



Photo: A. Christen

32 Land-atmosphere interactions in a changing climate

Learning objectives

- Describe how ecosystem-scale carbon fluxes respond to a changing climate.
- Give two examples of positive and/or negative feedbacks between land-surfaces and the climate system.
- Explain how we can modify land management practices for climate change mitigation & adaptation.

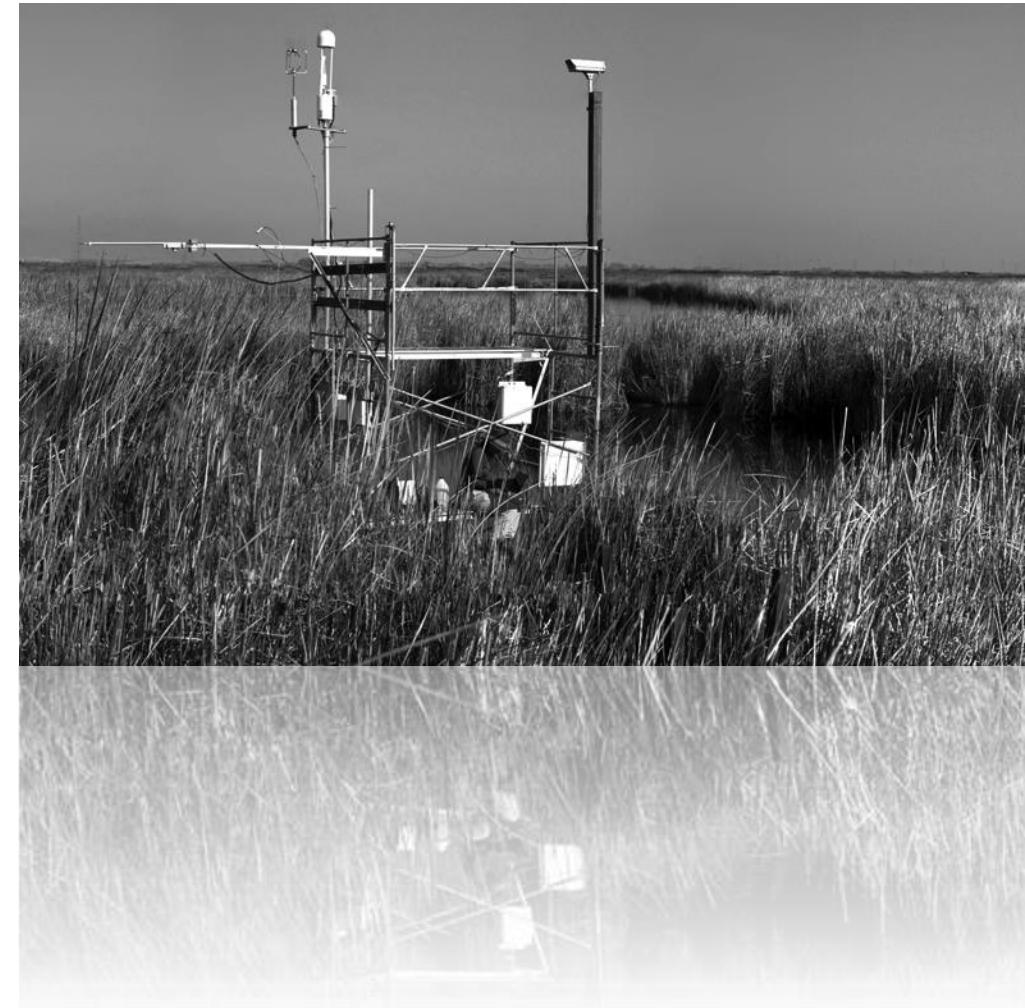
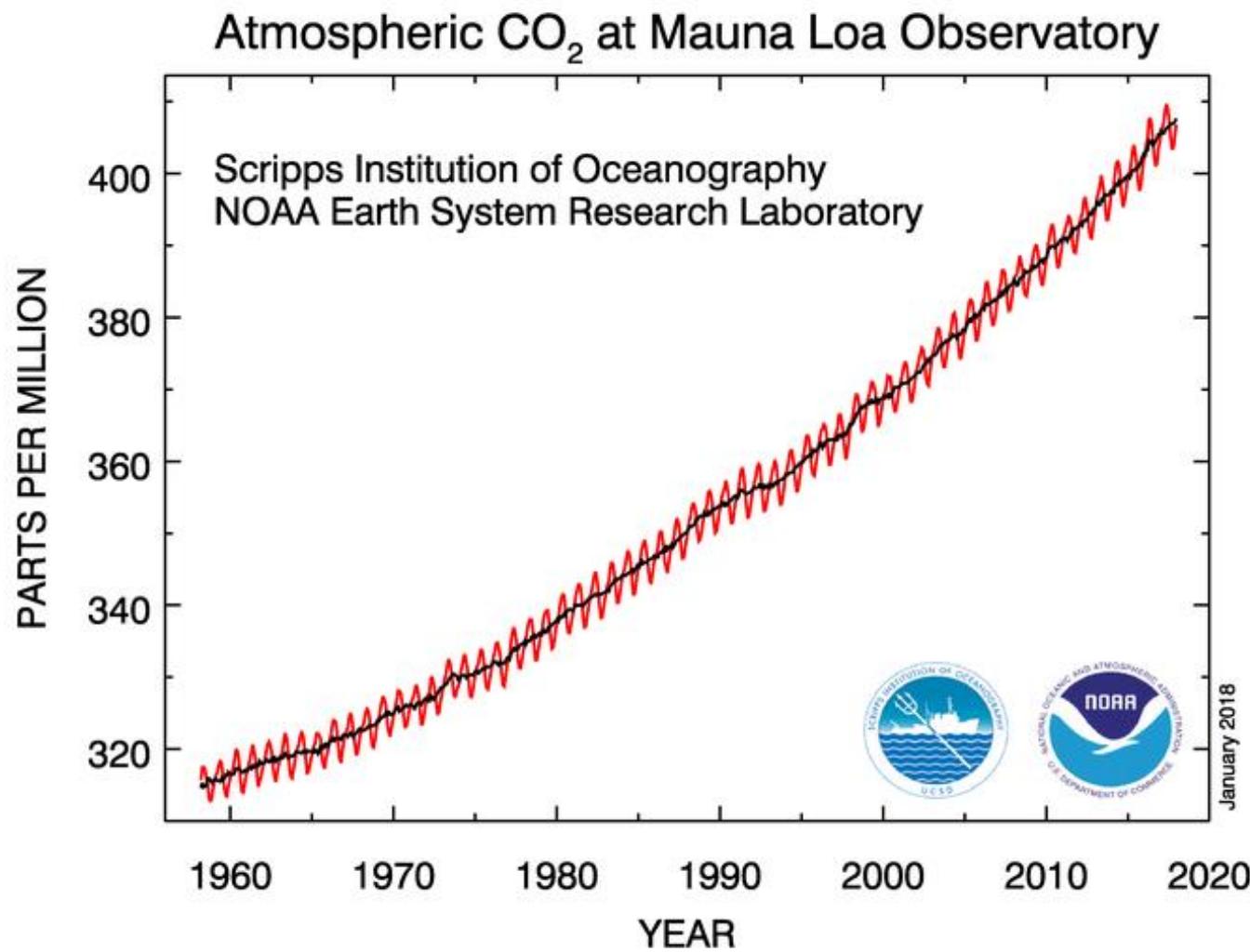
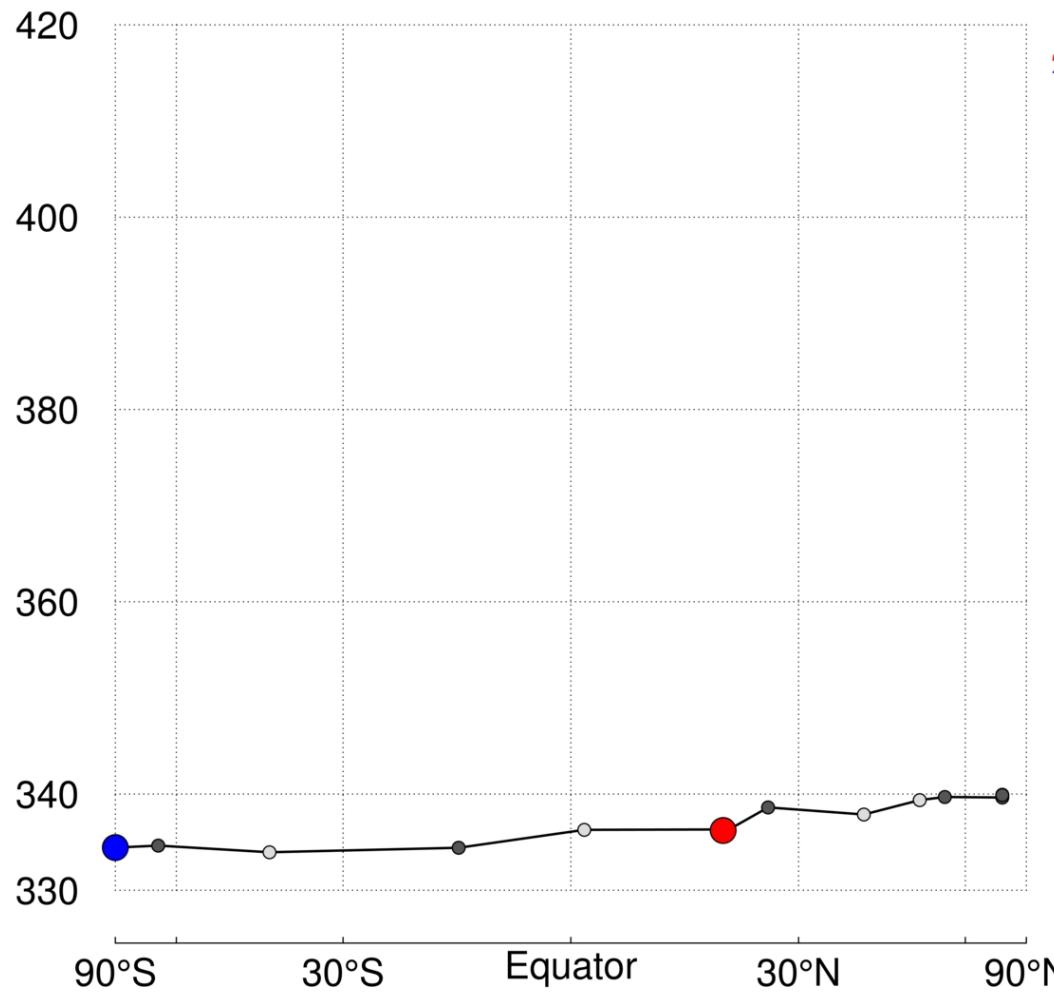


Photo: J. Verfaillie

Rising CO₂ concentrations

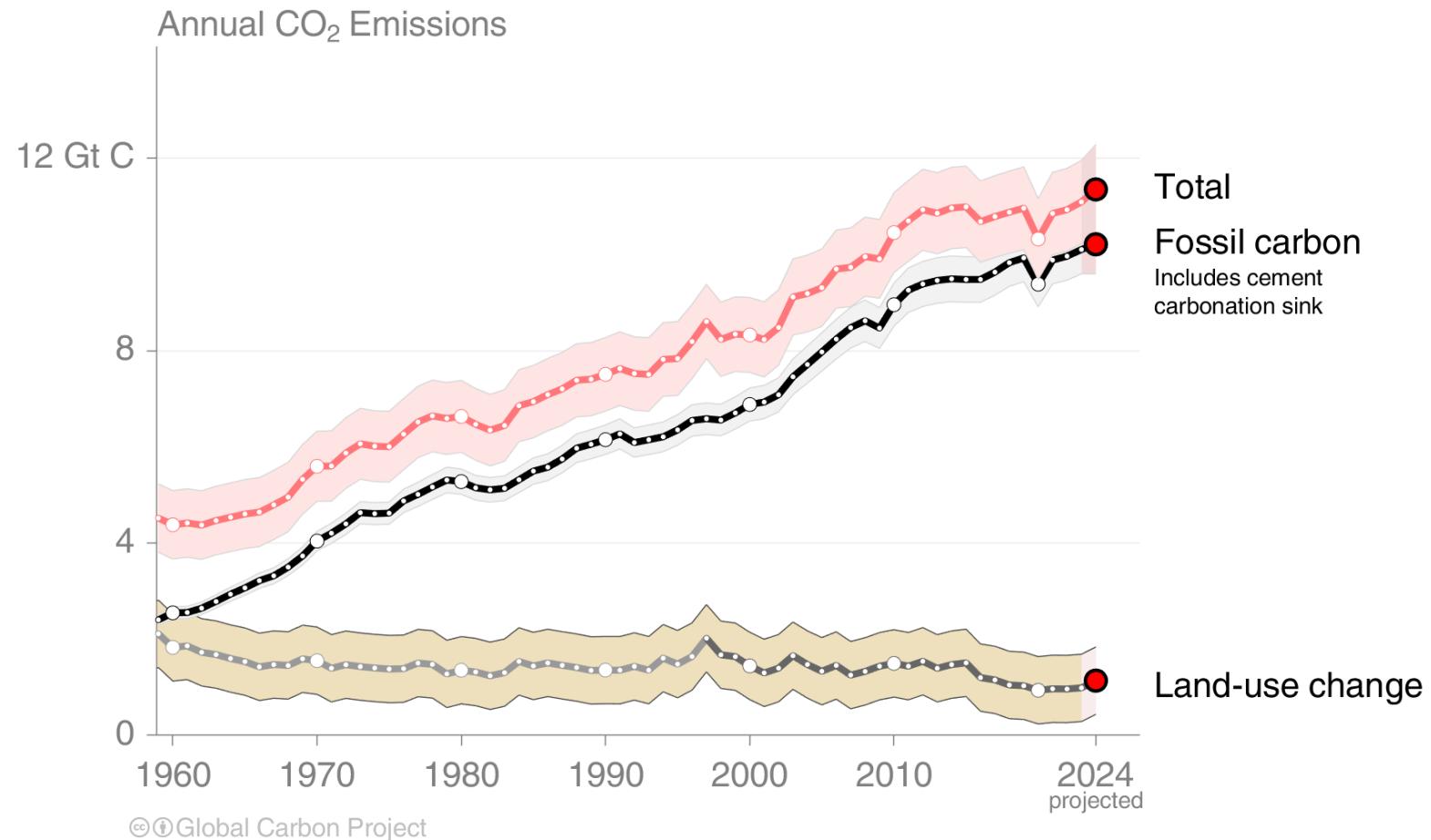


Rising CO₂ concentrations animation



Source: <https://www.esrl.noaa.gov/gmd/ccgg/trends/history.html>

CO₂ sources



Land-use change estimates from four bookkeeping models, using fire-based variability from 1997
Source: [Friedlingstein et al 2024](#); [Global Carbon Project 2024](#)

Where does the CO₂ go?

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Terrestrial ecosystems are key components of the global carbon cycle



9.7 GtC/yr
90%



10%
1.1 GtC/yr

5.2 GtC/yr
48%



29%
3.2 GtC/yr



26%
2.9 GtC/yr

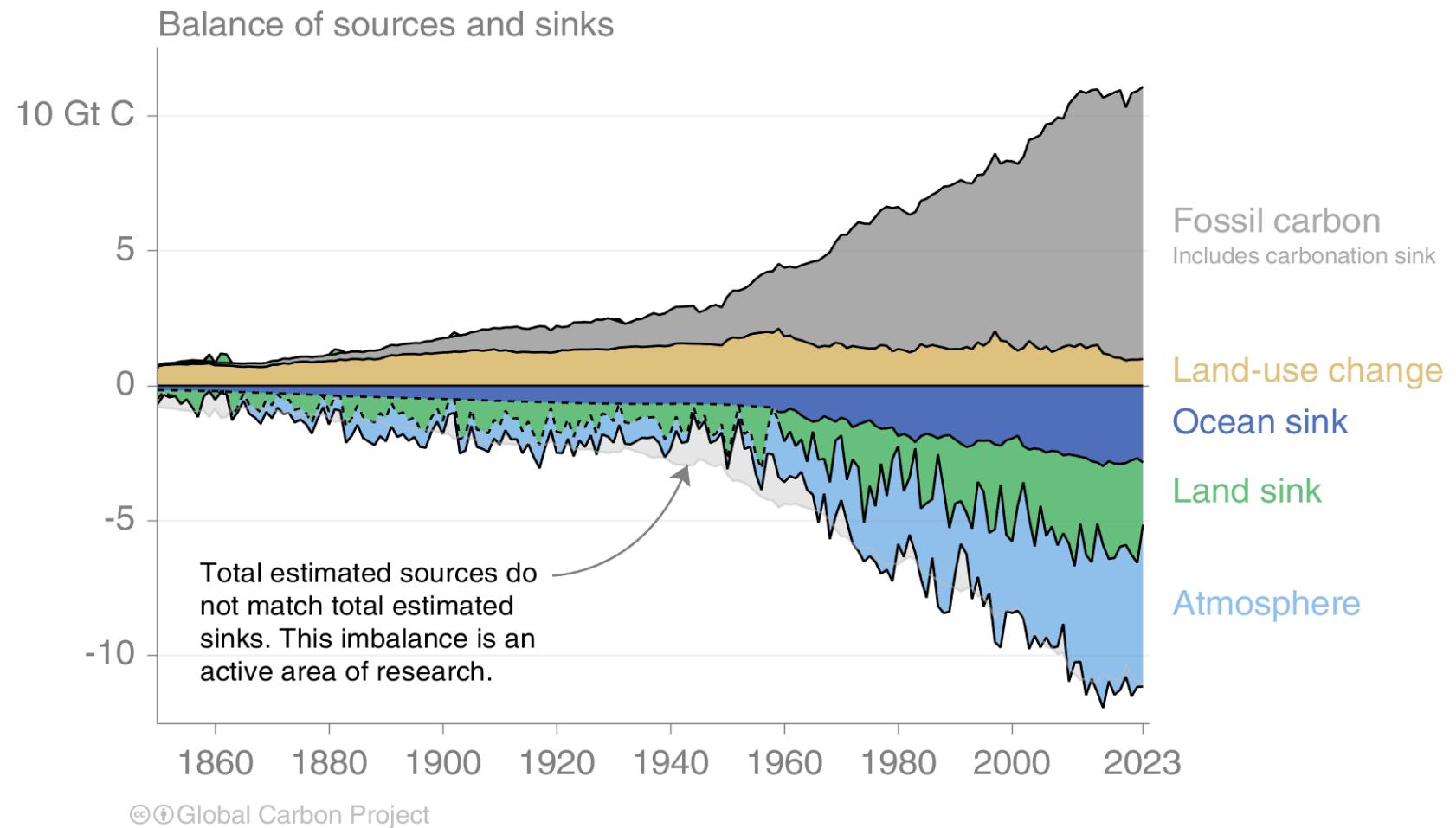


4%
-0.4 GtC/yr

Budget Imbalance:

(the difference between estimated sources & sinks)

Ocean and land carbon sinks slow the rise of CO₂ in the atmosphere.



Will ecosystems continue to help offset CO₂ emissions?

What will happen to the land sink in the future?

Low latency carbon budget analysis reveals a large decline of the land carbon sink in 2023

Piyu Ke ^{1,2}, Philippe Ciais ^{3,*}, Stephen Sitch², Wei Li¹, Ana Bastos ^{4,5}, Zhu Liu ¹, Yidi Xu³, Xiaofan Gui ⁶, Jiang Bian⁶, Daniel S. Goll³, Yi Xi³, Wanjing Li¹, Michael O'Sullivan², Jefferson Goncalves De Souza², Pierre Friedlingstein^{2,7} and Frédéric Chevallier³

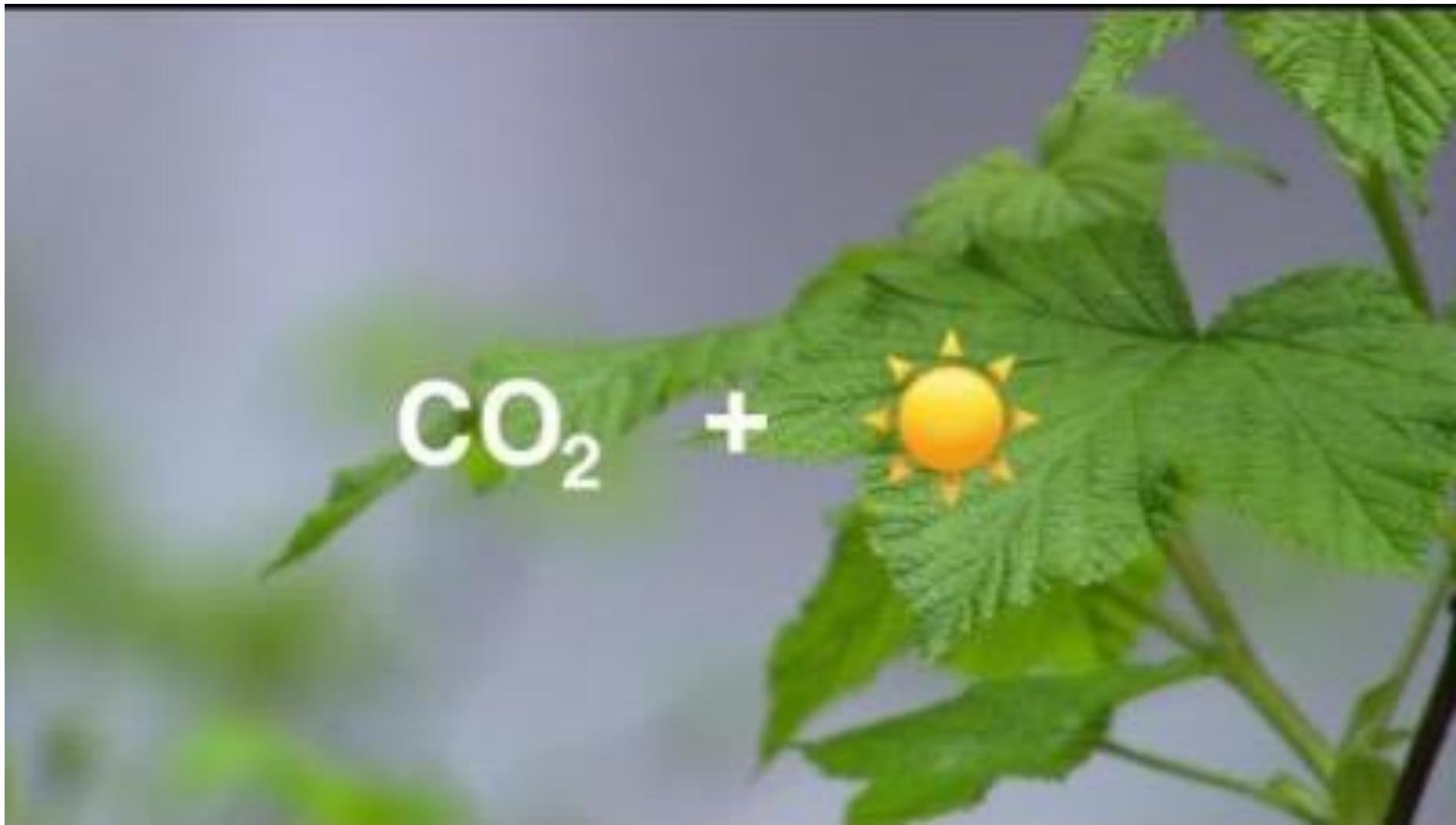
nature ecology & evolution

Article

<https://doi.org/10.1038/s41559-024-02576-5>

Weakening of global terrestrial carbon sequestration capacity under increasing intensity of warm extremes

Land ecosystems might be becoming less efficient at absorbing carbon dioxide

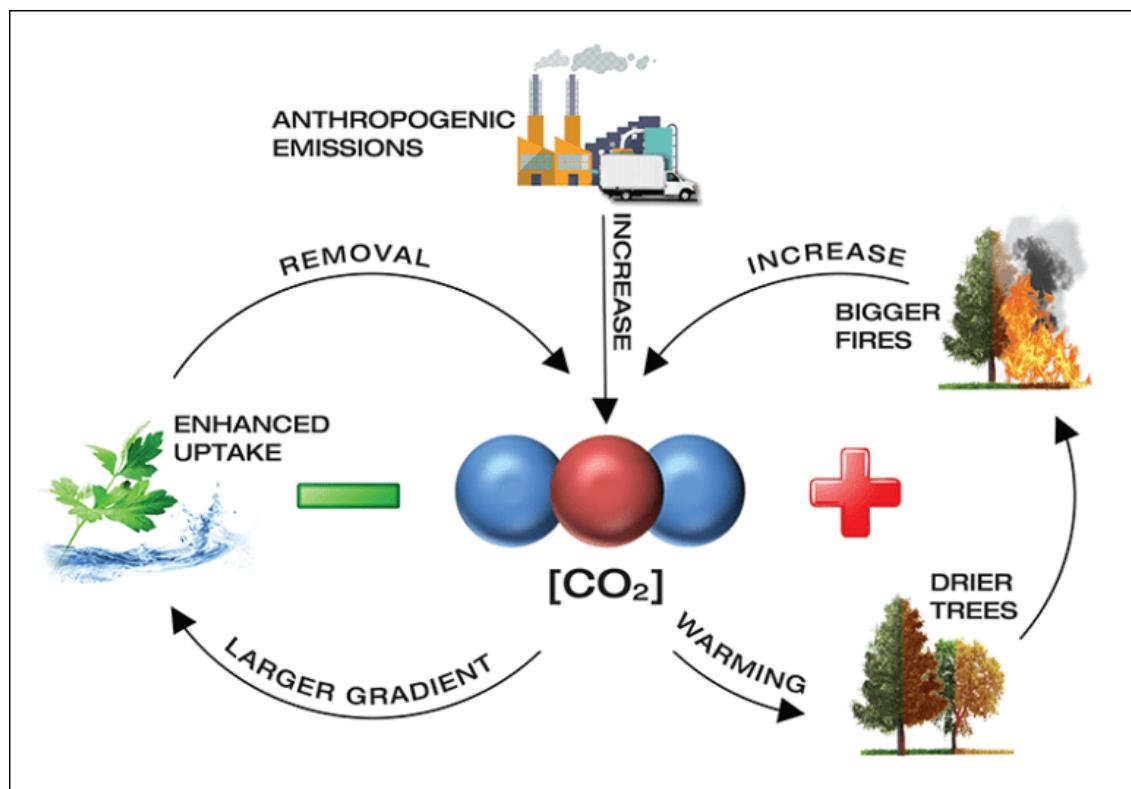


Radiative forcing

- The difference between incoming and outgoing radiation is known as a planet's radiative forcing (RF)
(i.e. Incoming Energy – Outgoing Energy = Radiative Forcing)
- When forcings result in incoming energy being greater than outgoing energy, the planet will warm (positive RF). Conversely, if outgoing energy is greater than incoming energy, the planet will cool.
- Allow us to compare various natural and human drivers of global climate change.

Feedbacks

- Carbon cycle feedbacks are interacting processes that amplify or dampen carbon emissions.



<https://eos.org/features/the-future-of-the-carbon-cycle-in-a-changing-climate>

IPCC Synthesis Reports

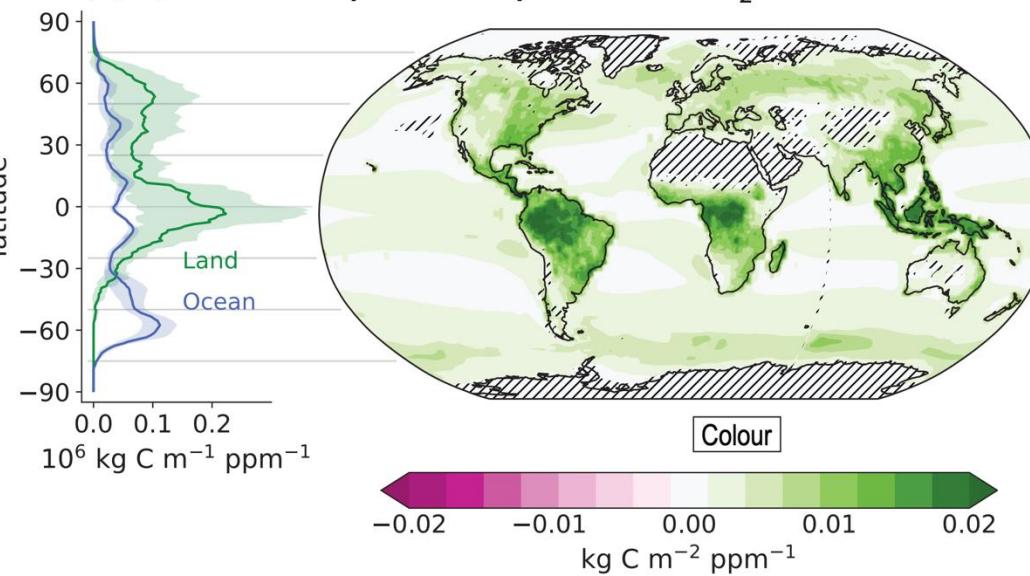
[REPORTS](#)[SYNTHESIS REPORT](#)[WORKING GROUPS](#)[ACTIVITIES](#)[NEWS](#) [FOLLOW](#) [SHARE](#)[CALENDAR](#)

Sixth Assessment Report

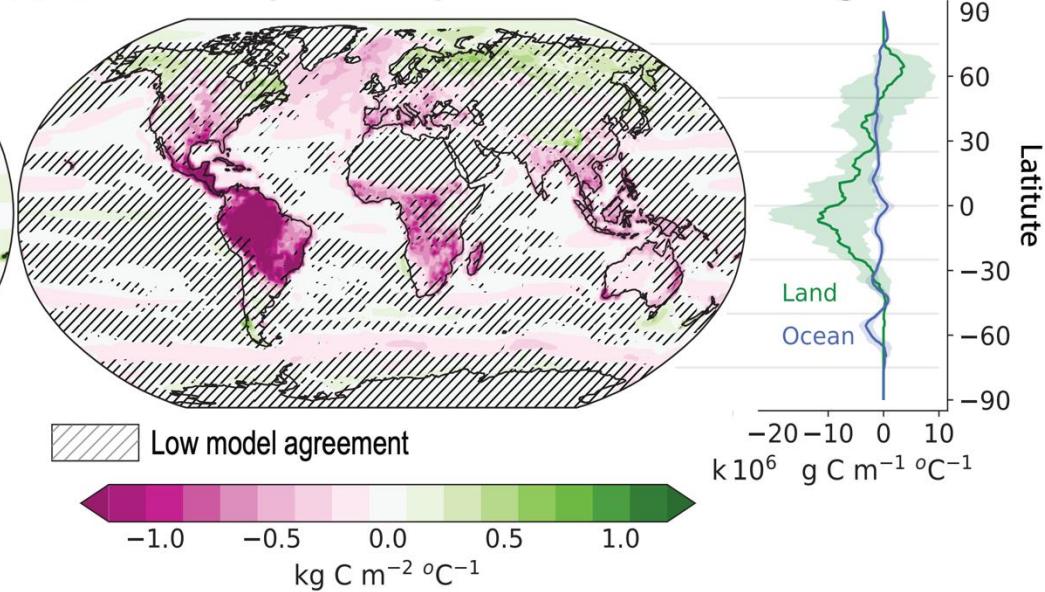
Response of ecosystems to rising CO₂ & climate warming

These figures shows changes in carbon storage in response to elevated CO₂ (a, b) and the response to climate warming (c, d)

(a, b) Carbon uptake response to CO₂



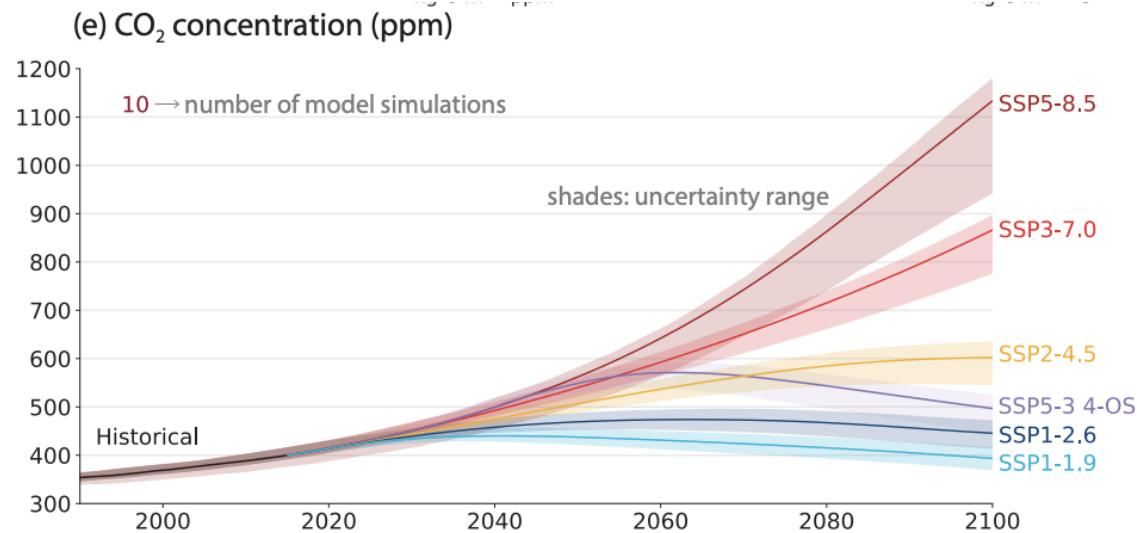
(c, d) Carbon uptake response to climate change



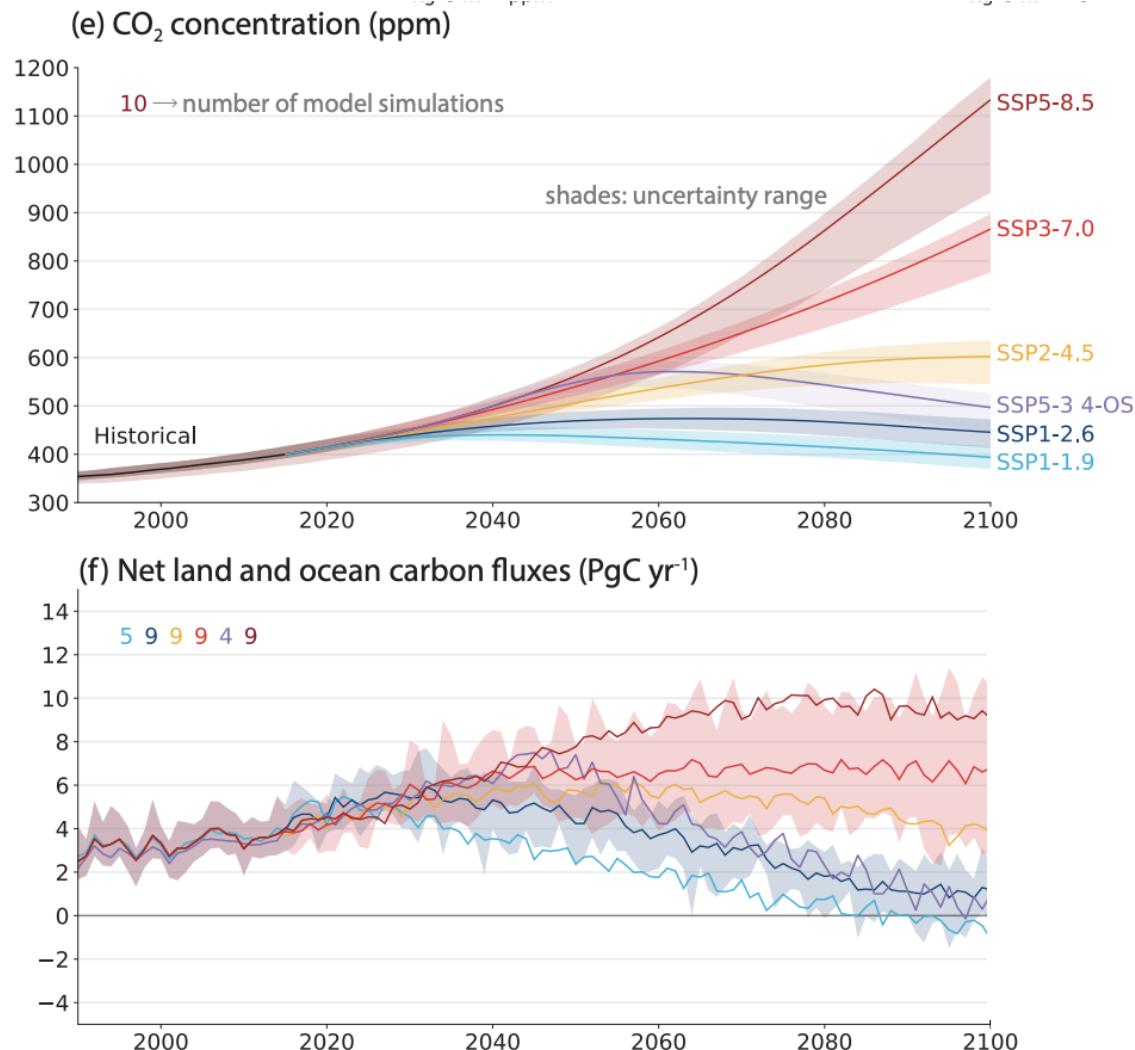
Since the 1980s, carbon fertilization from rising atmospheric CO₂ has increased the strength of the net land CO₂ sink (medium confidence).

Climate change alone is expected to increase land carbon accumulation in the high latitudes (not including permafrost), but also to lead to a counteracting loss of land carbon in the tropics (medium confidence).

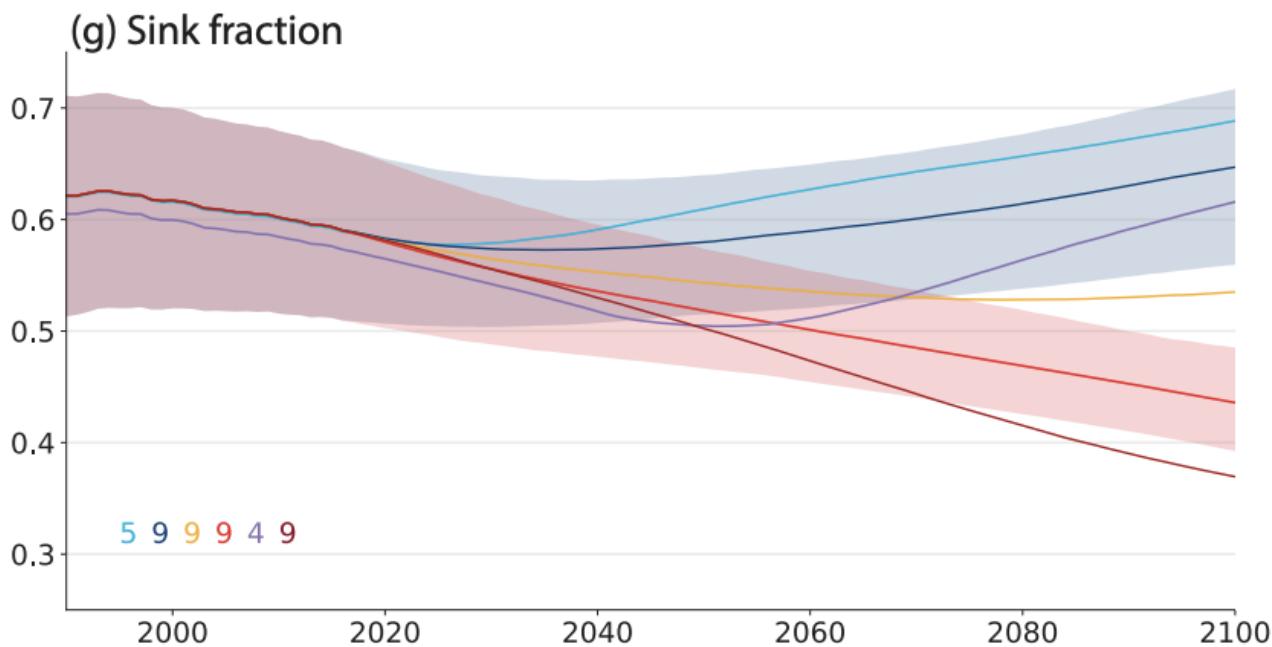
The future of the land sink



The future of the land sink

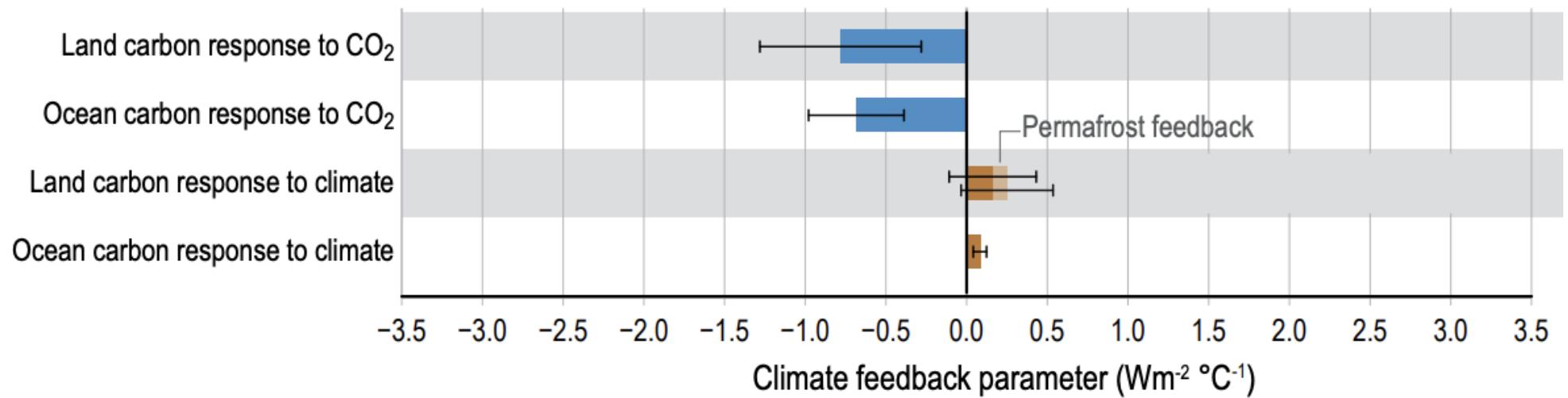


The future of the land sink



At higher CO₂ concentrations,
land and ocean carbon stores
take up a reduced fraction
of our emissions,
despite growing larger

Carbon-cycle climate feedback



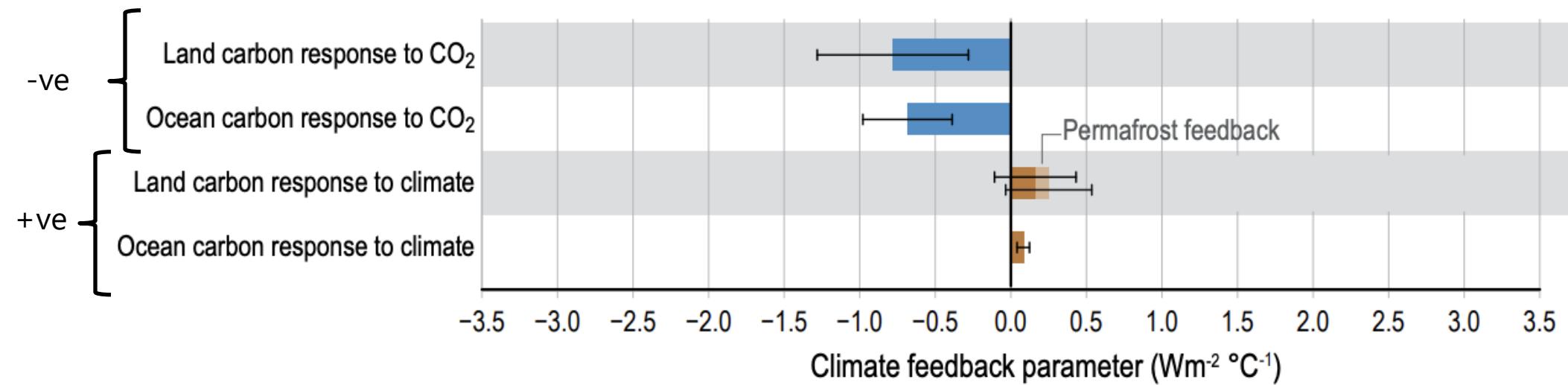
The land & ocean carbon response to CO₂ is a:

- A) Positive climate feedback
- B) Negative climate feedback

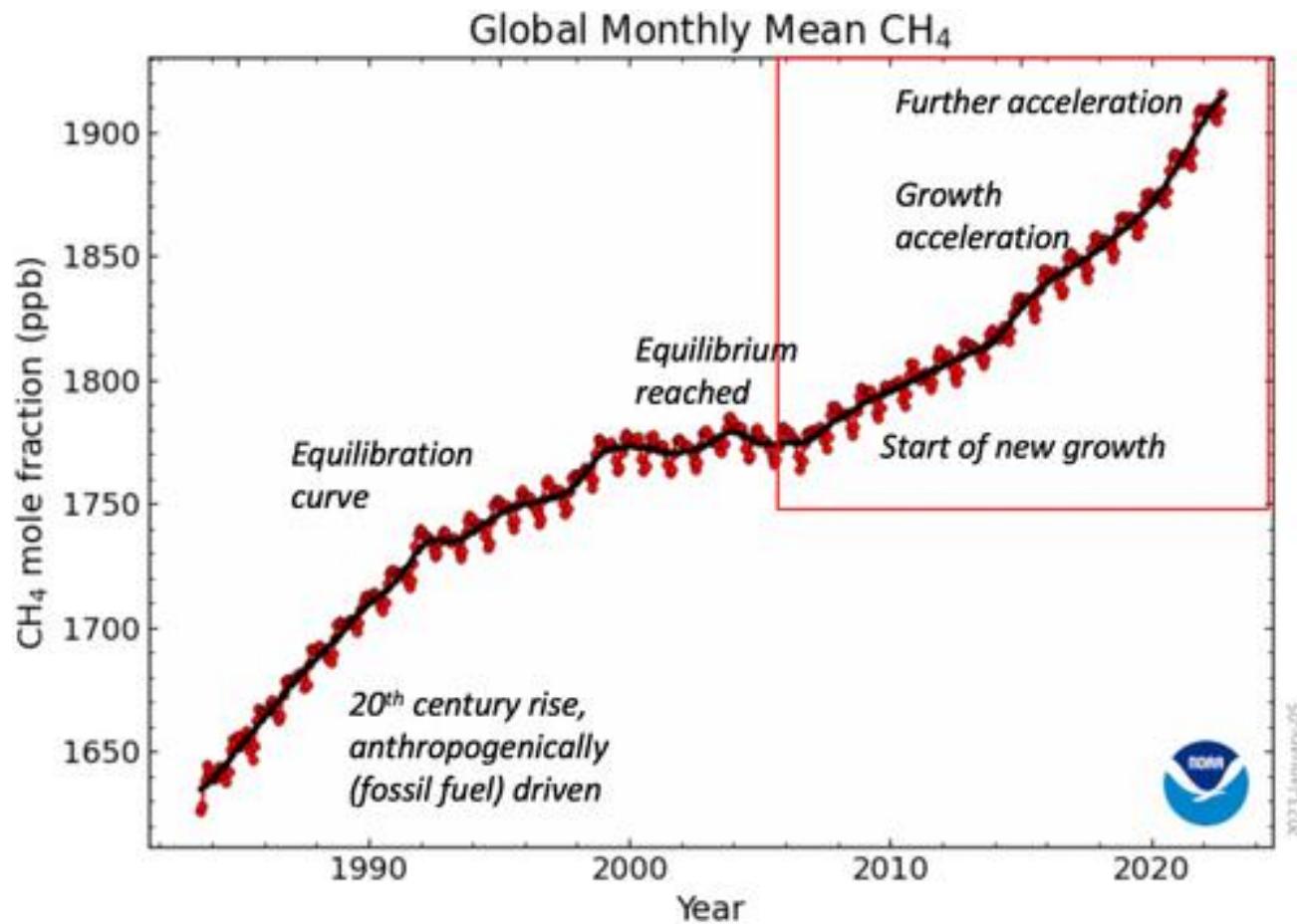
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Carbon-cycle climate feedback

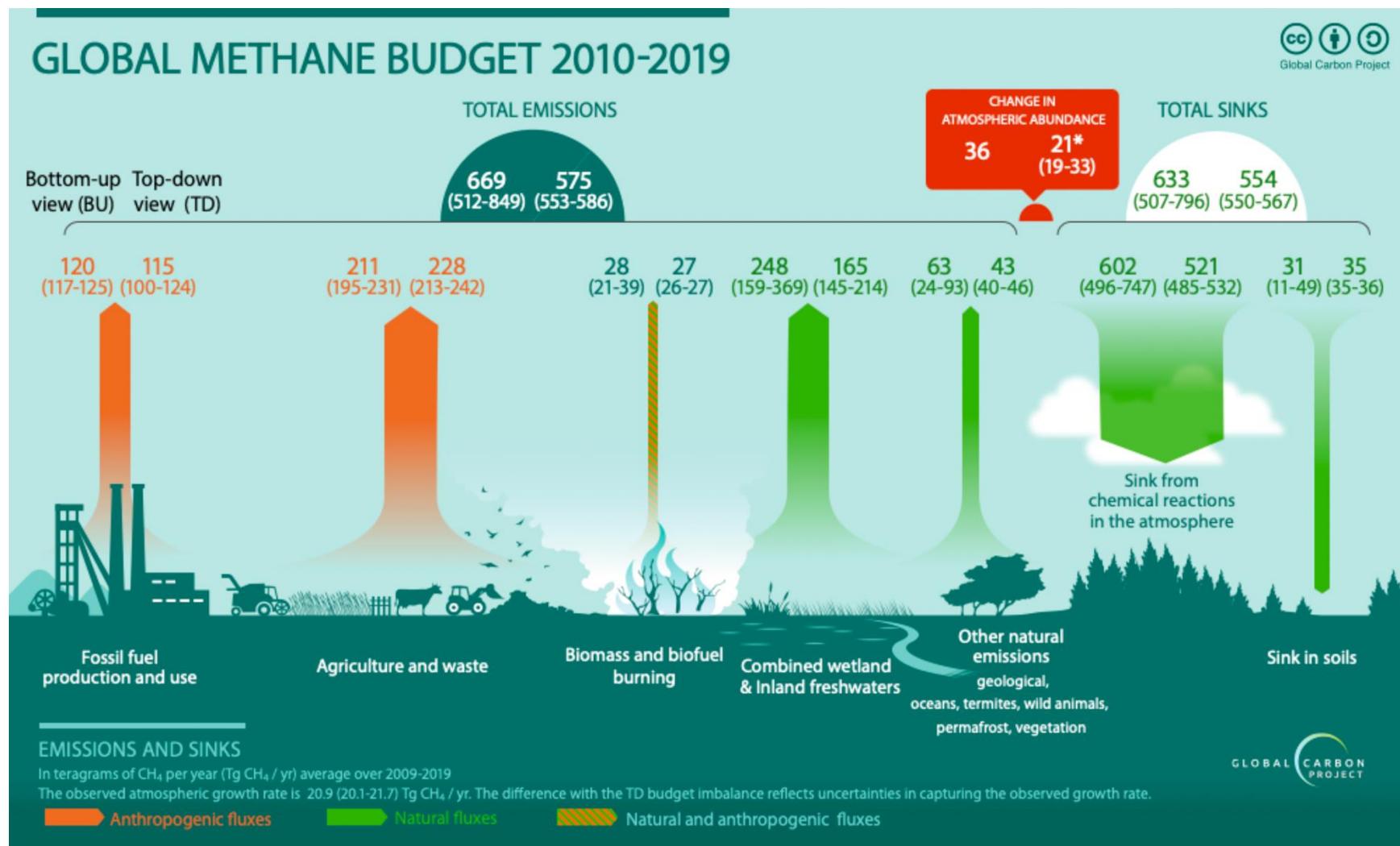


Changes in methane concentration

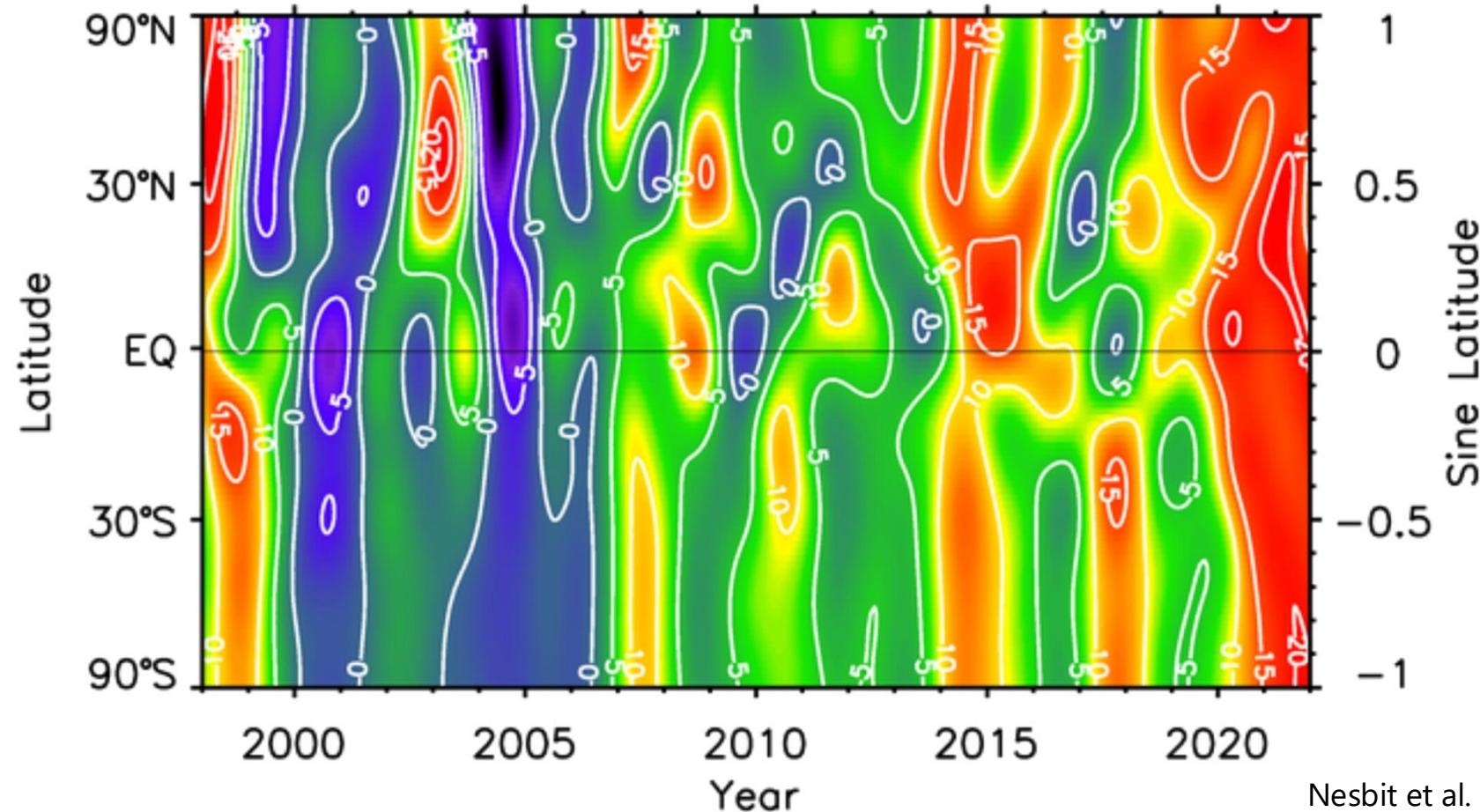


Nesbit et al. (2023) GBC

The global CH₄ budget



Methane sine-latitude growth plot - NOAA



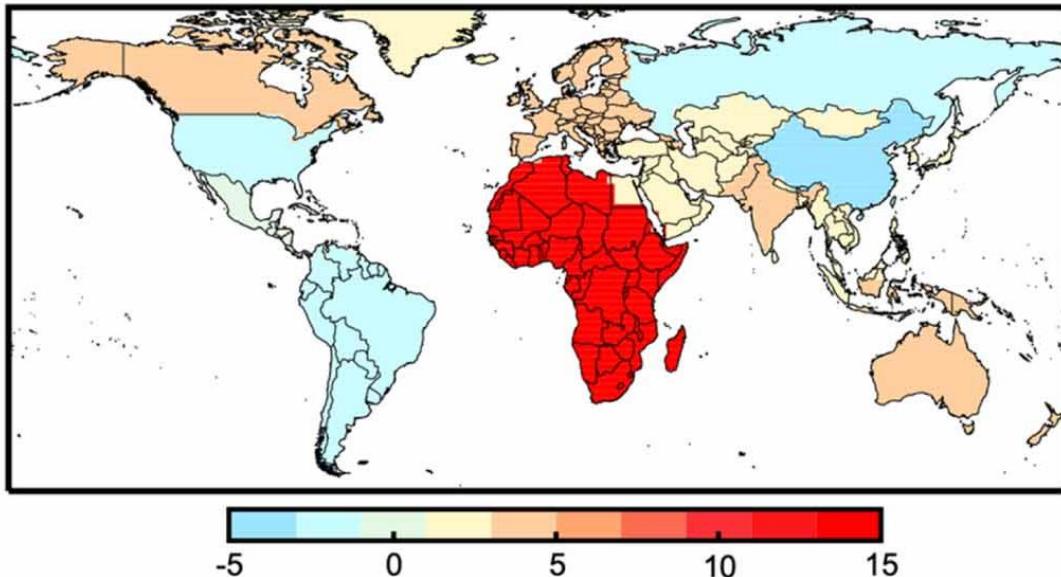
Nesbit et al. (2023) GBC

What's driving the renewed growth in CH₄?

- Total annual CH₄ emissions from human activities increased by 20% in the past two decades (2000-2020) and have continued to increase to 2022.
- Between the early 2000s and the late 2010s, all major sectors of anthropogenic CH₄ emissions rose substantially:
 - Emissions from cows (and other ruminants) increased of 14%
 - Emissions from landfills (and other waste) increased around 24%
 - Fossil fuel emissions increased between 18 to 28%
- Anthropogenic emissions are growing but can **only account for part** of the recent methane growth

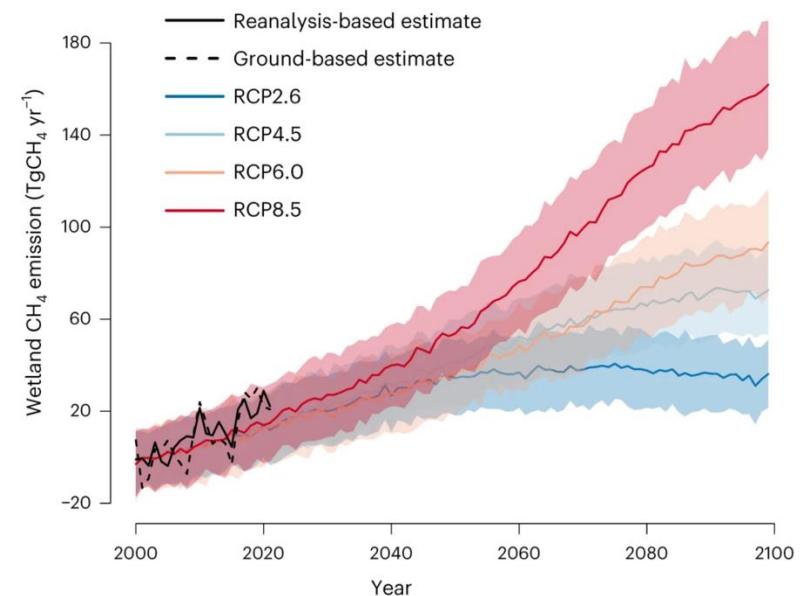
Wetlands likely a key player in the renewed growth rate

(b) 2020-2019 change in emissions [Tg a^{-1}]



Half of the increase in emissions is from Africa (15 Tg a^{-1}) and appears to be driven by wetland inundation.
There is also a large relative increase in emissions from
Canada and Alaska (4.8 Tg a^{-1} , 24%) that could be driven by temperature sensitivity of boreal wetland emissions.

- Tropical and sub-tropical wetlands, and also Northern Wetlands, may be responding strongly to climate change impacts
- Isotopic evidence also suggests wetlands are probably the dominant factor driving faster methane growth



Brief Communication

<https://doi.org/10.1038/s41558-023-01629-0>

Recent intensification of wetland methane feedback

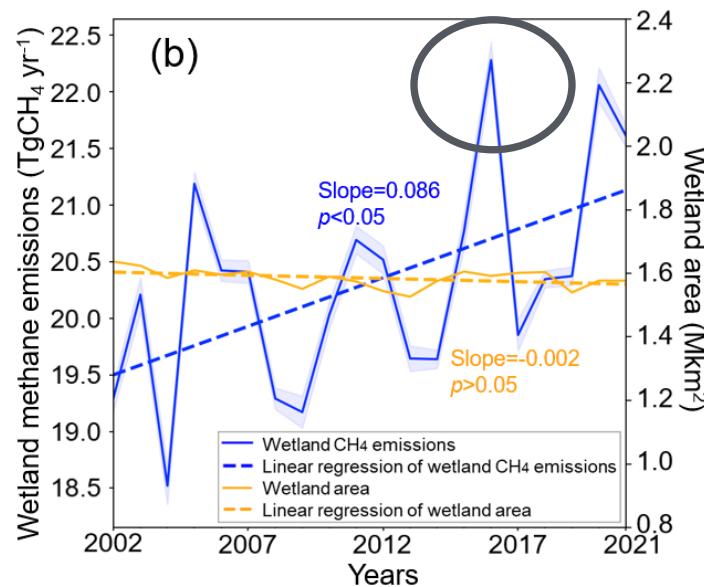
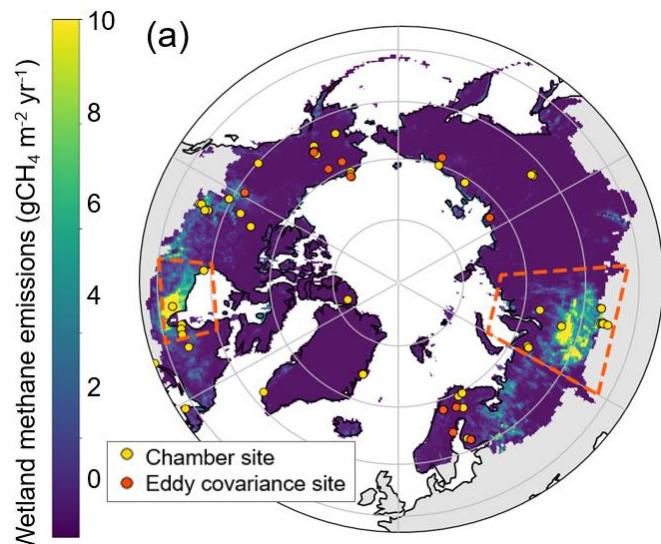
Received: 7 September 2022

Accepted: 10 February 2023

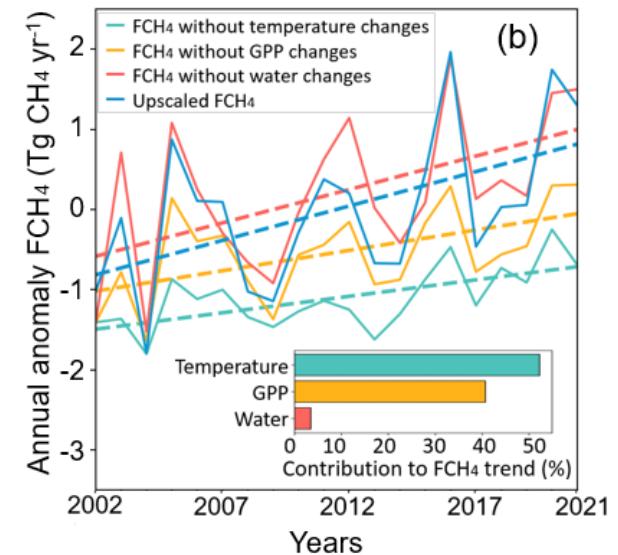
Zhen Zhang   Benjamin Poulter   Andrew F. Feldman   Qing Ying  

Philippe Ciais   Shushi Peng   & Xin Li 

Increasing trend of CH_4 emissions from Boreal and Arctic wetlands

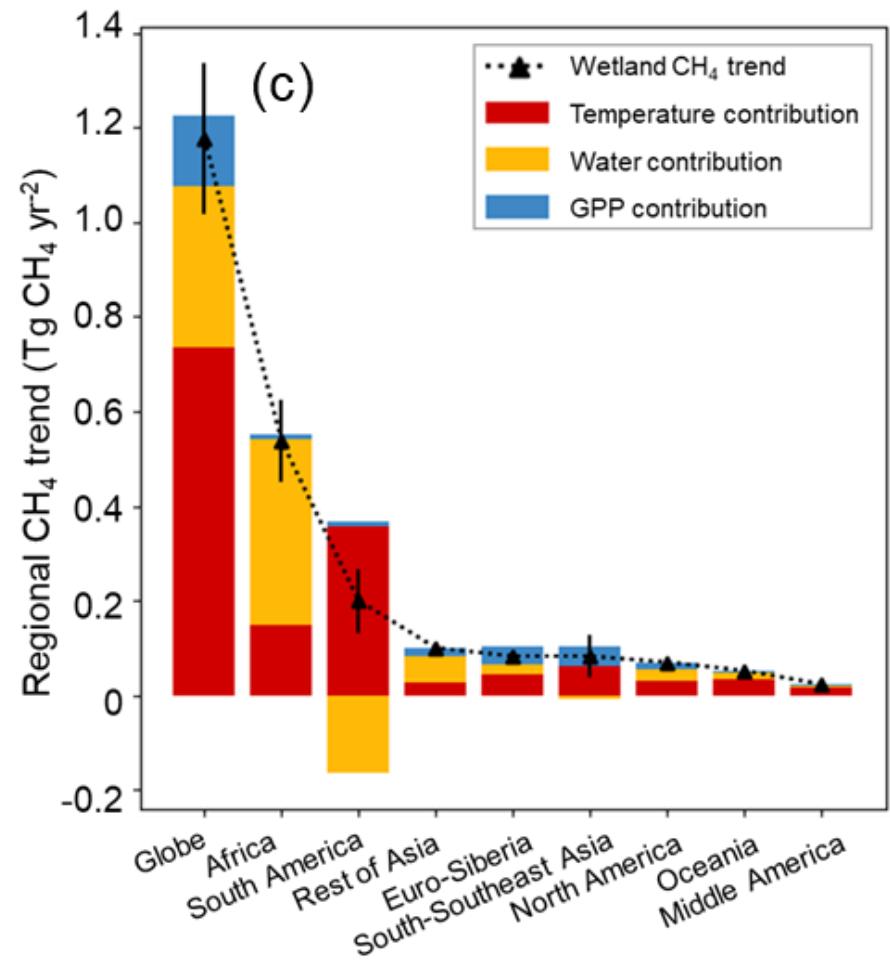
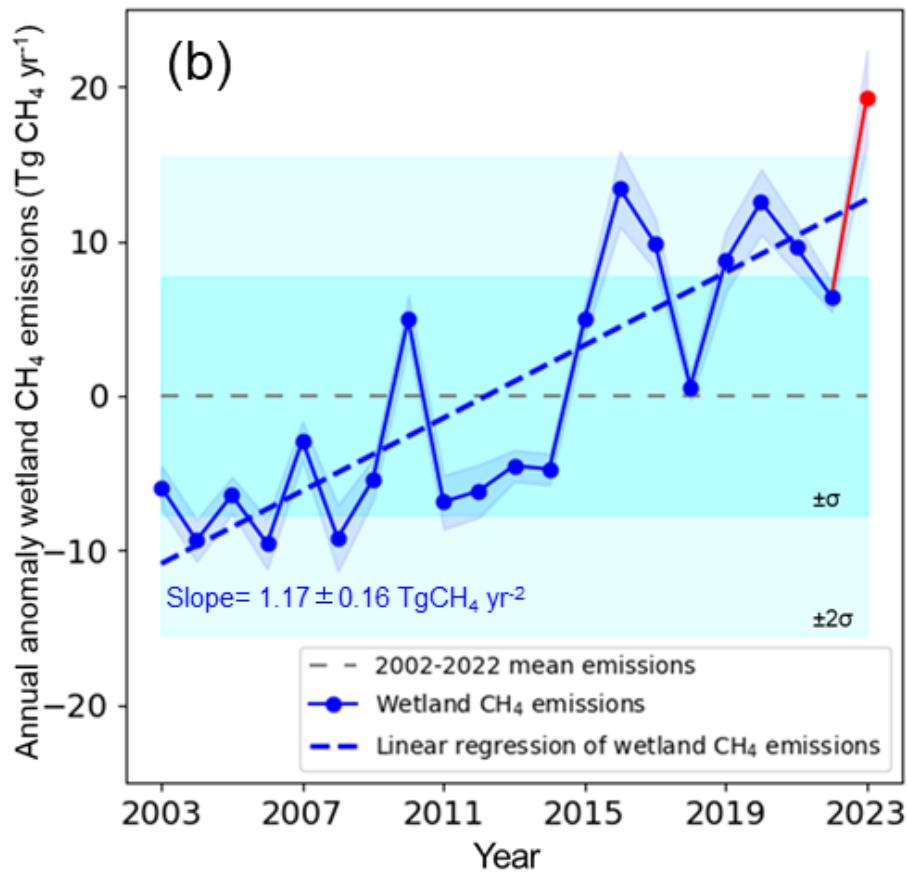


A robust increasing trend of CH_4 emissions (+8.9%) with strong inter-annual variability



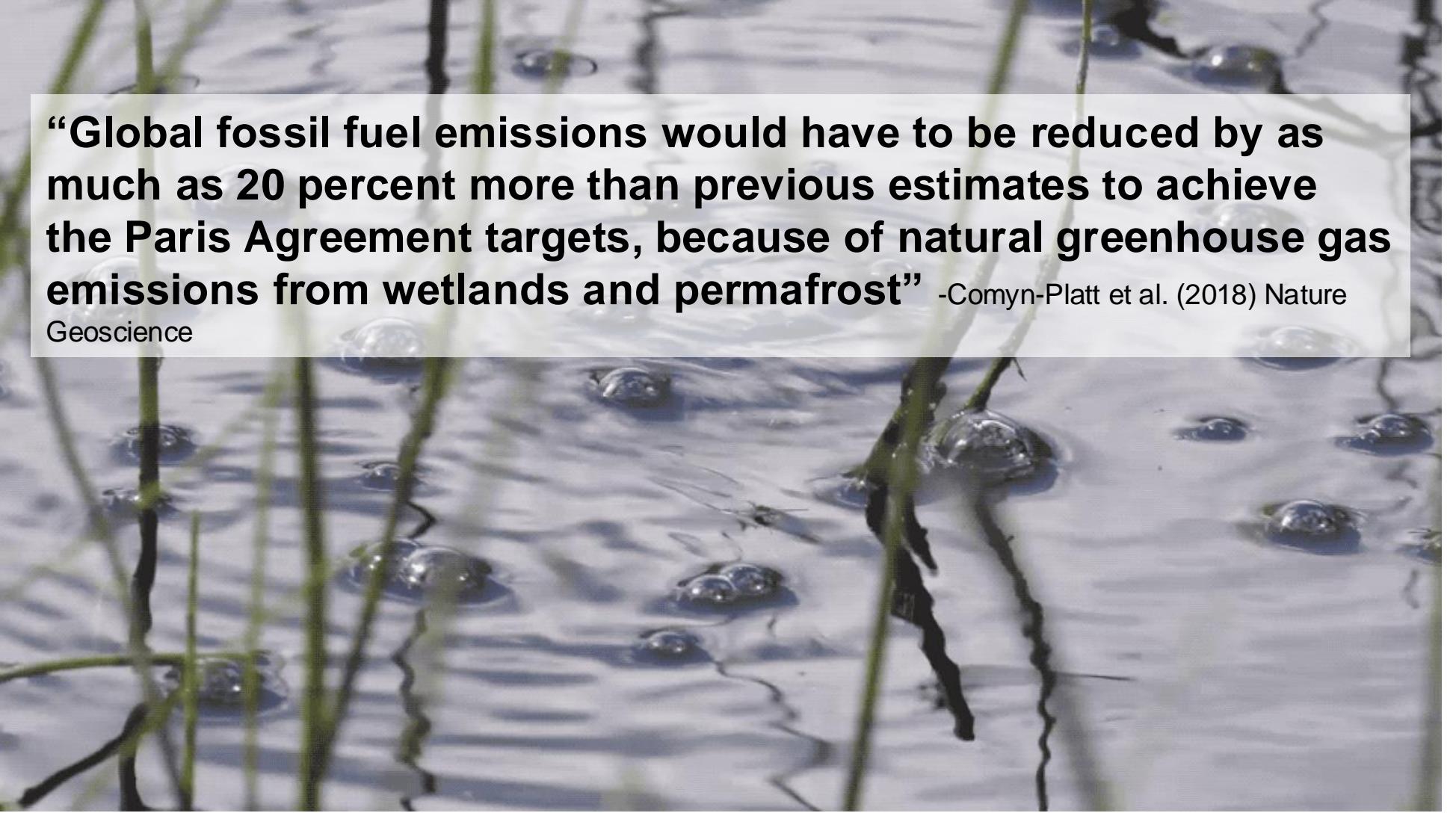
Emission increases mainly driven by warming (~52.3%) and ecosystem productivity (~40.7%).

Africa seems to dominates the long-term increase in global wetland CH₄ emissions due to warmer & wetter conditions



Yuan et al. (in review)

Methane feedbacks



“Global fossil fuel emissions would have to be reduced by as much as 20 percent more than previous estimates to achieve the Paris Agreement targets, because of natural greenhouse gas emissions from wetlands and permafrost”

-Comyn-Platt et al. (2018) Nature Geoscience

Source: <https://svs.gsfc.nasa.gov/13047>

Knox / GEOG 321

Topic 32 - Changing climate

How can ecosystems help with climate change mitigation and adaptation?

Natural Climate Solutions

The logo for The Guardian newspaper, featuring the word "The" above "Guardian" in a large, white, serif font.

Natural climate solutions

Natural climate solutions are conservation, restoration and improved land management actions that increase carbon storage or avoid greenhouse gas emissions in landscapes and wetlands across the globe.

Forests



Grasslands &
Agriculture

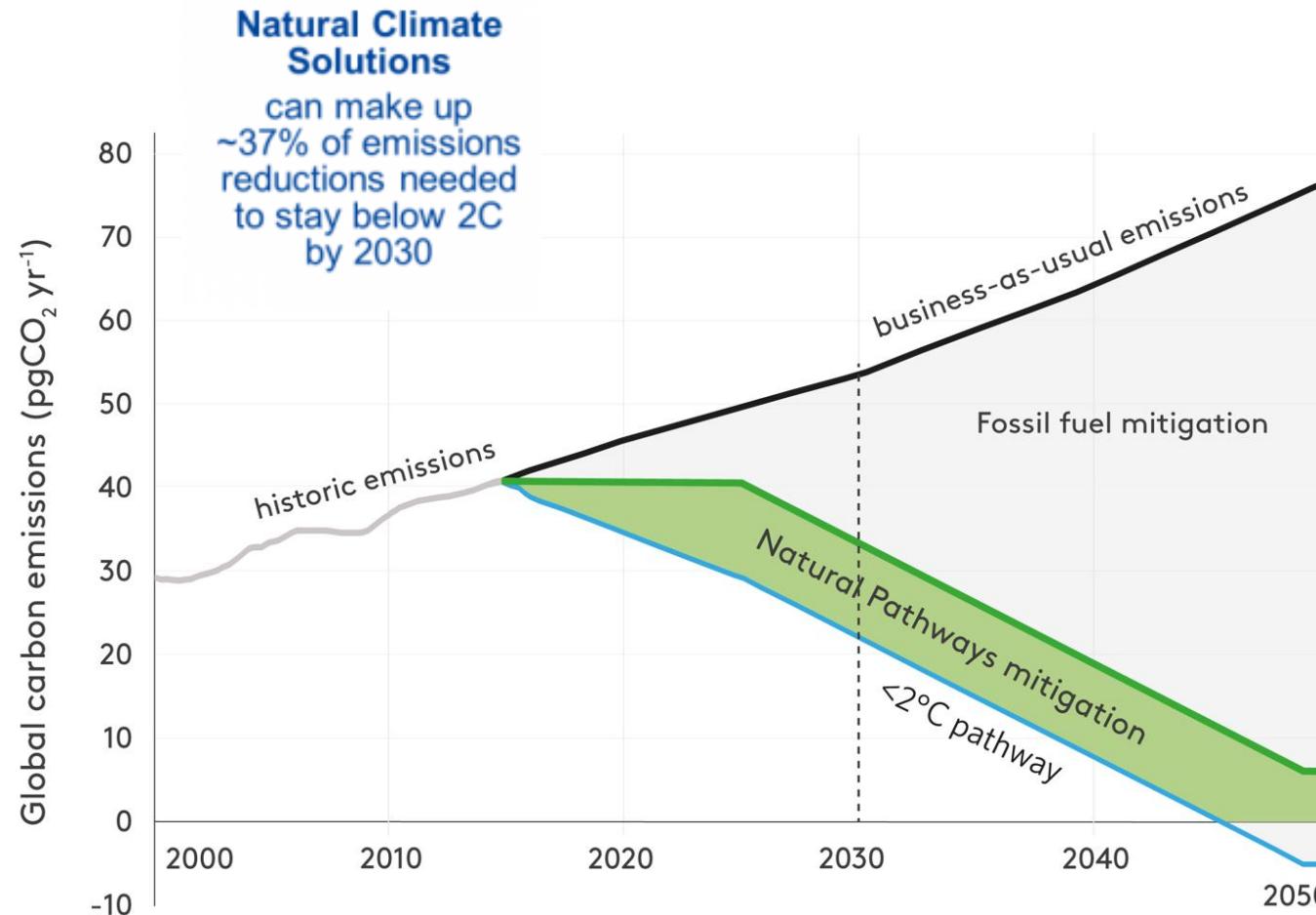


Wetlands



Source: Griscom et al. (2017) PNAS; <http://nature4climate.org/science/n4c-pathways>

Managing ecosystems to meet our climate goals



Source: Griscom et al. (2017) PNAS

Can you think of 2 specific examples of Natural Climate Solutions?

Forests



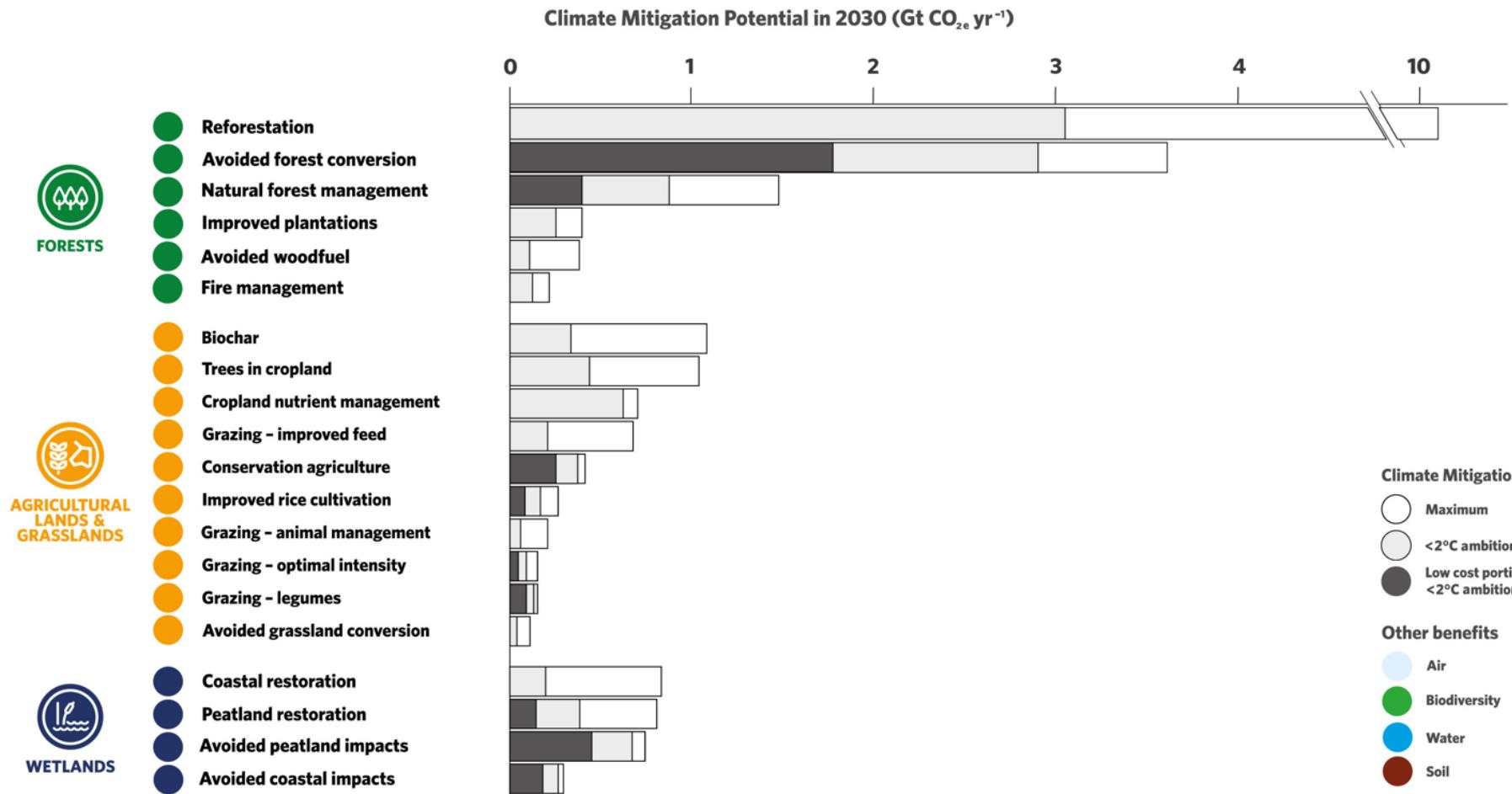
Grasslands &
Agriculture



Wetlands



Natural climate solutions



Source: <https://www.nature.org/en-us/what-we-do/our-insights/perspectives/natures-make-or-break-potential-for-climate-change/>

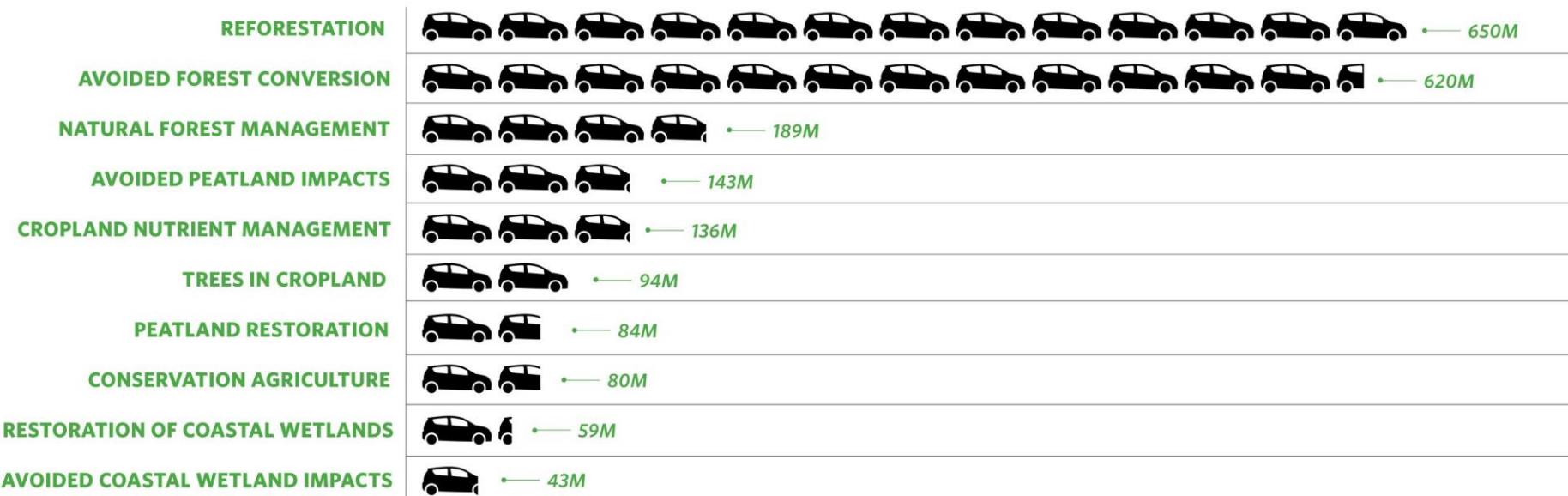
Natural climate solutions – in units of cars

NATURAL CLIMATE SOLUTIONS



TOP 10 MITIGATION PATHWAYS¹ WITH CO-BENEFITS

Natural Climate Solutions have the same impact on emissions as taking millions of cars off the road



Global Mitigation Potential: Approximate Number of Cars Removed Each Year in Millions

= 50M cars

¹Cost-Effective

Source: <https://www.nature.org/en-us/what-we-do/our-insights/perspectives/natures-make-or-break-potential-for-climate-change/>

Cost effective & numerous co-benefits



NCS in Canada



Government
of Canada Gouvernement
du Canada

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Nature-based climate solutions

See nature as something new



Canada has roughly:



24% of the world's boreal forests



1.5 million square kilometres of wetlands —
around 24% of the world's remaining total



2 million lakes and the world's longest
coastline

Our commitment

Canada is committed to protecting 30 % of its lands and 30 % of its oceans by 2030, using nature-based solutions to fight climate change, and reaching net-zero greenhouse gas emissions by 2050.

The Natural Climate Solutions Fund is one way Canada is working to achieve this commitment.

NCS in Quebec

PMO 2021-2026: Axe 1• Atténuer les changements climatiques

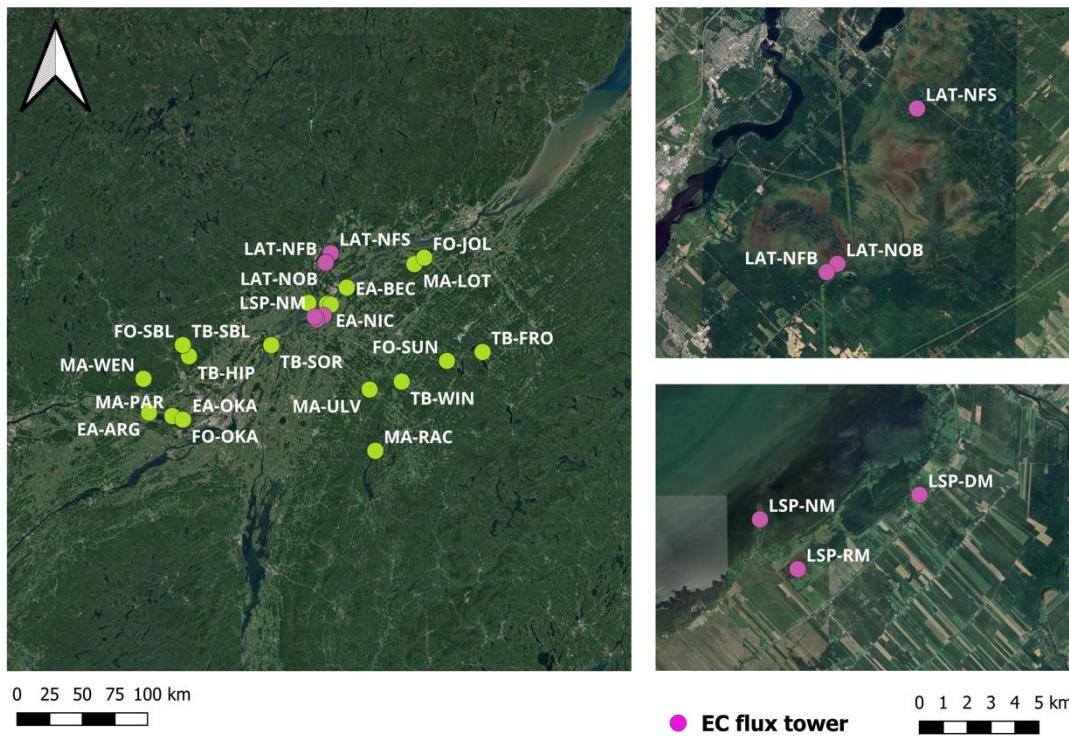
Milieux naturels et réservoir de carbone		
Axes d'intervention	Objectifs	Mesures
Conserver nos milieux naturels	1.11 : Éviter la destruction et la dégradation de nos réservoirs de carbone	1.11.1 Conserver les milieux naturels prioritaires
Valoriser le rôle des milieux naturels dans la protection du climat	1.13 : Mieux comprendre le rôle des milieux naturels dans l'atténuation	1.13.1 Développer les connaissances sur le potentiel de contribution des milieux naturels et des produits du bois à l'atténuation

<https://www.environnement.gouv.qc.ca/changementsclimatiques/air-pmo-pev-202101.pdf>





CARBONIQUE



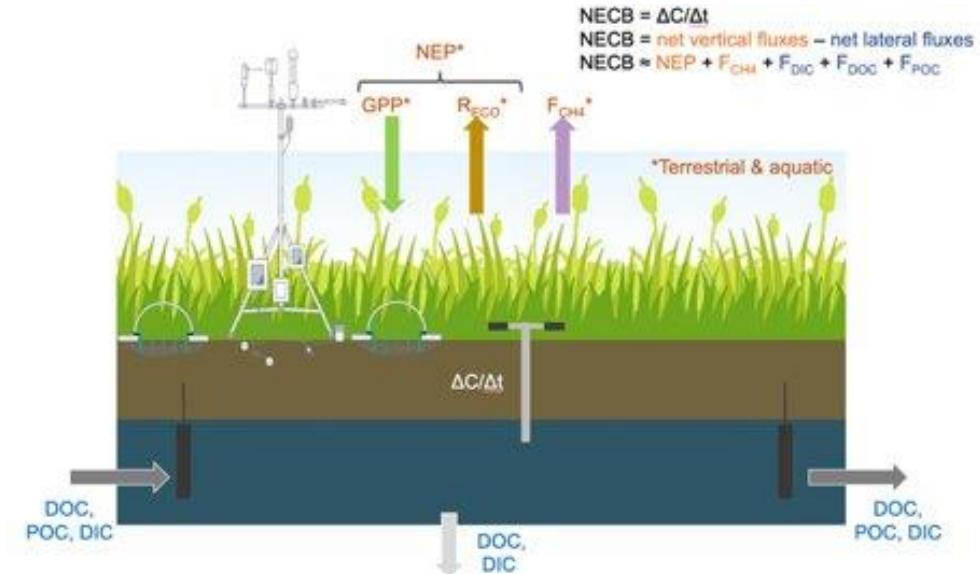
0 25 50 75 100 km



0 1 2 3 4 5 km



<https://carbonique.ca/>



UQÀM

UQTR
Université du Québec
à Trois-Rivières

Université
de Montréal

UNIVERSITÉ
LAVAL



Environnement,
Lutte contre
les changements
climatiques,
Faunes et Parcs

Québec



CARBONIQUE



Identify one strength and one limitation of NCS

Advantages & disadvantages of NCS?



Source:
<https://earthobservatory.nasa.gov/images/45056fires-in-british-columbia-canada>



Credit: Matthew Brown

Take home points

- Of the CO₂ that is emitted, ~46% remains in the atmosphere, 24% is absorbed by our **oceans** and 30% by the **land**.
- Terrestrial ecosystems can both **amplify** ('positive feedback') or **diminish** ('negative feedback') the effects of a change in climate forcing.
- Conservation, restoration, and improved land management can help provide cost-effective climate mitigation (i.e. natural climate solutions). However, natural climate solutions are themselves highly susceptible to the impacts of climate change and disturbance.

Fulfilled the learning goals? (1/3)

- ✓ You are now able to **read, understand and formulate budget equations** to describe interactions of energy, mass, and momentum between soil, vegetation and atmosphere.
- ✓ You can now **model the basics of radiation** transfer and radiation exchange at land-atmosphere interfaces.

Photo: A. Christen



Fulfilled the learning goals? (2/3)

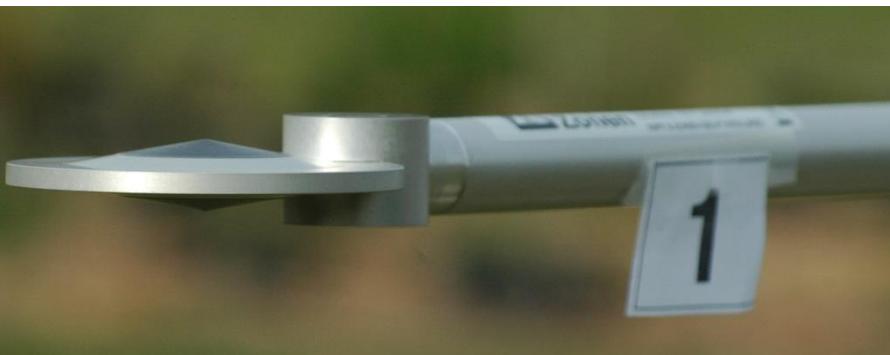
- ✓ You can **model soil climates** in simple conditions and describe transfer in laminar boundary layers.
- ✓ Understanding the **nature of wind and turbulence** in the ABL. Describe turbulent transfer of mass, momentum and energy (wind and temperature profiles, dynamic stability, gradient approaches, entrainment)

Photo: A. Christen

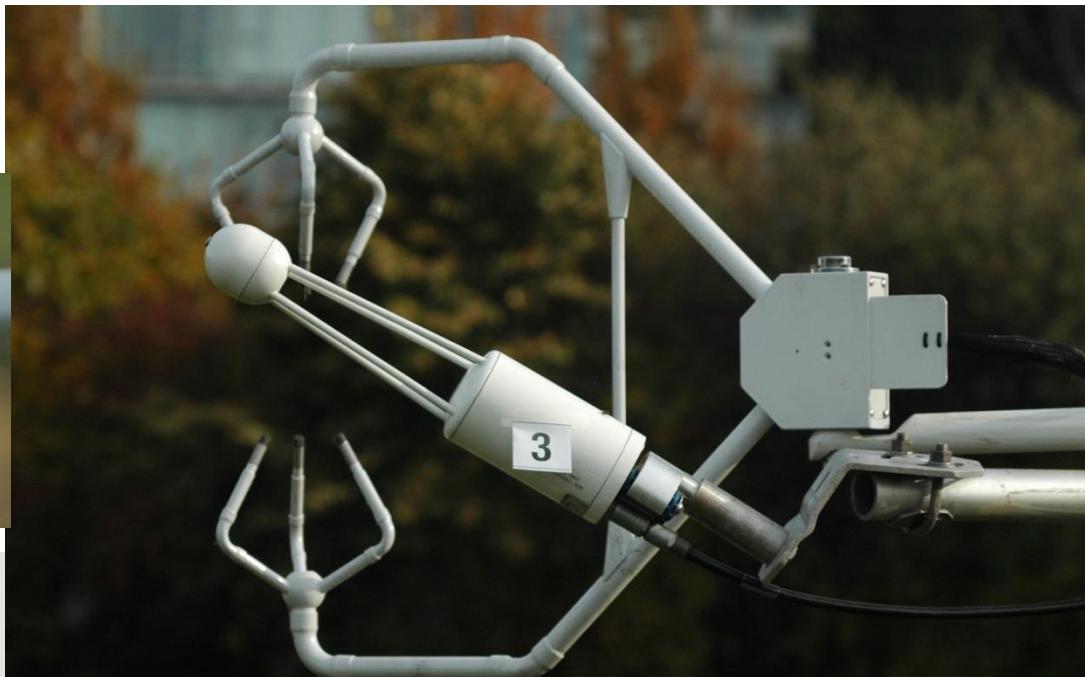


Fulfilled the learning goals? (3/3)

- ✓ You understand the **role of vegetation** in land-atmosphere interactions - physiological controls of water and carbon exchange.
- ✓ You became familiar **with basic and modern instrumentation** and simple models used in today's monitoring and modeling of surface-atmosphere exchange.



Photos: A. Christen



Course evaluations

- Evaluations are key to helping me **assess and improve** my teaching.
- Constructive feedback and specific examples are most helpful.
- Evaluations are also used to inform decisions about reappointment, tenure, promotion and merit for faculty.
- **Thanks for taking the time to fill out the course evaluation!**



THANK YOU!

Please do not forget to provide feedback on the course and good luck with the final exam!

