Photo: A. Christen

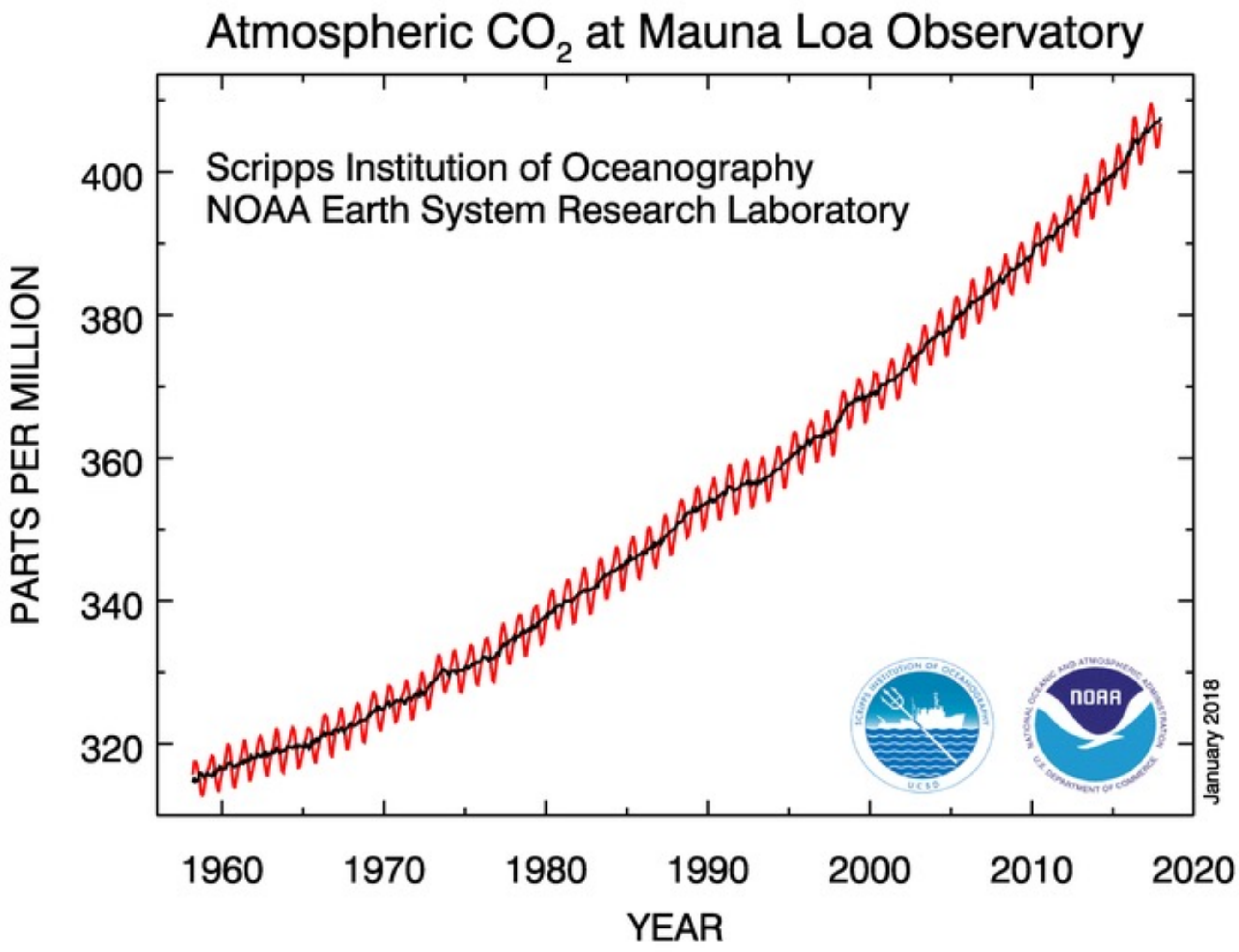
32 Land-atmosphere interactions in a changing climate

## Learning objectives

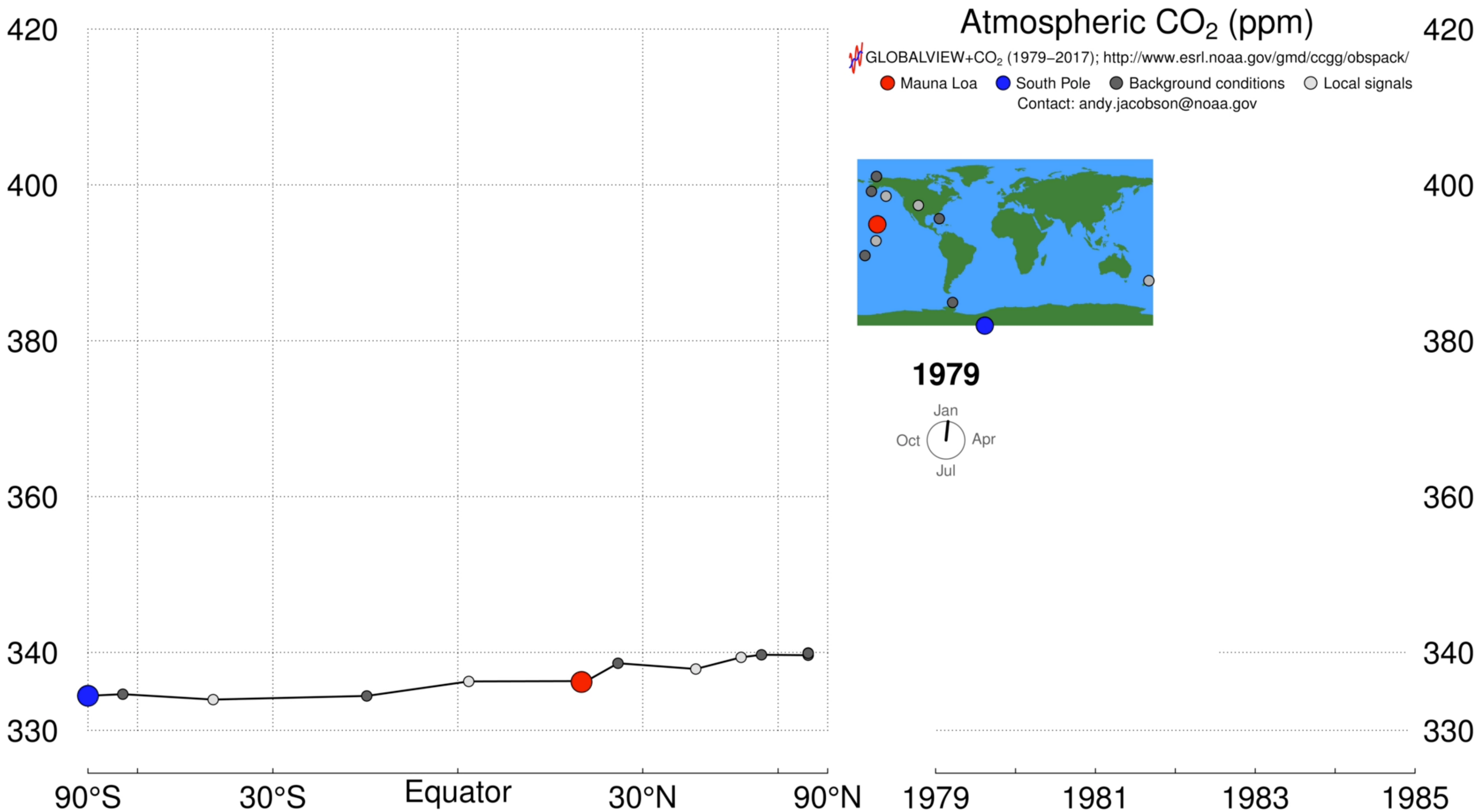
- Describe how ecosystem-scale carbon fluxes respond to a changing climate.
- Give two examples of positive and/or negative feedbacks between land-surfaces and the climate system.
- Explain how we can we modify land management practices for climate change mitigation & adaptation.

Photo: J. Verfaillie

# Rising $CO_2$ concentrations

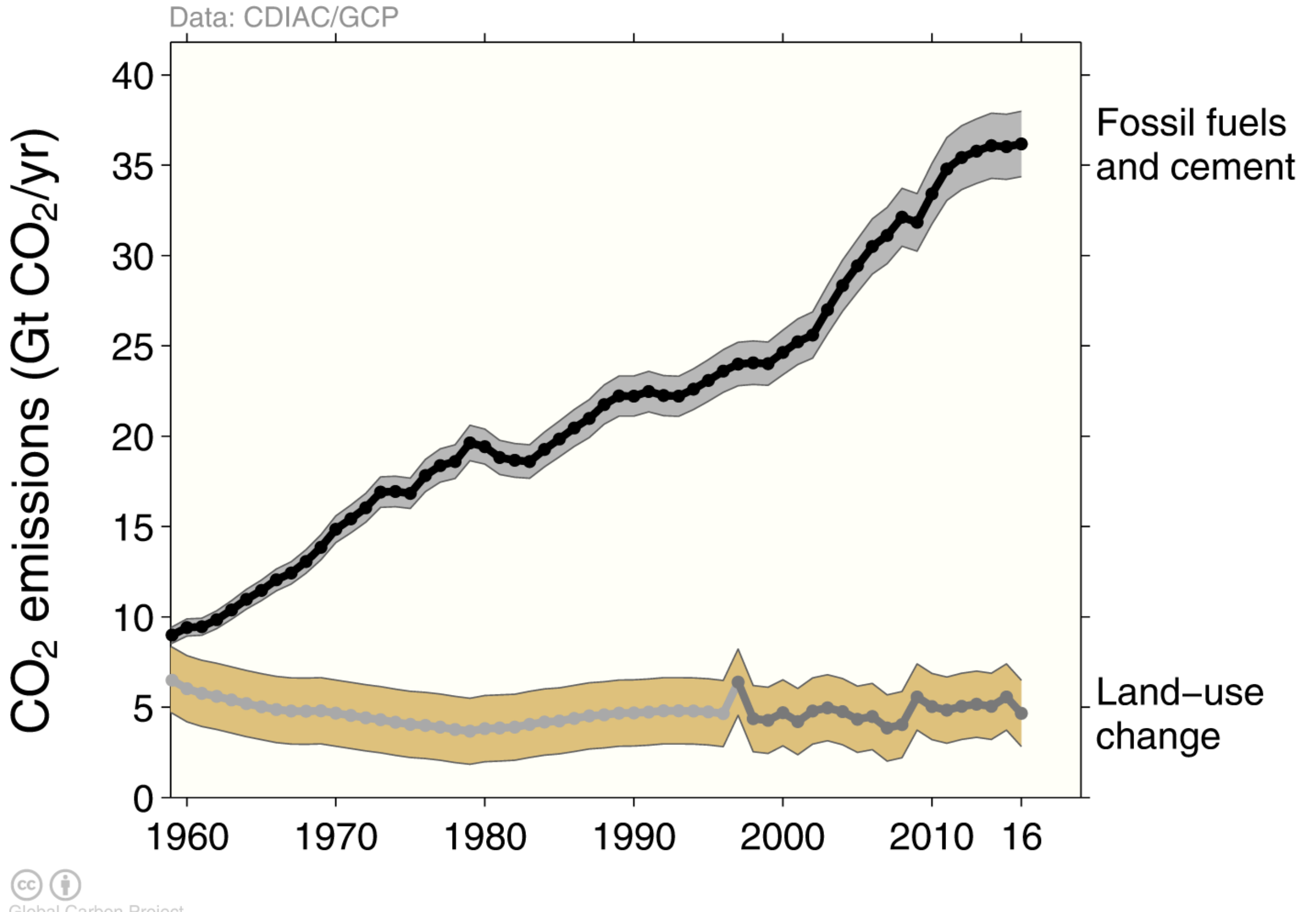


# Rising $CO_2$ concentrations animation




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

# $CO_2$ sources




Source: CDIAC; Houghton and Nassikas 2017; Hansis et al 2015; van der Werf et al. 2017; Le Quéré et al 2017; Global Carbon Budget 2017

# Where does the $CO_2$ go?

# Terrestrial ecosystems are key components of the global carbon cycle

## Sources

34.4 $GtCO_2$/yr

88%

12%

4.8 $GtCO_2$/yr

## Sinks

17.2 $GtCO_2$/yr

46%

24%

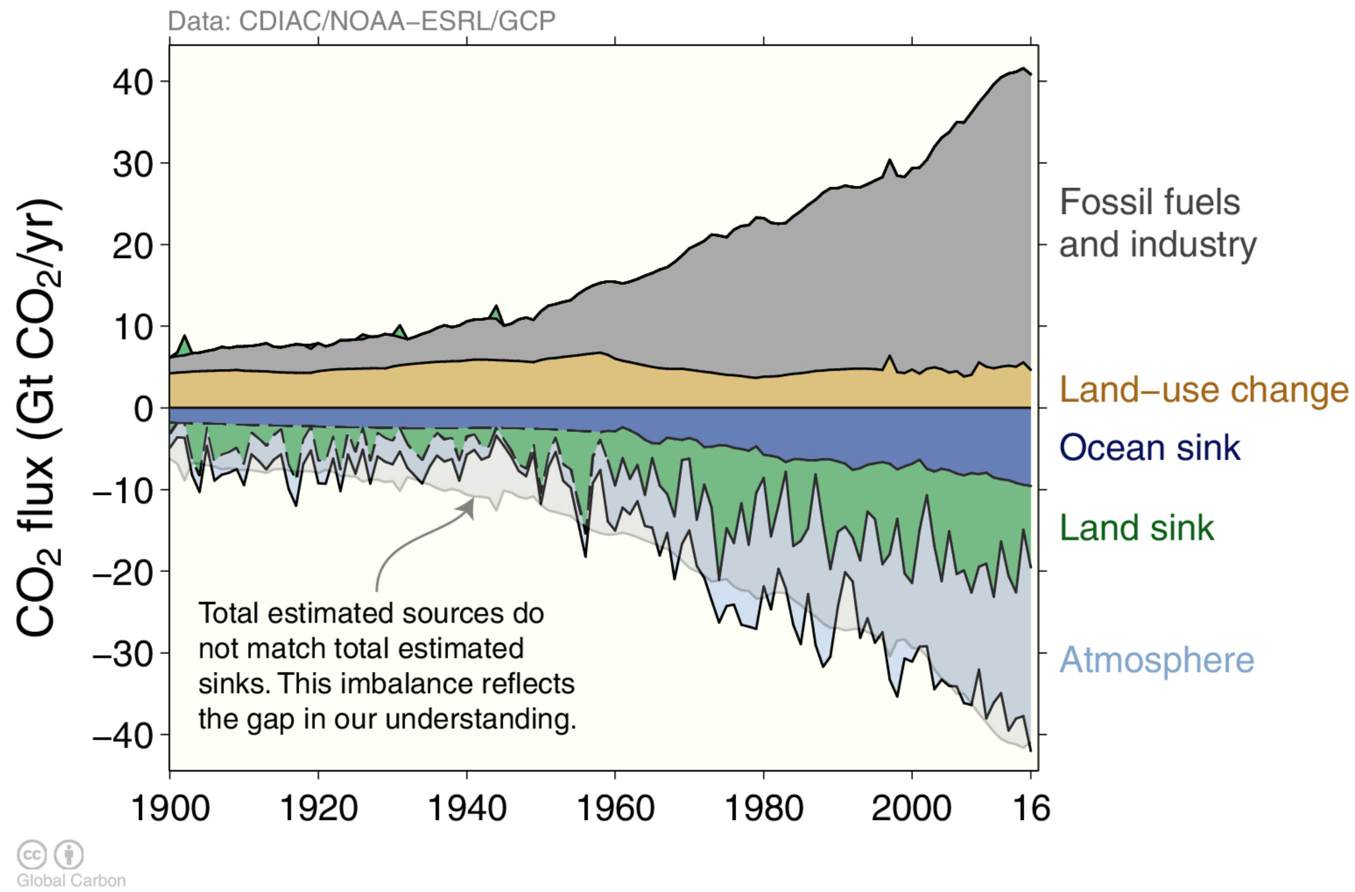
8.8 $GtCO_2$/yr

30%

11.0 $GtCO_2$/yr

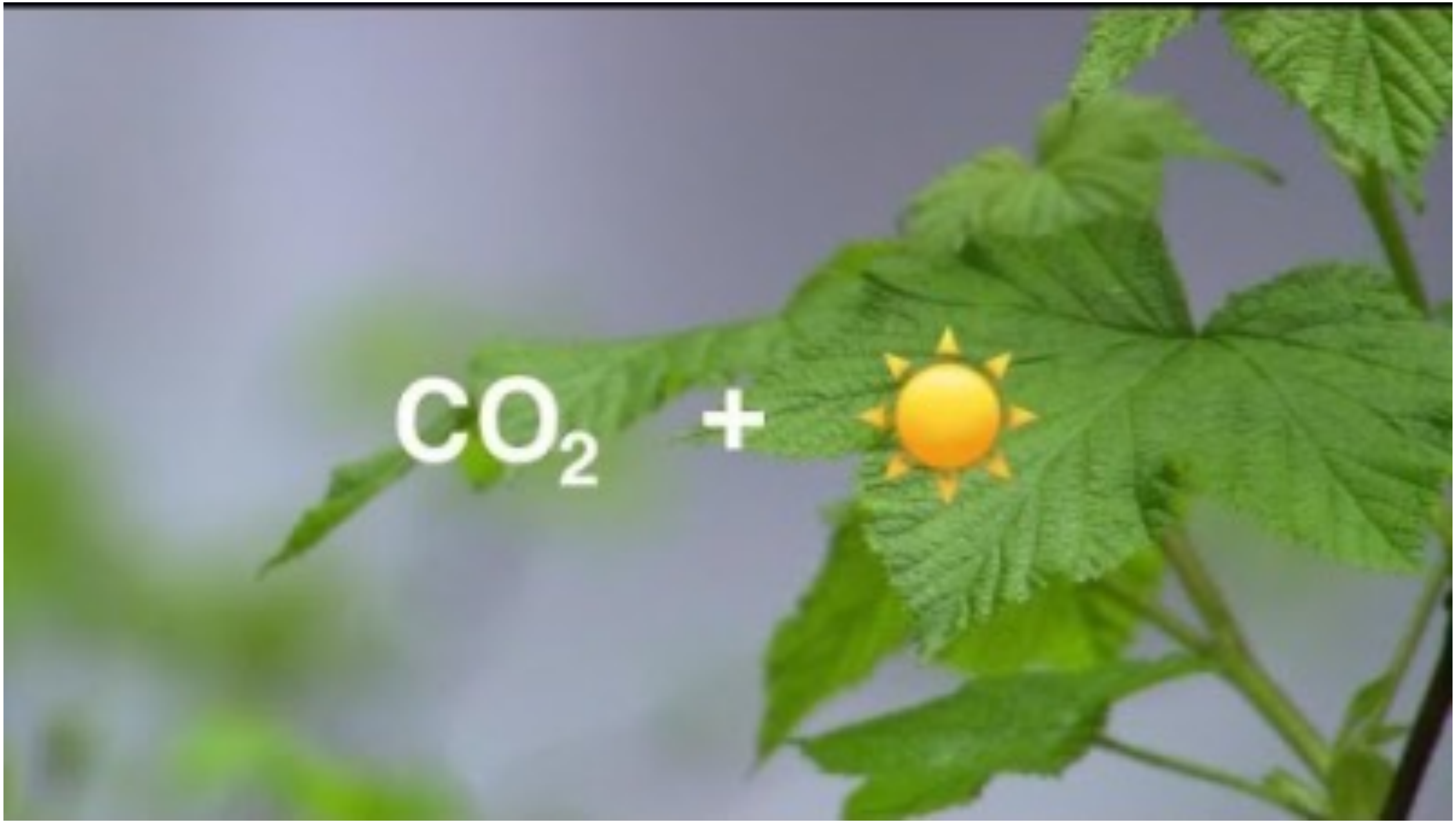
GLOBAL CARBON project

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




Will ecosystems continue to help offset $CO_2$ emissions?

# Land ecosystems might be becoming less efficient at absorbing carbon dioxide



## Radiative forcing

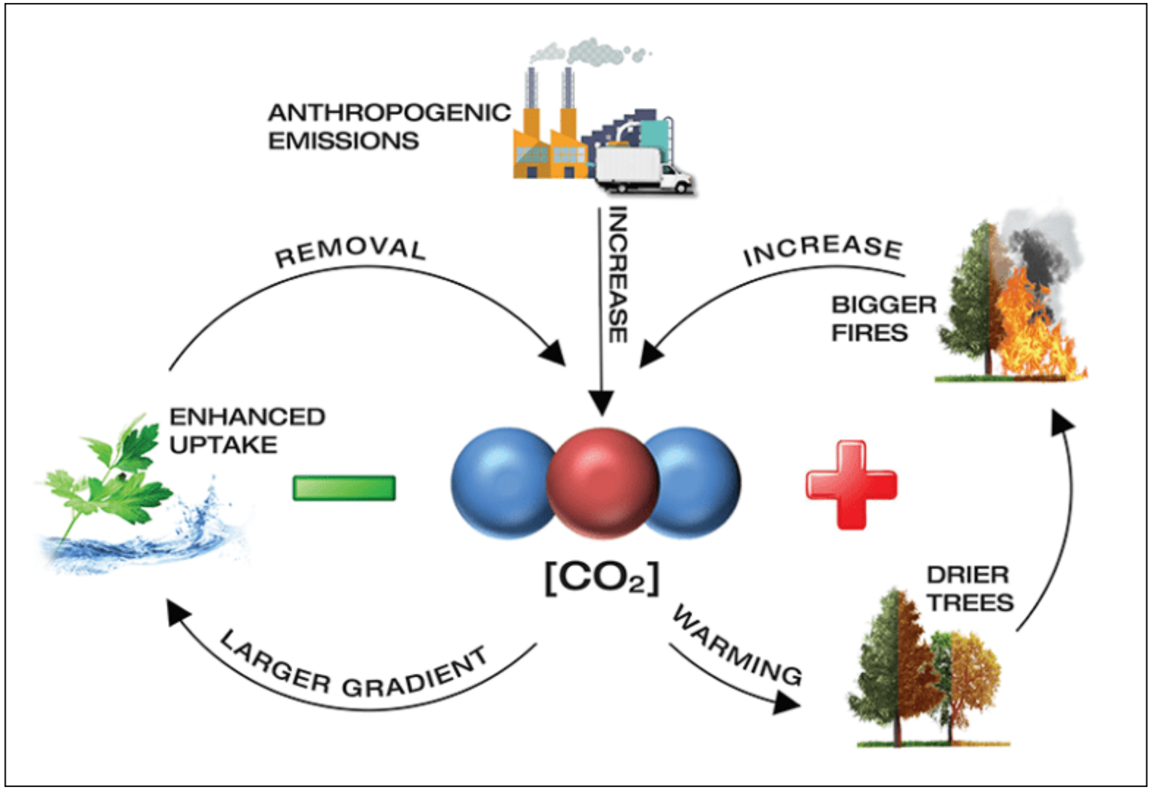
- The difference between incoming and outgoing radiation is known as a planet's radiative forcing (RF)

(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.

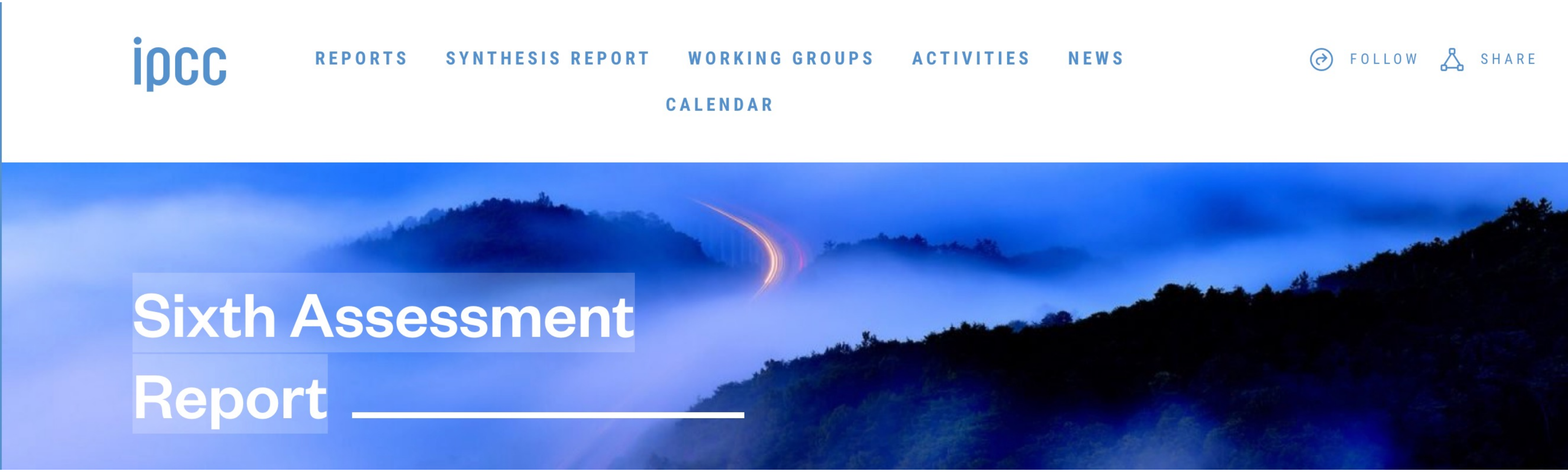
## Feedbacks

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



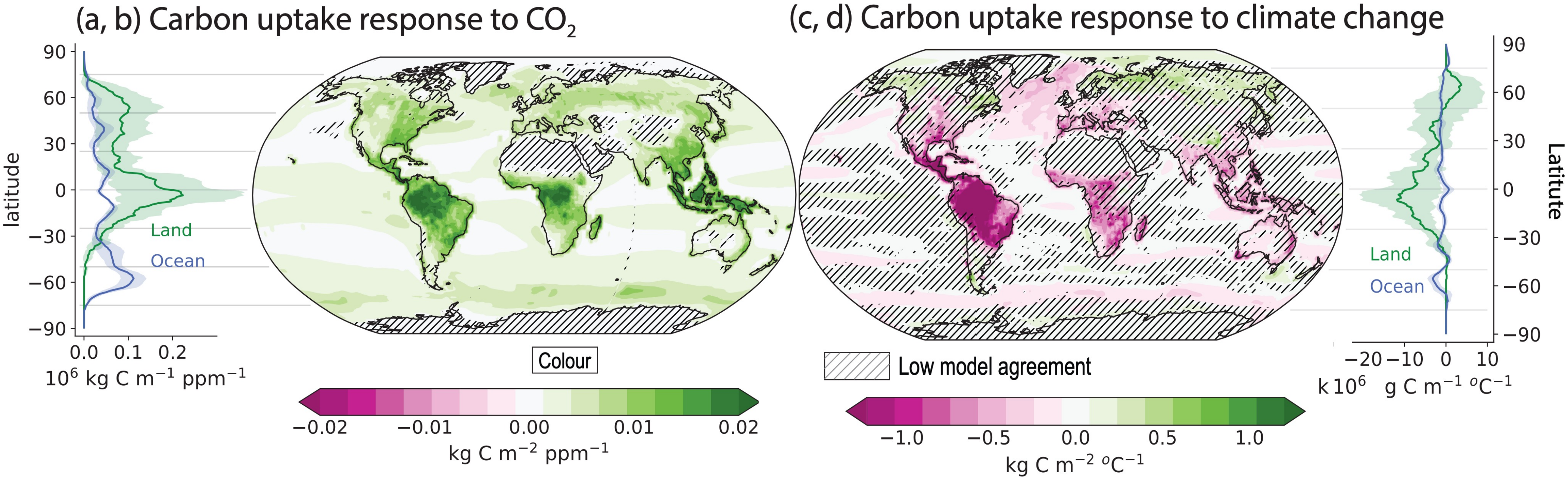

https://eos.org/features/the-future-of-the-carbon-cycle-in-a-changing-climate

# IPCC Synthesis Reports



# Response of ecosystems to rising $CO_2$ & climate warming

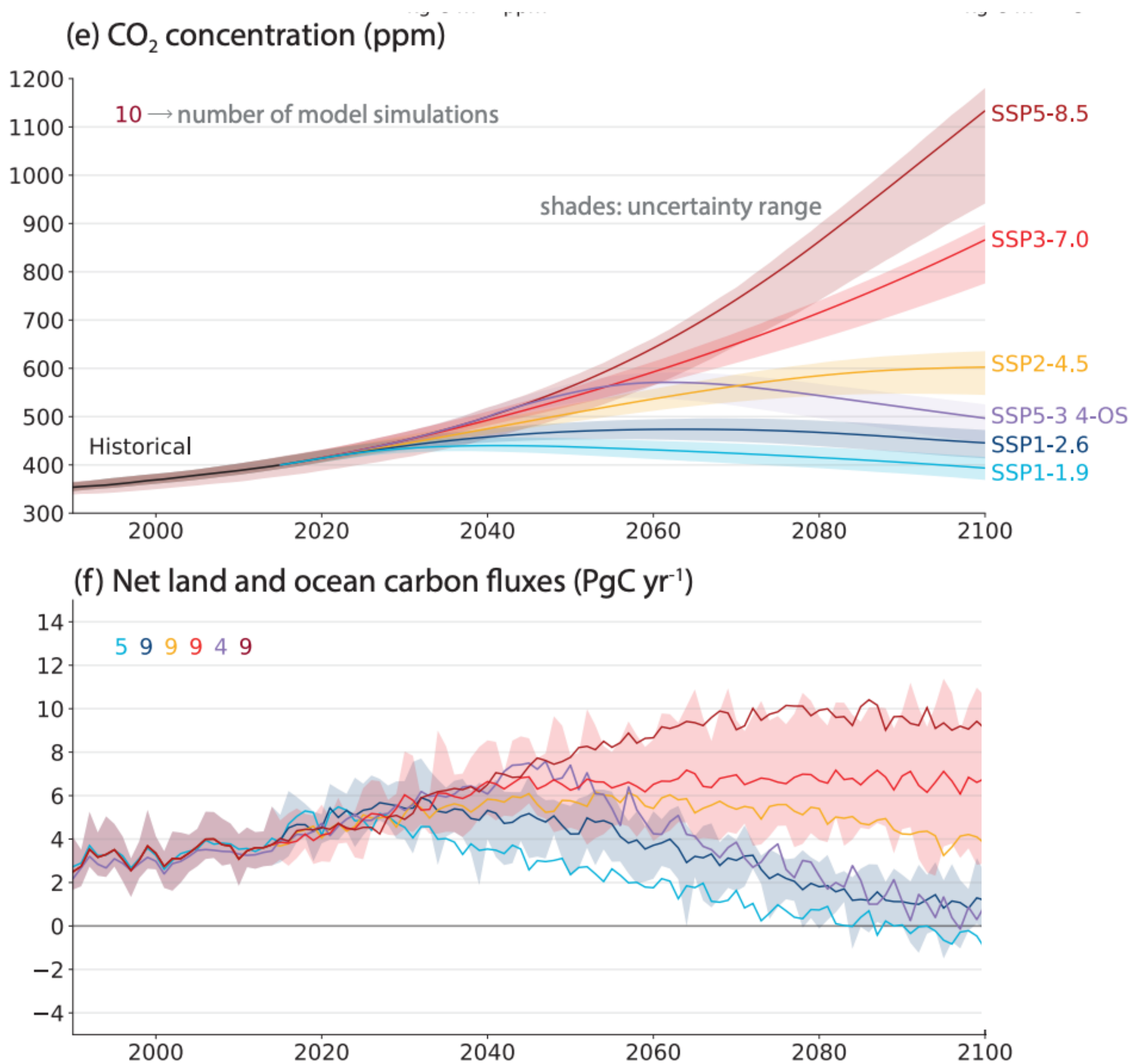
These figures shows changes in carbon storage in response to elevated $CO_2$ (a, b) and the response to climate warming (c, d)



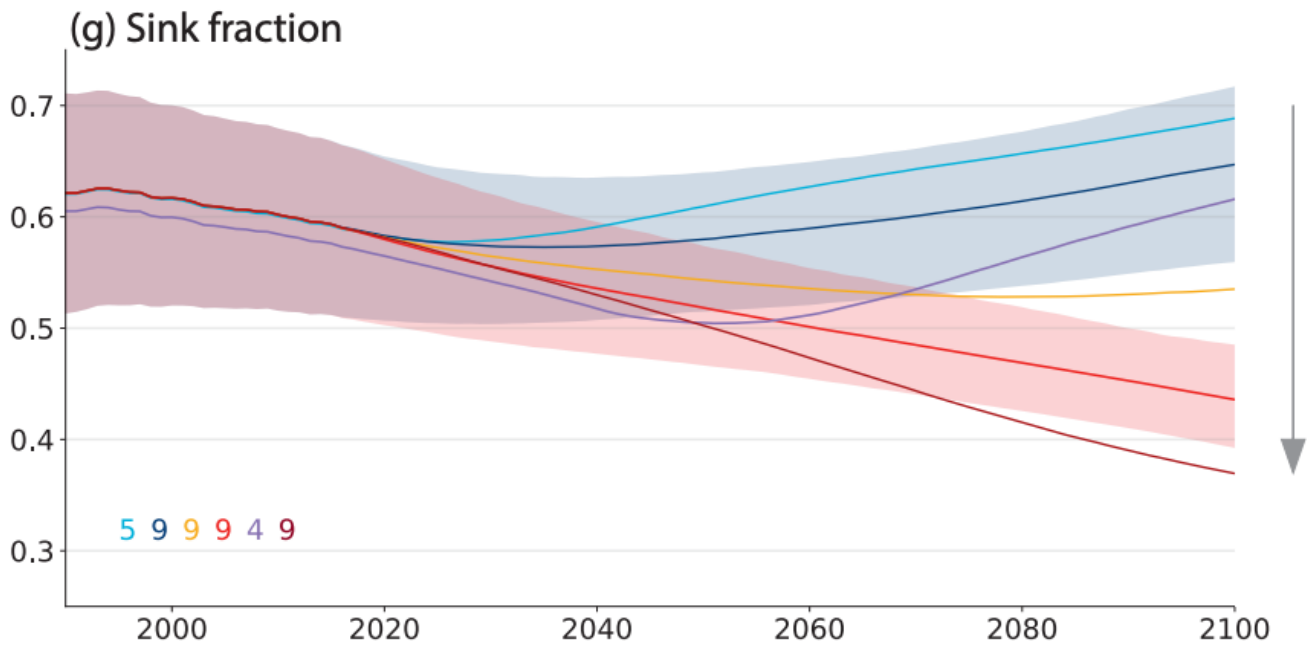

Since the 1980s, carbon fertilization from rising atmospheric $CO_2$ has increased the strength of the net land $CO_2$ sink (medium confidence).

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

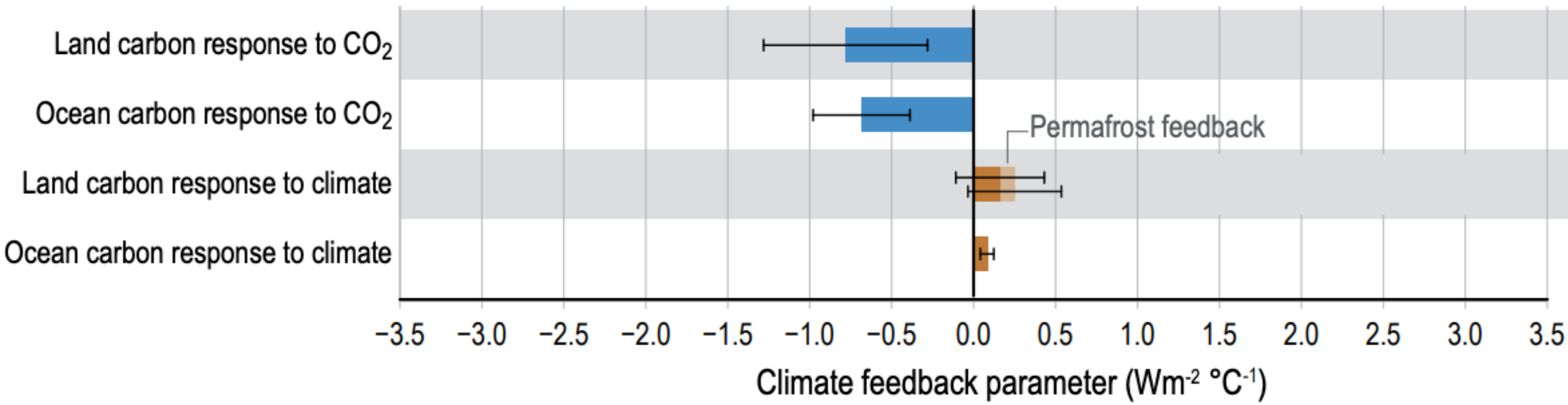


# The future of the land sink




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

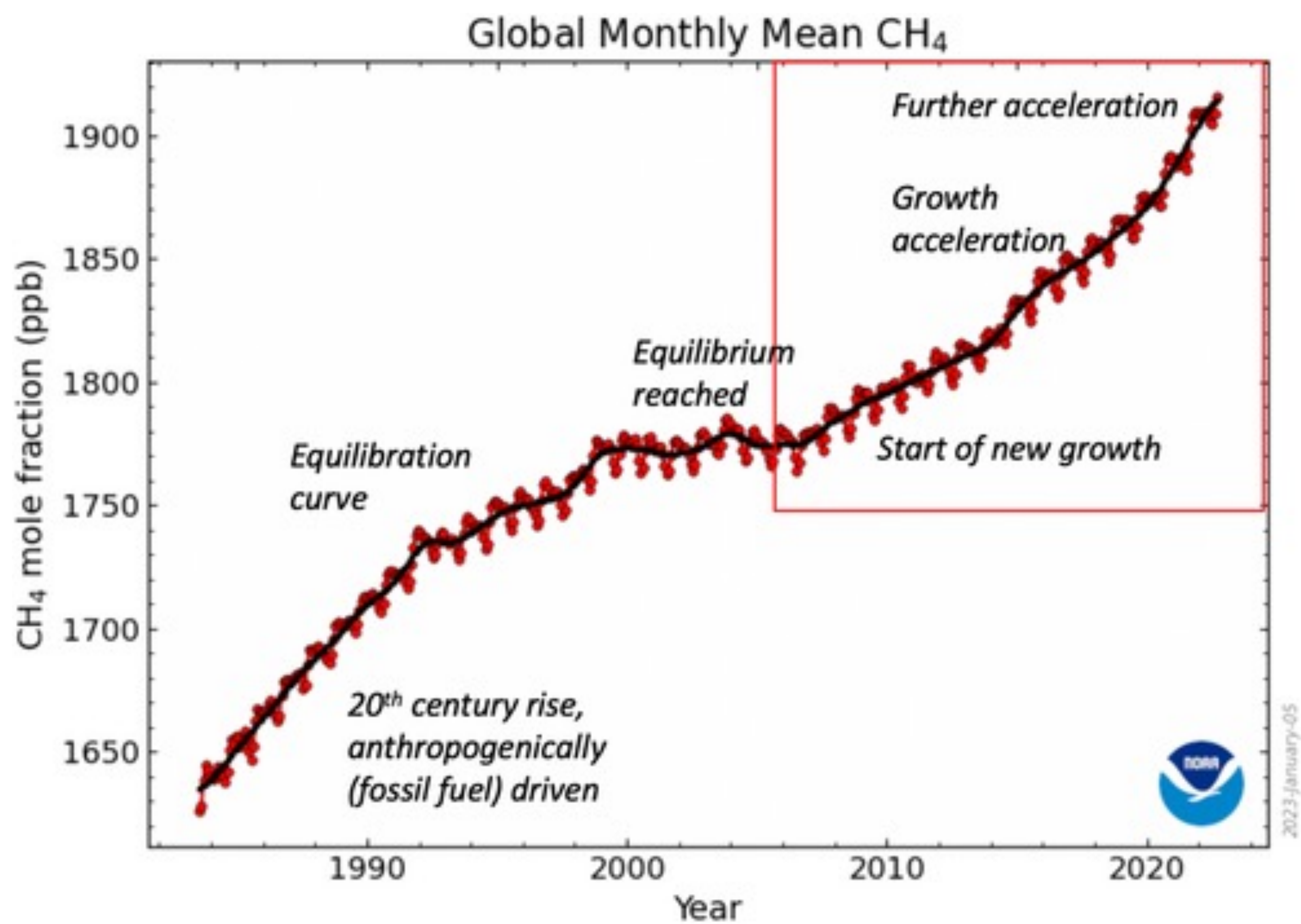


## The land & ocean carbon response to $CO_2$ is a:

A) Positive climate feedback

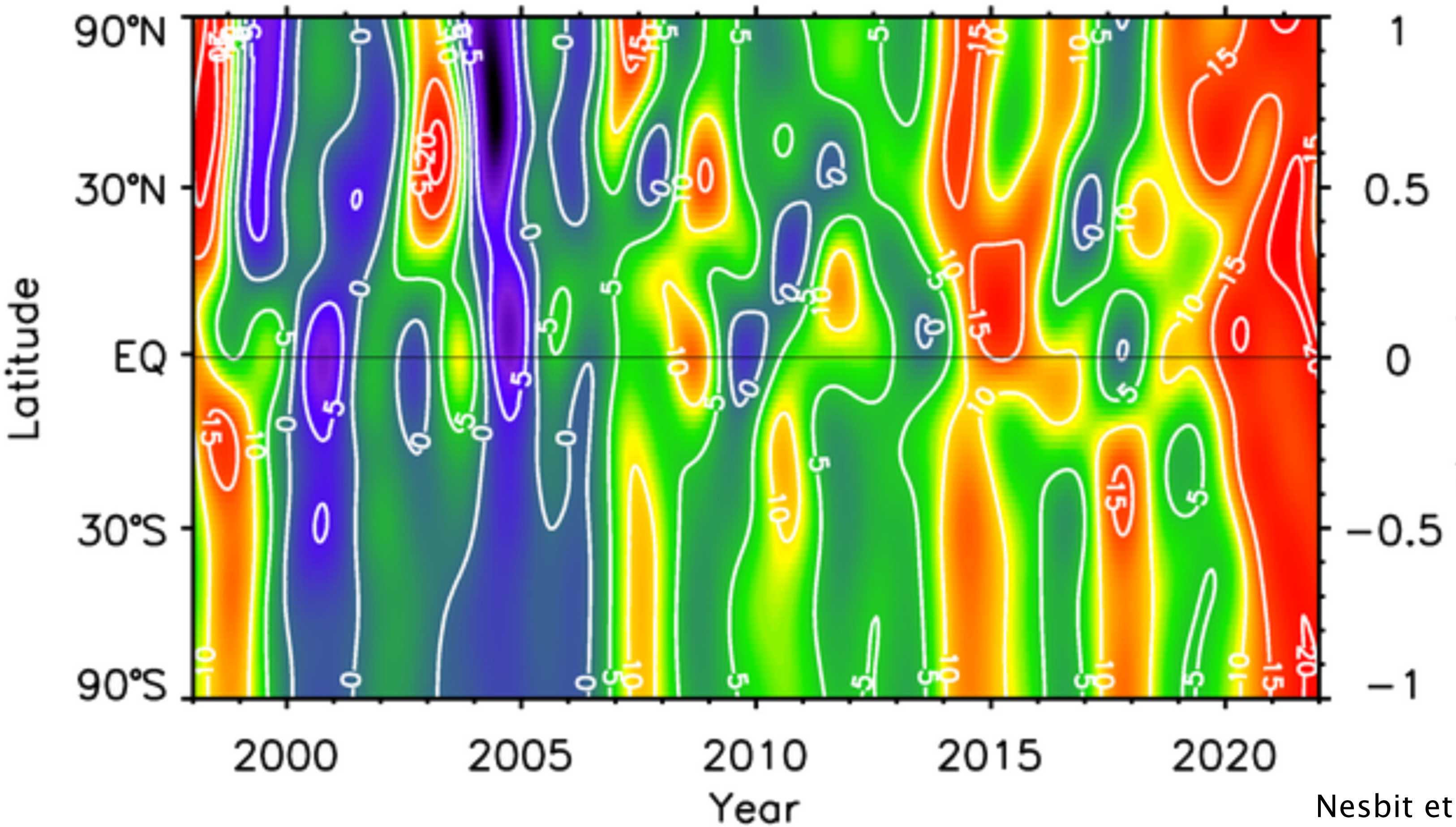
B) Negative climate feedback

# Changes in methane concentration



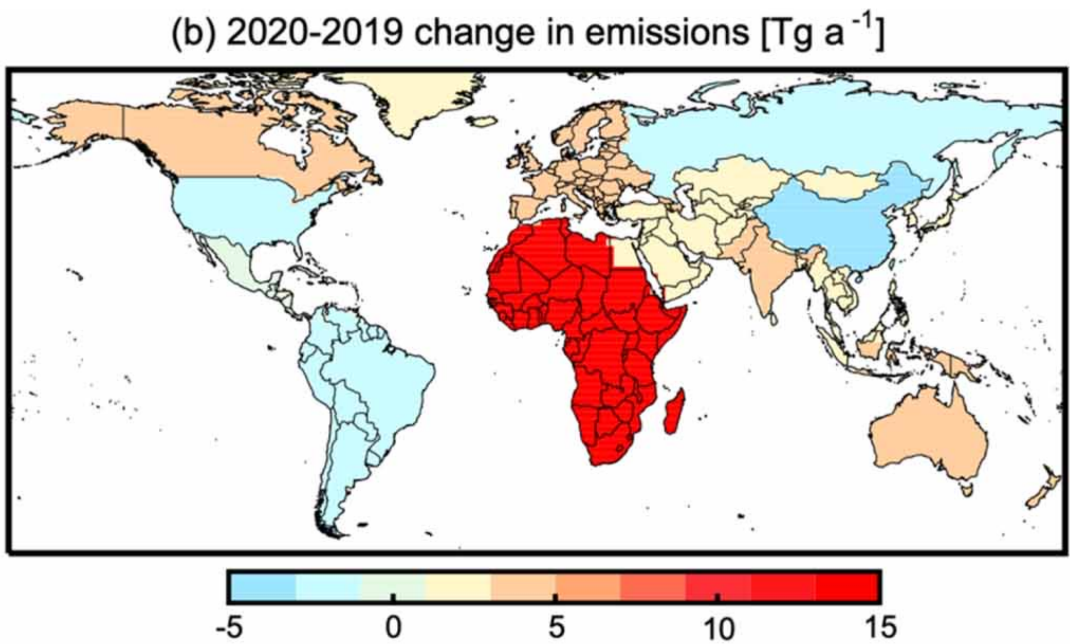

Nesbit et al. (2023) GBC

# Methane sine-latitude growth plot - NOAA



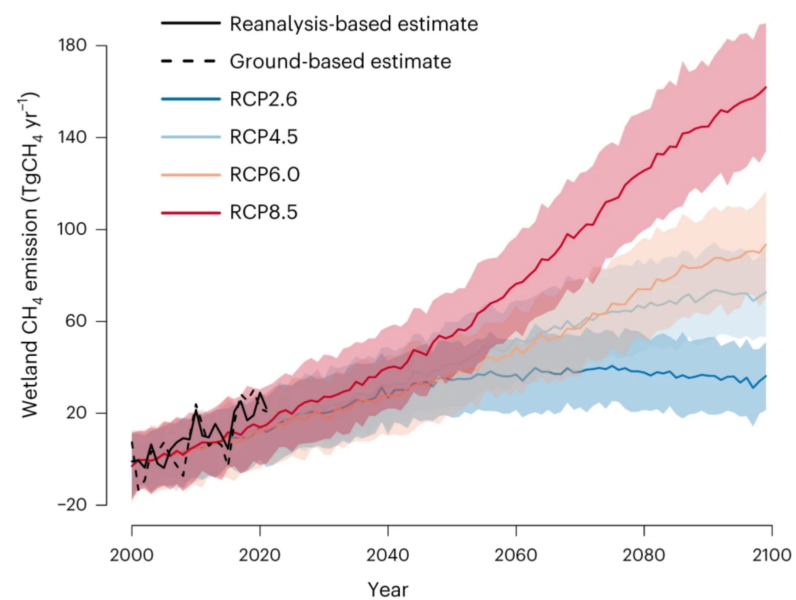

Nesbit et al. (2023) GBC

# Wetlands likely a key player in the renewed growth rate




- 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

**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**.



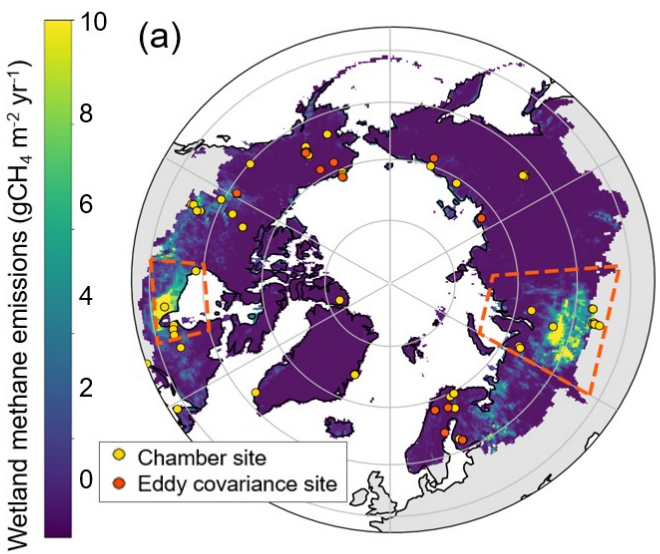

Brief Communication https://doi.org/10.1038/s41558-023-01629-0

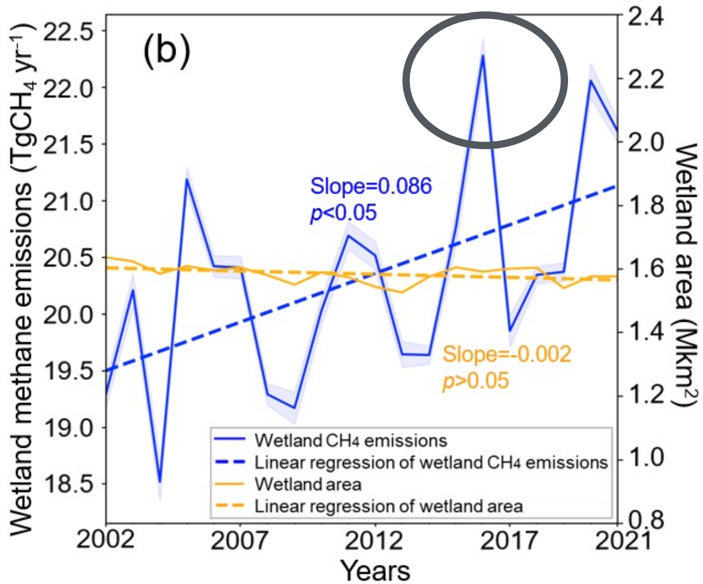
**Recent intensification of wetland methane feedback**

Received: 7 September 2022
Accepted: 10 February 2023

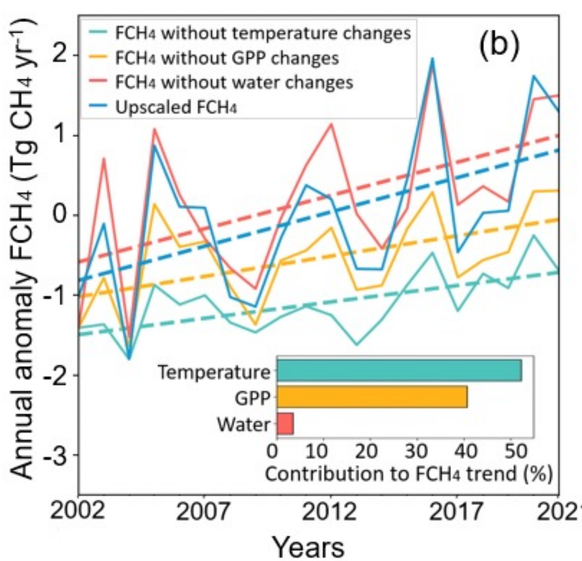
Zhen Zhang[1,2], Benjamin Poulter[3], Andrew F. Feldman[3,4], Qing Ying[2], Philippe Ciais[5], Shushi Peng[6] & Xin Li[1]

# 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

# 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*

# Natural Climate Solutions

## 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.

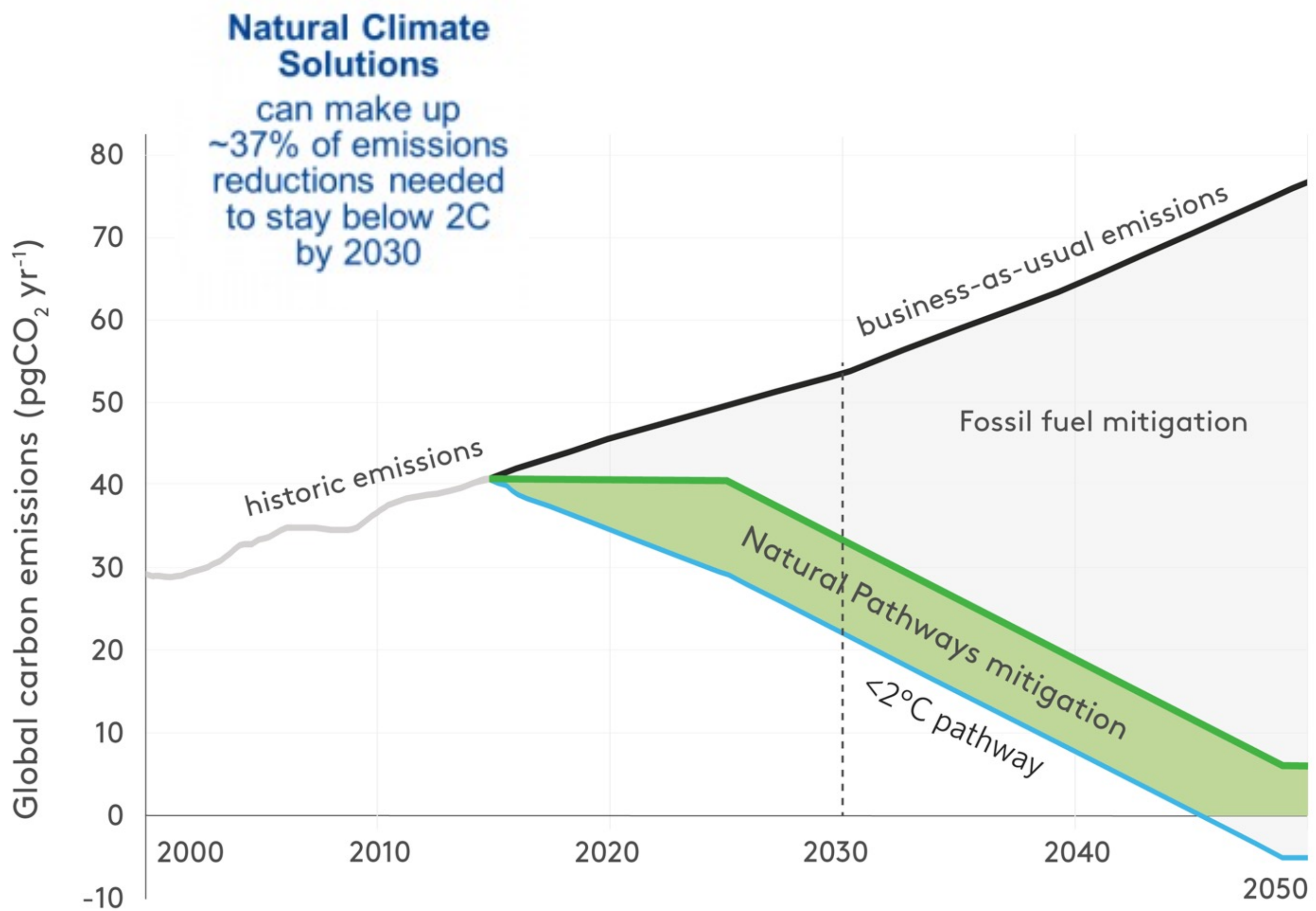
Forests

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

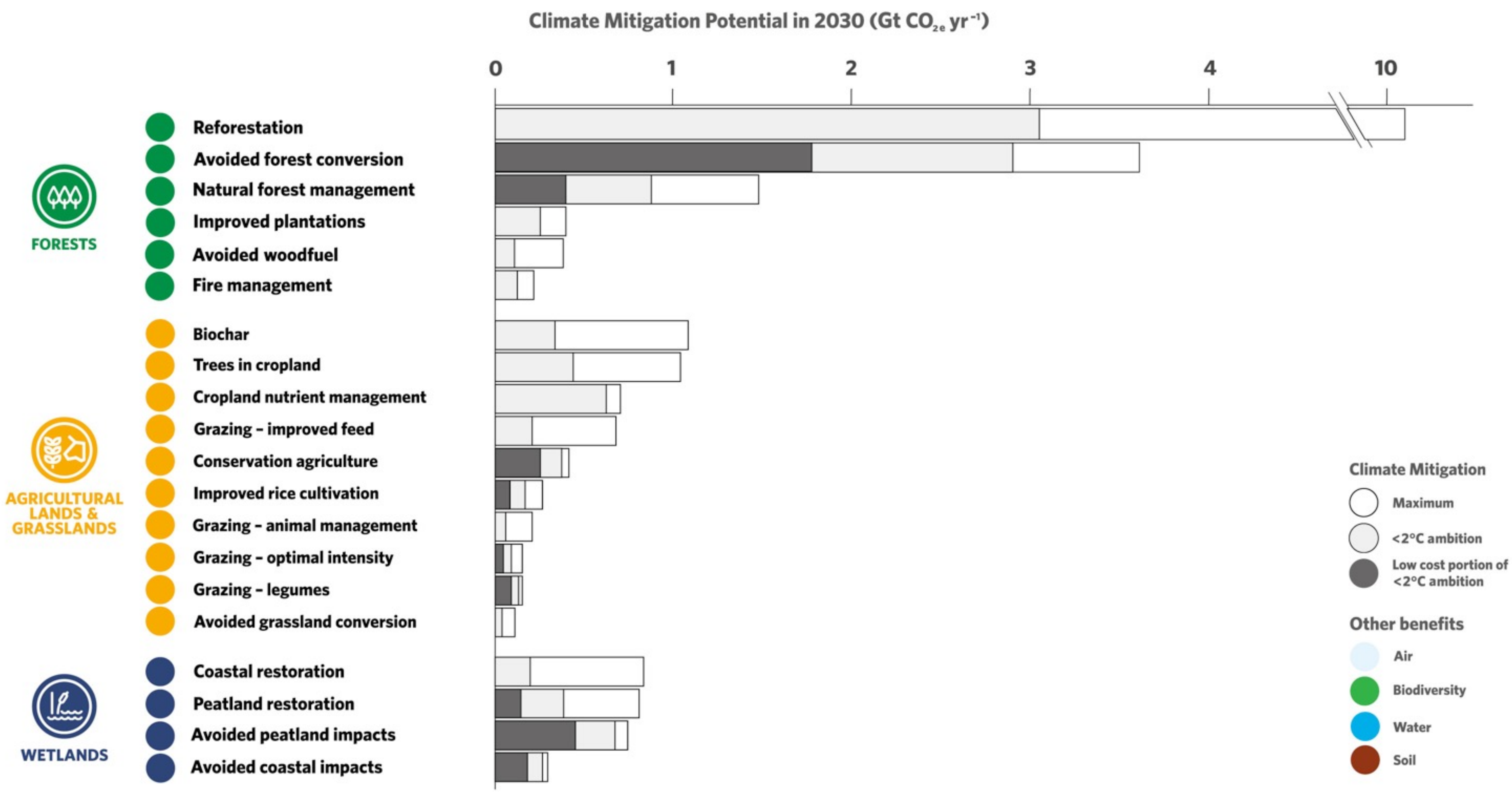
# Can you think of 2 specific examples of Natural Climate Solutions?

Forests

Grasslands & Agriculture

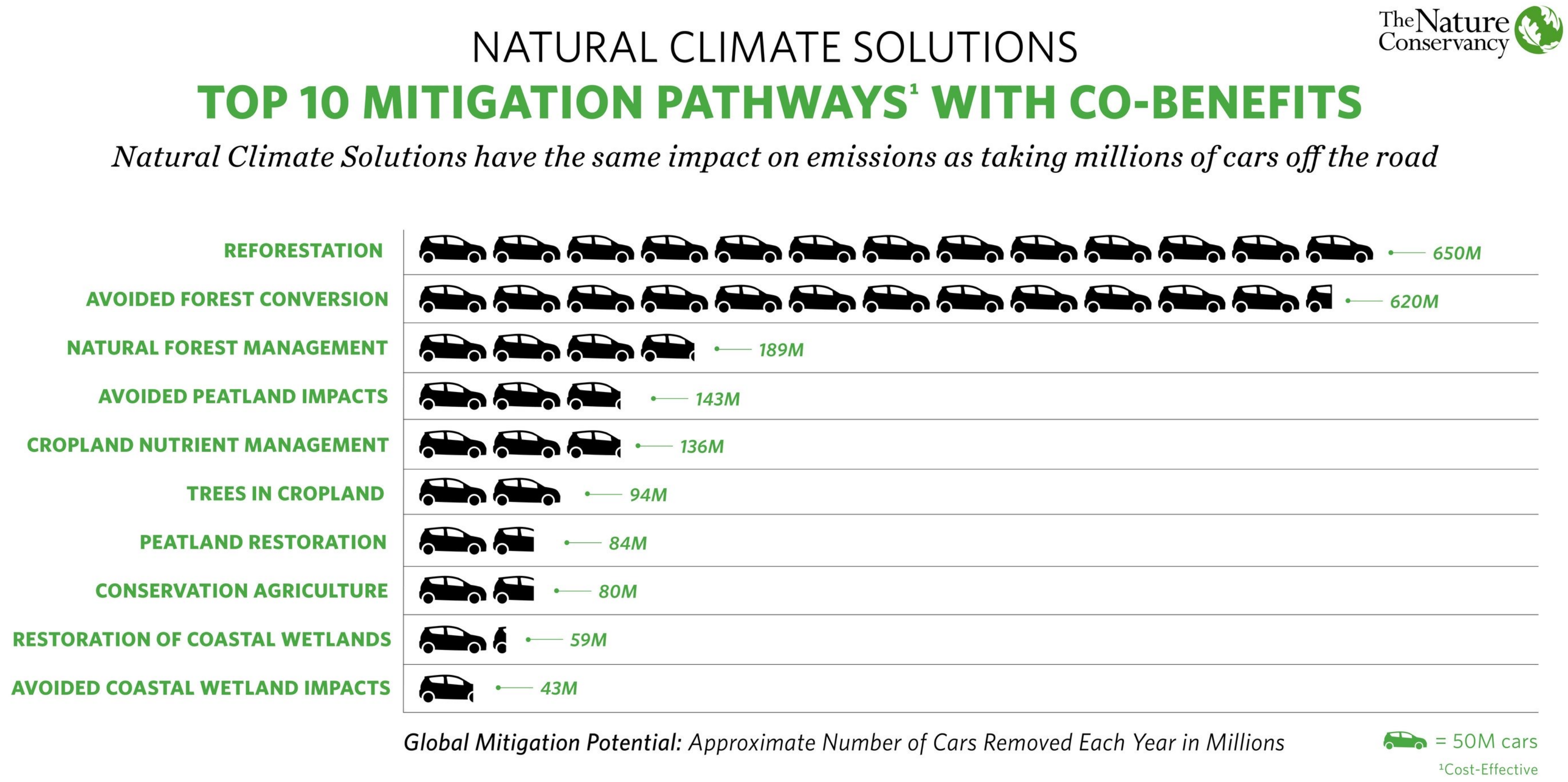
Wetlands

# Natural climate solutions



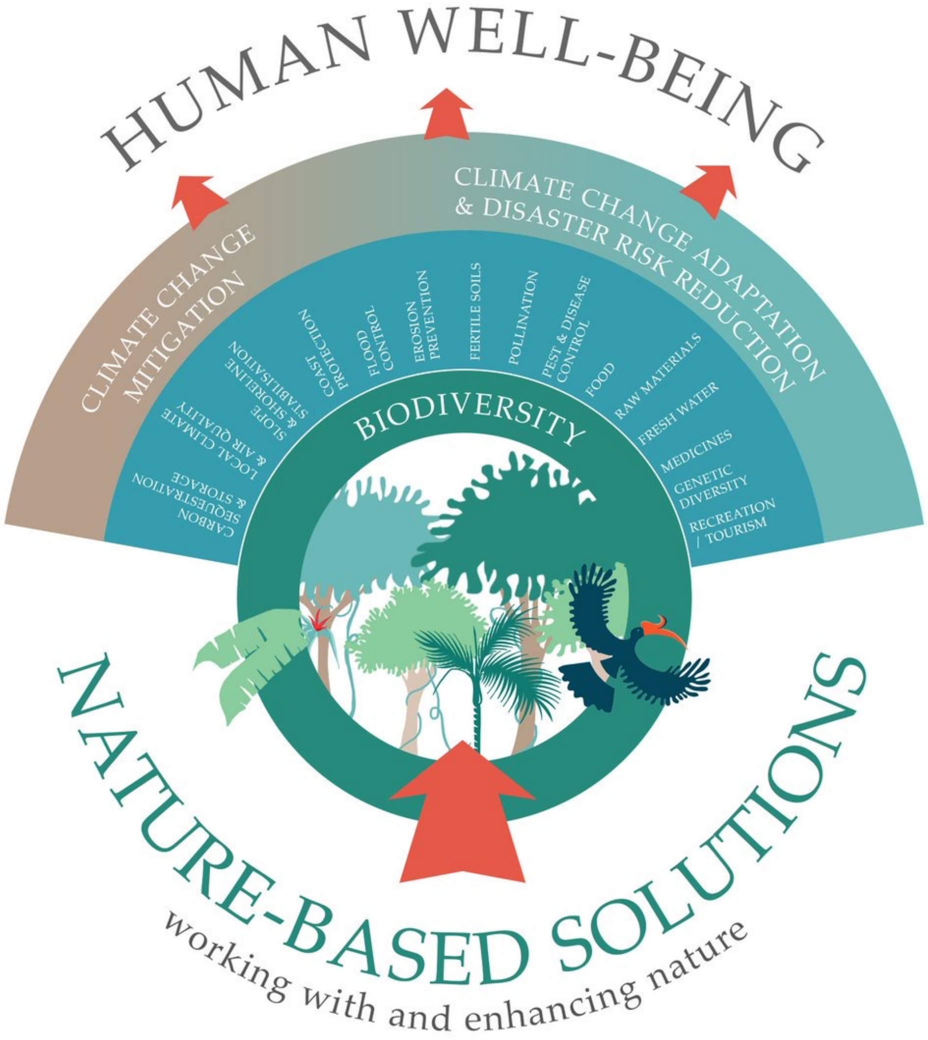

Source: https://www.nature.org/en-us/what-we-do/our-insights/perspectives/natures-make-or-break-potential-for-climate-change/

# Natural climate solutions – in units of cars



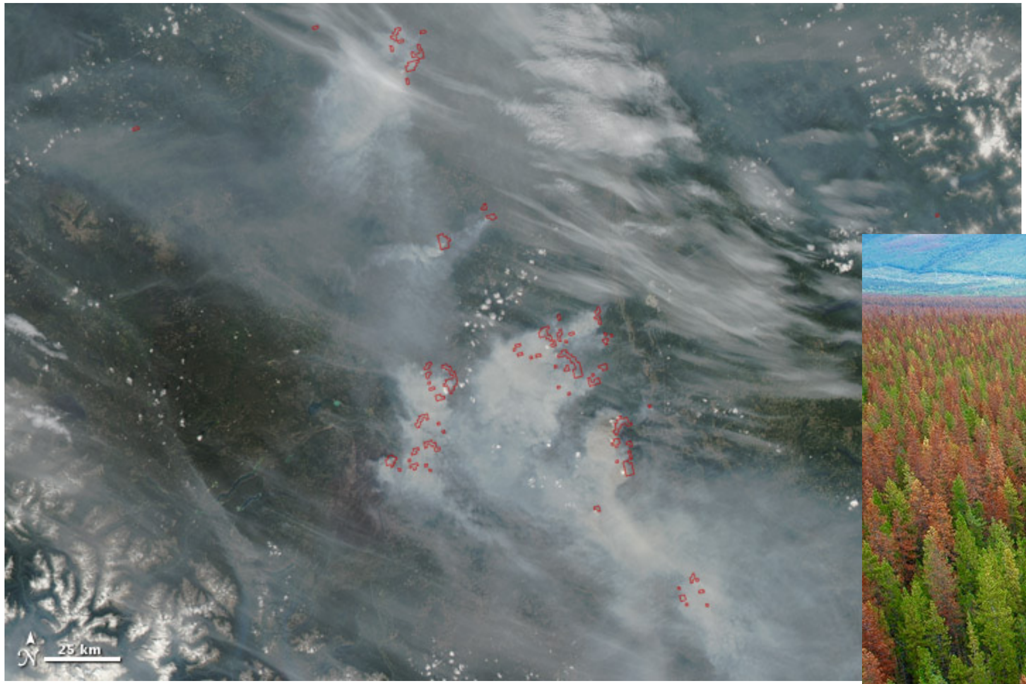

Source: https://www.nature.org/en-us/what-we-do/our-insights/perspectives/natures-make-or-break-potential-for-climate-change/

# Cost effective & numerous co-benefits



# 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.

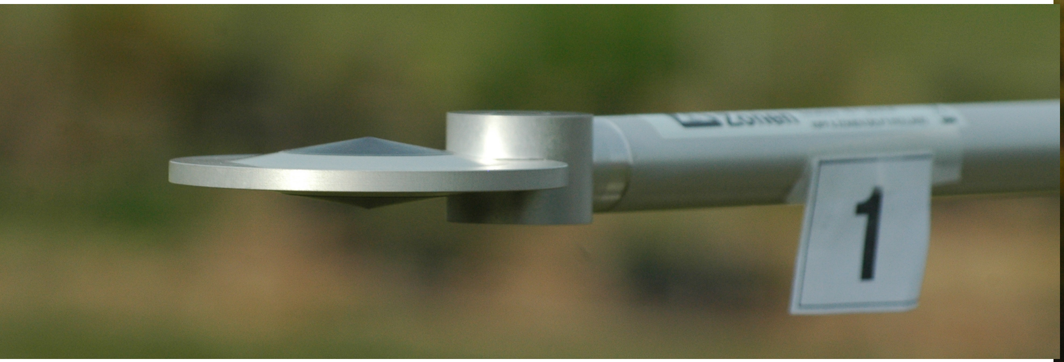
✓ Understanding the **nature of wind and turbulence** in the ABL. Describe turbulent transfer of mass, momentum and energy (wind and temperature profiles, dynamic stability, gradient approaches, entrainment)

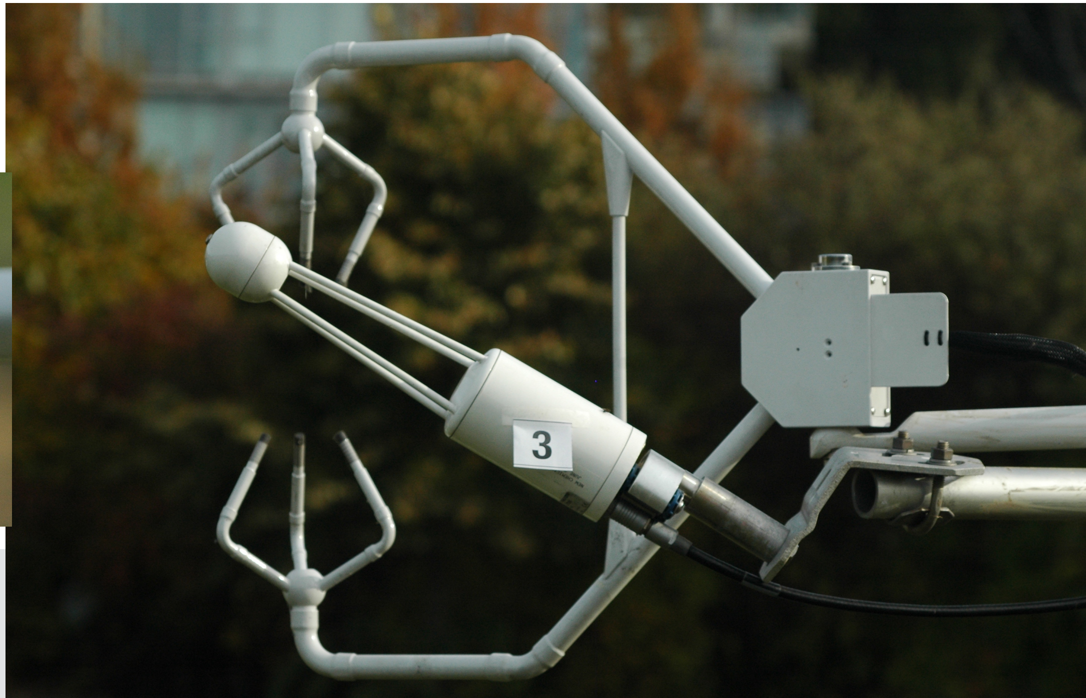
*Photo: A. Christen*

## 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!

# THANK YOU!

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