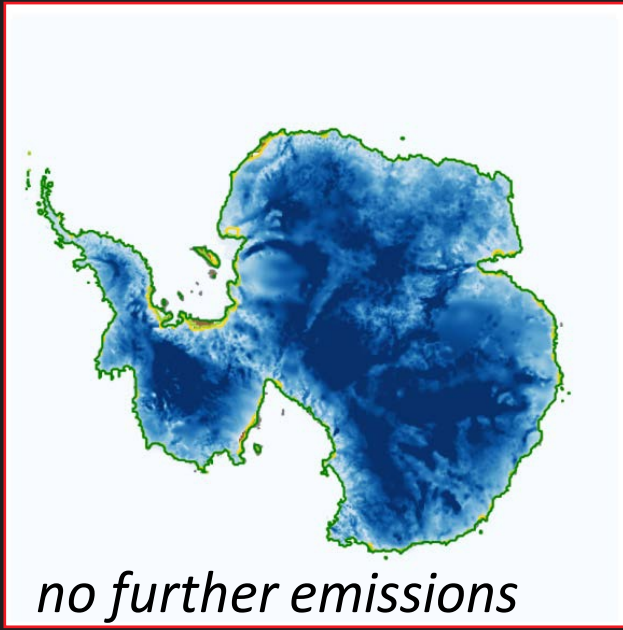




↔ $\Delta F \propto \ln(C/C_0)$



Projected ice sheet extent after 10,000 years



(III) Enhanced weathering (CO₂ removal geoengineering)

GEO250.2015

NOT GENIE



long-term feedbacks on atmospheric CO₂

Accepted Article

An impulse response function for the 'long tail' of excess atmospheric CO₂ in an Earth system model

N. S. Lord¹, A. Ridgway^{1,2}, M. C. Thomas¹ and D. J. Lunt^{1,3}

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²Climate Science, University of Bristol, Bristol, UK

³Department of Earth Sciences, University of California, Riverside, CA, USA

⁴MOE Phone and Associates Limited, Haverley, Baber, Ludlow, County Durham, UK

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This article has been accepted for publication and undergone full peer review but has not been certified by the copyediting, typesetting, and proofreading process which may lead to differences between this version and the Version of Record. Please refer to the final article as the 'Version of Record'.

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Lord et al. [in press]

AGU PUBLICATIONS

Global Biogeochemical Cycles

RESEARCH ARTICLE

The times scale of the silicate weathering negative feedback on atmospheric CO₂

G. Colburn¹, A. Ridgway^{1,2} & M. Lomas¹

Abstract The silicate weathering negative feedback on atmospheric CO₂ is a critical mechanism for Earth system stability. However, the timescale of this feedback is poorly understood. We use a coupled Earth system model to investigate the timescale of the silicate weathering negative feedback on atmospheric CO₂ by varying the rate of silicate weathering. We find that the timescale of the silicate weathering negative feedback on atmospheric CO₂ is approximately 1000 years, which is much longer than the timescale of the atmospheric CO₂ response to a step change in CO₂ concentration. This implies that the silicate weathering negative feedback on atmospheric CO₂ is a slow-acting mechanism that can help to stabilize Earth system temperatures over long timescales.

Colburn et al. [2015]

RESEARCH ARTICLE

CLIMATE CHANGE

Combustion of available fossil fuel resources sufficient to eliminate the Antarctic ice Sheet

K. Winkelman^{1,2}, A. Ridgway^{1,2}, M. Lomas¹, J. Ridgway^{1,2}, S. J. Gray^{1,2}, M. C. Thomas¹, D. J. Lunt^{1,3} & N. S. Lord^{1,3}

Abstract The Antarctic ice sheet is a critical component of Earth system stability. However, the timescale of the ice sheet response to a step change in CO₂ concentration is poorly understood. We use a coupled Earth system model to investigate the timescale of the ice sheet response to a step change in CO₂ concentration. We find that the timescale of the ice sheet response to a step change in CO₂ concentration is approximately 1000 years, which is much longer than the timescale of the atmospheric CO₂ response to a step change in CO₂ concentration. This implies that the ice sheet response to a step change in CO₂ concentration is a slow-acting mechanism that can help to stabilize Earth system temperatures over long timescales.

Winkelman et al. [2015]

nature climate change

LETTERS

Enhanced weathering strategies for stabilizing climate and averting ocean acidification

L. L. Taylor¹, J. Qu¹, R. M. M. Thomas¹, P. Hubner¹, D. Ridgway¹, J. Hameed¹, A. Ridgway^{1,2}, M. Lomas¹, S. J. Gray^{1,2}, M. C. Thomas¹ & D. J. Lunt^{1,3}

Abstract Enhanced weathering strategies for stabilizing climate and averting ocean acidification. We use a coupled Earth system model to investigate the effectiveness of enhanced weathering strategies for stabilizing climate and averting ocean acidification. We find that enhanced weathering strategies can help to stabilize Earth system temperatures and avert ocean acidification over long timescales.

Taylor et al. [in press]

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER

Assessing the controllability of Arctic sea ice extent by sulfate aerosol geoengineering

L. L. Taylor¹, J. Qu¹, R. M. M. Thomas¹, P. Hubner¹, D. Ridgway¹, J. Hameed¹, A. Ridgway^{1,2}, M. Lomas¹, S. J. Gray^{1,2}, M. C. Thomas¹ & D. J. Lunt^{1,3}

Abstract Assessing the controllability of Arctic sea ice extent by sulfate aerosol geoengineering. We use a coupled Earth system model to investigate the effectiveness of sulfate aerosol geoengineering for stabilizing Arctic sea ice extent. We find that sulfate aerosol geoengineering can help to stabilize Arctic sea ice extent over long timescales.

Jackson et al. [2015]

nature geoscience

LETTERS

Sensitivity of climate to cumulative carbon emissions due to compensation of ocean heat and carbon uptake

Philip Goodwin¹, Richard G. Williams¹ and Andy Ridgway¹

Abstract Sensitivity of climate to cumulative carbon emissions due to compensation of ocean heat and carbon uptake. We use a coupled Earth system model to investigate the sensitivity of climate to cumulative carbon emissions due to compensation of ocean heat and carbon uptake. We find that the sensitivity of climate to cumulative carbon emissions due to compensation of ocean heat and carbon uptake is approximately 1000 years, which is much longer than the timescale of the atmospheric CO₂ response to a step change in CO₂ concentration.

Goodwin et al. [2015]

RESEARCH ARTICLE

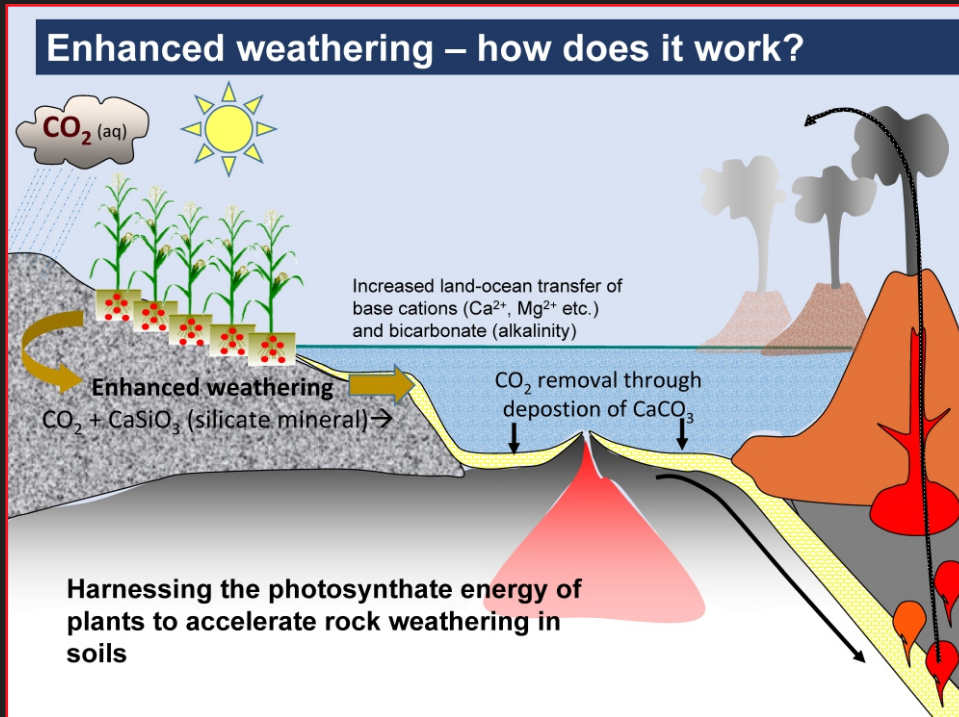
CLIMATE CHANGE

How warming and ice melt level the carbon cycle

Richard G. Williams¹, Philip Goodwin¹, Andy Ridgway¹, M. C. Thomas¹, D. J. Lunt^{1,3} & N. S. Lord^{1,3}

Abstract How warming and ice melt level the carbon cycle. We use a coupled Earth system model to investigate the effectiveness of warming and ice melt for leveling the carbon cycle. We find that warming and ice melt can help to level the carbon cycle over long timescales.

Williams et al. [2012]



David Beerling

Terrestrial weathering can be (approximately equally) divided into carbonate (CaCO₃) and calcium-silicate ('CaSiO₃') weathering:



Ultimately, the (alkalinity: Ca²⁺) weathering products must be removed through carbonate precipitation and burial in marine sediments:



It can be seen that in (2) + (3), that the CO₂ removed (from the atmosphere) during weathering, is returned upon carbonate precipitation (and burial). In (1) + (3) (silicate weathering) CO₂ is permanently removed to the geological reservoir. This CO₂ must be balanced by mantle (/volcanic) out-gassing on the very long term.

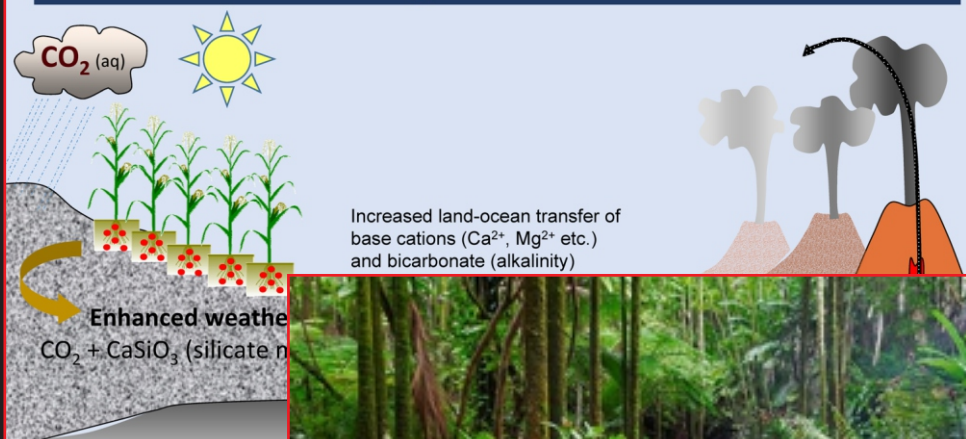
Furthermore, the rate of silicate weathering should scale with climate:

higher pCO₂ → higher temperatures (& rainfall) → higher weathering rates → lower pCO₂

Equally:

greater mineral surface availability → higher weathering rates → lower pCO₂

Enhanced weathering – how does it work?




The diagram illustrates the enhanced weathering process. On the left, a cloud labeled $\text{CO}_2(\text{aq})$ is shown with rain falling on a field of crops. A yellow arrow points from the crops down to the soil, labeled "Enhanced weathering". Below the soil, the chemical reaction $\text{CO}_2 + \text{CaSiO}_3$ (silicate mineral) is shown. On the right, a volcano is depicted with smoke rising from it, and a black arrow points from the volcano towards the left, indicating the transport of substances to the ocean.

Increased land-ocean transfer of base cations (Ca^{2+} , Mg^{2+} etc.) and bicarbonate (alkalinity)

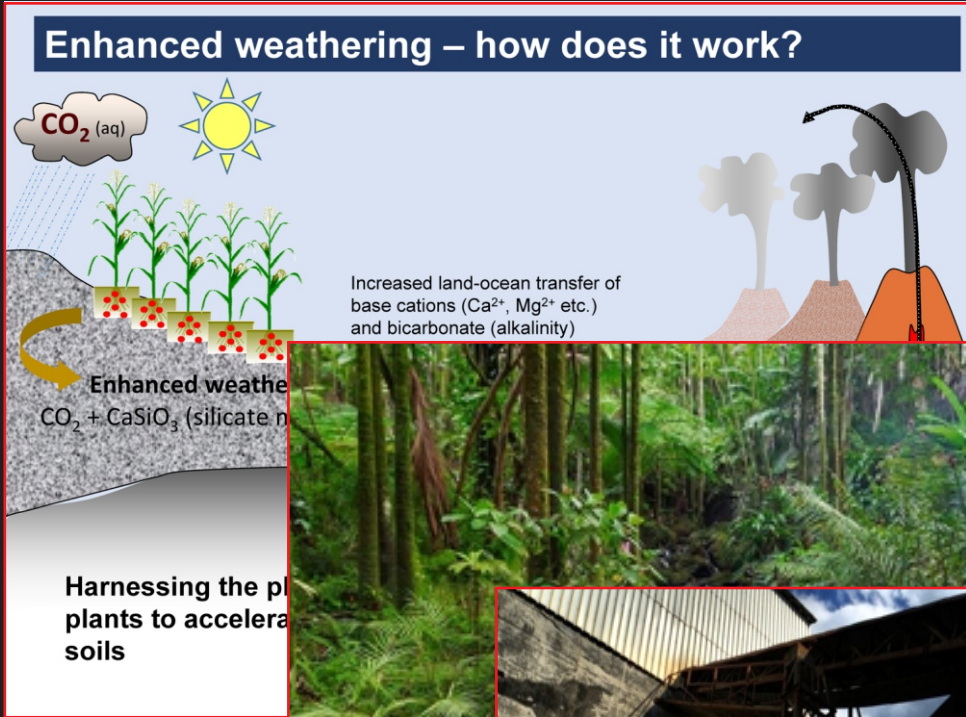
Enhanced weathering
 $\text{CO}_2 + \text{CaSiO}_3$ (silicate mineral)

Harnessing the power of plants to accelerate soil weathering

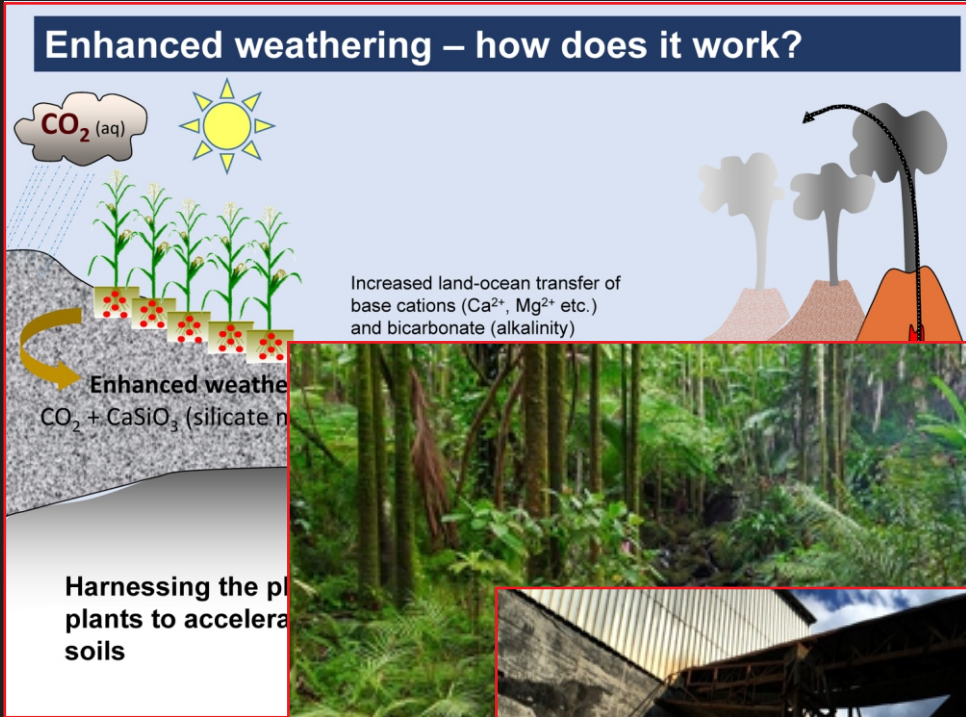


A photograph of a lush tropical forest with a small stream flowing over mossy rocks. The stream is surrounded by dense green vegetation, including ferns and tall trees.

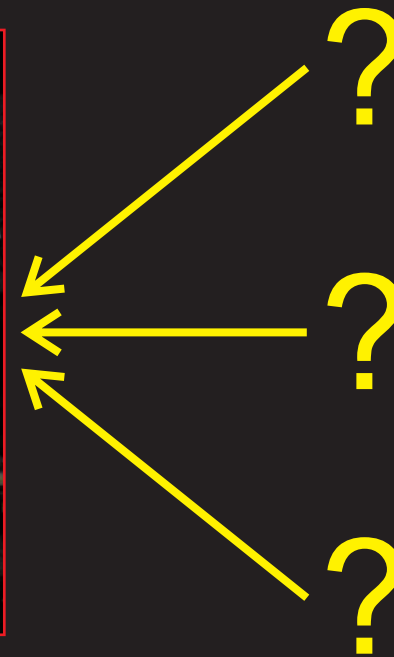
David Beerling

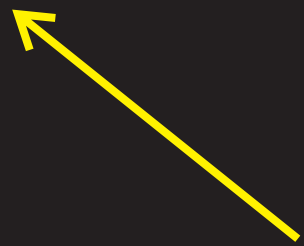
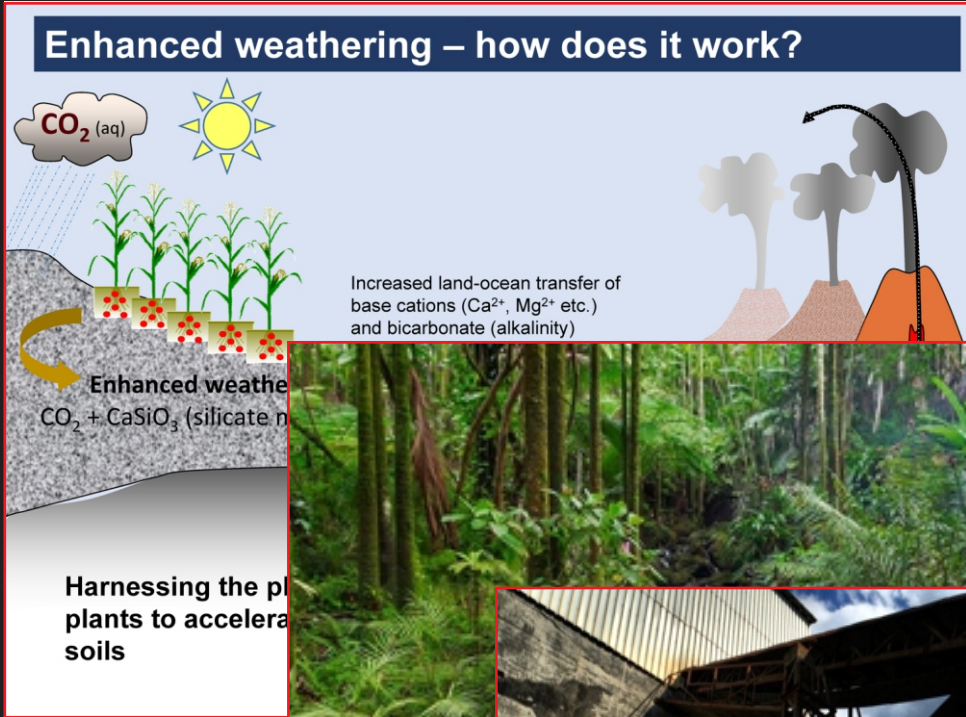


David Beerling

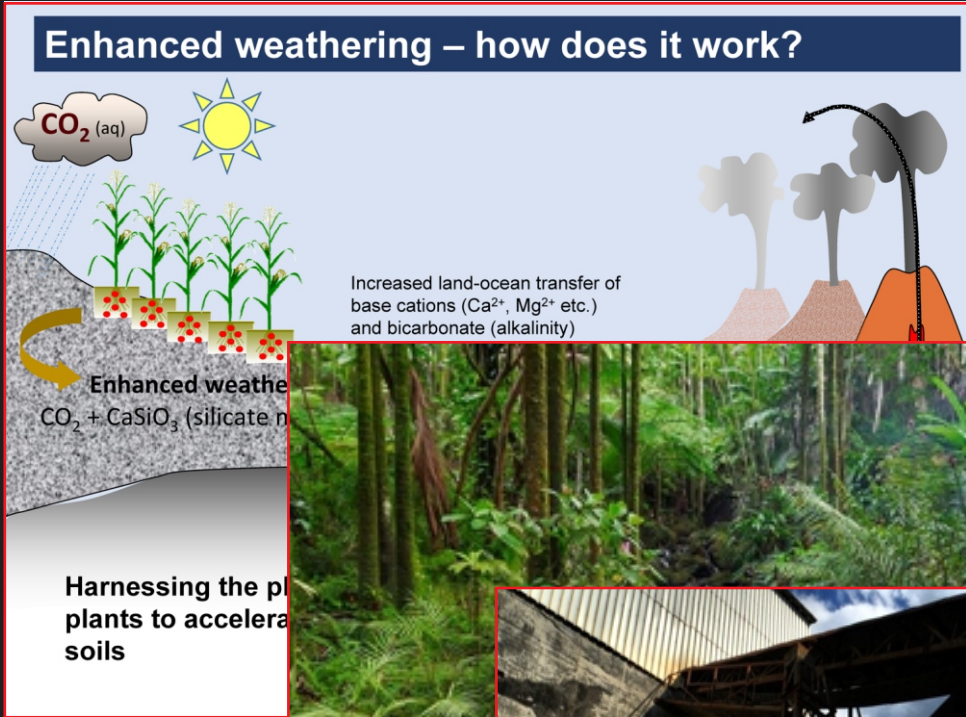


David Beerling





David Beerling

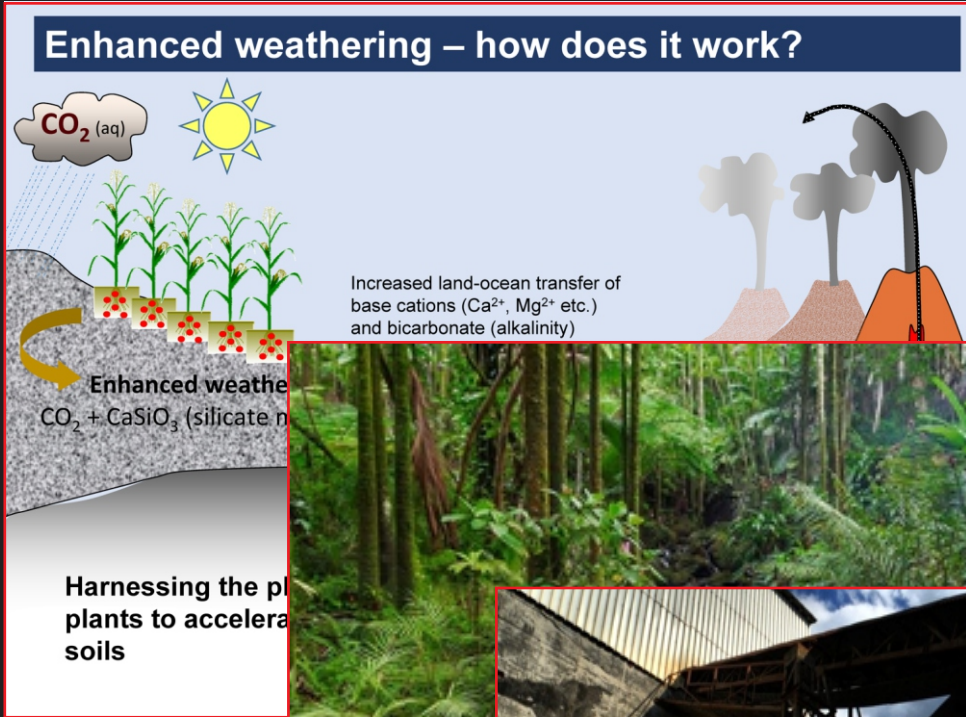


David Beerling

>90% olivine: (Mg⁺², Fe⁺²)₂SiO₄

Dunite



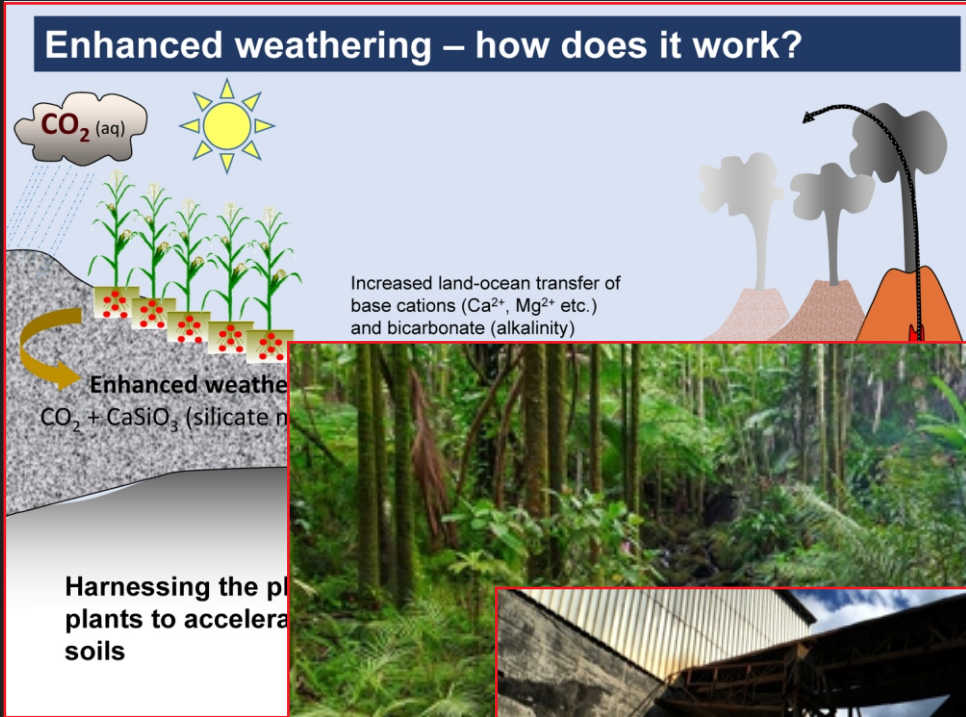


>90% olivine: (Mg⁺², Fe⁺²)₂SiO₄



Dunite

David Beerling



David Beerling

~ olivine + pyroxene

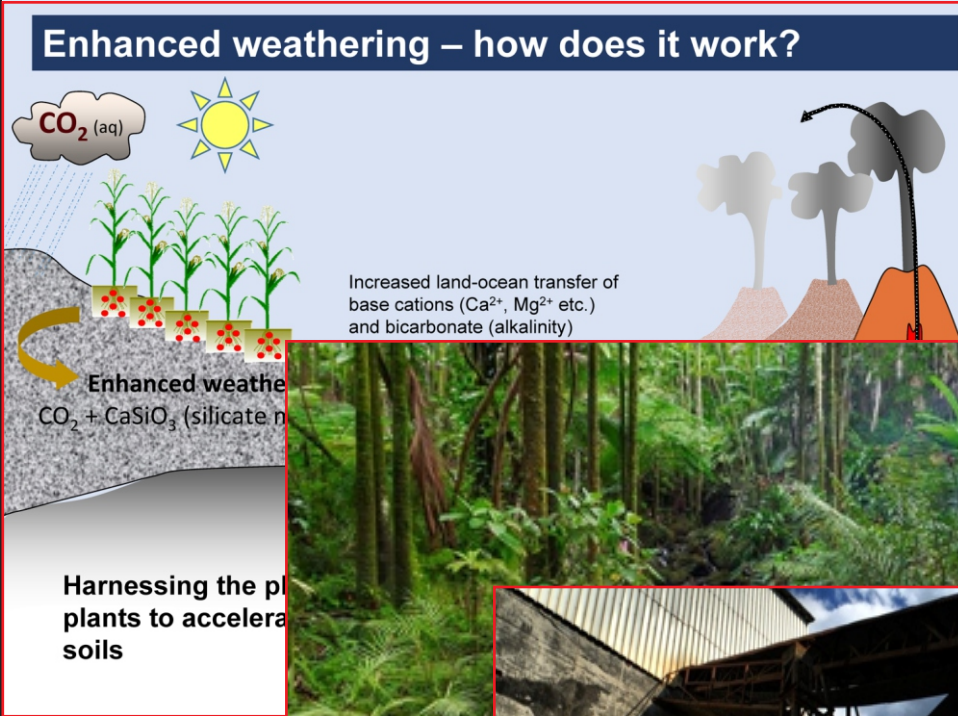
Harzburgite



>90% olivine: (Mg⁺², Fe⁺²)₂SiO₄

Dunite





David Beerling



~ olivine + pyroxene

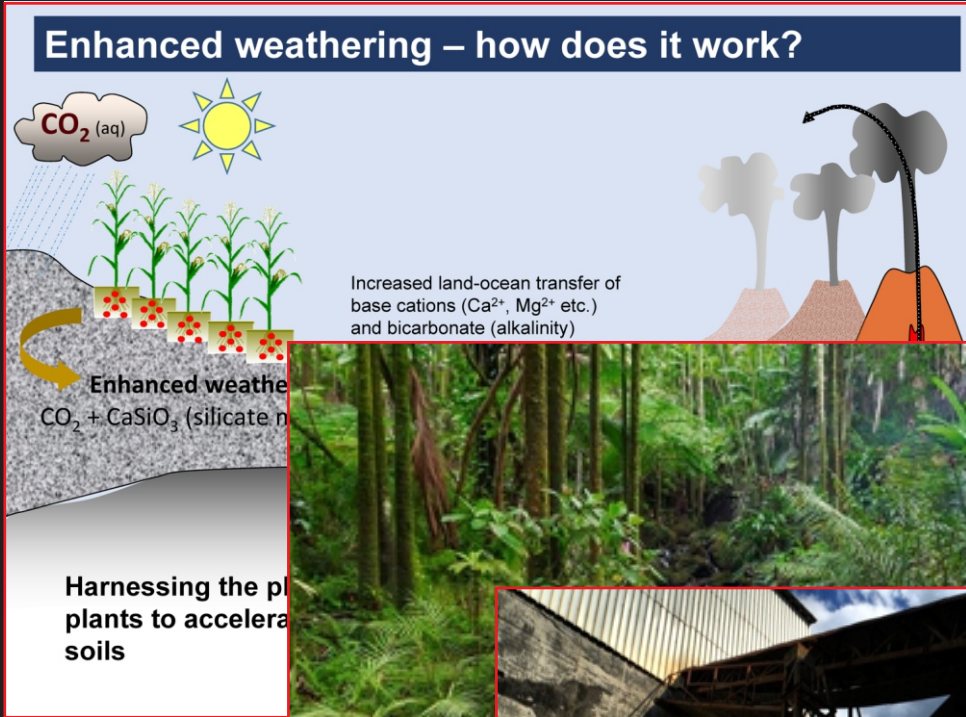
Harzburgite



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Dunite





David Beerling

Harzburgite

~ olivine + pyroxene



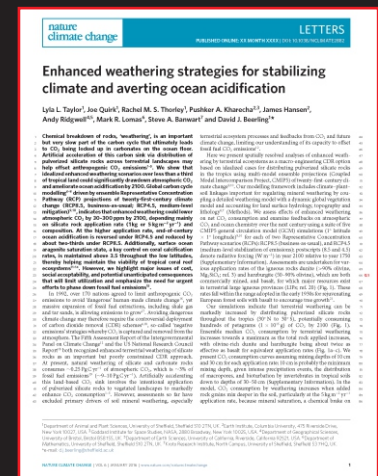
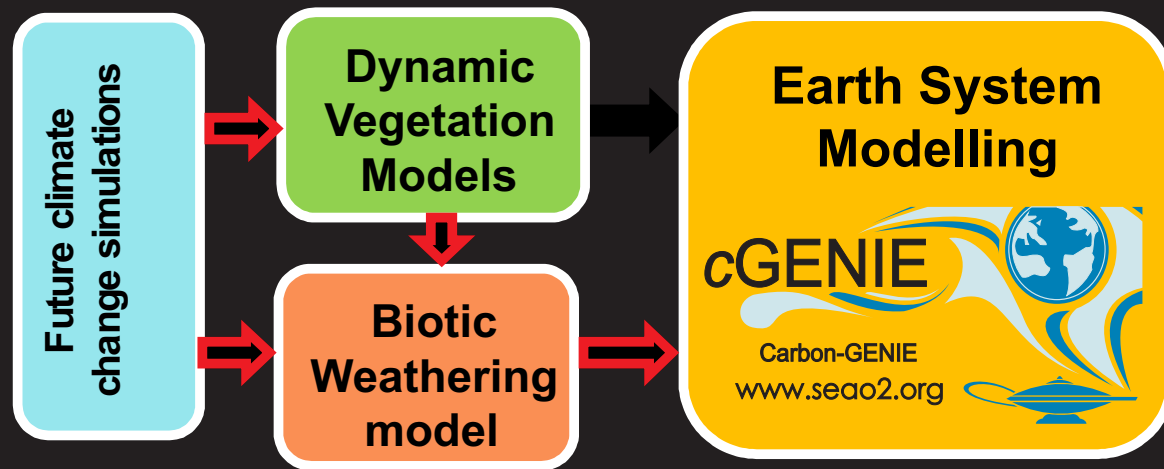
~ plagioclase + pyroxene (+olivine)



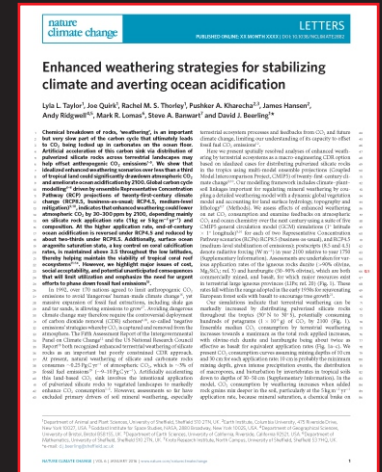
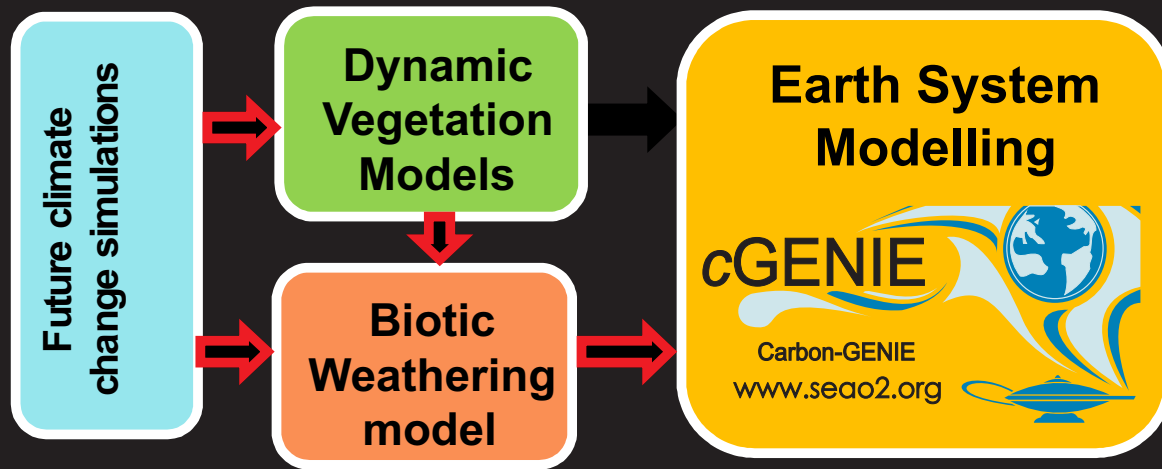
>90% olivine: (Mg⁺², Fe⁺²)₂SiO₄

Dunite

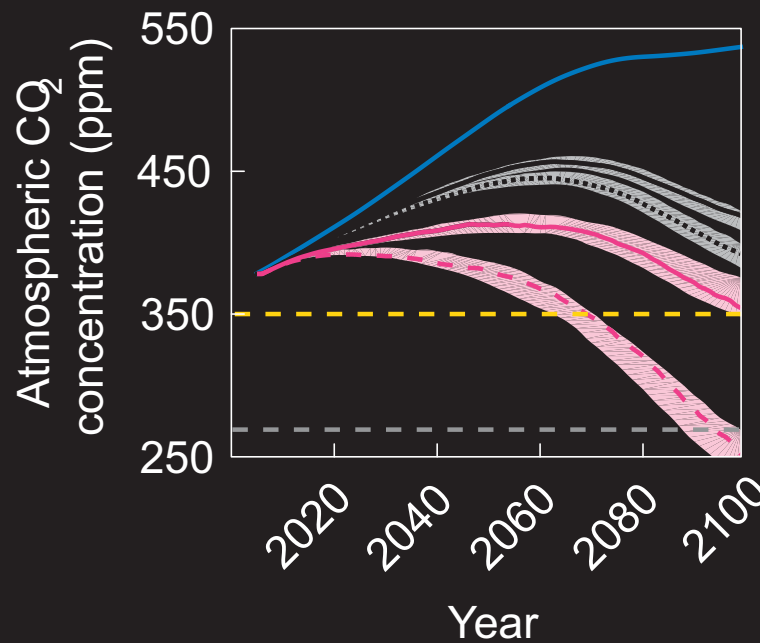
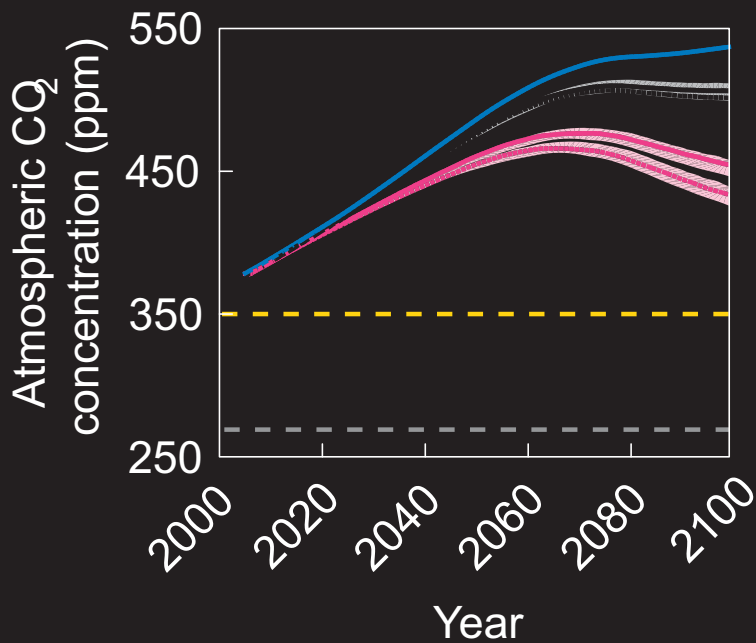




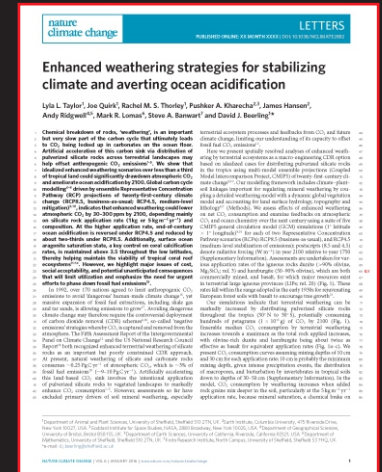
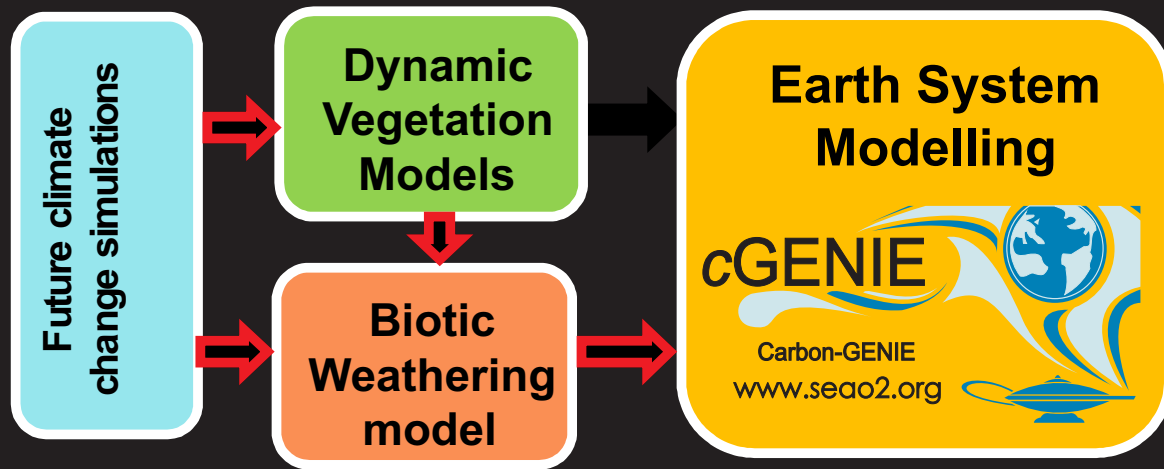
Taylor et al. [in press]



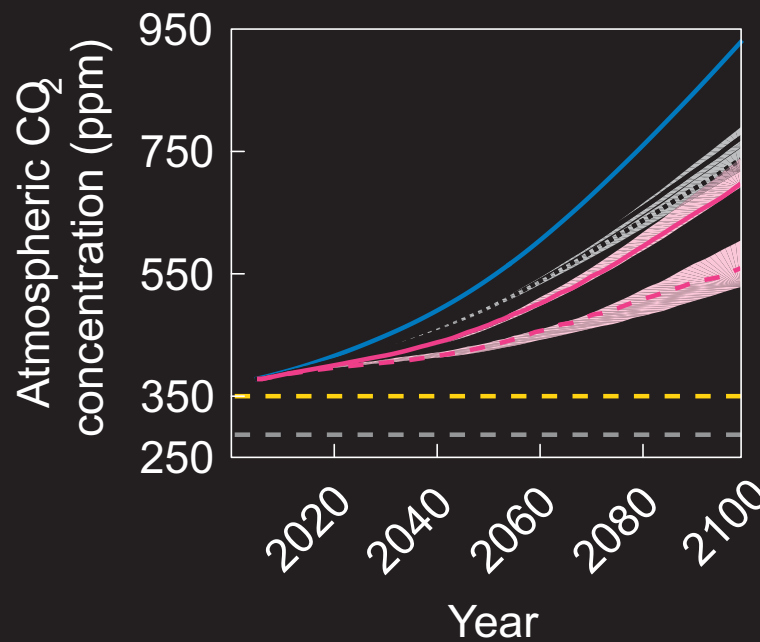
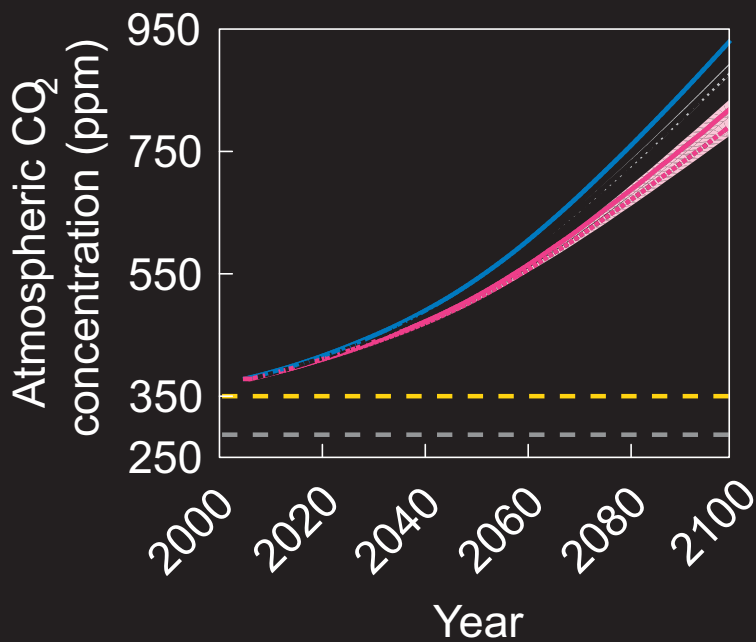
Taylor et al. [in press]



- RCP scenario
- Basalt 10 cm
- Basalt 30 cm
- Harzburgite 10 cm
- Harzburgite 30 cm
- - - 350 ppm CO₂
- · - Pre-industrial CO₂



Taylor et al. [in press]



- RCP scenario
- Basalt 10 cm
- Basalt 30 cm
- Harzburgite 10 cm
- Harzburgite 30 cm
- - - 350 ppm CO₂
- - - Pre-industrial CO₂

Current global oil
consumption =
90,136×10³ barrels per
day

$$\begin{aligned} 1.0 \text{ barrel} &= 159 \text{ l} \\ &= 159 \times 10^3 \text{ cm}^3 \end{aligned}$$

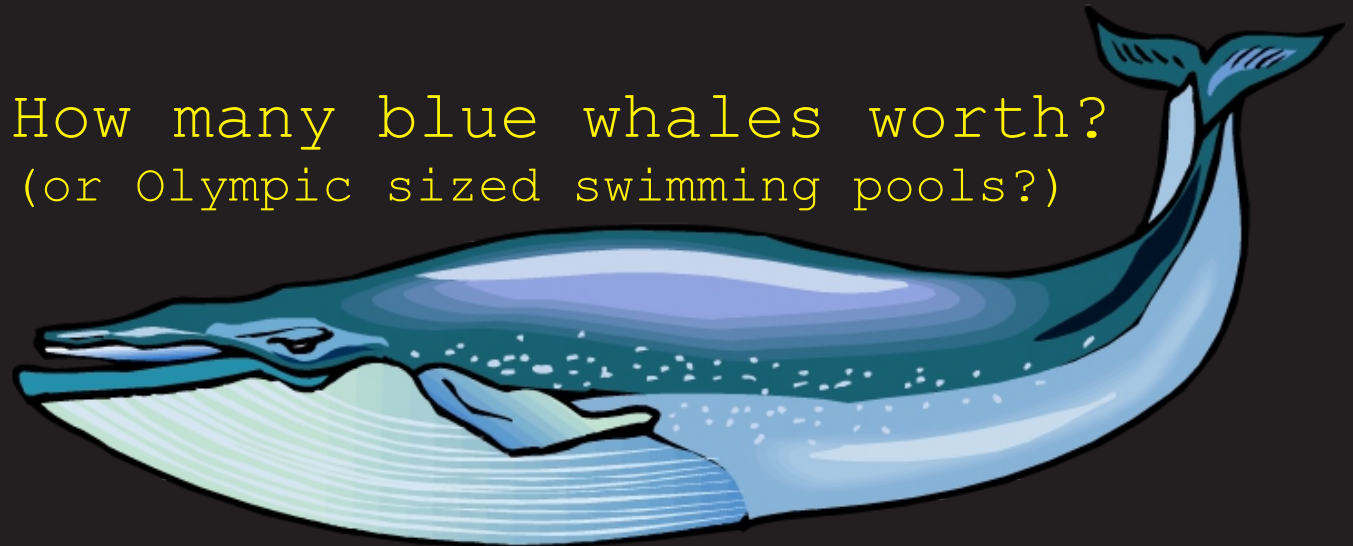
$$\begin{aligned} \Rightarrow \text{oil consumption} \\ &= 5.23 \times 10^{15} \text{ cm}^3 \text{ year}^{-1} \\ &= \mathbf{5.23 \text{ km}^3 \text{ year}^{-1}} \end{aligned}$$

Current global oil
consumption =
 $90,136 \times 10^3$ barrels per
day

1.0 barrel = 159 l
= 159×10^3 cm³

⇒ oil consumption
= 5.23×10^{15} cm³ year⁻¹
= **5.23 km³ year⁻¹**

How many blue whales worth?
(or Olympic sized swimming pools?)



Current global oil
consumption =
 $90,136 \times 10^3$ barrels per
day

1.0 barrel = 159 l
= 159×10^3 cm³

⇒ oil consumption
= 5.23×10^{15} cm³ year⁻¹
= **5.23 km³ year⁻¹**

How many Yosemite Valleys?
(equivalent volume)



Current global oil
consumption =
90,136×10³ barrels per
day

1.0 barrel = 159 l
= 159×10³ cm³

⇒ oil consumption
= 5.23×10¹⁵ cm³ year⁻¹
= 5.23 km³ year⁻¹

Yosemite Valley
(Wikipedia):

1,200m deep × 1,600m
across, 12.0 km long

⇒

volume = 1.2×1.6×12.0
= 23.0 km³

How many Yosemite Valleys?
(equivalent volume)



NOT GENIE



Geophysical Research Letters

RESEARCH LETTER Assessing the controllability of Arctic sea ice extent by sulfate aerosol geoengineering

Lead Authors: S. J. Jackson^{1,2}, A. Kravtsov³, R. Lindqvist⁴, A. Milinski⁵, M. Stouffer⁶, and M. R. Meade⁷

Abstract: An assessment of how large sea ice extent could be maintained in a warming world via sulfate aerosol geoengineering is presented. A range of sulfate aerosol concentrations and injection heights are considered, and the resulting impact on Arctic sea ice extent is assessed. The results show that sulfate aerosol geoengineering can maintain Arctic sea ice extent at or near preindustrial levels, but that the impact on Arctic sea ice extent is highly sensitive to the injection height and sulfate aerosol concentration. The results also show that sulfate aerosol geoengineering can maintain Arctic sea ice extent at or near preindustrial levels, but that the impact on Arctic sea ice extent is highly sensitive to the injection height and sulfate aerosol concentration.

1. Introduction

Sulfate aerosol geoengineering is a proposed method for reducing global temperatures and sea level rise by reflecting incoming solar radiation. This method has been proposed as a potential means of mitigating the effects of climate change, particularly the effects of global warming on sea level rise. Sulfate aerosol geoengineering is a proposed method for reducing global temperatures and sea level rise by reflecting incoming solar radiation. This method has been proposed as a potential means of mitigating the effects of climate change, particularly the effects of global warming on sea level rise.

Jackson et al. [2015]

NOT GENIE



AGU PUBLICATIONS
Geophysical Research Letters

RESEARCH LETTER
Assessing the controllability of Arctic sea ice extent by sulfate aerosol geoengineering

Lead Authors: L. A. Jackson¹, S. A. Kravitz², A. Bauer³, M. Lesins⁴, A. Rind⁵, M. Stouffer⁶, and M. M. Holland⁷

Abstract: An assessment of how Arctic sea ice extent could be controlled in a warming world via sulfate aerosol geoengineering is presented. A simple, but novel, model is used to assess the controllability of Arctic sea ice extent. The model is used to assess the controllability of Arctic sea ice extent under a range of sulfate aerosol geoengineering scenarios. The model is used to assess the controllability of Arctic sea ice extent under a range of sulfate aerosol geoengineering scenarios. The model is used to assess the controllability of Arctic sea ice extent under a range of sulfate aerosol geoengineering scenarios.

1. Introduction

Sulfate aerosol geoengineering is a proposed method for reducing global temperatures and sea level rise. It involves injecting sulfate aerosols into the stratosphere, where they can reflect incoming solar radiation and cool the Earth's surface. This method has been proposed as a potential means of mitigating the effects of climate change. However, there are concerns about the controllability of sulfate aerosol geoengineering, particularly in terms of its ability to control Arctic sea ice extent. This paper assesses the controllability of Arctic sea ice extent under a range of sulfate aerosol geoengineering scenarios.

Jackson et al. [2015]







