The Carbon Cycle behind Net Zero

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NET ZERO

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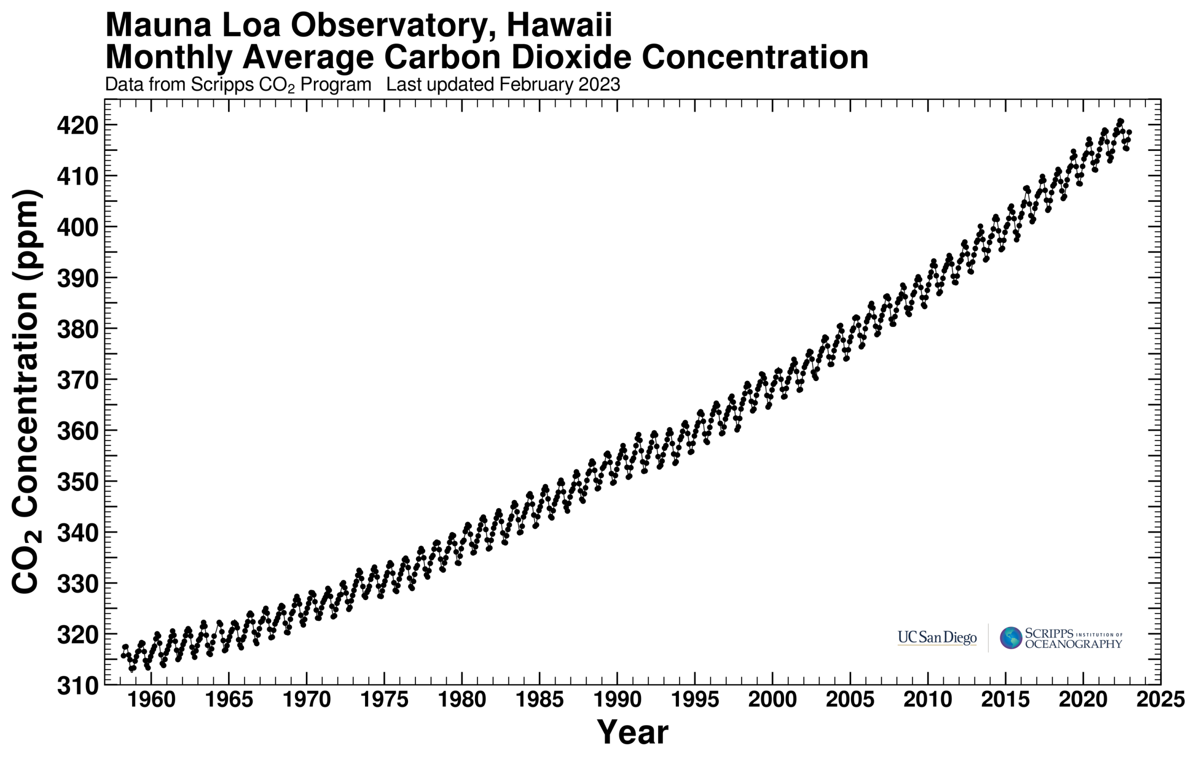
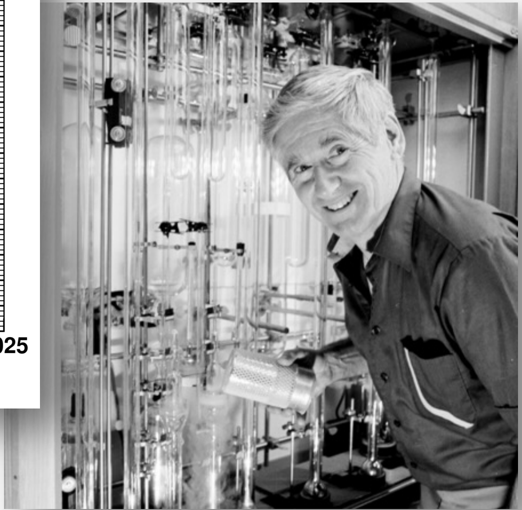
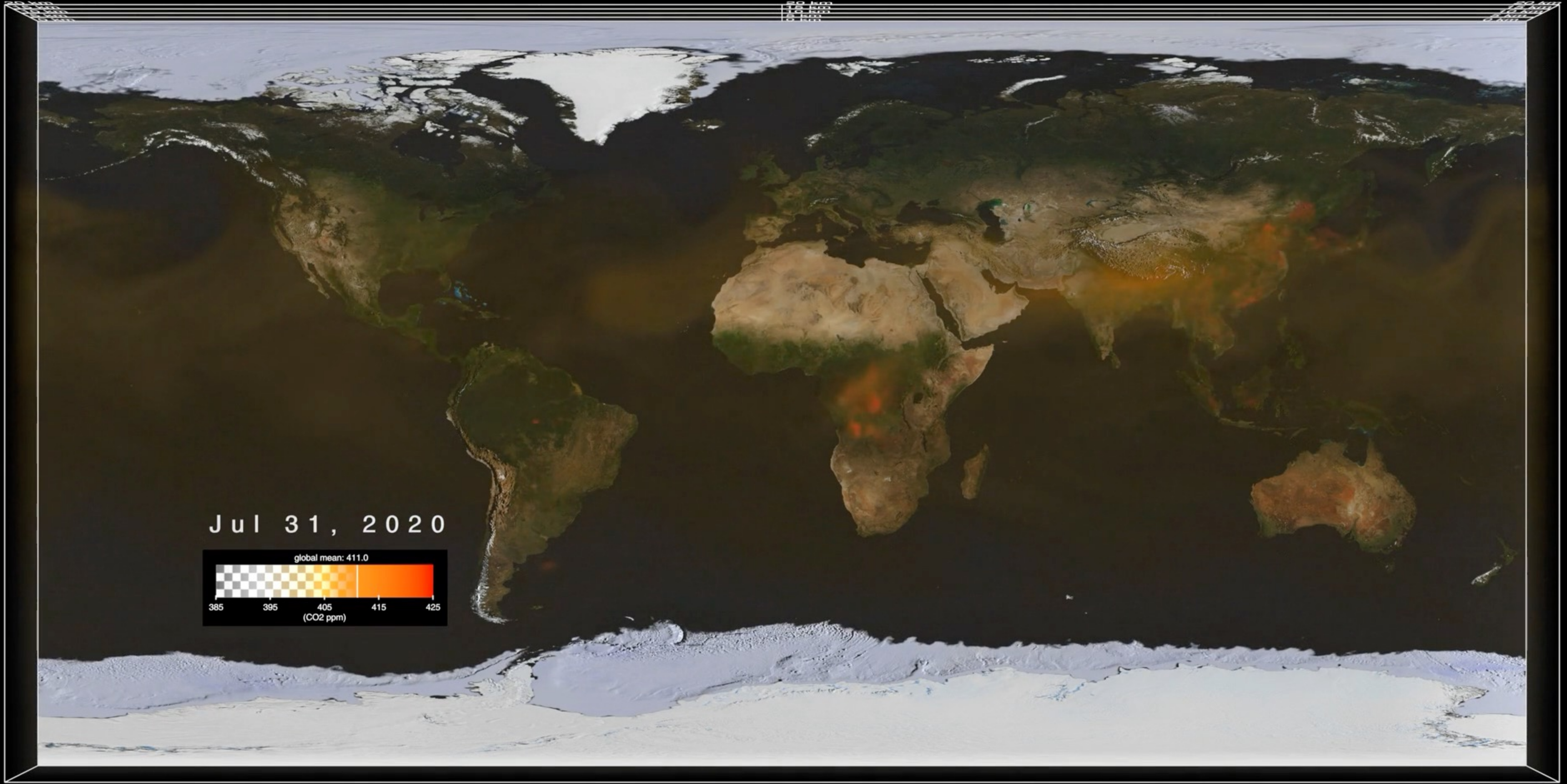
CO_2 concentrations are rising





Charles David Keeling

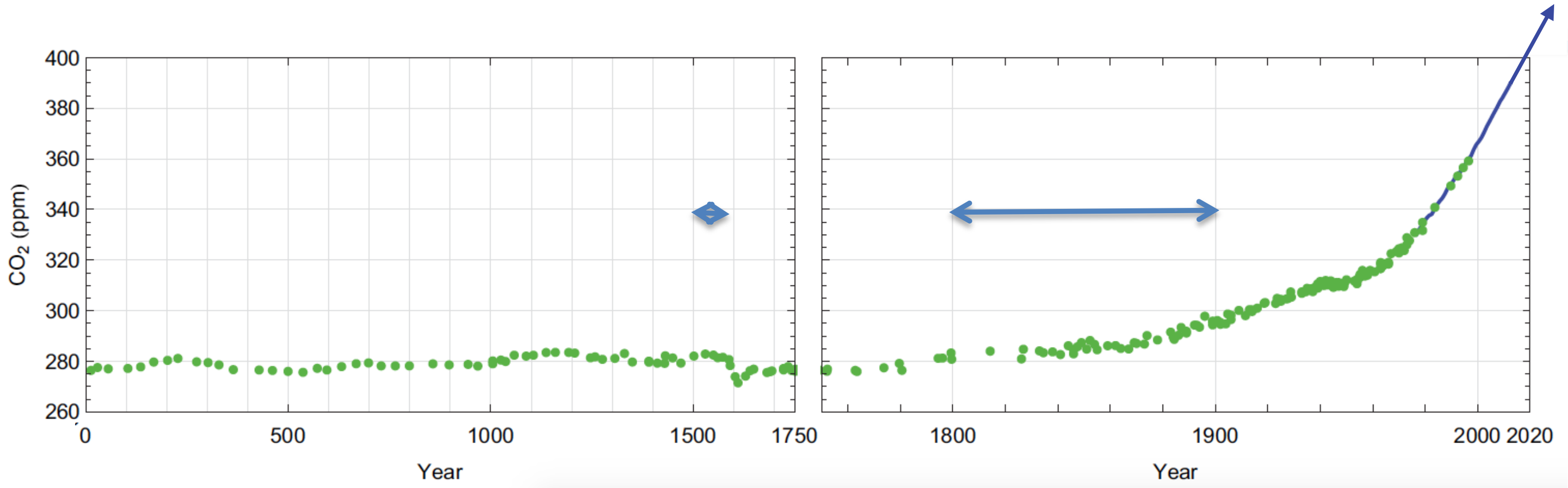
CO_2 concentrations over the course of a year



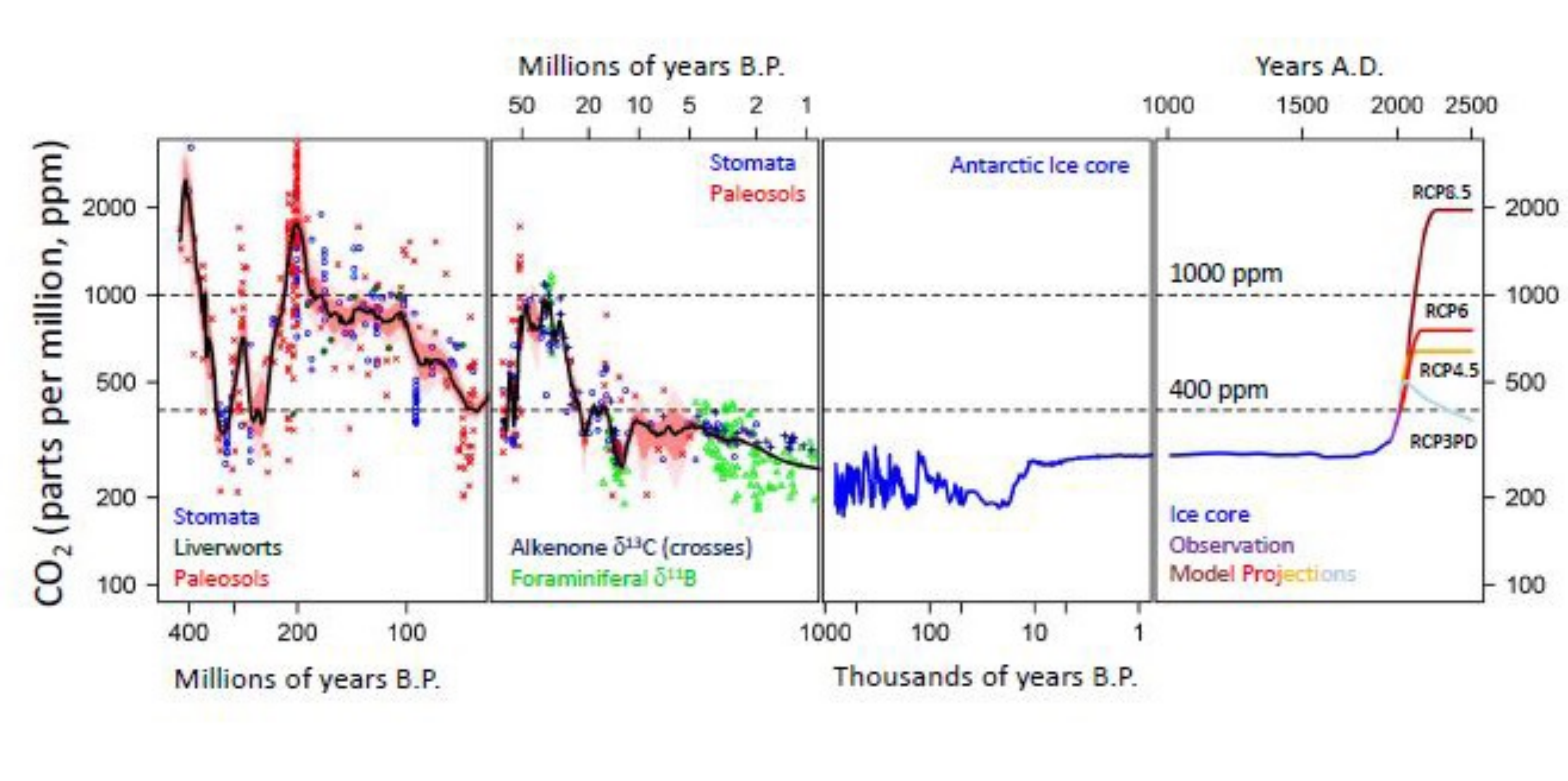
Global CO_2 concentrations on July 31st: 2020 - 411ppm; 2021 - 413ppm

Source: Nasa

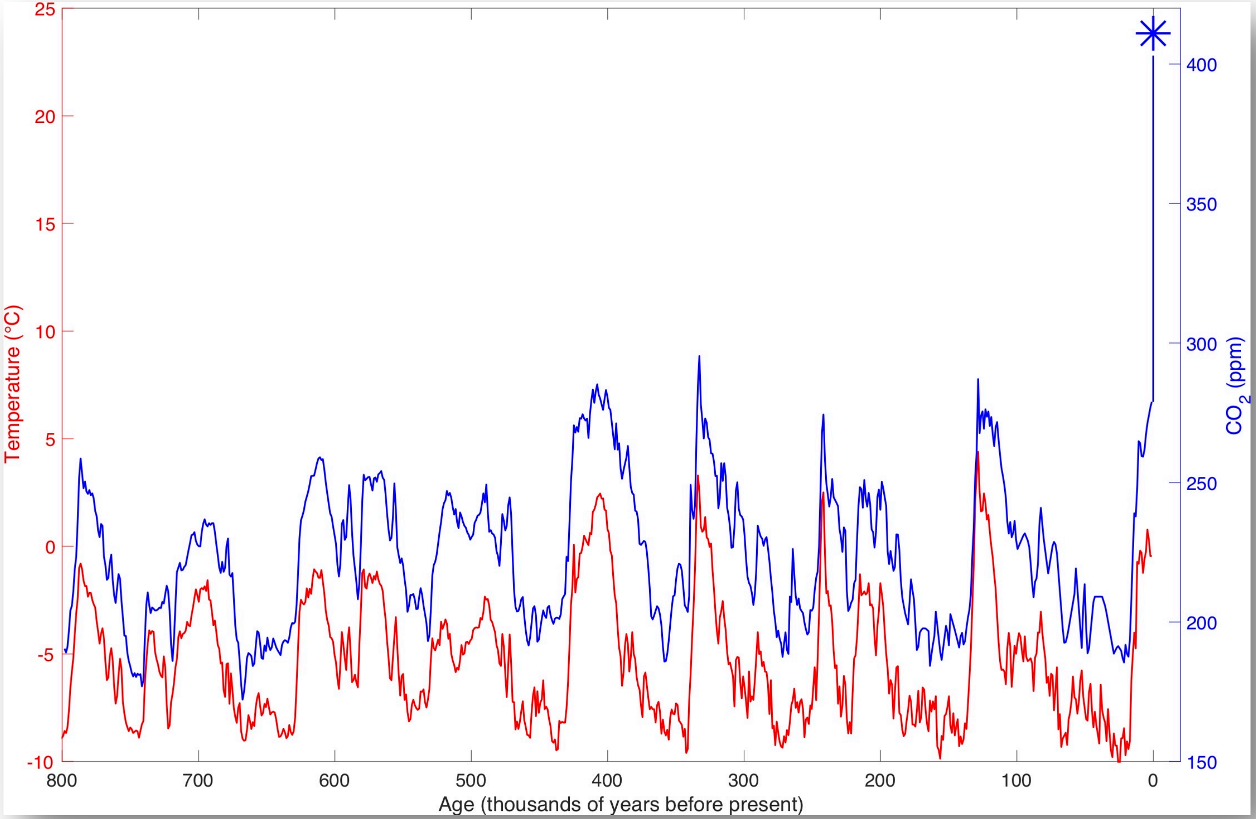
CO_2 concentrations over the past millennium



And over the past 20 million years

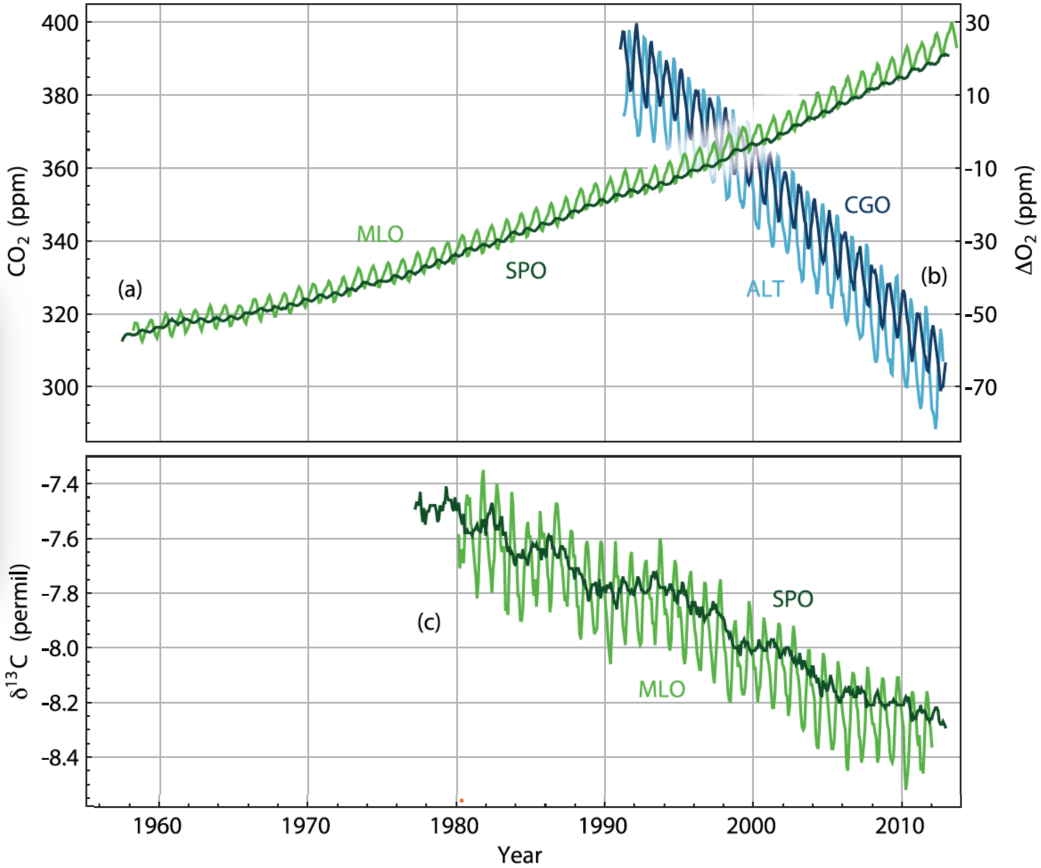


Carbon dioxide and Antarctic temperatures over the past 800,000 years: but which is driving which?



We have plenty of evidence where modern carbon dioxide is coming from

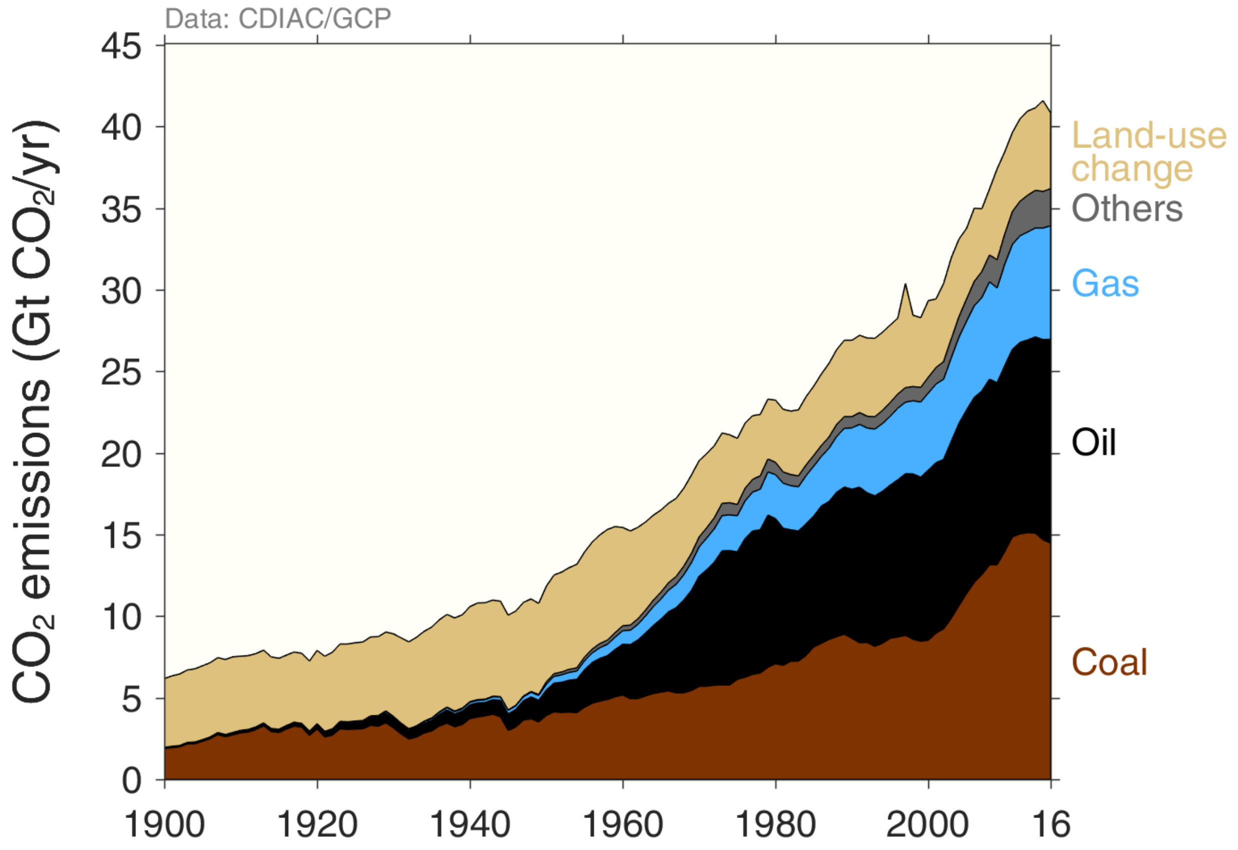
Ralph Keeling



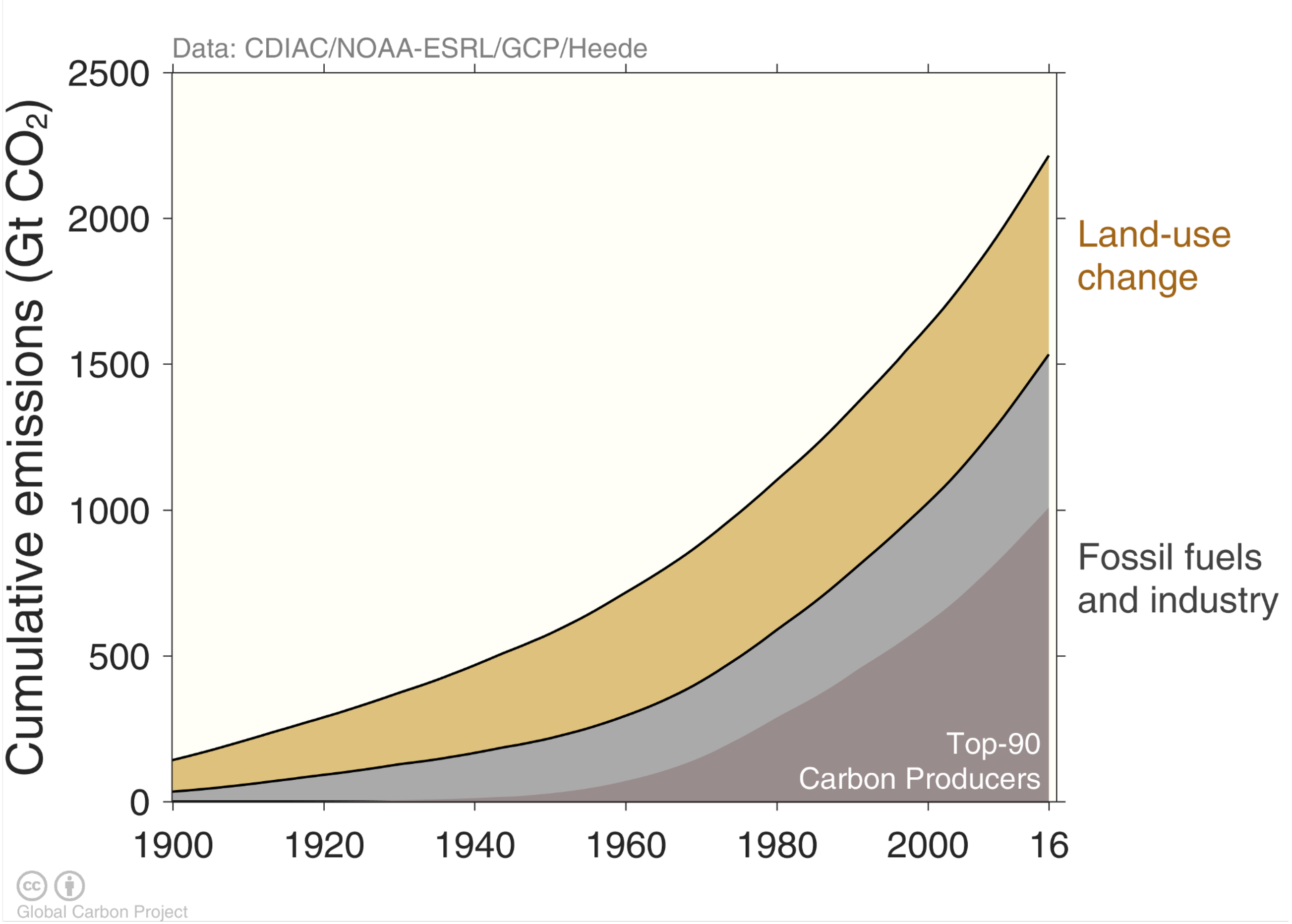
Oxygen levels are falling (by a tiny fraction)

And the fraction of fossil-origin isotopes in air is rising

Where the CO_2 is coming from

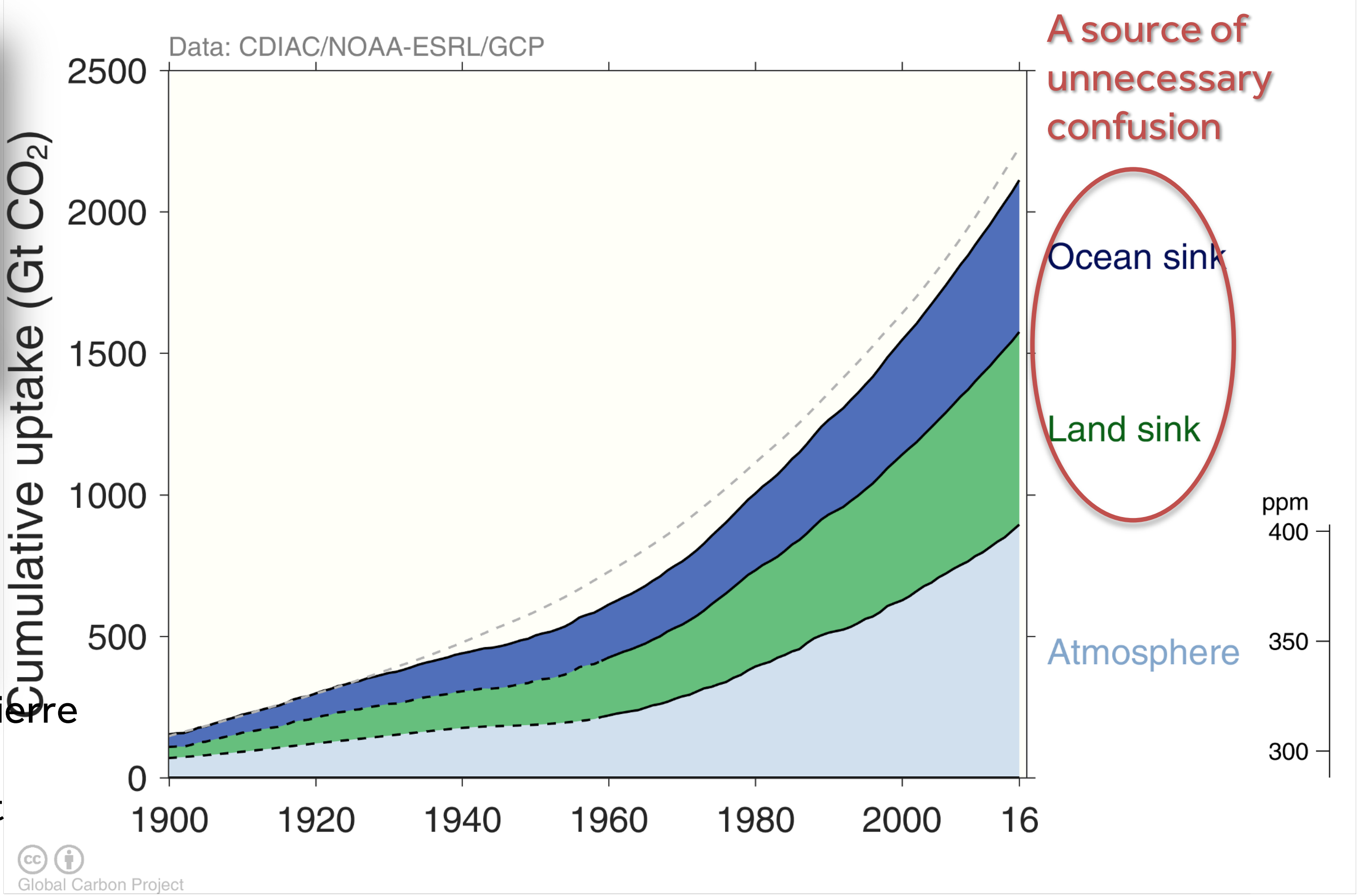


Where the CO_2 is coming from: added up over time



And where the CO_2 is going: added up over time

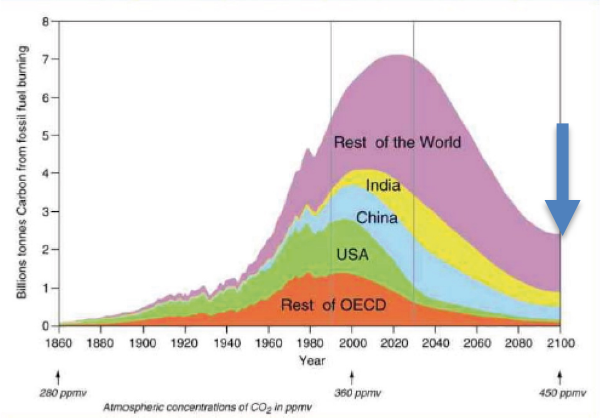
Corinne Le Quéré & Pierre Friedlingstein,
Global Carbon Project



"If nature is absorbing half our CO_2 emissions, we need to halve emissions to stabilize concentrations…"

3 Solution – contraction and convergence

First advocated in 1990 by Aubrey Meyer



"Long-term convergence of per capita emissions is … the only equitable basis for a global compact on climate change"

Manmohan Singh, 30 June 2008

50% reduction from 1990 emissions?

Introducing the Gresham Carbon Cycle Model

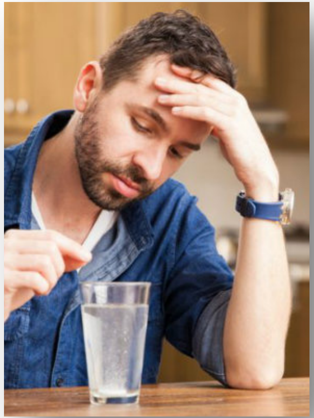
Three connected plastic tubes representing:

1. Additional carbon (in the form of CO_2) in the atmosphere above pre-industrial: level indicates concentration.
2. Additional carbon in the biosphere and near-surface ocean: level indicates the increase in atmospheric CO_2 concentrations that would accompany this much extra carbon in these reservoirs in equilibrium.
3. Additional carbon in the deep ocean: level also indicates "equivalent atmospheric CO_2 concentration".

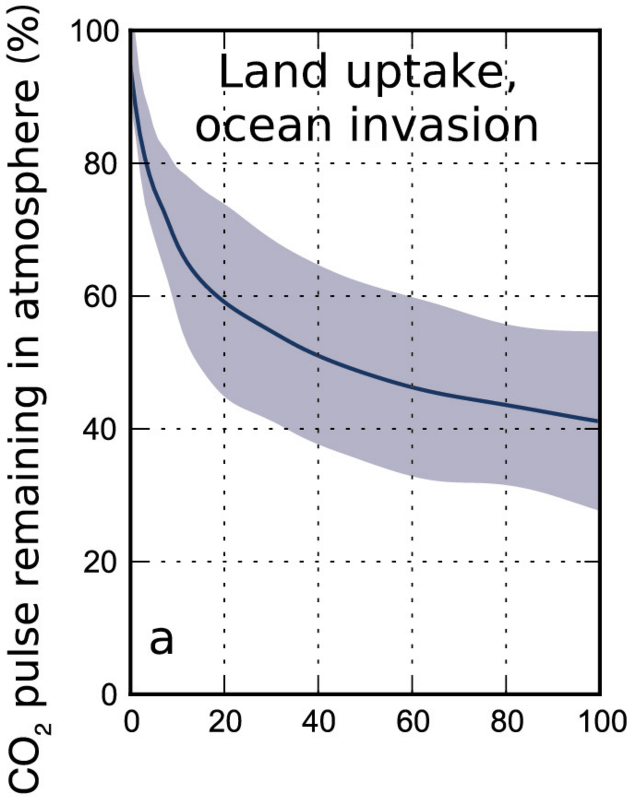
Why is the "carbon capacity" of the oceans so small?

- There are ~40 trillion tonnes of natural carbon in the oceans = 148 trillion tonnes of CO_2
  - 50 times the CO_2 in the atmosphere
  - 10 times global fossil fuel resources.
- So why can't we rely on the oceans to dilute away our CO_2 indefinitely?
- Answer: the oceans act as a giant buffer solution
  - Keeps ocean pH relatively stable, allowing life to exist
  - Reduces their ability to "dilute away" additional CO_2

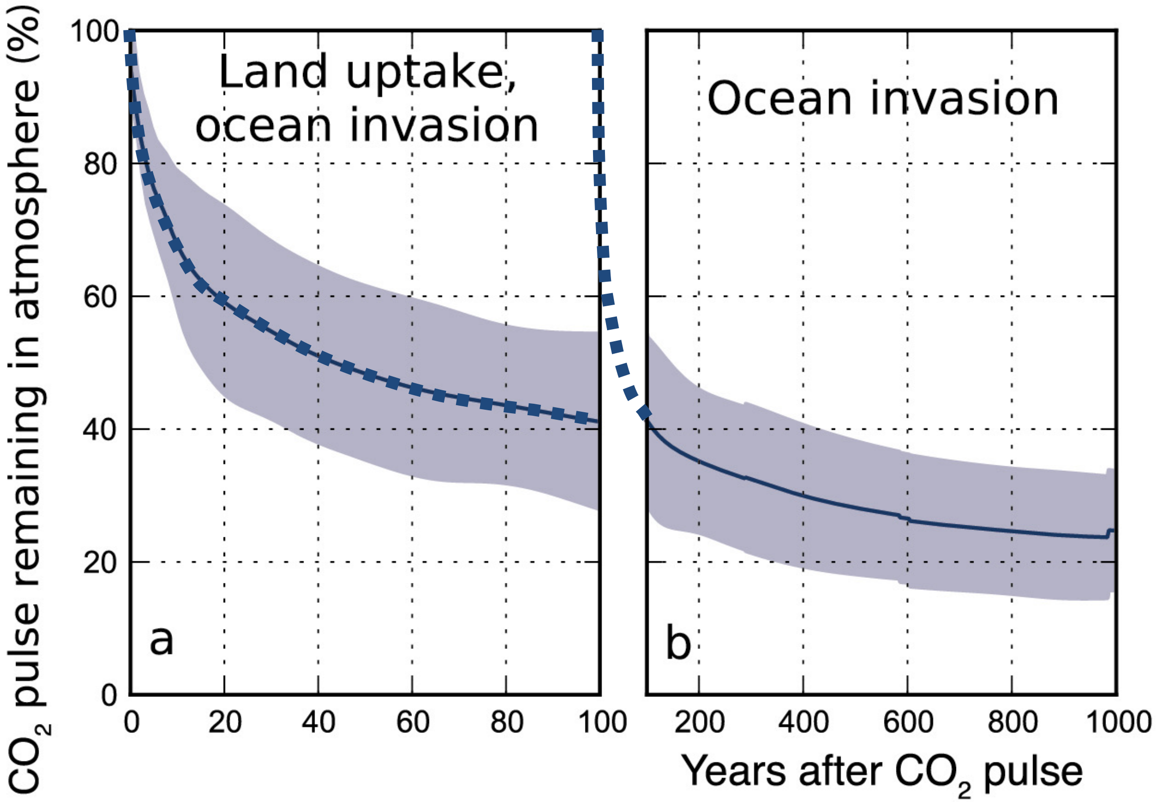
Roger Revelle



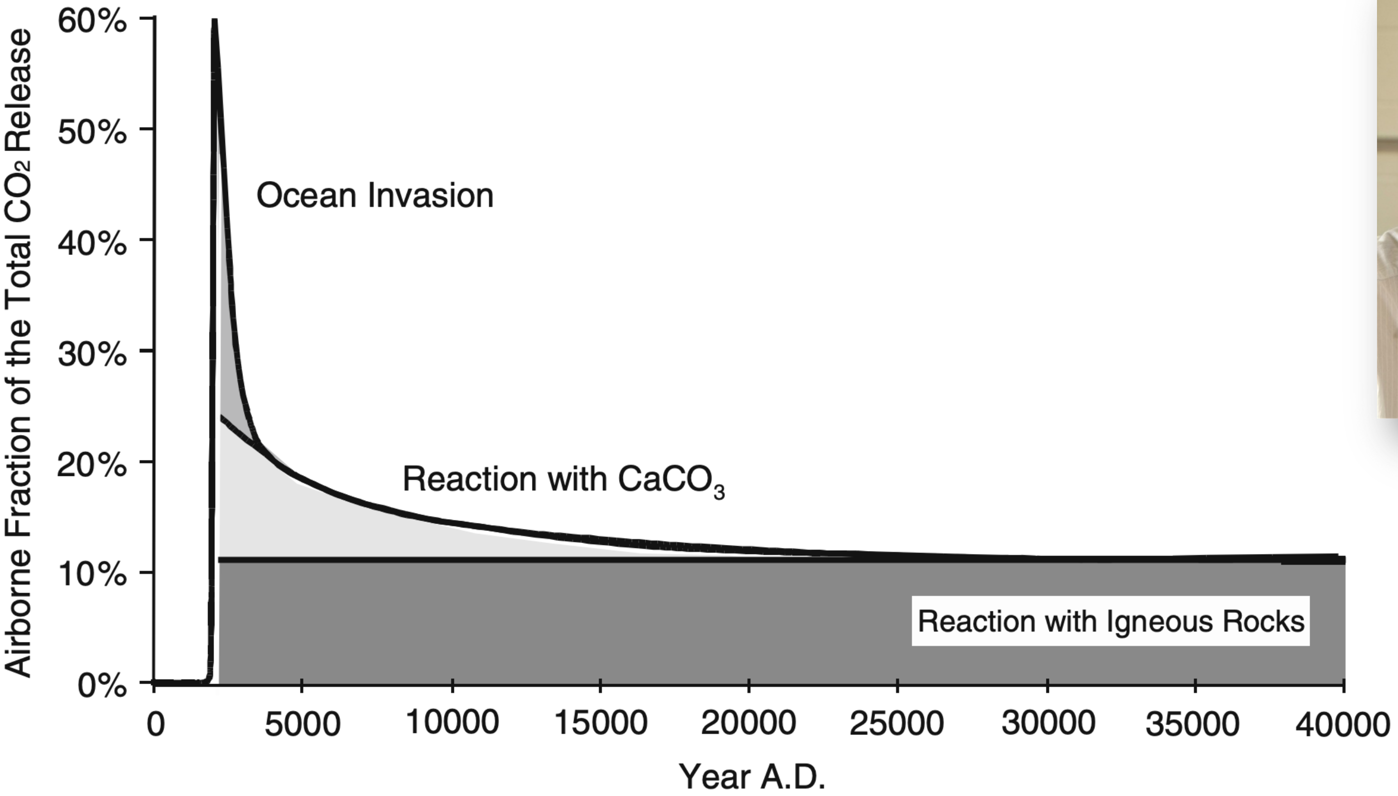
So we can expect the impact of CO_2 emissions to last for a very long time: 100 years after emission



So we can expect the impact of CO_2 emissions to last for a very long time: 1,000 years after emission



So we can expect the impact of CO_2 emissions to last for a very long time: 40,000 years after emission

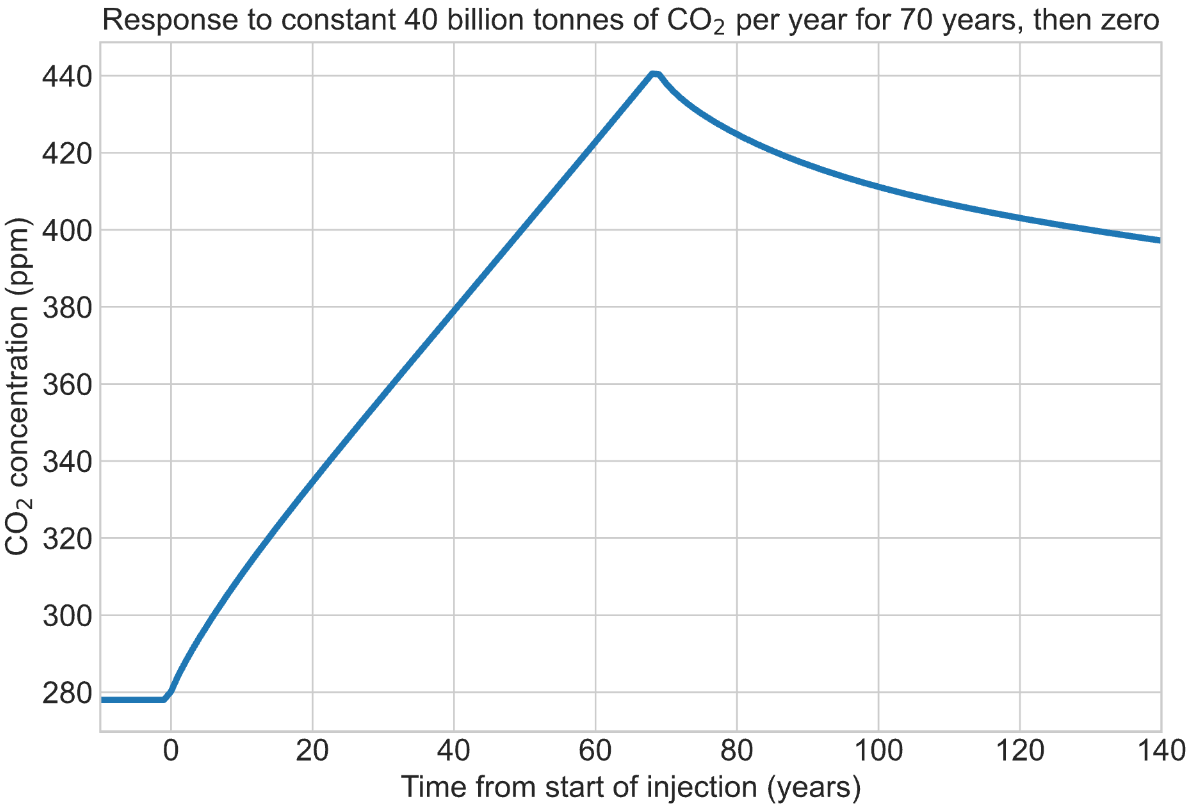


David Archer

But how do atmospheric concentrations behave on "policy-relevant", say 10- to 200-year, timescales?

Response of our Gresham carbon cycle model to a steady emission of CO_2, which is then switched off:

CO_2 concentrations



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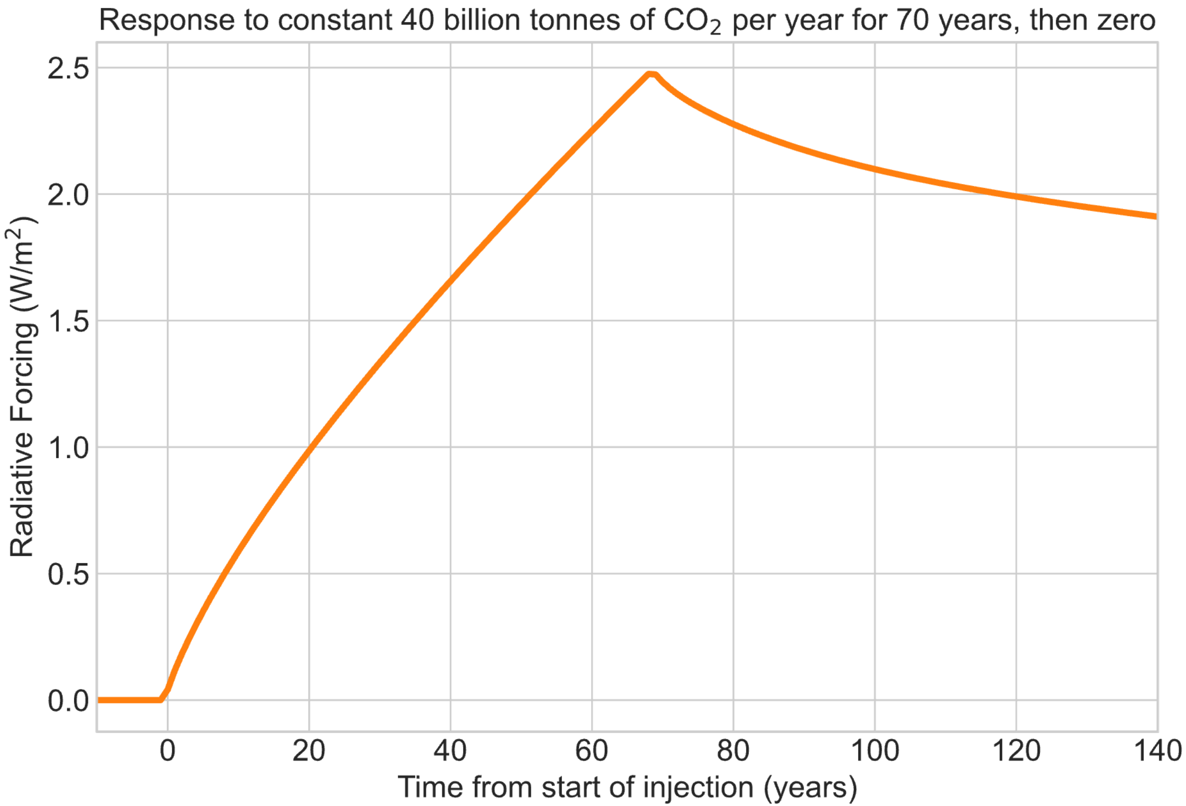
Response of our Gresham carbon cycle model to a steady emission of CO_2, which is then switched off:

Energy imbalance due to excess CO_2



Understanding the response of our Gresham carbon cycle model

- Changes in fluid depth in tube 1, assuming tube 2 has adjusted but tube 3 has not:

$$\Delta h_1 = k_1 \times \overline{E} \times \Delta t - \rho_2 \times \overline{h_1} \times \Delta t$$

  - Δh_1 is the change in depth in tube 1 over a “shortish” time interval.
  - $\overline{E}$ is the average rate of fluid flowing in over that time-interval.
  - Δt is the length of the time-interval.
  - $\overline{h_1}$ is the average depth of fluid in tube 1 over that time-interval.
  - k_1 is constant(ish), determines partitioning between tubes 1 & 2.
  - ρ_2 is constant(ish), determines fractional rate of decline if $\overline{E} = 0$

Understanding the response of our Gresham carbon cycle model: rearranging

- Changes in fluid depth in tube 1, assuming tube 2 has adjusted but tube 3 has not:

$$k_1 \times \overline{E} \times \Delta t = \Delta h_1 + \rho_2 \times \overline{h_1} \times \Delta t$$

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Understanding the response of our Gresham carbon cycle model: in terms of the carbon cycle

- Changes in energy imbalance (forcing) due to atmospheric CO_2 assuming biosphere has adjusted but deep ocean has not:

$$k_1 \times \overline{E_C} \times \Delta t = \Delta F_C + \rho_C \times \overline{F_C} \times \Delta t$$

  - ΔF_C is the change in CO_2 forcing over a "shortish" time interval.
  - $\overline{E_C}$ is the average rate of CO_2 emissions over that time-interval.
  - Δt is the length of the time-interval.
  - $\overline{F_C}$ is the average level of CO_2 forcing over that time-interval.
  - k_1 is constant(ish), determines short-term "efficacy" of emissions.
  - ρ_C is constant(ish), determines fraction rate of forcing decline if $\overline{E} = 0$

How atmospheric concentrations and hence energy imbalance (forcing) declines after zero emissions

Response of our Gresham carbon cycle model to a steady emission of CO_2, which is then switched off:

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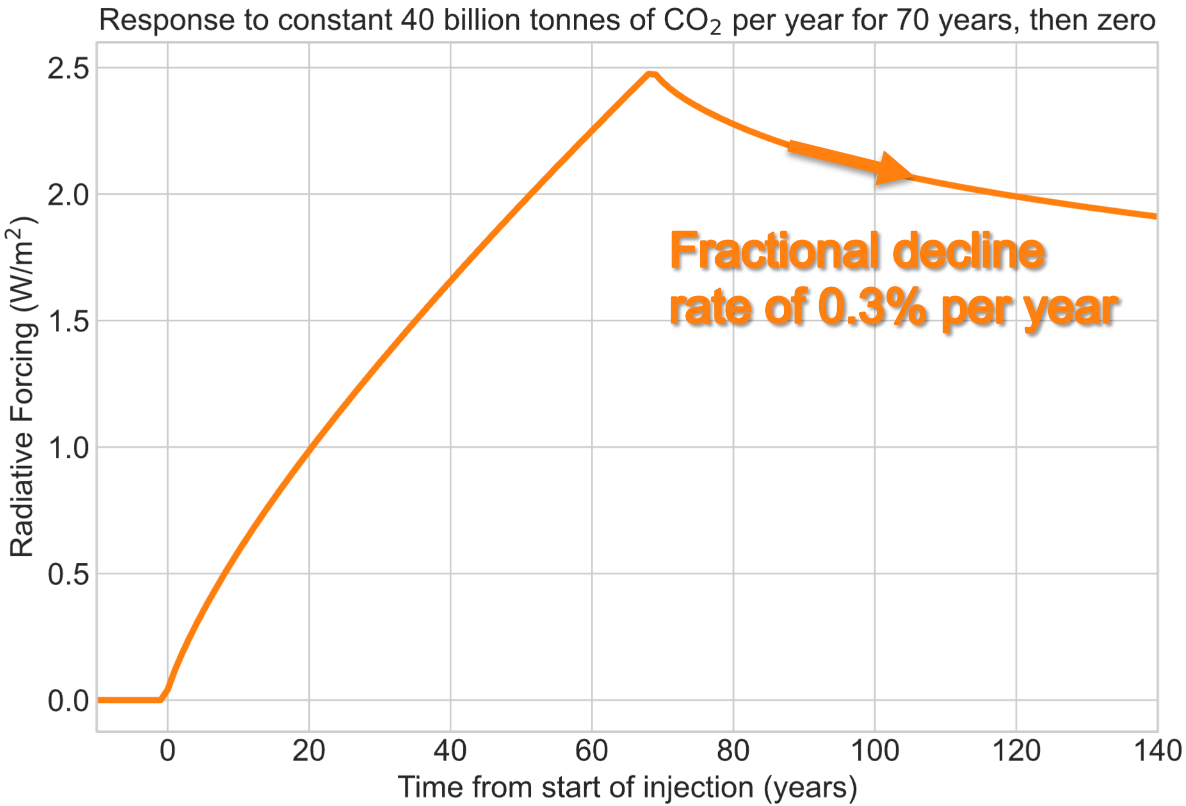

You have seen an expression rather like this before

- Changes in temperature over decade to century timescales:

$$\Delta T = \kappa_F \times (\Delta F + \rho_F \times \bar{F} \times \Delta t)$$

  - ΔT is the change in global average surface temperature.
  - ΔF is the change in energy flow in due to change in greenhouse gases.
  - $\bar{F}$ is the average energy flow in due to level of greenhouse gases.
  - Δt is the length of the time-interval.
  - κ_F is a constant "Transient Climate Response to Forcing".
  - ρ_F is a constant "Rate of Adjustment to Constant Forcing".

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You have seen an expression rather like this before

- Temperature response to forcing:

$$\Delta T/\kappa_F \qquad = \quad \Delta F + \rho_F \times \overline{F} \times \Delta t$$

- Forcing response to CO_2 emissions:

$$k_1 \times \overline{E_C} \times \Delta t = \Delta F_C + \rho_C \times \overline{F_C} \times \Delta t$$

So if $\rho_F \approx \rho_C$ and $F = F_C$ (focusing on the impact of CO_2) then ΔT is proportional to $\overline{E_C} \times \Delta t$, meaning…

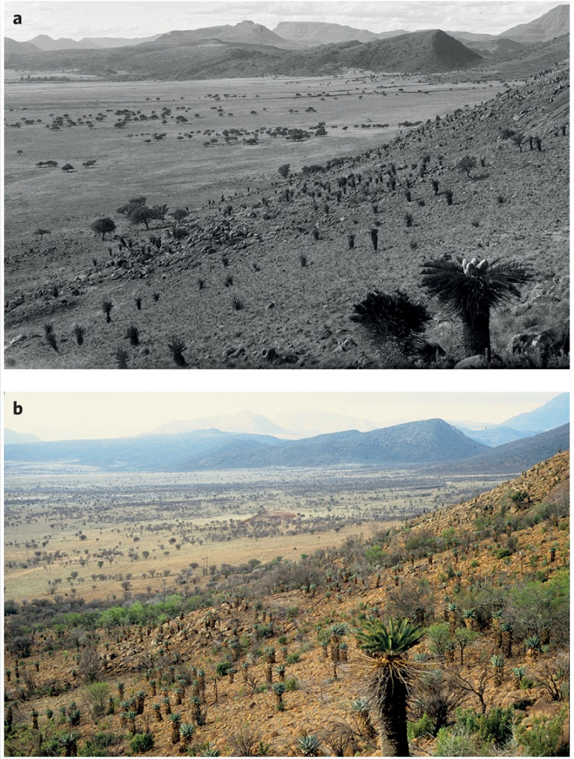
- CO_2-induced warming over a multi-decade interval is proportional to cumulative CO_2 emissions over that interval.

So are we all done with the carbon cycle and net zero? Unfortunately, there is a problem...

- What do people actually mean by net CO_2 emissions?
  - Carbon cycle scientists: emissions minus removals resulting directly from ongoing human activities.
  - Emissions accountants: include CO_2 uptake on "managed land" that results indirectly from past emissions as a "negative emission".
  - Suddenly, all land is managed...

Our biosphere is already responding to past emissions: and we are counting on that response

1925



1993

2011

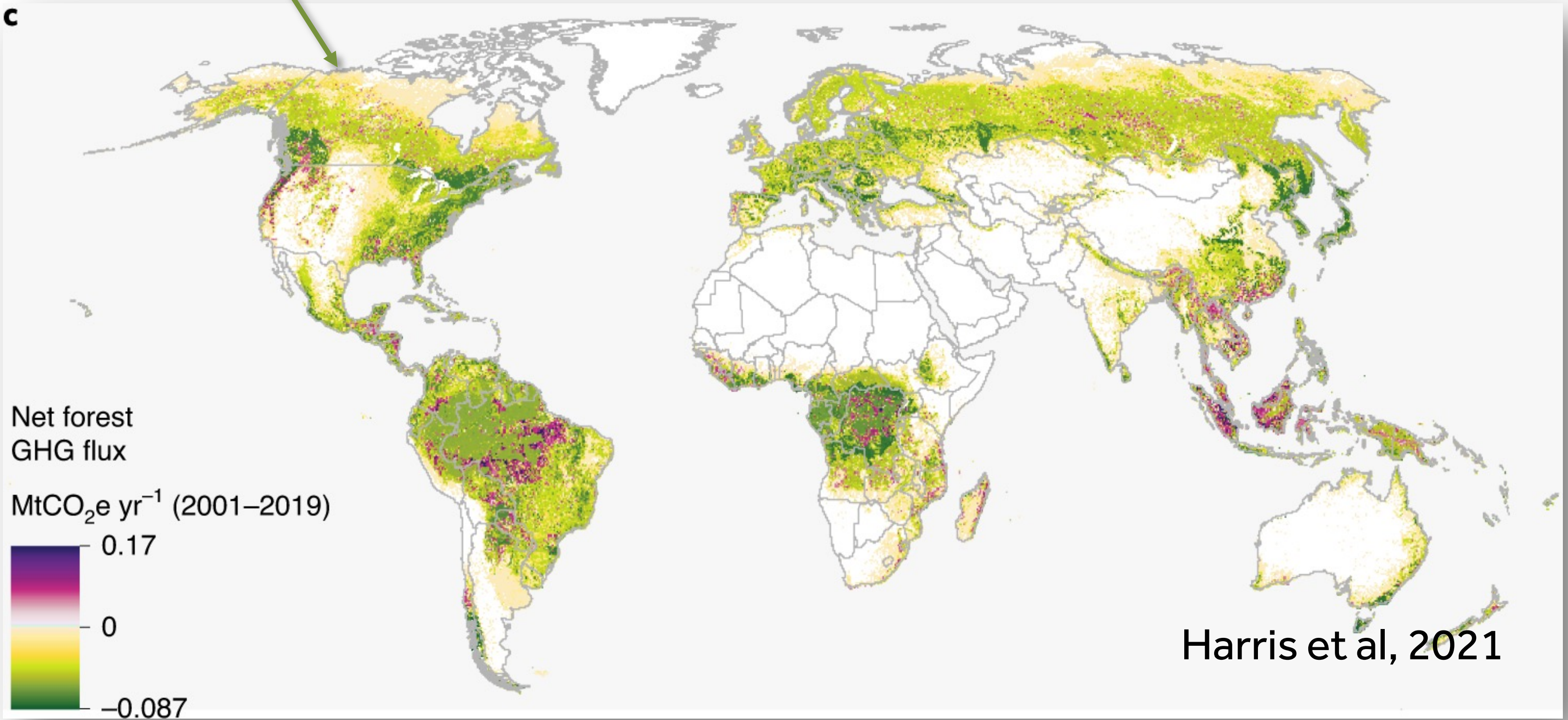
"CO_2 fertilization" in a relatively undisturbed African savannah

Midgeley & Bond, 2015

Who owns these helpful forests?

Canada's forest sink 2001-2019: -950 $MtCO_2e$ per year

Canada's emissions 2001-2019 : +730 $MtCO_2e$ per year



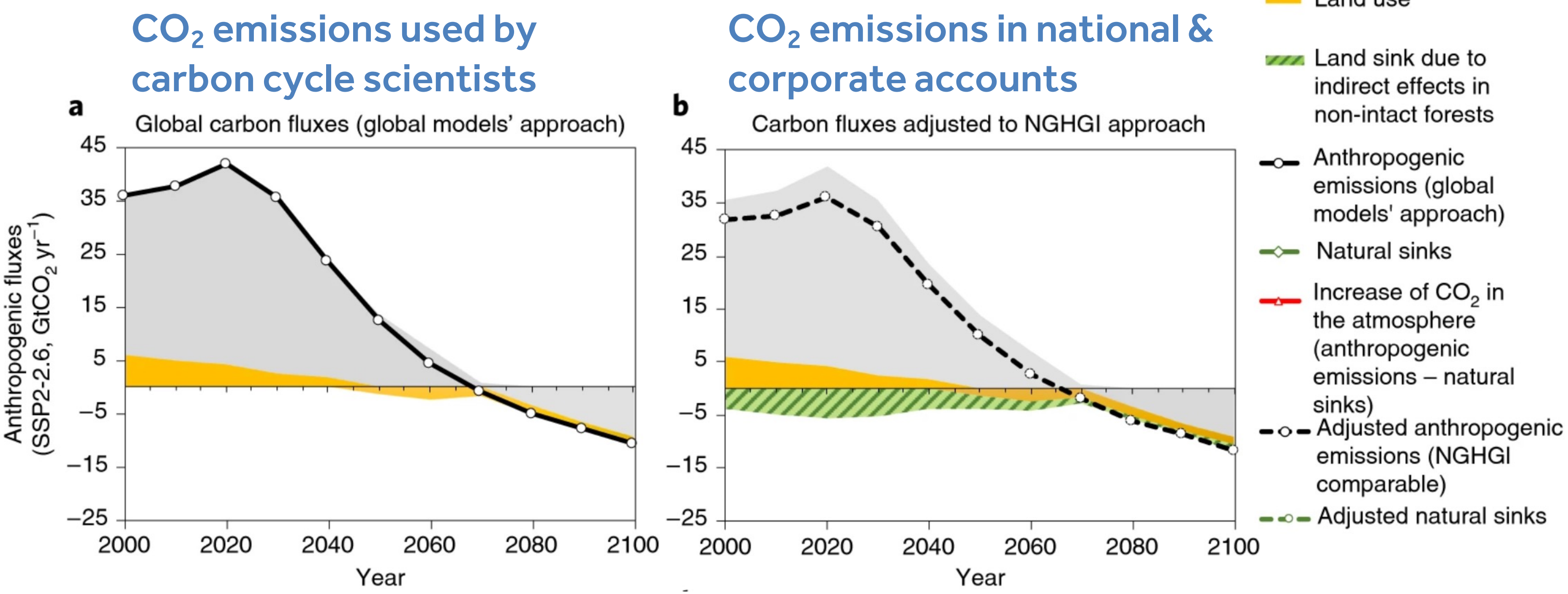
Harris et al, 2021

Are these really equivalent?

Canadian forest

Canadian tar sands

Carbon accounting rules allow anyone to take credit for natural uptake on “managed land”

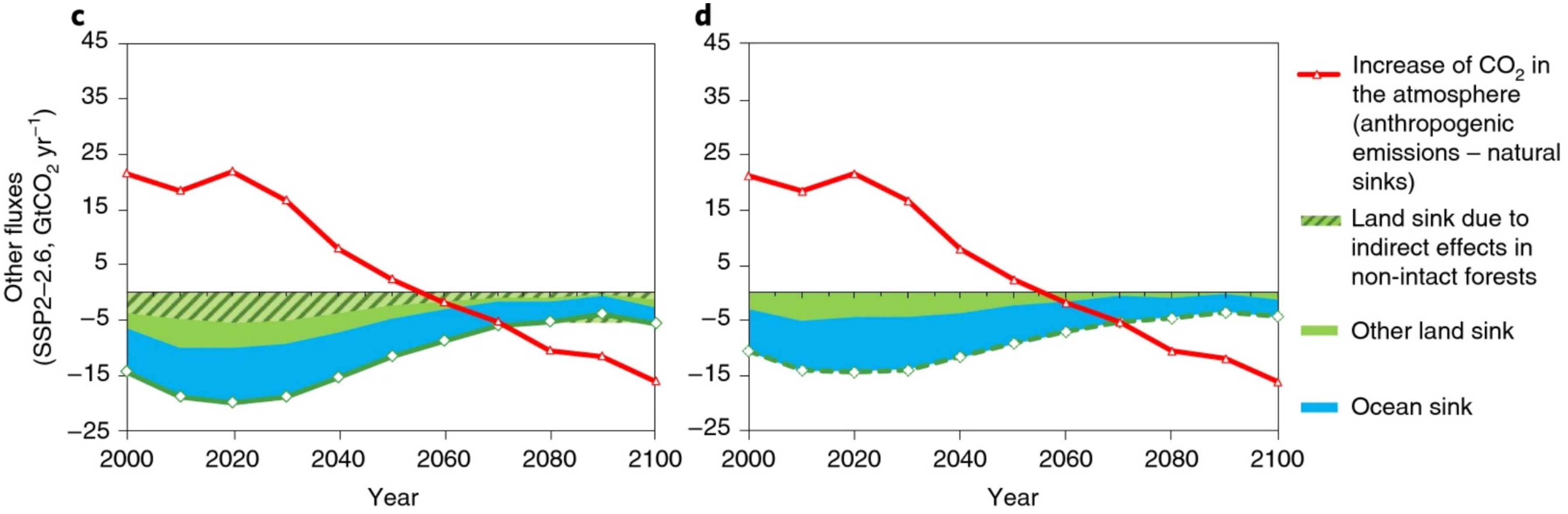


Grassi et al, 2021

Carbon accounting rules allow anyone to take credit for natural uptake on "managed land"

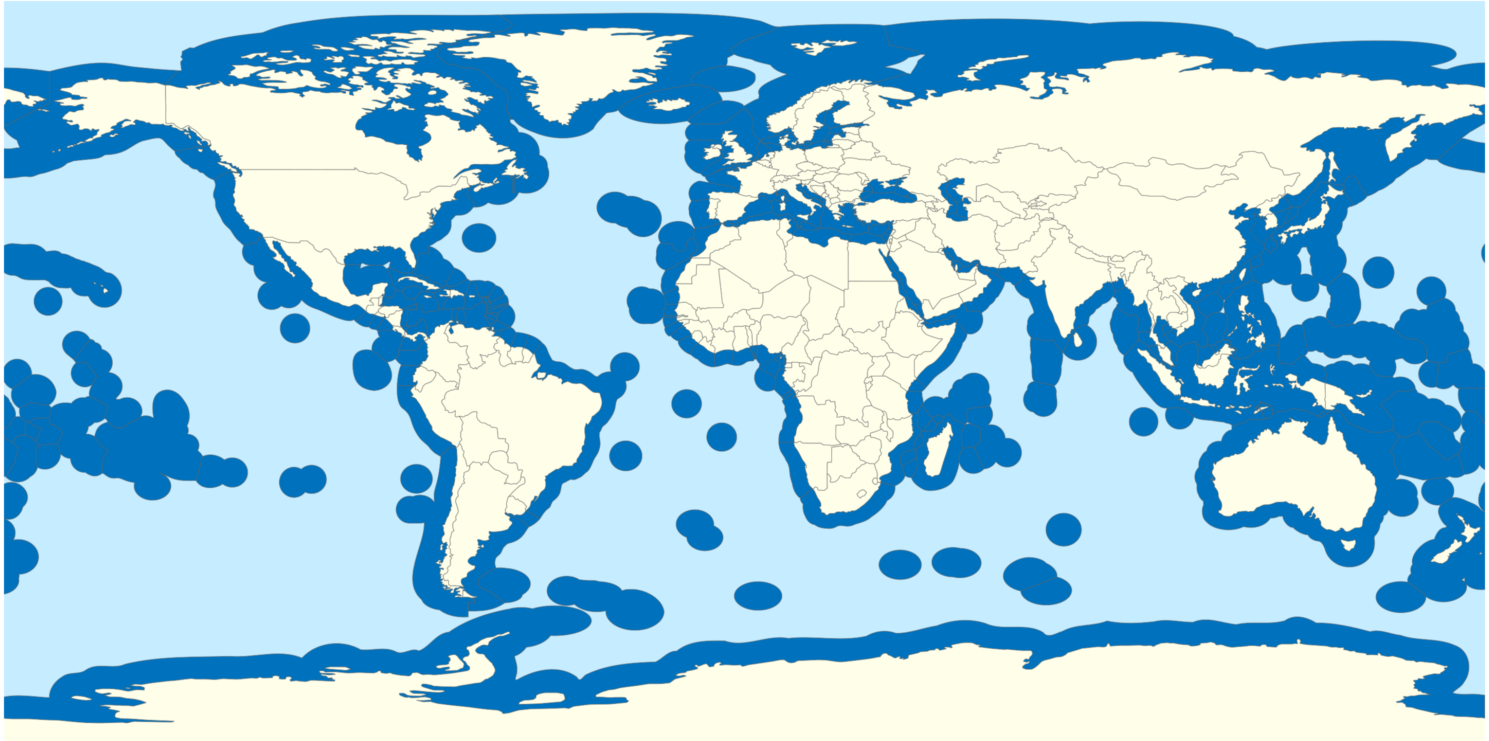
Natural uptake used by carbon cycle scientists

Natural uptake in national & corporate accounts



Grassi et al, 2021

What happens when everyone starts taking credit for CO_2 uptake on "managed oceans"?

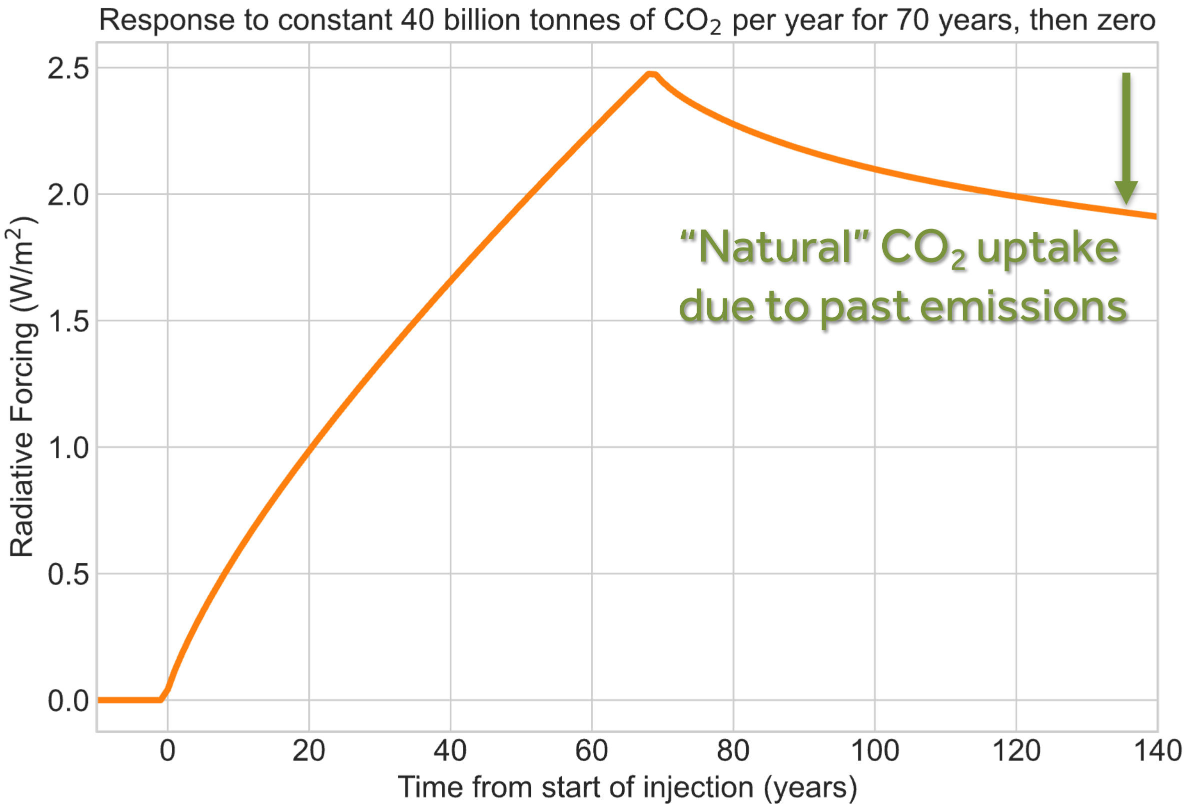


30% of global oceans are in someone's Exclusive Economic Zone

So what do we mean by net zero CO_2 emissions?

Response of our Gresham carbon cycle model to a steady emission of CO_2, which is then switched off:

Energy imbalance



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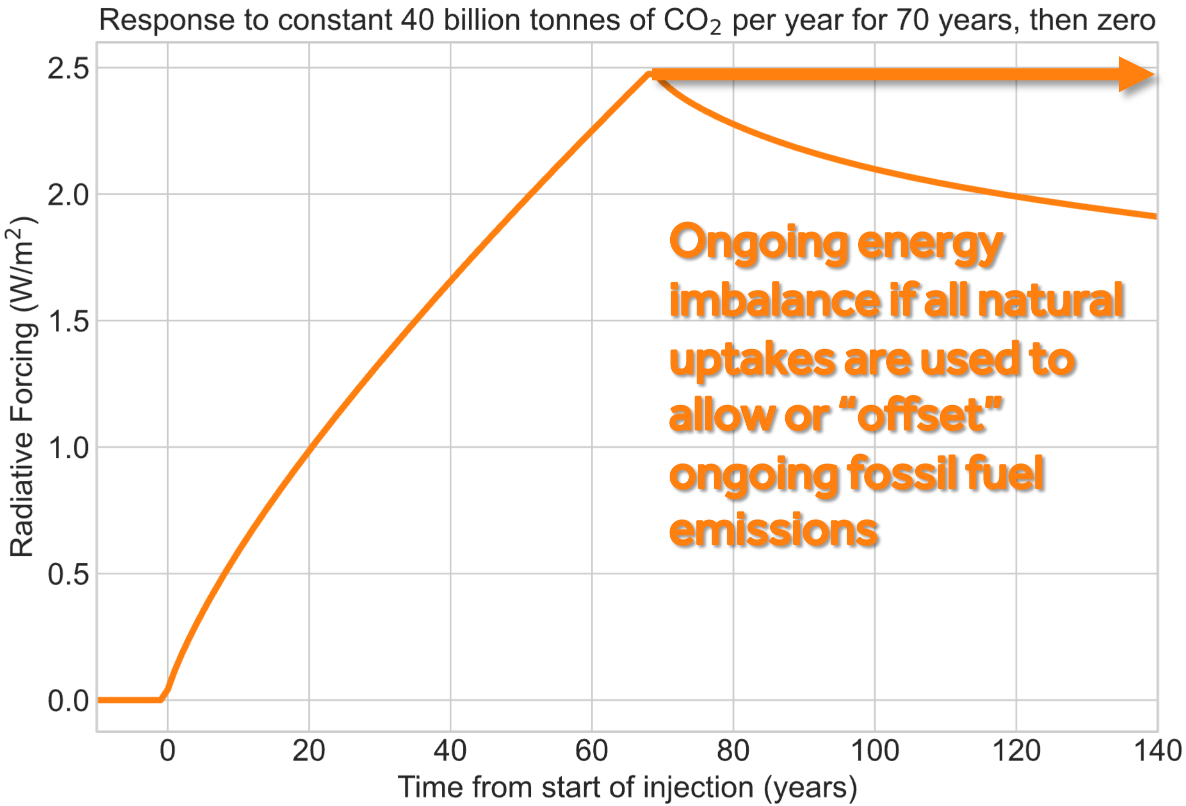

Getting back to what we originally meant by net CO_2 emissions

- Allowing biological (and potentially ocean – "blue carbon") CO_2 uptake to offset ongoing fossil fuel emissions opens a massive loophole in carbon accounting.
- Grassi et al (2021) argue (in effect) "don't worry, this loophole will shrink as the world warms and emissions decline"
  - Seems unfair on the next generation, and if we allow uptake due to past emissions to count against ongoing fossil fuel use, we won't stabilize temperatures anyway.

The solution: Geological Net Zero

- **Geological Net Zero** means any ongoing production of CO_2 from geological sources (like fossil fuel burning) is balanced by permanent (geological-timescale) CO_2 storage.
- The impact of fossil fuel emissions lasts forever, unless an equal quantity of CO_2 is permanently removed & disposed of.
- Geological Net Zero is needed to stabilize our carbon cycle **in addition to** ending deforestation & biosphere recovery.
- Nature-based Solutions have many wonderful benefits, but we can't turn rocks into trees forever.

So, will the UK Government commit to Geological Net Zero in the current Energy Bill?

Geological net zero

Government should **consider setting fossil fuel producers operating domestically a 10% storage obligation target to restore carbon dioxide to the geosphere by at least 2035**, separate to any investment on nature-based solutions.

Government should **recognise the importance of geological net zero and work to align international ambitions toward geo zero by 2050**, in line with net zero.

From Chris Skidmore, "Mission Zero: Independent Review of Net Zero", 2023

The Carbon Cycle behind Net Zero

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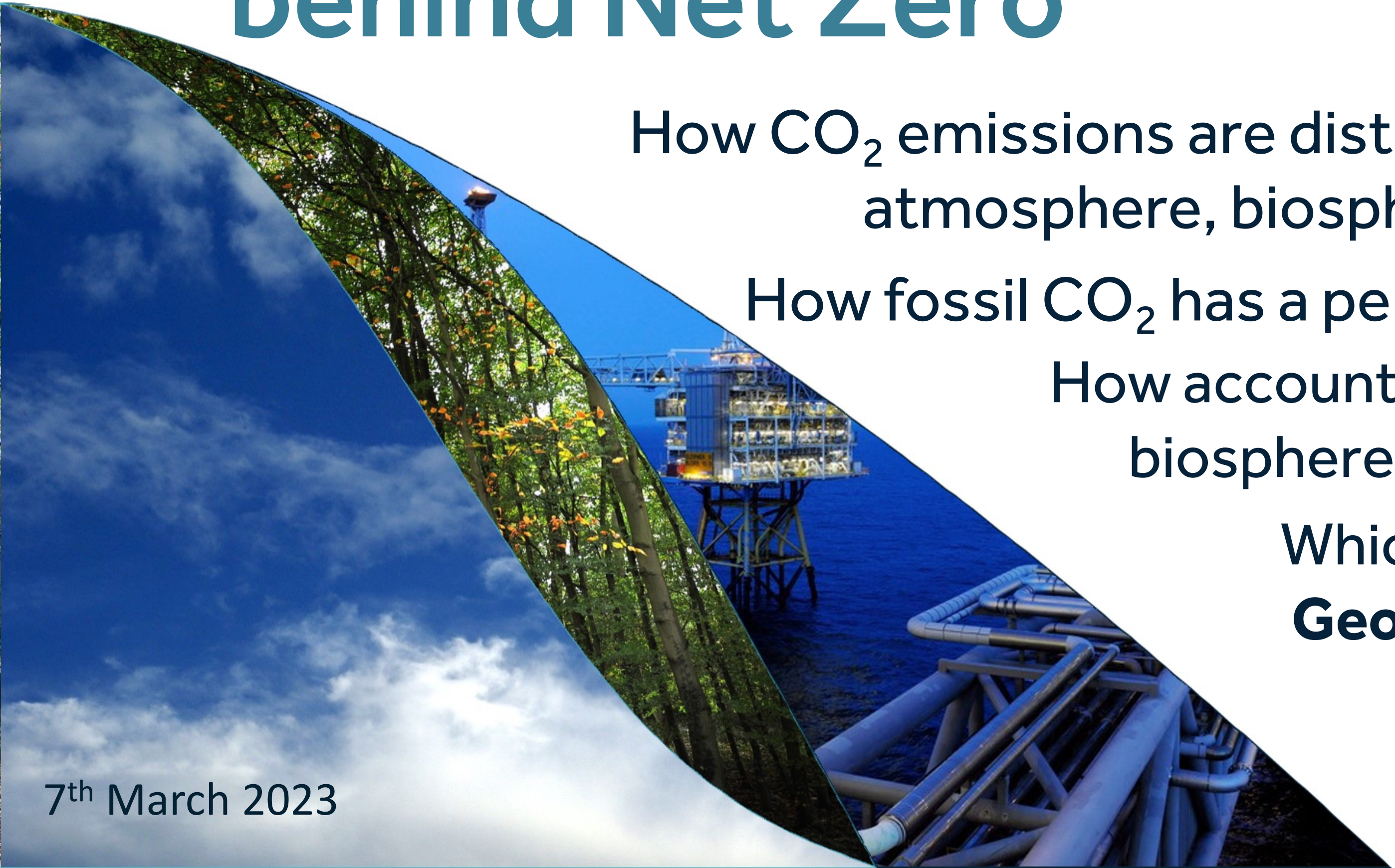

How CO_2 emissions are distributed between atmosphere, biosphere and oceans.

How fossil CO_2 has a permanent impact.

How accounting for CO_2 in the biosphere is a bit of a mess.

Which is why we need **Geological Net Zero**.

7th March 2023

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