Towards a better understanding of ecosystem-atmosphere interactions using ICOS flux towers

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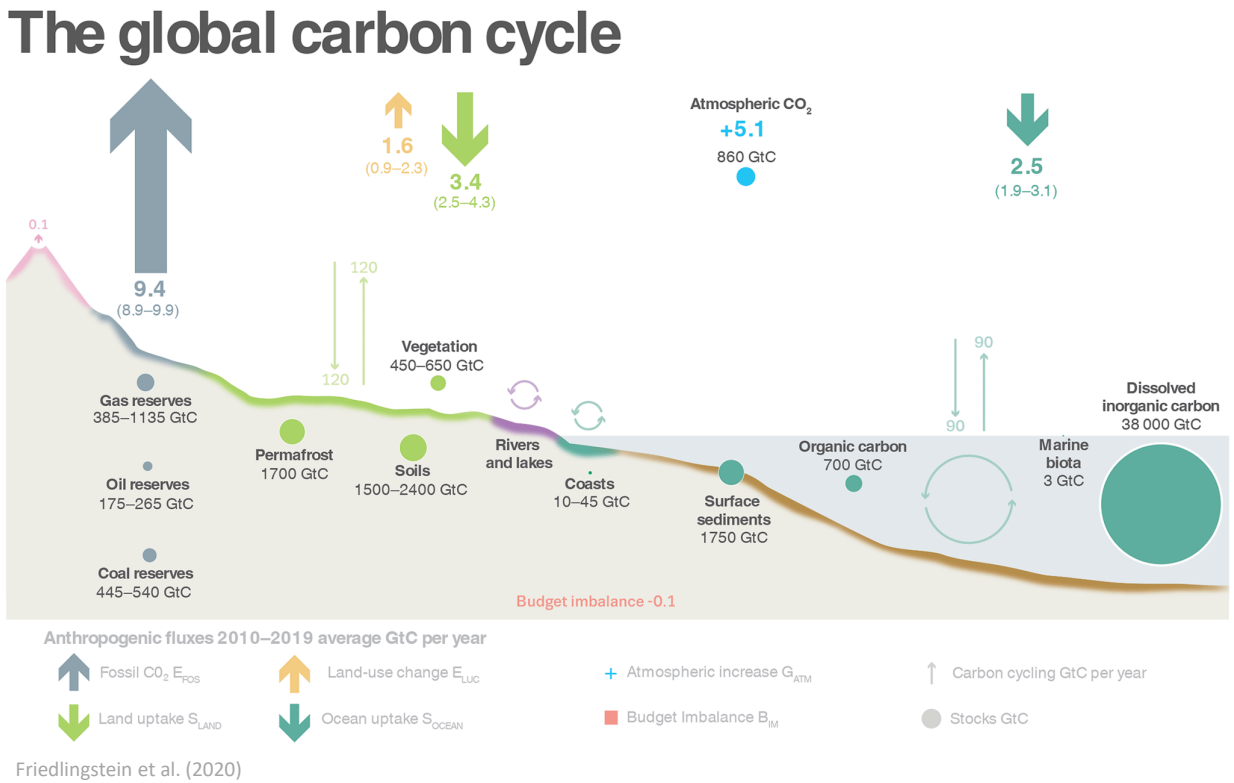
ICOS Integrated Carbon Observation System

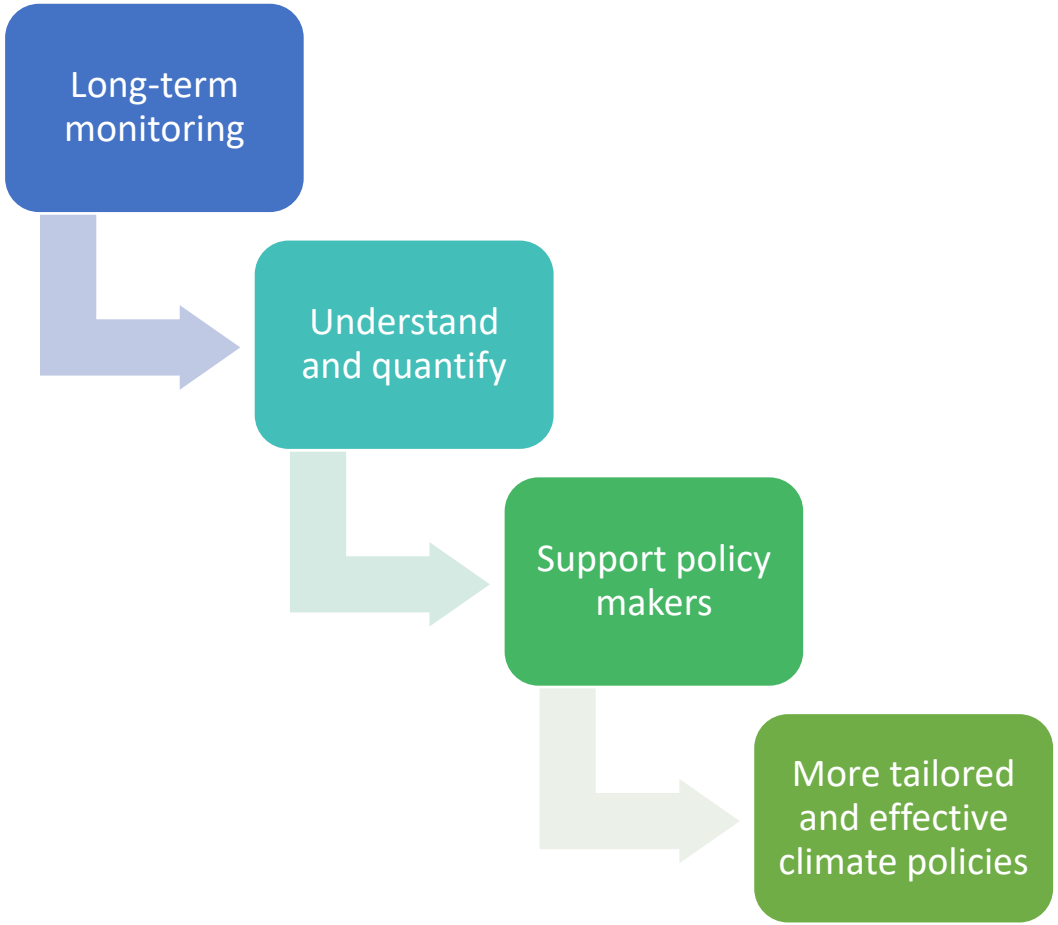
LIÈGE université Gembloux Agro-Bio Tech

Why measure gaseous exchanges?

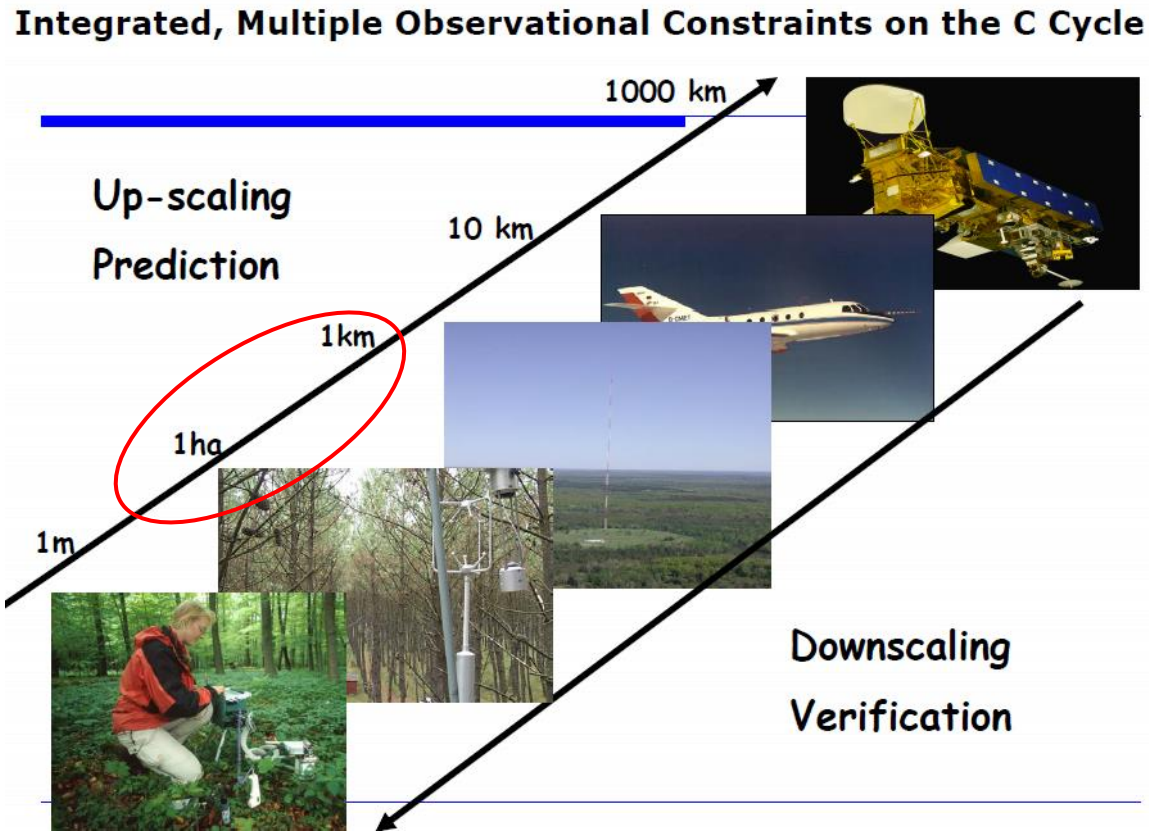
- Context: climate change
- Role of the ecosystems as carbon sinks
- Incomplete knowledge of dynamics and processes involved



Friedlingstein et al. (2020)



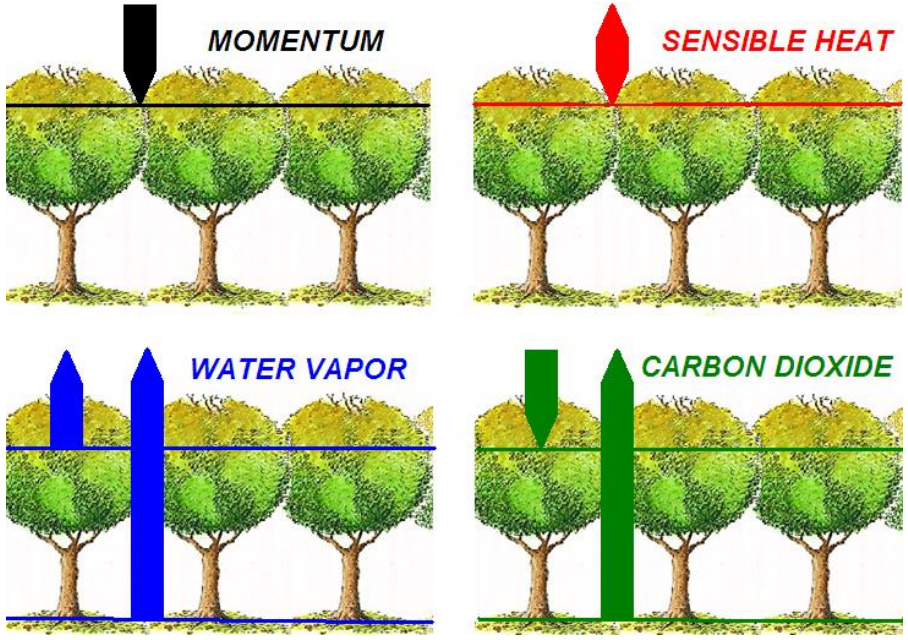
How to measure gaseous exchanges?

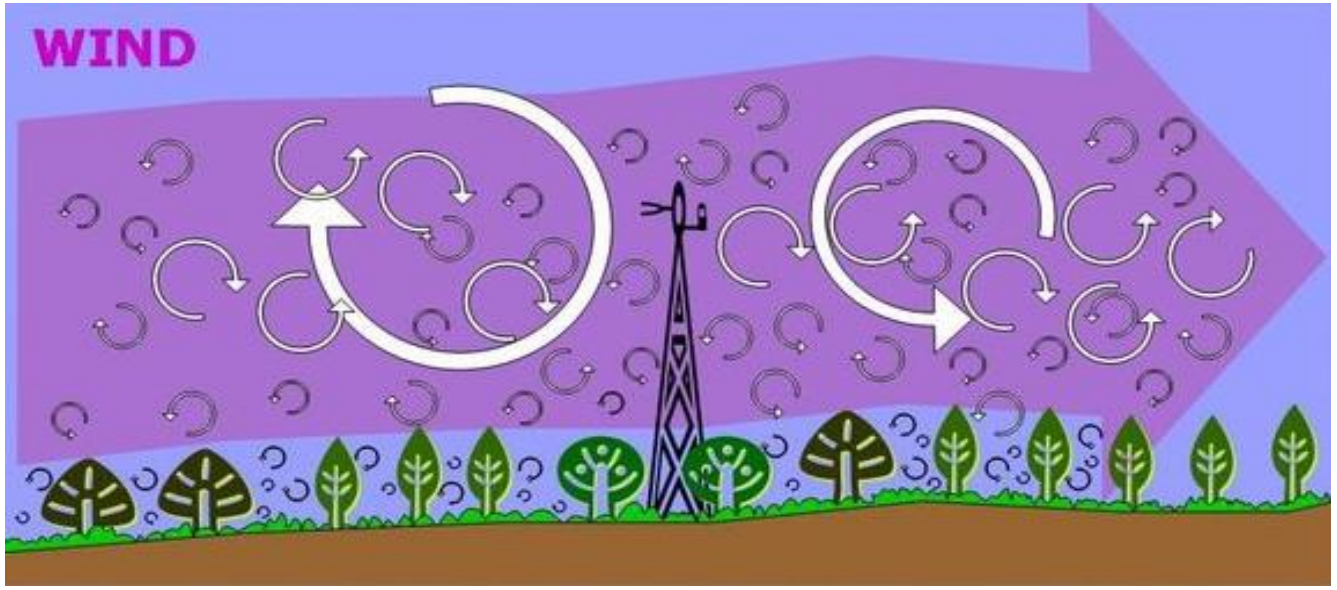


- Multiple techniques, multiple time and spatial scales
- Importance and difficulties in upscaling and downscaling: complementarity between techniques allows verification
- **Micrometeorology**: spatial scale of ~ 1 m – 1 km, temporal scale of ~ 1 s – 1 h

Micrometeorology: eddy covariance technique

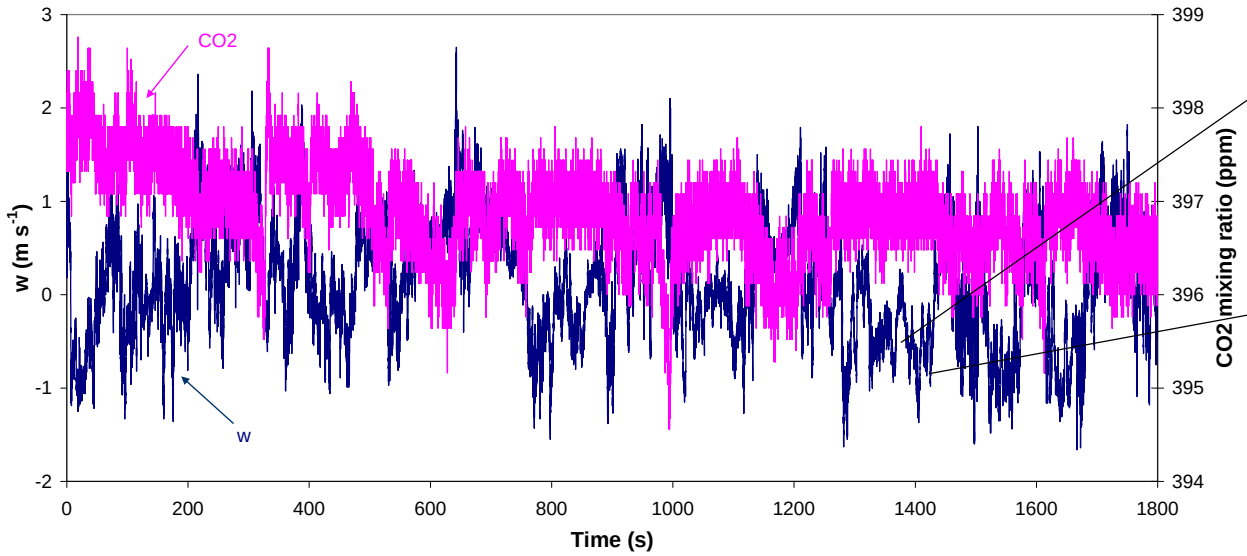
- Direct, non-invasive, continuous and reliable method
- Technique used to measure the **net** fluxes exchanged between an ecosystem and the atmosphere
- In the SBL the main transport mechanism is turbulence, movement of eddies created from a mechanical or thermic source

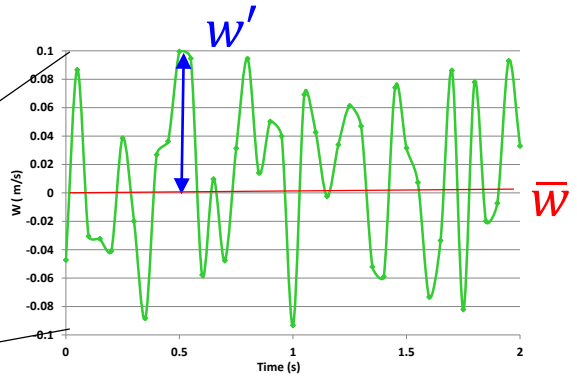




Burba (2013)

EC: a little bit of theory



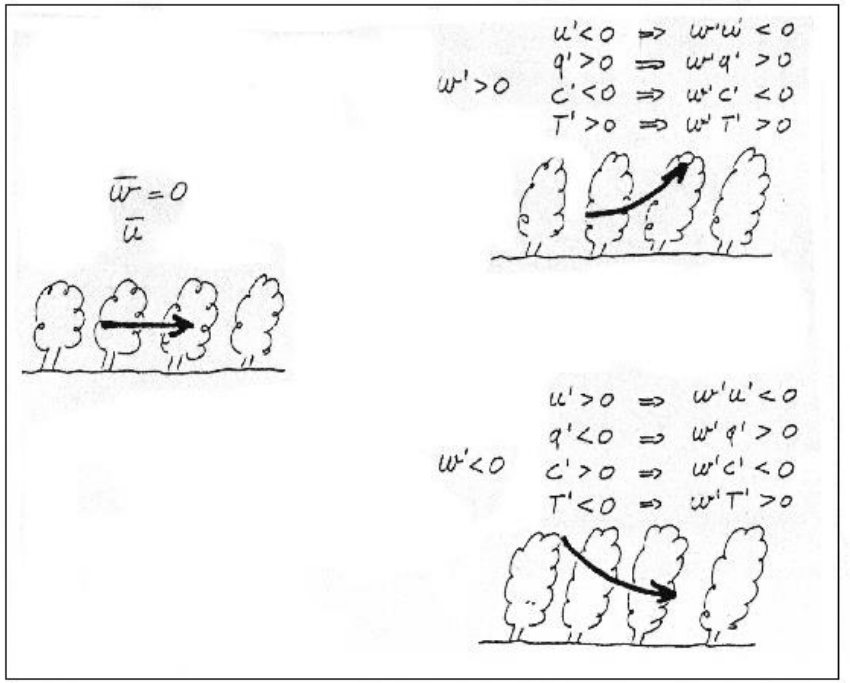


Same for the scalars (T, $[CO_2]$, $[H_2O]$, …) !

$$w = \bar{w} + w'$$

$$\overline{w'\chi_s'}\Big|_h$$

- Measure of mass carried by one or several eddies
- Decomposition of each measured variable in sum of the mean value and the fluctuations around it
- Computation of the covariance between the two time series → averaged on 30 minutes



$\overline{w'c'}$ ⟶ net CO_2 flux [$\mu molm^{-2}s^{-1}$]

Instruments for EC

Sonic Anemometer (SA)

Transit time of an acoustic signal between a pair of transducers → 3D wind speed

- No inertia, so no minimum wind speed : precise measurements at 20 Hz

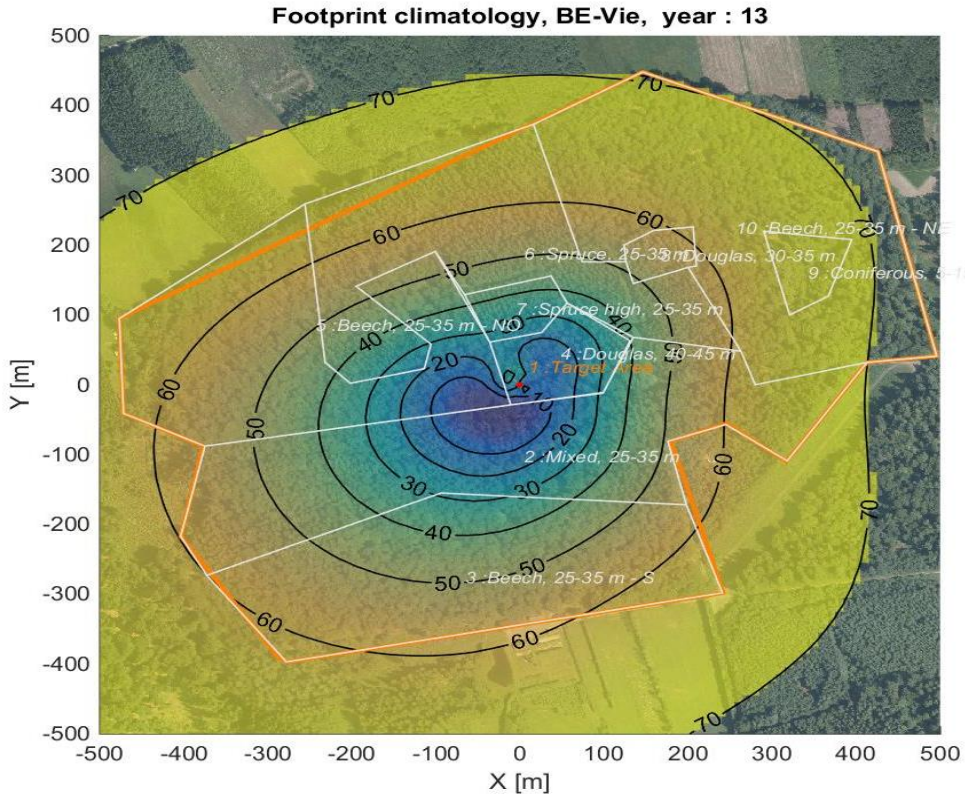
Infra-Red Gas Analyser (IRGA)

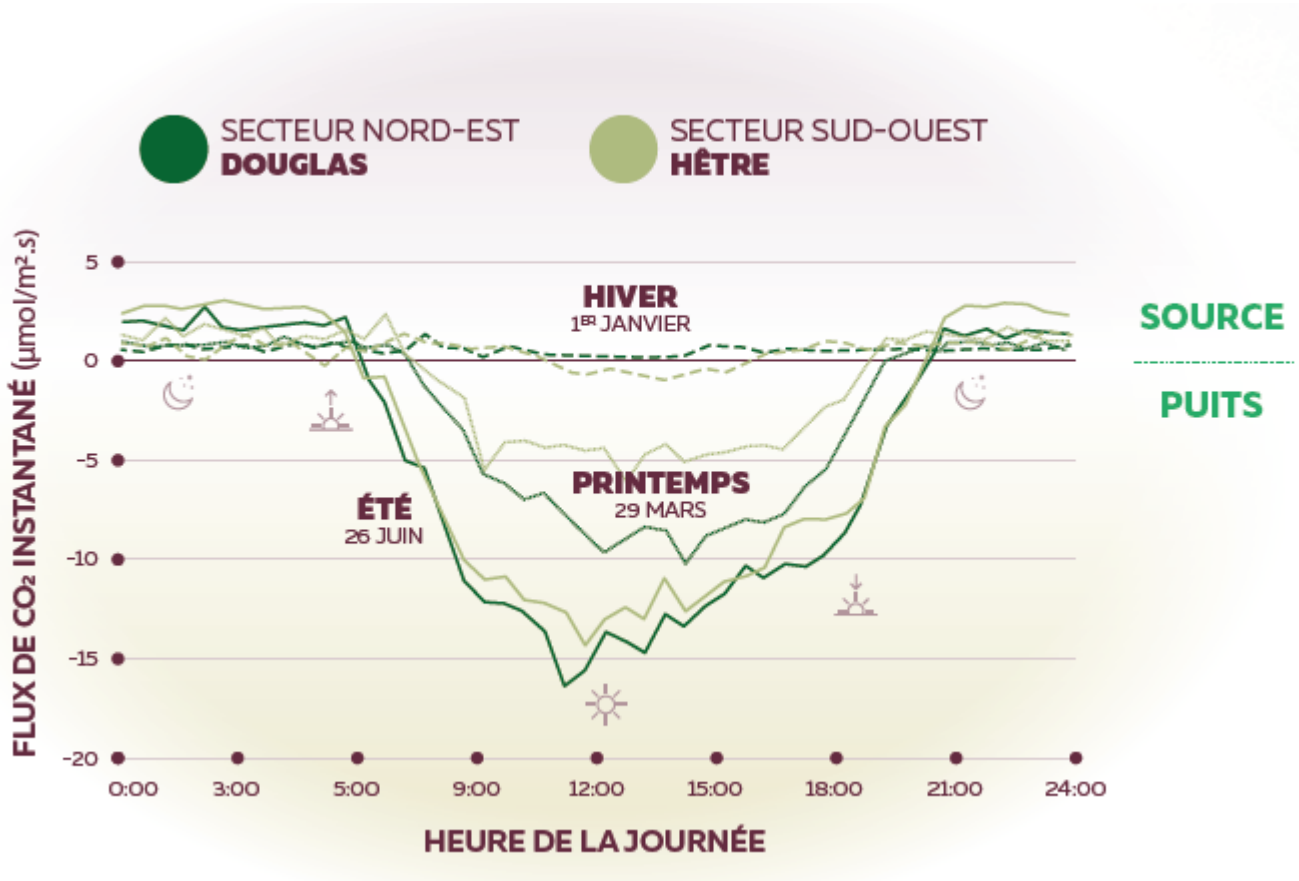
https://www.licor.com/env/products/eddy_covariance/LI-7200RS.html

Concentration of gas linked to its absorption in the (far) infra-red.

- Optic method, fast (20 Hz) and precise (0.1 ppm for CO_2)

Typical exchanges

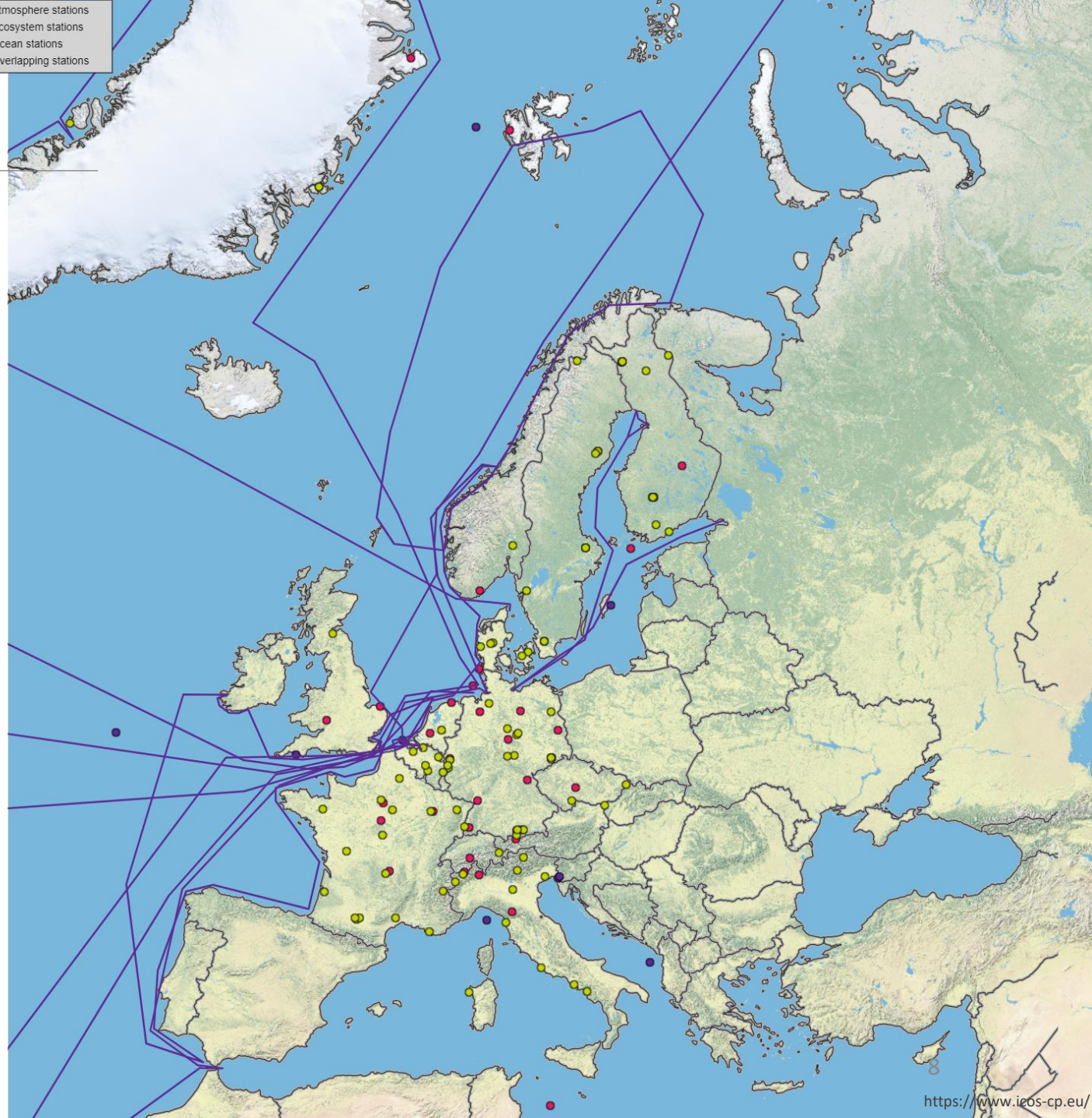




- Footprint: source area of the fluxes
- Output: continuous ½ hour data time-series of gas, energy and momentum
  - High resolution data
  - Possibility to compute budgets over longer periods

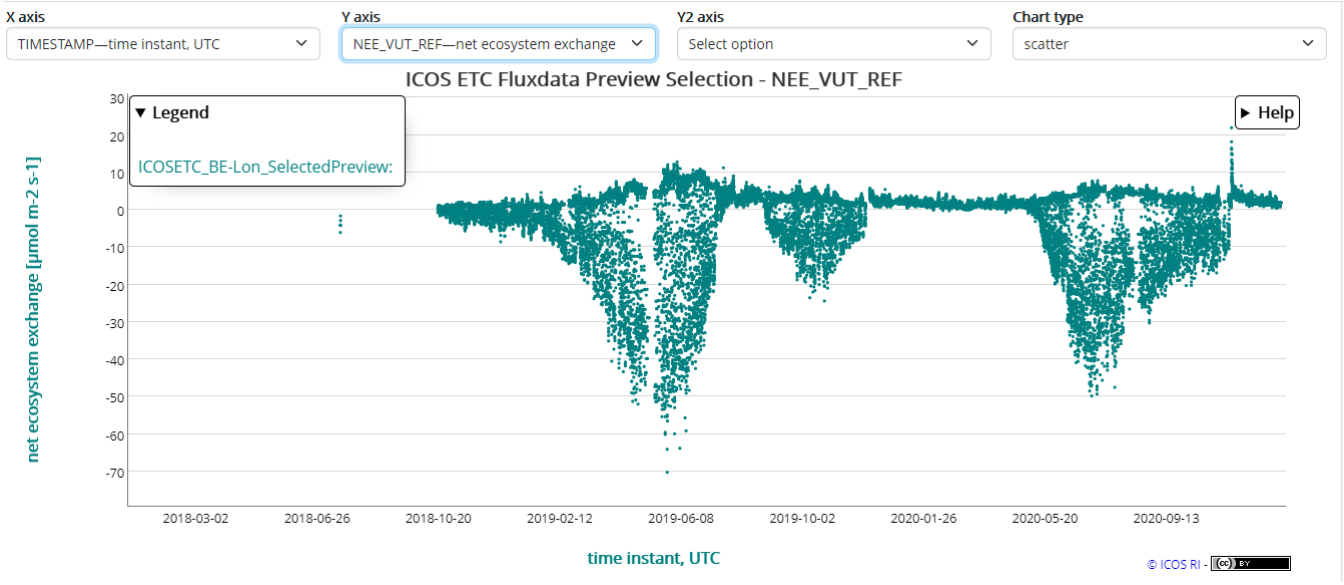
ICOS Network

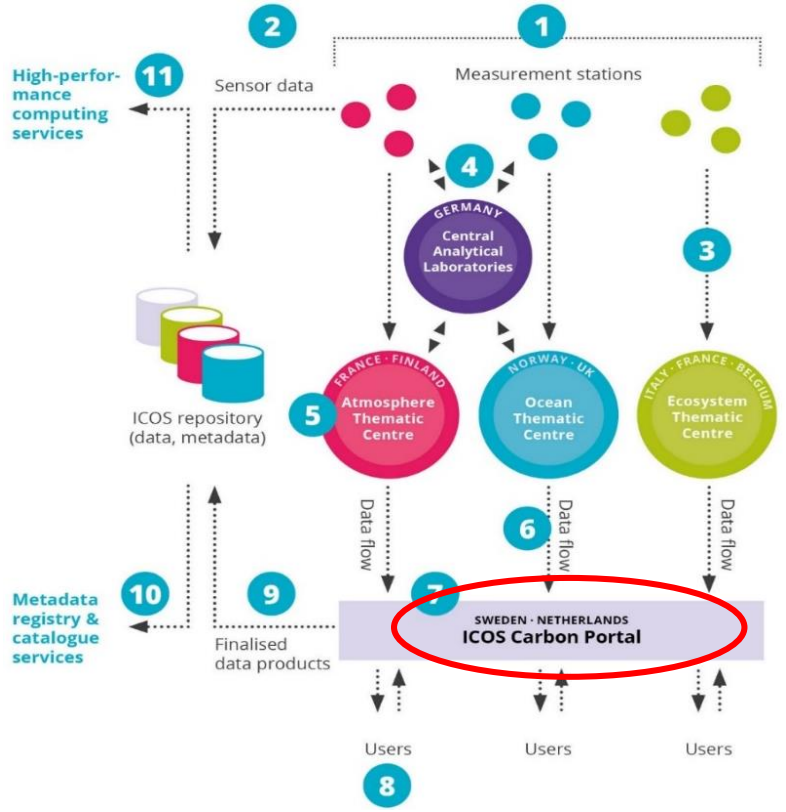
- Mission: “to produce **standardised**, **high-precision** and **long-term** observations and facilitate research to understand the carbon cycle and to provide necessary information on greenhouse gases”
- Key facts and figures:
  - 140+ monitoring stations
  - 13 EU countries
  - 500+ researchers
  - 80+ research institutes and universities
- Three domains: **Ecosystem**, Ocean and Atmosphere

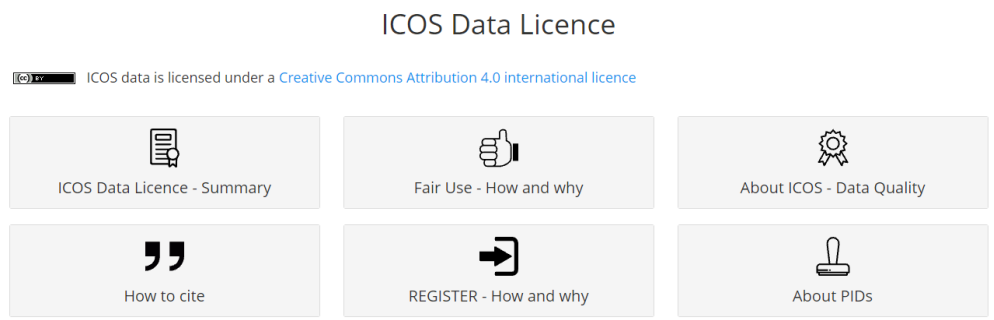


Carbon Portal

- All ICOS products (and more) available here
- FAIR (meta)data: **F**indable, **A**ccessible, **I**nteroperable, **R**eusable
- Licence CC4BY
- Tools to exploit data: Jupyter notebooks, visualisation options on the website

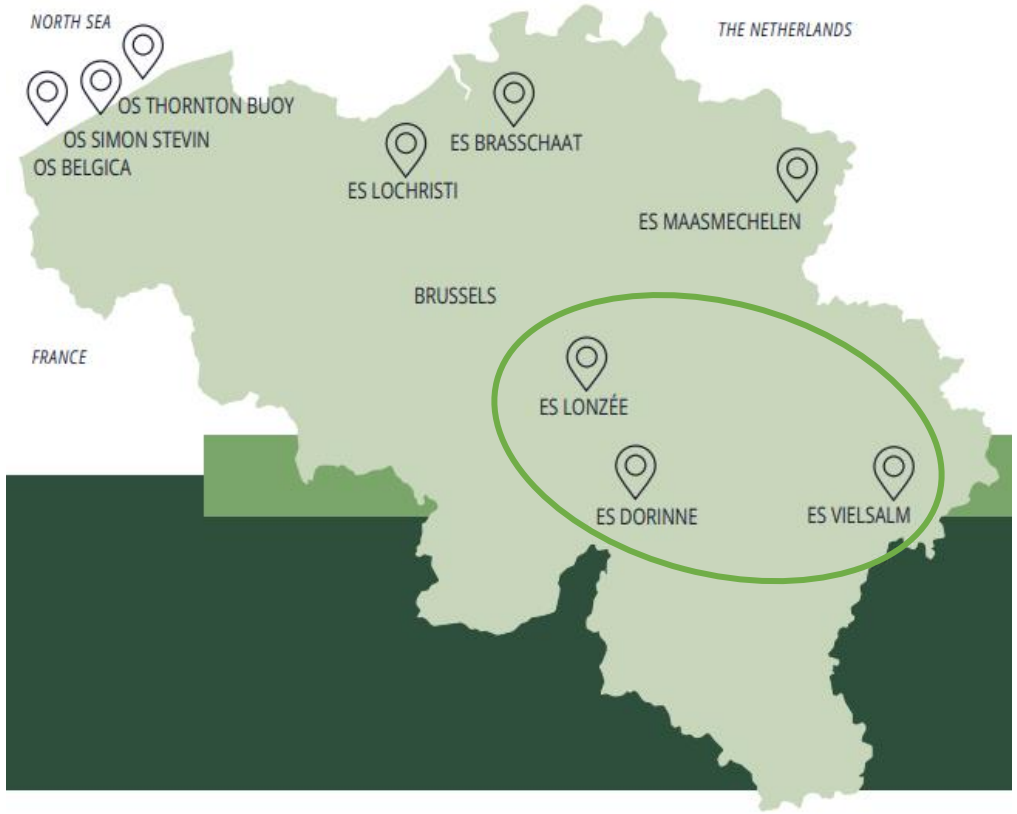






Belgian Network

- 10 monitoring stations operated by 6 different research institutes
  - 6 Ecosystem stations (+ CongoFlux tower)
  - 1 Atmosphere station (Reunion island)
  - 3 Ocean stations (Northern sea vessels/buoy)
- University of Antwerp co-host of the Ecosystem Thematic Centre (ETC)
- Walloon stations:
  - Dorinne (grassland)
  - Lonzée (cropland)
  - Vielsalm (forest)



FLUX TOWERS

Flux towers are at the heart of stations. They measure fluxes with the eddy covariance method, which is based on an atmospheric turbulence analysis. This technique requires the capture and treatment of 300.000 measurements every half hour. These fluxes are complemented by a tight follow up of soil and air meteorological variables, as well as an extensive biomass (stemps/trunk, leaves, fruit, etc.) and soil sampling in order to follow up biomass dynamics and carbon and nitrogen content. Integrated over several years/decades, fluxes are representative of the net flux of an ecosystem of several hectares and reveal the budget of all processes at work in the ecosystem. Flux responses to climate, management and climatic anomalies are then analyzed.

Lonzée station

LONZÉE

STATION **2004**

One of the longest and most complete data series on cropland in Europe

SITE : 4 year rotation, typical of central Belgium.

ADDITIONAL RESEARCH THEMES : Crop and rotation carbon budget, soil respiration (autotrophic and heterotrophic discrimination), soil carbon content, growth/yield and GHG fluxes modeling, N_2O emissions, VOC exchanges, nitrogen deposition.

Formerly part of CARBOEUROPE network.

Upgrade in 2014 and official integration in ICOS on November 2017.

VIELSALM

STATION **1996**

One of the longest and most complete data series in the world.

SITE : Mature mixed forest (beech, douglas fir, spruce, silver fir, 80 to 110 years). Eddy covariance measurements at 52 m height.

ADDITIONAL RESEARCH THEMES : Soil respiration, advection, site water balance, CO_2 and CO_2 diffusion in the soil, VOC exchanges, soil carbon content, nitrogen deposition, dissolved organic compounds flows.

Formerly part of EUROFLUX and CARBOEUROPE networks.

Upgrade in 2014 and expected official integration in ICOS in 2018.

DORINNE

STATION **2010**

One of the very few grassland stations in Europe

SITE : Intensive grassland grazed by Belgian Blue heifers.

ADDITIONAL RESEARCH THEMES : Complete carbon budget, management impact on CO_2 fluxes (stoking density, rotational grazing), soil and enteric CH_4 exchanges, grassland restoration (impact on GHG balance), N_2O emissions, soil respiration, VOC exchanges, ozone exchanges.

Formerly running on regional fundings.

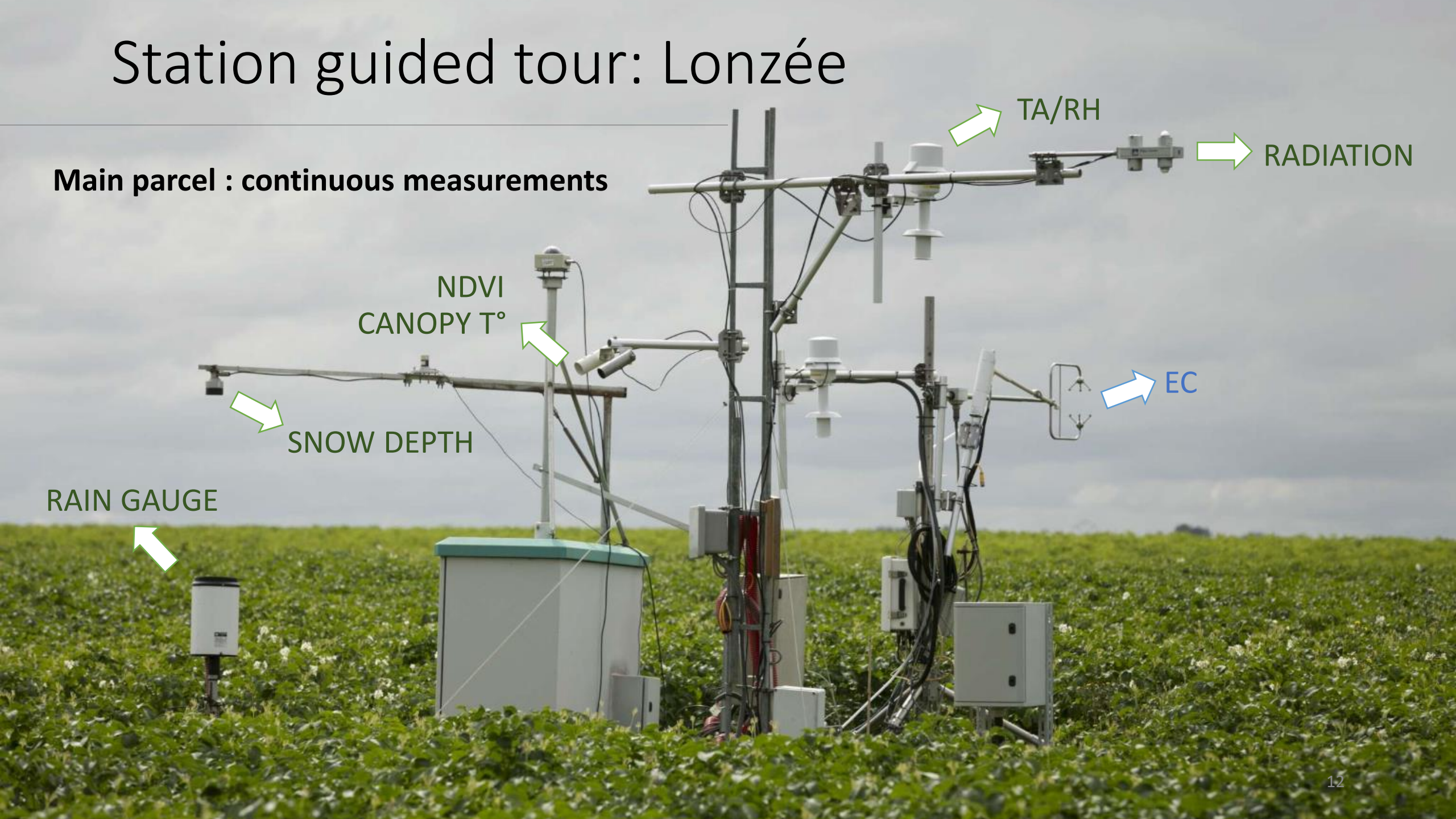
Expected official integration in ICOS in 2019.

Dorinne station

Vielsalm station

Station guided tour: Lonzée

Main parcel : continuous measurements



Station guided tour: Lonzée

Table 7. List of variables that are collected at the various ICOS Ecosystem stations (Class 1 and Class 2) for the various ecosystem types.

VARIABLES	FOREST	GRASS-LAND	CROP-LAND	WET-LAND*	MA-RINE**	LAKES**
CO_2, H_2O and H fluxes (eddy covariance, including profile for storage)	1 & 2	1 & 2	1 & 2	1 & 2	1 & 2	1 & 2
CH_4 and N_2O fluxes (eddy covariance, including profile for storage)	1	1	1	1	1	1
Air H_2O concentration	1	1	1	1	1	1
Incoming, outgoing and net SW and LW radiations	1 & 2	1 & 2	1 & 2	1 & 2	1	1
Incoming SW radiation (high quality)	Fac	Fac	Fac	Fac	Fac	Fac
Incoming PPFD	1 & 2	1 & 2	1 & 2	1 & 2	1 & 2	1 & 2
PPFD below canopy + ground reflected	Fac	Fac	Fac	N.R.	N.R.	N.R.
Outgoing PPFD	1 & 2	1 & 2	1 & 2	1 & 2	Fac	Fac
Diffuse PPFD and/or SW radiation	1	1	1	1	Fac	Fac
Spectral reflectance	Fac	Fac	Fac	Fac	Fac	Fac
Soil heat flux	1 & 2	1 & 2	1 & 2	1 & 2	N.R.	N.R.
Air temperature and humidity profile	1 & 2	1 & 2	1 & 2	1 & 2	Fac	Fac
Backup meteo station (TA, RH, SW_IN, precipitation)	1 & 2	1 & 2	1 & 2	1 & 2	1 & 2	1 & 2

VARIABLES	FOREST	GRASS-LAND	CROP-LAND	WET-LAND*	MA-RINE**	LAKES**
Total high-accuracy precipitation	1 & 2	1 & 2	1 & 2	1 & 2	1 & 2	1 & 2
Snow height	1 & 2	1 & 2	1 & 2	1 & 2	Fac	Fac
Soil water-content profile	1 & 2	1 & 2	1 & 2	1 & 2	N.R.	N.R.
Soil temperature profile	1 & 2	1 & 2	1 & 2	1 & 2	N.R.	N.R.
Air pressure	1 & 2	1 & 2	1 & 2	1 & 2	1 & 2	1 & 2
Trunk and branches temperature	Fac	N.R.	N.R.	N.R.	N.R.	N.R.
Water-table depth	1 & 2	1 & 2	1 & 2	1 & 2	N.R.	N.R.
Tree diameter (continuous)	1	N.R.	N.R.	N.R.	N.R.	N.R.
Phenology/camera	1	1	1	1	N.R.	N.R.
Soil CO_2 automatic chambers	1	1	1	1	1	1
CH_4 and N_2O fluxes by automatic chambers	1	1	1	1	1	1
Wind speed and wind direction (additional to 3D sonic)	1	1	1	1	1	1
GAI	1 & 2	1 & 2	1 & 2	1 & 2	N.R.	N.R.
Above-ground biomass	1 & 2	1 & 2	1 & 2	1 & 2	N.R.	N.R.
Soil carbon content	1 & 2	1 & 2	1 & 2	1 & 2	N.R.	N.R.
Litterfall	1	1	1	1	N.R.	N.R.
Leaf nutrients content	1 & 2	1 & 2	1 & 2	1 & 2	N.R.	N.R.
Soil-water N content	Fac	Fac	Fac	Fac	N.R.	N.R.
DOC concentration	Fac	Fac	Fac	Fac	N.R.	N.R.
C and N import/export by management	1 & 2	1 & 2	1 & 2	1 & 2	N.R.	N.R.
Oxygen and pCO_2 surface concentration	N.R.	N.R.	N.R.	Fac	2	2
Oxygen, pCO_2 and pN_2O concentration profile	N.R.	N.R.	N.R.	Fac	1	1
Salinity	N.R.	N.R.	N.R.	N.R.	1 & 2	N.R.
Wave properties	N.R.	N.R.	N.R.	N.R.	Fac	Fac
Water-temperature profile	N.R.	N.R.	N.R.	N.R.	1	1
Management and disturbances information	1 & 2	1 & 2	1 & 2	1 & 2	1 & 2	1 & 2

Station guided tour: Lonzée

Monitoring station vs manipulation site

- Focus on long-term and in-situ monitoring
- Not experimental sites but understanding the ecosystem functioning
- Importance of the presence of a network

Connection to other networks

- Possibility to host other experiments on the ICOS infrastructure and support other research works with ICOS data
- Beyond CO_2 : measures of other compounds such as CH_4, N_2O, VOC…
- Integration into other networks
- Linked projects or networks:
  - Validation of remote sensing products (**LPV**)
  - Ecotron : validation or ecosystem manipulation (**AnaEE**)
  - Ecosystem health monitoring (**NEC**, **eLTER**)
  - Study on atmospheric pollution : installation of a PTR-TOF-MS in Be-Vie by BIRA (**ACTRIS**)

Examples of scientific exploitation

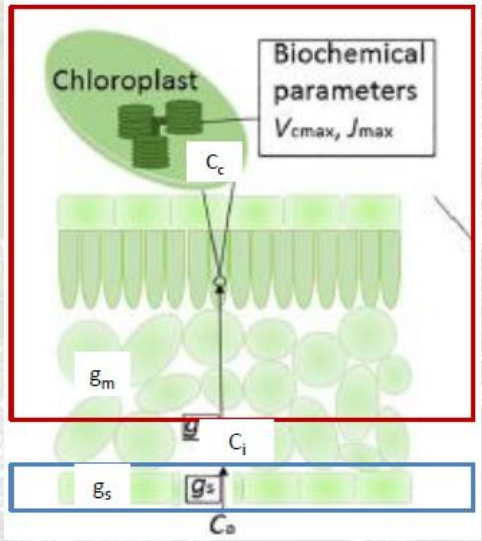
- L. Gourlez de la Motte and the strength of a network: rapid reaction to an extreme event thanks to multi-site data availability
- P. Buysse and the strength of having long high quality time series, not only of EC data (continuous) but also of ancillary measurements, essentials for the complete carbon budget.


Sites location
Légende
Élément 2
DK-SOR
BE-BRA
DE-HAI
BE-VIE
CZ-RAJ
CZ-STN
CZ-LNZ
FR-HES
FR-BIL
IT-SR2
Google Earth
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
© 2009 GeoBasis-DE/BKG
© 2018 Google
N
900 km

Quantification of the 2018 drought for European forests and impacts of stomatal and non stomatal limitation of photosynthesis

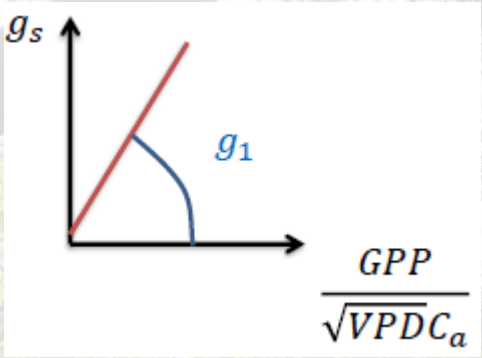
Louis Gourlez de la Motte

Theory and basic concepts



Non - Stomatal → Changes in **apparent Vcmax** with measured C_i values

Stomatal → Changes in C_i which are associated with changes in **g1**



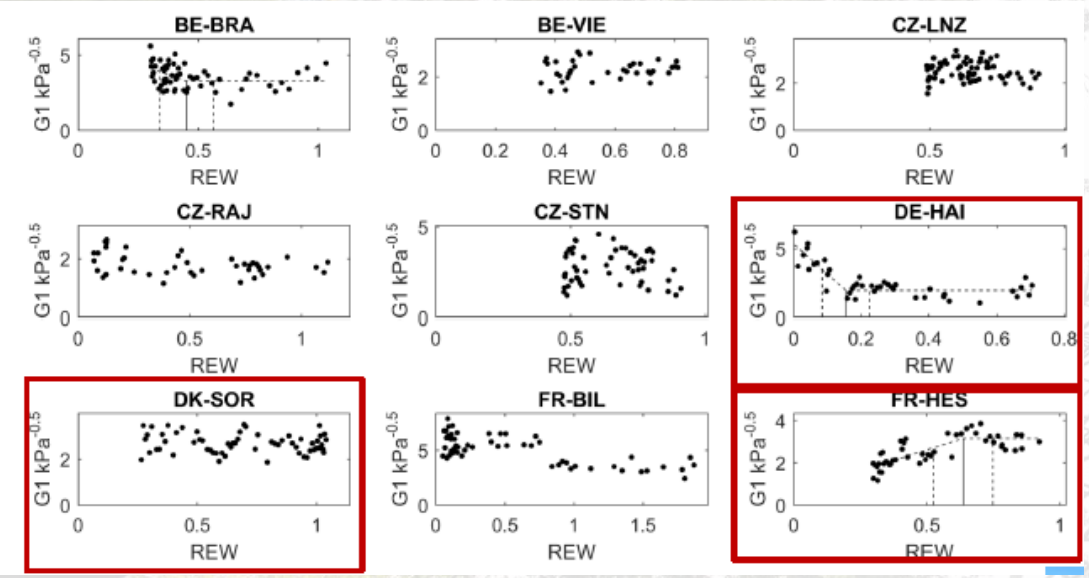
$$\begin{cases} GPP = \dfrac{V_{cmax}(C_i - \Gamma*)}{(C_i + K_m)} \\ C_i = C_a - \dfrac{GPP}{g_c} \\ g_s = g_0 + 1.6\left(1 + \dfrac{g_1}{\sqrt{VPD}}\right)\dfrac{GPP}{C_a} \end{cases}$$

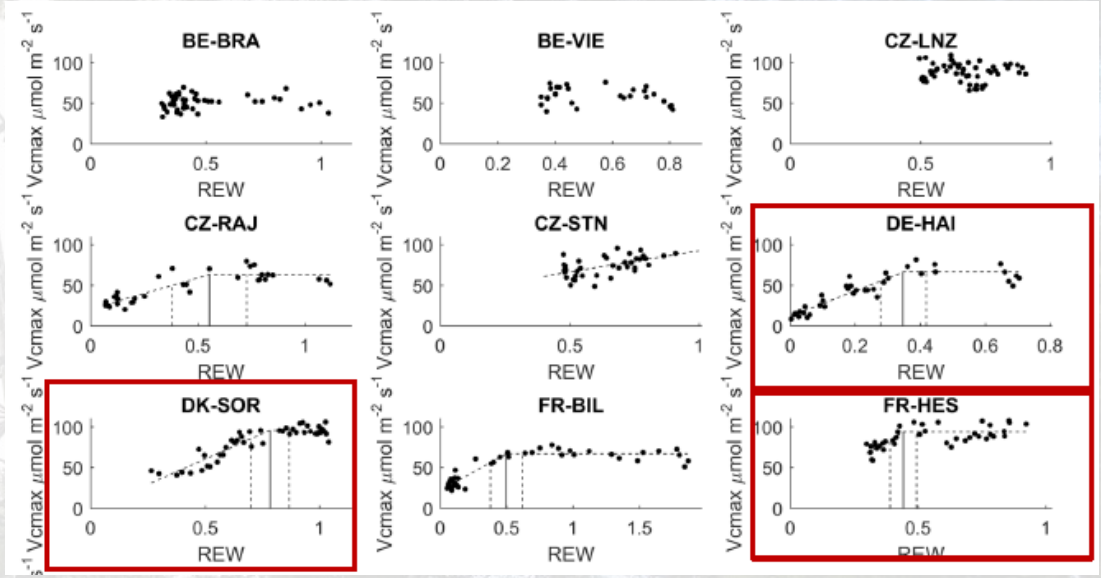
- C_a = air concentration
- GPP = EC flux
- g_s = stomata conductance
- C_i = interior concentration

Quantification of the 2018 drought for European forests and impacts of stomatal and non stomatal limitation of photosynthesis

Louis Gourlez de la Motte

RESULTS: stomatal (G1) and non-stomal (VCMAX,APP) limitations





- No consistent stomatal behaviour across ecosystems
- Non stomatal limitations are observed at almost all sites where REW felt < 0.4

DoL: In most ecosystems, non-stomatal limitation is the dominant mechanism

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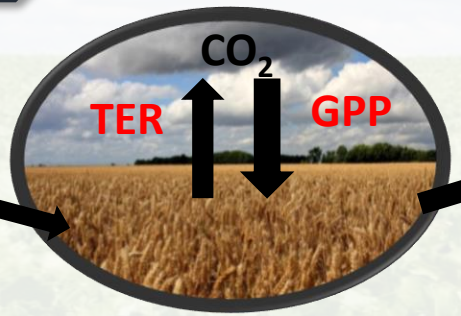
Carbon budget measurement over 12 years at a crop production site

Pauline Buysse – post-doc

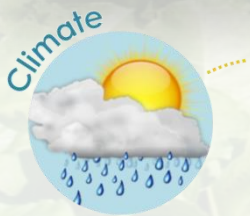
Context

C import (liming, manuring)



C export (harvest)

C budget = NBP = NEE + C import + C export

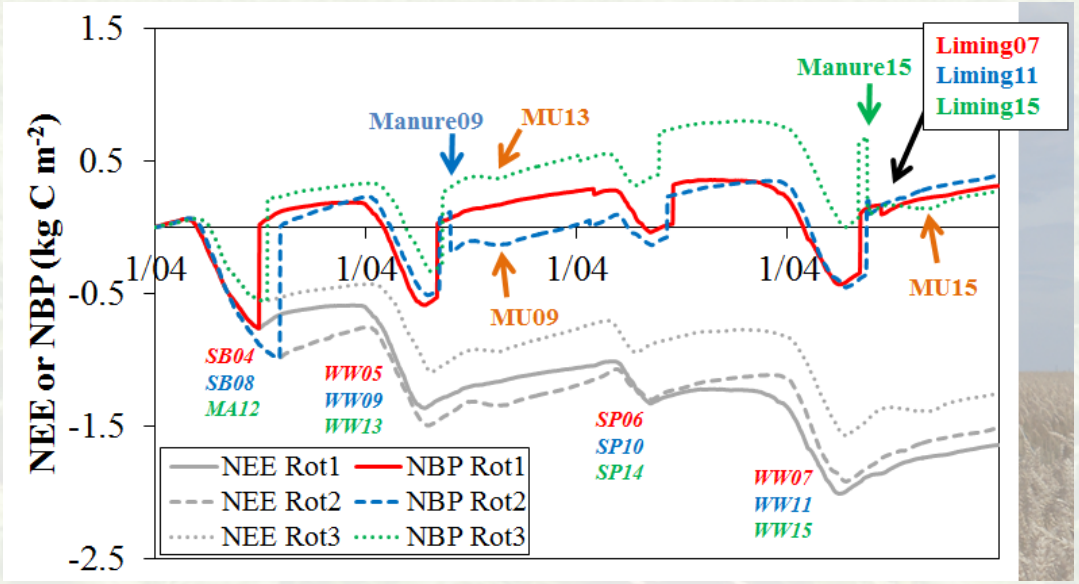


Objectives

Compute the **carbon budget** of a crop production site and study its response to **climatic stresses** and **agricultural practices**

Results

Example : Net production of the ecosystem for 3 rotations



=> The field is a non-negligible source of carbon for the atmosphere (82.5 ± 22 gC m^{-2} yr^{-1})

Thank you for your attention!

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icos-belgium.be

Useful links:

- CP : https://www.icos-cp.eu/ (→ Data & Services/Data Portal)
- ETC : http://www.icos-etc.eu/icos/documents/instructions (ICOS instructions)
- Protocols : http://www.international-agrophysics.org/Search/?s=ICOS (or cited in the instructions)
- ICOS Belgium : https://www.icos-belgium.be/index.php#index