D486 | EGU2020-18822

Measuring oxygen fluxes in a European beech forest - results from the OXYFLUX project

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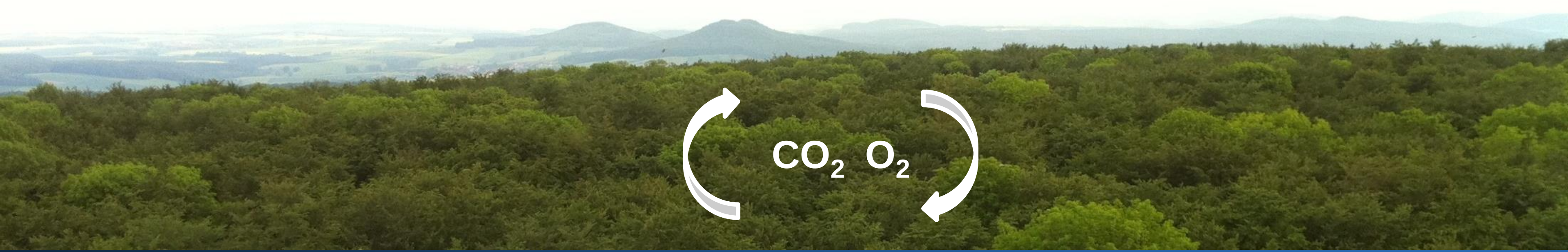
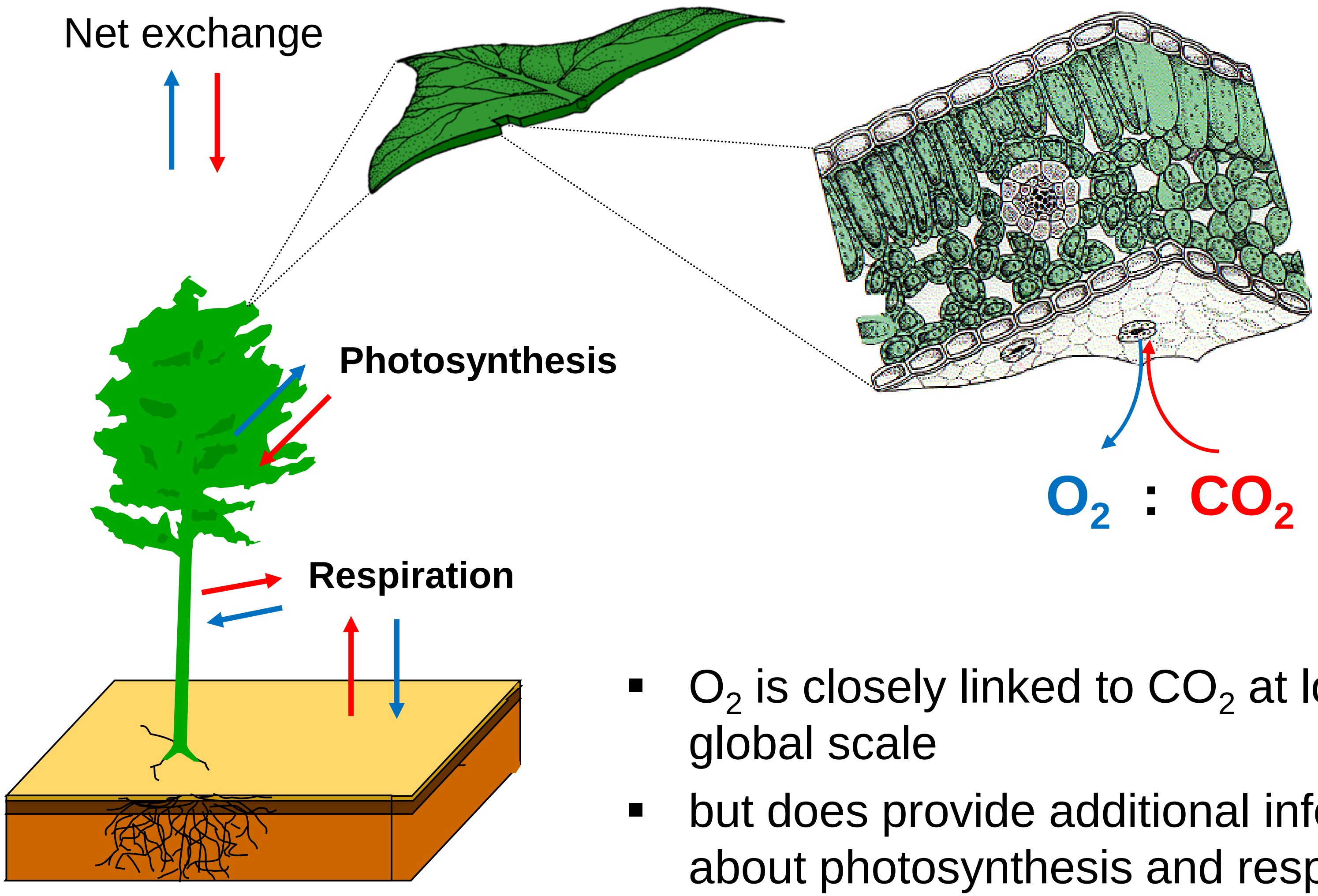
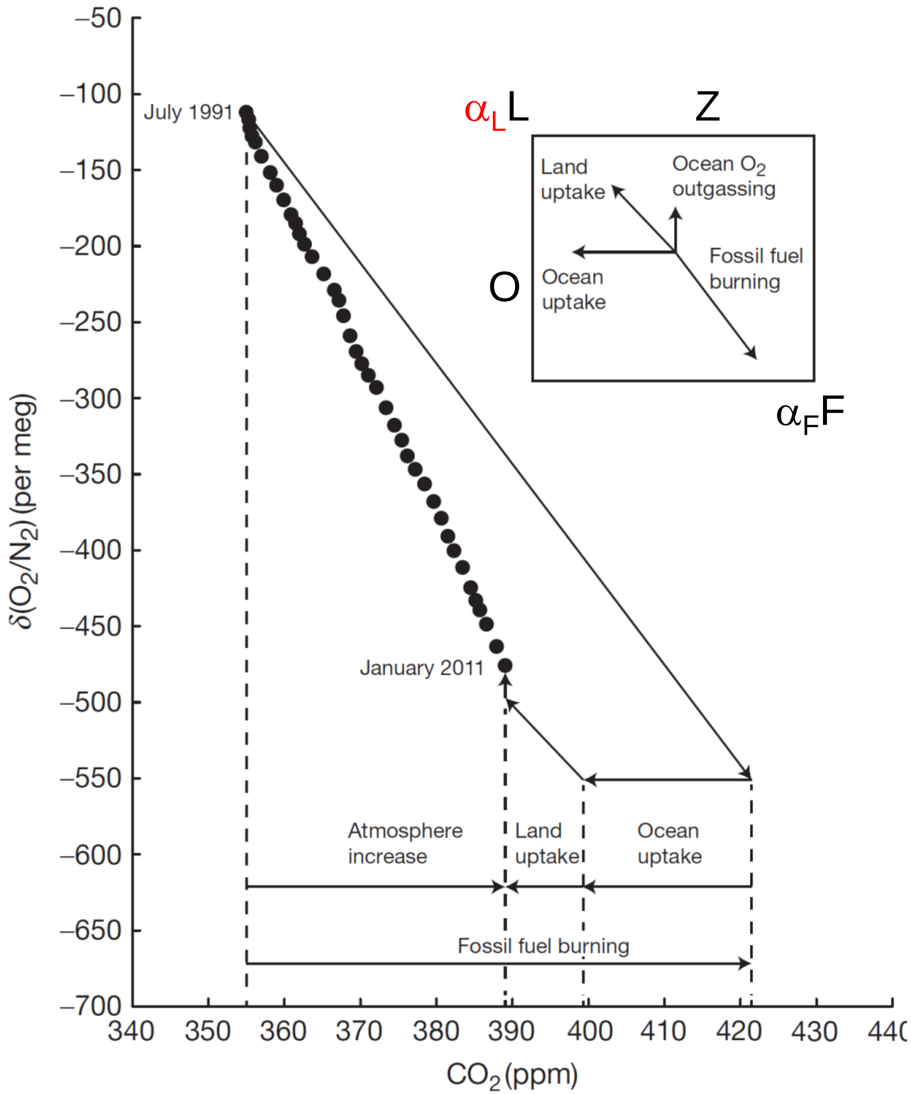


O_2 provides new opportunities



- O_2 is closely linked to CO_2 at local to global scale
- but does provide additional information about photosynthesis and respiration

O_2 as powerful tool to partition global land and ocean carbon sinks



$$\Delta CO_2 = F - O - L$$

$$\Delta O_2 = -\alpha_F F + \alpha_L L + Z$$

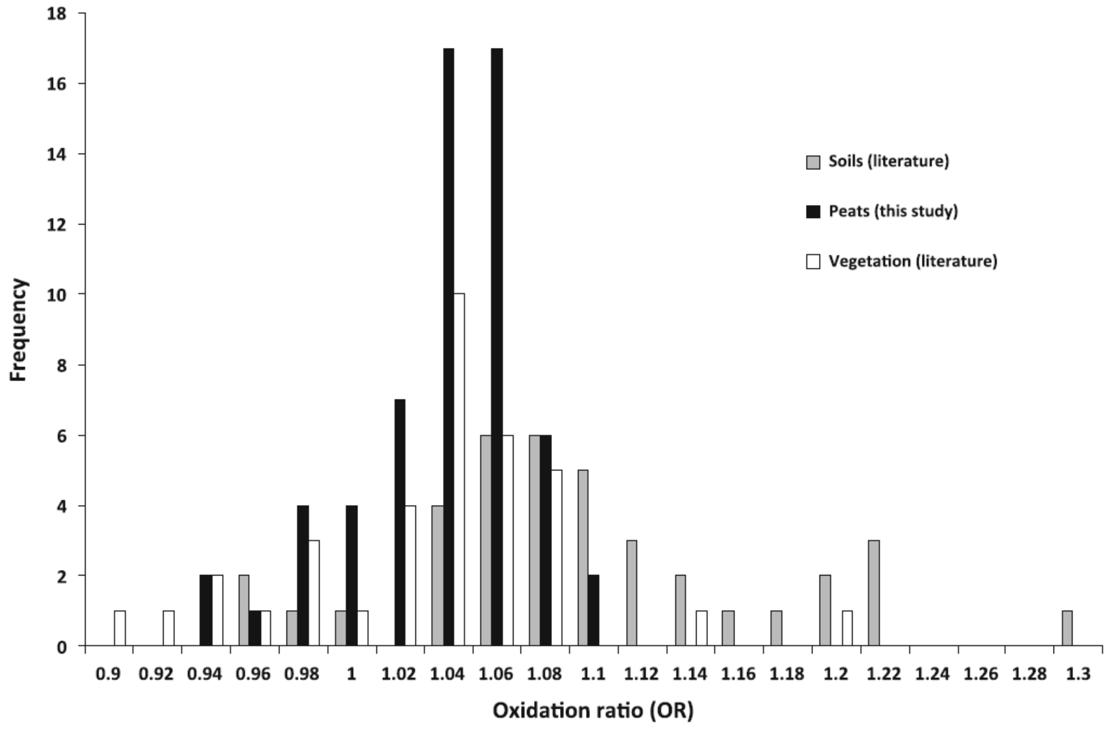
Little data on land O_2:CO_2 exchange ratio typically assumed to be constant at 1.1

	1990-2000	2000-2010
Fossil-fuel emissions:	6.4 ± 0.4	7.8 ±0.5
Atmos. CO_2 increase:	3.2 ± 0.0	4.0 ±0.0
Net oceanic sink:	1.9 ± 0.6	2.7 ±0.6
Net land sink:	1.2 ± 0.8	1.1 ±0.8

Units: Pg C yr^{-1}

Keeling and Manning (2014)

Indirect data: Oxidative ratios from organic samples



Worrall al. 2013

- Oxidative ratios of organic material (based on elemental analysis) are indirect estimates of long-term O_2:CO_2 exchange ratios
- Considerable variation with global mean probably smaller than 1.1

Challenge I

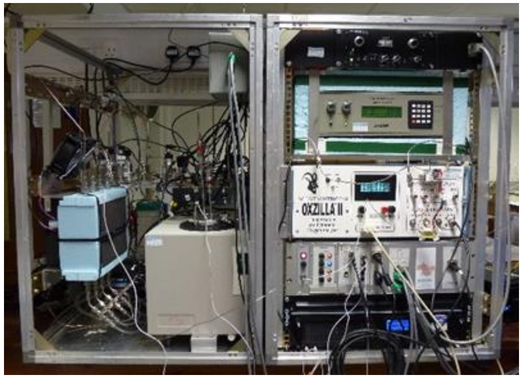
- Very little data exists where direct $O_2:CO_2$ flux measurements are done at field sites

  - Angert et al. 2015 ➔ $O_2:CO_2$ ratio of soil respiration higher than 1.1
  - Hilman et al. 2019 ➔ $O_2:CO_2$ ratio of stem respiration higher than 1.1
  - Battle et al. 2019 ➔ large variation in $O_2:CO_2$ ratio of canopy level measurements

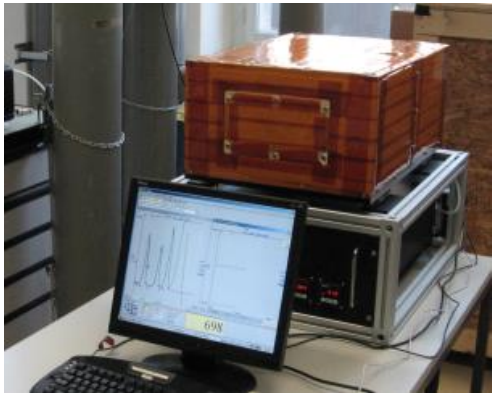
Challenge II : Measuring O_2 is difficult

- 1 ppm precision out of 210 000 ppm O_2 compared to
  1 ppm precision out of 400 ppm CO_2
- a number of instruments now available but all with their own strengths and weaknesses

Cavity ring down spectroscopy (Picarro Inc.)



Custom-made O_2 measurement unit (UEA) based on fuel cell (Oxzilla, Sable Systems)



Tunable direct absorption spectroscopy (Aerodyne Inc.)

Objectives

Overall objective

To determine the O_2:CO_2 ratio of gas exchange of a forest ecosystem in Germany

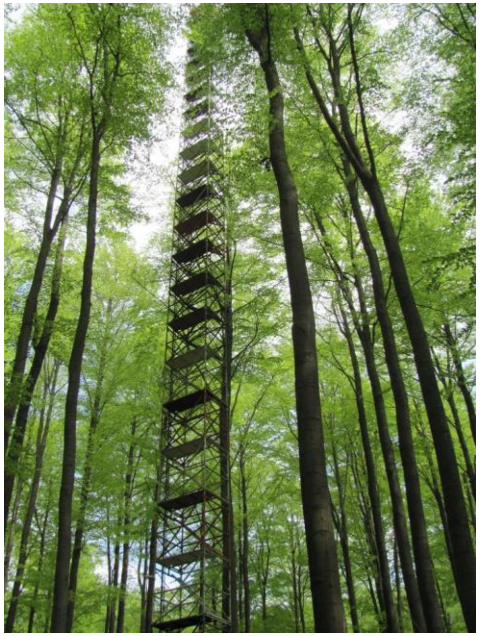
Specific objectives

I. To measure the O_2:CO_2 gas exchange from branches, stems and soils using a custom-made fully automated chamber system

II. To measure the O_2:CO_2 gas exchange of the entire ecosystem using canopy air profile measurements and Inverse Lagrangian modelling

Field site Leinefelde

- Fully equipped Fluxnet site (DE-Lnf) in Central Germany
- Beech monoculture
- Canopy height: 35 m
- Age: 140 years



I. Chambers for ecosystem component measurements

<u>Component fluxes</u>
- Branch
- Stem
- Soil

-> 4 chambers each

<u>Non-measurement mode</u>
Chamber concentrations are kept at constant level close to <u>ambient concentration</u> in between measurements

Switching Unit

Branch chambers

Stem chambers

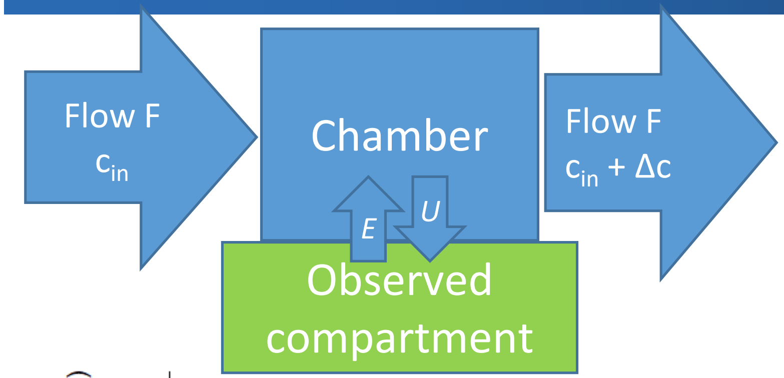
Soil chambers

Known carrier gas

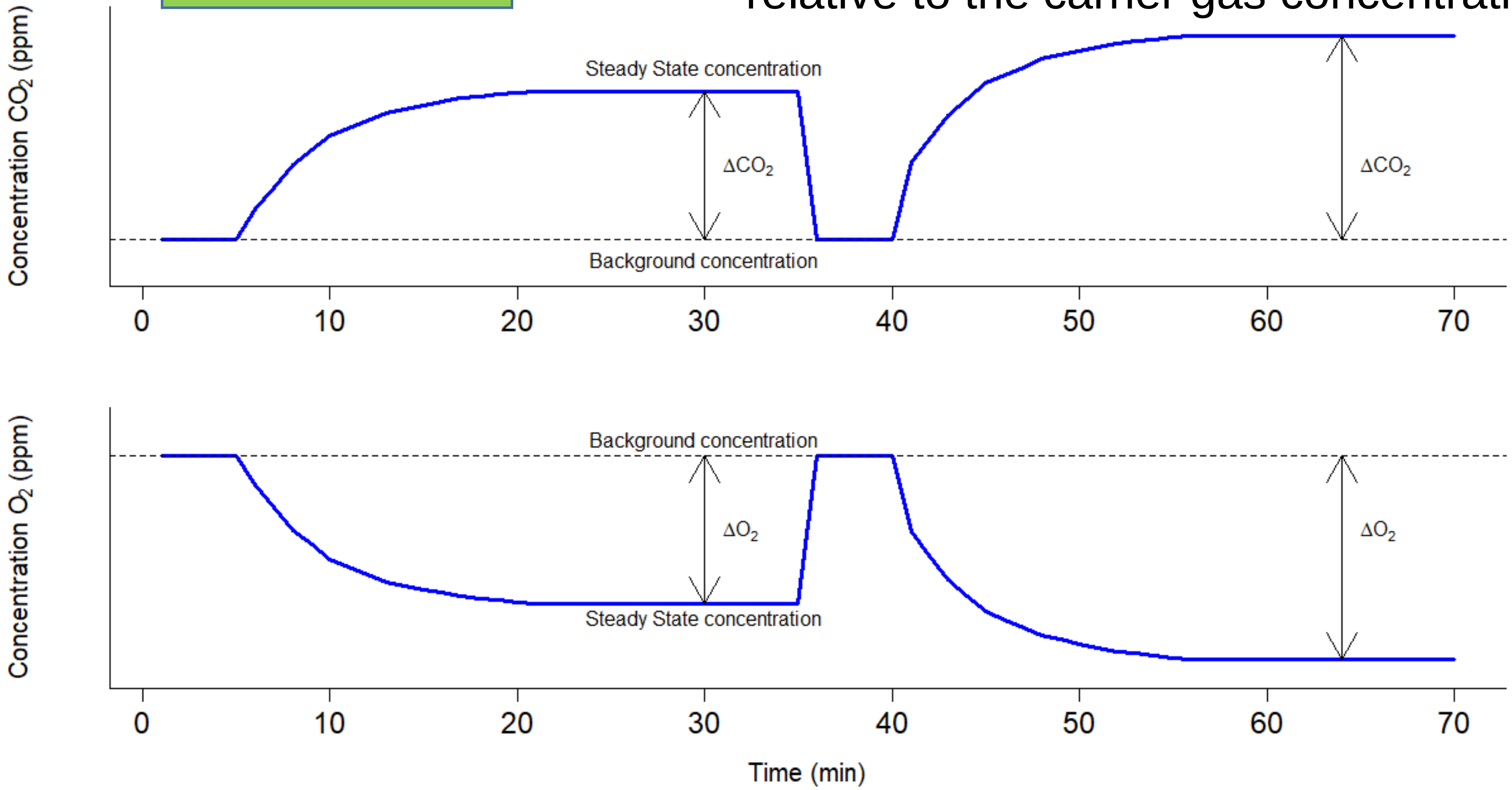
<u>Measurement mode</u>
Chambers are measured one-by-one
Gas of known concentration is pumped through the chamber and concentration changes (ΔO_2, ΔCO_2) are measured
-> **Open throughflow steady state (see next slide)**

Analyzer unit for O_2 and CO_2
Precision: 1 ppm O_2
0.5 ppm CO_2

Open throughflow steady state chambers



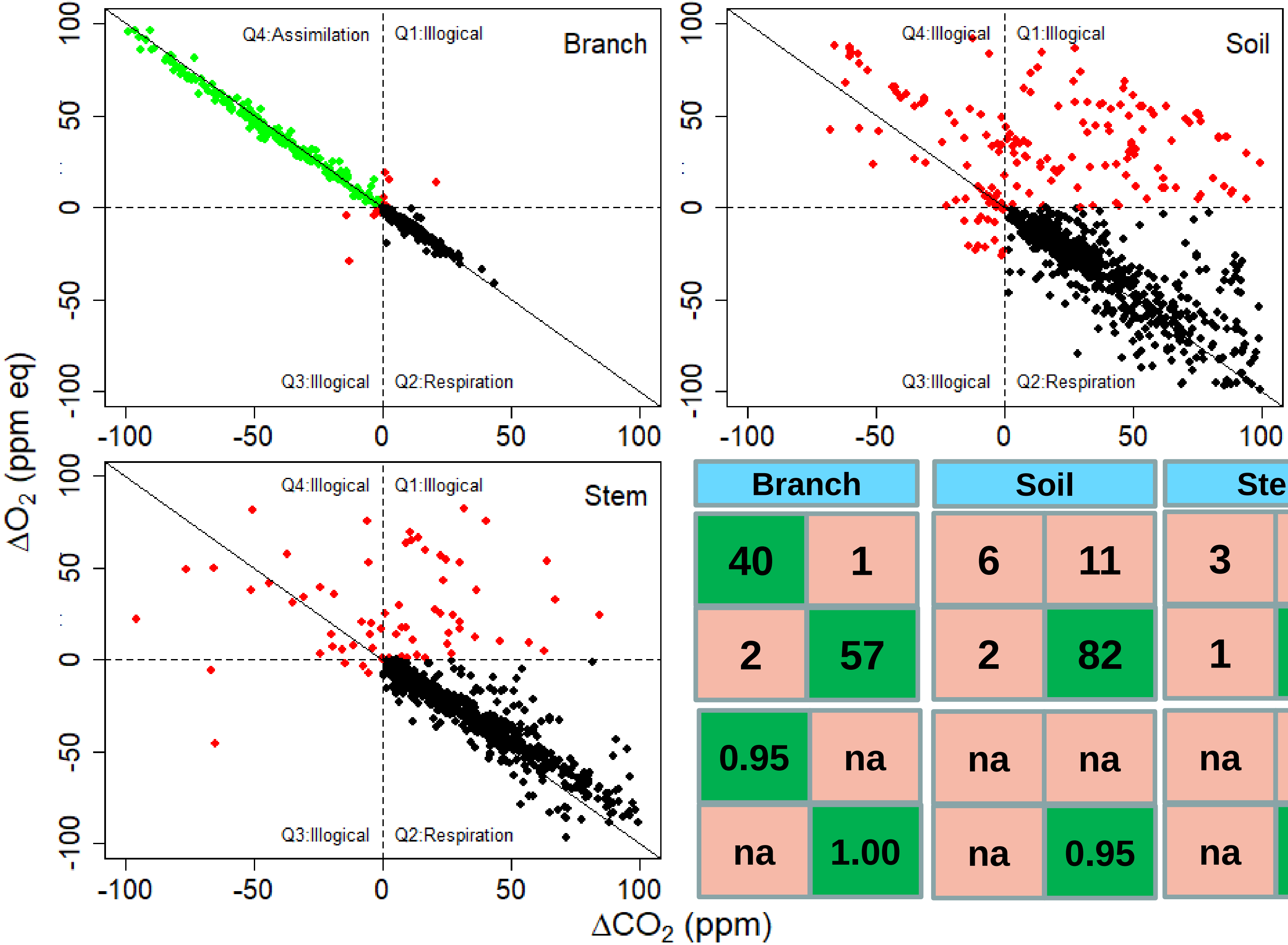
At steady state (i.e. stable c_{in}+Δc):
Net gas exchange = Δc x F
After starting measurement of a chamber we have to wait until steady new [O_2] and [CO_2] and then measure the change (ΔO_2, ΔCO_2) relative to the carrier gas concentration



Interpreting ΔO_2 and ΔCO_2

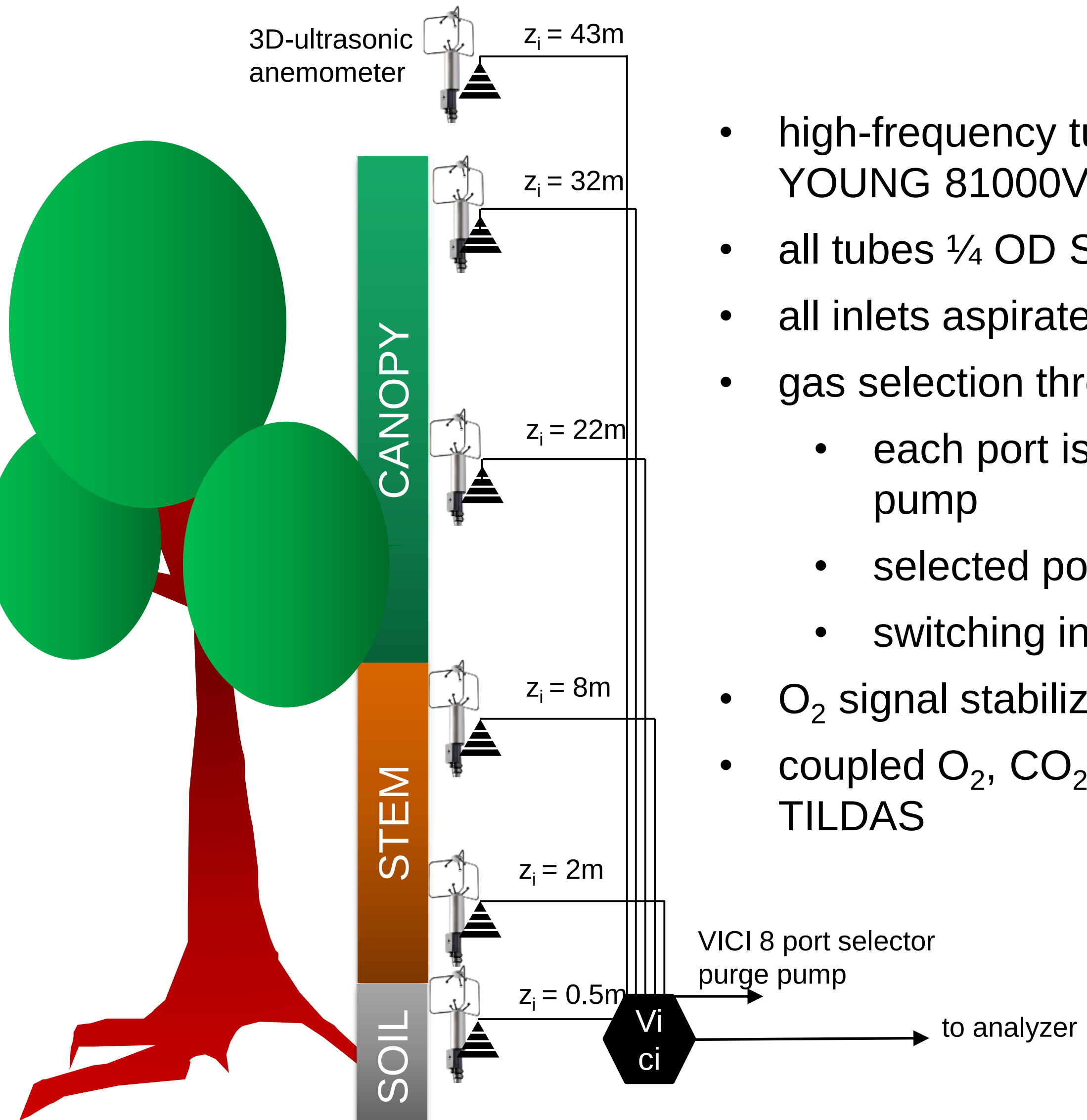
- ΔO_2 and ΔCO_2 can be used to calculate the current exchange rates (i.e. calculate the fluxes)
- Alternatively, the ratio ($- \Delta O_2 / \Delta CO_2$) can be calculated. For anti-correlated fluxes of the same magnitude, this ratio would be 1.0, which usually is expected for assimilation and for respiration of carbohydrates
- A ratio different than 1.0 can be due to
  a. Respiratory substrates other than carbohydrates
  b. Alternative sources/sinks for CO_2/O_2
  c. Measurement artifacts (technical problems)

ΔO_2 ~ ΔCO_2 by chamber location



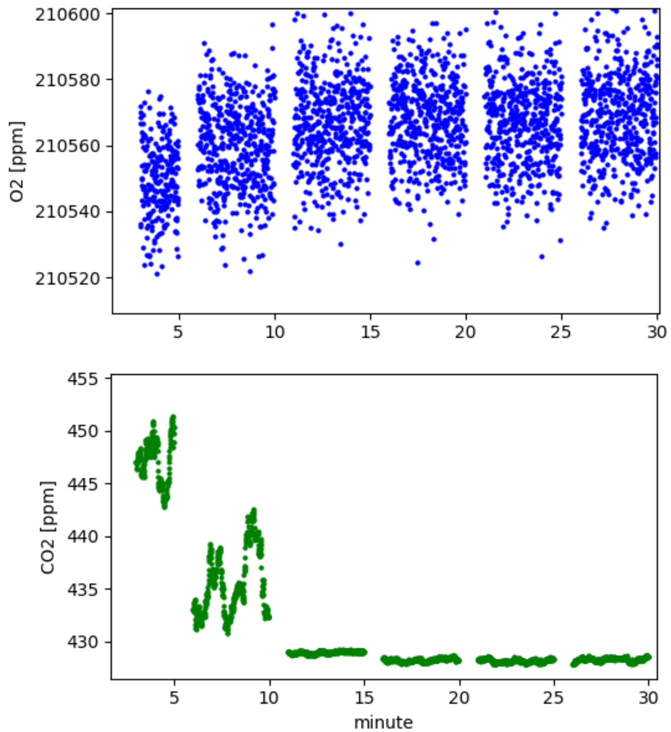
Branch		Soil		Stem		
40	1	6	11	3	4	Data in % of total
2	57	2	82	1	92	
0.95	na	na	na	na	na	$-\Delta O_2/\Delta CO_2$
na	1.00	na	0.95	na	0.94	

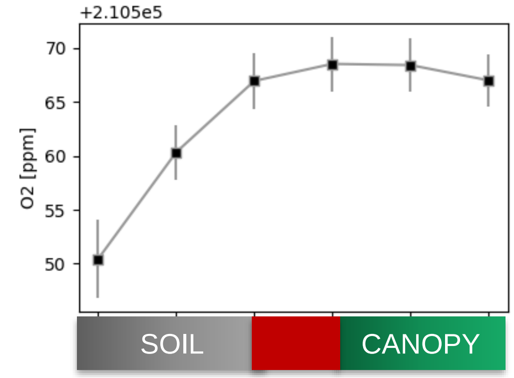
II. Setup Canopy profile



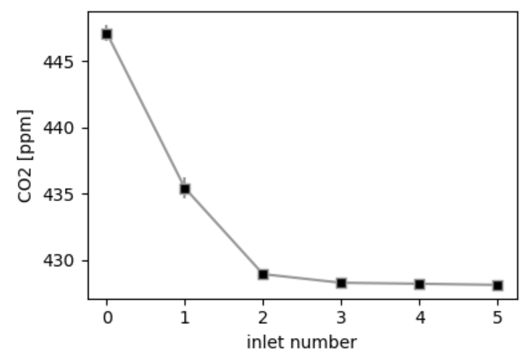
- high-frequency turbulence profile measurements with YOUNG 81000VRE
- all tubes ¼ OD Synflex 1300, same length (50 m)
- all inlets aspirated Stevenson huts
- gas selection through constant flow VICI 8 port valve
    - each port is continuously sampled @ 1slpm by purge pump
    - selected port is sampled @ 1slpm by vacuum pump
    - switching increment 5 min
- O_2 signal stabilization in < 1 min
- coupled O_2, CO_2 measurements @ 2Hz in Aerodyne QCL-TILDAS

One vertical profile over 30 min

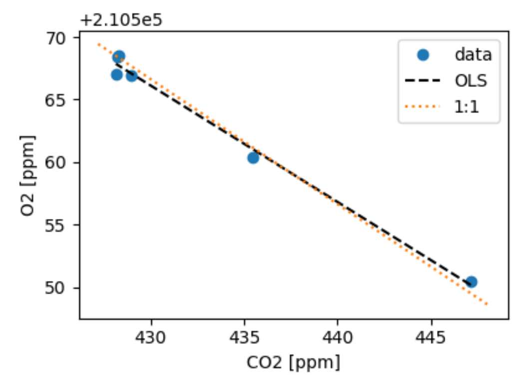




Vertical O_2 profile



Vertical CO_2 profile

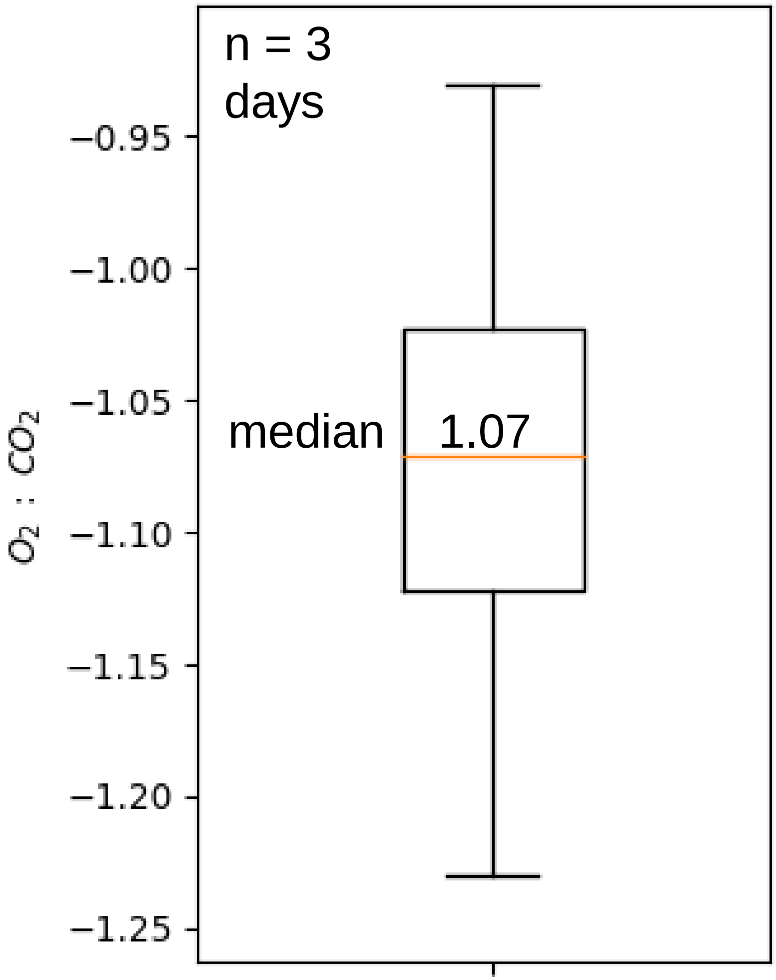


O_2 : CO_2 ratio

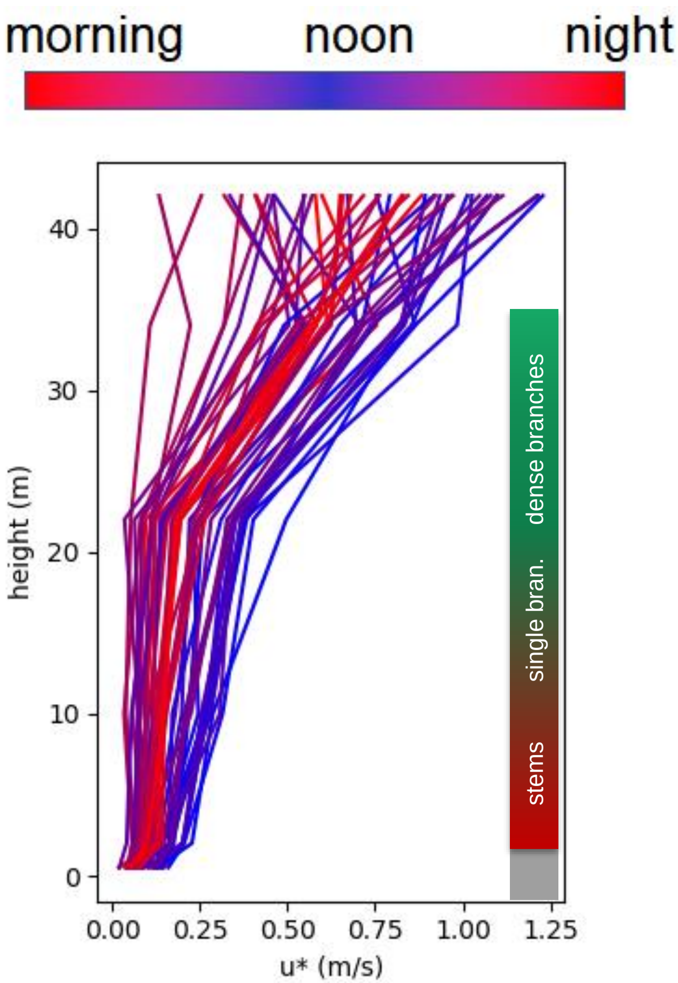
- O_2 measurements precise enough to resolve soil respiration gradient at night.
- standard error on 4 min mean ± 0.5 ppm.
- standard deviation ± 11 ppm.

Ecosystem-scale O_2:CO_2 exchange ratio close to 1.1

- Night-time data, 3 days in April, before leaf emergence.
- mostly soil respiration signal.
- measured exchange ratio is statistically not different from -1.1.
- However, this ratio is purely based on concentration measurements that might not be fully representative of forest ecosystem.
- next task: inverse ecosystem-scale flux calculation based on concentration- and turbulence profile
- requires vertical profile of turbulence measurements



Vertical turbulence measurements



turbulence profile (u*) before leaf emergence

- Mechanical turbulence (u*) decreases inside the canopy as expected from theory

Next steps:

- use near-/far-field Lagrangian particle framework
- inferred by measured turbulence $u_*(z)$ and O_2 and CO_2 concentration profile $C(z)$
- Inversely solve for vertical source distribution profile $S(z)$: sinks and sources of O_2 and CO_2 inside canopy

- derive the net ecosystem flux of O_2 and CO_2 $= \int_0^z S(z), dz$
- compare $S(z)$ of O_2 and CO_2 with compartment-scale chamber flux measurements

Summary

- Fully automated chambers and profile systems for measurements of O_2:CO_2 gas exchange developed
- Instrument precision sufficient to resolve small variations in O_2:CO_2 gas exchange
- Preliminary results indicate average O_2:CO_2 close to 1.1 but with considerable temporal and spatial variation

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Funding

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement no. 682512 - OXYFLUX)