10. Turbulent fluxes II

Trace gas fluxes, e.g. CO_2

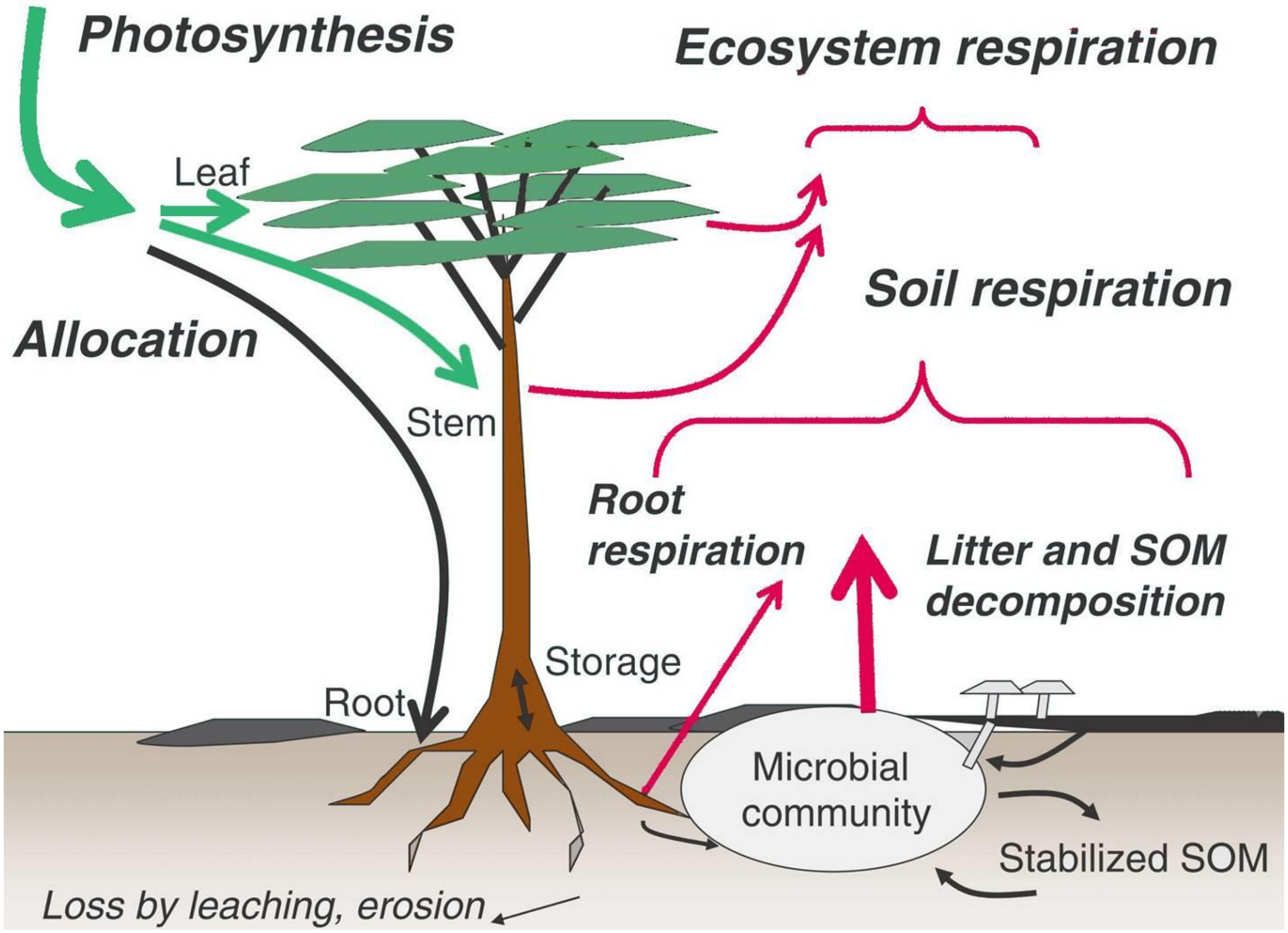
Dr. Christian Markwitz and Prof. Alexander Knohl

Experimental bioclimatology

What will we learn today?

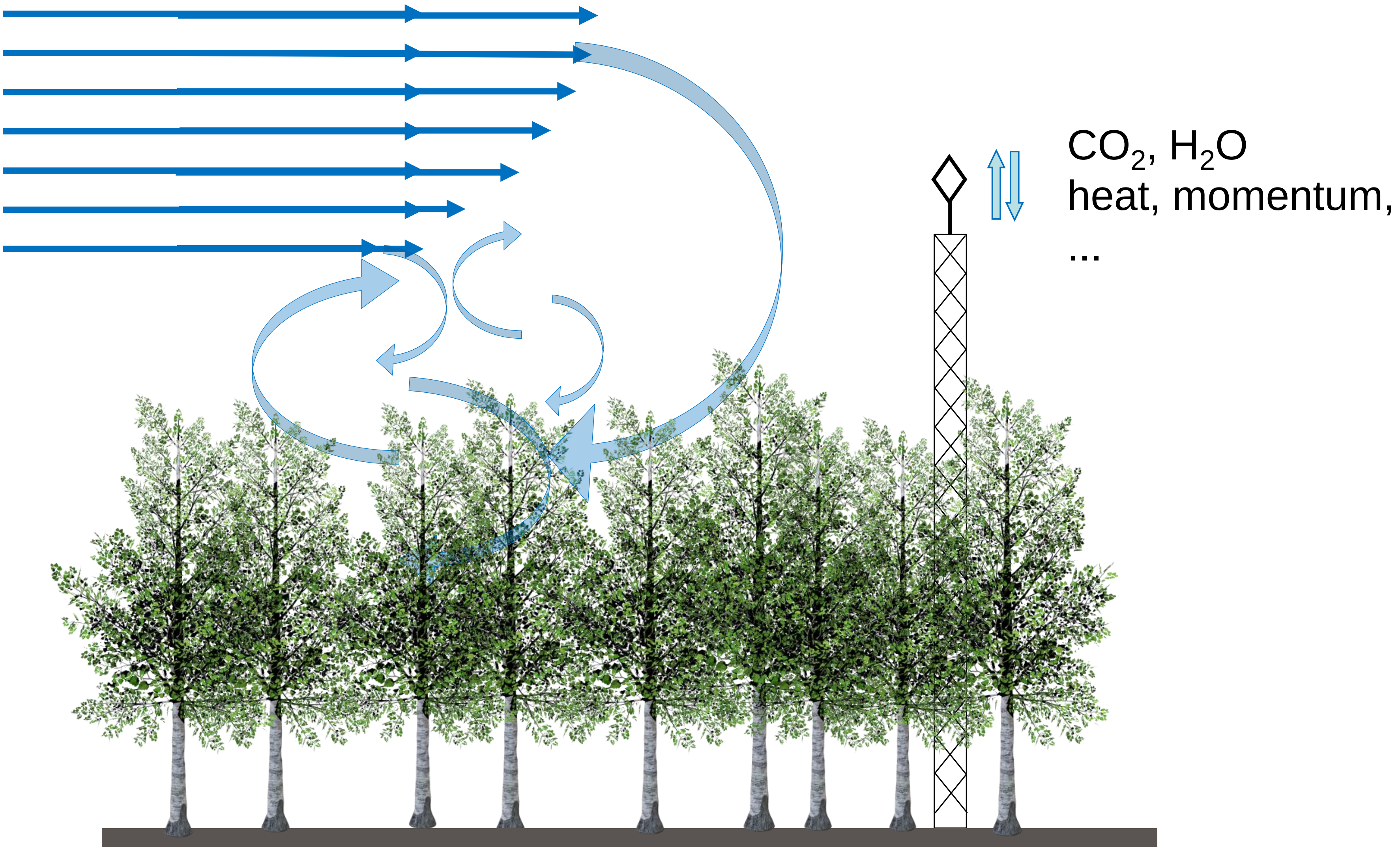
- How is CO_2 exchanged between the land surface and the atmosphere?
- What governs the fluxes of CO_2 between the land surface and the atmosphere?
- What is eddy covariance?
- What kind of sensors and calculations do we need to measure CO_2 fluxes?

Carbon cycle in land ecosystems

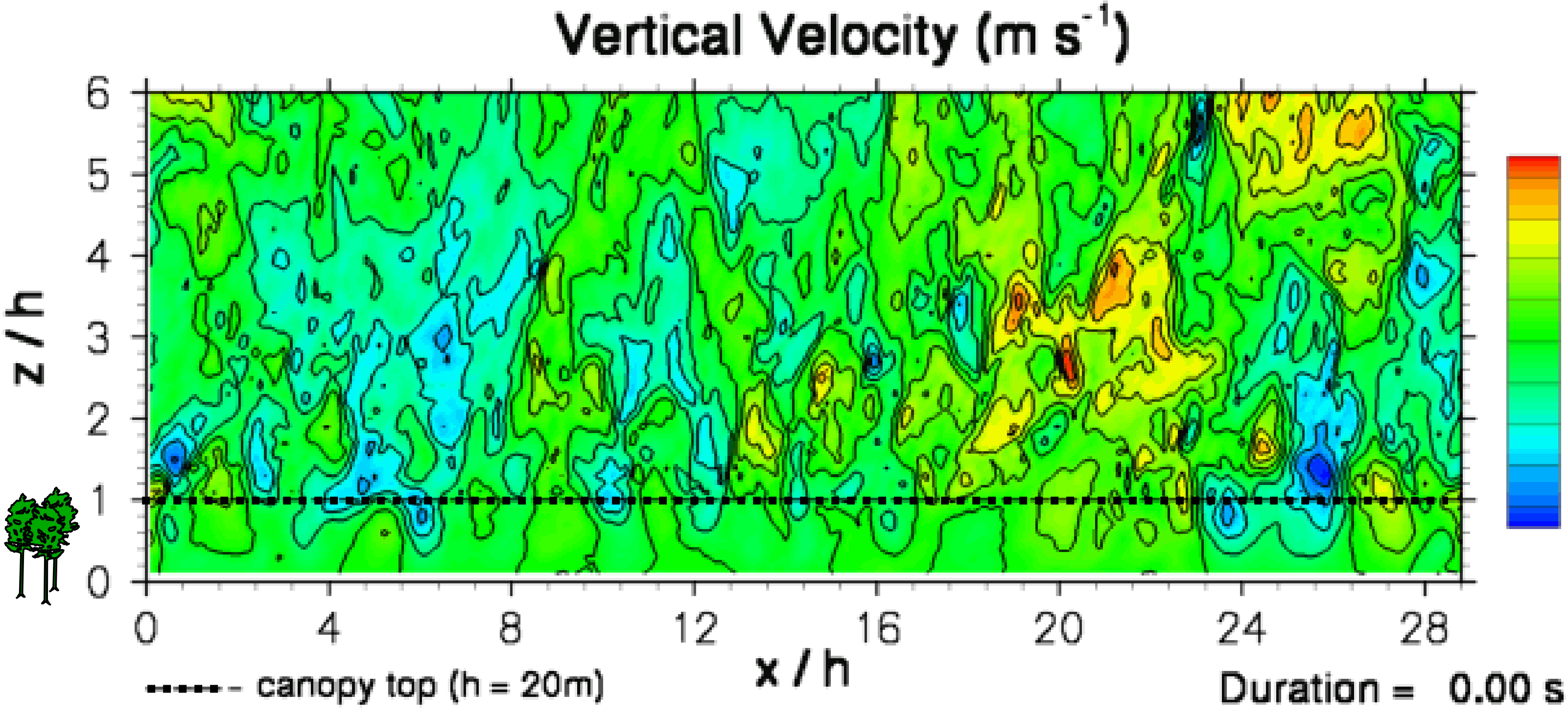


Trumbore (2006)

Turbulent exchange over forests

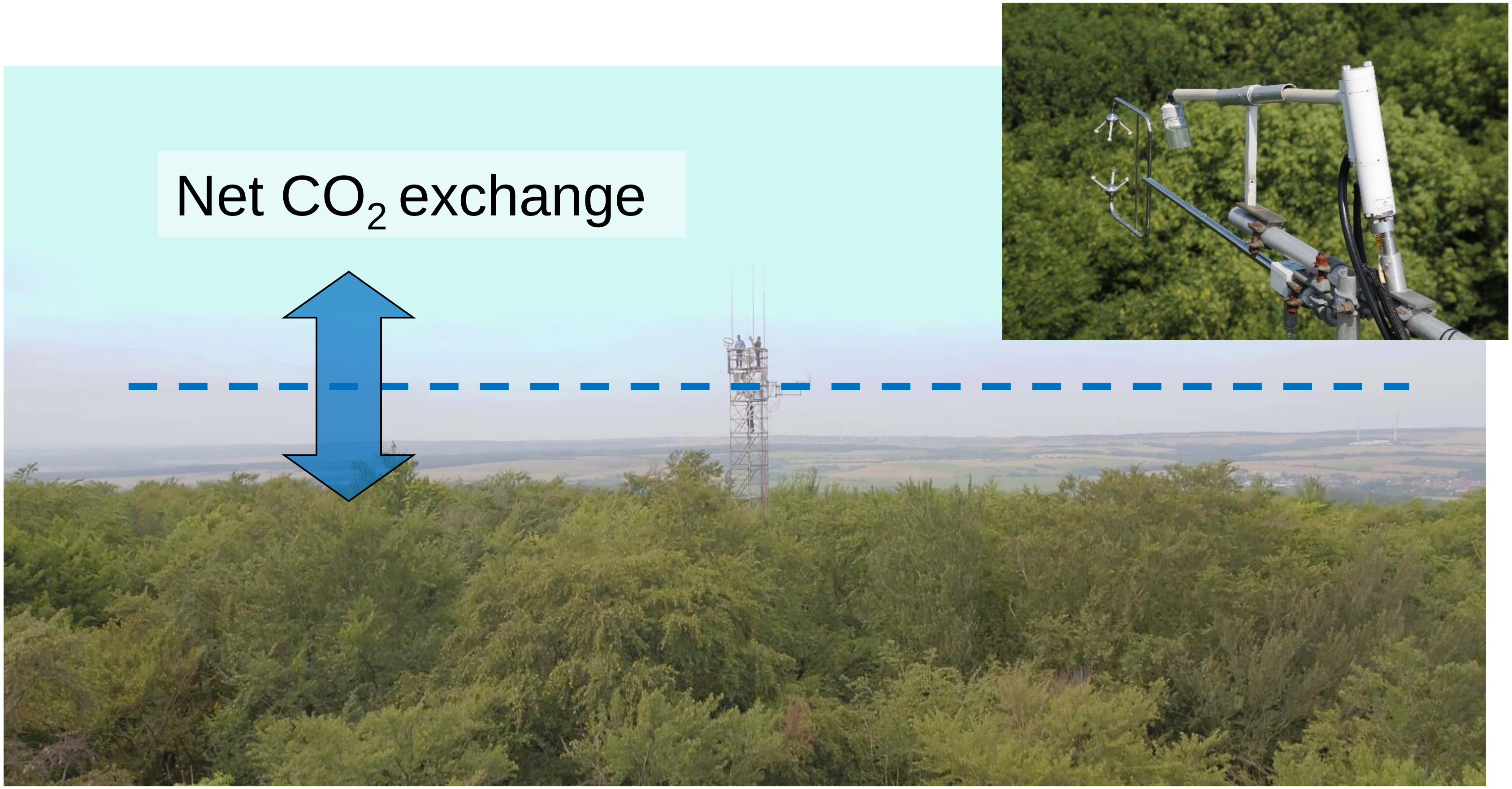


Simulation of vertical wind velocity



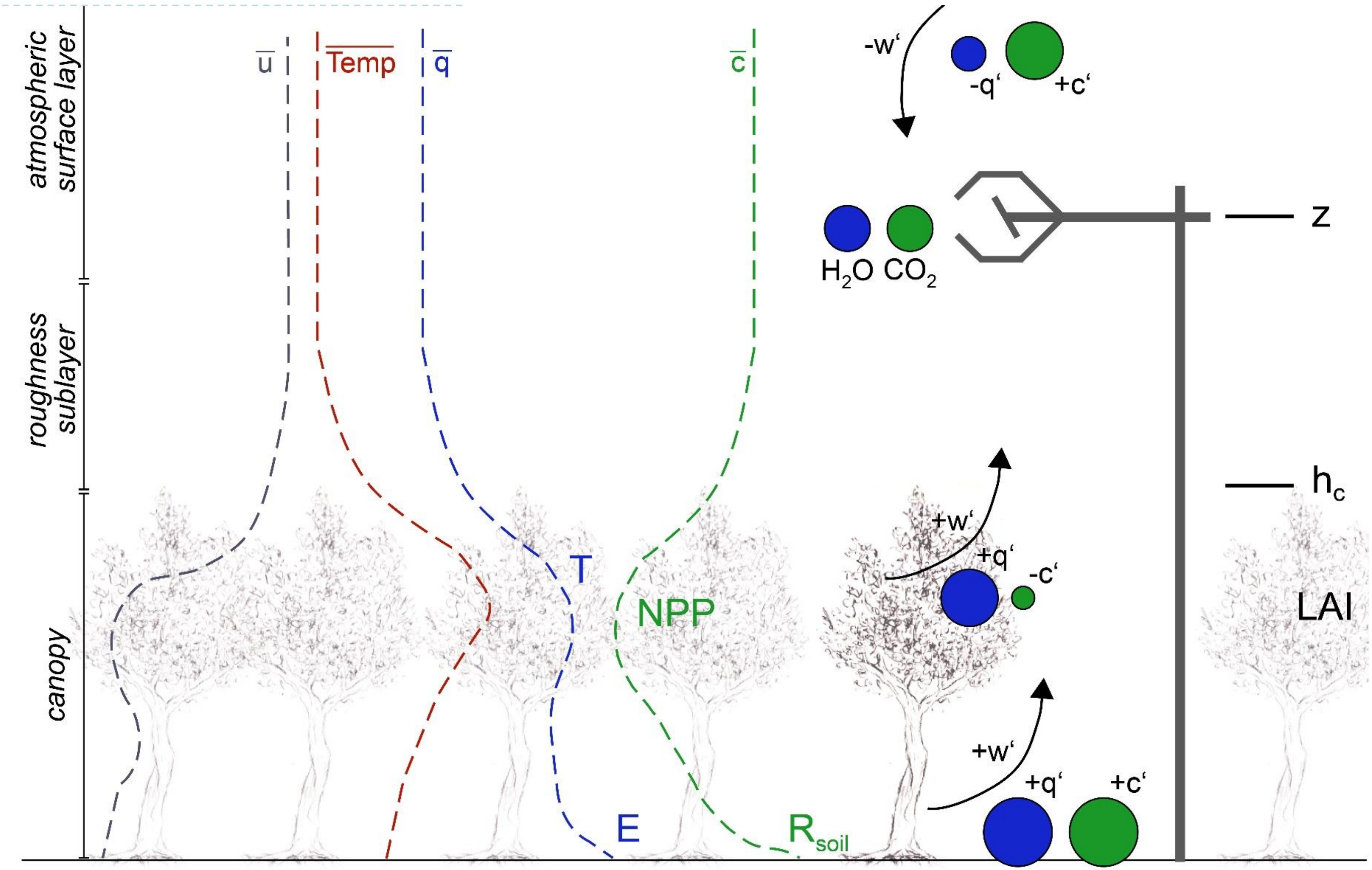
Source: Ned Patton, NCAR

Measurement of the net CO_2 exchange

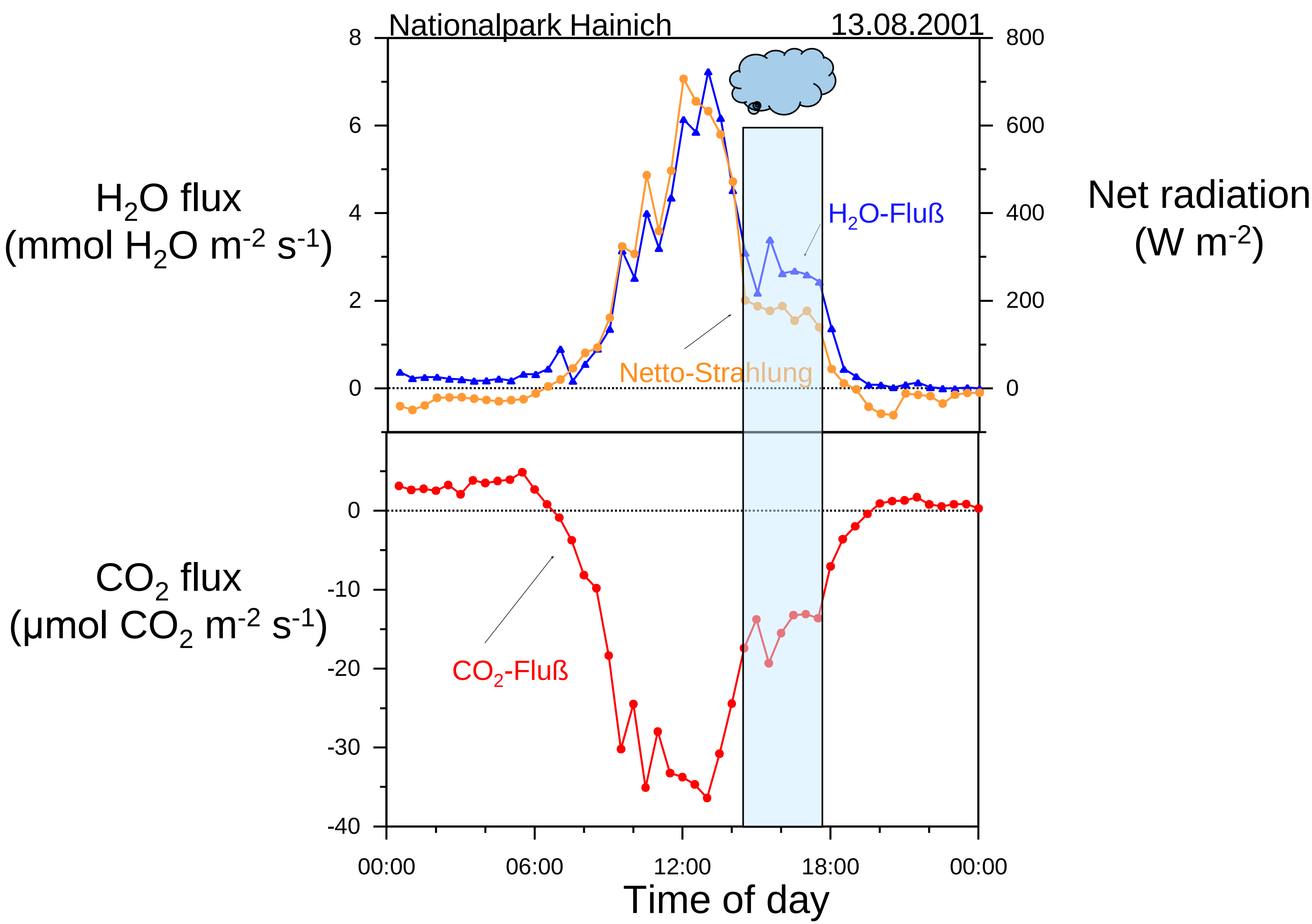


- direct and continuous, no disturbance of the ecosystem
- integrating over the entire ecosystem (plants and soil)

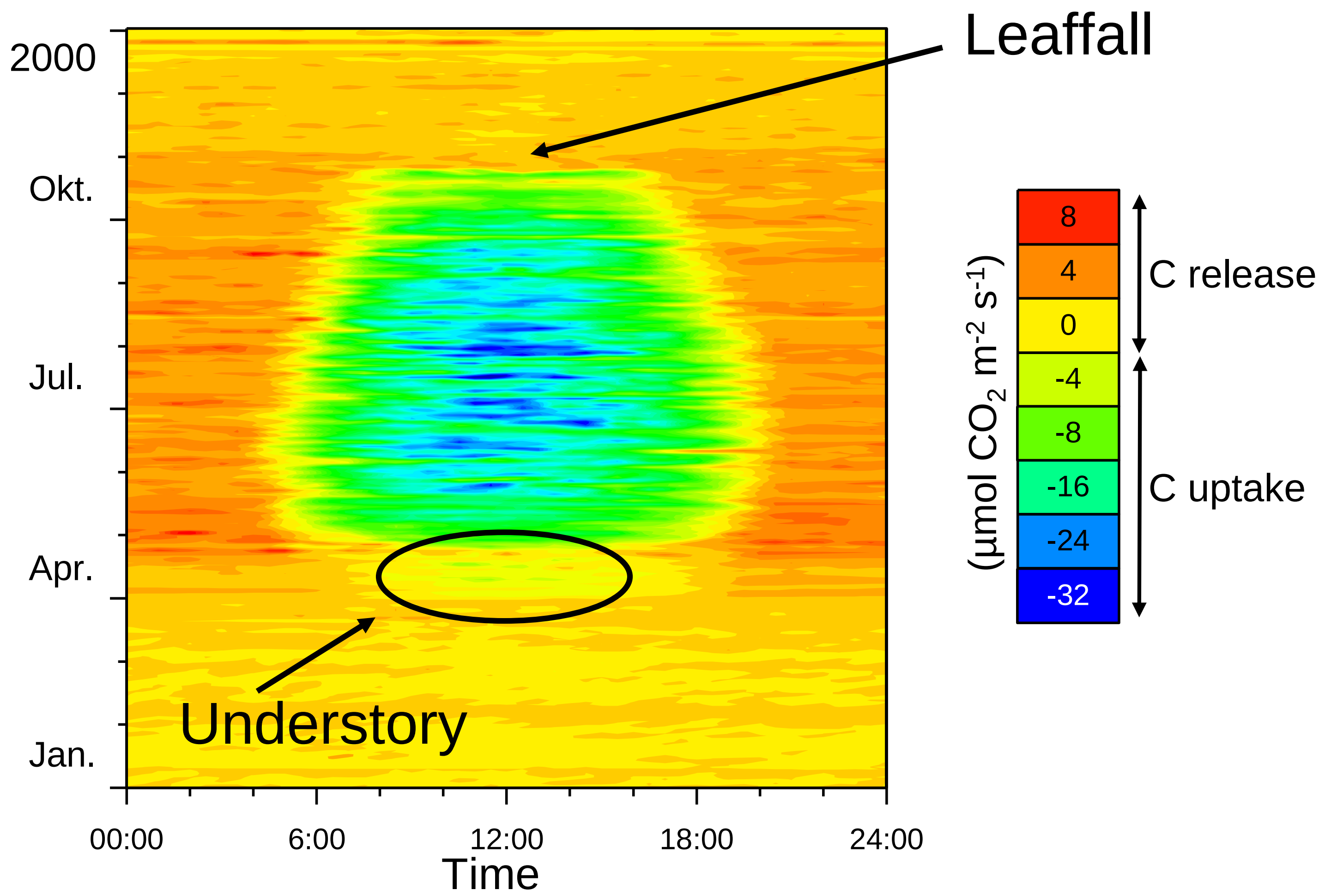
Profiles and fluxes



Breath of the ecosystem

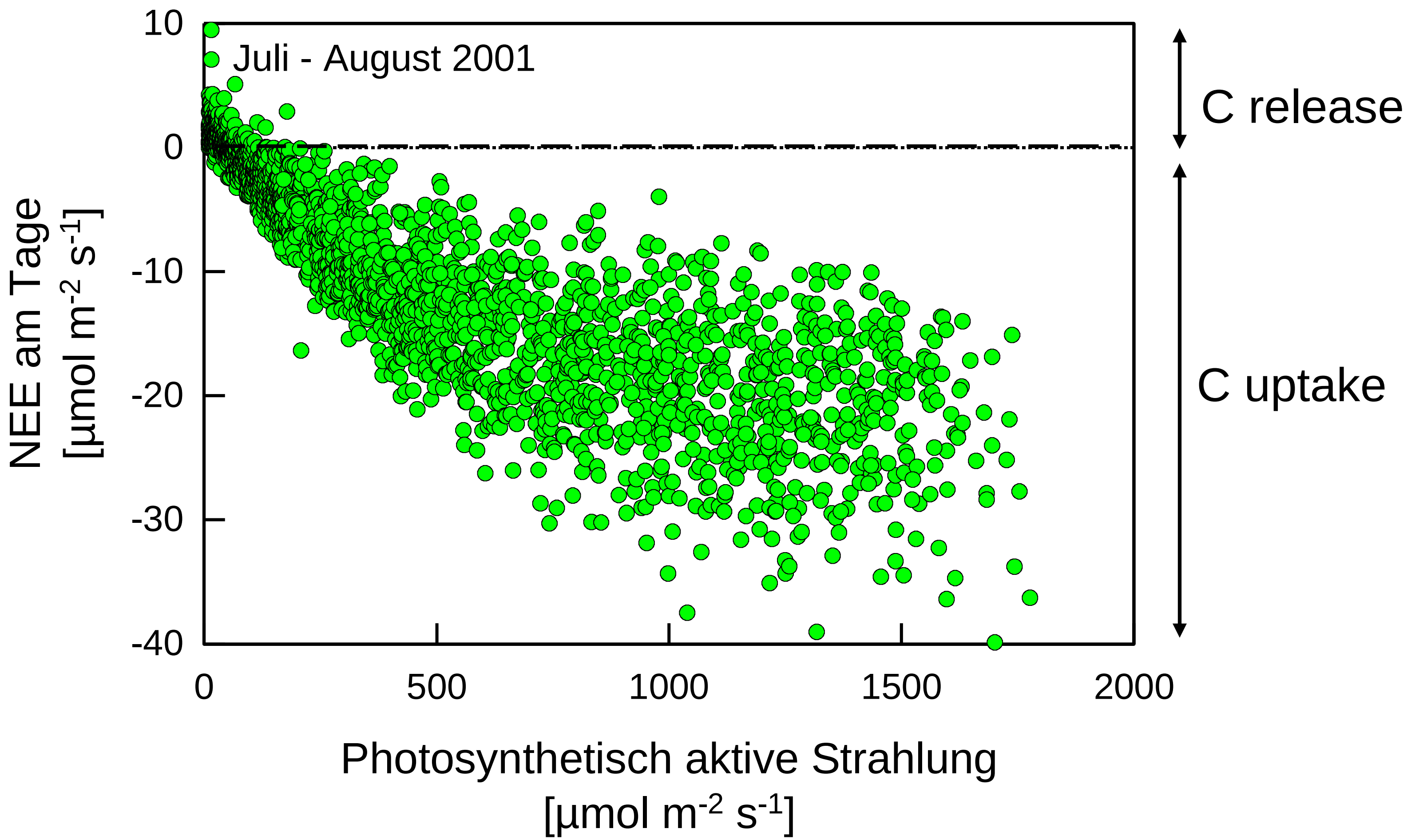


CO_2 fluxes in 2000



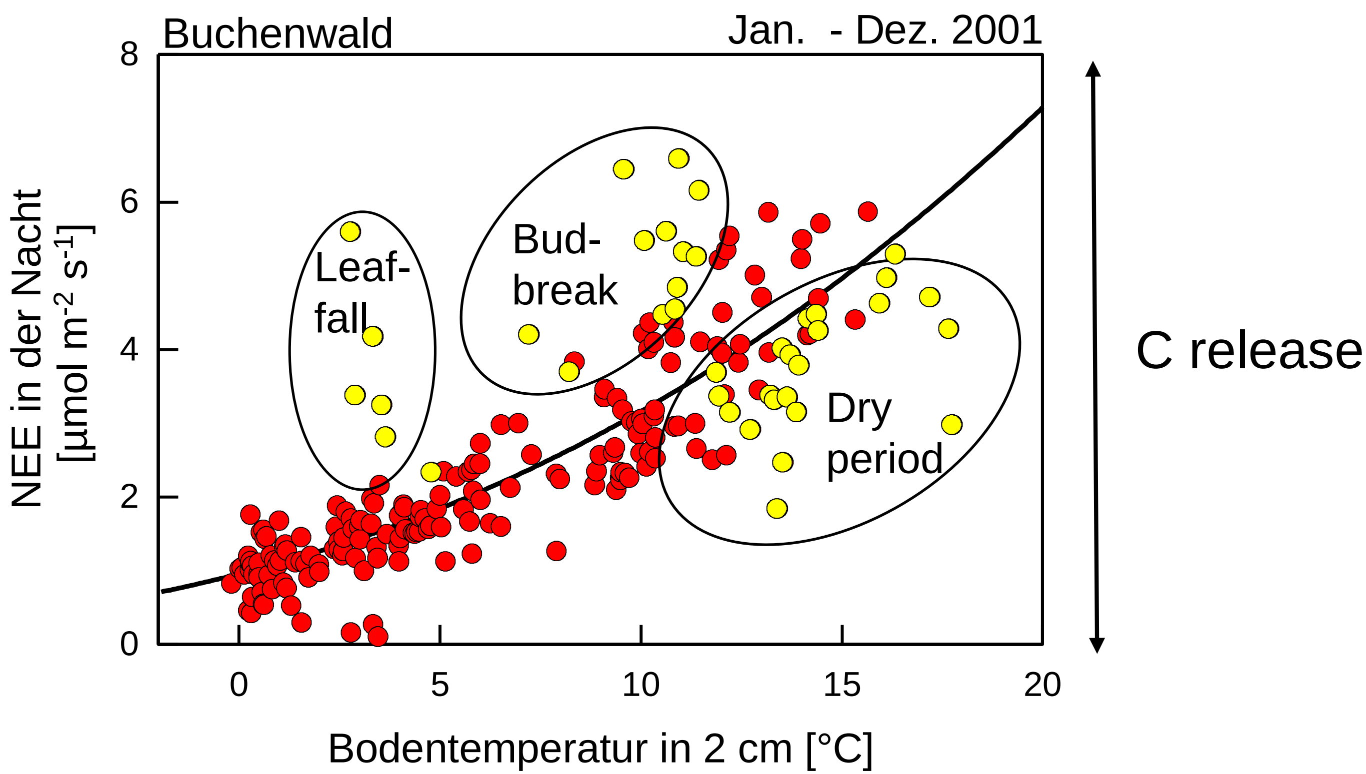
- **NEE**: Net ecosystem CO_2 exchange: - 470 g C m^{-2} y^{-1}

Daytime fluxes



- Stronger CO_2 uptake with increasing PAR, saturation at high PAR

Nighttime fluxes



➢ Ecosystem respiration increases with soil temperature

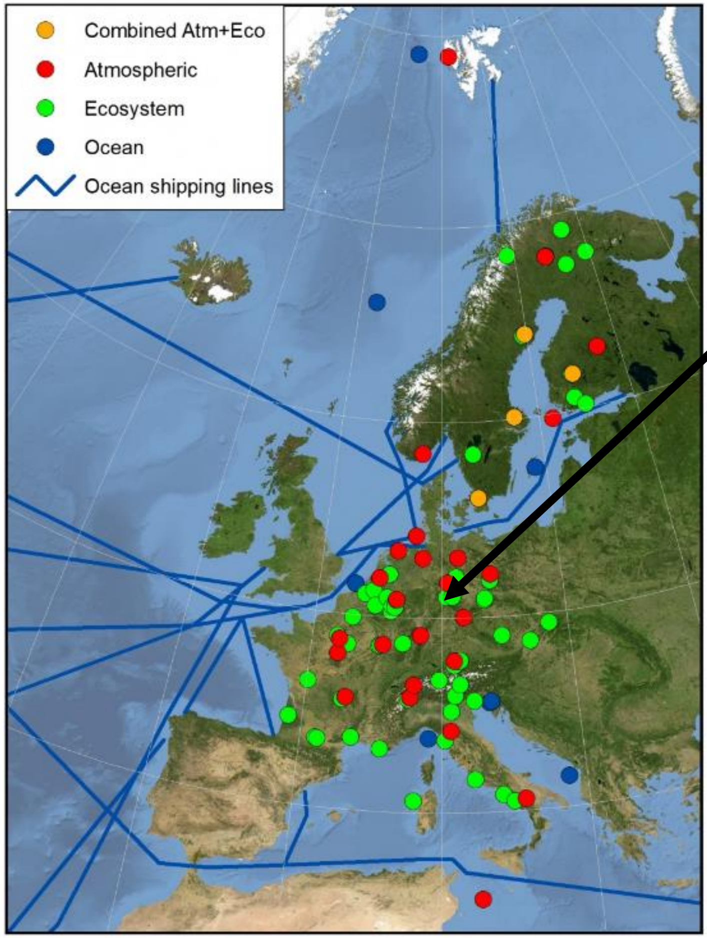
Integrated Carbon Observation System (ICOS)

- Long-term assessment of European carbon balance

Atmosphere

Terrestr. ecosystems

Ocean



Hainich

ICOS INTEGRATED CARBON OBSERVATION SYSTEM

Fluxnet – a global network

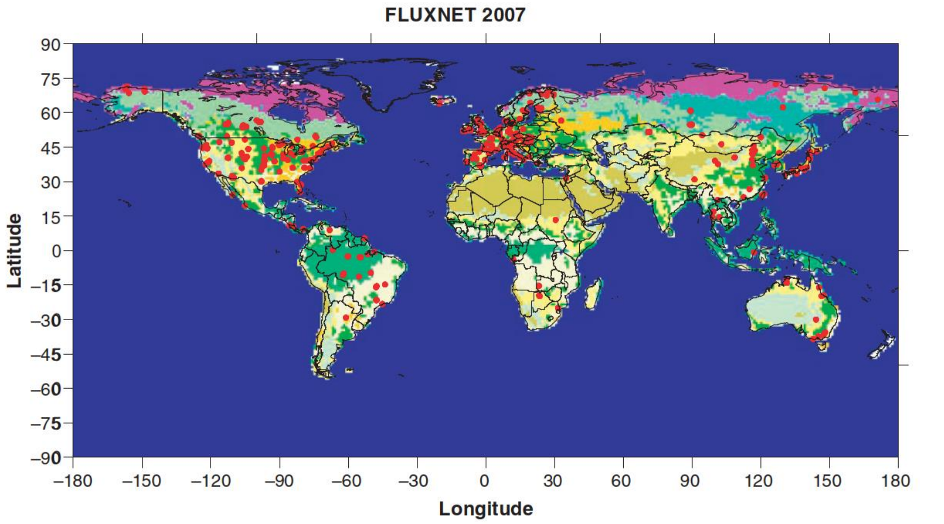
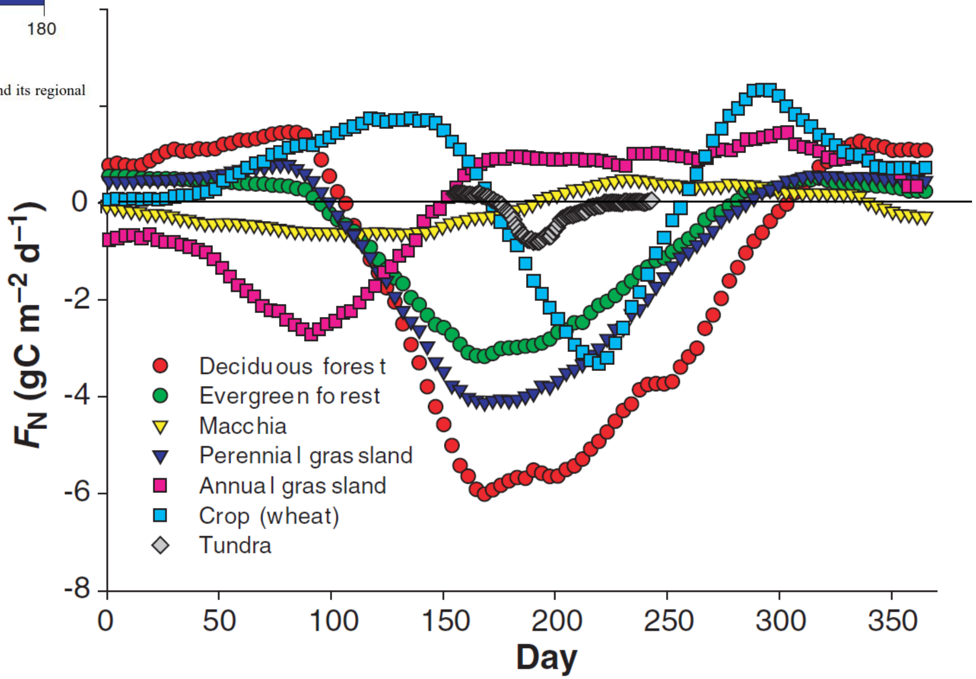


Fig. 1. Global distribution of long-term CO_2, water-vapour and energy-flux measurement sites, associated with the FLUXNET program and its regional partners. The sites overlay the University of Maryland land-use map.



Baldocchi 2008, doi:10.1071/BT07151

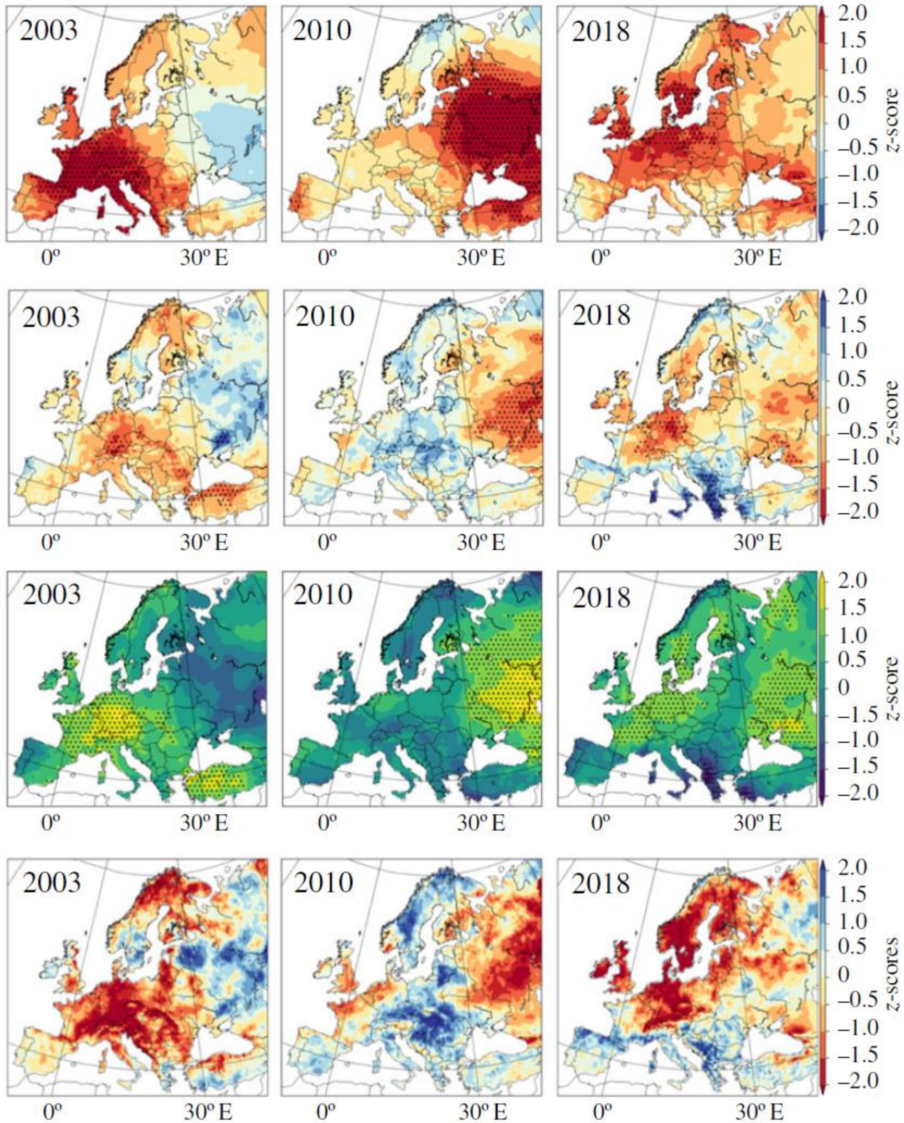
Droughts over Europe

Temperature

Precipitation

Radiation

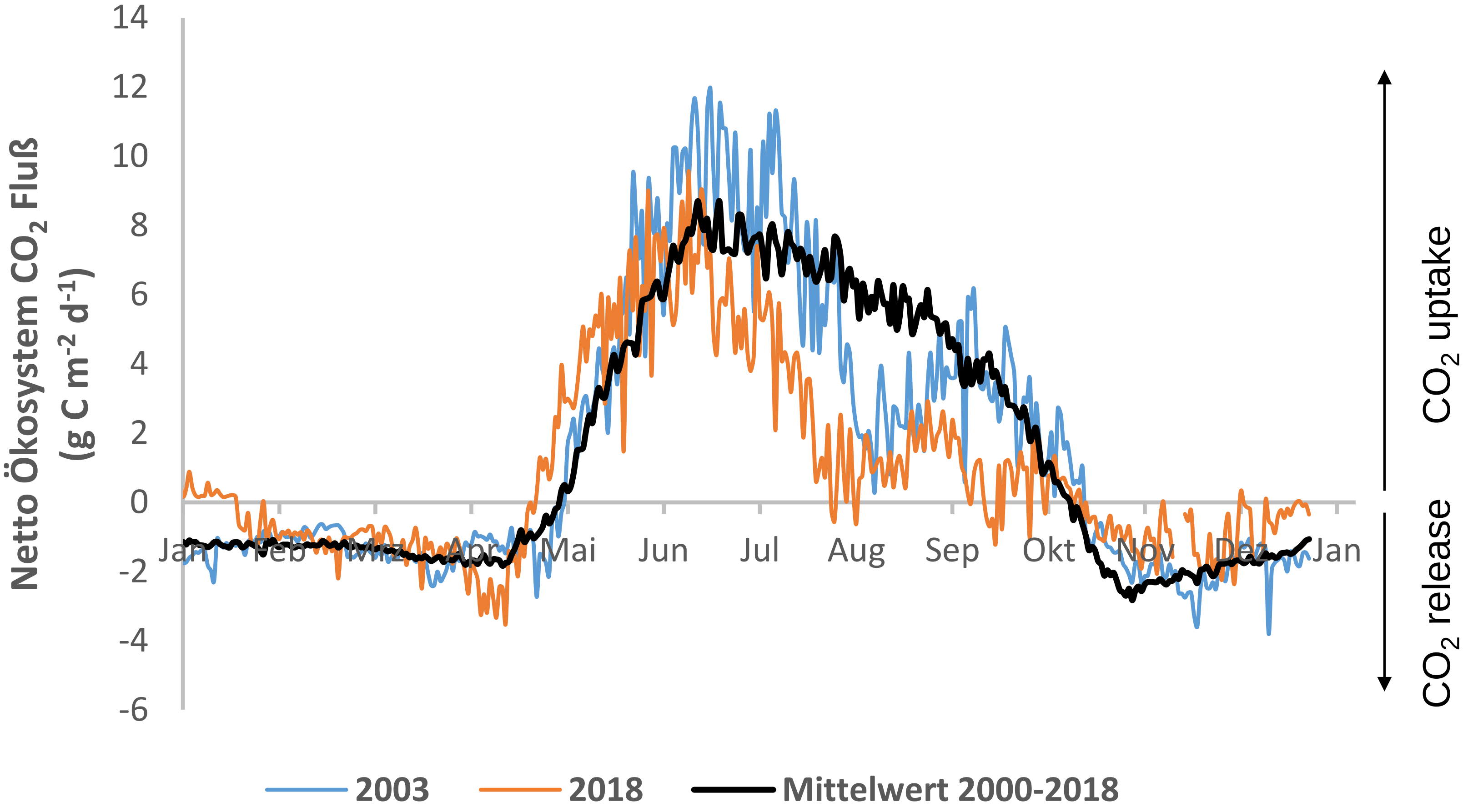
Soil moisture



Anomalies

Peters et al. 2020, S. 4,
doi:10.1098/rstb.2019.0505

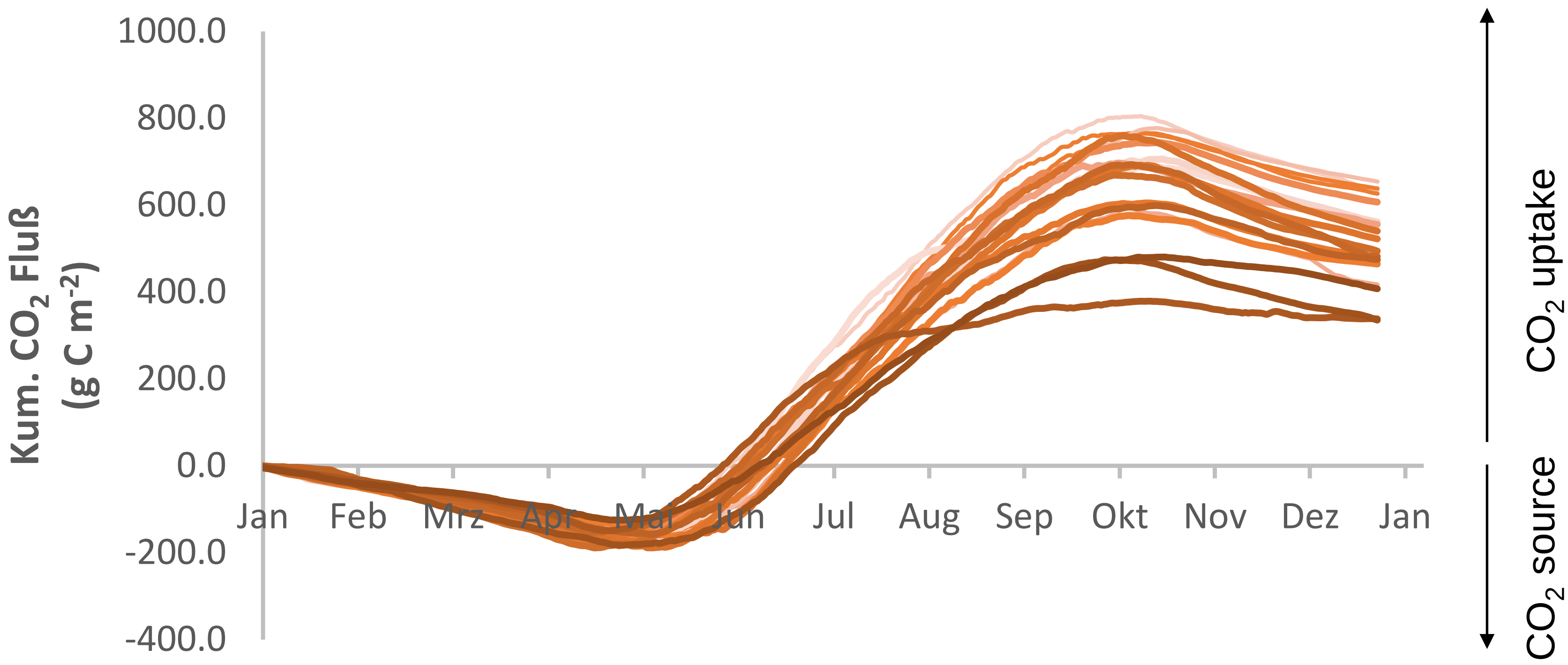
CO_2 exchange of Hainich



Anomaly of annual CO_2 uptake

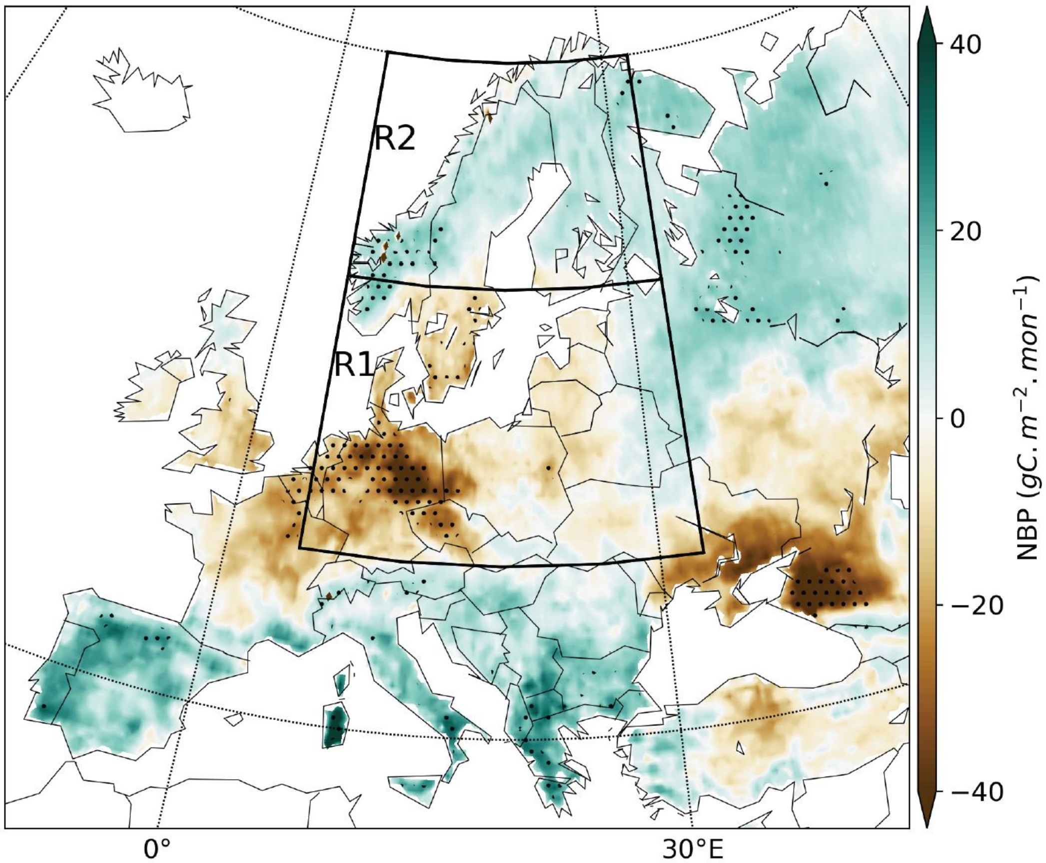
2003 : +6% 2018: -35%

CO_2 uptake over 20 years



- ➢ Only small inter-annual variability over 20 years
- ➢ 2018, 2019 and 2020 with clearly lower annual CO_2 uptake

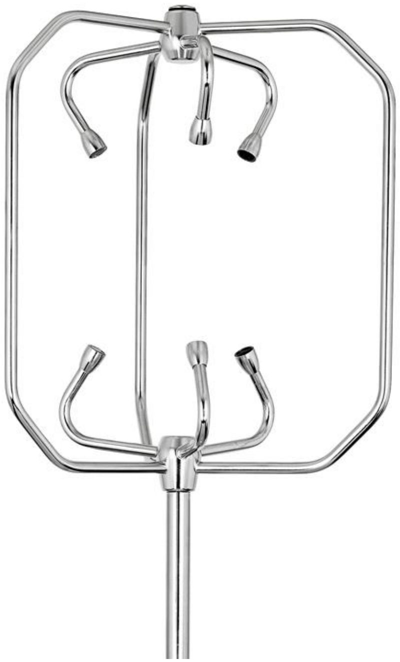
Drought 2018 at continental scale

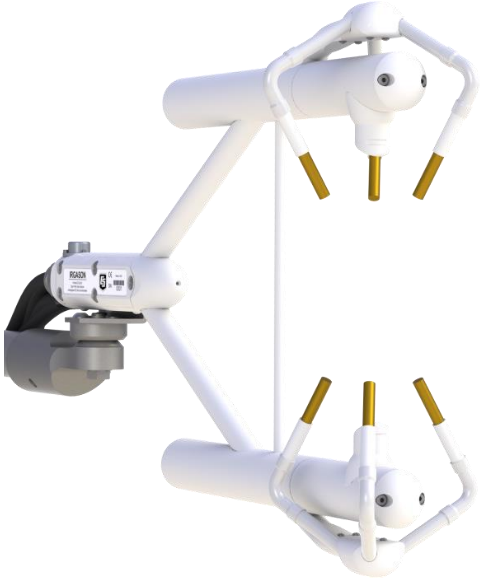


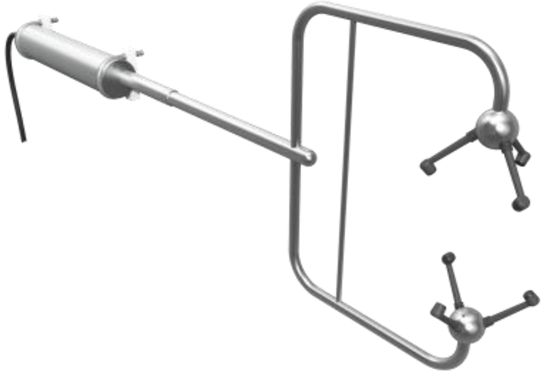
Batos et al., 2020

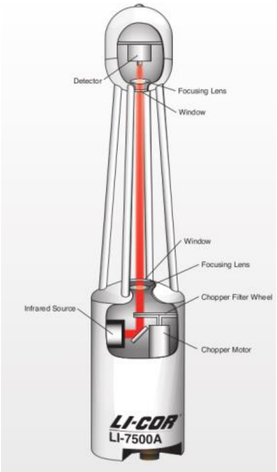
- Strong reduction of CO_2 uptake in central Europe
- Increased CO_2 uptake in Southern and Northern Europe
- Strong regional effects, but on European average smaller effect than in 2003

Eddy covariance measurements









What is a flux?

Flux: exchange of any quantity per area and time

CO_2 flux = $\mu mol\ m^{-2}\ s^{-1}$

H_2O flux = $mmol\ m^{-2}\ s^{-1}$

LE and H = $J\ m^{-2}\ s^{-1} = W\ m^{-2}$

Eddy covariance method

CO_2 flux is computed as follows:

$$F_c = \rho_m \overline{w`c`} = \rho_m \frac{1}{N-1} \sum_{i=0}^{N-1} [(w_i - \overline{w})*(c_i - \overline{c})]$$

F_c: net vertical CO_2 flux (µmol m^{-2} s^{-1})

$\rho_m = p/(R_{uni}\ T)$: molar density (mol m^{-3})

N: number of observations per time interval

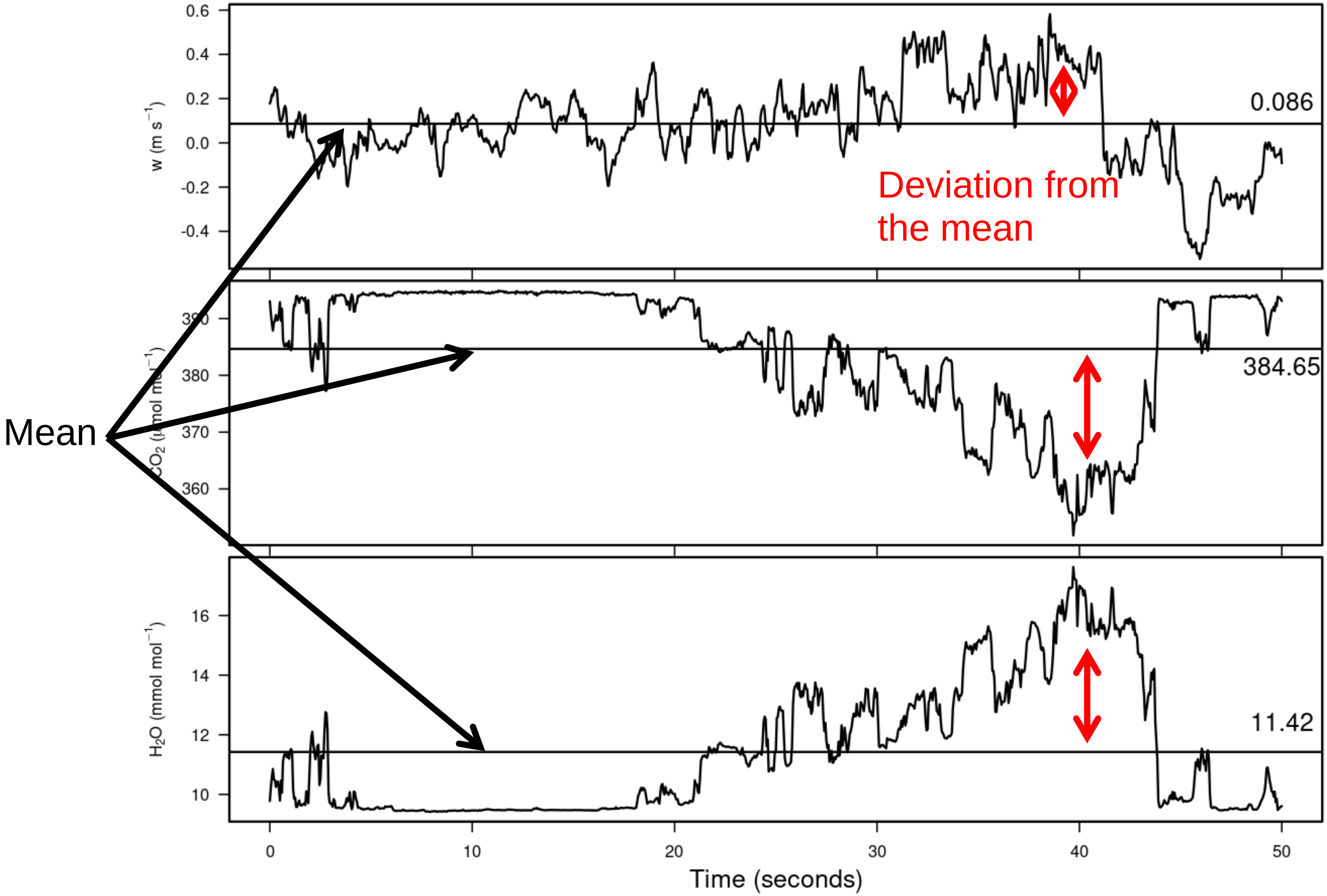
w: vertical wind velocity (m s^{-1})

c: CO_2 dry air mole fraction (µmol mol^{-1})

$w' = w_i - \overline{w}$ -> deviation from the mean for w

$c' = c_i - \overline{c}$ -> deviation from the mean for CO_2

Eddy covariance method



Eddy covariance method

Other fluxes are:

CO_2 flux: $F_c = \rho_m \overline{w`c`}$ (μmol m^{-2} s^{-1})

Sensible heat flux: $H = \rho_a c_p \overline{w`T`}$ (W m^{-2})

H_2O flux: $E = \rho_m \overline{w`c\,H2O`}$ (μmol m^{-2} s^{-1})

Latent heat flux: $LE = \lambda E$ (W m^{-2})

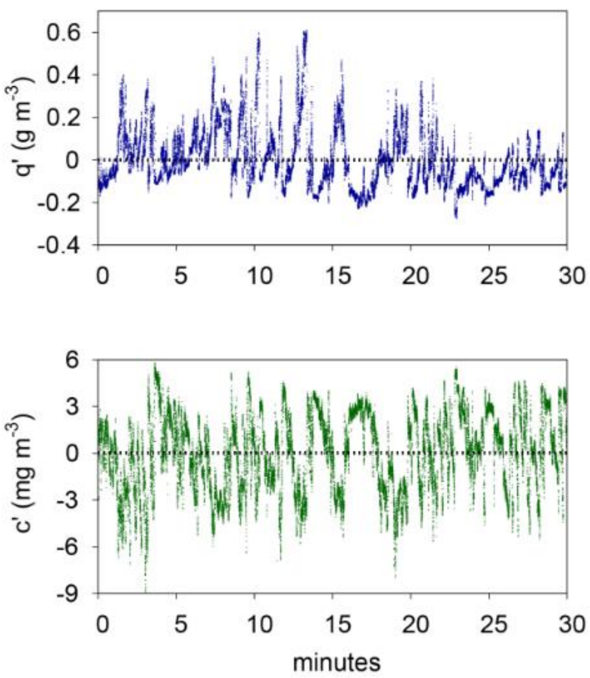
Momentum flux: $\tau = \rho_a (\overline{w`u`}^2 + \overline{w`v`}^2)^{1/2}$ (kg m^{-1} s^{-2})

Eddy covariance method - assumptions

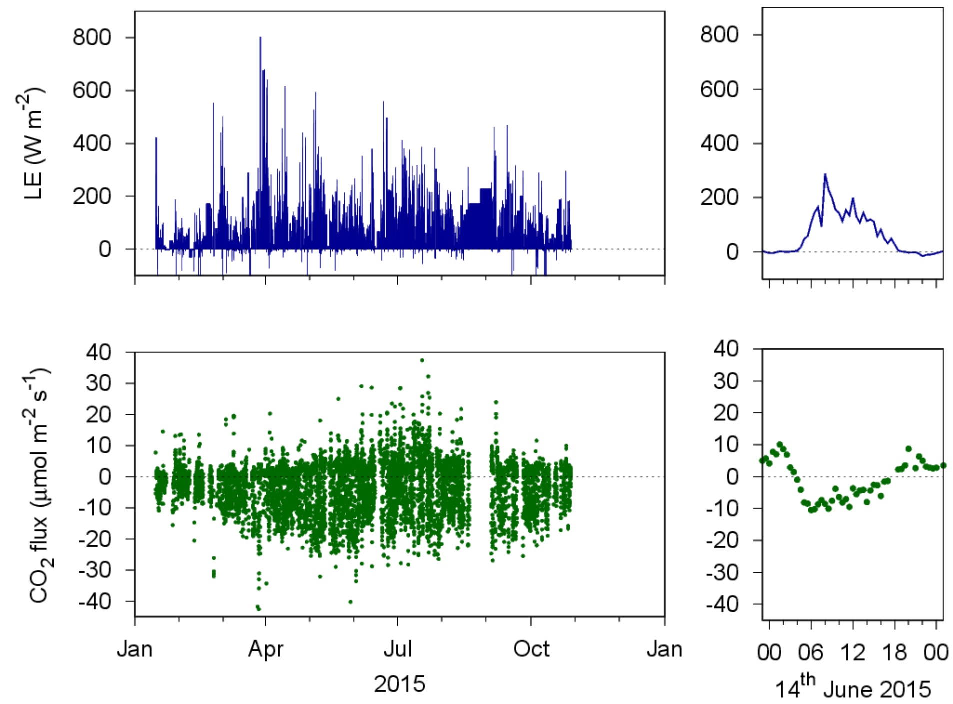
- Horizontal homogeneous terrain -> mean zero vertical wind speed
- turbulent atmosphere
- Measurements are representative for an area upwind
- A large enough flux footprint -> fluxes originate from the area of interest
- instruments detect turbulent eddies at high frequency (small eddies)
- no flow distortion by obstacles

Eddy covariance method

Raw data one 30 minute period (20 Hz)
14.06.2015 12:00 - 12:30



Processed fluxes 30 minute averages



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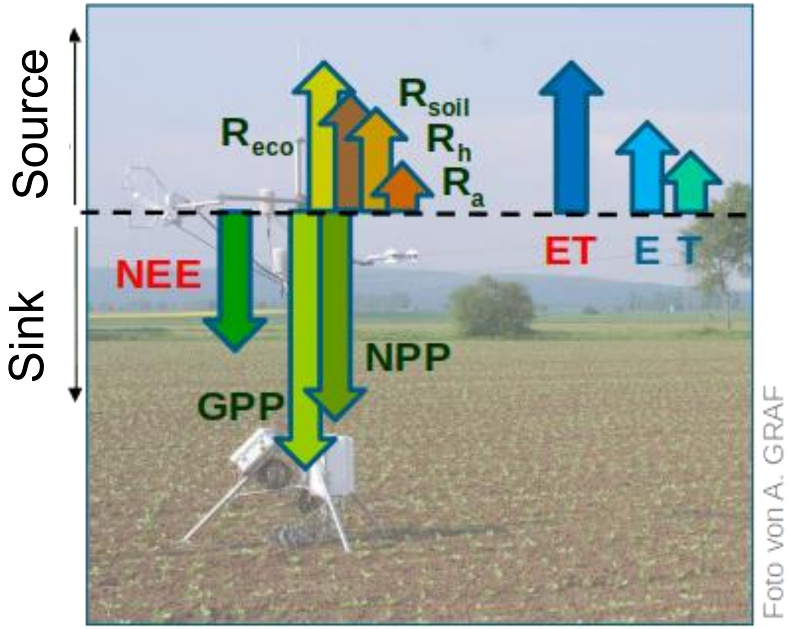
Processing steps will follow next week

Source partitioning



NEE: net ecosystem exchange
GPP: gross primary production
R_{eco}: ecosystem respiration
NPP: net primary production
R_{soil}: soil respiration
R_h: respiration by heterotrophs
R_a: respiration by autotrophs

$NEE = GPP + R_{eco}$
$R_{eco} = R_h + R_a$

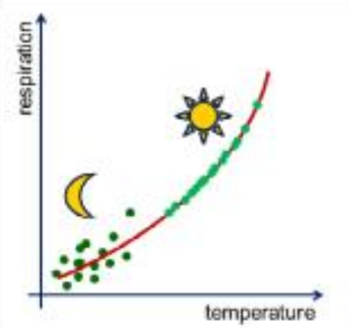
ET: evapotranspiration
E: evaporation
T: transpiration

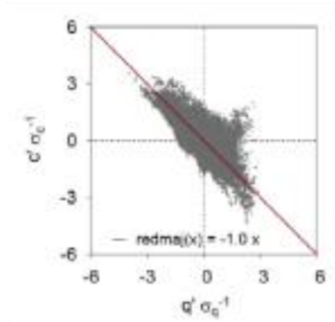
$ET = E + T$

Source Partitioning

„data-driven“:
can be applied to any existing station

- regressions with environmental drivers: „**gap-filling**“ models
- higher order statistics of **high-frequency** turbulence **raw data**



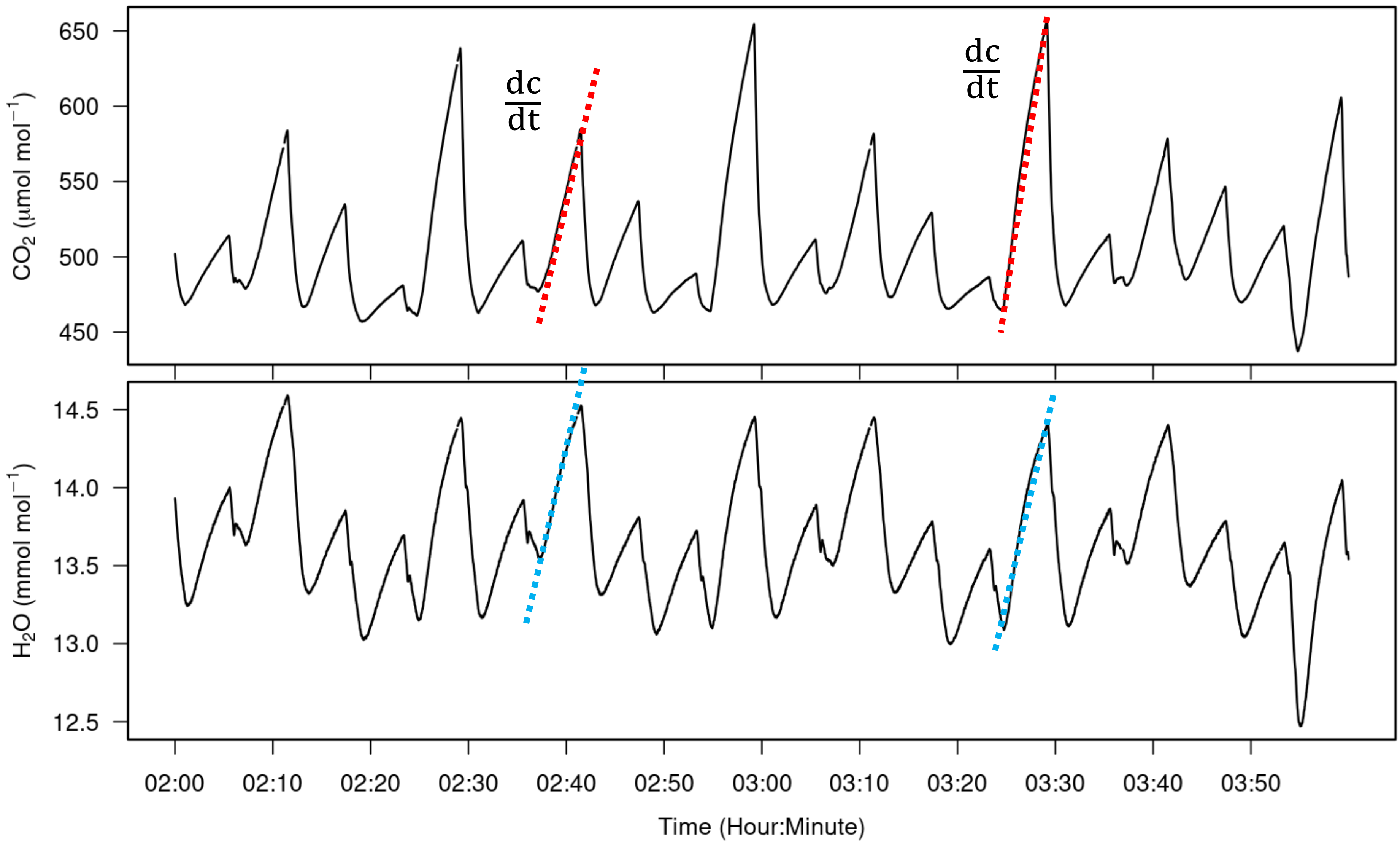


„instrumental“:
require additional equipment

- same gas at extra points of system: **chambers, profile system, lysimeter, sap flow**
- natural tracer measurements (**isotopes**)

„ecosystem models“:
require data for calibration and tuning

Chamber measurements - soil respiration



Chamber measurements - soil respiration

The soil CO_2 flux, F_c (μmol m^{-2} s^{-1}) is assumed to linearly increase, using following equation:

$$F_c = \frac{dc}{dt} \frac{M\,V}{A}$$

dc: change of CO_2 concentration from t_1 to t_2 (μmol mol^{-1})
dt: change in time (s)
$M = \frac{p}{R\,T}$ molar volume (mol m^{-3})
$R = 8.314$ J mol^{-1} K^{-1}
V: chamber volume (m^3)
A: chamber surface area (m^2)

Soil respiration - exercise

$$F_c = \frac{dc}{dt}\frac{M\,V}{A};\quad M = \frac{p}{R\,T};\quad R = 8.314\ \mathrm{J\ mol^{-1}\ K^{-1}}$$

$c_1 = 486$ µmol mol^{-1}
$c_2 = 658$ µmol mol^{-1}
$T = 15.5$°C $= 288.65$ K
$p = 95800$ Pa
$dt = 240$ s
$V = 15.55*10^{-3}$ m^3
$A = 0.071$ m^2
$dc = ?$ µmol mol^{-1}
$M = ?$ mol m^{-3}
$F_c = ?$ µmol m^{-2} s^{-1}

This weeks exercise

1. Calculate the half-hourly latent heat flux, the net ecosystem exchange of CO_2 and the sensible heat flux from the high-frequency turbulence data.

Questions?