In situ measurement techniques for trace gas fluxes in terrestrial ecosystems

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Outline

- Trace Gas fluxes and Interaction with Terrestrial Ecosystems
- Carbon storage and Carbon Inventories
- Flux measurements methods
  - Chambers
  - Eddy Covariance
  - Networks and infrastructures

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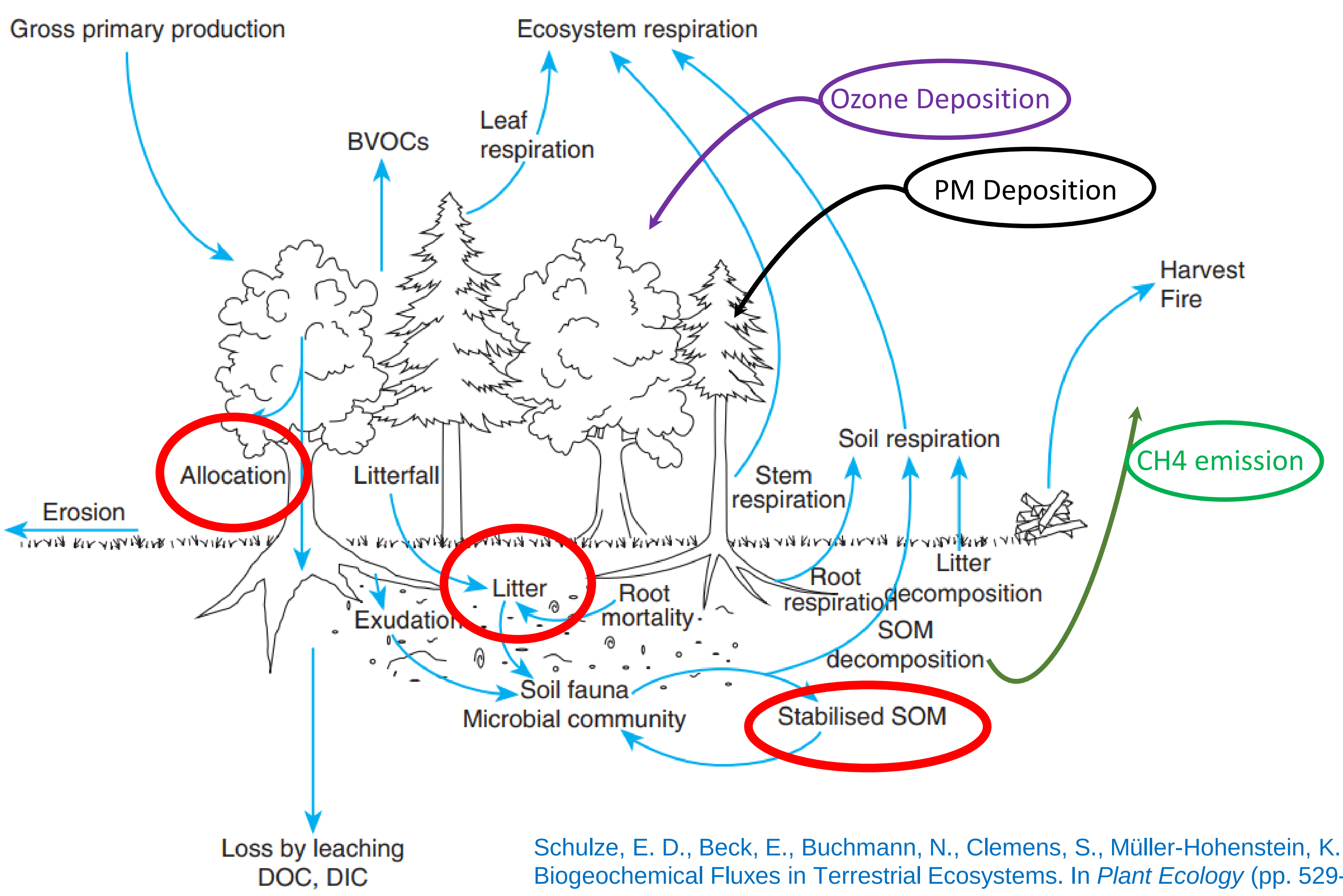
Trace Gas fluxes and Interaction with Terrestrial Ecosystems



CARBON FLUXES

NPP = GPP-RA

NEP = GPP-RA-RH

NEP = NPP-RH

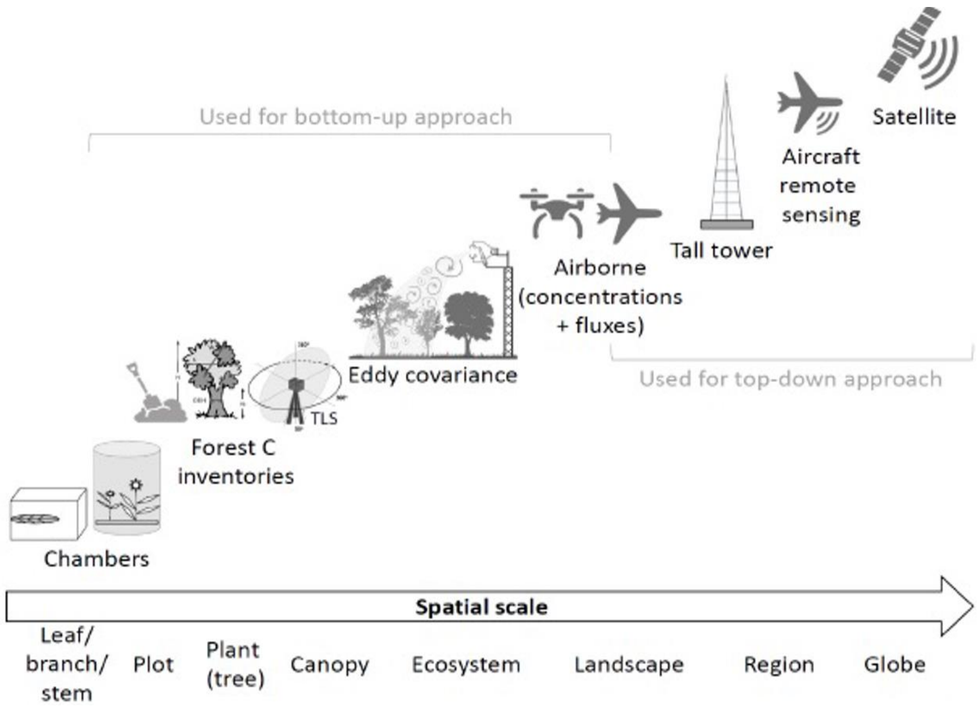
OZONE FLUXES

METHANE FLUXES

Schulze, E. D., Beck, E., Buchmann, N., Clemens, S., Müller-Hohenstein, K., & Scherer-Lorenzen, M. (2019). Biogeochemical Fluxes in Terrestrial Ecosystems. In *Plant Ecology* (pp. 529-577). Springer, Berlin, Heidelberg.

Trace Gas fluxes and Interaction with Terrestrial Ecosystems

The selection depends on the scale, the measured area will guide for the suitable method



Carbon storage changes can be calculated

- from the change in carbon stock
- integrating the net carbon flux over time

STORAGE CHANGE = FLUX x TIME

so

FLUX = STORAGE CHANGE / TIME

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Pools Measurements
Forest C Inventories

1) Stratification of Land Area

Collection of basic information: land use history, maps of soil, vegetation, and topography

2) Establishing type and number of sampling plots

Permanent or temporary sampling plots selection.
Number: A reasonable estimate of the net change carbon stocks that can be achieved at a reasonable cost. Larger the number and the size, smaller the error and larger the cost

3) Selecting Carbon pools to measure and monitor

- Above-ground biomass (stems, stumps, branches, bark, seeds, foliage.)
- Below-ground biomass (live roots)
- Woody necro-mass (dead wood)
- Organic litter (Fine woody debris, leaf Litter, Humus)
- Soil

Pools Measurements- Forest C Inventories

MEASUREMENTS

Above-ground biomass **Direct methods (field inventory)** all the trees in the sample plots above a minimum diameter are measured. The minimum diameter often is 5 cm in d.b.h. **Non Destructive sampling**, using general allometric relationship (less accurate, less cost). **Destructive sampling**, whereby vegetation is harvested, dried to a constant mass and the dry-to-wet biomass ratio established (more accurate, more cost).

Below-ground biomass Measuring above-ground biomass is relatively established and simple. It can also be assessed locally by taking soil cores from which roots are extracted. Measuring below-ground biomass (coarse and fine roots) is **time consuming**!! Often **regression model** to estimate below-ground biomass as a function of above-ground biomass. **Uncertainty becomes high!**

Organic Litter **Harvesting techniques in small subplots** (0.25 m2) within each plot.

Soil To obtain an accurate inventory of organic carbon stocks in the soil, is necessary to measure: **soil depth**, soil **bulk density** (calculated from the oven-dry weight of soil from a known volume of sampled material), and **concentrations of organic carbon** within the sample

Pools Measurements- Forest C Inventories

TEMPORAL

Mediterranean Beech Forest in Italy

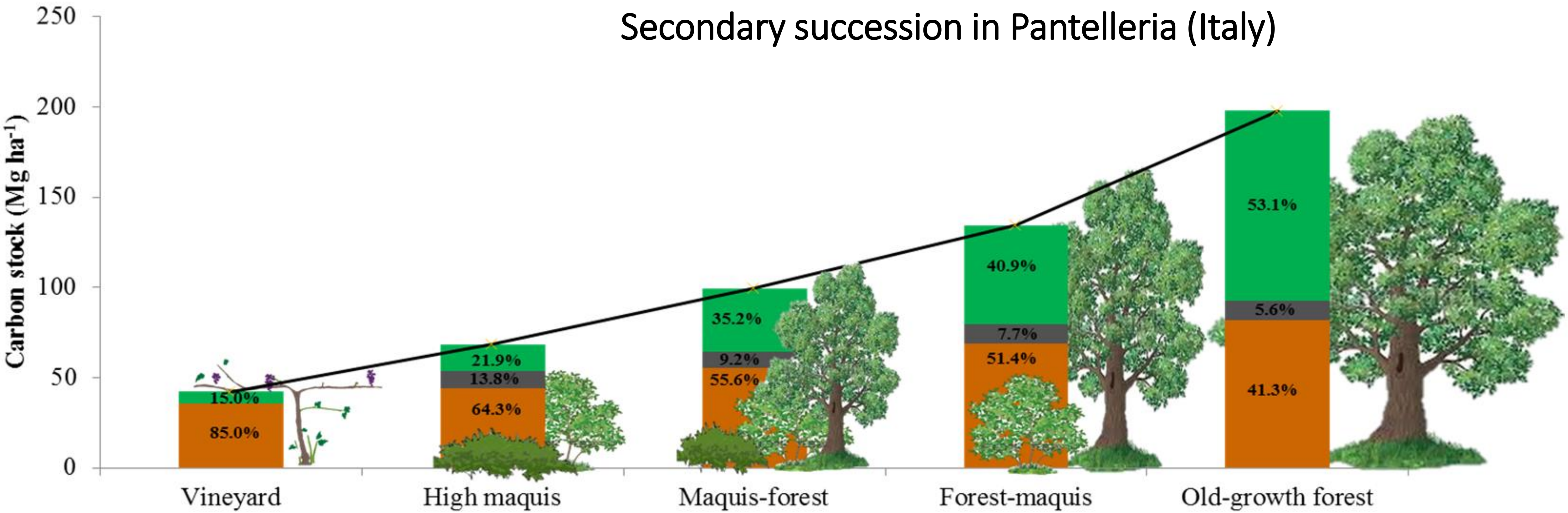
$Mg\ C\ ha^{-1}$	1992	2002
Above-Ground	217	269
Below-Ground	65	80
Total	**282**	**349**

$NPP = 6.68\ Mg\ C\ ha^{-1}\ yr^{-1}$

Curtesy of Ettore D'Andrea

Pools Measurements- Forest C Inventories

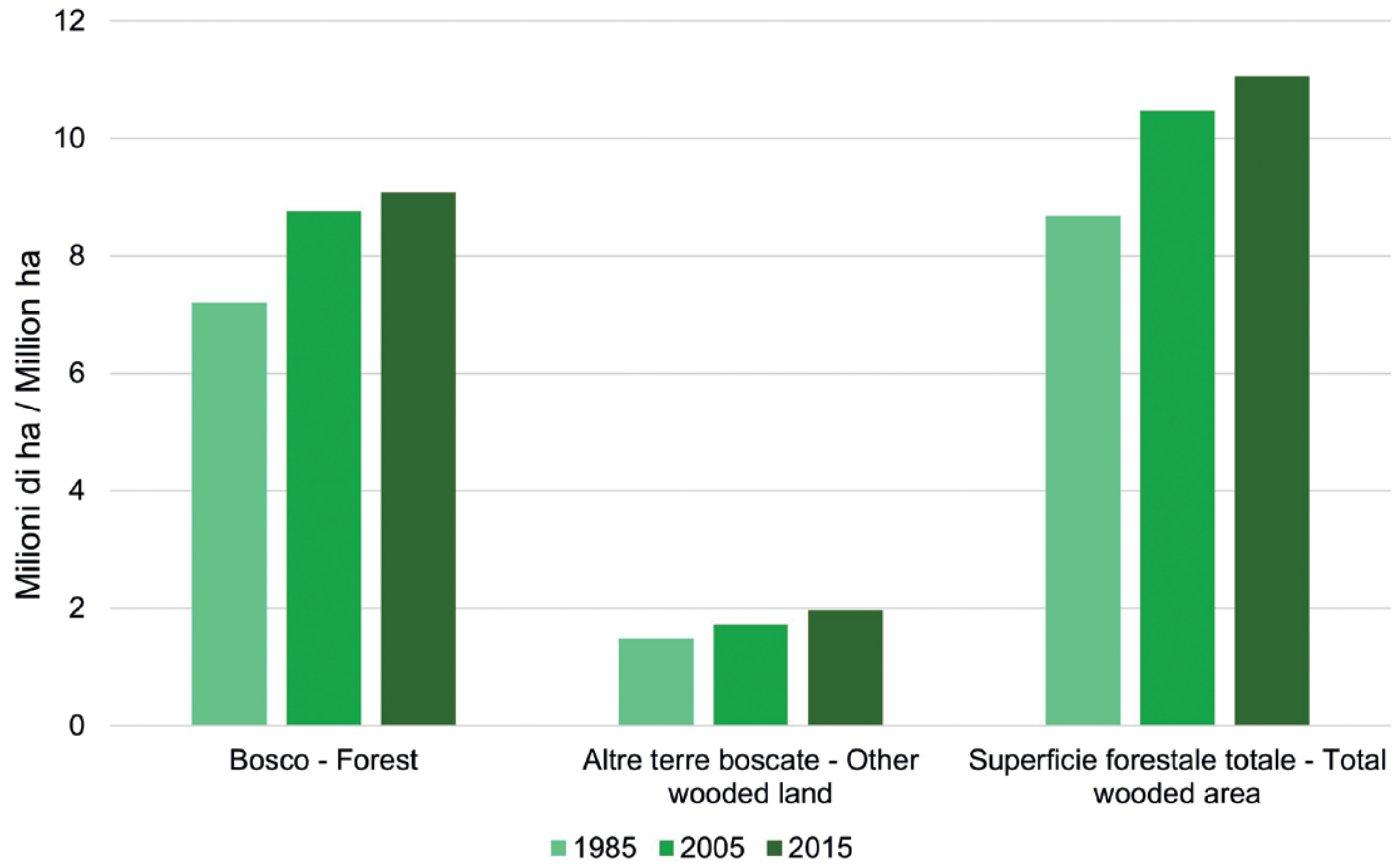
SPATIAL

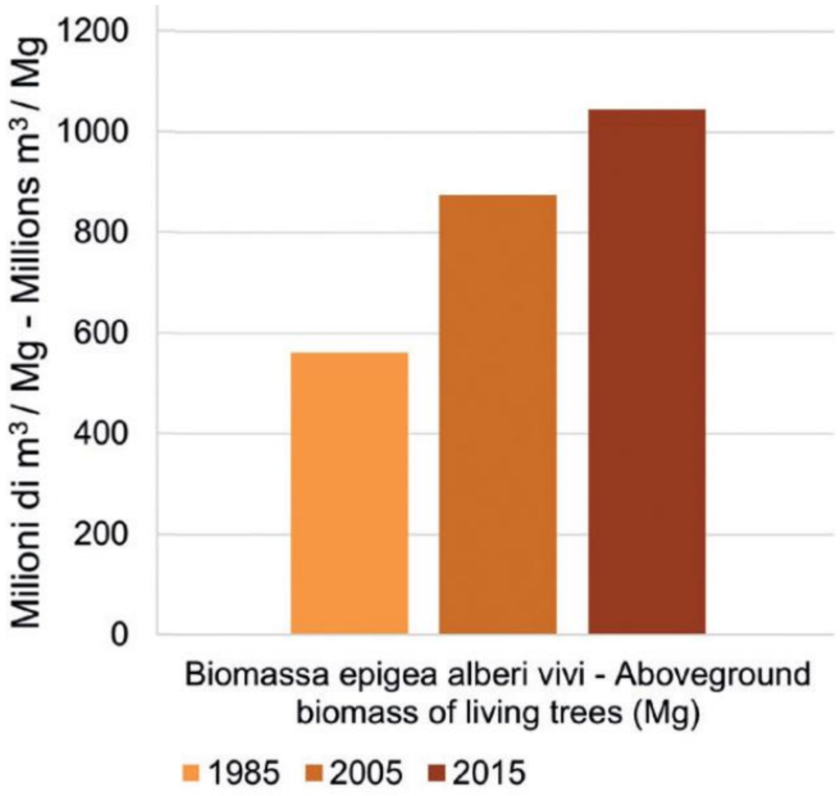


Badalamenti et al. "Carbon stock increases up to old growth forest along a secondary succession in Mediterranean island ecosystems." *PLoS One* 14.7 (2019)

SPATIO-TEMPORAL

National Forest Inventory INFC 2015





https://www.inventarioforestale.org/en

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Flux Measurements - Chambers

Chamber carbon flux measurements are routinely used to **assess ecosystem dynamics** of the whole ecosystems or its components.

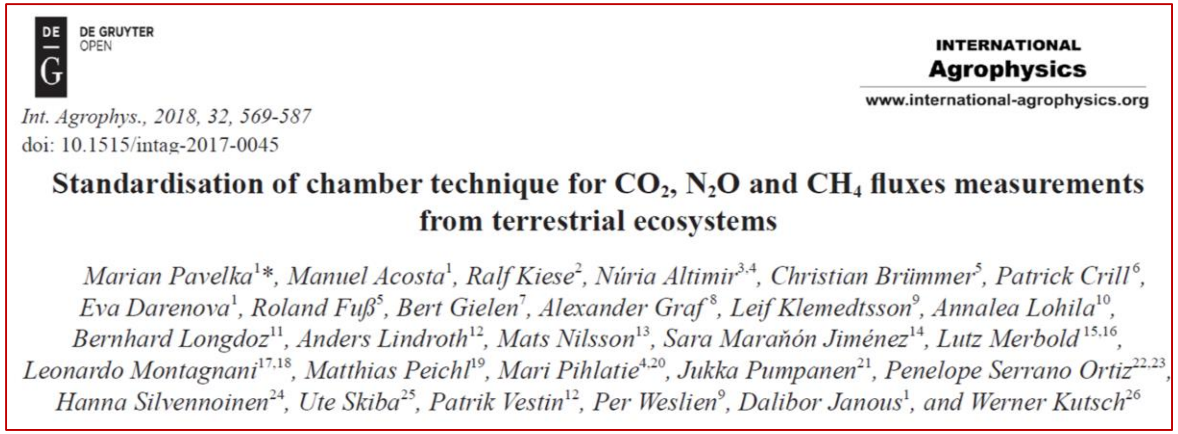
"**steady state**" type: an external airflow passes through the chamber and the fluxes are calculated on the base of the differential CO_2 concentration of the incoming and outgoing air

"**non-steady state**" type: the fluxes are calculated on the basis of the CO_2 concentration changes in the air passing inside the chamber in a closed loop.

Can be developed Low-cost (e.g. Arduino based sensors)

Fluxes need to be **up-scaled** in space and time for each vegetation type. **Uncertainty becomes high!**

Enclosing a portion of an ecosystem inside a chamber produces several **artifacts**, caused by the chamber characteristics and deployment (chamber effect).



DE G DE GRUYTER OPEN

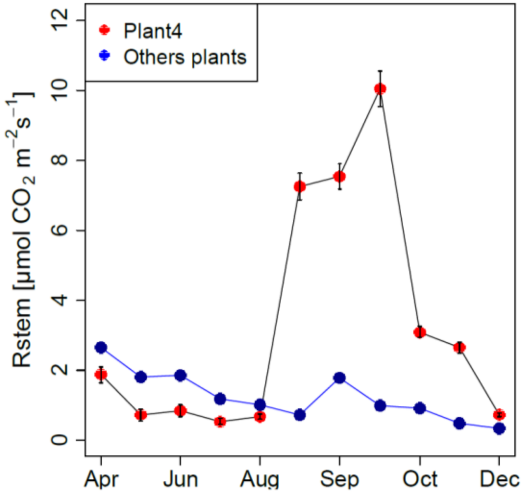
INTERNATIONAL Agrophysics
www.international-agrophysics.org

Int. Agrophys., 2018, 32, 569-587
doi: 10.1515/intag-2017-0045

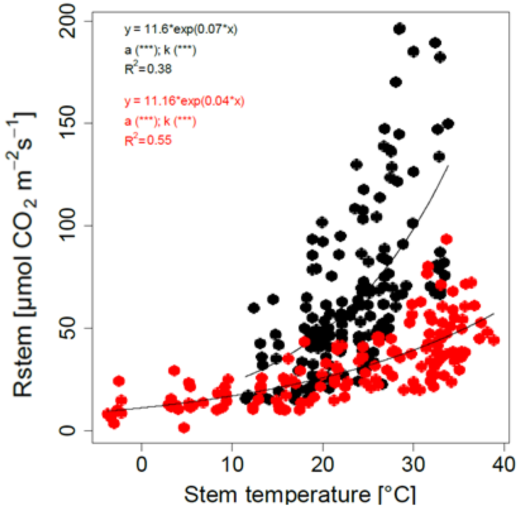
Standardisation of chamber technique for CO_2, N_2O and CH_4 fluxes measurements from terrestrial ecosystems

Marian Pavelka[1], Manuel Acosta[1], Ralf Kiese[2], Núria Altimir[3,4], Christian Brümmer[5], Patrick Crill[6], Eva Darenova[1], Roland Fuß[5], Bert Gielen[7], Alexander Graf[8], Leif Klemedtsson[9], Annalea Lohila[10], Bernhard Longdoz[11], Anders Lindroth[12], Mats Nilsson[13], Sara Marañón Jiménez[14], Lutz Merbold[15,16], Leonardo Montagnani[17,18], Matthias Peichl[19], Mari Pihlatie[4,20], Jukka Pumpanen[21], Penelope Serrano Ortiz[22,23], Hanna Silvennoinen[24], Ute Skiba[25], Patrik Vestin[12], Per Weslien[9], Dalibor Janous[1], and Werner Kutsch[26]*

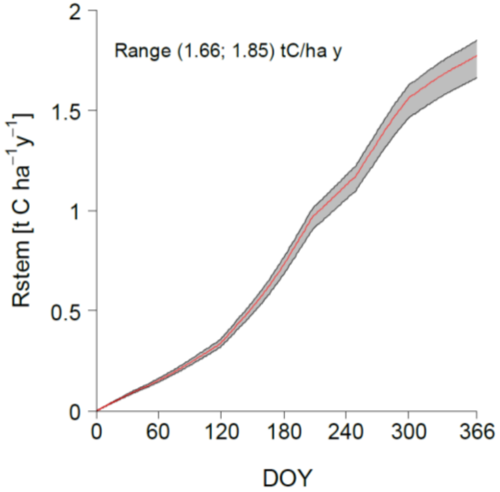
Flux Measurements - Chambers



Time Course of Stem CO2 Emission



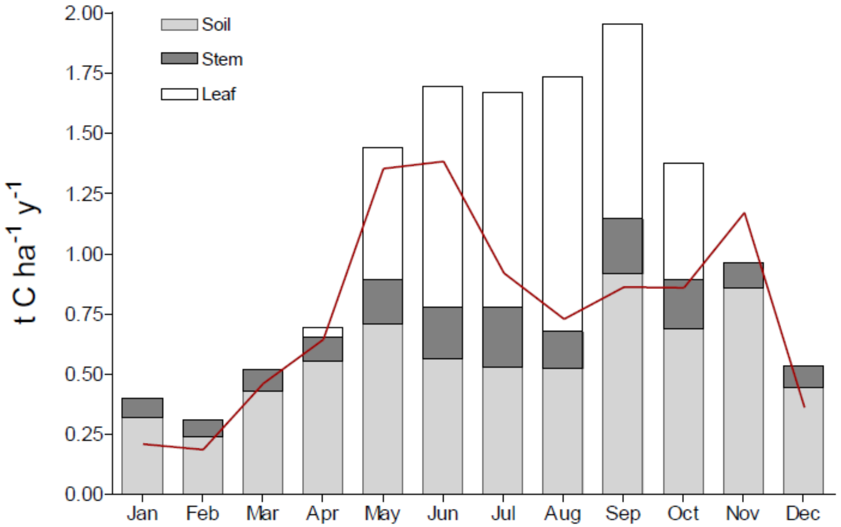
Relationship with temperature



Spatial and Temporal Scaling up

Seasonal Trend of **Stem CO_2 emission** in a Mediterranean Turkey Oak Forest in Central Italy in 2012.

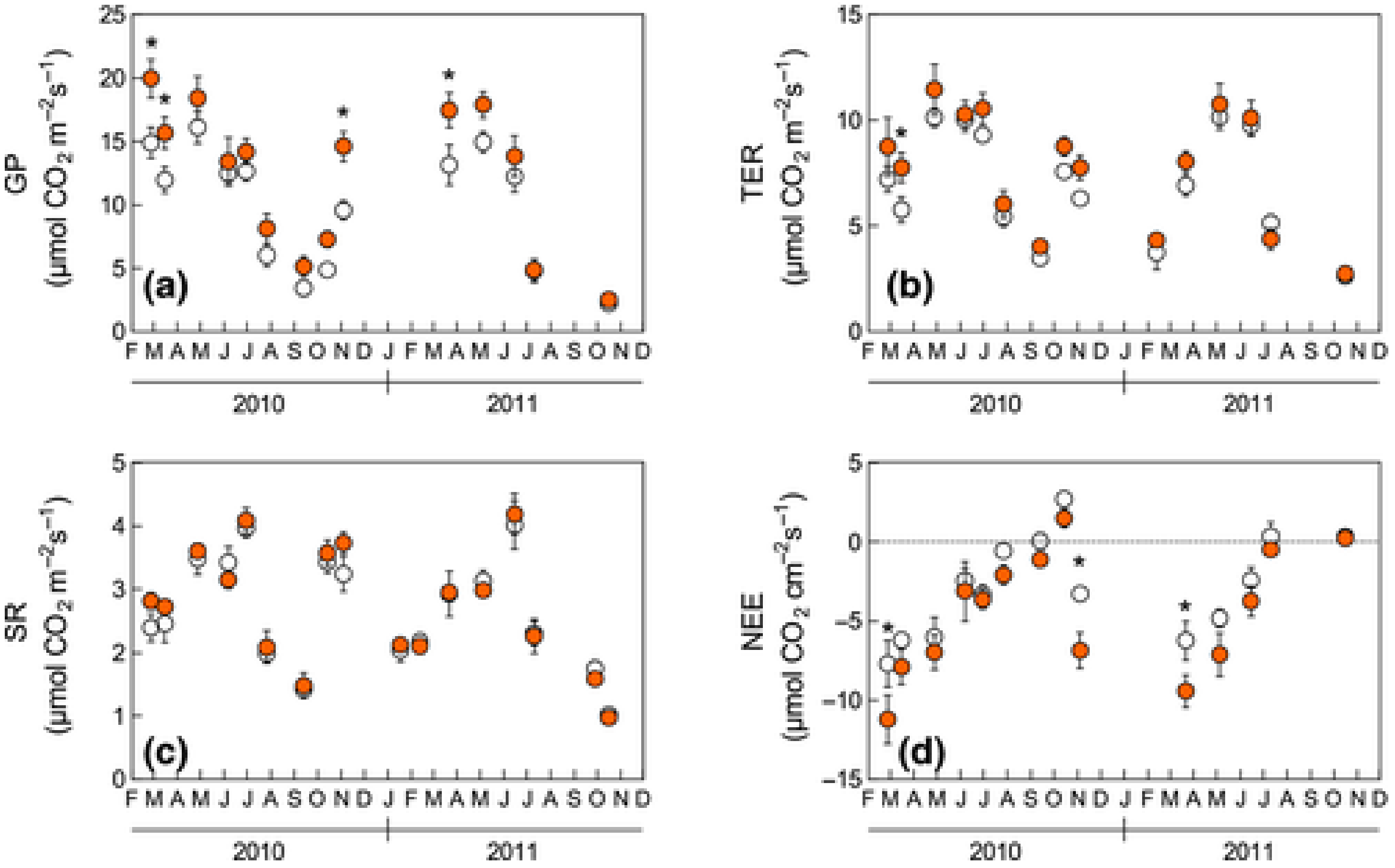
The **die back** of the tree as a consequence of a strong period of drought caused a huge amount of CO_2 release from the stem since the end of August. The contribution of these emissions to the total ecosystem emission have been estimated up to **3%** (after the estimated that the density of these **die back** plants).



Flux Measurements - Chambers

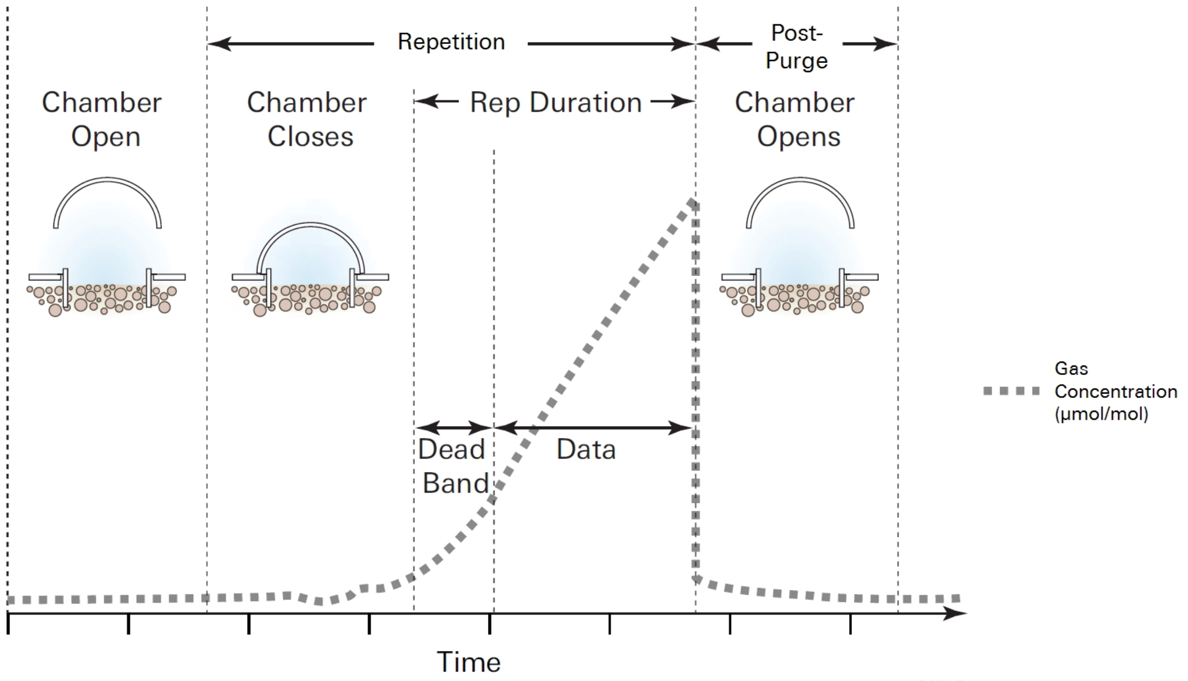
Net CO2 exchange (NEE), provides a measure of the difference between C flows entering the ecosystem (**GPP**) and C ecosystem output (**TER**– which includes both autotrophic and heterotrophic respiration).

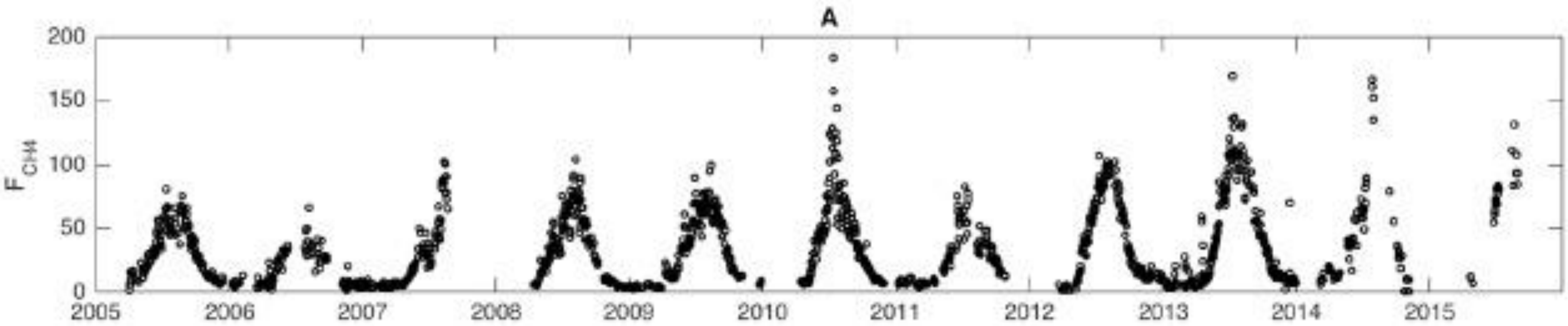
GPP, TER and NEE in a semi-arid Mediterranean garrigue, identifying a **strong seasonality of CO_2 fluxes** with the highest rates during spring and lowest rates recorded during the hot dry non-vegetative summer.



Liberati, D., Guidolotti, G., de Dato, G., & De Angelis, P. (2021). Enhancement of ecosystem carbon uptake in a dry shrubland under moderate warming: The role of nitrogen-driven changes in plant morphology. *Global Change Biology*, *27*(21), 5629-5642.

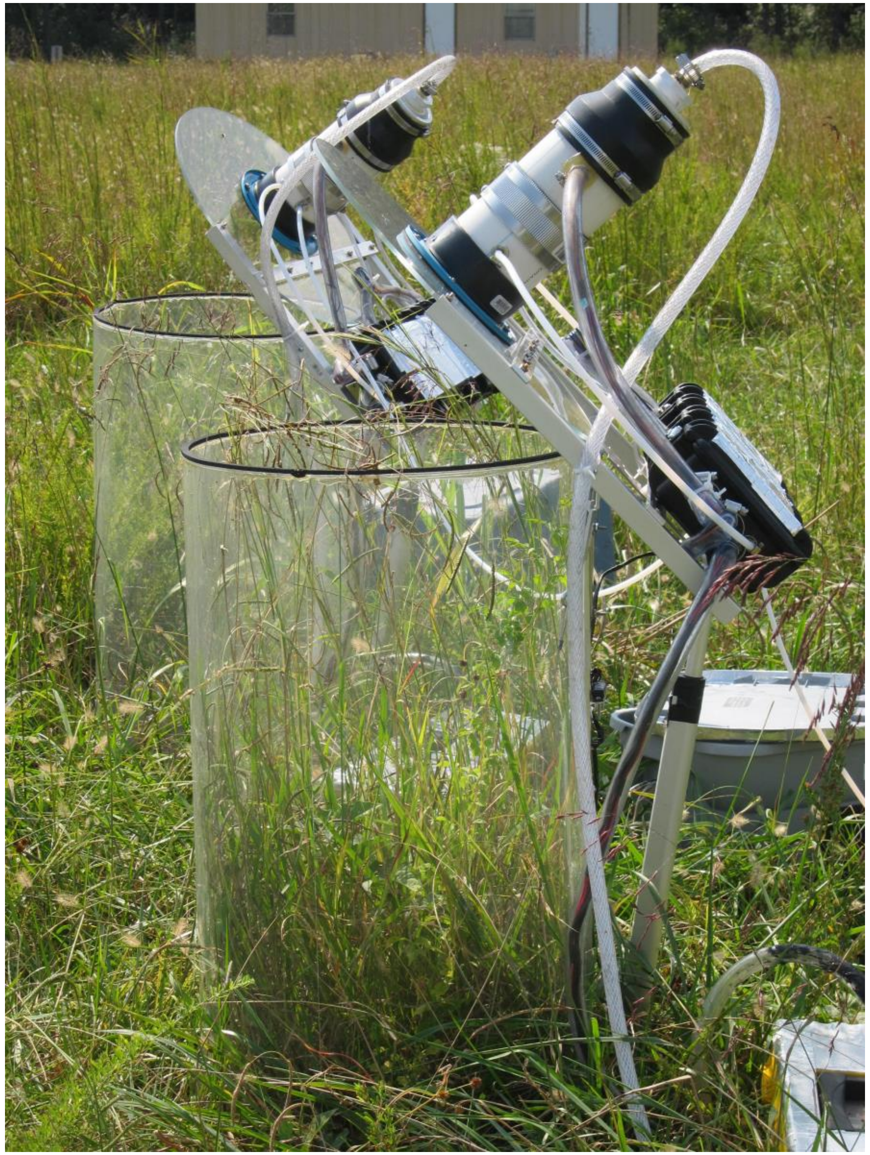
Flux Measurements - Chambers

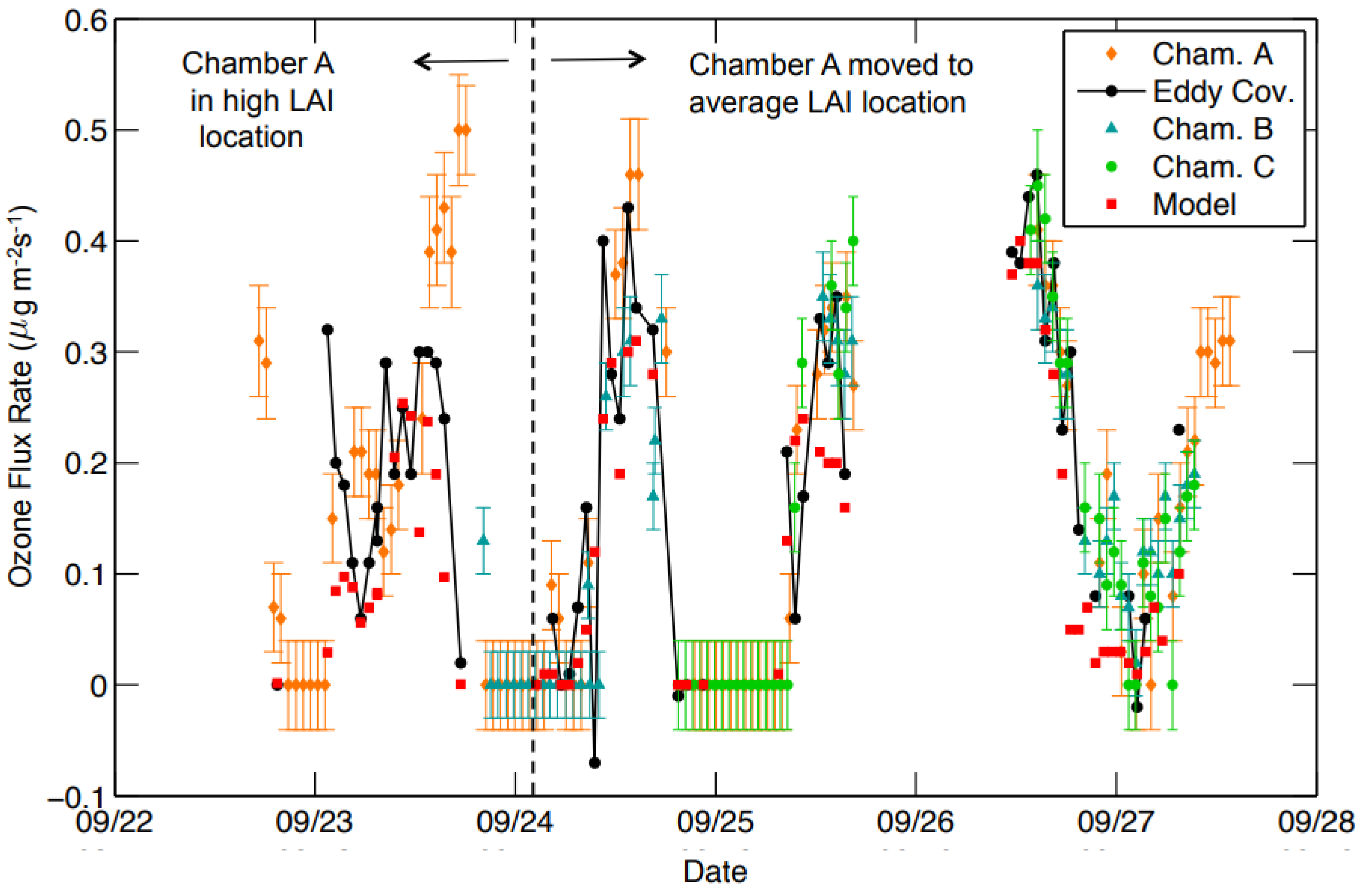




Daily averages of methan flux (nmol m-2s-1Siikaneva wetland) Rinne et al. 2018

Flux Measurements - Chambers





Almand-Hunter et al 2015

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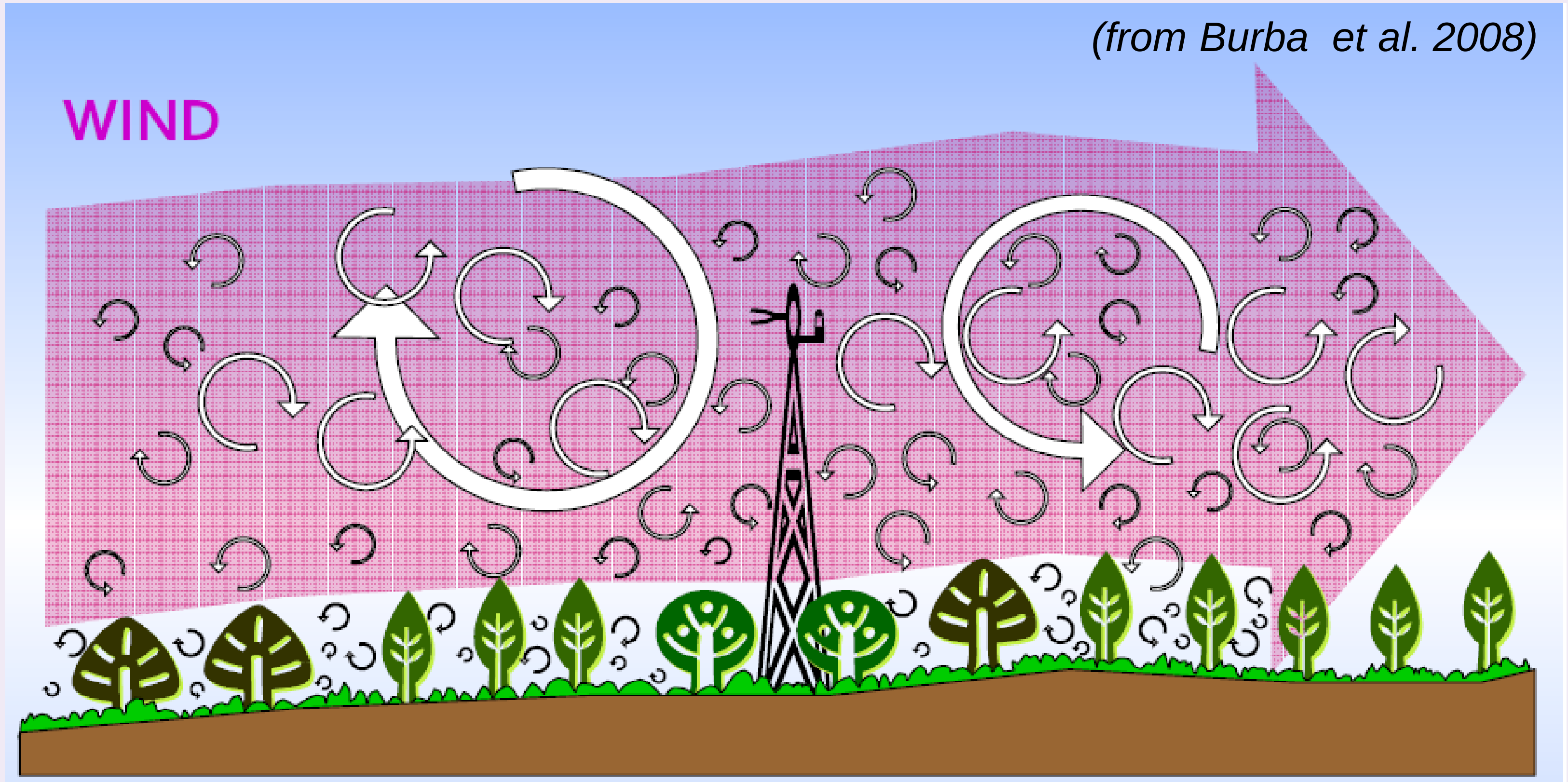
Eddy Covariance

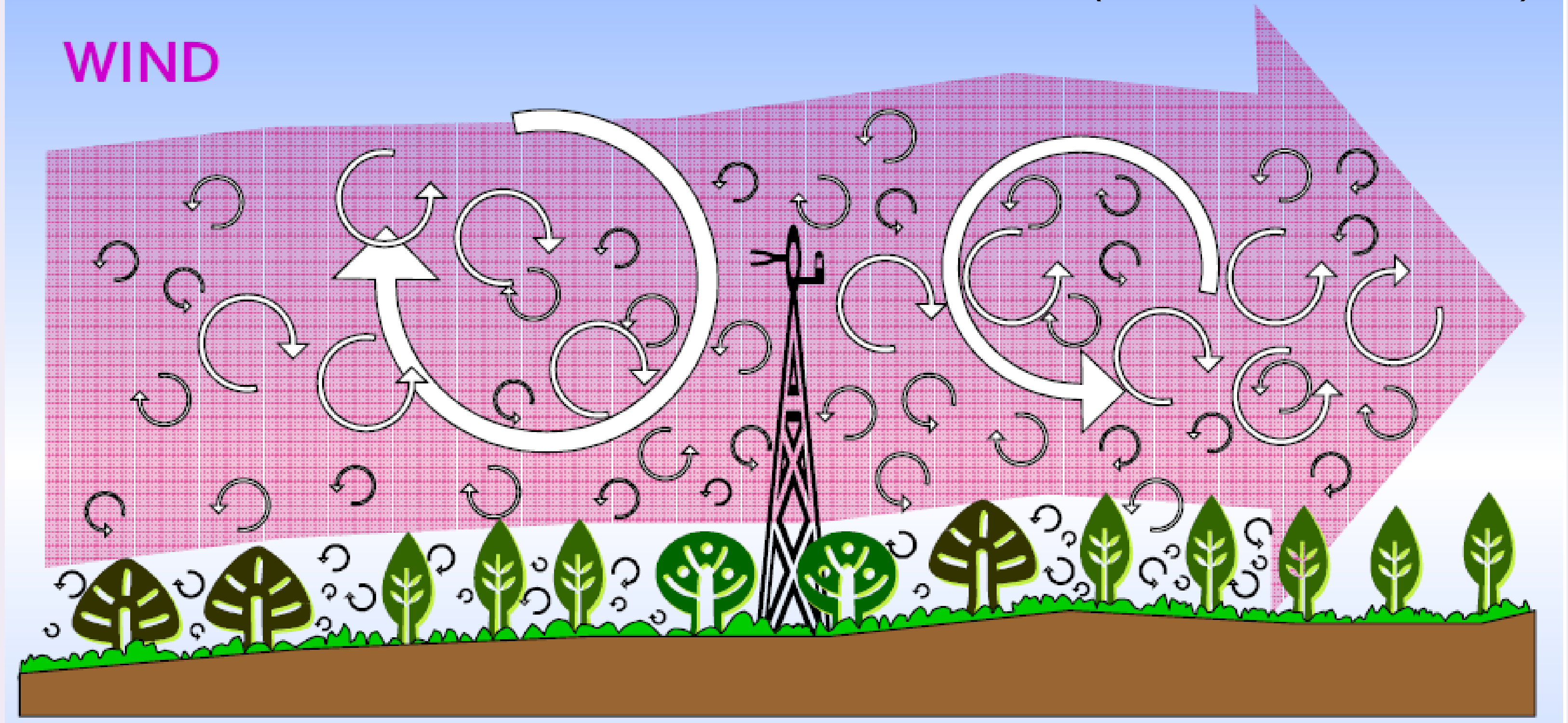
- It is a reliable method to assess exchange of masses between biosphere and atmosphere.



- micro-meteorological technique, based on the turbulent upward and downward movement of the air (eddies) transporting masses (gases, PM).

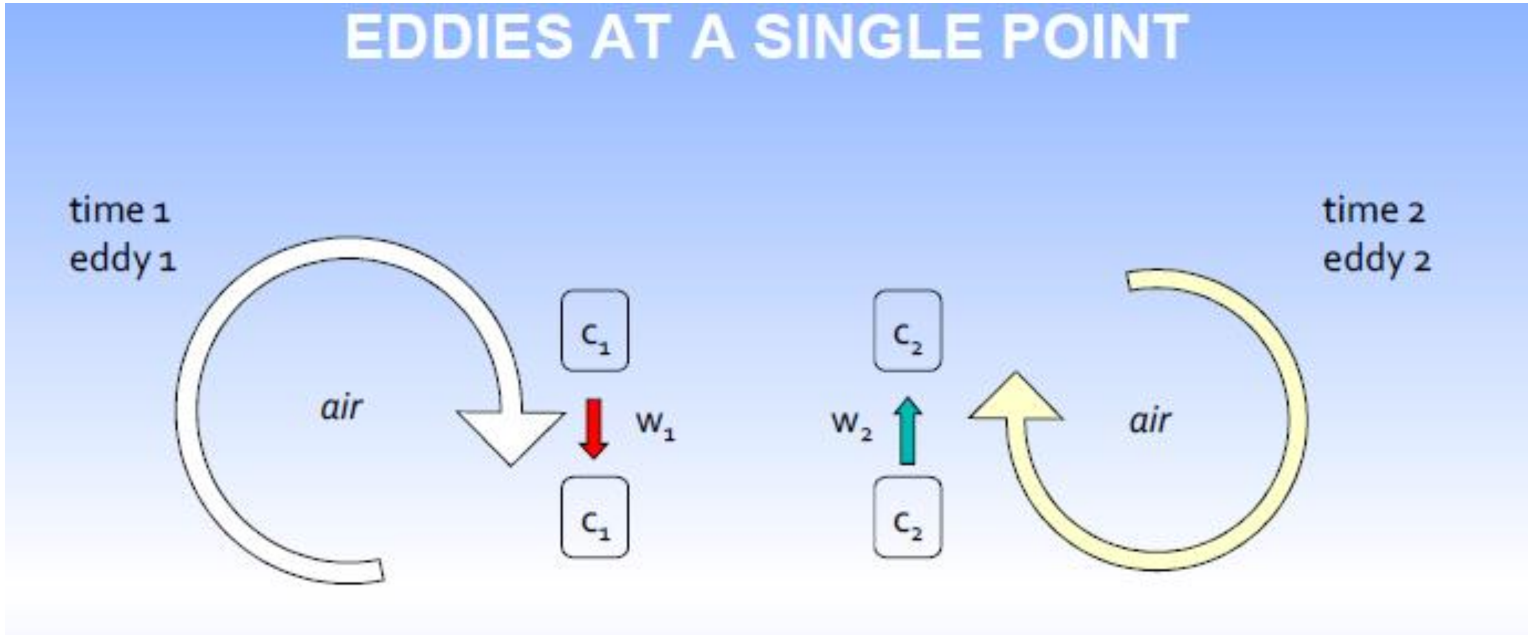
Eddy Covariance

- Air flow can be imagined as a horizontal flow of numerous rotating eddies
- Each eddy has 3-D components, including a vertical wind component
- The diagram looks chaotic but components can be measured from tower



(from Burba et al. 2008)

Eddy Covariance

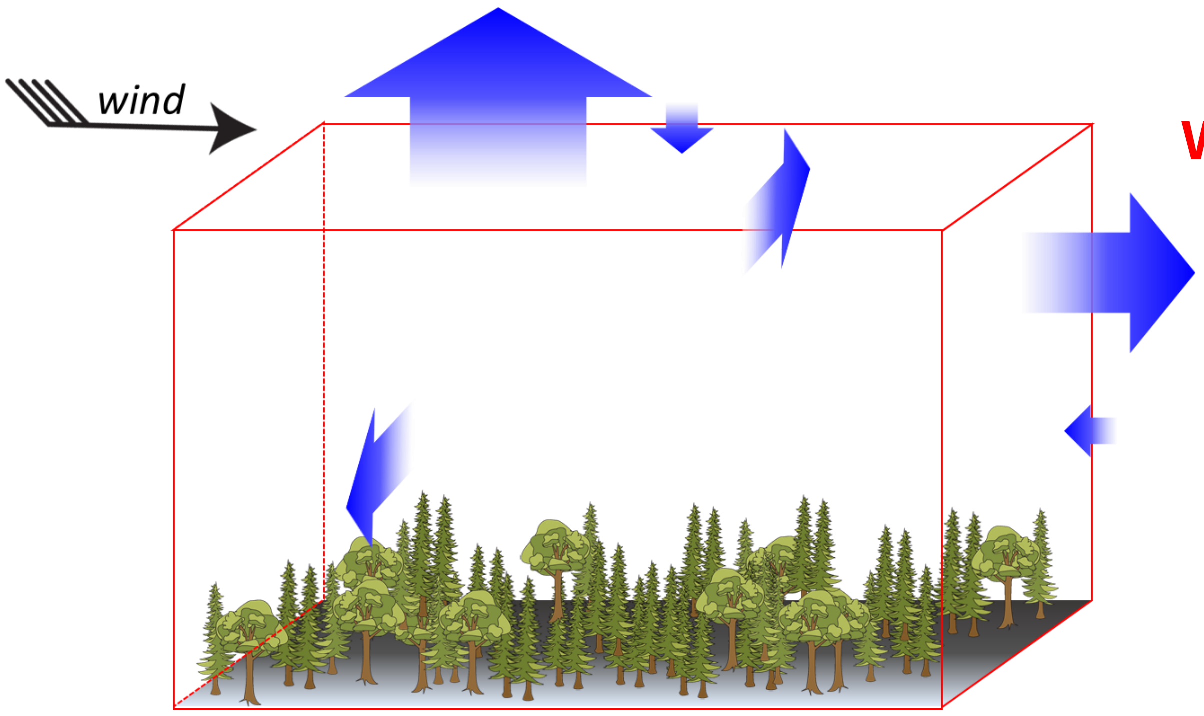


At a single point on the tower

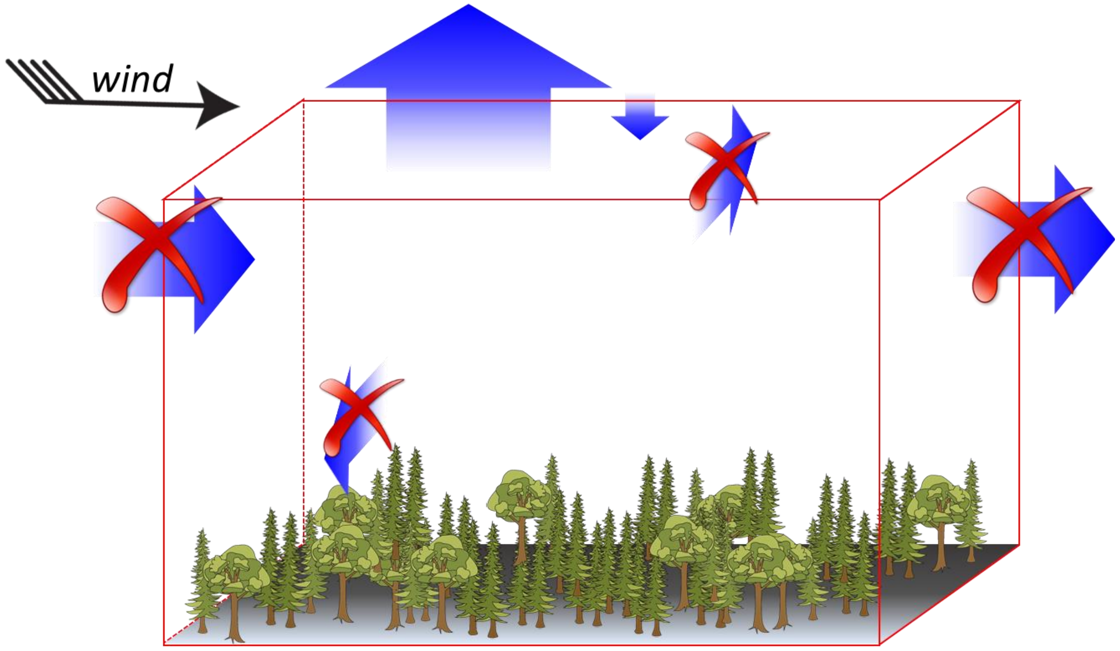
Eddy 1 moves parcel of air C1 down with the speed w1
Eddy 2 moves parcel C2 up with the speed w2

Each parcel has a concentration, temperature, humidity if we know these and the speed-we know the flux

Eddy Covariance



WHY ONLY VERTICAL WIND SPEED (W)?



- IF THE SURFACE IS LARGE & FLAT
- WE CAN ASSUME THIS

Eddy Covariance

Mathematical Formulation

$$F = d_a \cdot w \cdot c$$

ISTANTANEUS VERTICAL FLUX

AIR DENSITY

ISTANTANEOUS VERTICAL WIND SPEED

ISTANTANEOUS CONCENTRATION

ISTANTANEOUS FLUX

$$F = d_a \cdot w \cdot c$$

ISTANTANEUS VERTICAL FLUX

AIR DENSITY

ISTANTANEOUS VERTICAL WIND SPEED

ISTANTANEOUS CONCENTRATION

- The instantaneous flux is highly variable thus not representative.

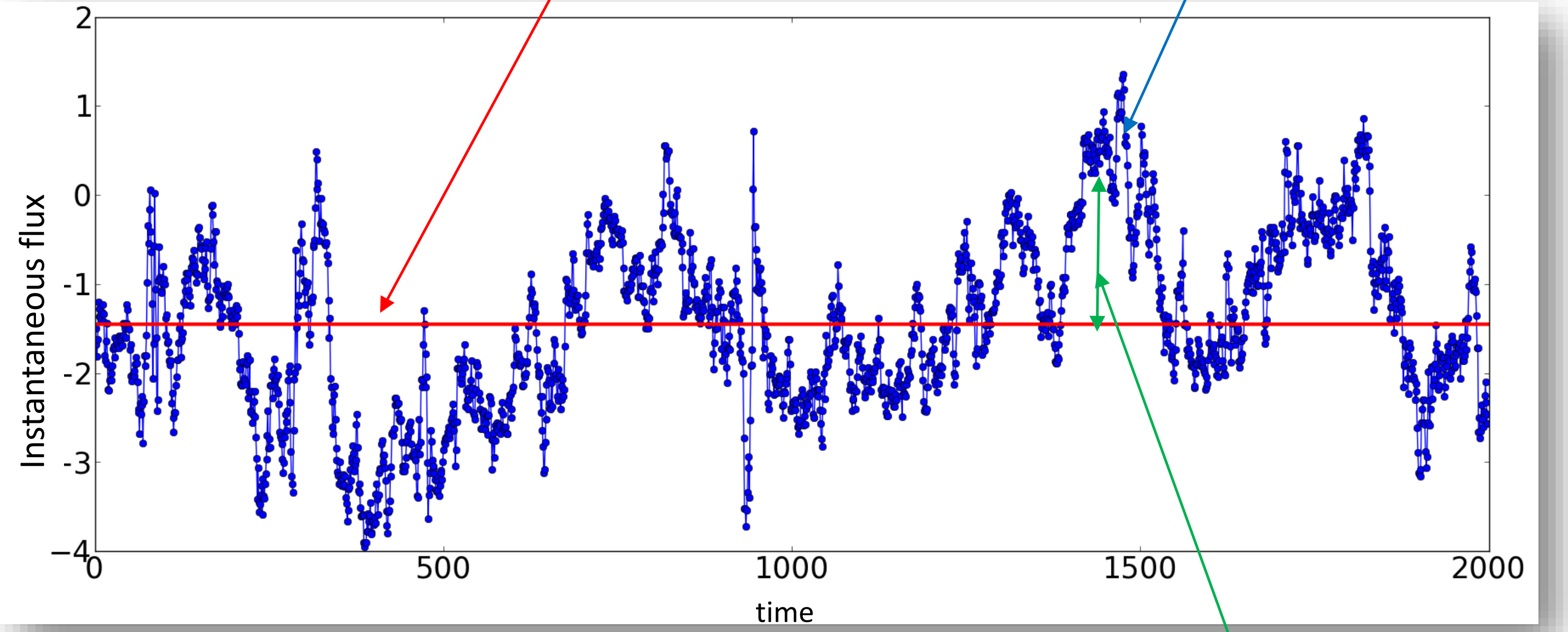
Thus we use the **average flux** of a certain time interval (typically half hour)

$$\overline{x} = \frac{1}{N}\sum_{i=1}^{N} x_i$$

$$x'_i = x_i - \overline{x}$$

Average value of the 2000 points $\overline{x}$

Instantaneous flux x_i



x'_i Fluctuation

Flux Measurements – Eddy Covariance

$$\overline{F} = \overline{d_a} \cdot \overline{w'c'}$$

Vertical average Flux

Average Air Density

Average Covariance of products of fluctuation of W and C

$$F = d_a \cdot w \cdot c$$

ISTANTANEUS VERTICAL FLUX (F)

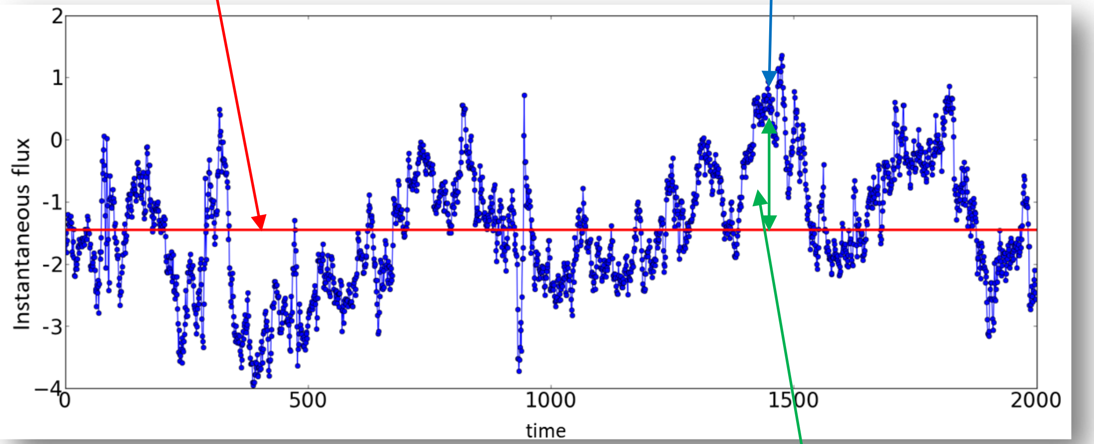
AIR DENSITY (d_a)

ISTANTANEOUS VERTICAL WIND SPEED (w)

ISTANTANEOUS CONCENTRATION (c)

Average value of the 2000 points $\overline{x}$

Instantaneous flux x_i



$$\overline{x} = \frac{1}{N}\sum_{i=1}^{N} x_i \qquad x'_i = x_i - \overline{x}$$

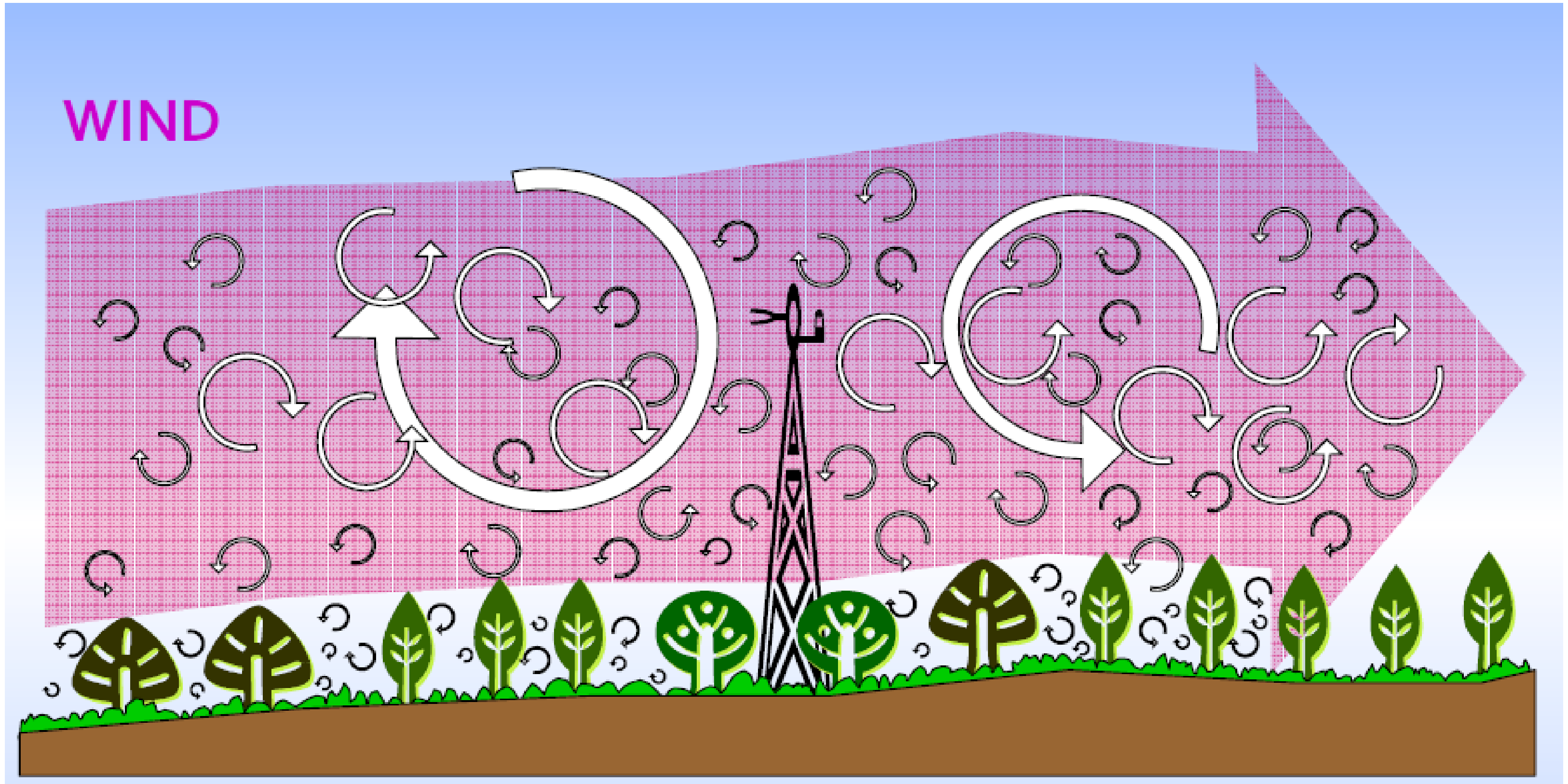
x'_i

Eddy Covariance

- Turbulent fluctuation occur very rapidly

- measurement of wind and concentration should be done very fast

Minimum sampling frequency is 10 Hz



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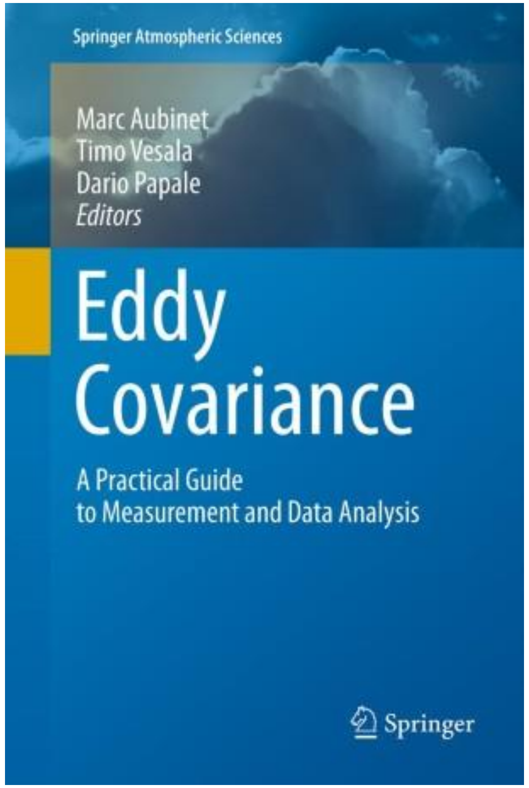
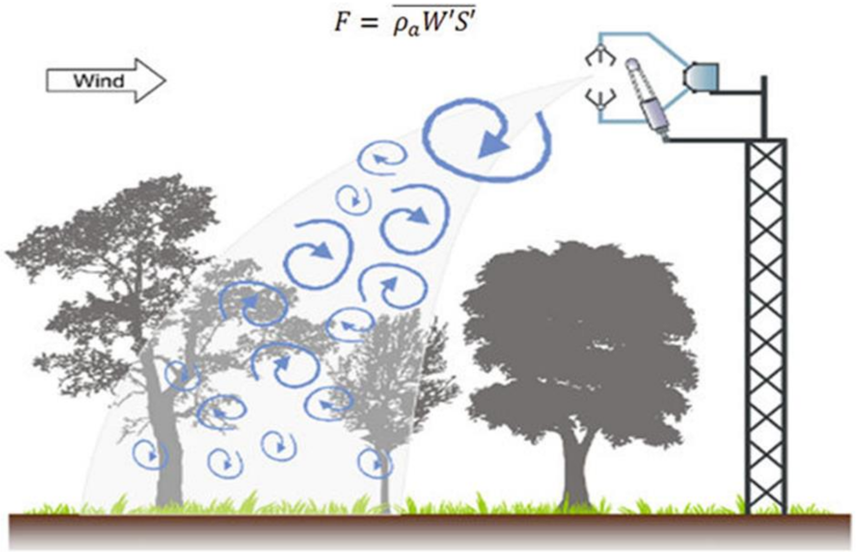




PROS

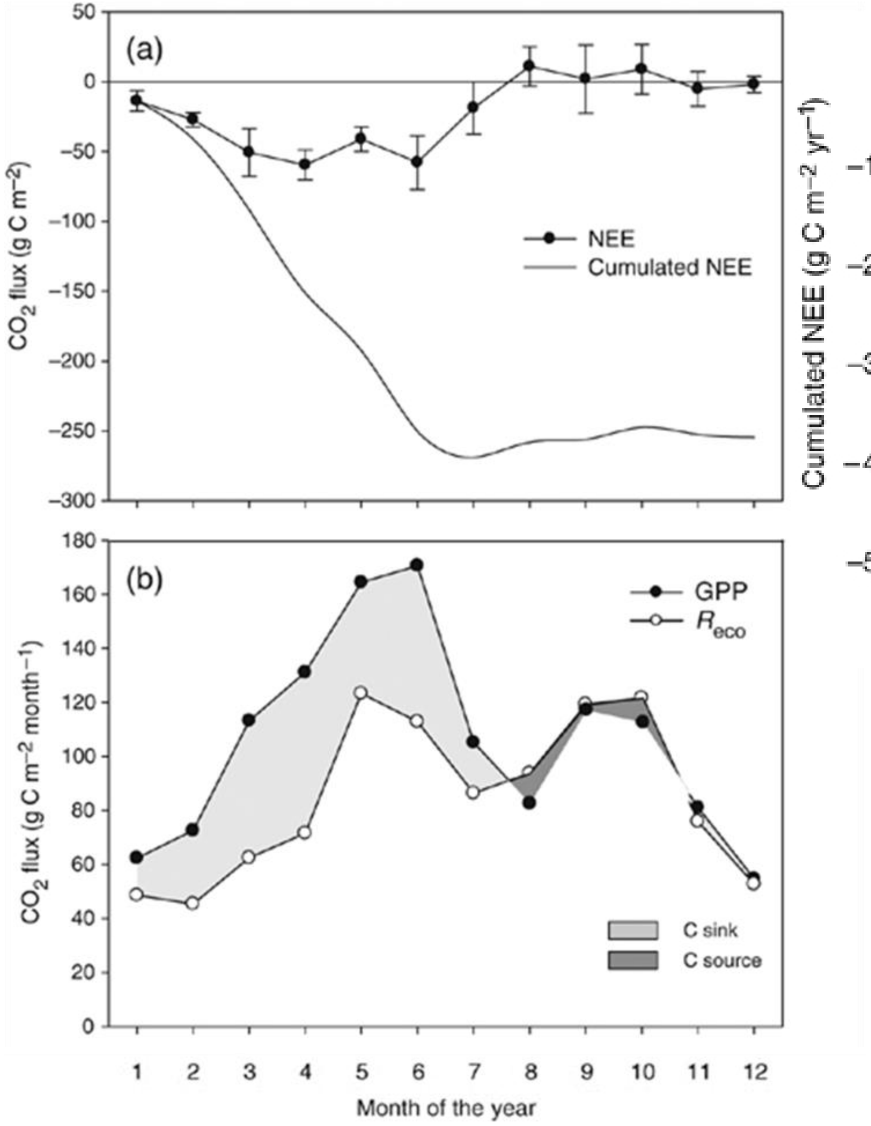
- Large Areas Integration (0.1-10 km)
- Not Altering Surrounding Environment
- Continuously Measurements (24h/day for years)
- Allowing the possibility to investigate how ecosystem performances responds to a plethora of biophysical forcings
- High ratio quality/cost

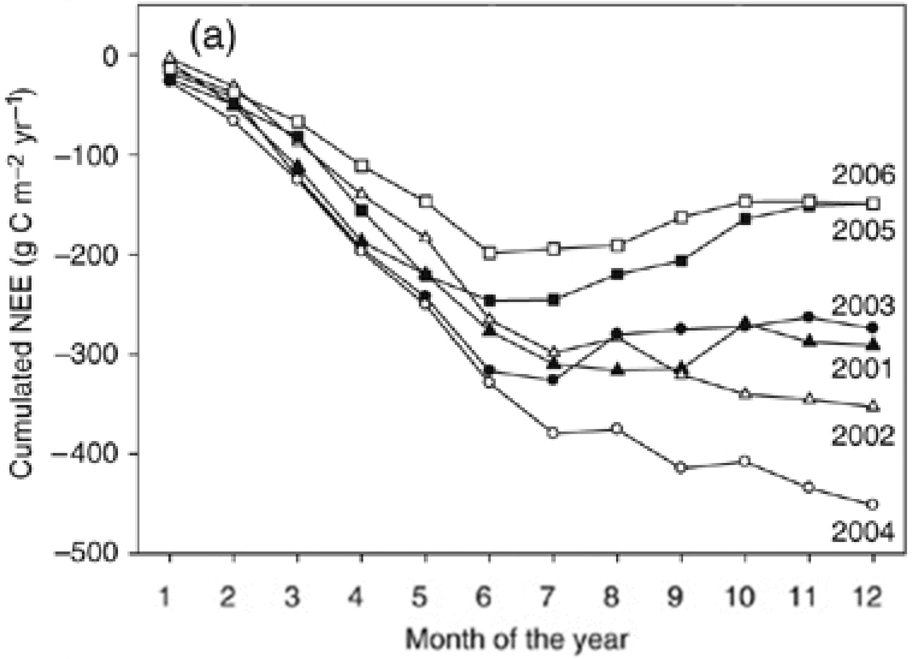
CONS

- Need flat and homogeneous terrain (difficult)
- Need wind (turbulence)
- Night fluxes difficult
- Enormous dataset to analyze (min 10 Hz sampling frequency)

flux measurement methods

Eddy Covariance





Puéchabon State Forest

Allard, V et al. (2008). Seasonal and annual variation of carbon exchange in an evergreen Mediterranean forest in southern France. Global Change Biology.

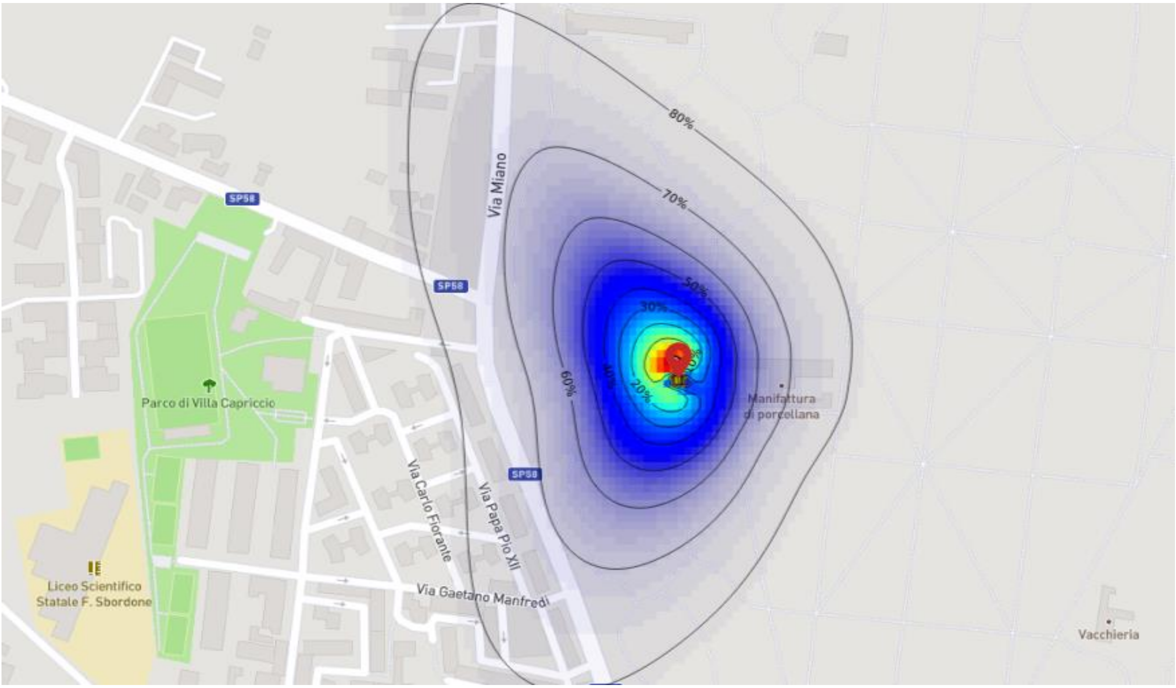
Approximately 80% of the net annual C sink occurred between March and June.

Exceptional events such the insect-induced partial canopy defoliation (2005), droughts (2005 and 2006) **reduced the carbon sink**

Eddy Covariance

The experimental site is located inside the Real Bosco di Capodimonte a green area of about 125 ha located inside the urban area of Naples. The area is characterized by a **mixed urban - Mediterranean forest**

The site is equipped with an **Eddy Covariance (EC) system** for the CO_2 and H_2O fluxes, as well as, other GHGs and the main environmental variables



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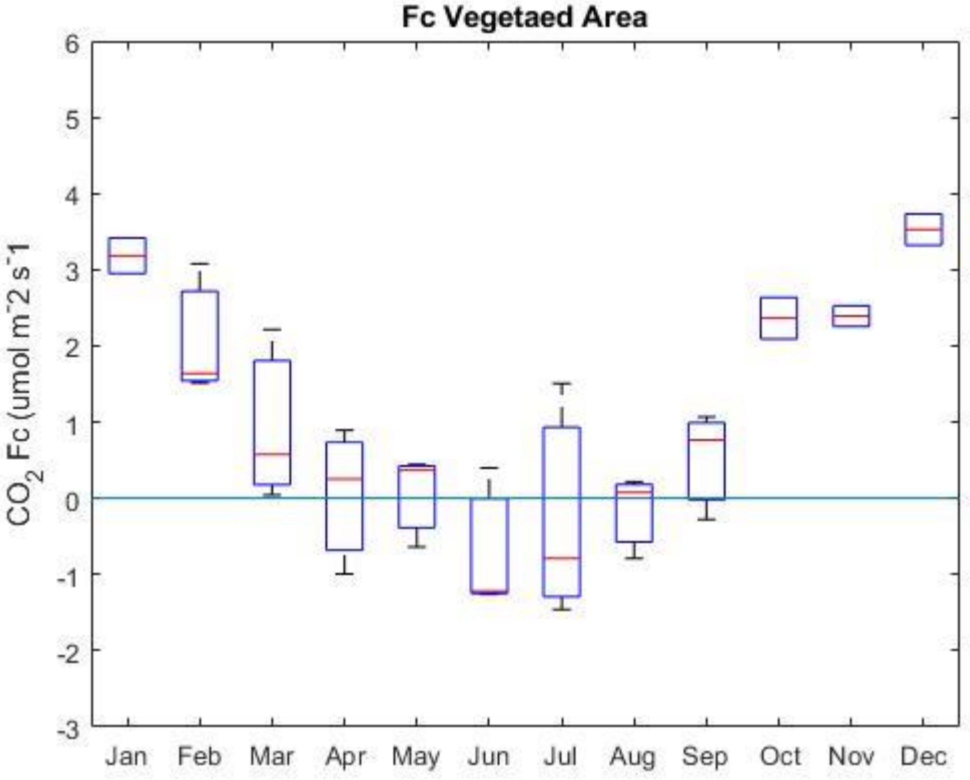
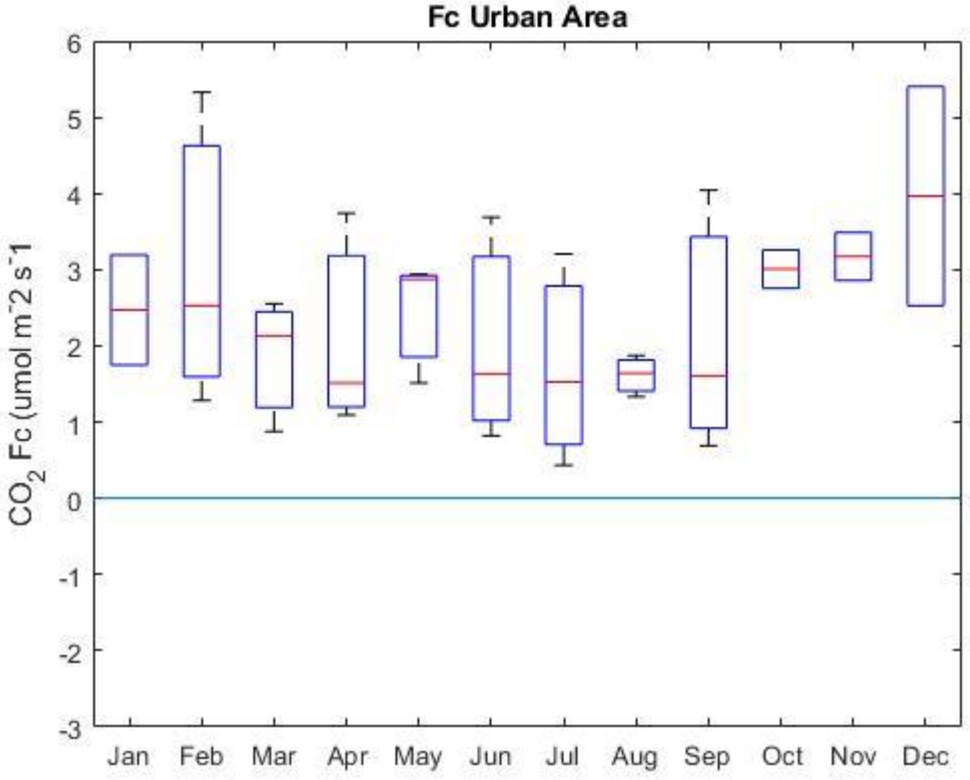
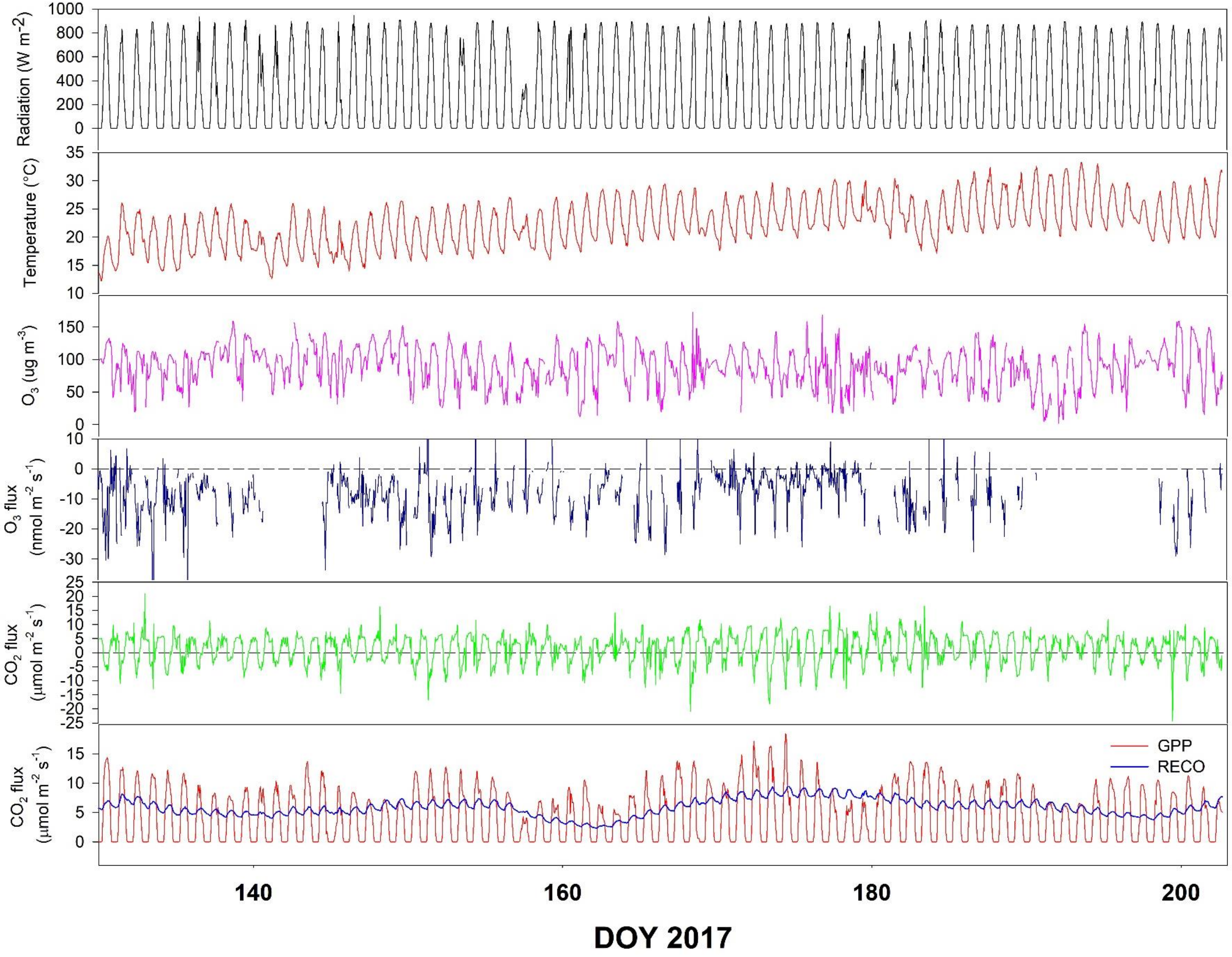




Box plot of the CO_2 Fluxes within the vegetated area of the park and the Urban area within the footprint of the EC tower. On each box, the central mark indicates the median, and the bottom and top edges of the box indicate the 25th and 75th percentiles, respectively.

Eddy Covariance



Stable Radiative period

High temperature

Stable O_3 concentration range

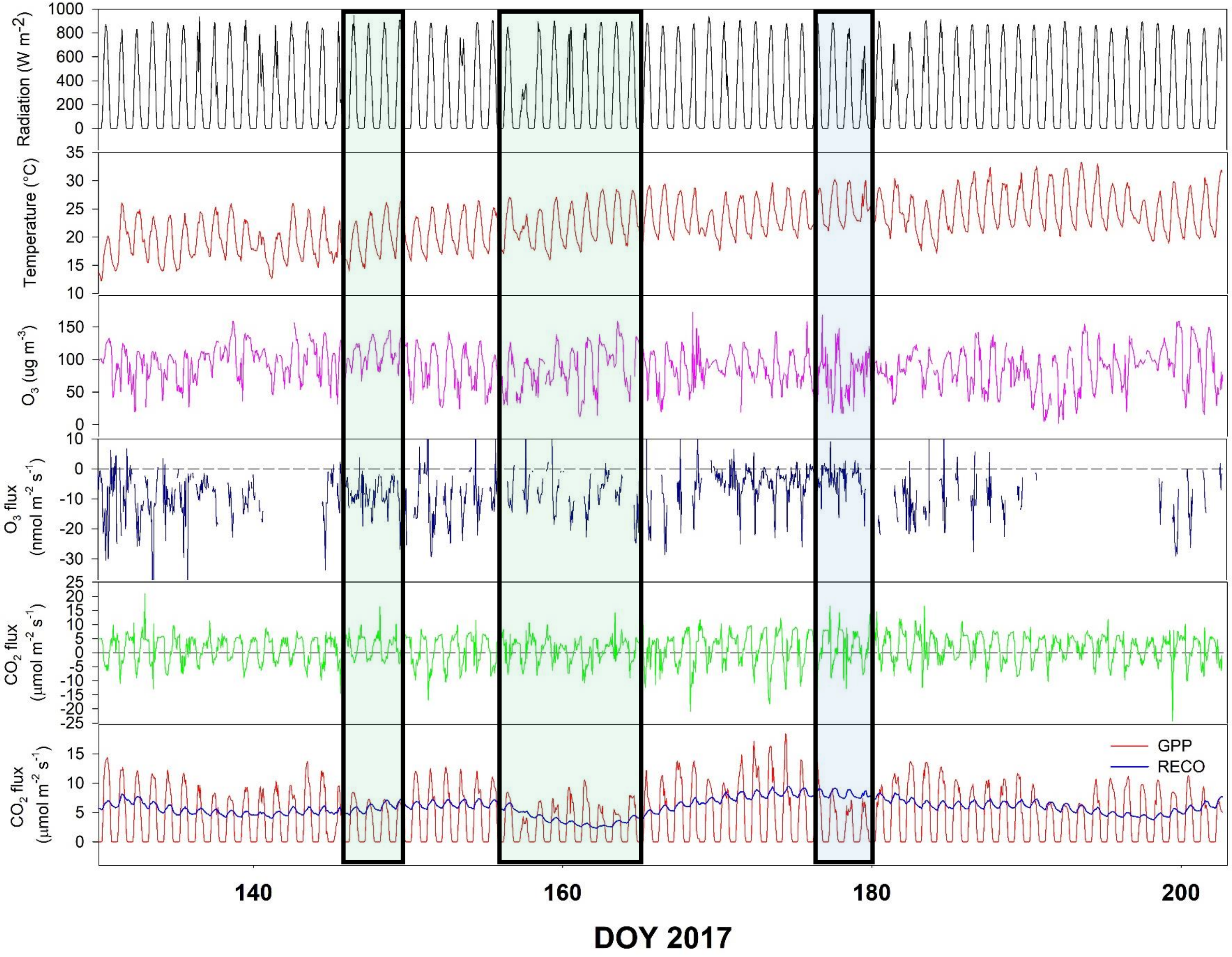
O_3 Fluxes up to – 30 nmol $m^{-2}s^{-1}$

CO_2 Fluxes from -15 to +10 µmol $m^{-2}s^{-1}$

GPP/RECO Partitioning

flux measurement methods

Eddy Covariance



REDUCTION OF O_3 DEPOSITION

REDUCTION OF

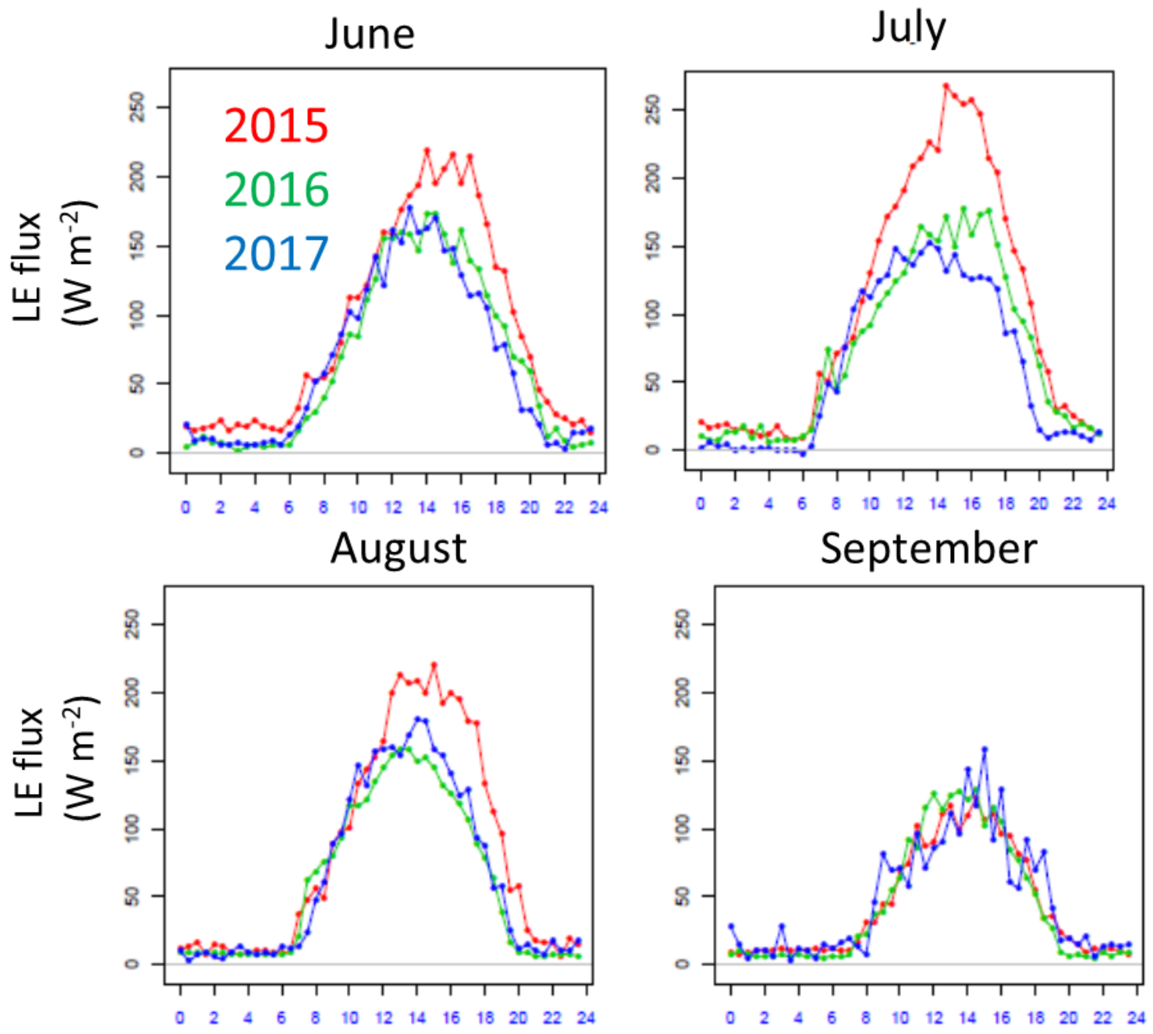
NEE

GPP

SUGGESTS

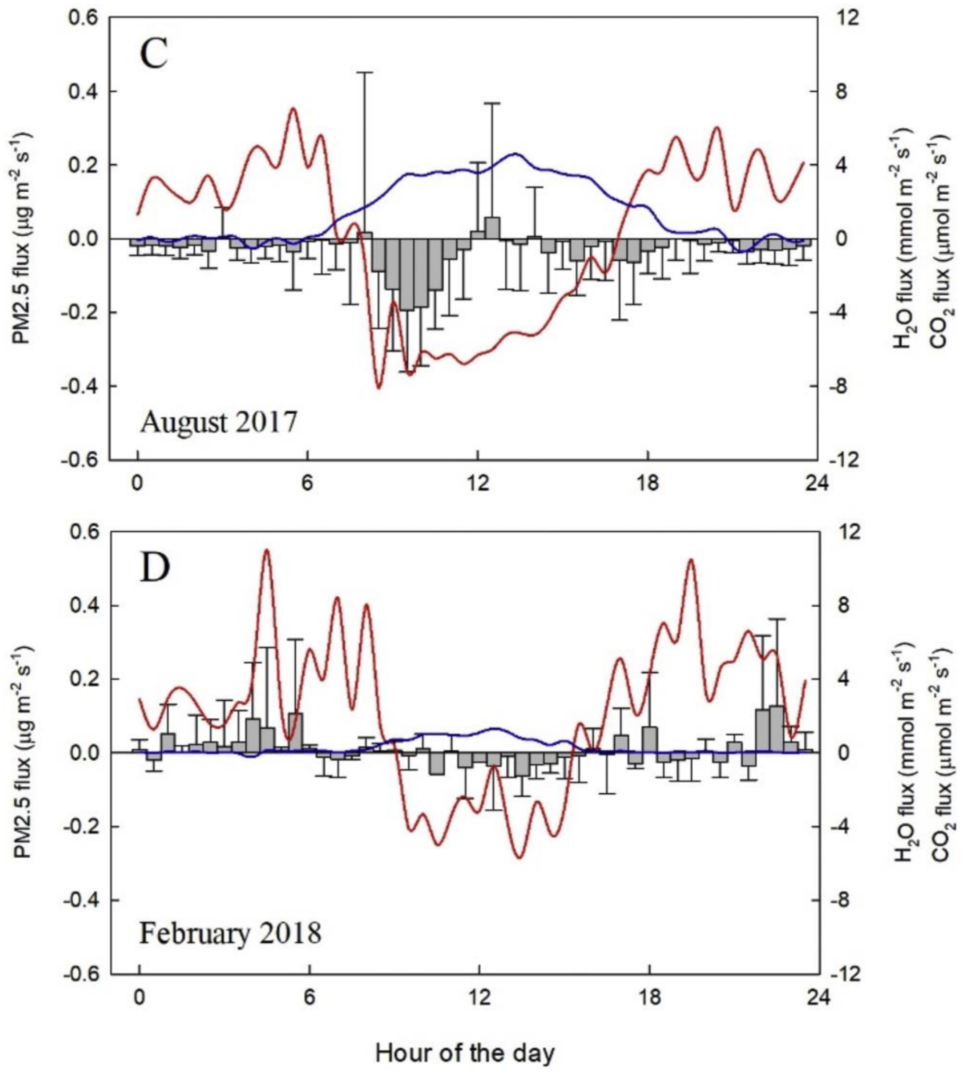
LARGE EFFECT OF STOMATA

Eddy Covariance



Summer Latent Heat Fluxes

≈ a Cooling Effect up to 3°C



Average Monthly PM 2.5 Removal 200 kg ≈ 50000 car Euro6 (mileage 1700 km/month)

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Networks and infrastructures

The application and potential information contained in the collected data of a network goes beyond the individual sites!

The capacity to integrate carbon fluxes in time and space from a sparse network, **was not expected when the flux networks were formed in the 1990s** (Baldocchi et al. 2019).

Vol 455 | 11 September 2008 | doi:10.1038/nature07276 nature

LETTERS

Old-growth forests as global carbon sinks

Science AAAS

Terrestrial Gross Carbon Dioxide Uptake: Global Distribution and Covariation with Climate
Christian Beer, *et al.*
Science **329**, 834 (2010);
DOI: 10.1126/science.1184984

Vol 451 | 3 January 2008 | doi:10.1038/nature06444 nature

LETTERS

Net carbon dioxide losses of northern ecosystems in response to autumn warming

Shilong Piao[1], Philippe Ciais[1], Pierre Friedlingstein[1], Philippe Peylin[2], Markus Reichstein[3], Sebastiaan Luyssaert[4], Hank Margolis[5], Jingyun Fang[6], Alan Barr[7], Anping Chen[8], Achim Grelle[9], David Y. Hollinger[10], Tuomas Laurila[11], Anders Lindroth[12], Andrew D. Richardson[13] & Timo Vesala[14]

ECOLOGY LETTERS

Ecology Letters, (2012) **15**: 520–526 doi: 10.1111/j.1461-0248.2012.017

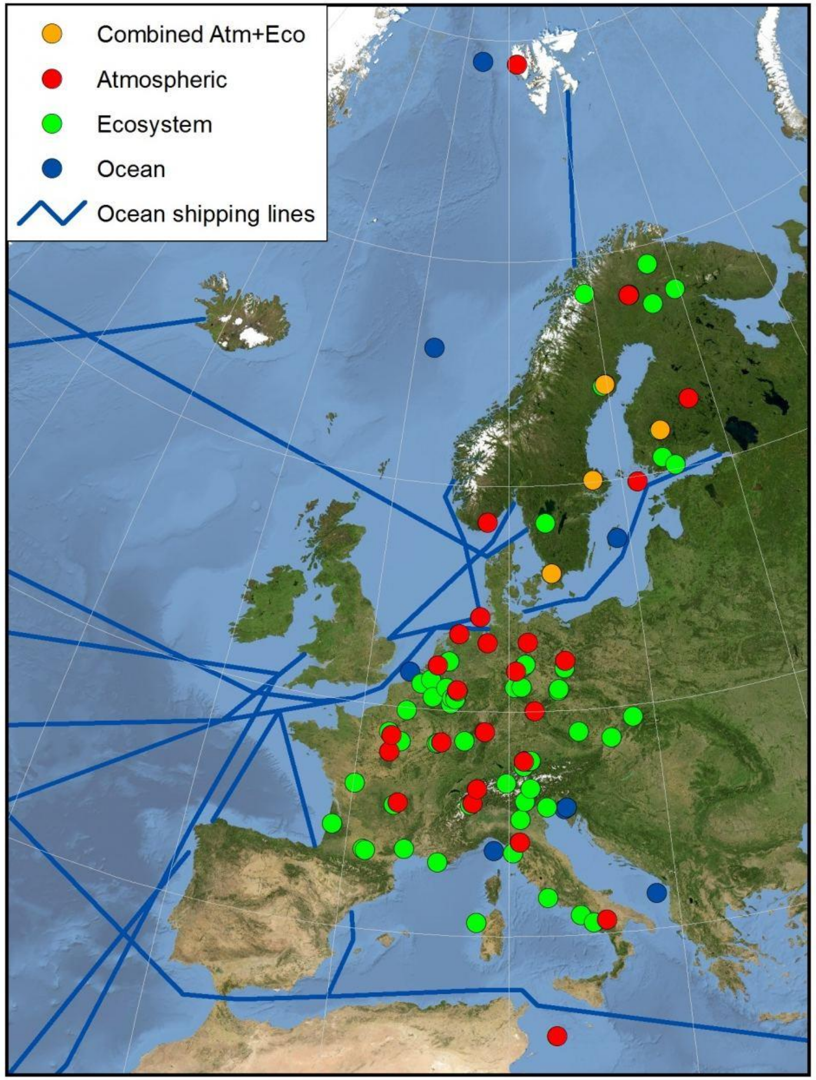
E

Fertile forests produce biomass more efficiently

Networks and infrastructures

ICOS integrated carbon observation system

A European infrastructure dedicated to high precision monitoring of greenhouse gases



European monitoring network for greenhouse gases

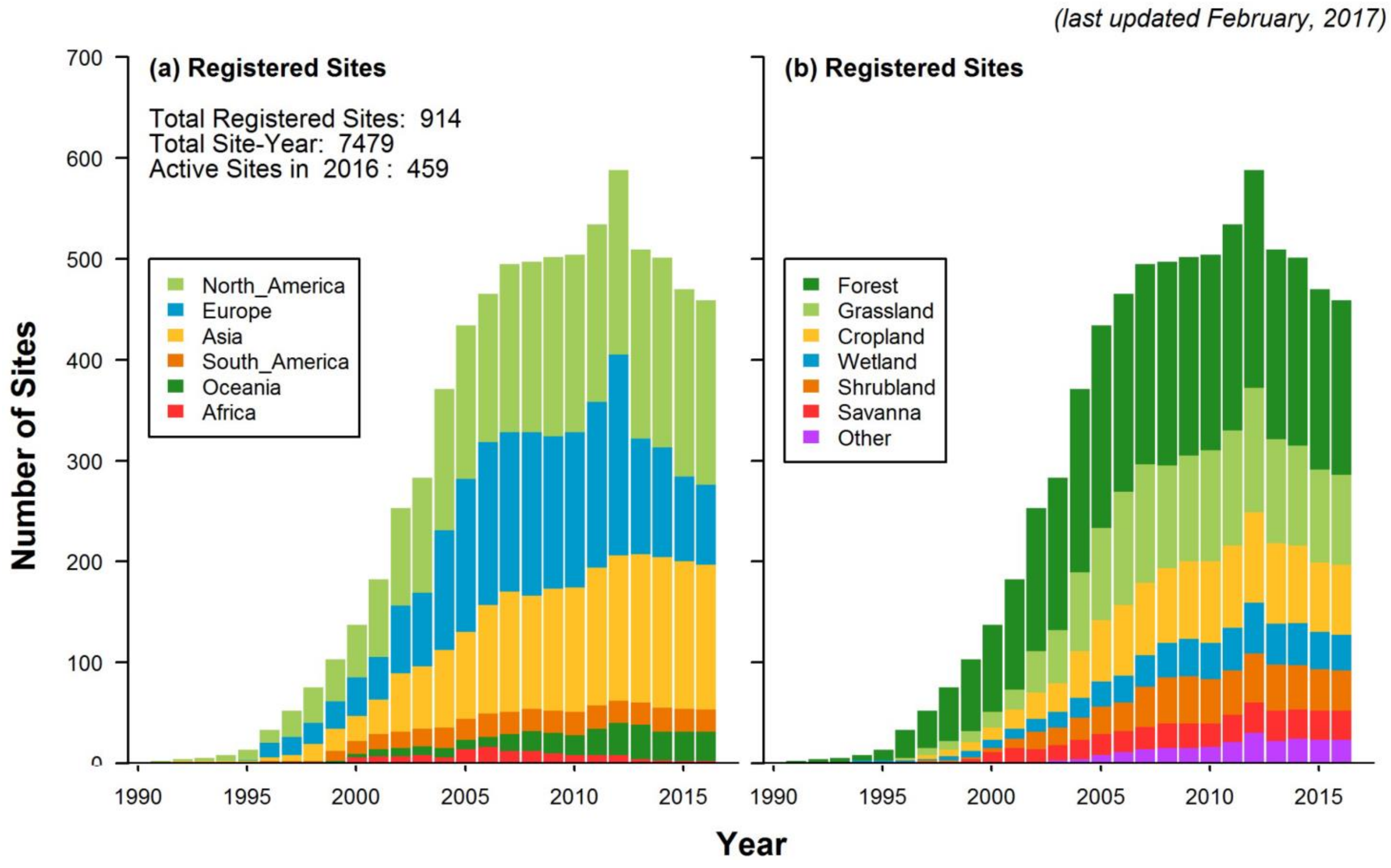
- Concentrations and fluxes of CO_2, CH_4 and N_2O
- Evapo-transpiration and ecosystem observations
- Carbon sinks and biogeochemical cycles
- Terrestrial ecosystems (especially forest, wetland, arable land, grassland) and oceans
- Standardized protocols and instructions

Networks and infrastructures

FLUXNET

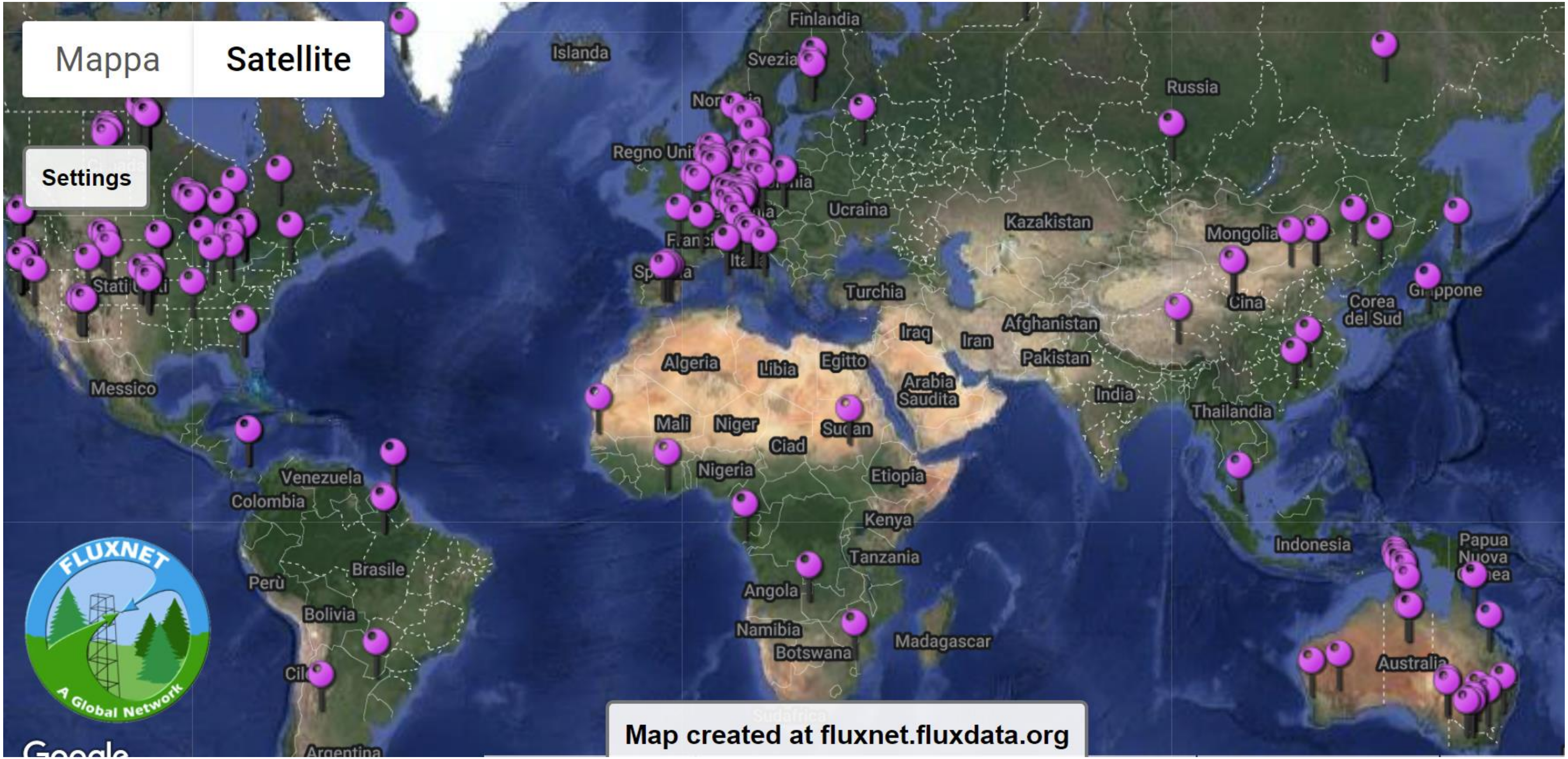
https://fluxnet.org/

THE NETWORK OF THE NETWORKS

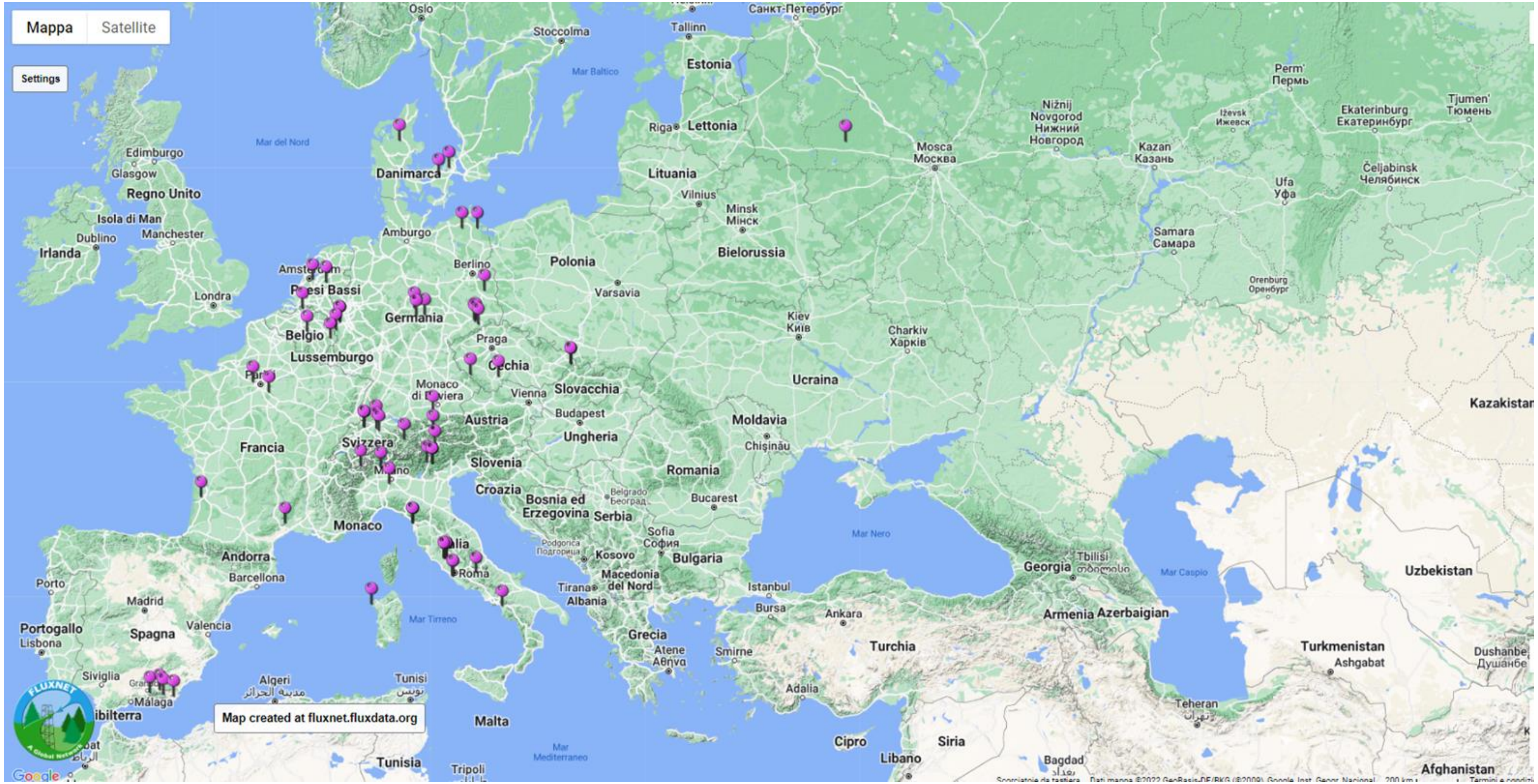


"FLUXNET is probably the largest geophysical experiment in Earth"

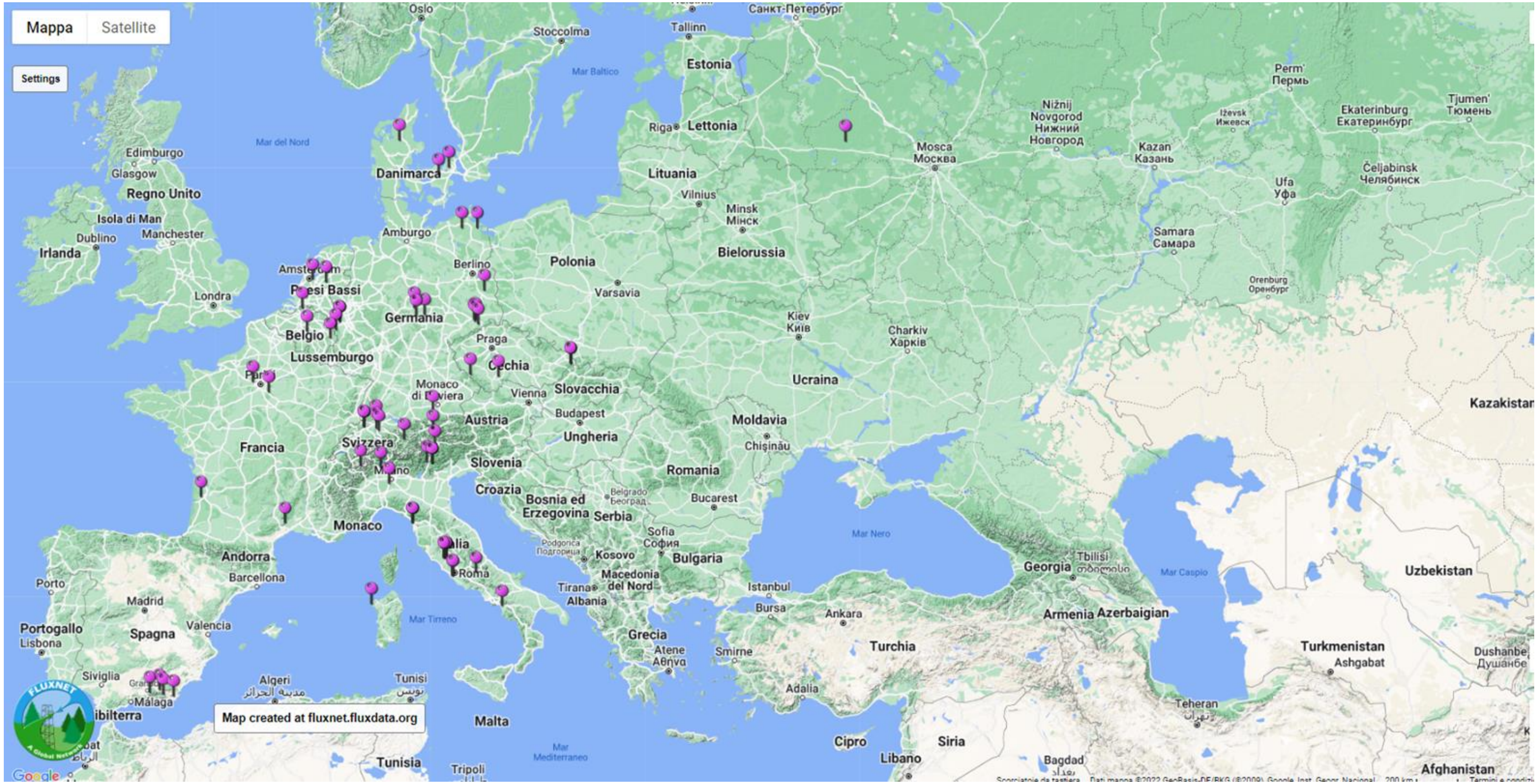
Networks and infrastructures



Networks and infrastructures



Networks and infrastructures



THANK YOU

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