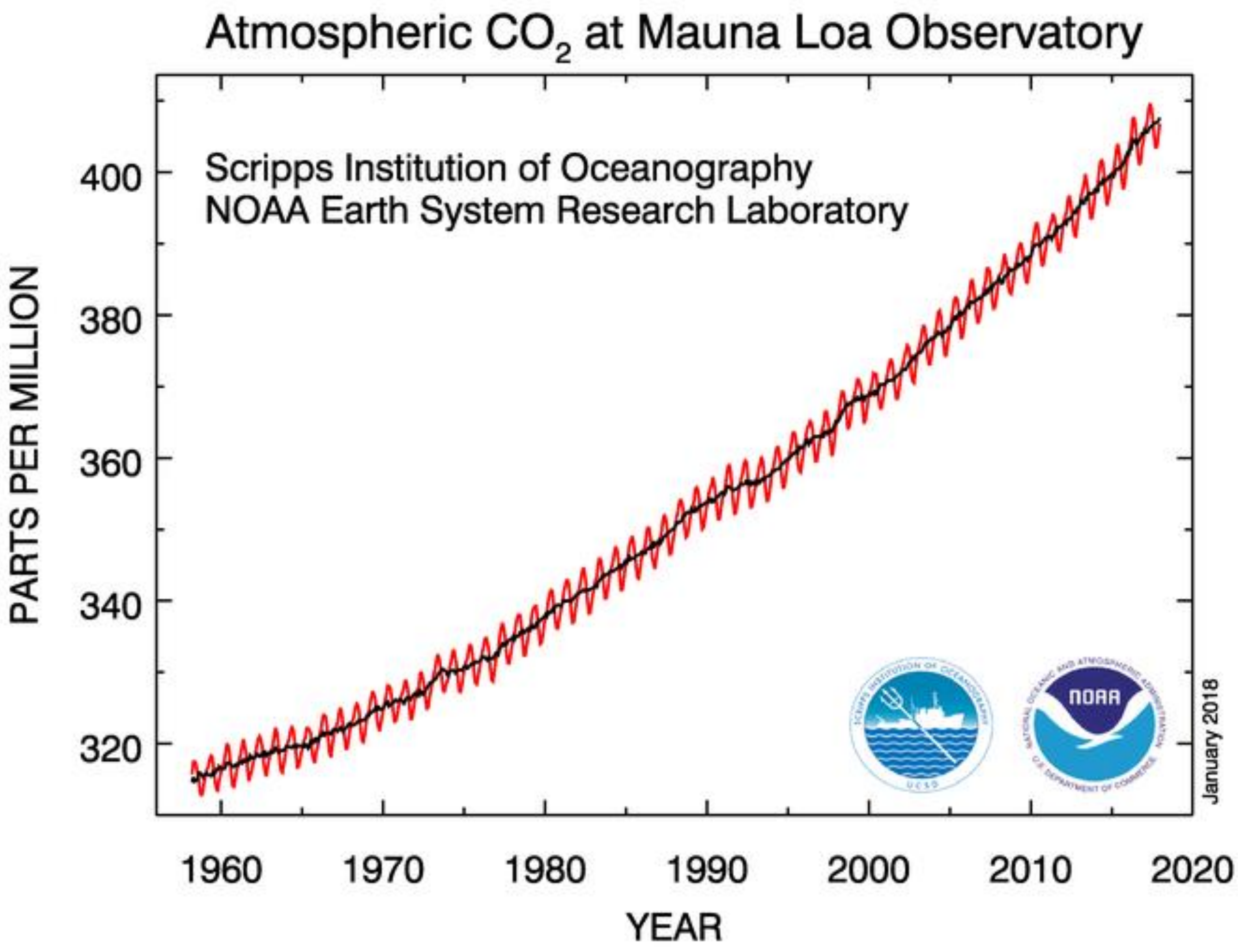

Photo: A. Christen

Learning objectives

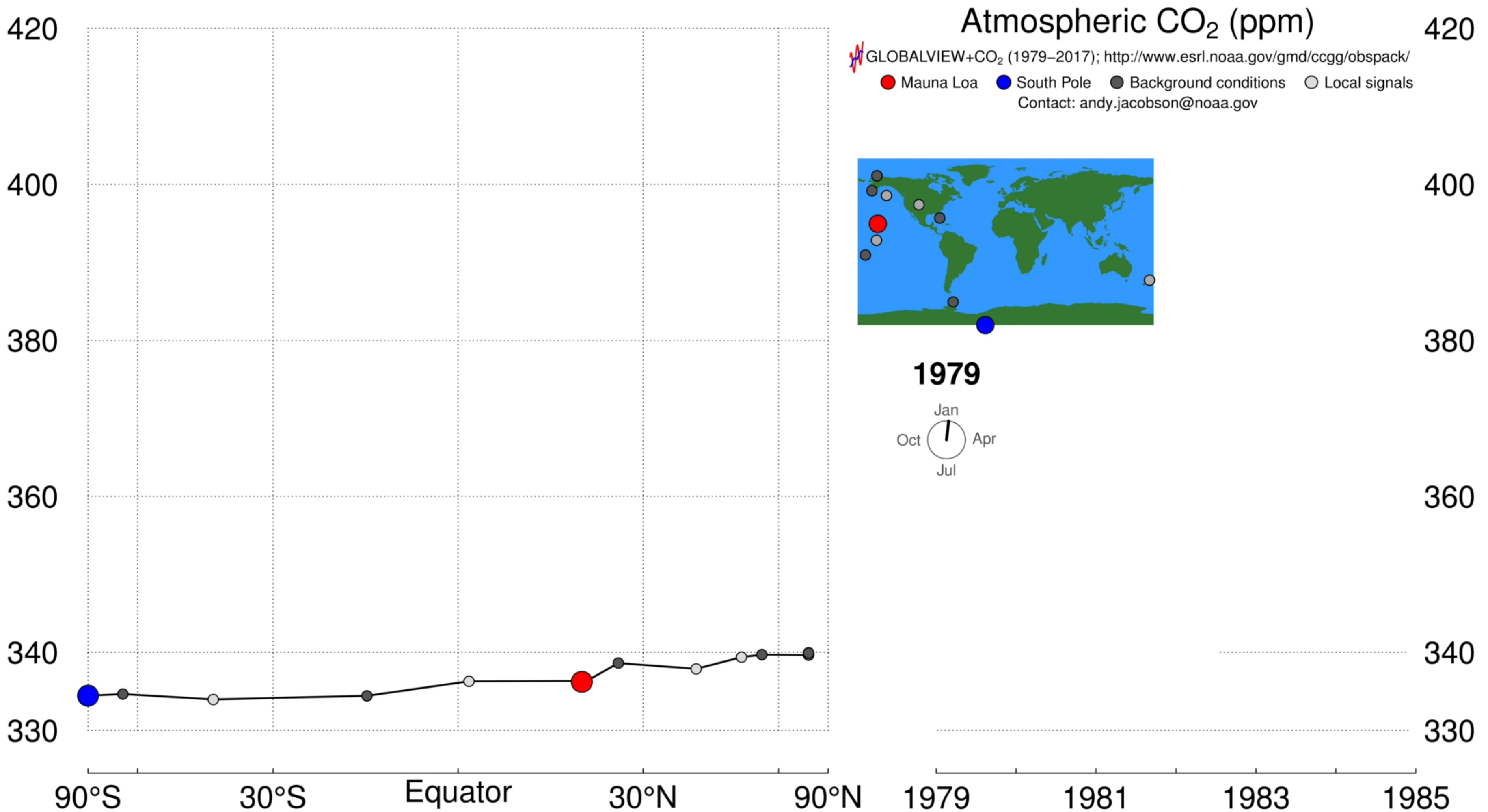
- Describe how ecosystem-scale carbon fluxes respond to a changing climate.
- Give two examples of positive and/or negative feedbacks between land-surfaces and the climate system.
- Explain how we can we modify land management practices for climate change mitigation & adaptation.

Photo: J. Verfaillie

Rising CO_2 concentrations

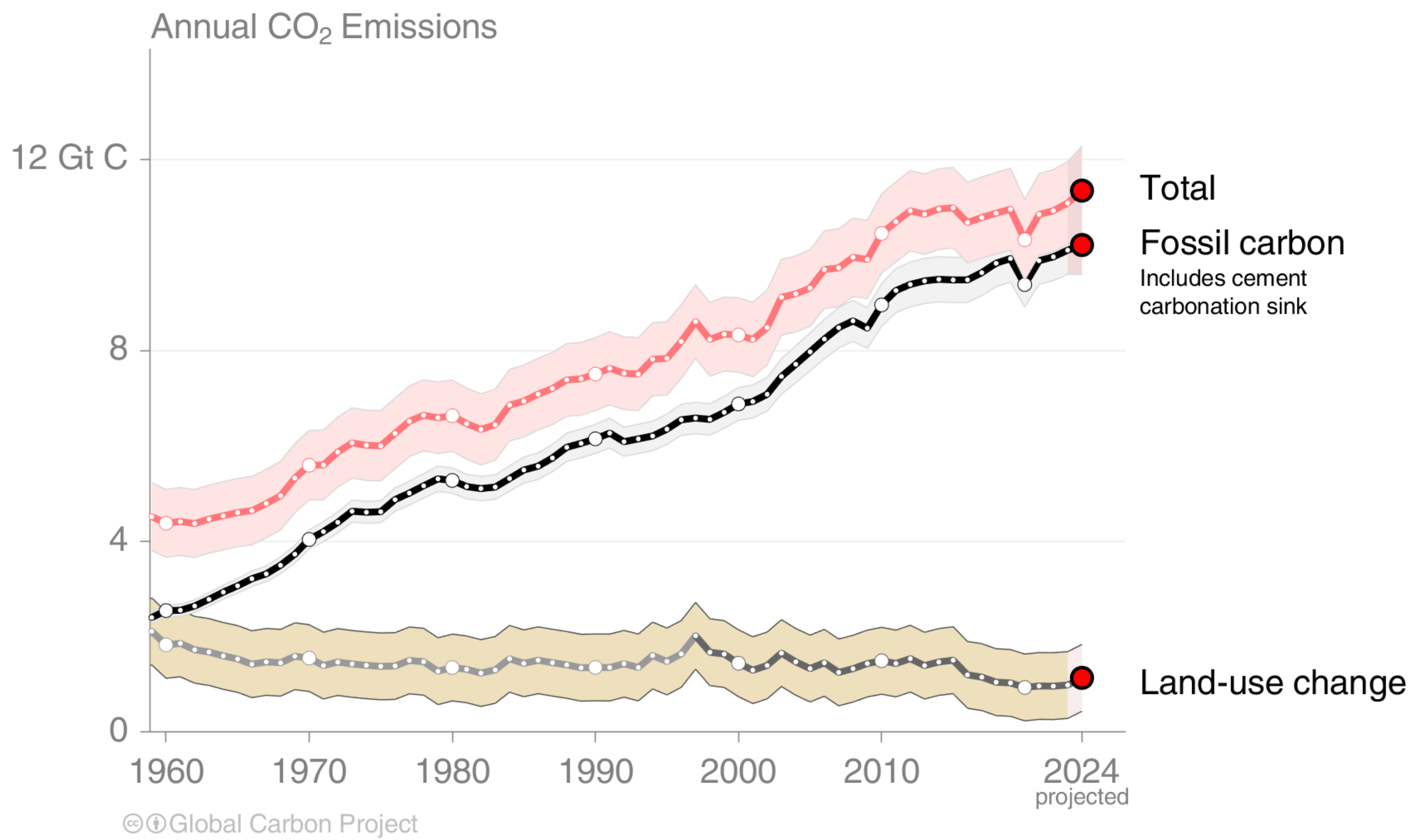


Rising CO_2 concentrations animation



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

CO_2 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 CO_2 go?

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433-971-976

Terrestrial ecosystems are key components of the global carbon cycle

9.7 GtC/yr

90%

5.2 GtC/yr

48%

29%

3.2 GtC/yr

10%

1.1 GtC/yr

26%

2.9 GtC/yr

Budget Imbalance:

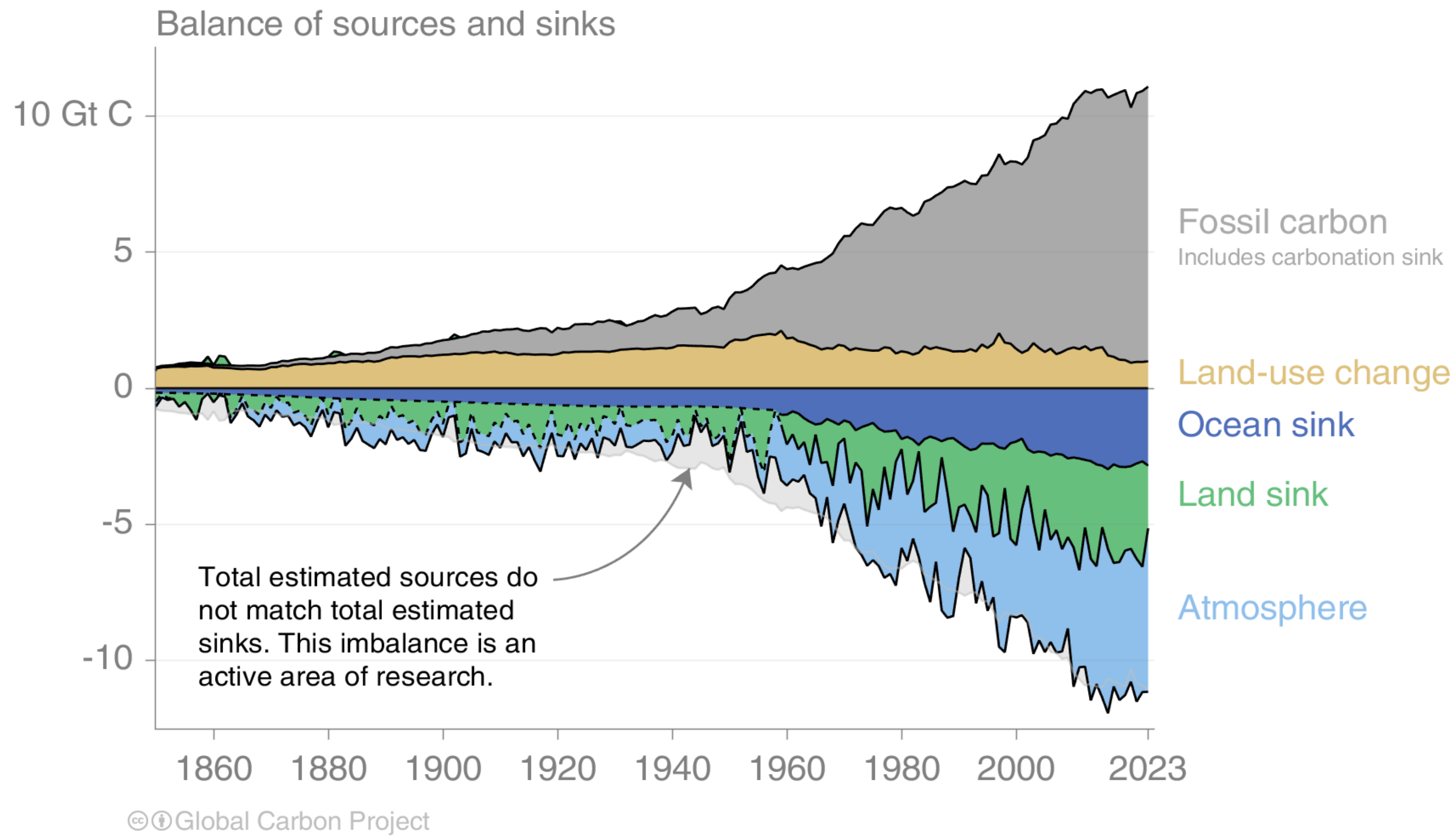
(the difference between estimated sources & sinks)

4%

-0.4 GtC/yr

Source: [Friedlingstein et al 2024](); [Global Carbon Project 2024]()

Ocean and land carbon sinks slow the rise of CO_2 in the atmosphere.



Will ecosystems continue to help offset CO_2 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

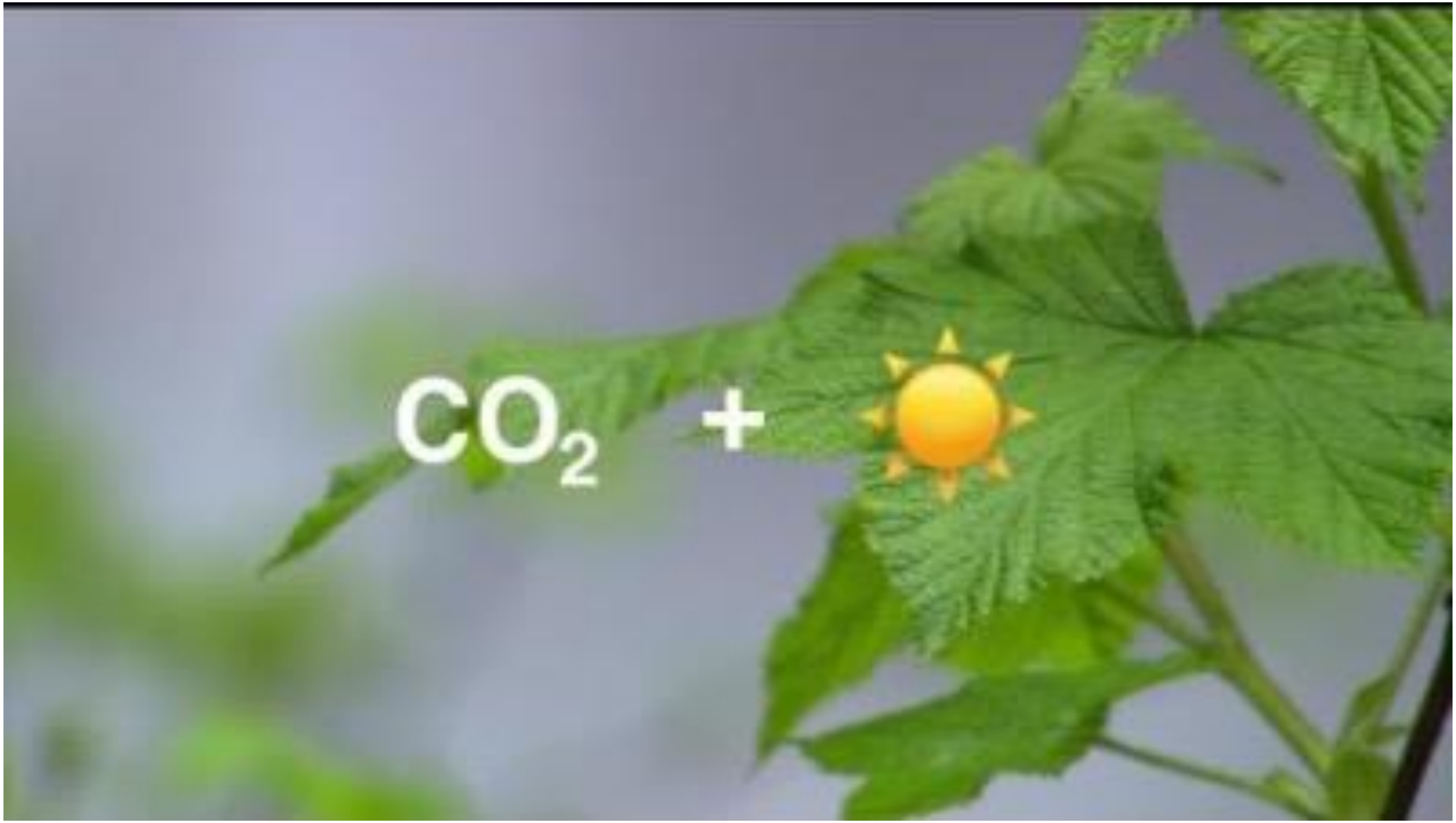
Piyu Ke[1,2], Philippe Ciais[3,*], Stephen Sitch[2], Wei Li[1], Ana Bastos[4,5], Zhu Liu[1], Yidi Xu[3], Xiaofan Gui[6], Jiang Bian[6], Daniel S. Goll[3], Yi Xi[3], Wanjing Li[1], Michael O'Sullivan[2], Jefferson Goncalves De Souza[2], Pierre Friedlingstein[2,7] and Frédéric Chevallier[3]

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

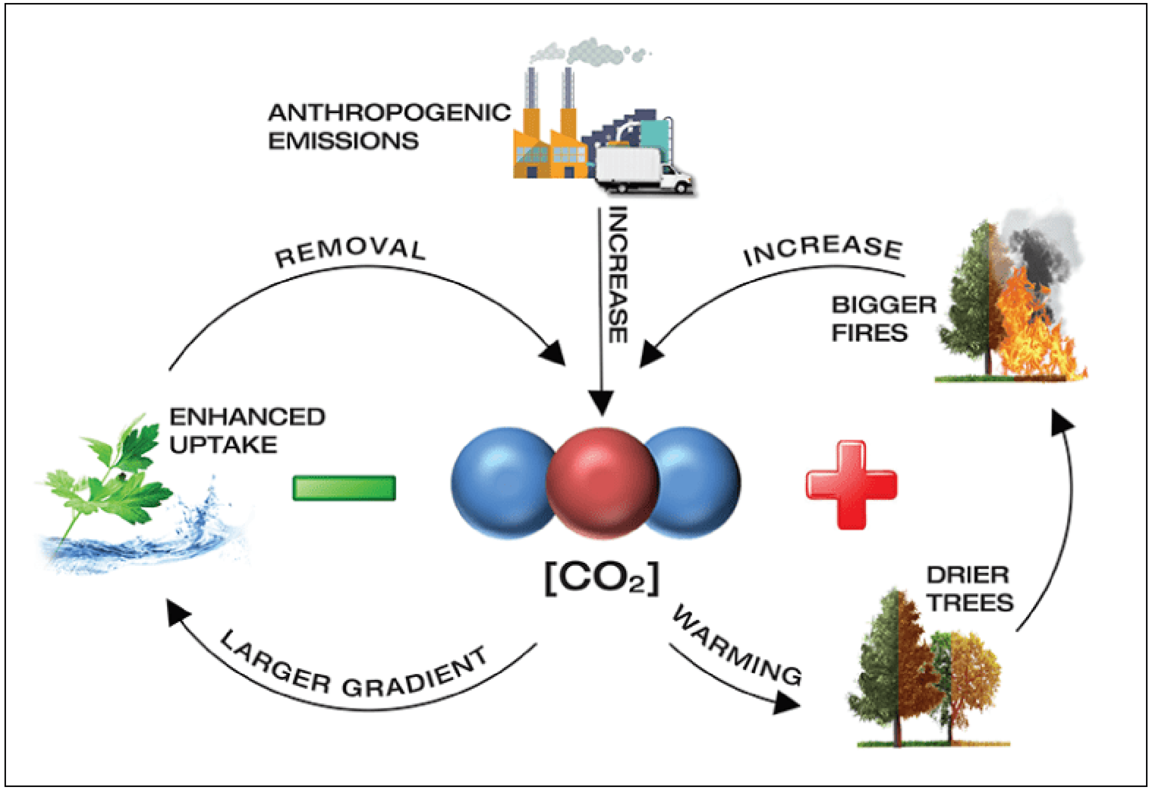
- The difference between incoming and outgoing radiation is known as a planet's radiative forcing (RF)

(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.

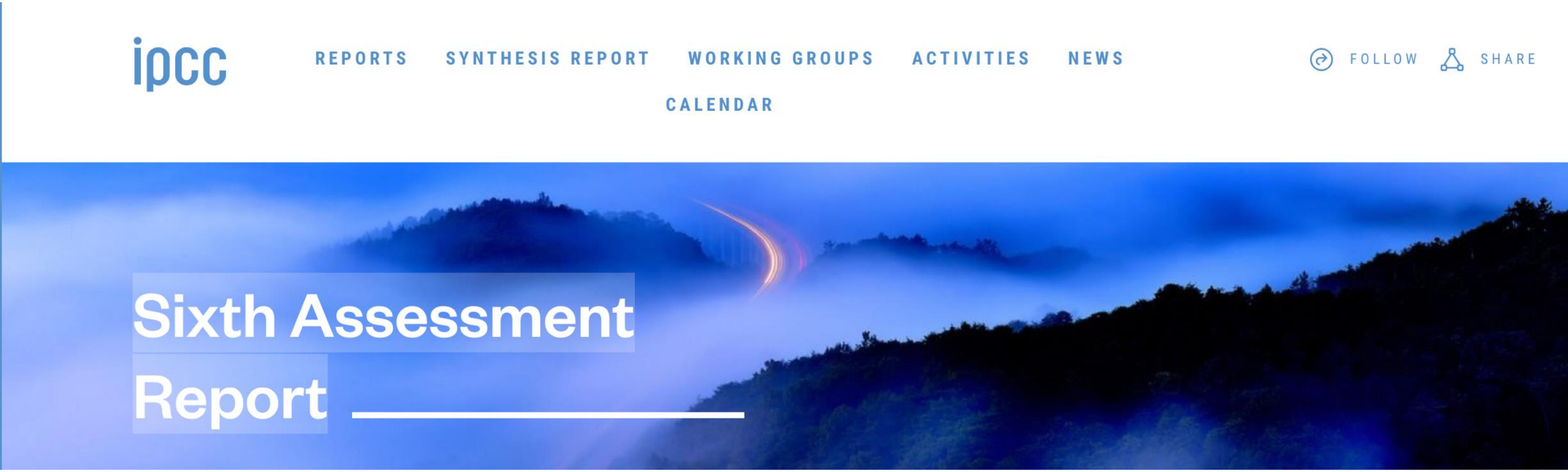
Feedbacks

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



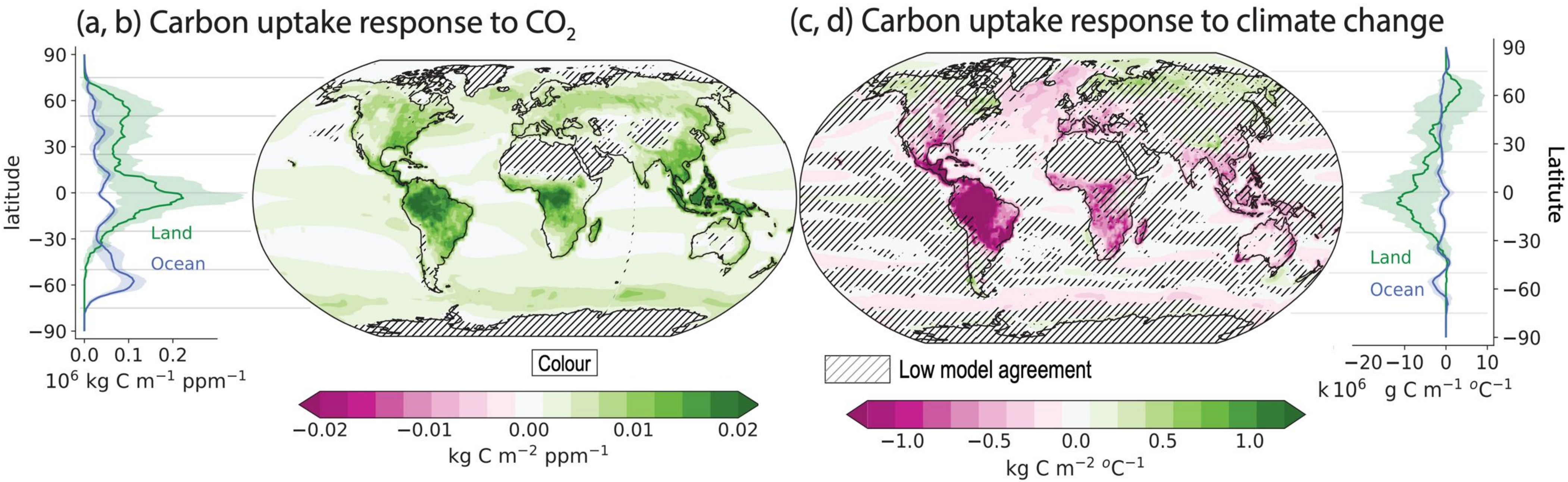
https://eos.org/features/the-future-of-the-carbon-cycle-in-a-changing-climate

IPCC Synthesis Reports



Response of ecosystems to rising CO_2 & climate warming

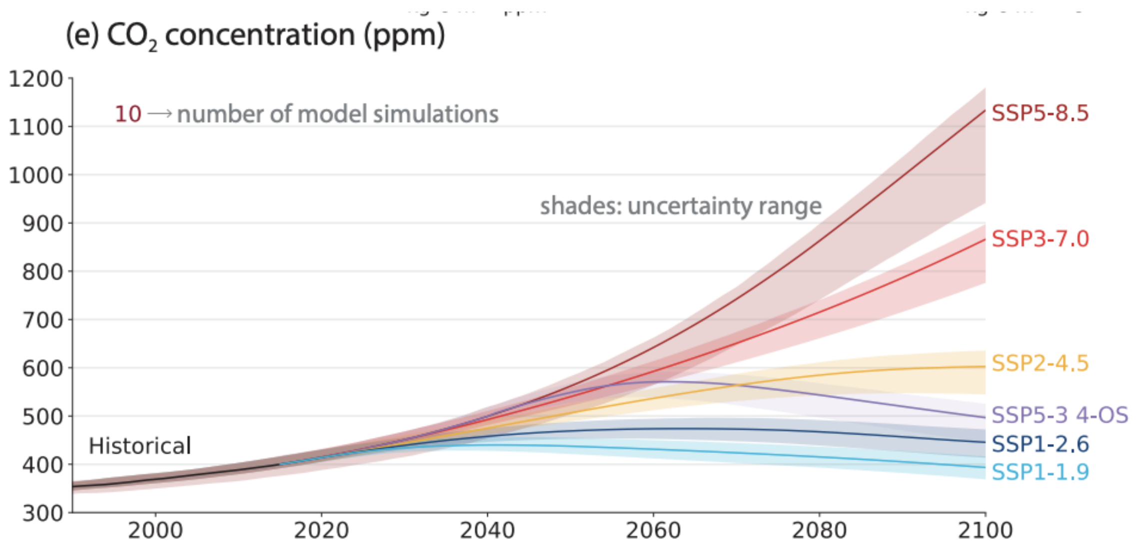
These figures shows changes in carbon storage in response to elevated CO_2 (a, b) and the response to climate warming (c, d)



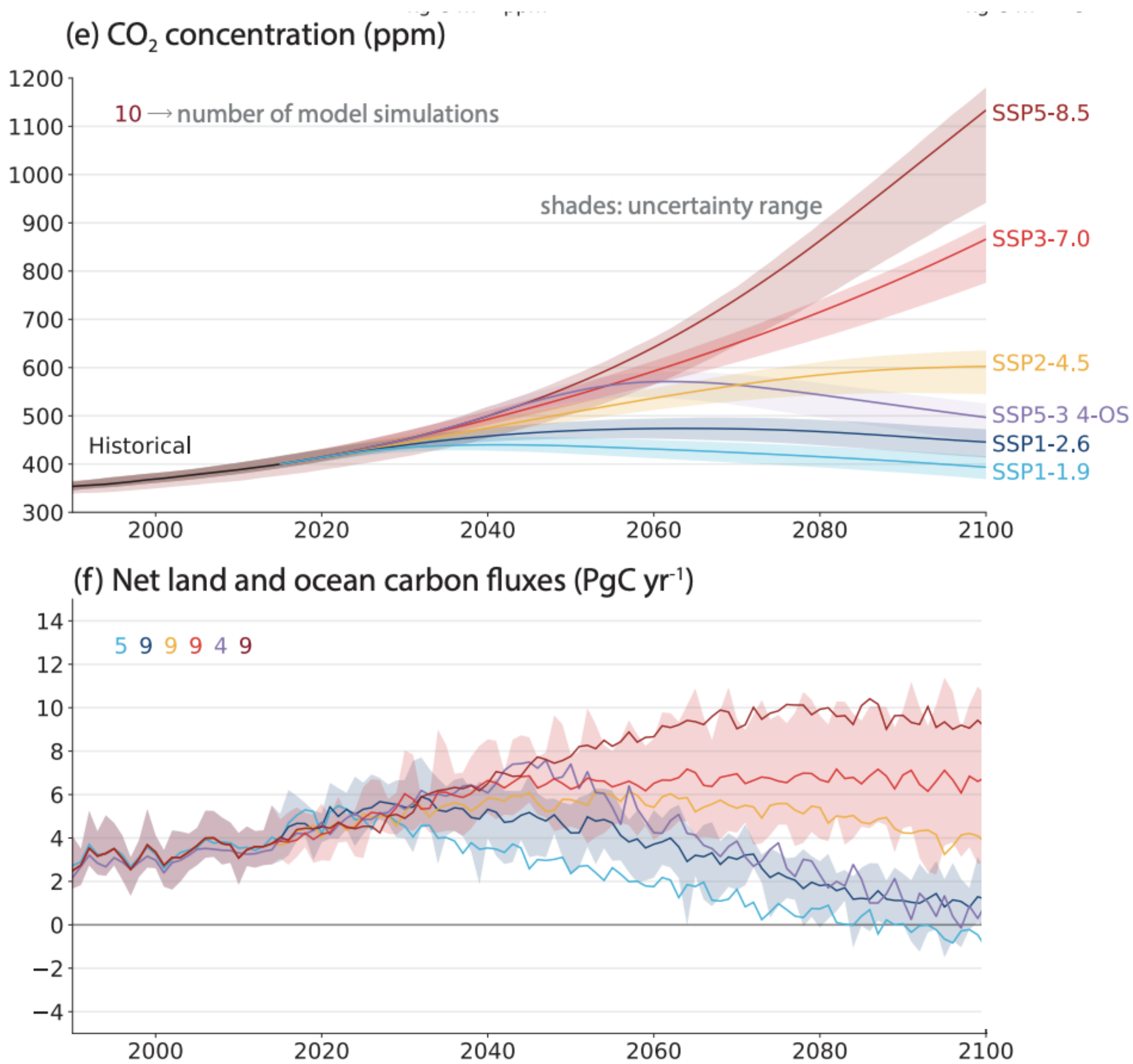
Since the 1980s, carbon fertilization from rising atmospheric CO_2 has increased the strength of the net land CO_2 sink (medium confidence).

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).

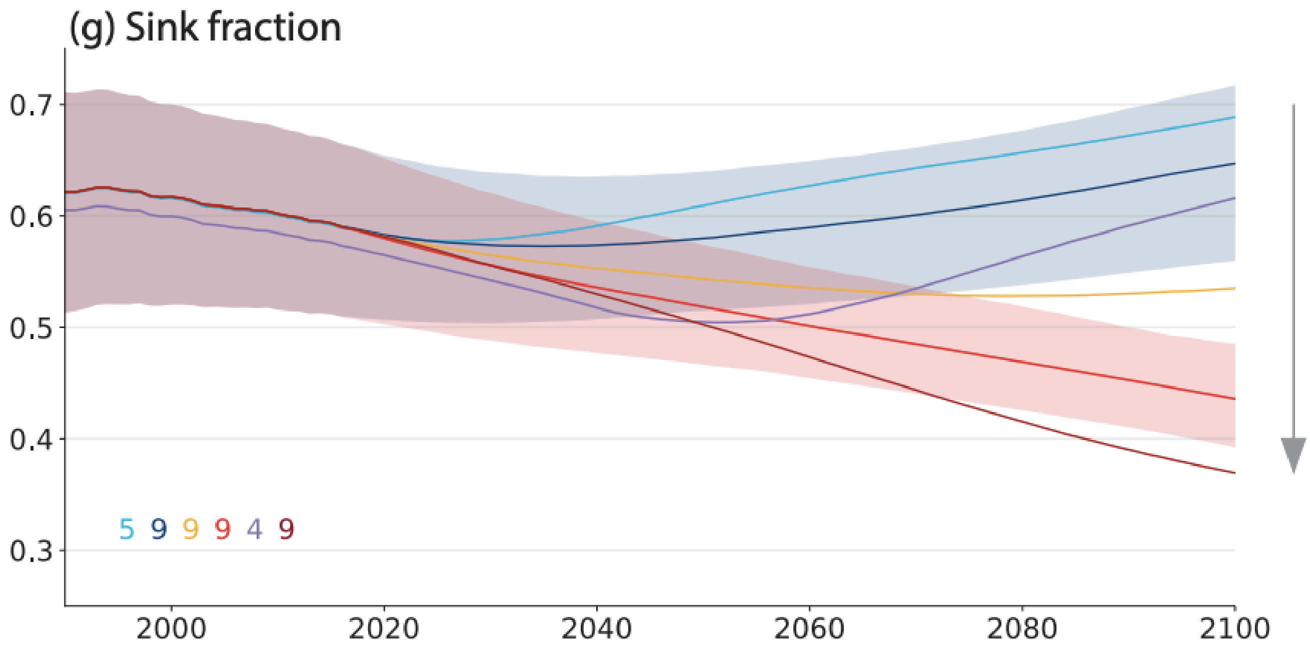
The future of the land sink



The future of the land sink

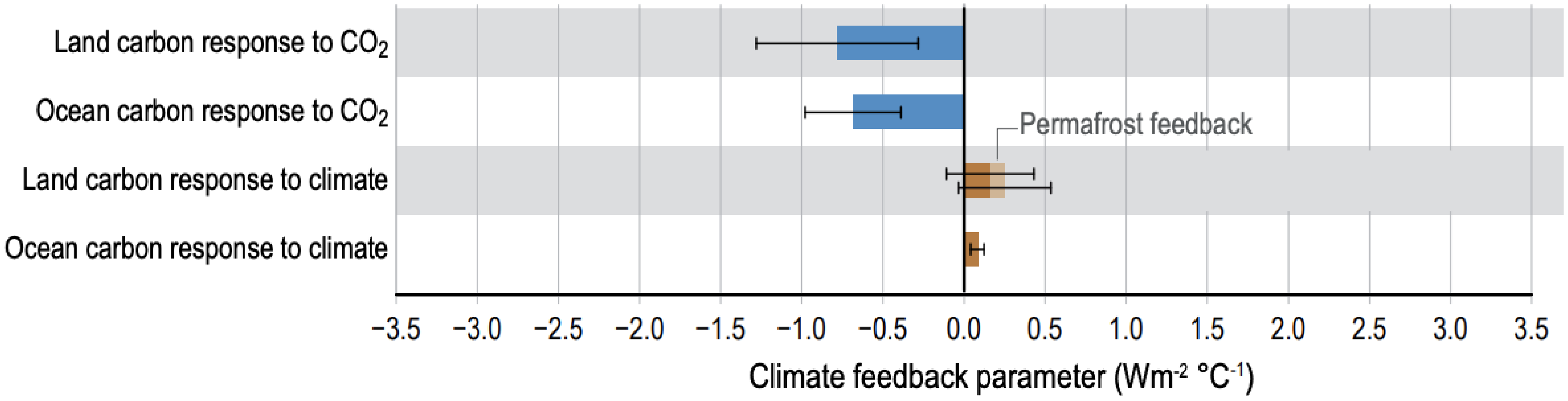


The future of the land sink



At higher CO_2 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 CO_2 is a:

A) Positive climate feedback

B) Negative climate feedback

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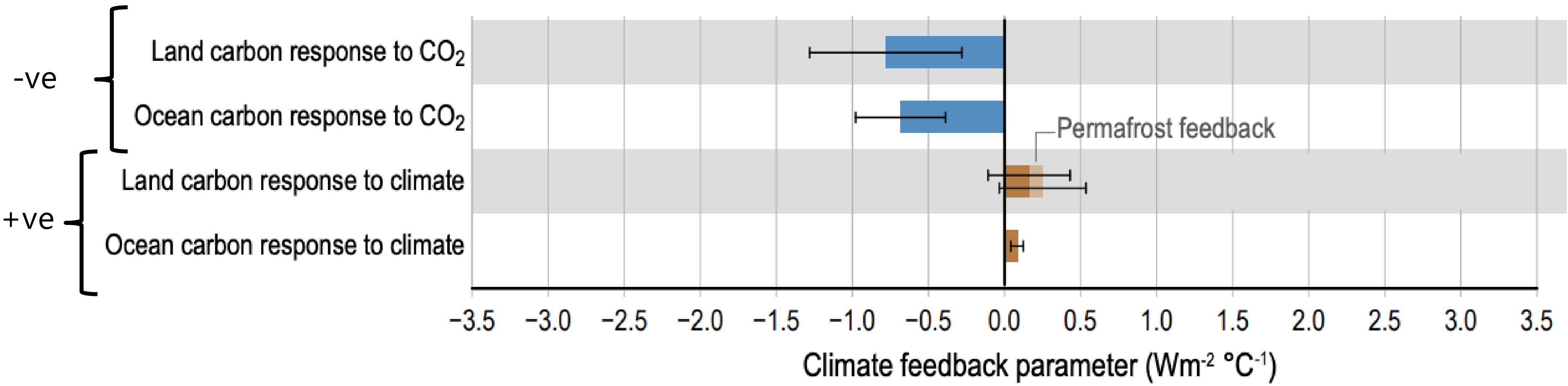
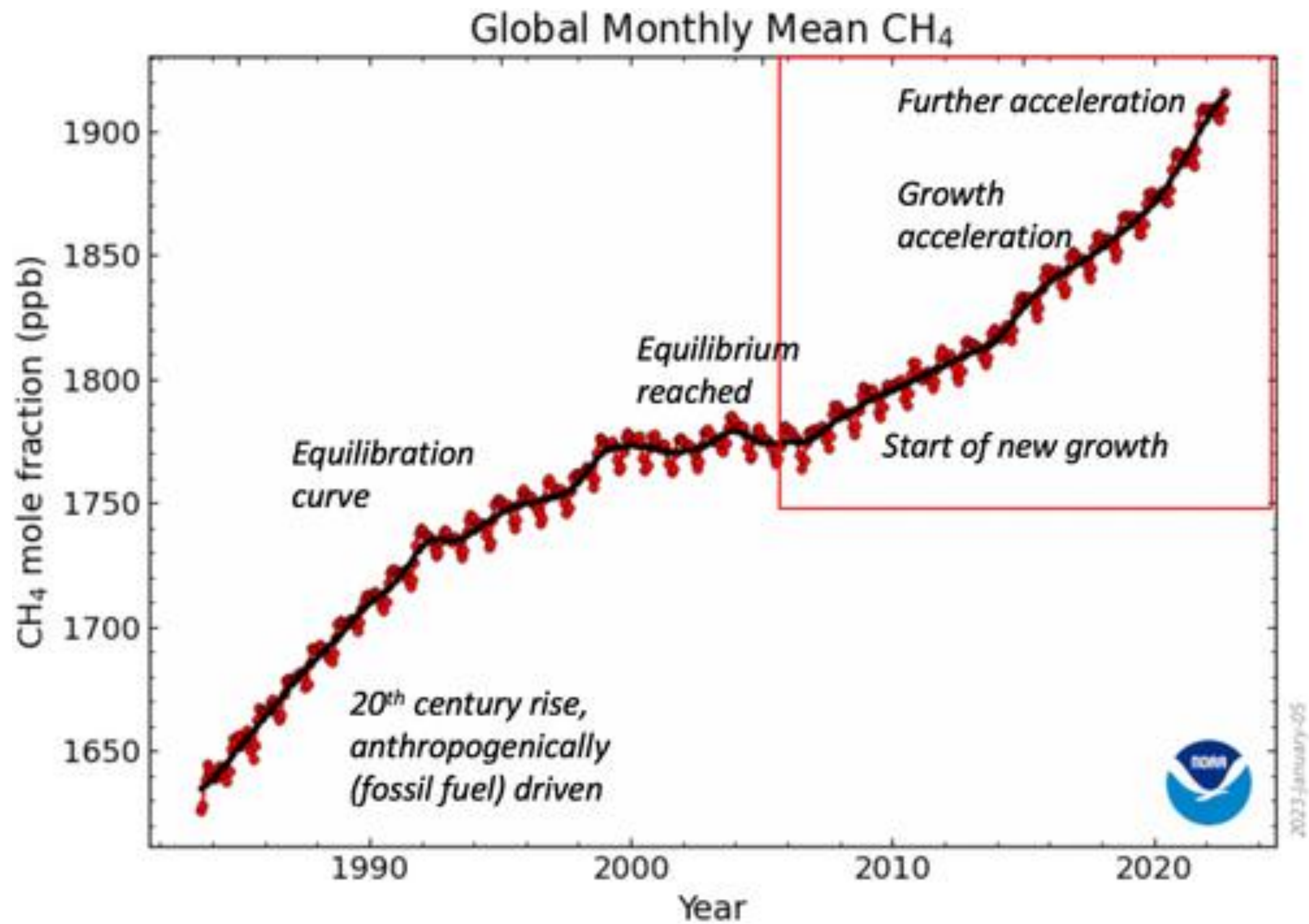
Carbon-cycle climate feedback

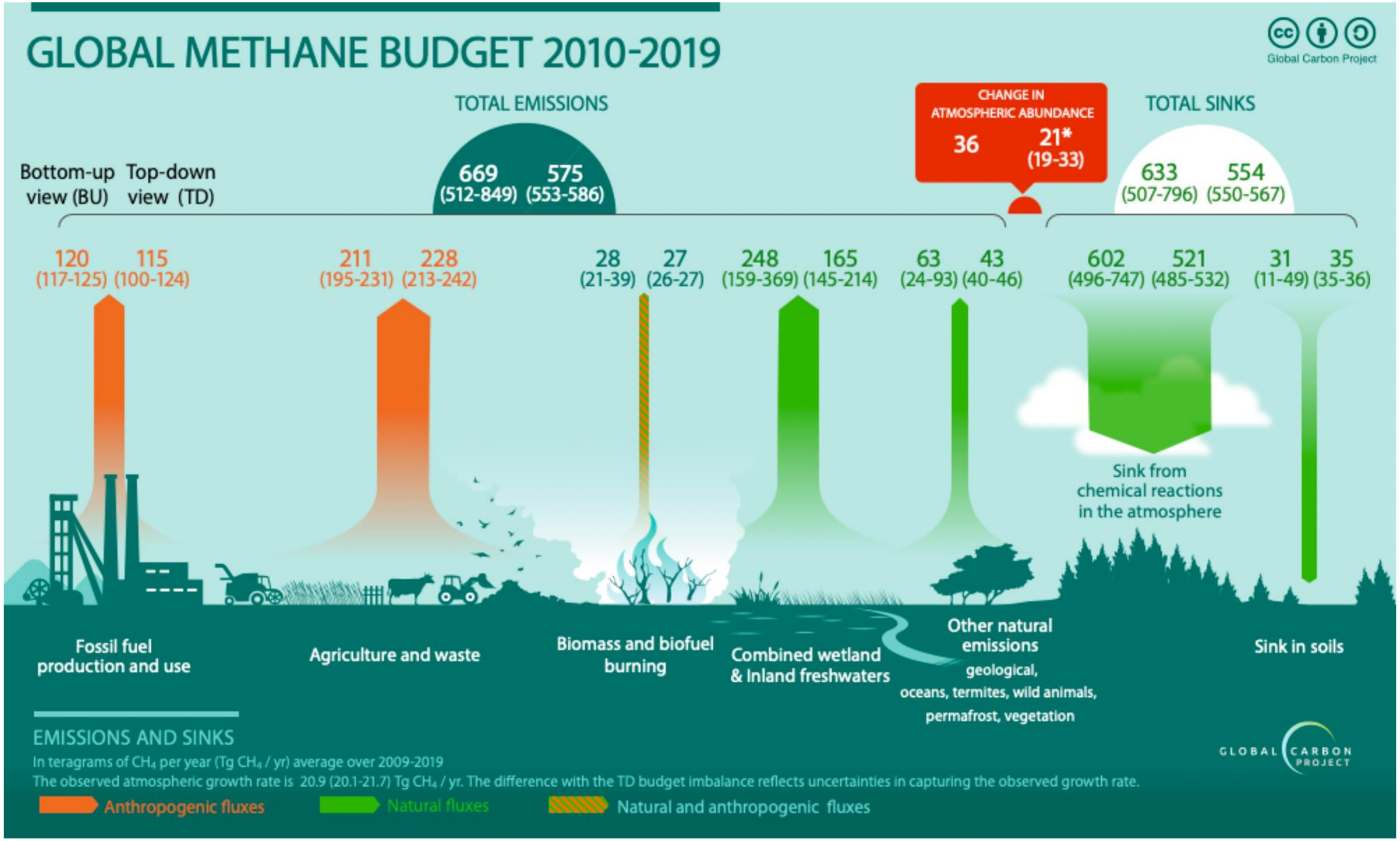


Changes in methane concentration

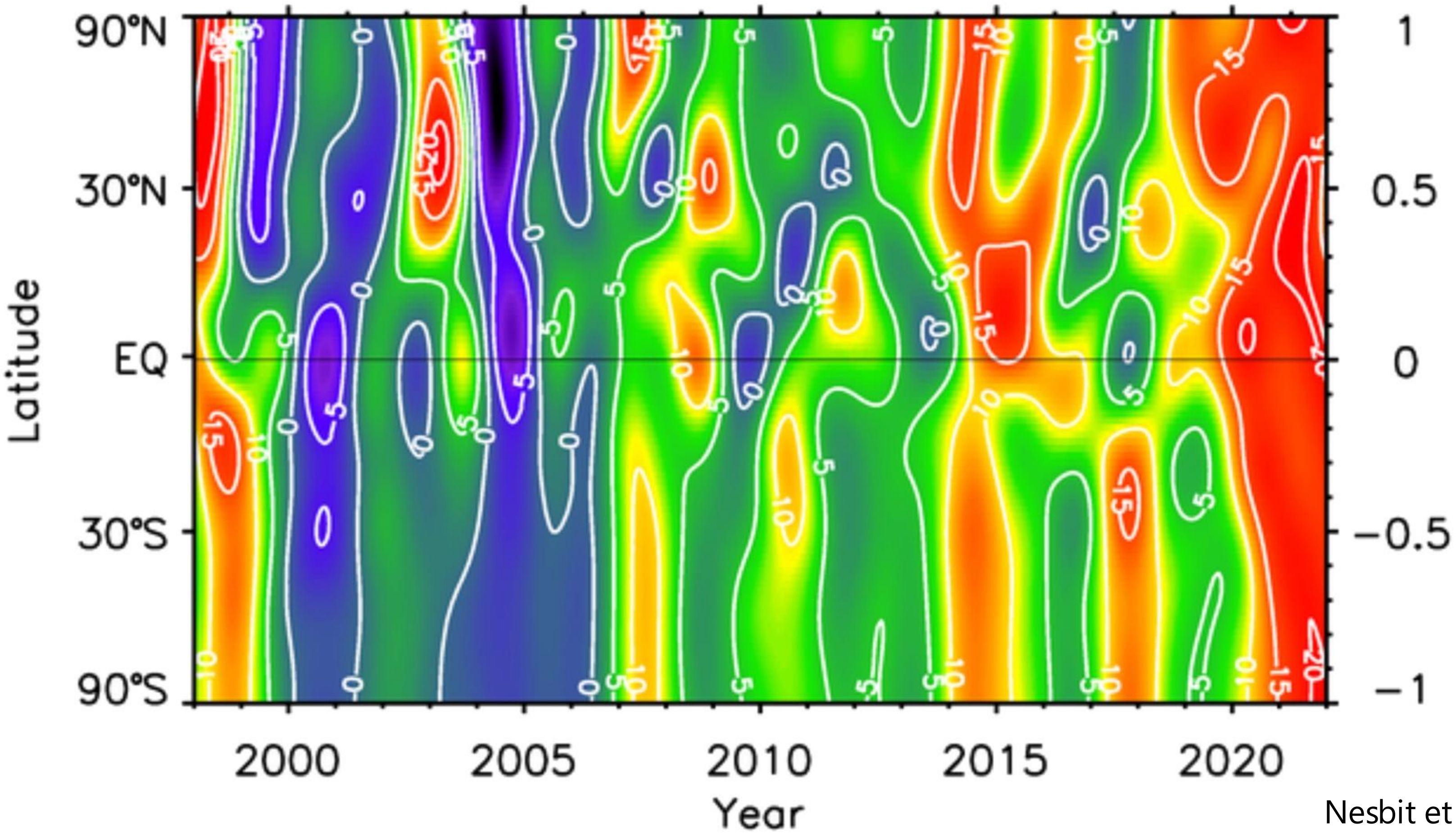


Nesbit et al. (2023) GBC

The global CH_4 budget



Methane sine-latitude growth plot - NOAA



Nesbit et al. (2023) GBC

What's driving the renewed growth in CH_4?

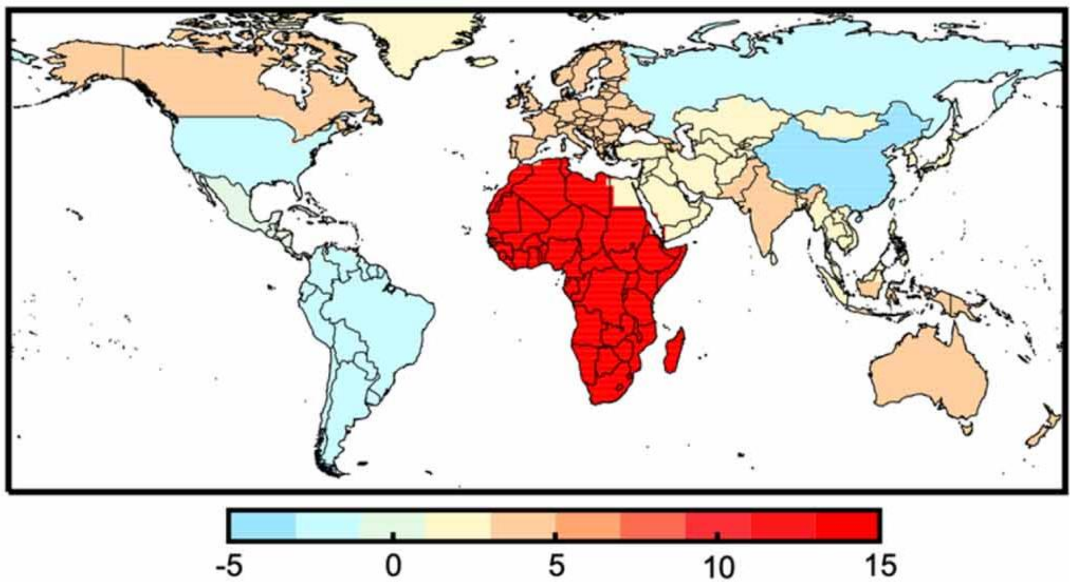
- Total annual CH_4 emissions from human activities increased by 20% in the past two decades (2000-2020) and have continued to increase to 2022.

- Between the early 2000s and the late 2010s, all major sectors of anthropogenic CH_4 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 <u>part</u>** of the recent methane growth

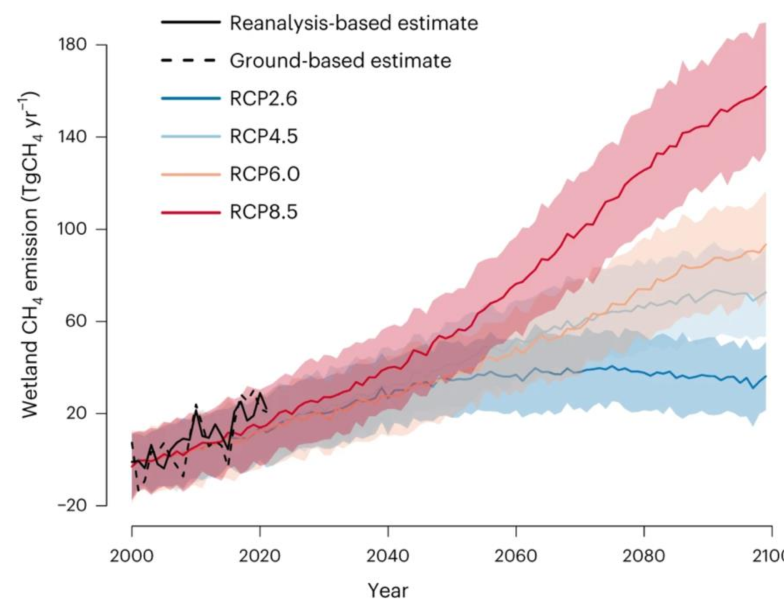
Wetlands likely a key player in the renewed growth rate

(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



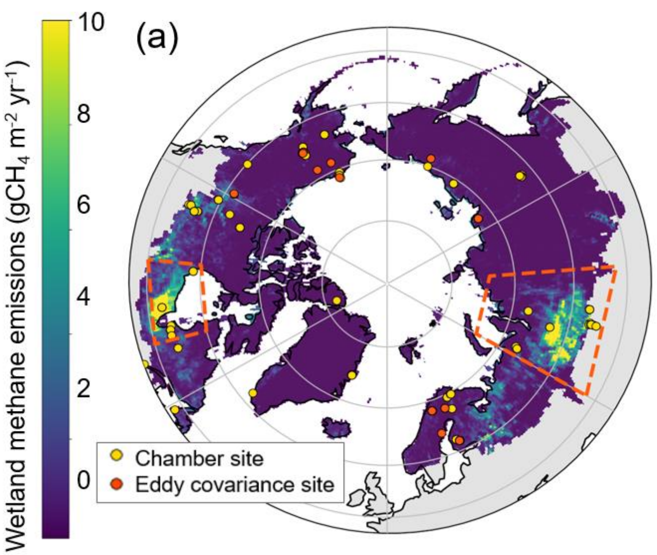
Brief Communication
https://doi.org/10.1038/s41558-023-01629-0

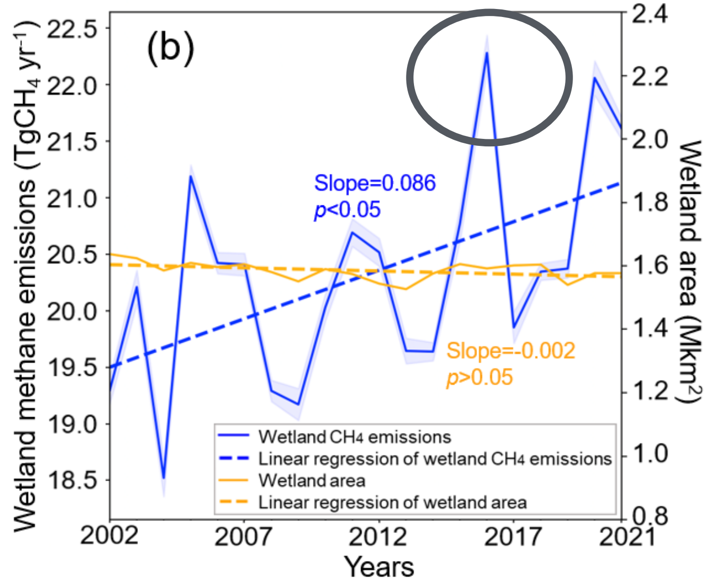
Recent intensification of wetland methane feedback

Received: 7 September 2022
Accepted: 10 February 2023

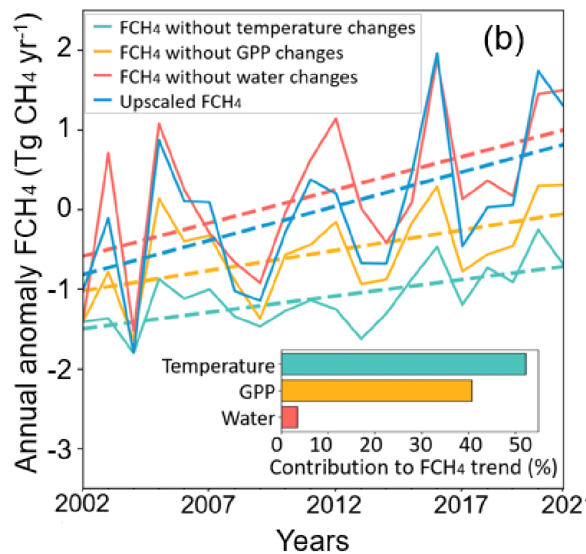
Zhen Zhang[1,2], Benjamin Poulter[3], Andrew F. Feldman[3,4], Qing Ying[2], Philippe Ciais[5], Shushi Peng[6] & Xin Li[1]

Increasing trend of CH_4 emissions from Boreal and Arctic wetlands





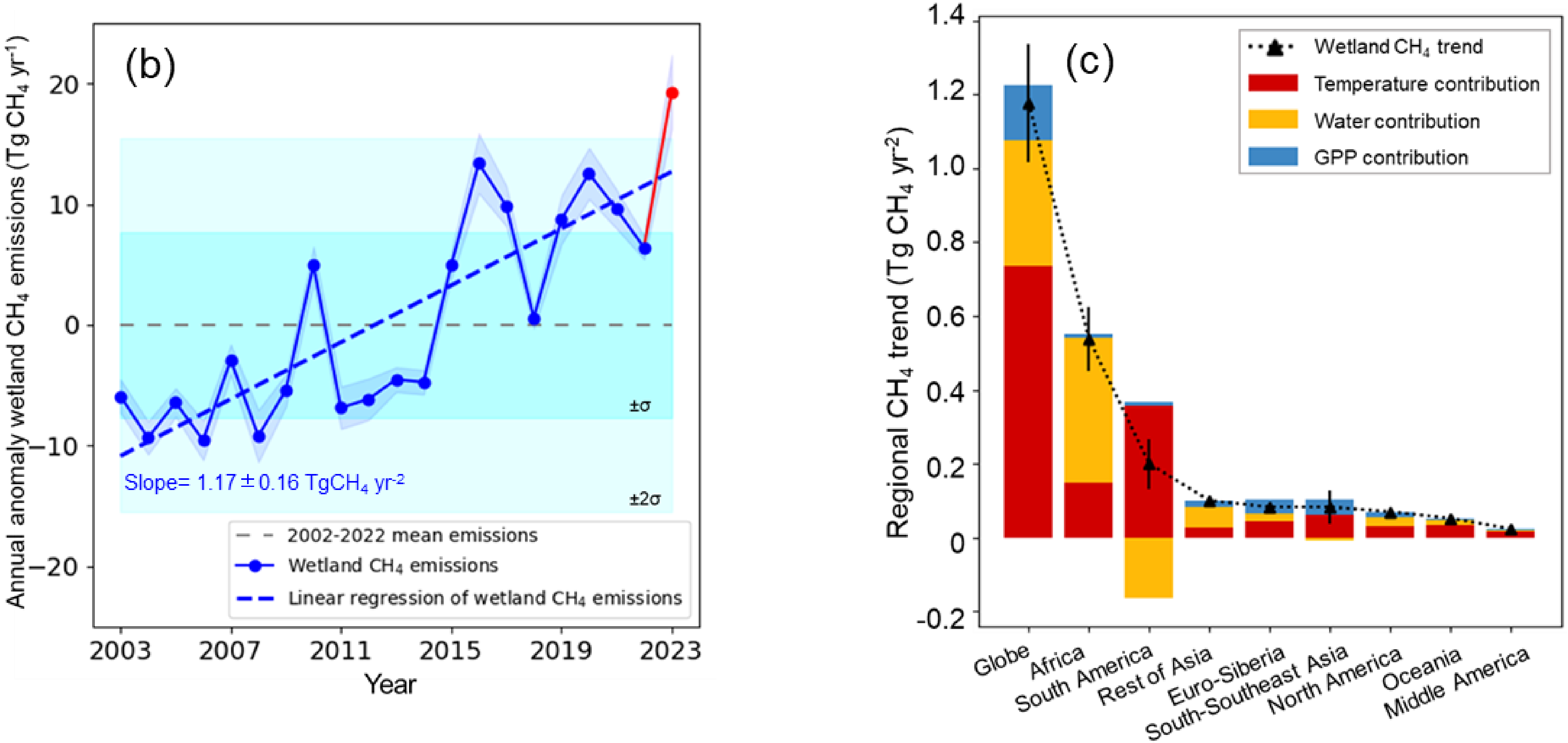
A robust increasing trend of CH_4 emissions (+8.9%) with strong inter-annual variability



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

Yuan et al. (2024) NCC

Africa seems to dominates the long-term increase in global wetland CH_4 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

How can ecosystems help with climate change mitigation and adaptation?

Natural Climate Solutions

The Guardian

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.

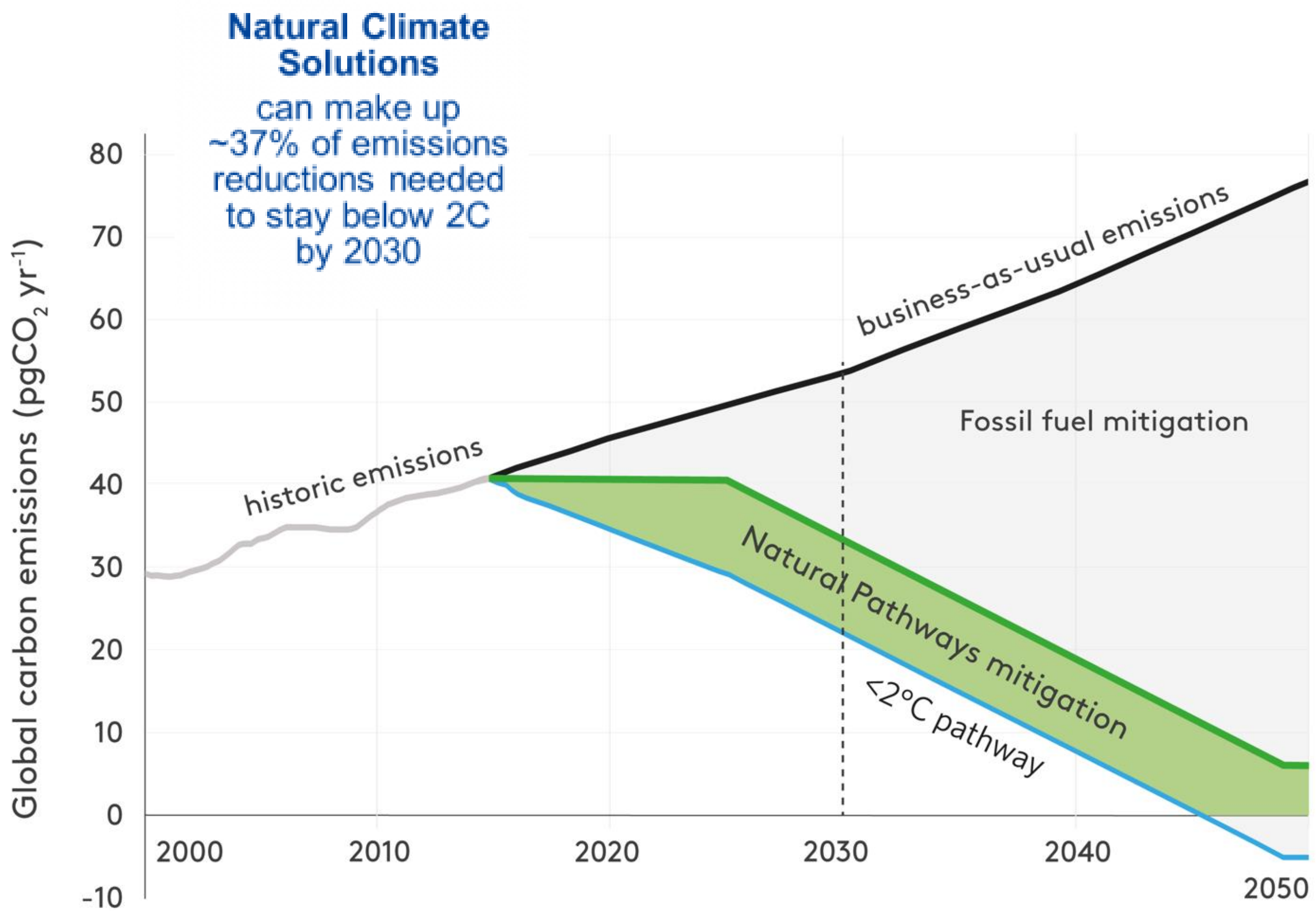
Forests

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

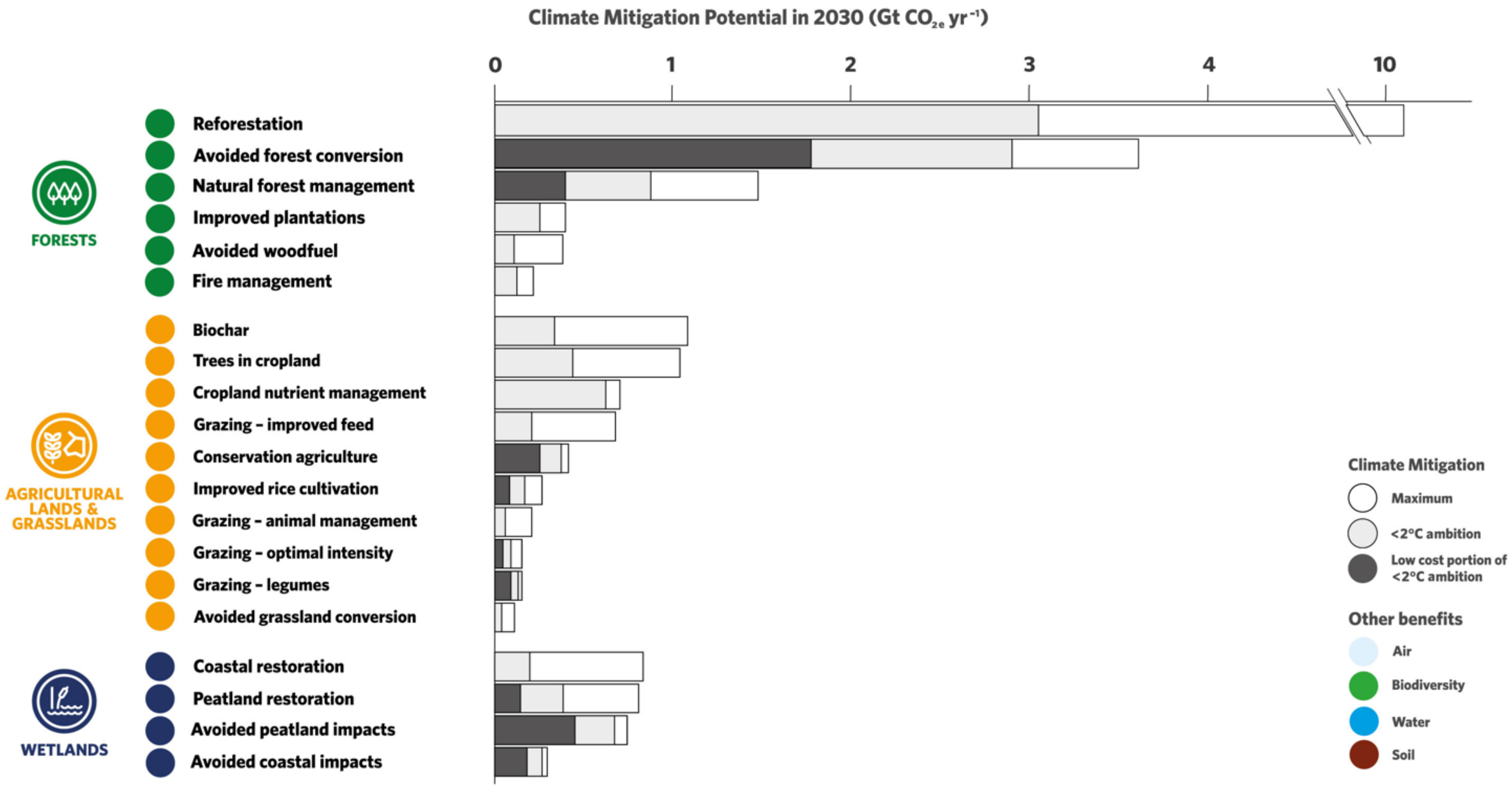
Can you think of 2 specific examples of Natural Climate Solutions?

Forests

Grasslands & Agriculture

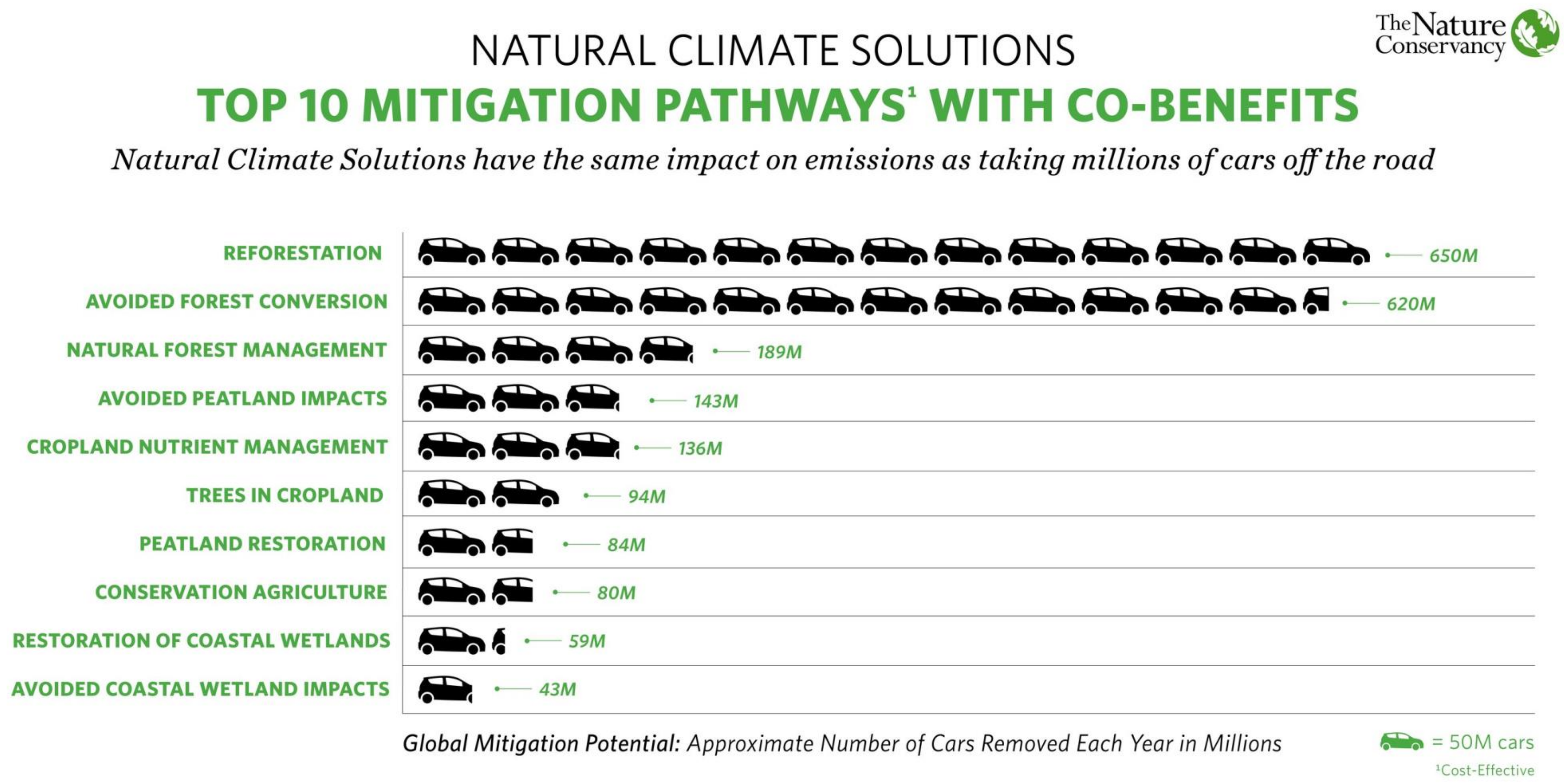
Wetlands

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



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

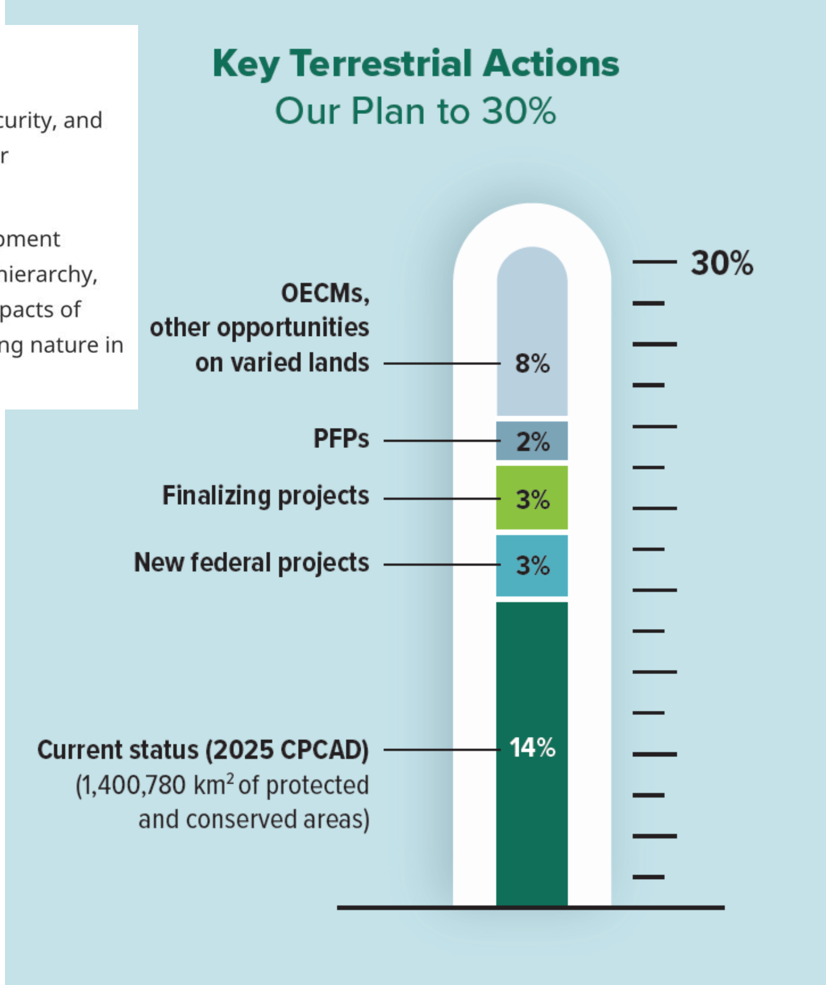
Cost effective & numerous co-benefits

NCS in Canada

Pillar 2: Building Canada Well

Nature underpins much of our economic prosperity and climate action. It is essential to Canada's growth, security, and nation-building. When conservation and economic activities are seen as competing priorities this risks weaker conservation outcomes and project delays. However, these goals need not be at odds.

As part of our second pillar, Canada will integrate its nature and economic agendas to support timely development decisions while protecting nature. This work will be informed by science and proven tools like the mitigation hierarchy, which is a structured approach to avoiding, minimizing, mitigating, and then offsetting the environmental impacts of development. Nature-based solutions are one tool that can help us meet our goals, by protecting and restoring nature in ways that also strengthen climate adaptation and mitigation.



https://www.canada.ca/en/services/environment/nature/nature-strategy.html

NCS in Quebec

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

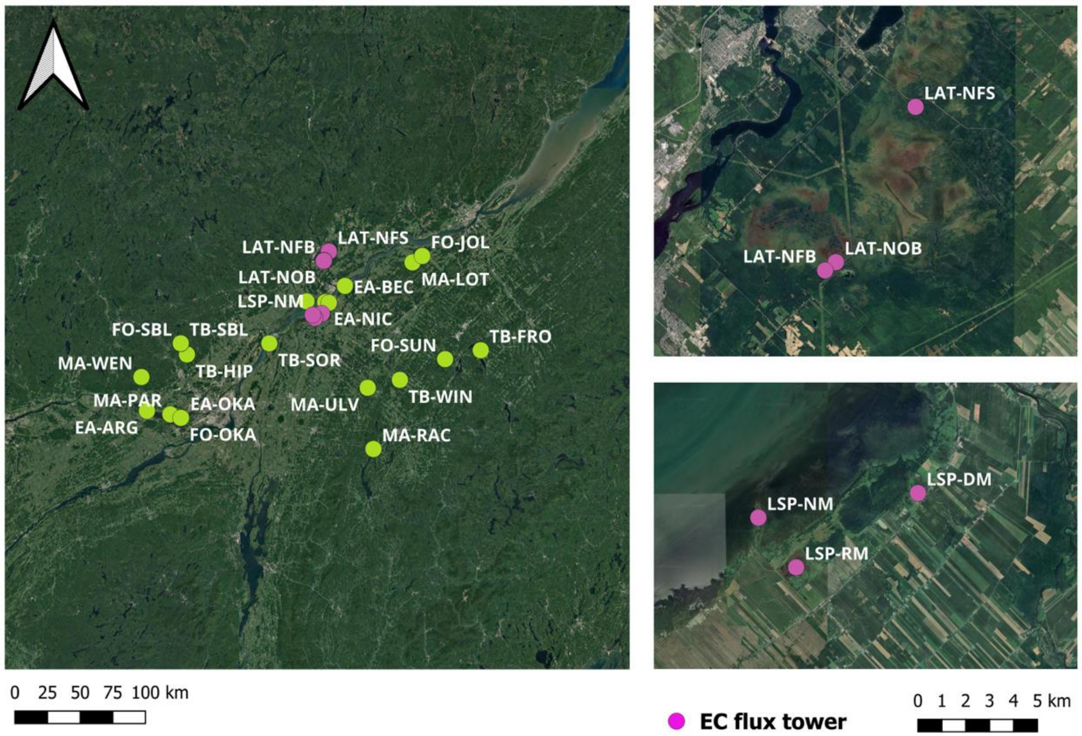
Milieux naturels et réservoir de carbone		
Axes d'intervention	**Objectifs**	**Mesures**
Conserver nos milieux naturels	1.11 : Éviter la destruction et la dégradation de nos réservoirs de carbone	1.11.1 Conserver les milieux naturels prioritaires
Valoriser le rôle des milieux naturels dans la protection 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

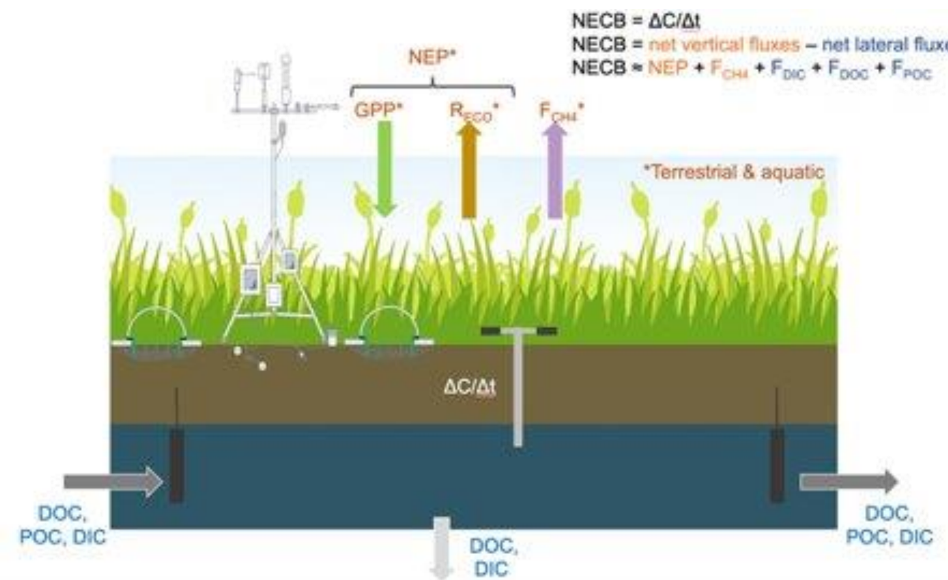
https://www.environnement.gouv.qc.ca/changementsclimatiques/air-pmo-pev-202101.pdf

Votre gouvernement

Québec

CARBONIQUE





https://carbonique.ca/

UQÀM

UQTR Université du Québec à Trois-Rivières

Environnement, Lutte contre les changements climatiques, Faunes et Parcs

Québec

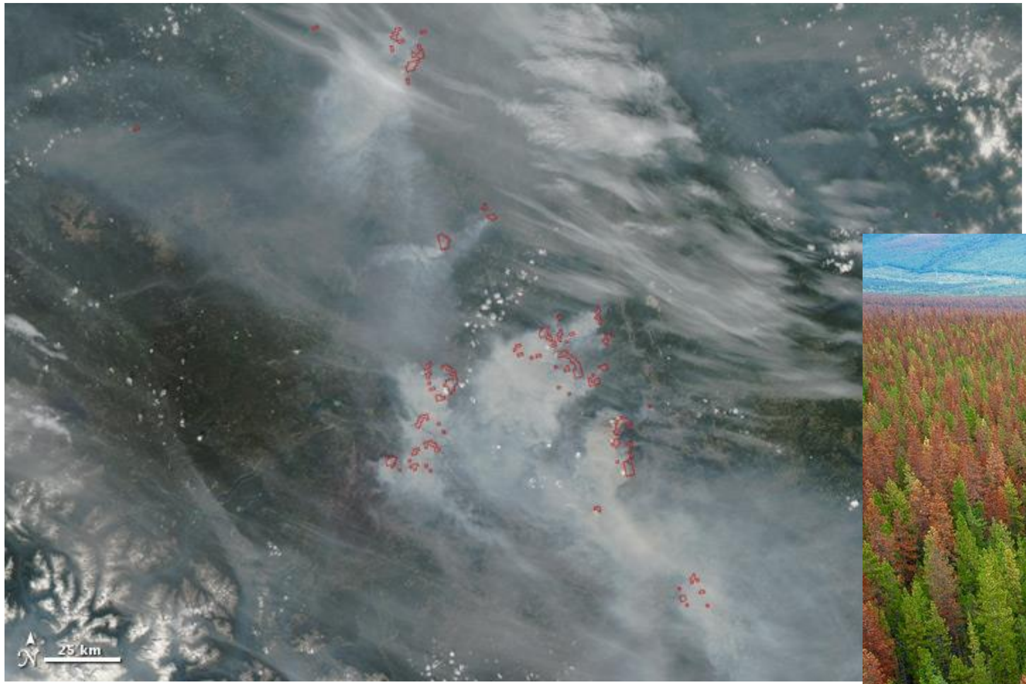
Université de Montréal

Université Laval

CARBONIQUE

Identify one strength and one limitation of NCS

Advantages & disadvantages of NCS?



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

Credit: Matthew Brown

Take home points

- Of the CO_2 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)

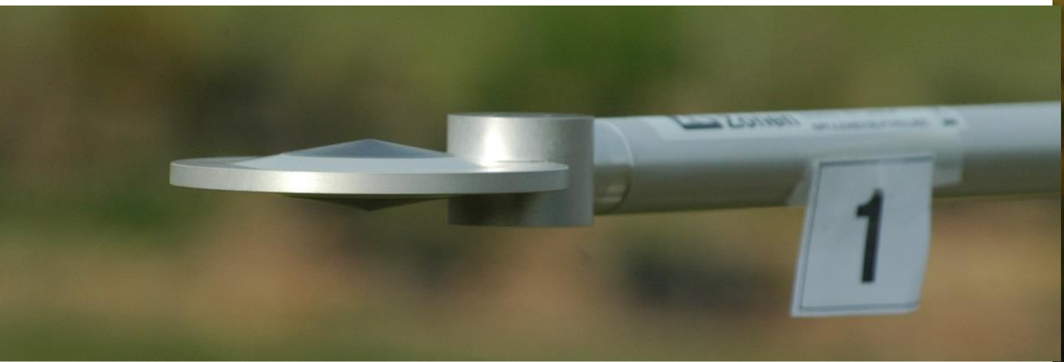
✓You can **model soil climates** in simple conditions and describe transfer in laminar boundary layers.

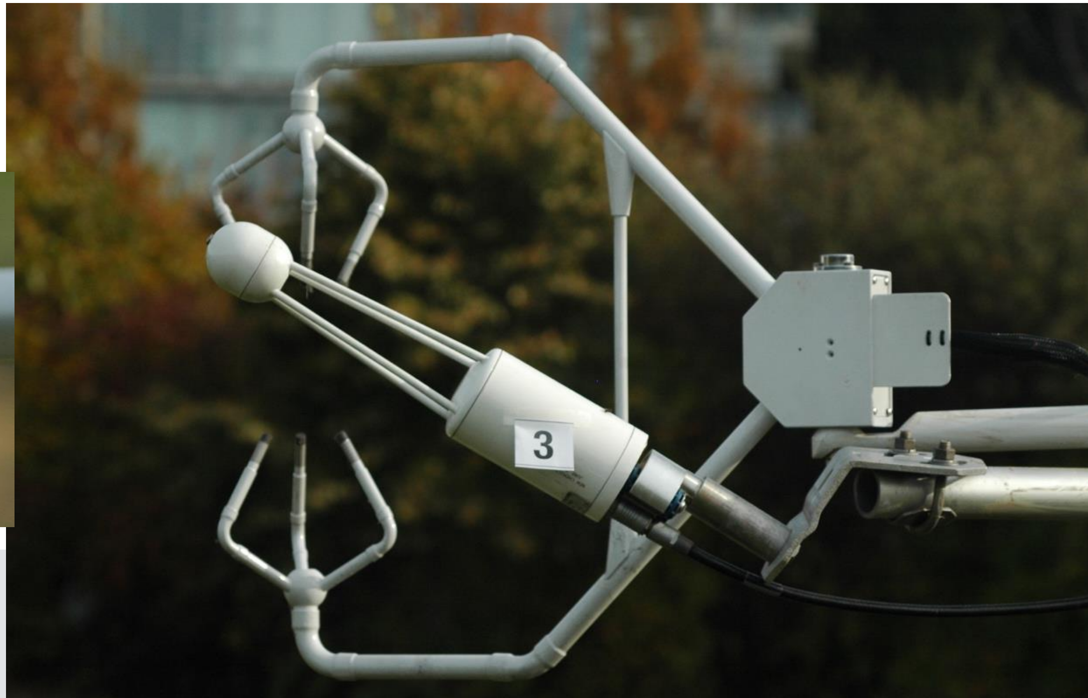
✓ Understanding the **nature of wind and turbulence** in the ABL. Describe turbulent transfer of mass, momentum and energy (wind and temperature profiles, dynamic stability, gradient approaches, entrainment)

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 <u>improve</u>** 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!**