Introduction to the Biosphere-Atmosphere system

Lecture Autumn 2025

Part III

Steffen M. Noe

The concept of Biosphere

Concept introduced by geologist Eduard Suess in 1875.

One thing seems to be foreign on this large celestial body consisting of spheres, namely, organic life. But this life is limited to a determined zone at the surface of the lithosphere. The plant, whose deep roots plunge into the soil to feed, and which at the same time rises into the air to breathe, is a good illustration of organic life in the region of interaction between the upper sphere and the lithosphere, and on the surface of continents it is possible to single out an independent biosphere.

The concept of Biosphere

Eduard Suess concept is of geological origin!

It already determines the typical features which we accept also today.

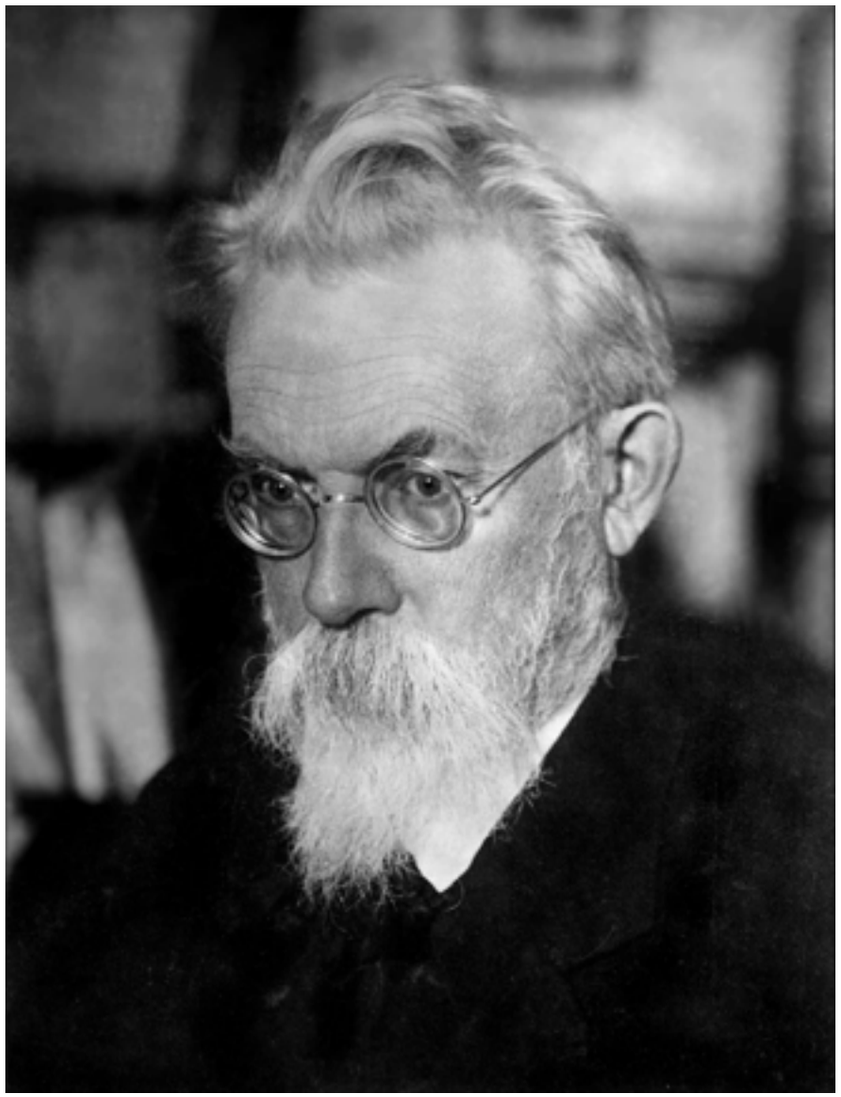
The Earth system is described in spheres.

The biosphere links the soil, on top of the lithosphere, with the atmosphere.

The concept of Suess ignores the oceans.

The concept of Biosphere

Vladimir Ivanovich Vernadsky



The concept was refined to the modern form we usually accept today by him. But he is not much recognised in the west.

In his book “The Biosphere” (1926) he hypothesised that the life is the geological force that shapes the Earth.

In this theory, the principles of both life and cognition are essential features of the Earth's evolution, and must have been implicit in the earth all along.

It’s a systems within systems approach!

Excursion: Gaia hypothesis

Developed by James Lovelock (chemist) and Lynn Margulis (microbiologist) in the 1970'ies

The Gaia hypothesis or principle proposes that the Earth forms a synergistic, self-regulating complex system that maintains the climatic and biogeochemical conditions on Earth in a preferred homeostasis.

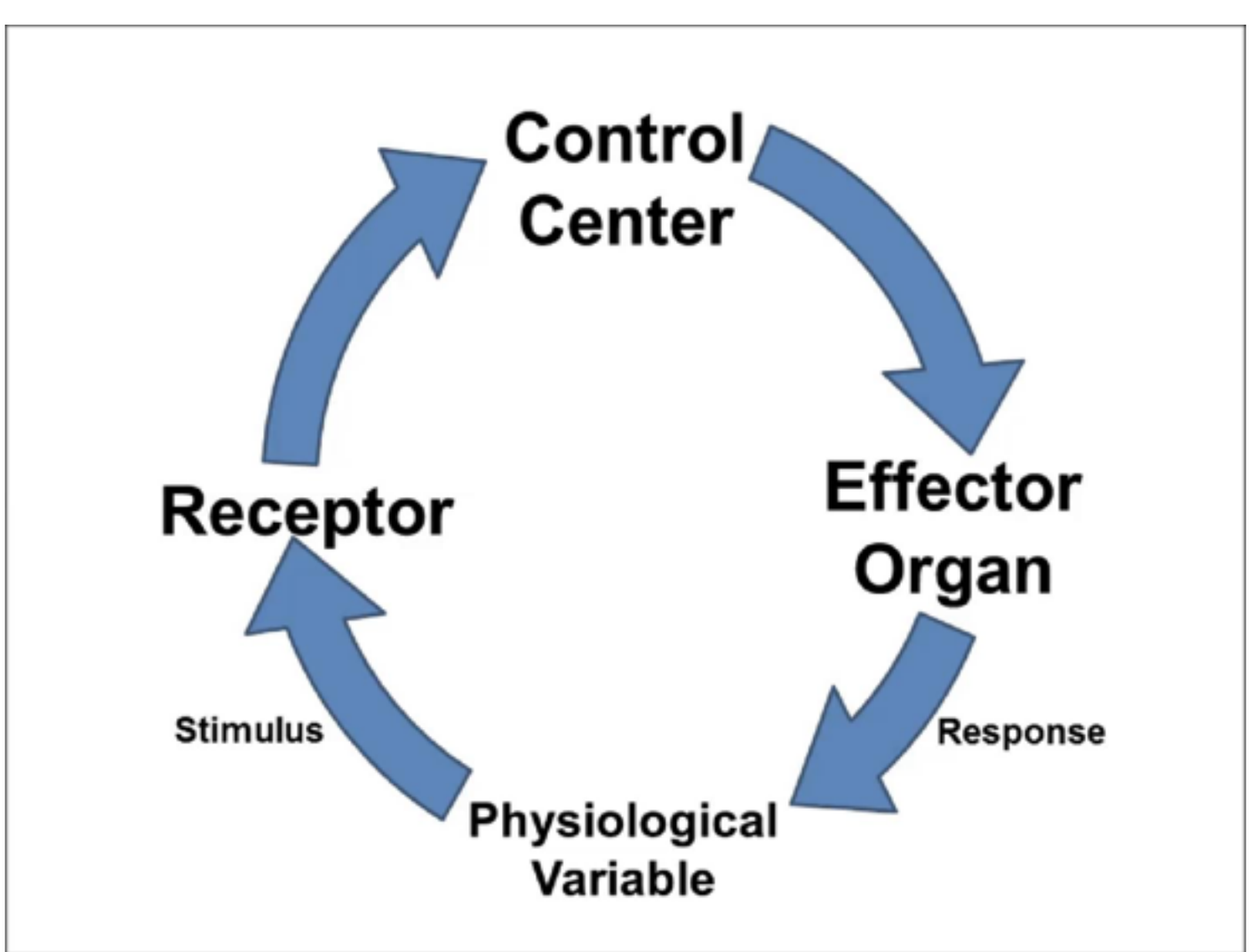
Originally it was proposed as Earth feedback system.

Sometimes, the Earth as a whole is seen as the "Biosphere".

Excursion: homeostasis

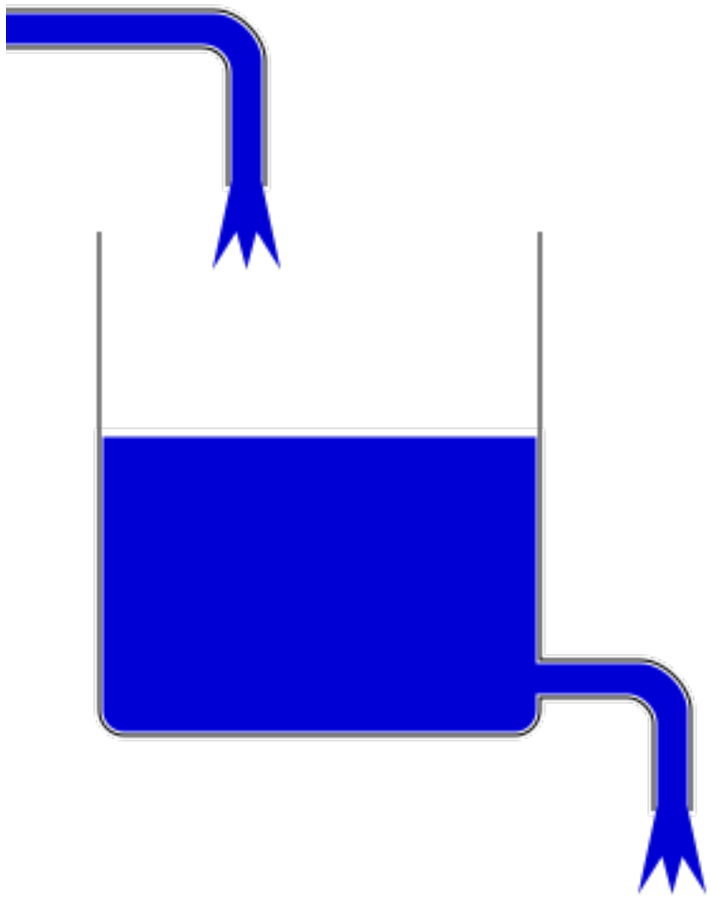
Any self-regulating process by which biological systems tend to maintain stability while adjusting to conditions that are optimal for survival. If homeostasis is successful, life continues; if unsuccessful, disaster or death ensues. The stability attained is actually a dynamic equilibrium, in which continuous change occurs yet relatively uniform conditions prevail.

Source: Encyclopaedia Brittanica



Excursion: dynamic equilibrium or steady state

Exchange of matter or energy in an open system in a way that the “net” amount of the substance remains of the same amount.



Some definitions…

The **biosphere** also known as the ecosphere, is the worldwide sum of all ecosystems.

Source Wikipedia

The part of the world in which life can exist.
Living organisms together with their environment

Source: Merriam Webster

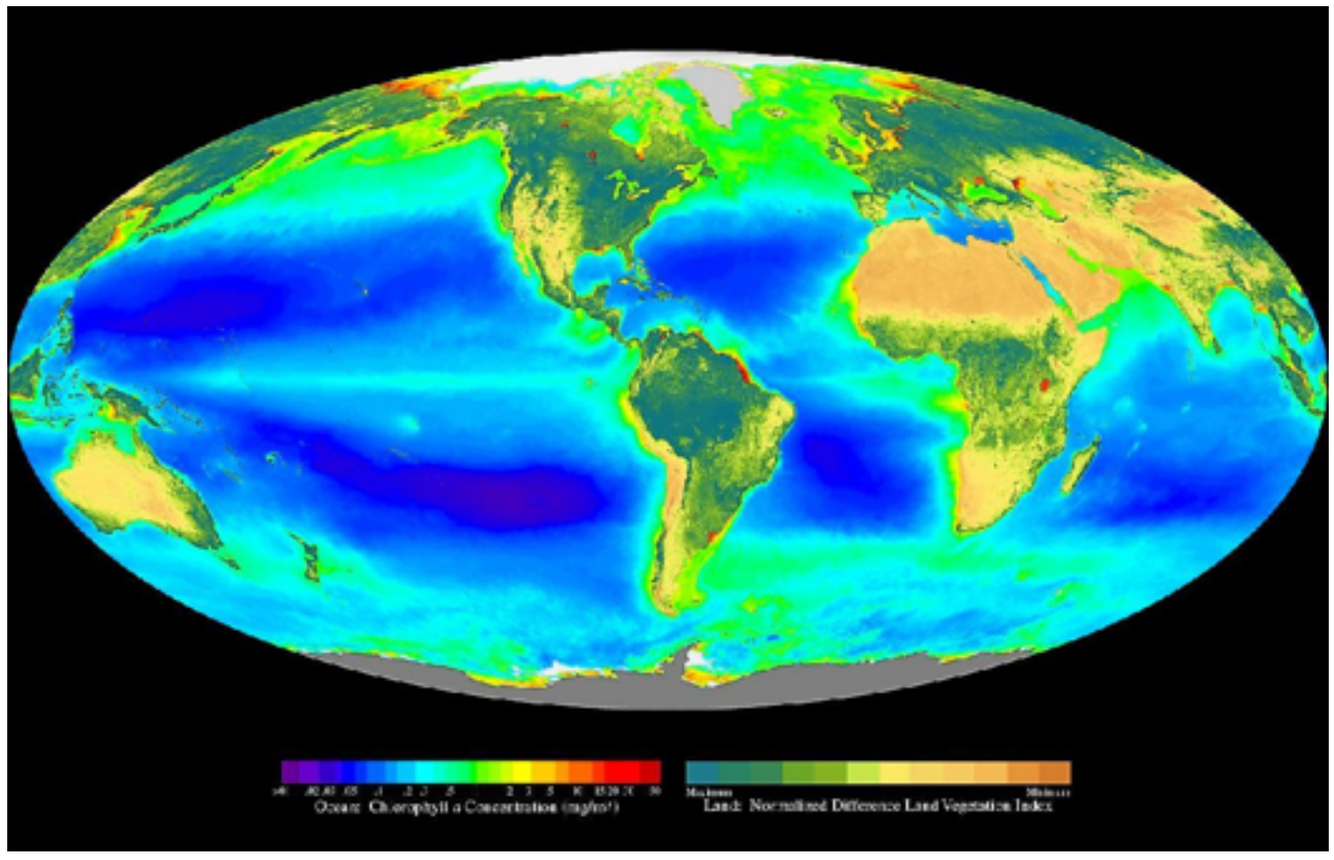
The regions of the surface and atmosphere of the earth or another planet occupied by living organisms.

Source: Oxford dictionary

The most comprehensive definition

Biosphere, relatively thin life-supporting stratum of Earth's surface, extending from a few kilometres into the atmosphere to the deep-sea vents of the ocean. The biosphere is a global ecosystem composed of living organisms (biota) and the abiotic (nonliving) factors from which they derive energy and nutrients.

Source: Encyclopædia Britannica



The concept of Biosphere revisited

If we take it together:

The Earth system is seen as spheres.
The Earth is a system of systems (complex adaptive system).
The Biosphere is one sphere.
The Biosphere is a system of systems (complex adaptive system)
The building blocks of the Biosphere are the ecosystems.

How many Biospheres exist?

We call the Earth – Biosphere 1

Biosphere 2, constructed 1987-1991, as the largest artificial closed system created. It's purpose was to demonstrate the viability of a closed system to maintain human life in space.

However, an earlier experiment called BIOS-3 (1965) in Russia, Krasnoyarsk, is still used to do research on space travel and recycling.

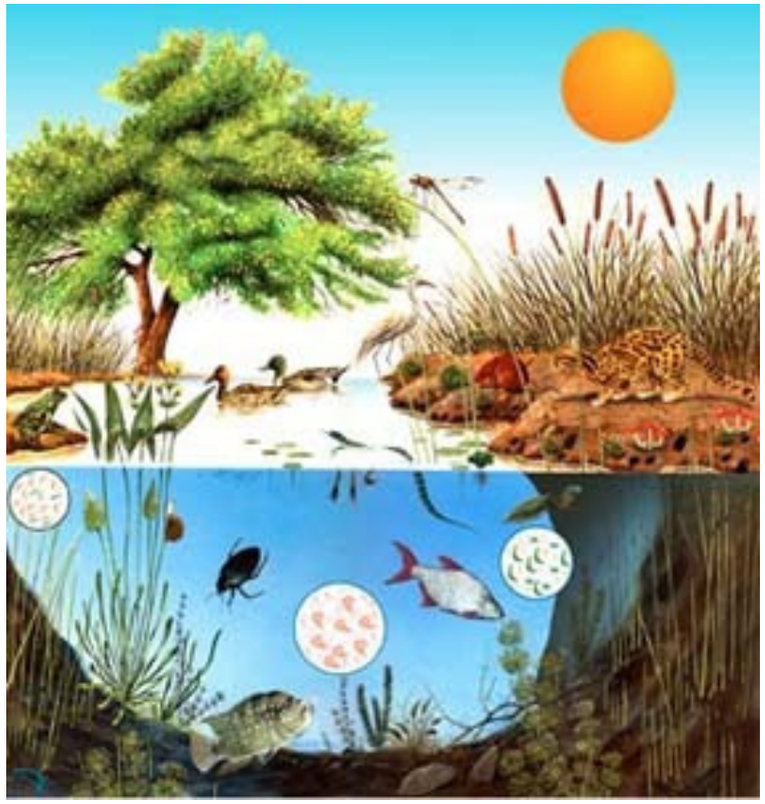
Biota

A 'biota' is the total collection of organisms of a geographic region or a time period, from local geographic scales and instantaneous temporal scales all the way up to whole-planet and whole-timescale spatiotemporal scales. The biotas of the Earth make up the biosphere.

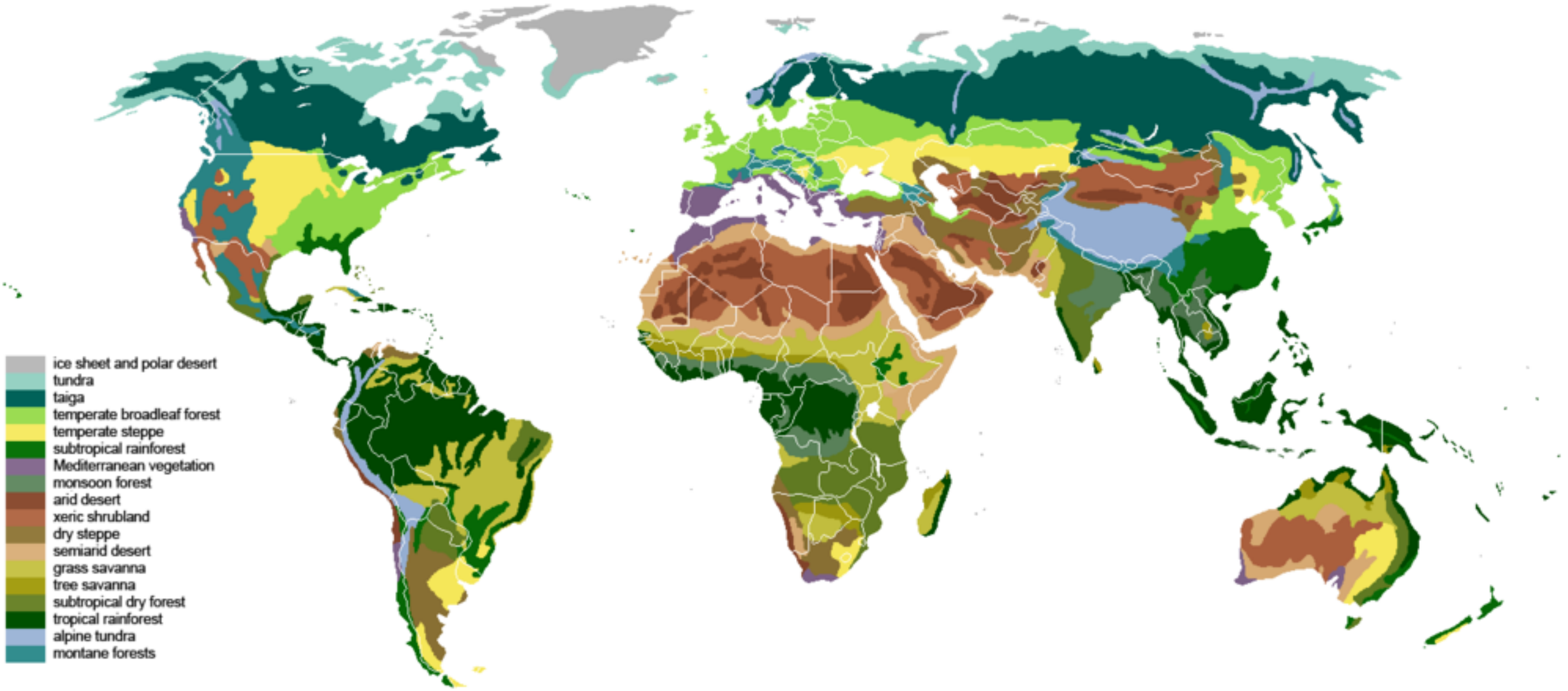
Source: Wikipedia

Because biota are defined as collections of things, they must not have a systems character!

If they have interconnections and purpose, we'd rather name them Ecosystem.



Biome



Terrestrial biomes according the Köppen scheme

The biome concept

A **biome** is a formation of plants and animals that have common characteristics due to similar climates and can be found over a range of continents. Spanning continents, biomes are distinct biological communities that have formed in response to a shared physical climate.

Source: Wikipedia

The biome concept unites already the climatic influence on the living organisms.

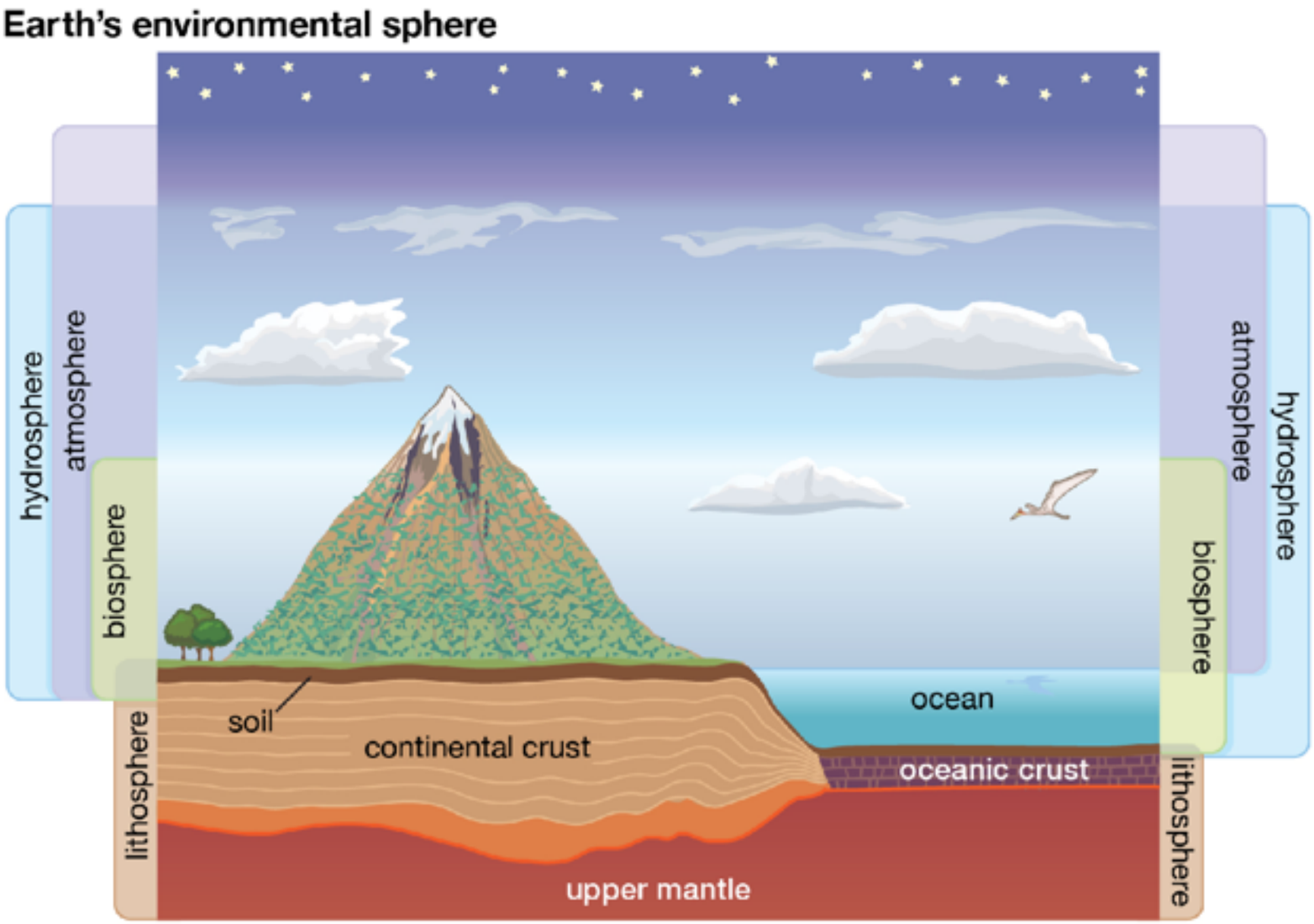
The physical climate led to common characteristics given similar climatic conditions.

The interactions between biosphere and environment are not yet explicitly named but recognised.

Sorting the puzzle

Living communities and their nonliving environment are **inseparably interrelated and constantly interact** upon each other. For convenience, any segment of the landscape that includes the biotic and abiotic components is called an ecosystem.

Source: Encyclopædia Britannica



Primary producers

All life on Earth depends ultimately upon green plants, as well as upon water.

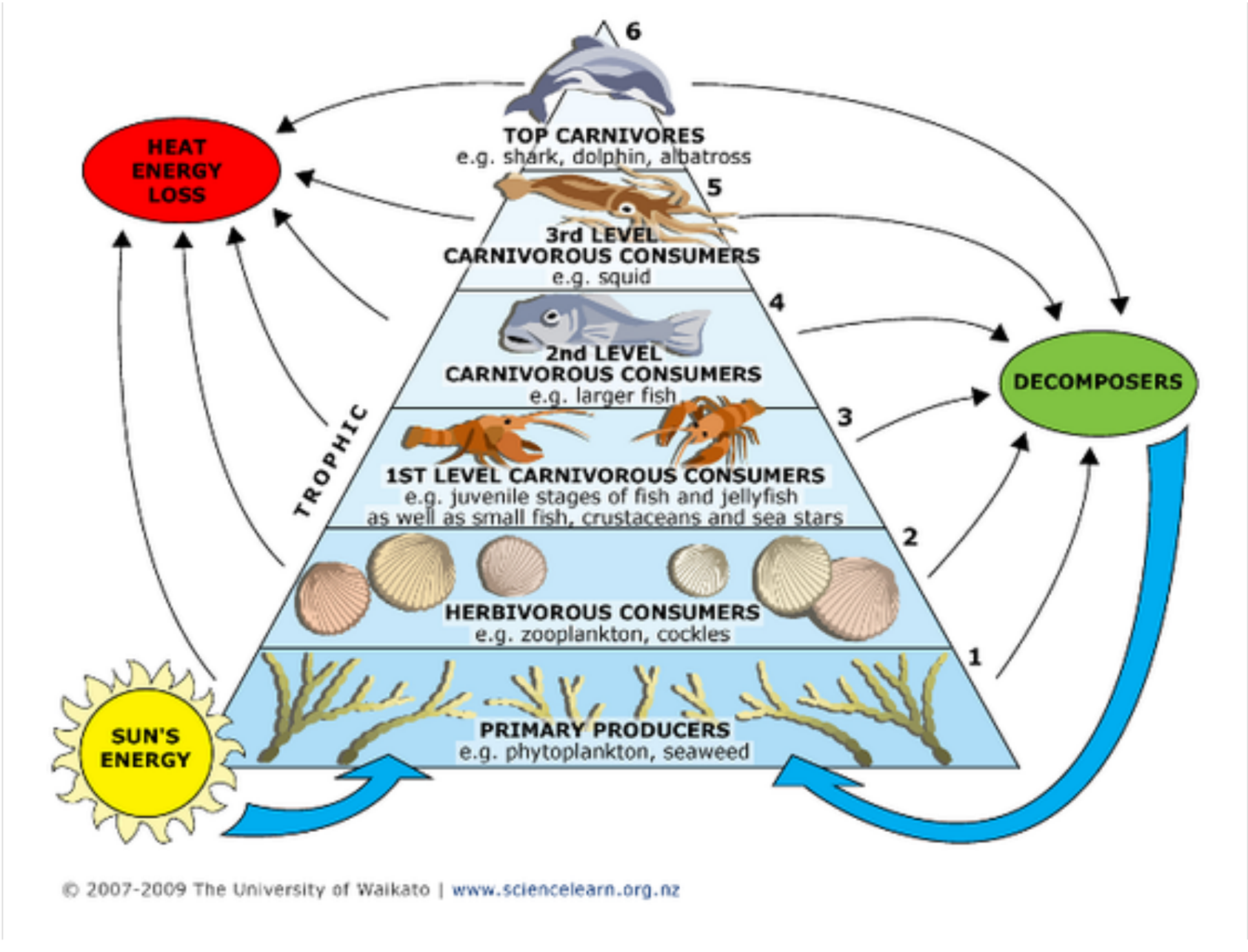
Plants are called primary producers. They utilise the energy of the sunlight to produce biomass by the process of photosynthesis.

Consumers

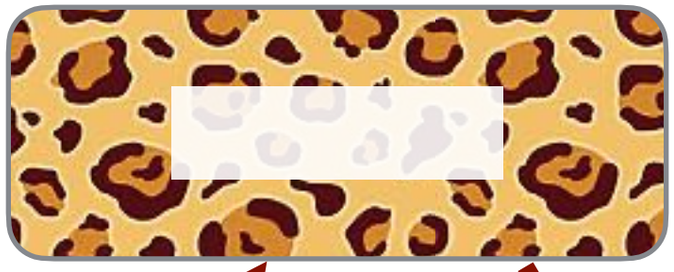
Decomposers

Decomposers are organisms that utilise the biomass produced by primary producers and decompose it in order to utilise the stored energy within this biomass.

Example of a marine food web



Energy flow in the biosphere

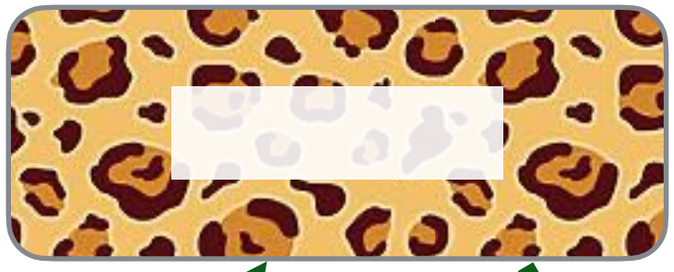


Primary production

gases

Nutrients

Matter flow in the biosphere



Primary production

gases

Nutrients

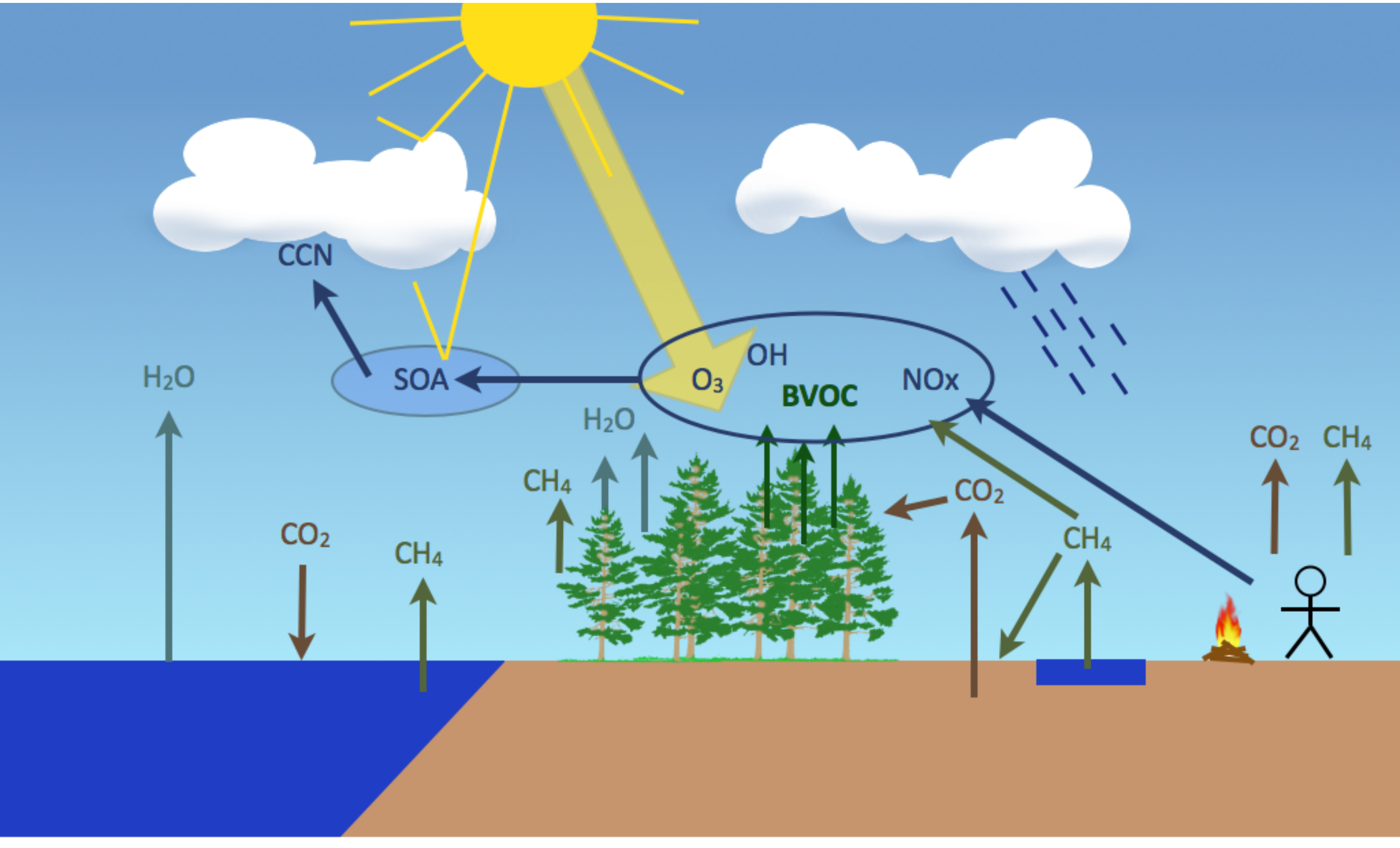
Major equation of the biosphere

$$NPP = GPP - Re$$

NPP is the net primary production
GPP is the gross primary production
Re is the ecosystem respiration

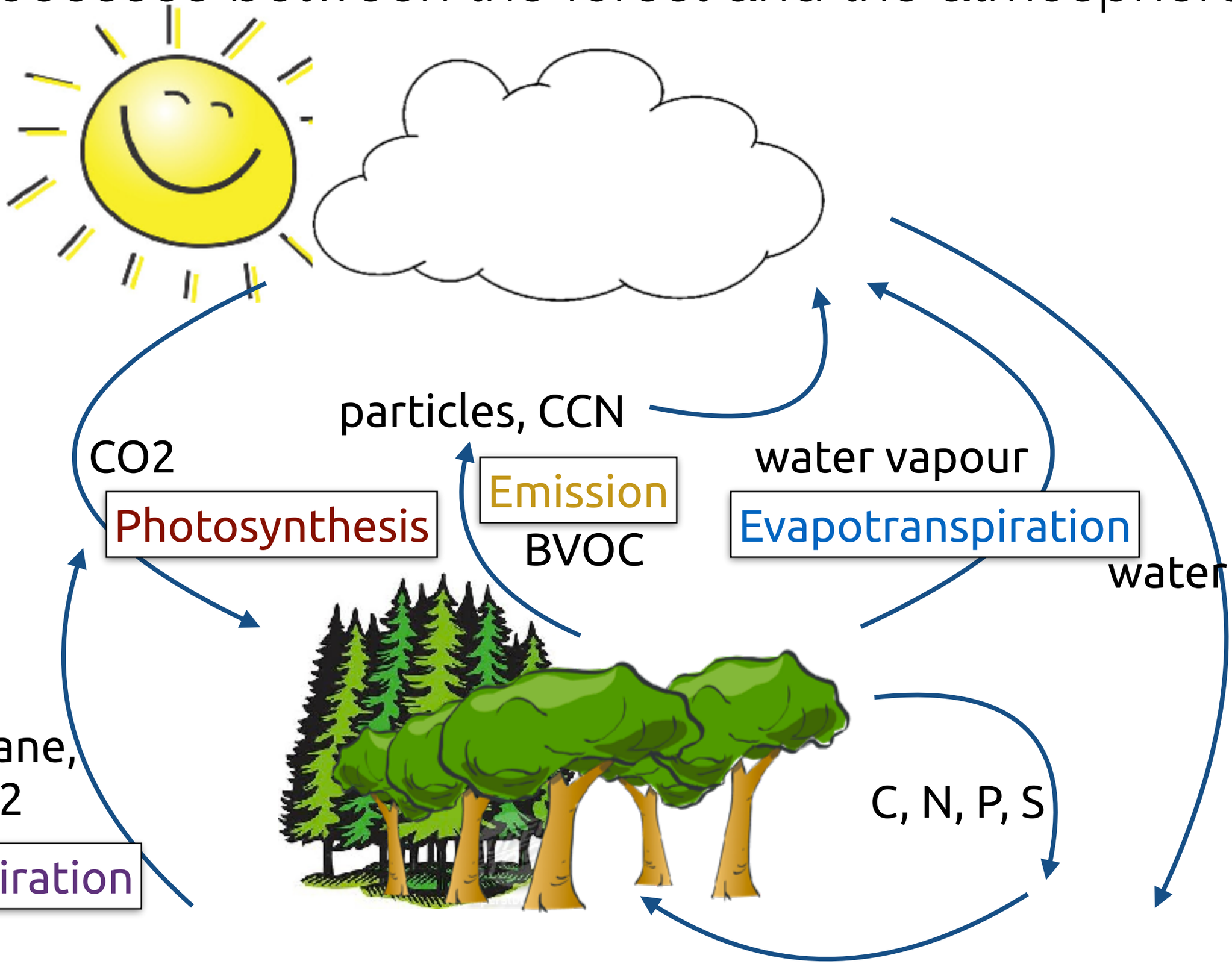
NPP is the rate of net chemical energy production in an ecosystem. which is the difference at which rate chemical energy is produced (GPP) and the rate at which chemical energy is lost to the ecosystem by respiration (Re).

Feedbacks in the biosphere-atmosphere system

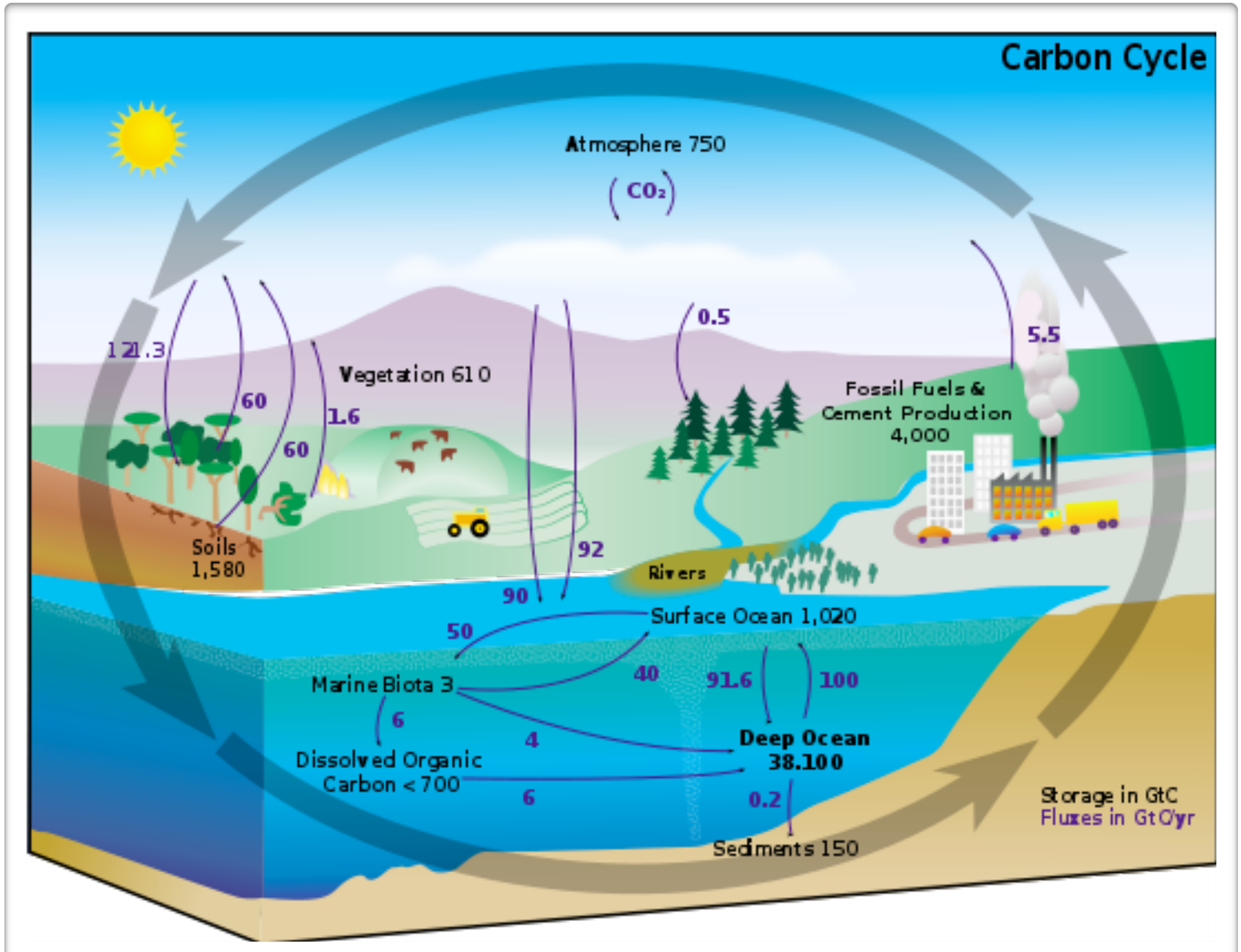


Forest ecosystems

Processes between the forest and the atmosphere



Example: Carbon cycle



Example: Carbon cycle

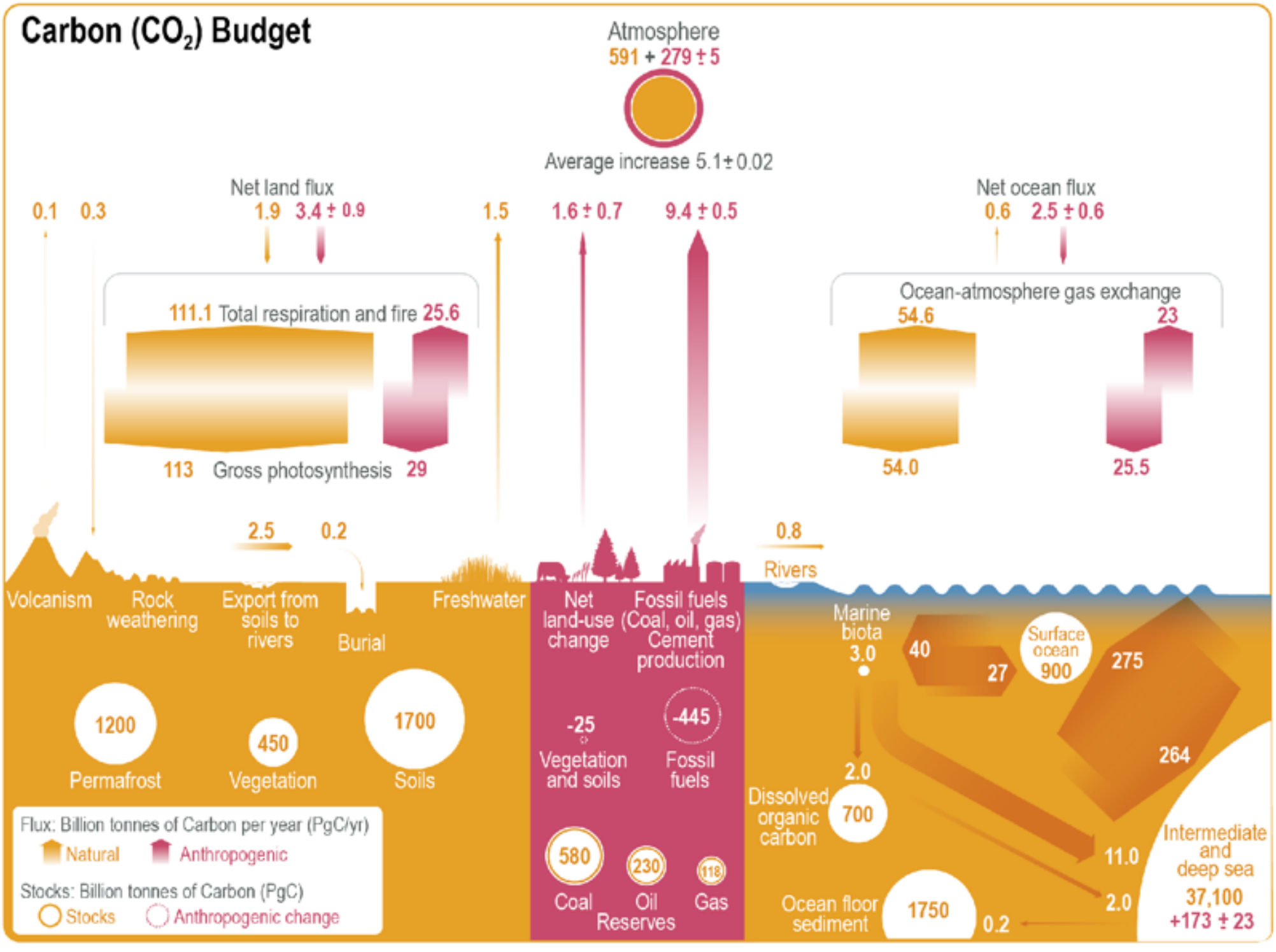
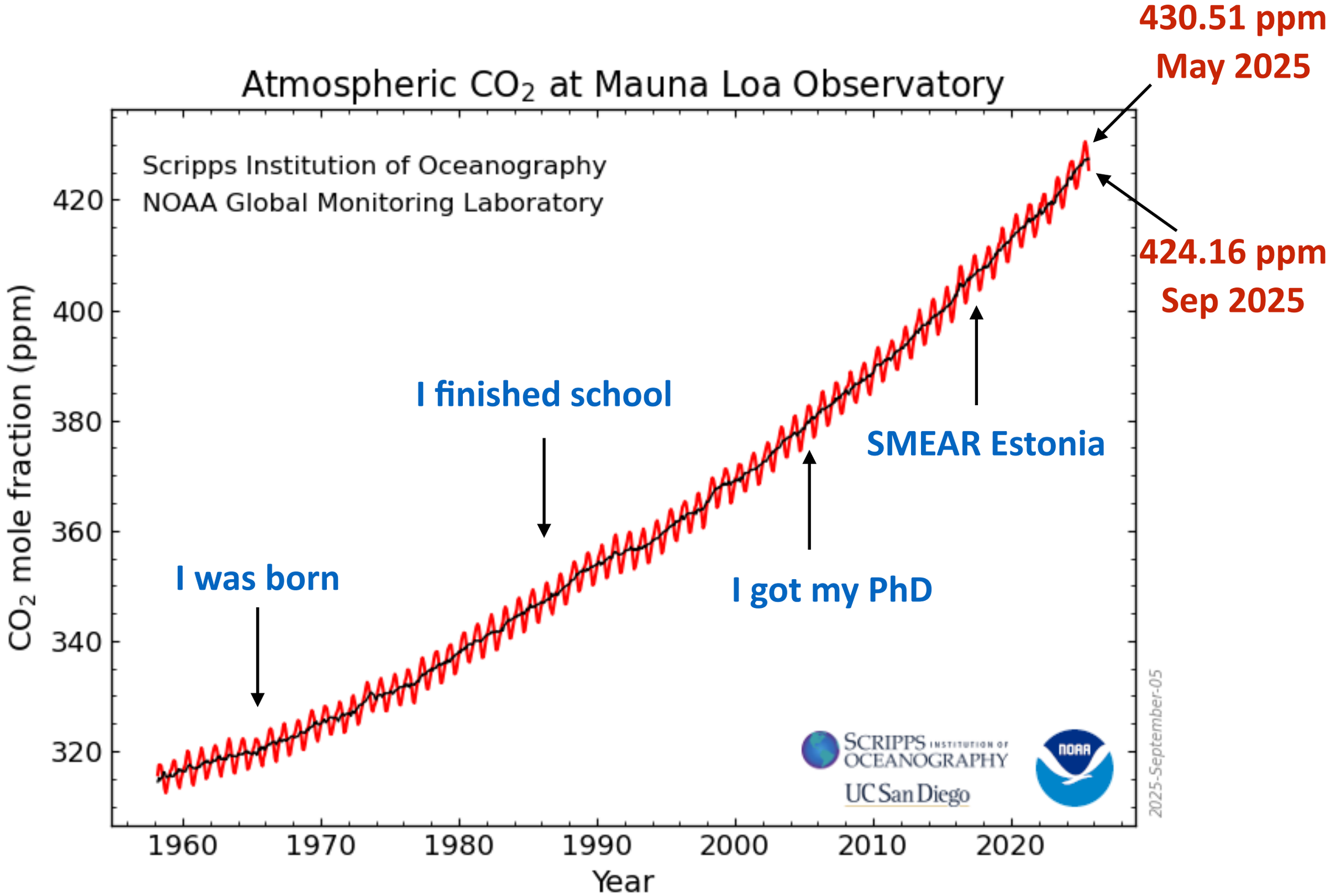


Figure 5.12 in IPCC, 2021: Chapter 5. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Canadell, J.G., P.M.S. Monteiro, M.H. Costa, L. Cotrim da Cunha, P.M. Cox, A.V. Eliseev, S. Henson, M. Ishii, S. Jaccard, C. Koven, A. Lohila, P.K. Patra, S. Piao, J. Rogelj, S. Syampungani, S. Zaehle, and K. Zickfeld, 2021: Global Carbon and other Biogeochemical Cycles and Feedbacks. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 673–816, doi: 10.1017/9781009157896.007 .]

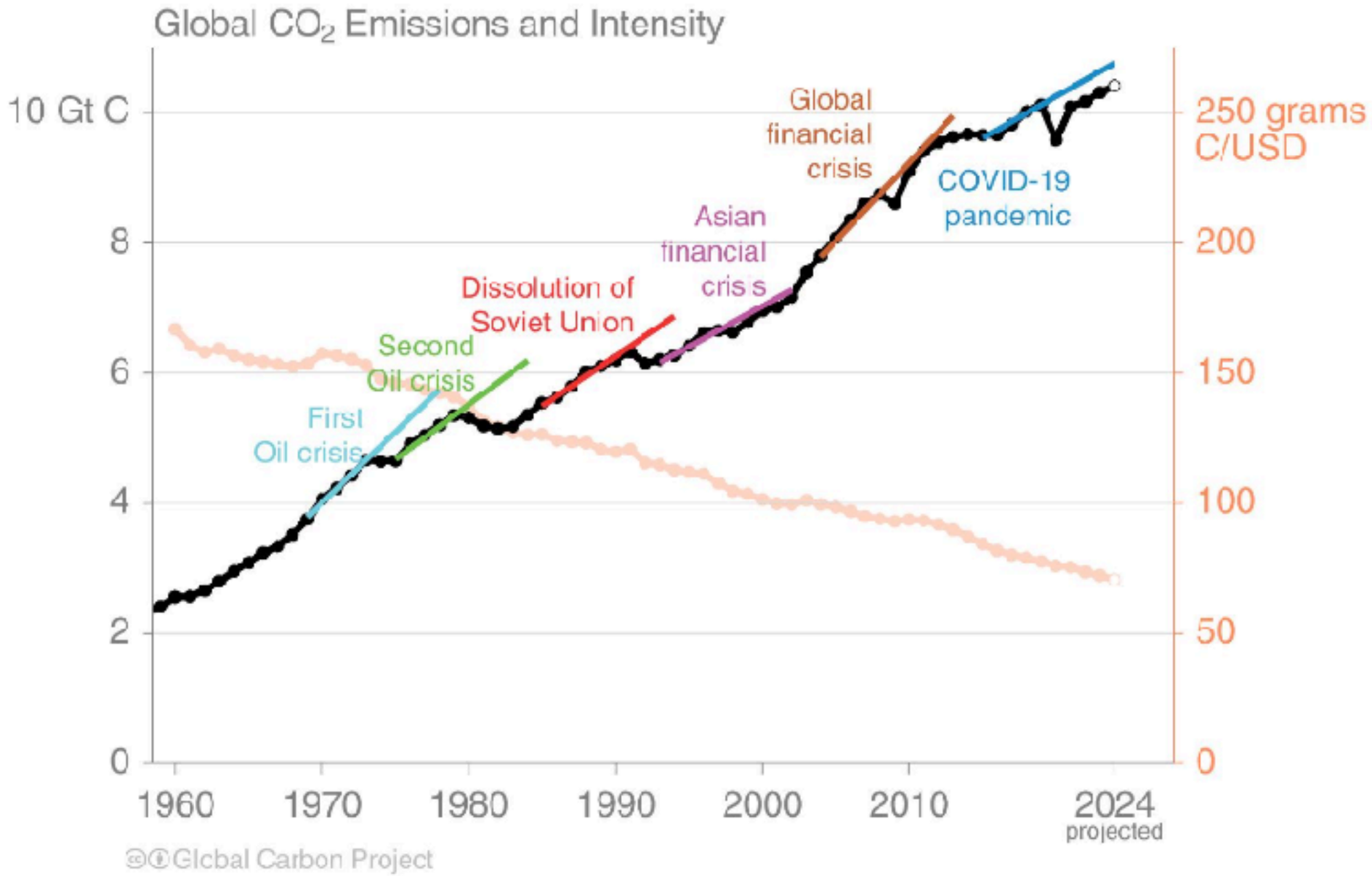
Measured rise of atmospheric CO_2 since the 60'ies



Measured rise in atmospheric CO_2 since the 60ties

Carbon and economic growth

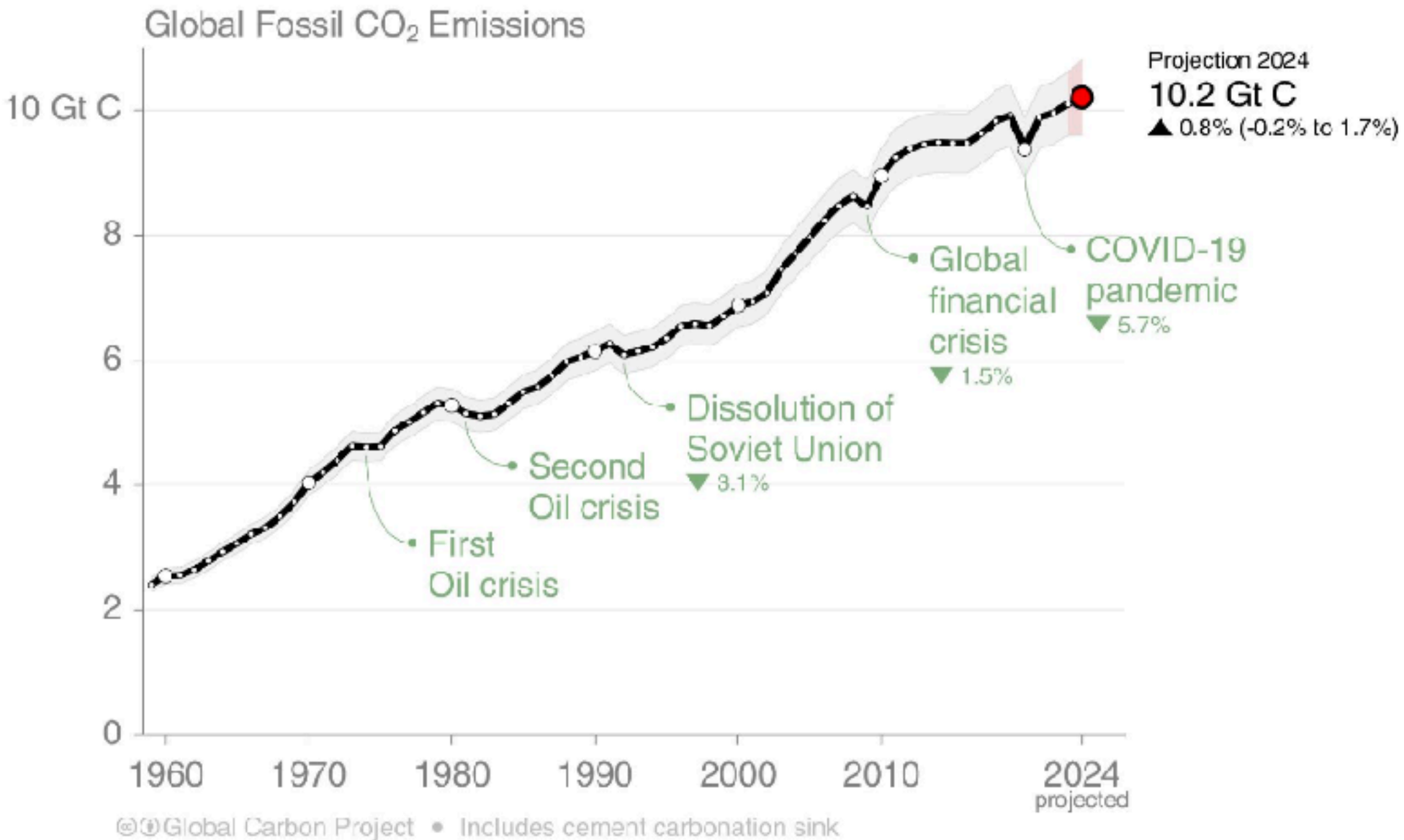
Global CO_2 emissions growth has generally resumed quickly from global crises.
Emission intensity has steadily declined but not sufficiently to offset economic growth.



Each trend line is based on the five years before the crisis and extended to five years after.
Economic activity is measured in purchasing power parity (PPP) terms in 2017 US dollars.
Source: Friedlingstein et al 2024; Global Carbon Project 2024

Carbon and economic growth

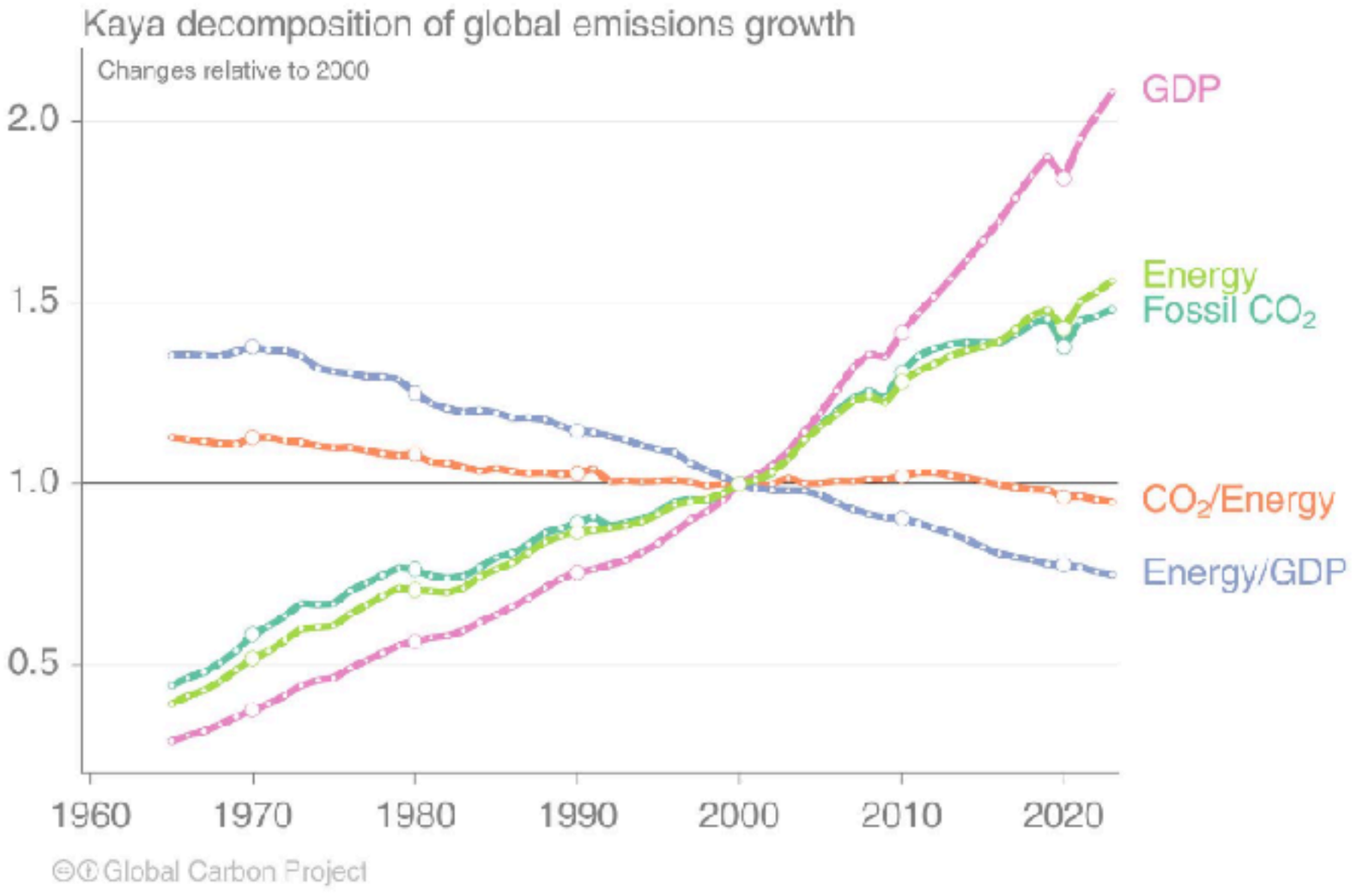
Global fossil CO_2 emissions have risen steadily over the last decades.
Emissions are set to grow again in 2024.



The 2024 projection is based on preliminary data and modelling.
Source: Friedlingstein et al 2024; Global Carbon Project 2024

Carbon and economic growth

The Kaya decomposition illustrates that relative decoupling of economic growth from CO_2 emissions is driven by improved energy intensity (Energy/GDP) and, recently, carbon intensity of energy (CO_2/Energy)



GDP: Gross Domestic Product (economic activity)

Source: Friedlingstein et al 2024; Global Carbon Project 2024

Where the carbon goes…

Fate of Anthropogenic CO_2 Emissions (2010)

9.1±0.5 PgC y^{-1}

0.9±0.7 PgC y^{-1}

5.0±0.2 PgC y^{-1}

50%

2.6±1.0 PgC y^{-1}

26%

Calculated as the residual of all other flux components

24%

2.4±0.5 PgC y^{-1}

Average of 5 models

Global Carbon Project 2010; Updated from Le Quéré et al. 2009, Nature Geoscience; Canadell et al. 2007, PNAS

Change in carbon dynamic

RESEARCH: Sources and sinks of carbon

1.1 Pg C y^{-1}

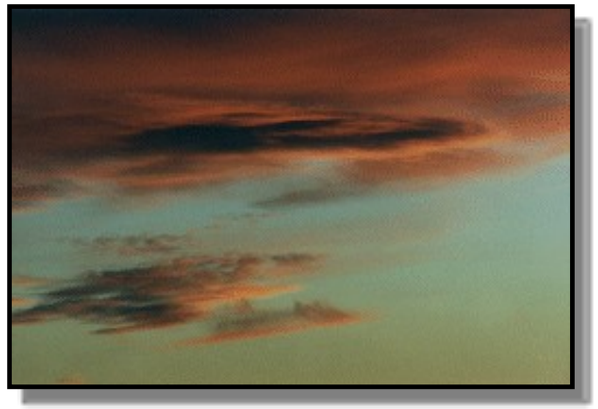
+

7.8 Pg C y^{-1}

4.0 Pg C y^{-1}

Atmosphere

44%



2.6 Pg C y^{-1}

Terrestrial ecosystems

30%

2.3 Pg C y^{-1}

Oceans

26%

Pg = 10^{15} g = 10^{9} tn

Sources: CDIAC NOAA-ESRL; Houghton et al, 2012; Giglio et al 2013; Le Quéré et al 2015; Global Carbon Budget 2015

Where the carbon goes… (last year estimates)

Sources = **Sinks**

34.4 $GtCO_2/yr$

86%

14%

5.7 $GtCO_2/yr$

18.6 $GtCO_2/yr$

46%

31%

12.5 $GtCO_2/yr$

23%

9.2 $GtCO_2/yr$

Budget Imbalance:
(the difference between estimated sources & sinks)

0.4%

0.2 $GtCO_2/yr$

Source: Friedlingstein et al 2020; Global Carbon Budget 2020

Where the carbon goes… (recent year estimates)

Sources = **Sinks**

34.8 $GtCO_2/yr$

89%

11%

4.1 $GtCO_2/yr$

18.6 $GtCO_2/yr$

48%

29%

11.2 $GtCO_2/yr$

26%

10.2 $GtCO_2/yr$

Budget Imbalance:
(the difference between estimated sources & sinks)

3%

-1.0 $GtCO_2/yr$

Source: Friedlingstein et al 2021; Global Carbon Project 2021

Where the carbon goes… (recent year estimates)

Sources

9.7 GtC/yr

90%

10%

1.1 GtC/yr

= Sinks

5.2 GtC/yr

48%

29%

3.2 GtC/yr

26%

2.9 GtC/yr

Budget Imbalance:
(the difference between estimated sources & sinks)

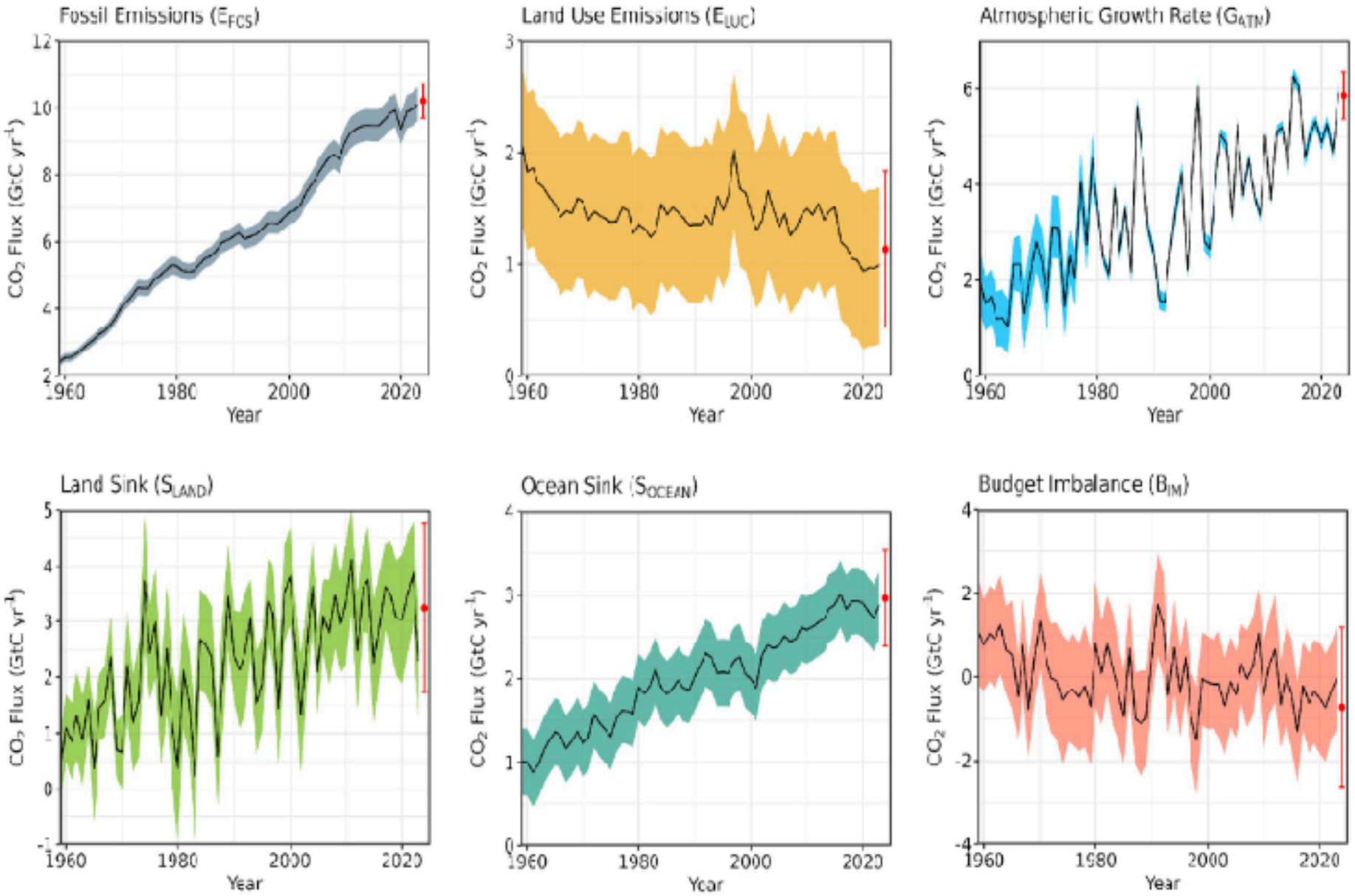
4%

-0.4 GtC/yr

Source: Friedlingstein et al 2024; Global Carbon Project 2024

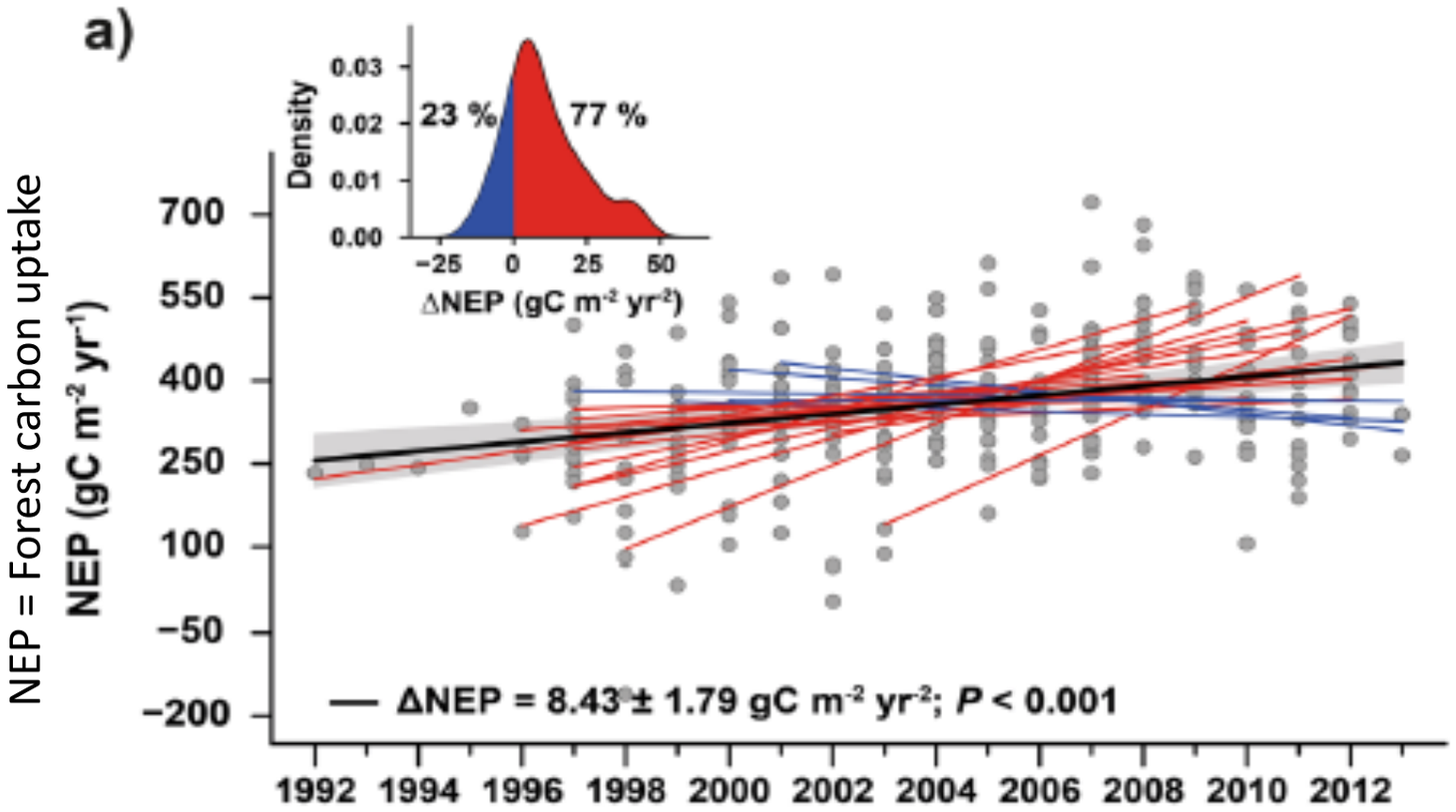
Changes in the sources/sinks over time

The sinks have continued to grow with increasing emissions, but climate change will affect carbon cycle processes in a way that will exacerbate the increase of CO_2 in the atmosphere



The budget imbalance is the total emissions minus the estimated growth in the atmosphere, land and ocean.
It reflects the limits of our understanding of the carbon cycle.
Source: Friedlingstein et al 2024; Global Carbon Project 2024

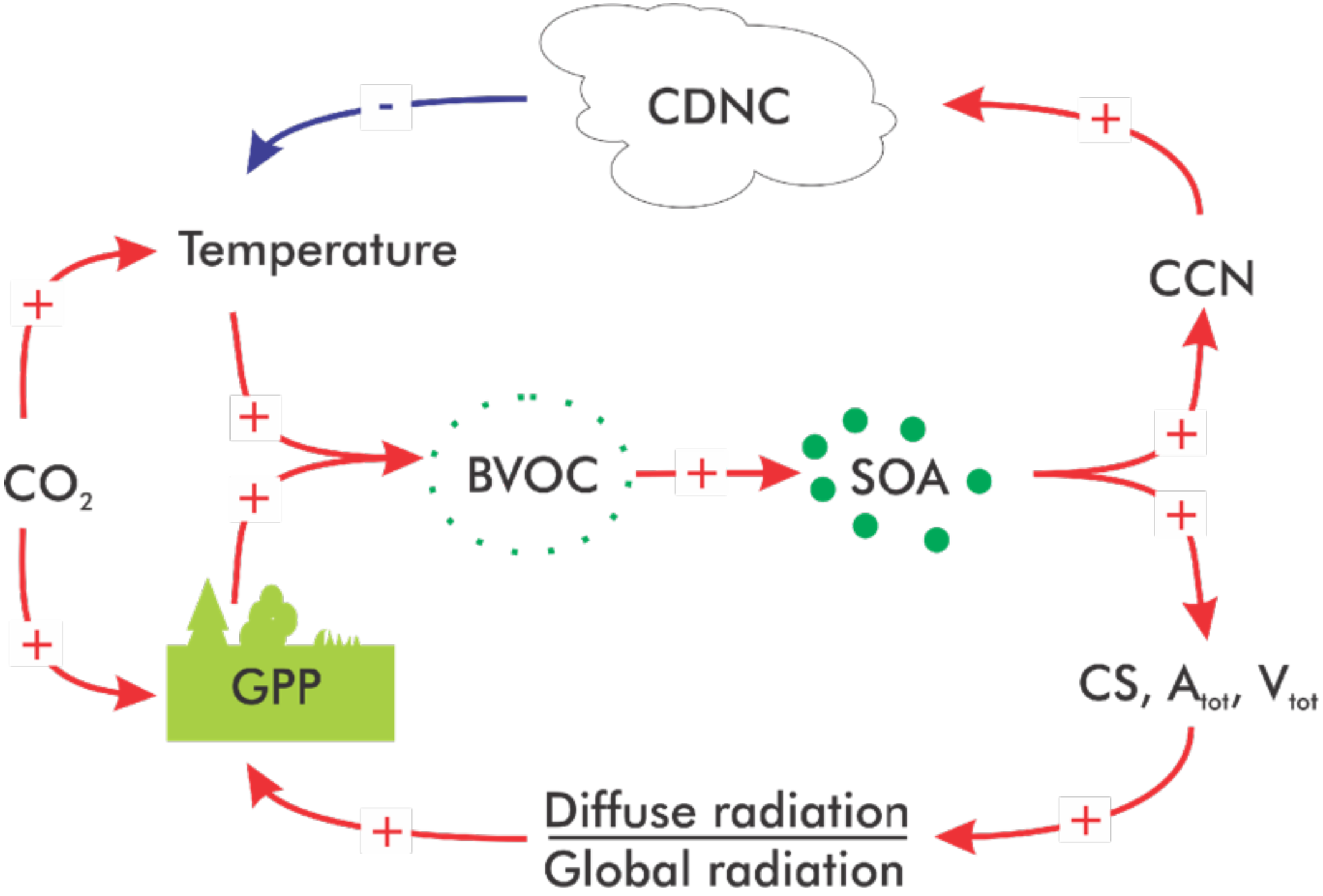
Forest uptake is increasing



Fernandez-Martinez et al. 2017, Sci.Rep.

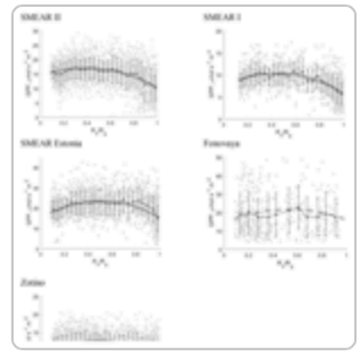
Role of forests in the climate system

CO2 induced terrestrial climate feedback



Aerosol effect on the climate feedback system

Direct effect of aerosols on solar radiation and gross primary production in boreal and hemiboreal forests



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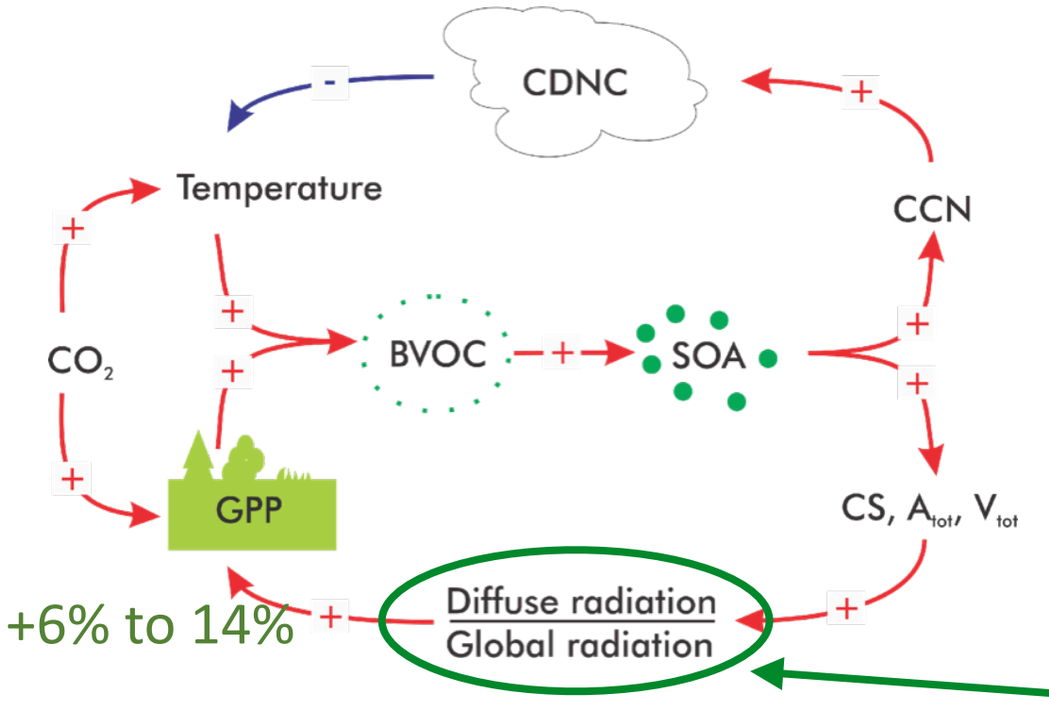


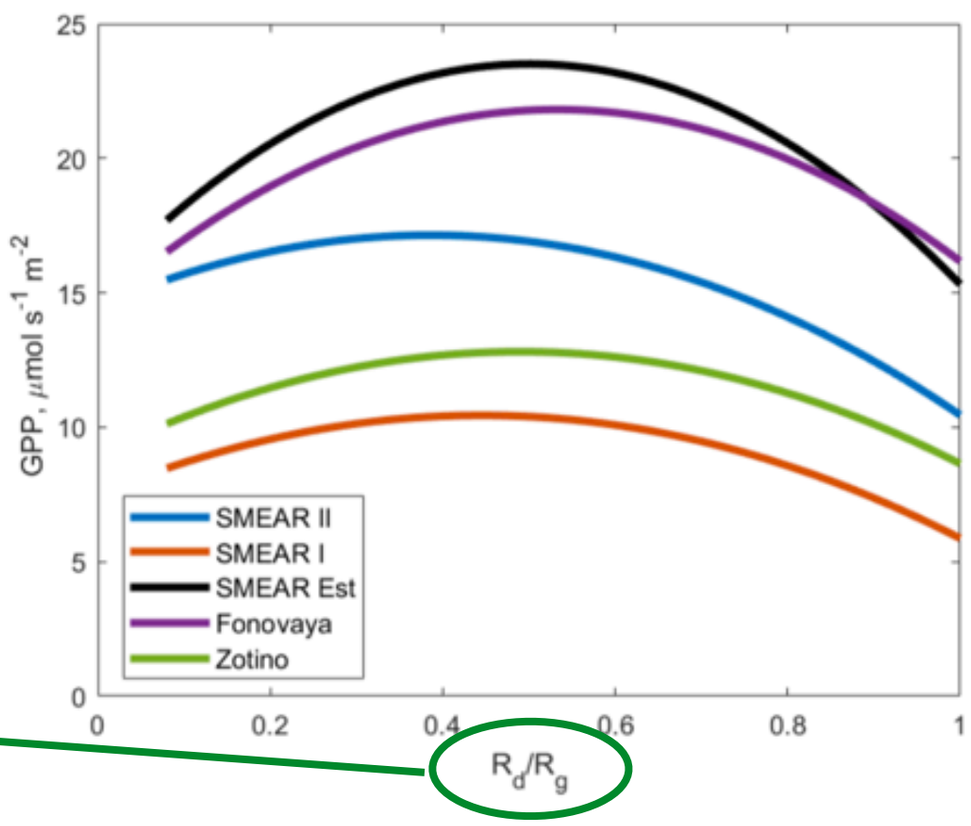
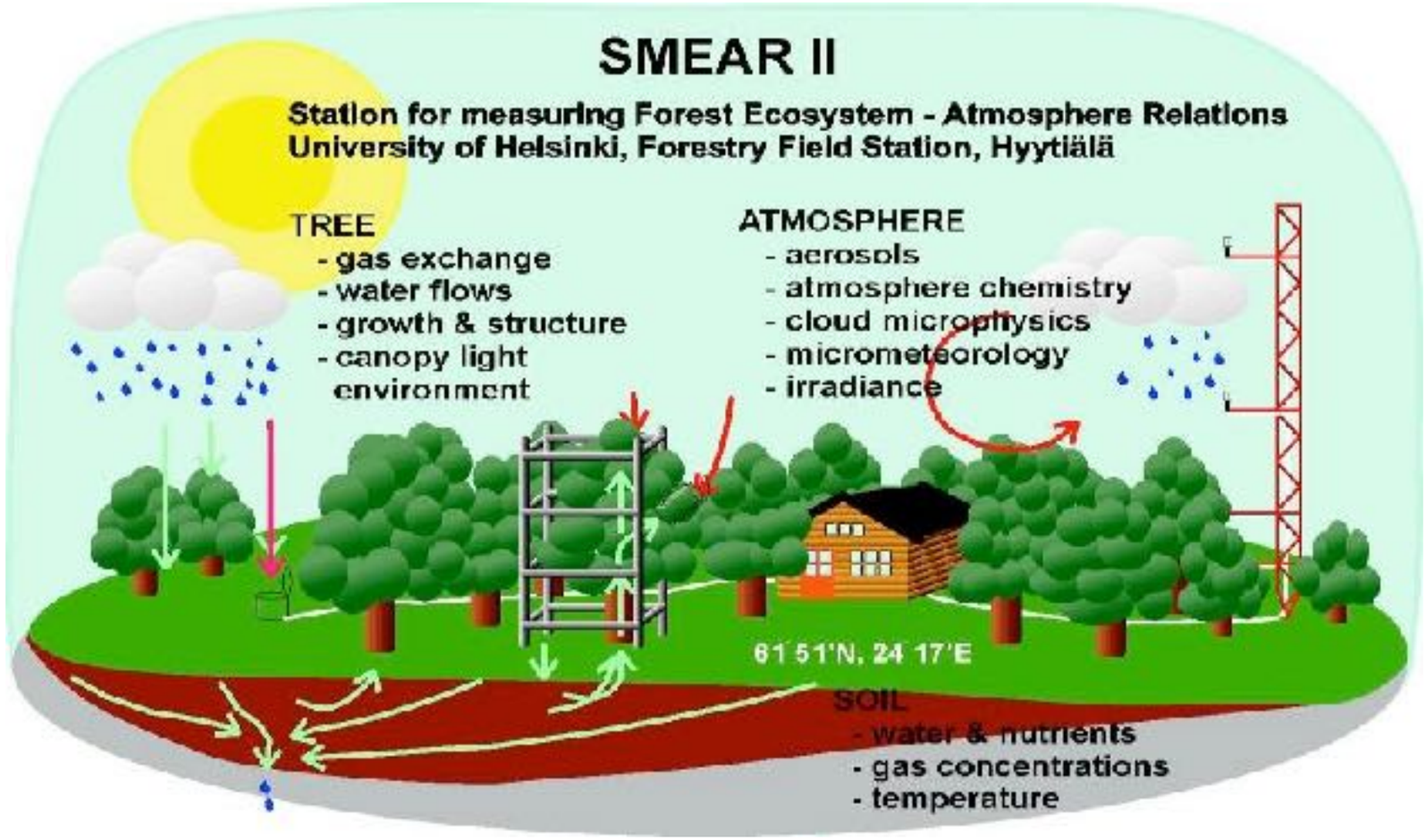


Figure 8. Estimated GPP dependences on R_d/R_g for all the sites (obtained as GPP = LUE · PAR using the coefficients for PAR and LUE dependences on R_d/R_g reported in Table 4).

How to measure biosphere-atmosphere interactions



The goal is to measure energy and mass fluxes in a continuous and comprehensive way.

Linking processes between atmosphere and forest ecosystem to assess their impact on climate.

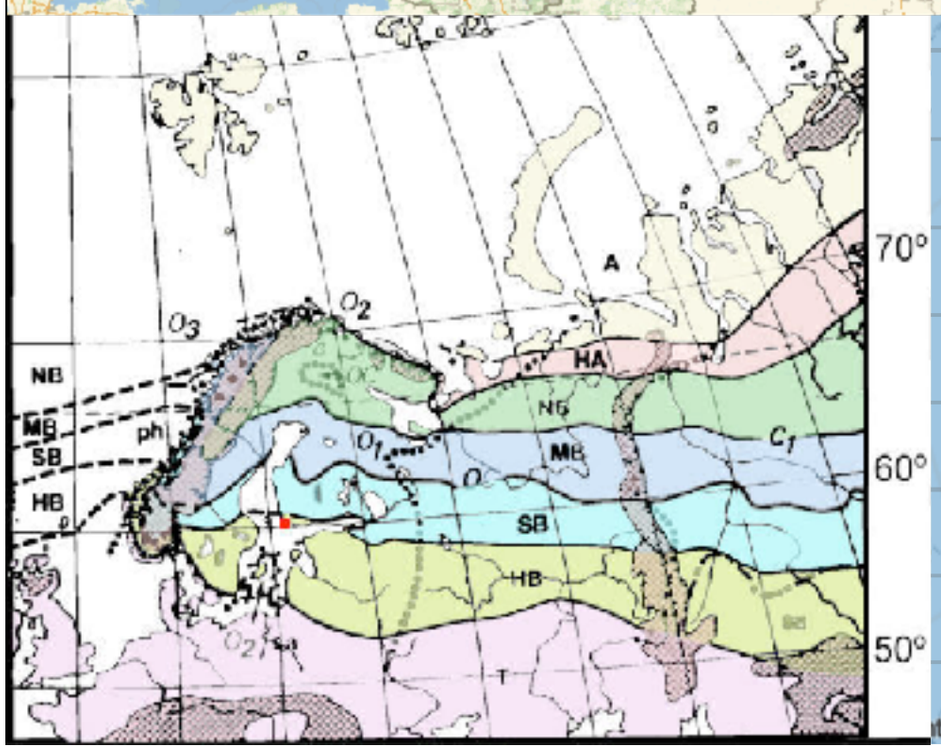
Info: http://smear.emu.ee and http://www.atm.helsinki.fi/SMEAR/

The SMEAR measurement network

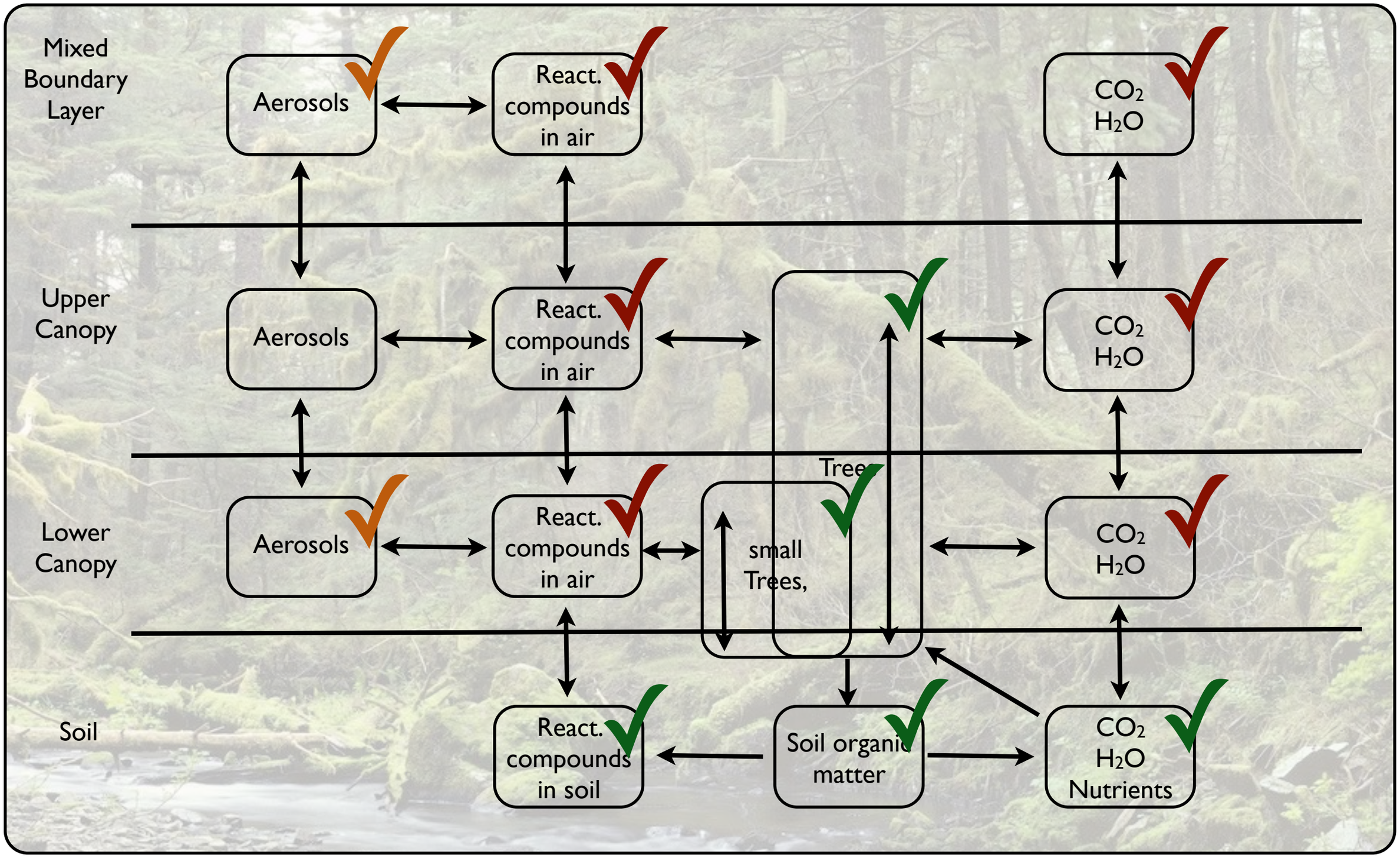
The Järvselja forest site:

heterogenous hemiboreal mixed forest (~55% conifers,~45% deciduous) main species are Norway Spruce, Scots Pine, Silver Birch, Downy Birch

Total area 11 000 ha, ~6 000 ha forest, ~4 500 ha managed



SMEAR Estonia working hypothesis



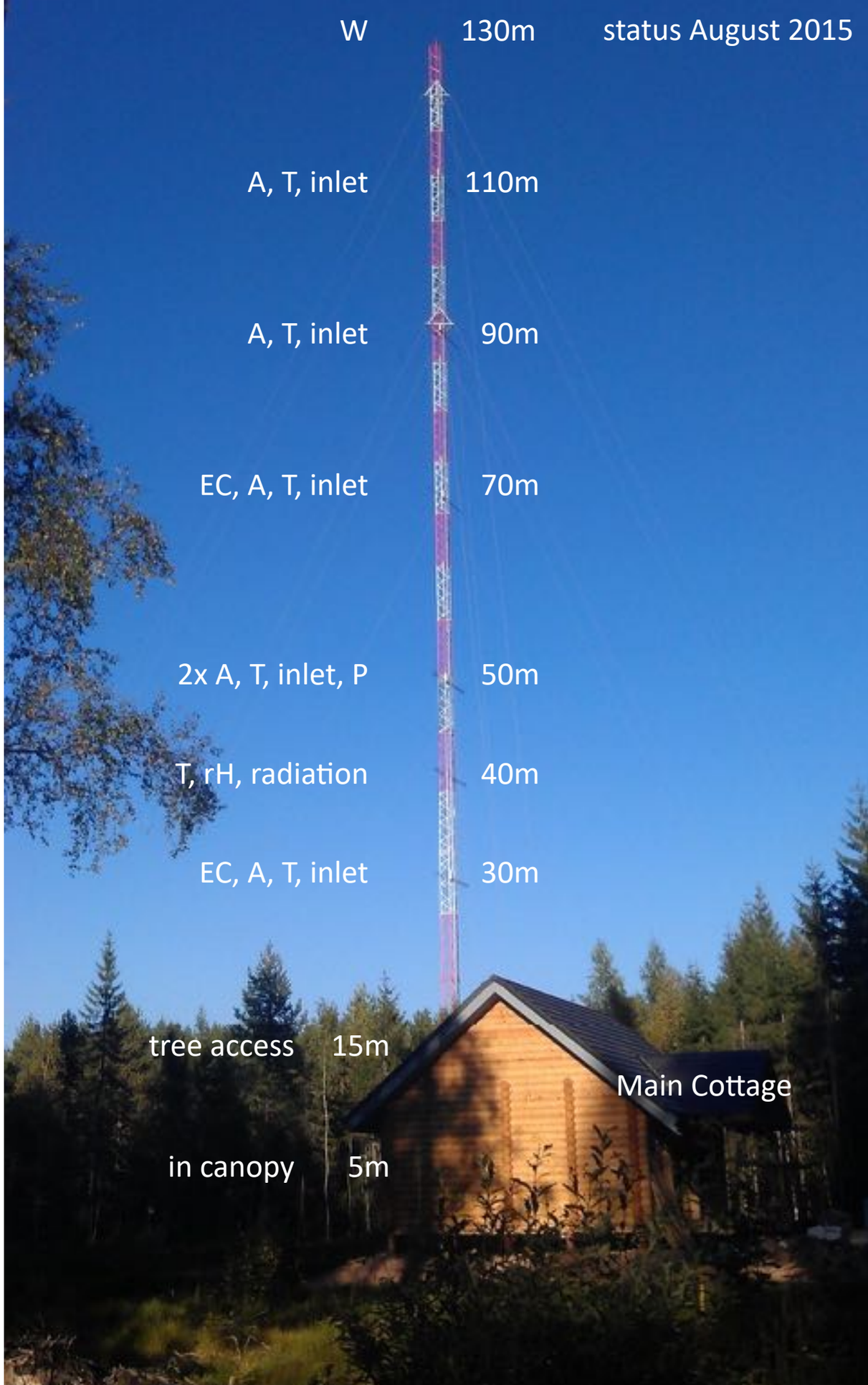
✓ continouus ✓ episodes ✓ continuous (two locations)

SMEAR Estonia

Järvselja/Apna 130 m tower

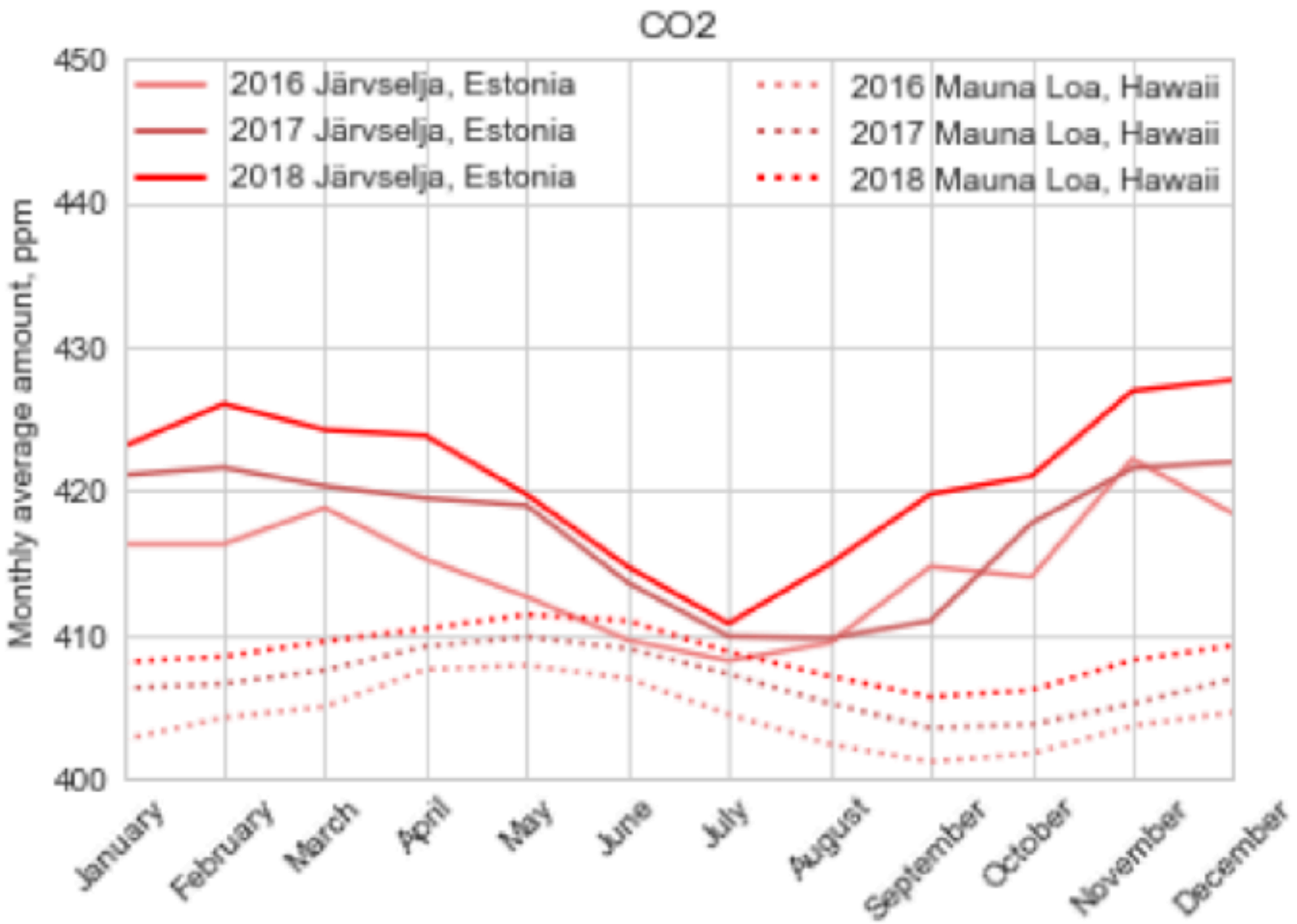
Current measurements

- Eddy covariance at 30 and 70 m
- Gases CO2, H2O, Methane, Ozone, NO, NO2, SO2 at 30, 50, 70, 90, 110m
- Turbulence and temperature at 30, 50, 70, 90, 110m
- Radiation 40m
- Meteorology (W, T, P, rH, rain)
- Soil fluxes
- Dendometers
- Above and below ground biomass
- Aerosol and air ion measurements
- Scaffolds 30m in Pine and Birch dominated forest



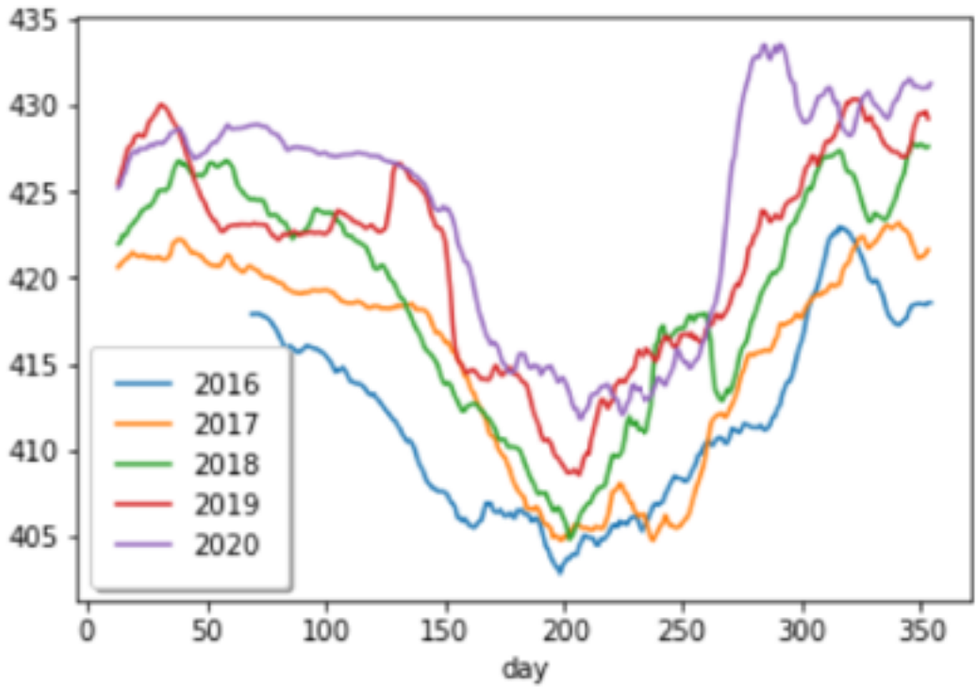
Monthly CO2 mixing ratio

Comparison between NOAA Mauna Loa and SMEAR Estonia

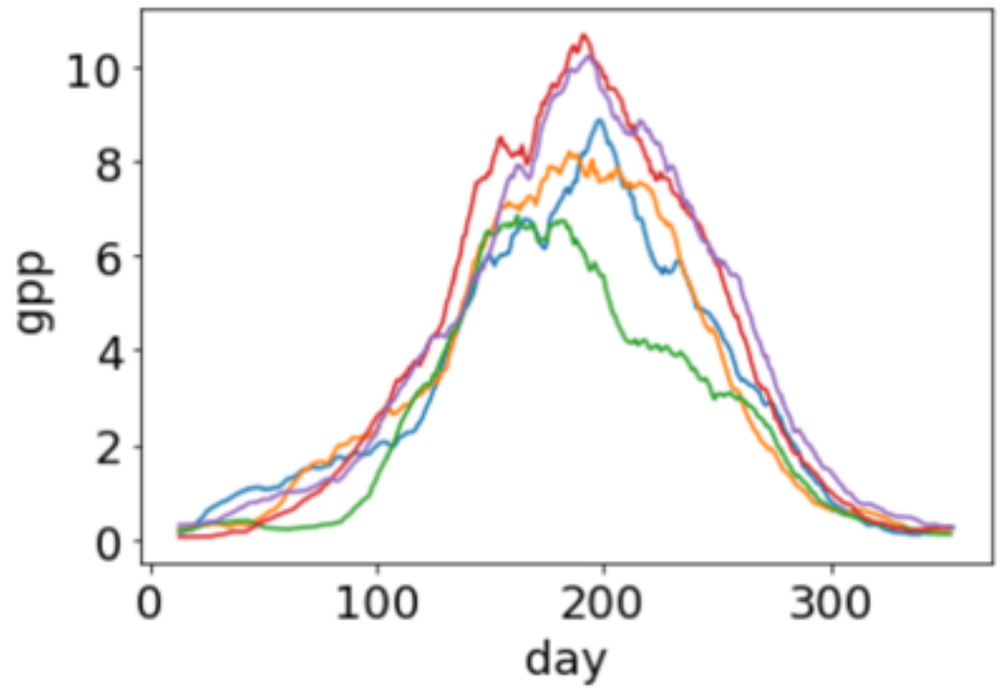


Monthly average CO2 mixing ratio in ppmv

SMEAR Estonia daily averages

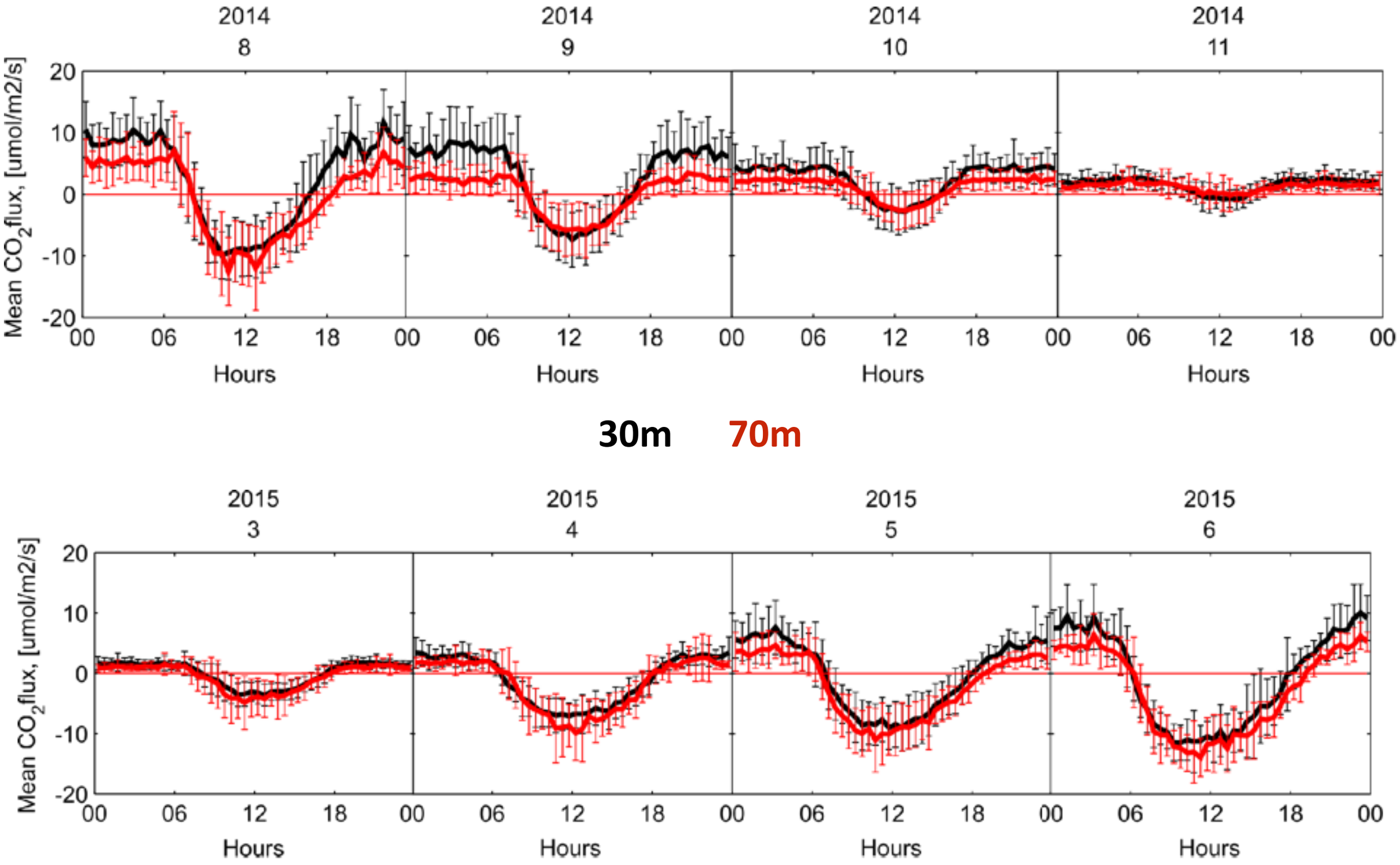


Daily average CO2 mixing ratio in ppmv



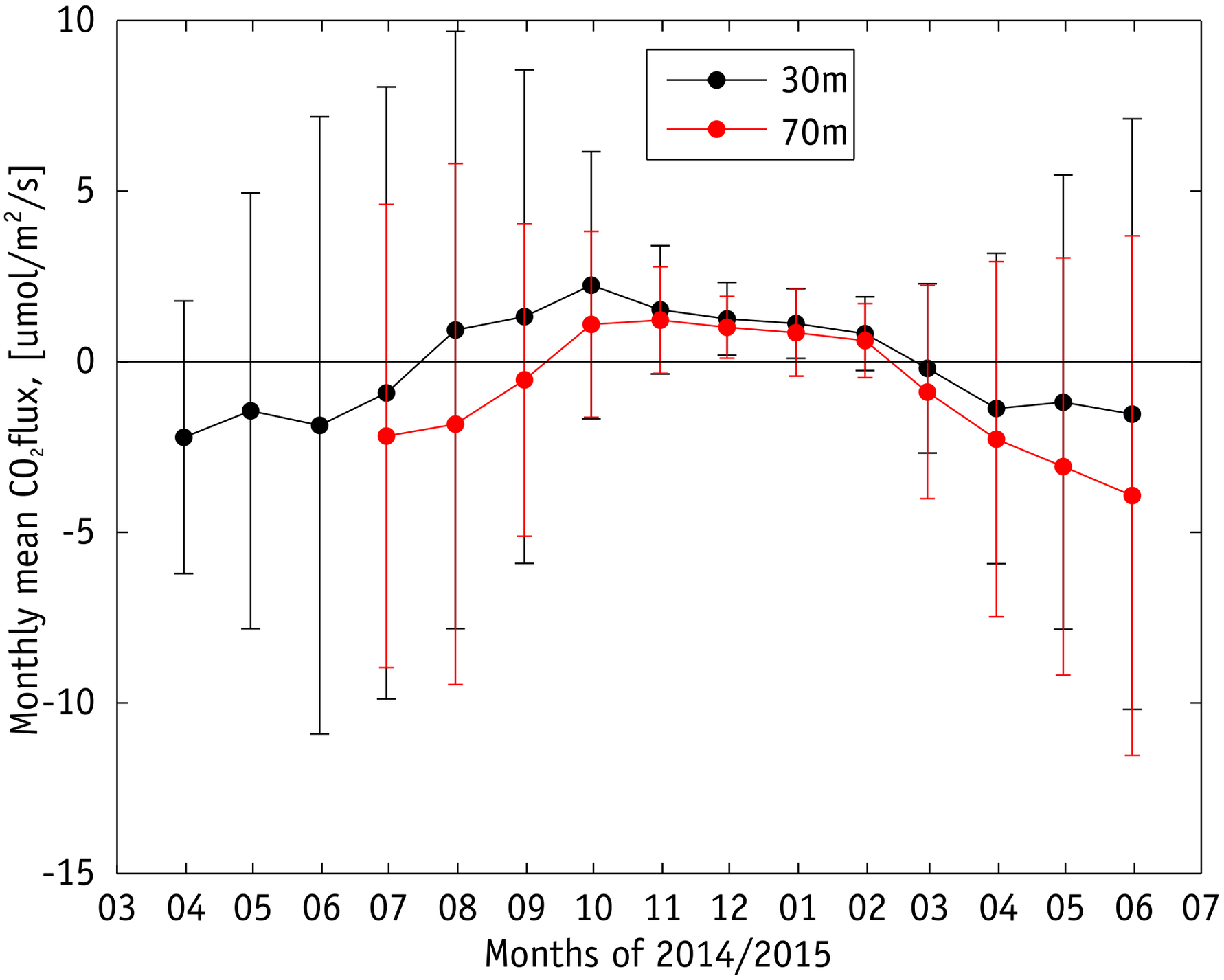
Daily average carbon uptake, GPP in μmol m^{-2} s^{-1}

Carbon fluxes at SMEAR Estonia



30m **70m**

Monthly CO_2 flux



Lecture