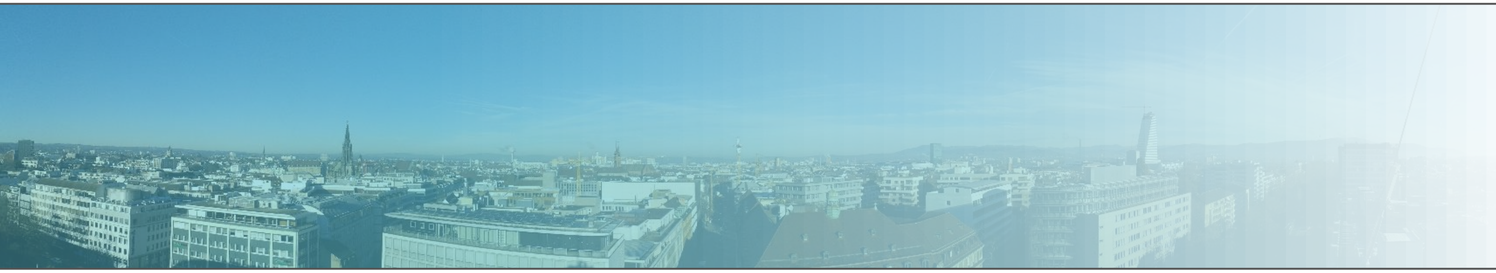

diFUME
Urban carbon dioxide Flux Monitoring using Eddy Covariance and Earth Observation

Urban carbon dioxide flux monitoring using Eddy Covariance and Earth Observation:

An introduction to diFUME project

Stavros Stagakis

Postdoc, ATM

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Current Studies in Physical Geography and Atmospheric Sciences

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mcr meteorology climatology remote sensing

University of Basel

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Contents

- Introduction
- Scope
- Methodology
- Preliminary results

Introduction

Urban Areas:

- Cover **1 - 3 %** of Earth's landmass
- **55 %** (4.2 billion) of world population lives in cities
- Projected to increase to **68 %** (6.7 billion) by 2050

UN, 2018


Credit: P. Lopez Luz

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Introduction

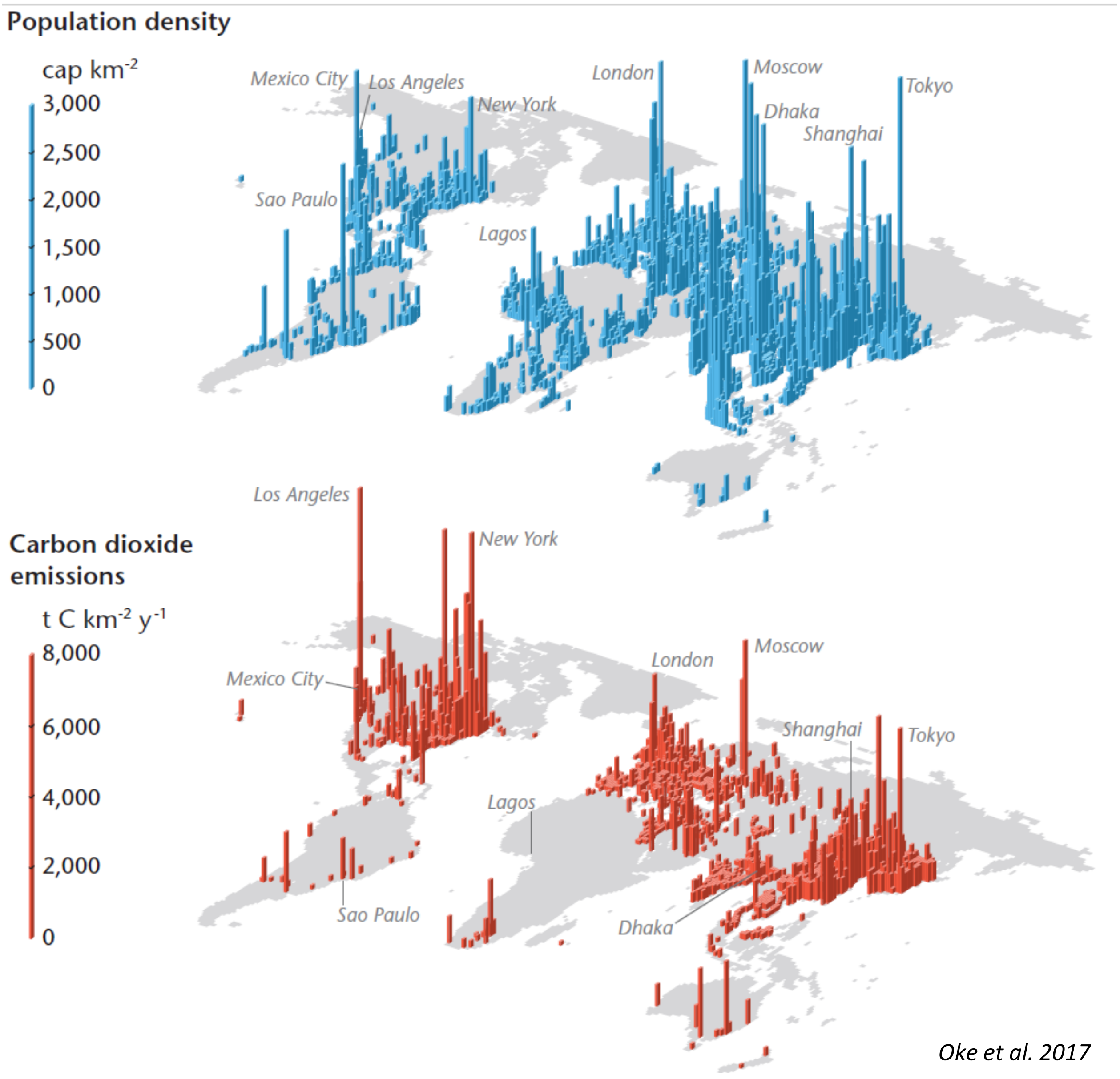
Urban Areas:

- **70 %** of total anthropogenic CO_2 emissions originate from urban areas

Canadell et al., 2009

- **50 %** of urban CO_2 emissions are attributable to urban form characteristics (e.g. density, land use mix, building type, vegetation)

Christen et al. 2010



Oke et al. 2017

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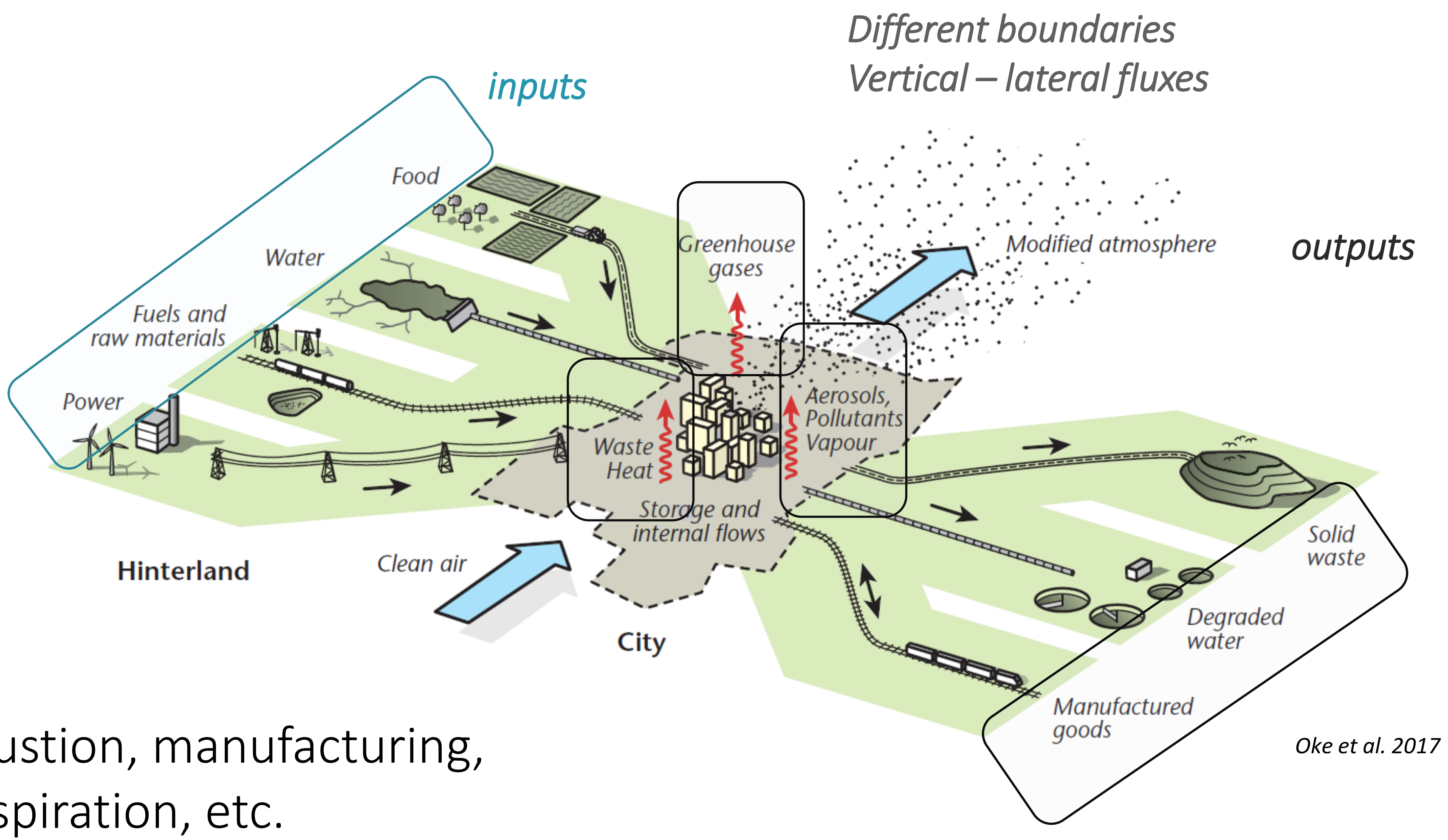
Introduction

Urban Metabolism

Flow and transformation of materials and energy in a city, related to energy, water and carbon budgets.

Relevant processes: combustion, manufacturing, irrigation, construction, respiration, etc.



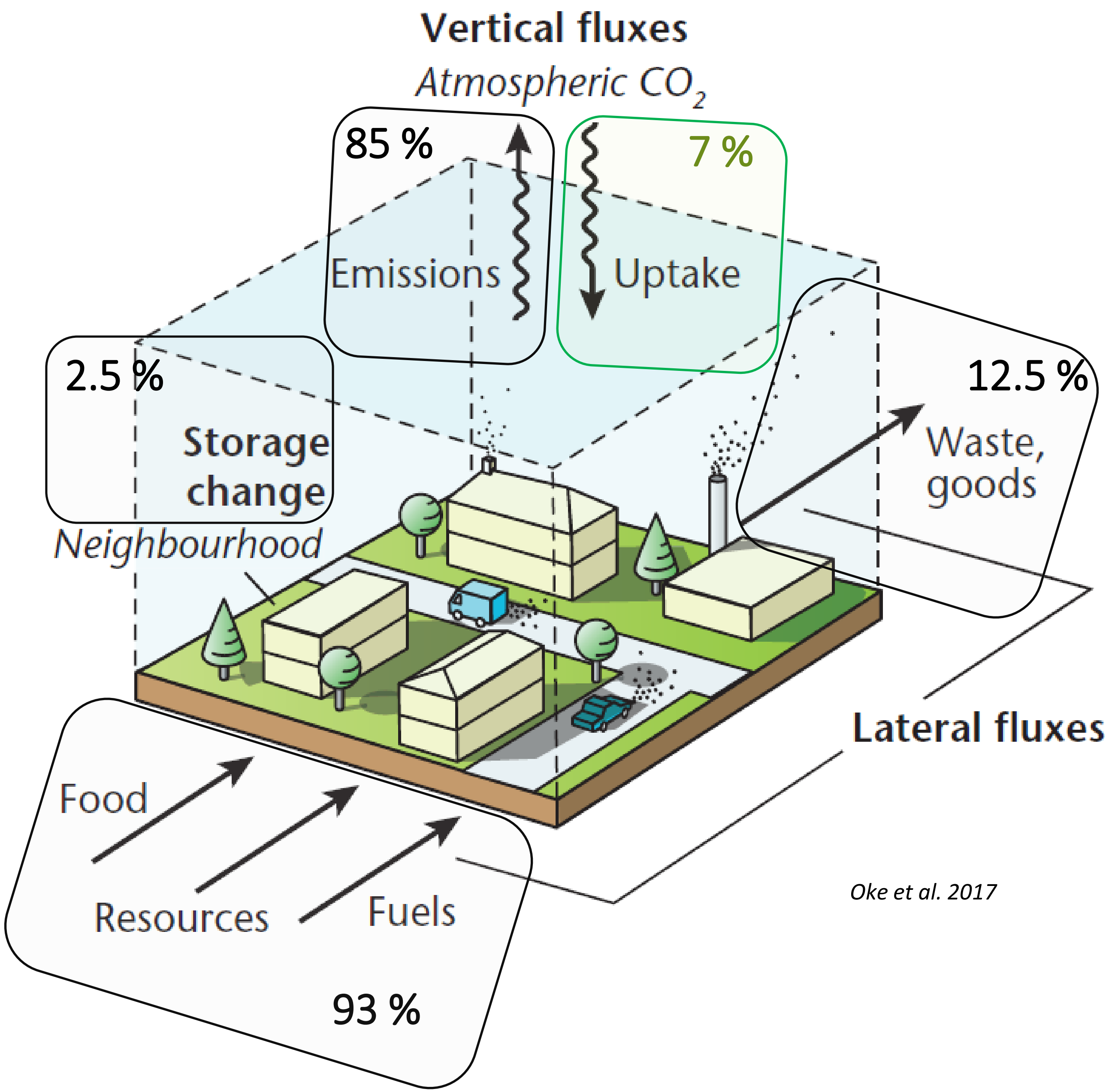
Oke et al. 2017

Introduction

Urban carbon fluxes

Lateral: entirely anthropogenic processes, carbon mostly in solid or liquid organic compounds

Vertical: exchange between surface and atmosphere, anthropogenic-biogenic processes, carbon in the form of CO_2



Oke et al. 2017

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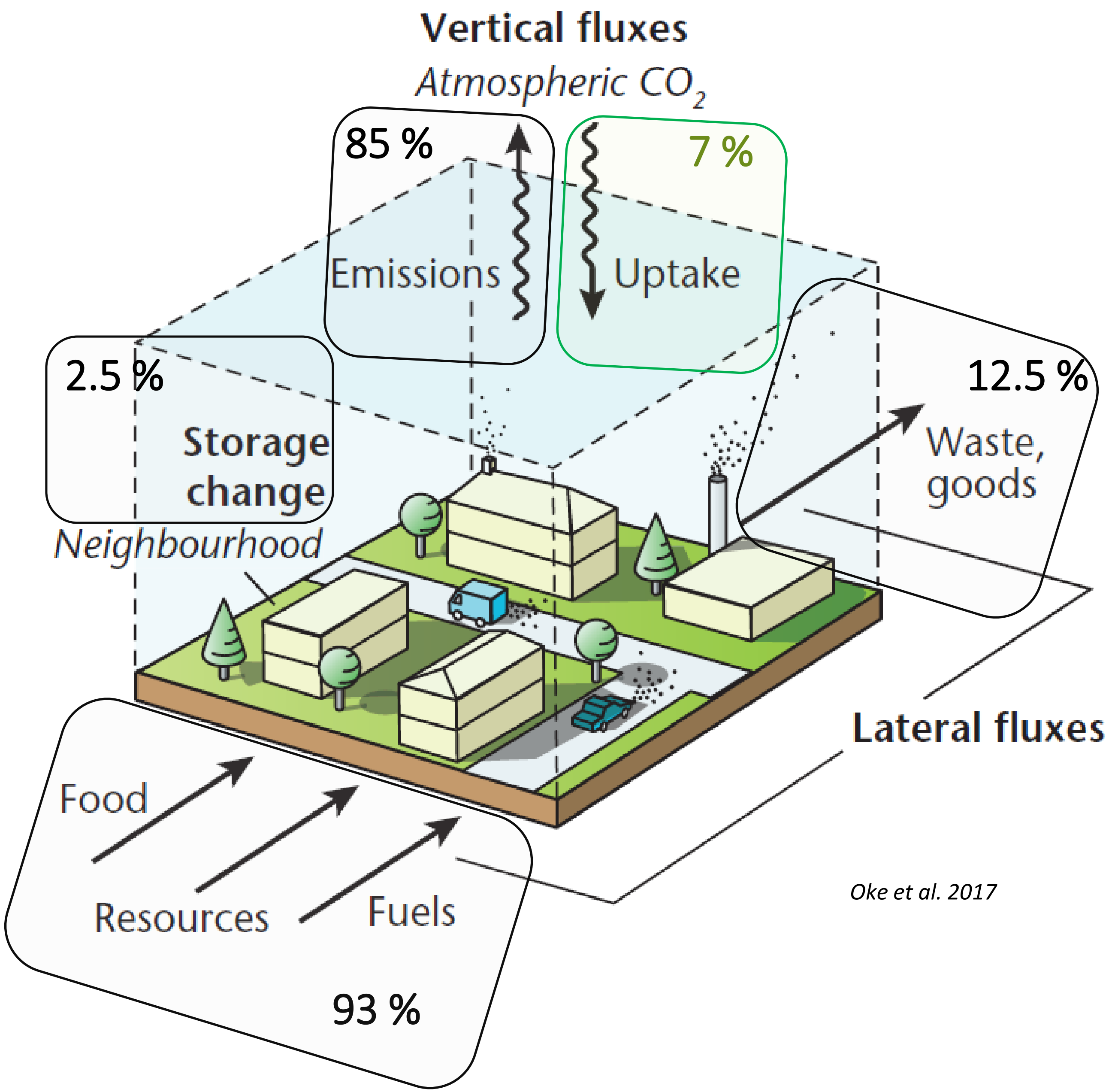
Introduction

Vertical fluxes

Processes:

- Combustion
  fossil fuels, biofuels, wood
- Respiration
  humans, animals, plants, microbes
- Photosynthesis
  plants, the only carbon sink!



Oke et al. 2017

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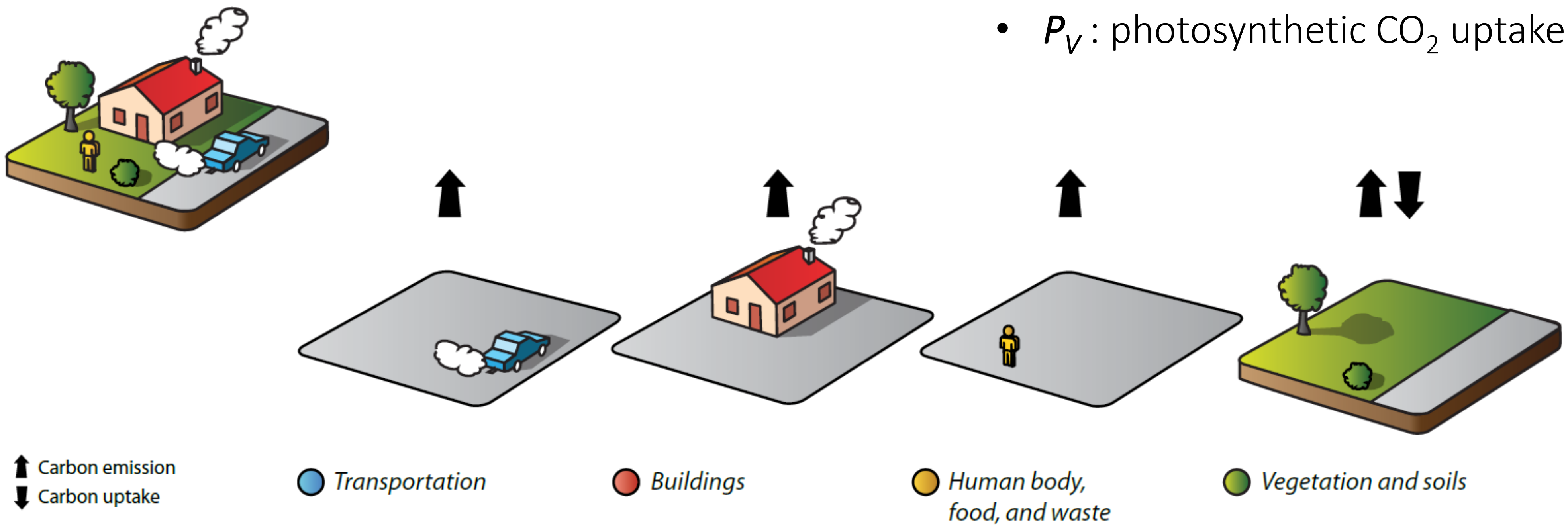
Introduction

Urban CO_2 Flux

$$F_C = E_V + E_B + R_H + R_S + (R_V - P_V)$$

- F_C : total net CO_2 flux
- E_V : traffic emissions
- E_B : building emissions
- R_H : human metabolic CO_2 release
- R_S : soil respiration
- R_V : plant respiration
- P_V : photosynthetic CO_2 uptake



Christen et al. 2010

Introduction

Monitoring Carbon Fluxes in Cities

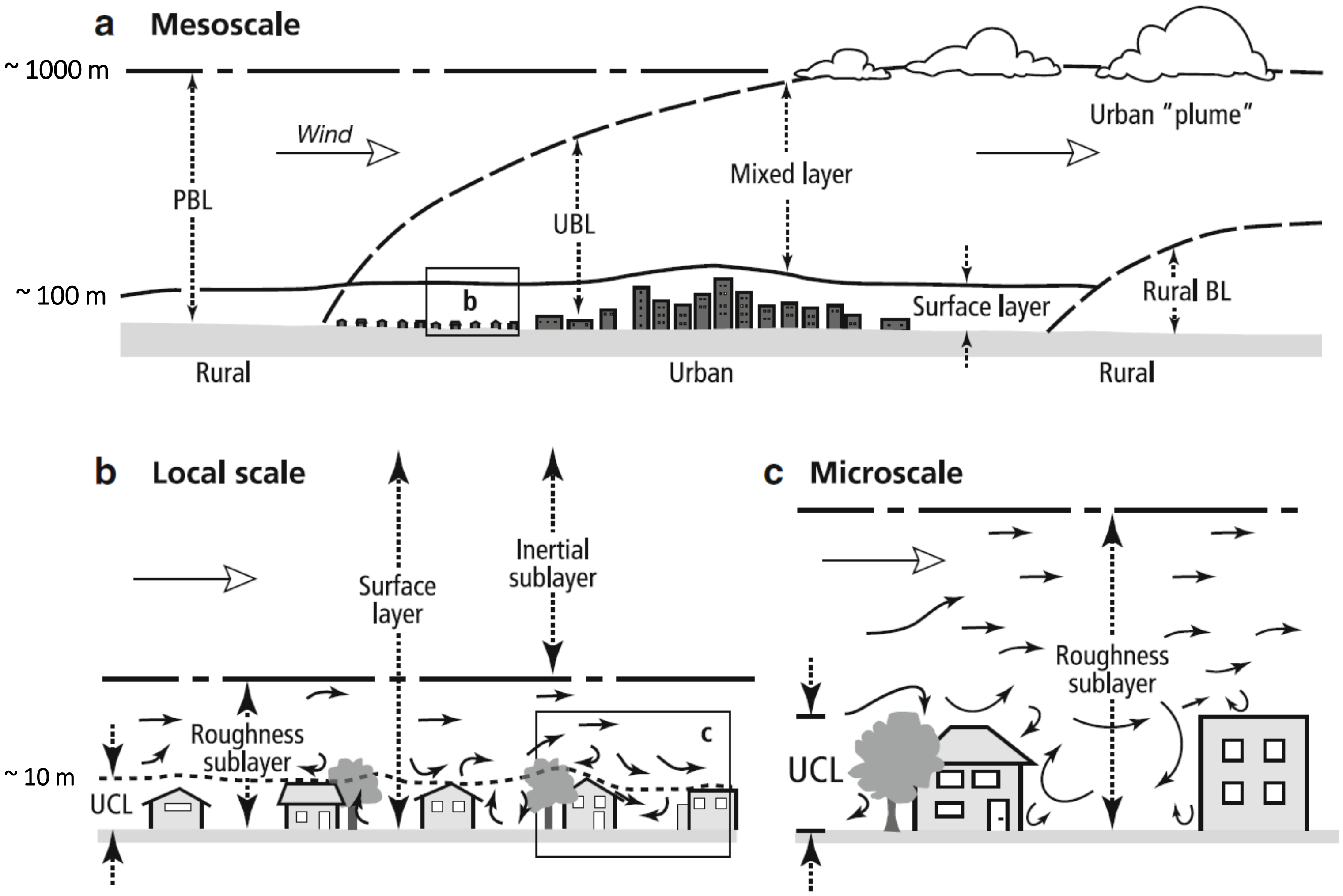
Inventory or bottom-up approaches (indirect)

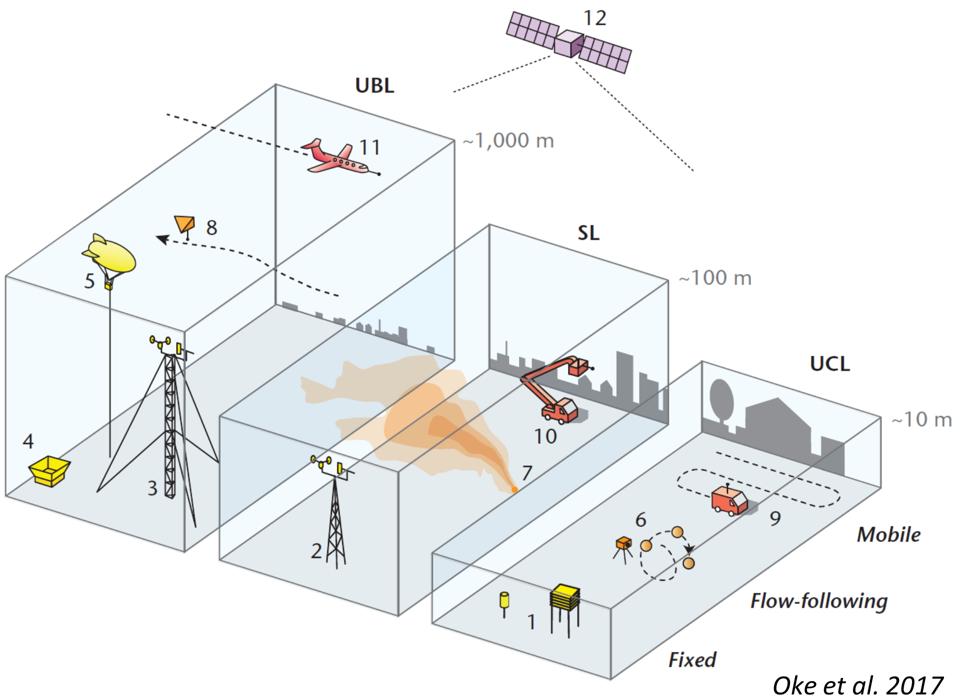
- Fuel and electricity consumption data-statistics and emission factors
- Restricted spatial and temporal scales
- Downscaled according to bottom-up or top-down procedures (e.g. using population density as a proxy)
- Data/methodology consistency issues
- Biogenic compounds usually neglected

Direct measurements

- Approaches depending on scale (micro, local, regional)
- Sensors at various heights (towers, balloons, airplanes)
- Hampered by the extreme heterogeneity of the urban environment (sources, sinks) and the complexity of UBL dynamics
- Source/sink attribution is challenging
- Link between scales is difficult
- Emerging satellite technologies

Introduction





Oke et al. 2017

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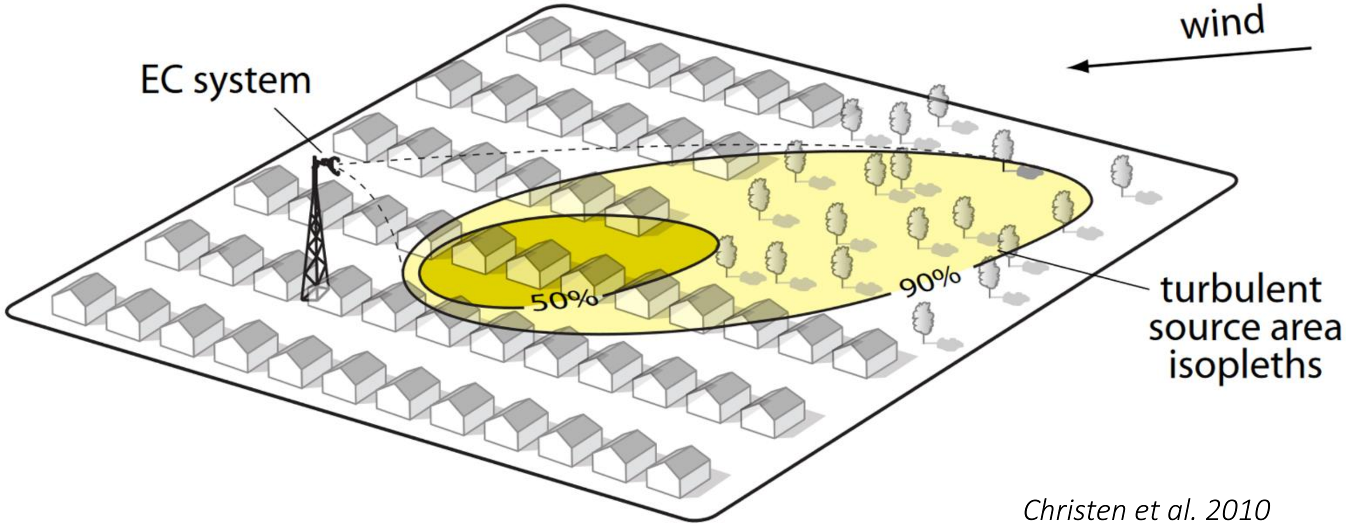
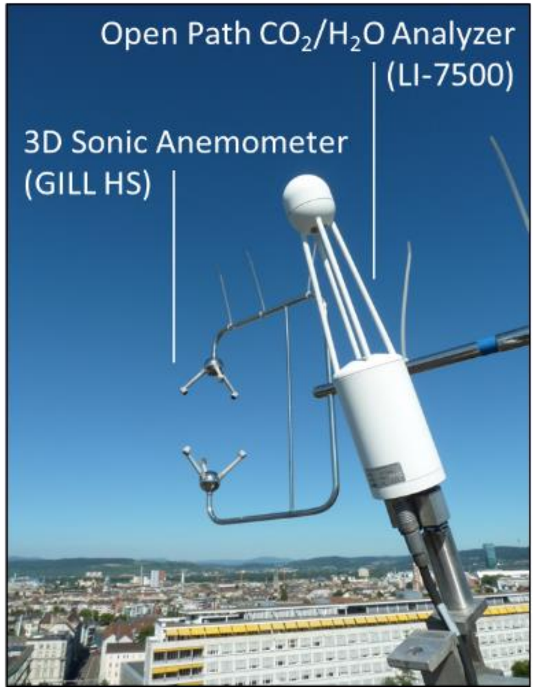
Introduction

Eddy Covariance

- Direct *Fc* at local scale
- Variable measurement footprint (sources/sinks)



Christen et al. 2010

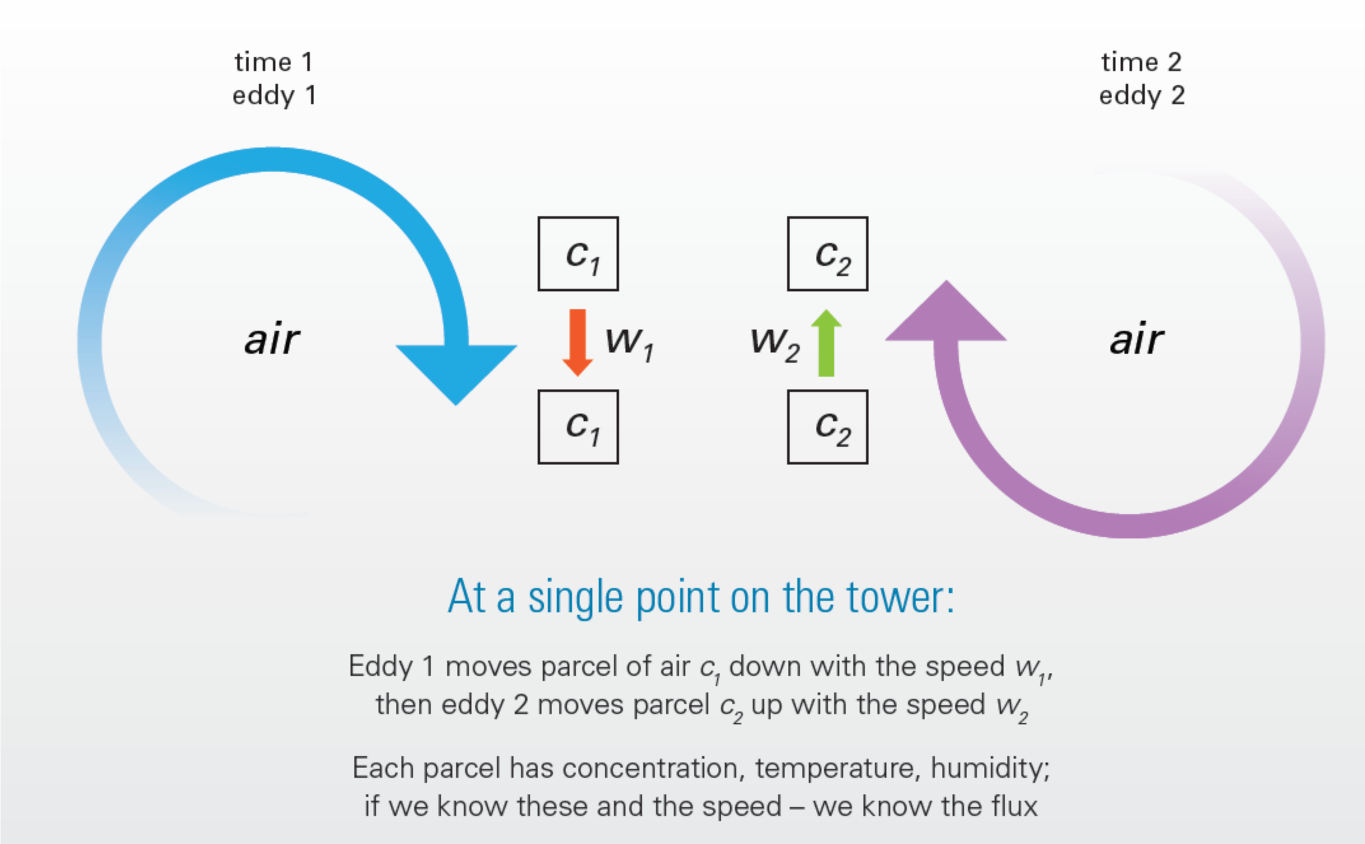


Introduction

Eddy Covariance

- Direct *Fc* at local scale
- Variable measurement footprint (sources/sinks)

$$F_c = \overline{w'c'}$$



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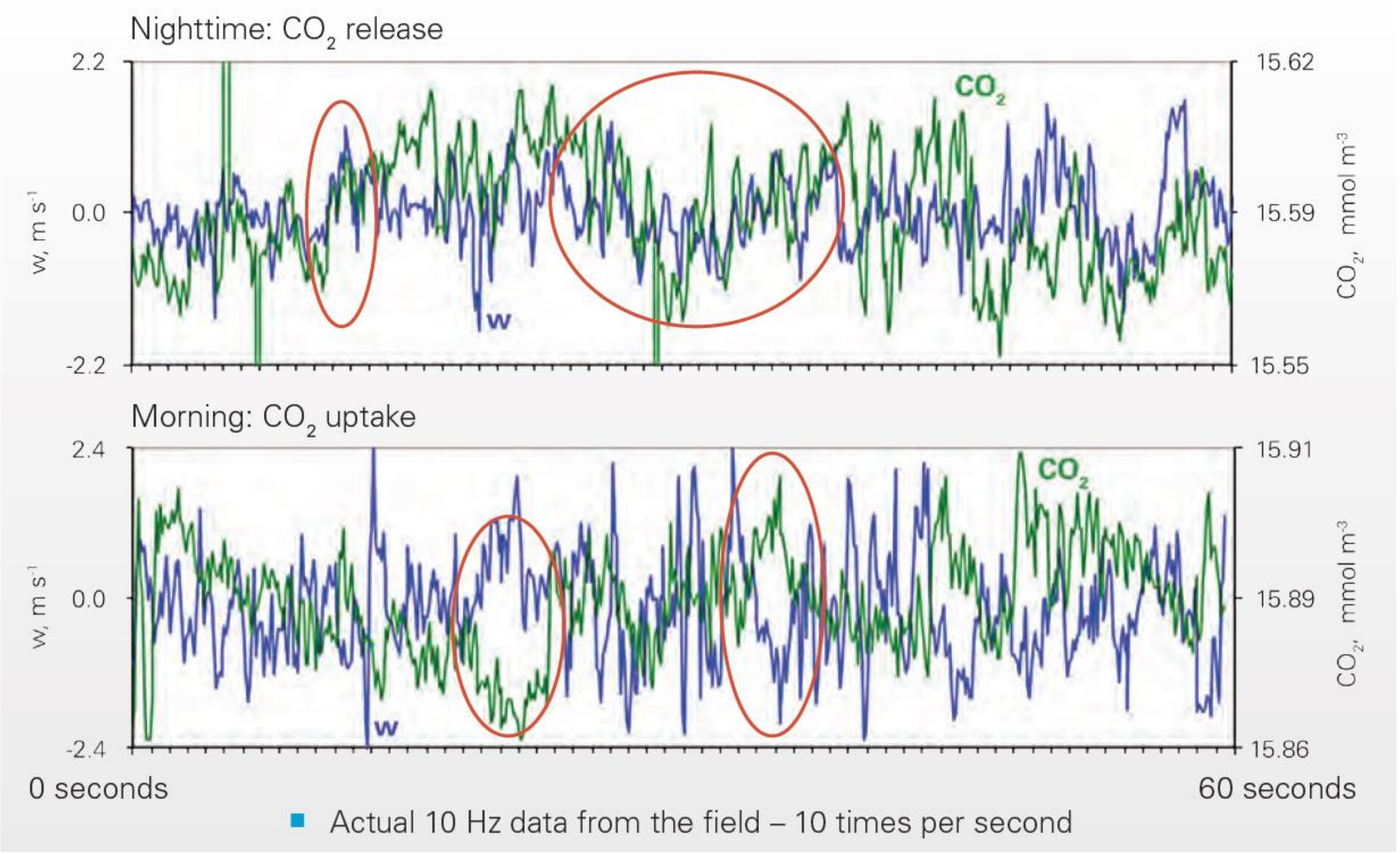

Covariance W – CO2 : **positive** → flux away from the surface (source)

Covariance W – CO2 : **negative** → flux towards the surface (sink)

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Introduction

Eddy Covariance

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- Variable measurement footprint (sources/sinks)

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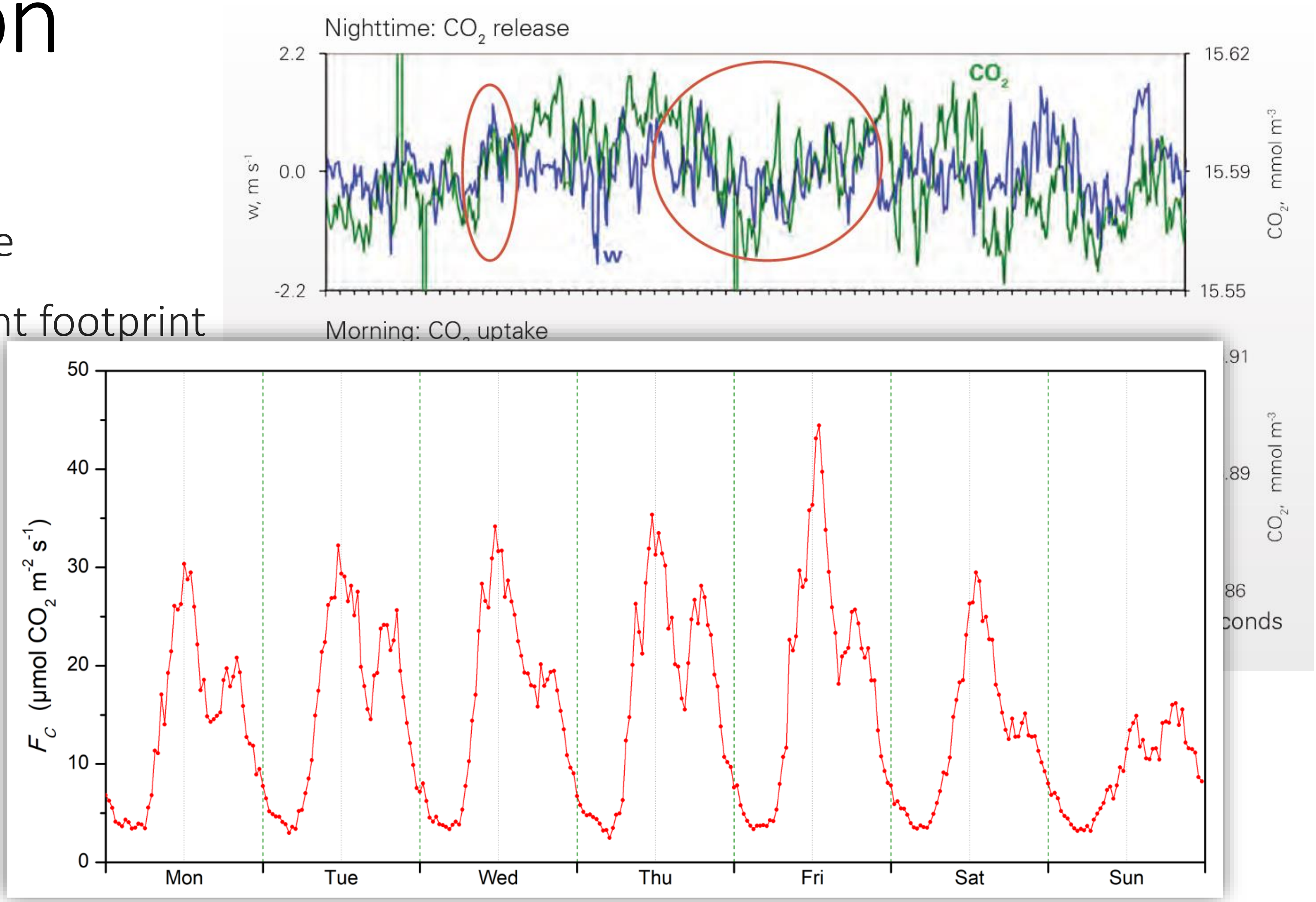

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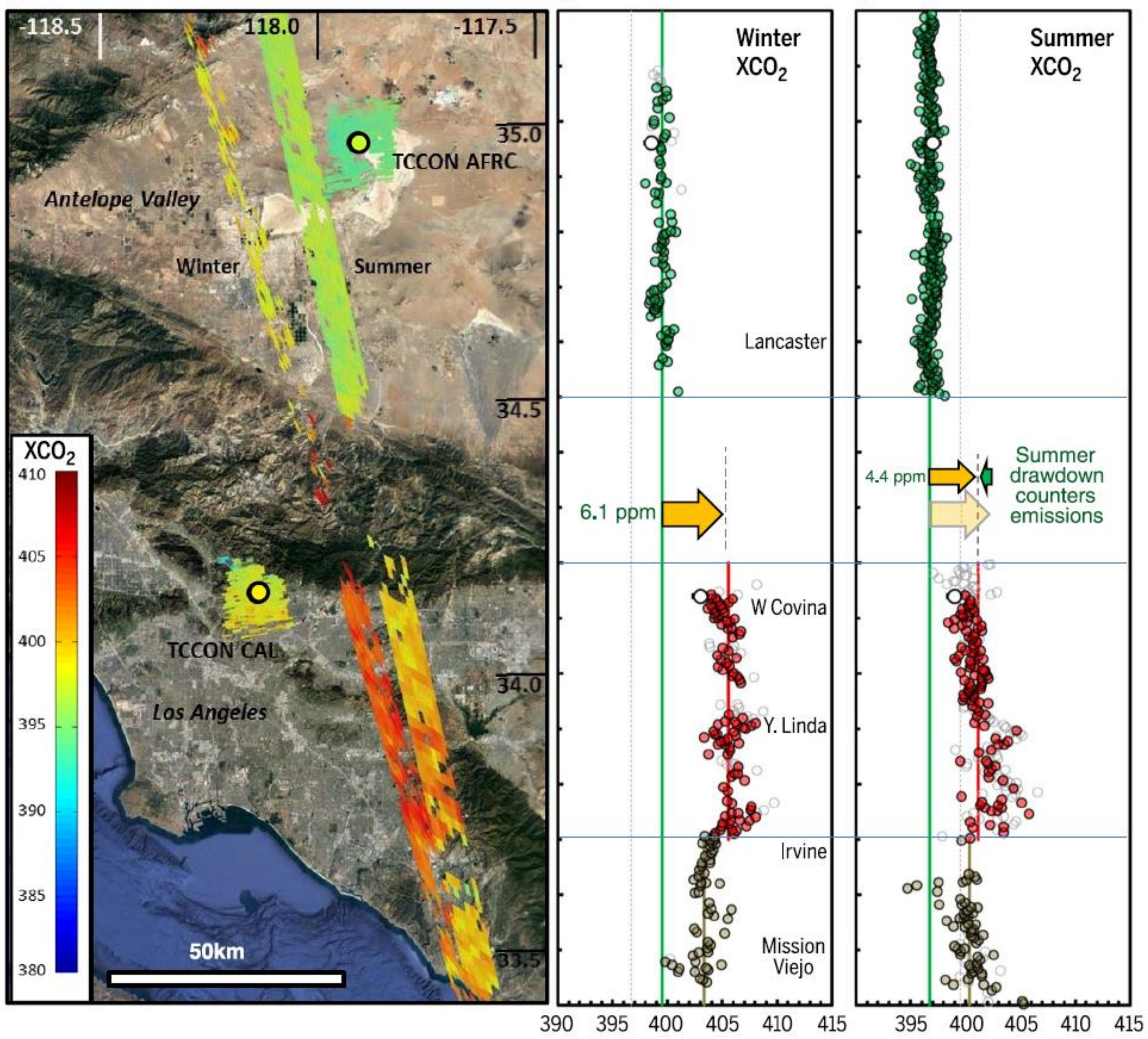
Introduction

Earth Observation

- Low resolution (> 1 km)
- Sparse acquisitions (~ 16 days)

OCO-2, NASA



Schwandner et al. 2017

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Introduction

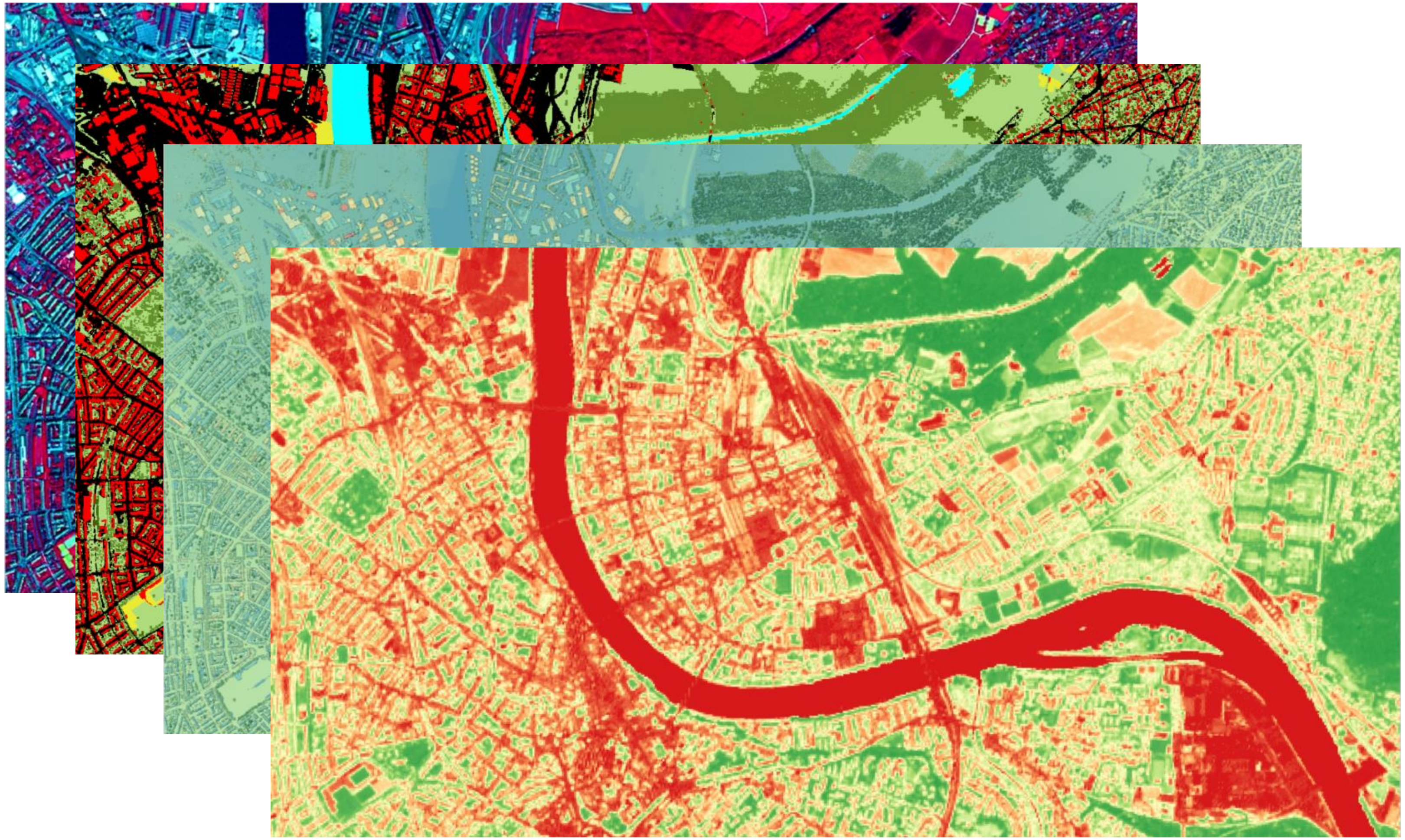
Earth Observation

Current capabilities:

- Urban cover
- Urban morphology
- Biophysical/biochemical parameters

Multiple spatial scales

Trade-off spatial - temporal



Scope

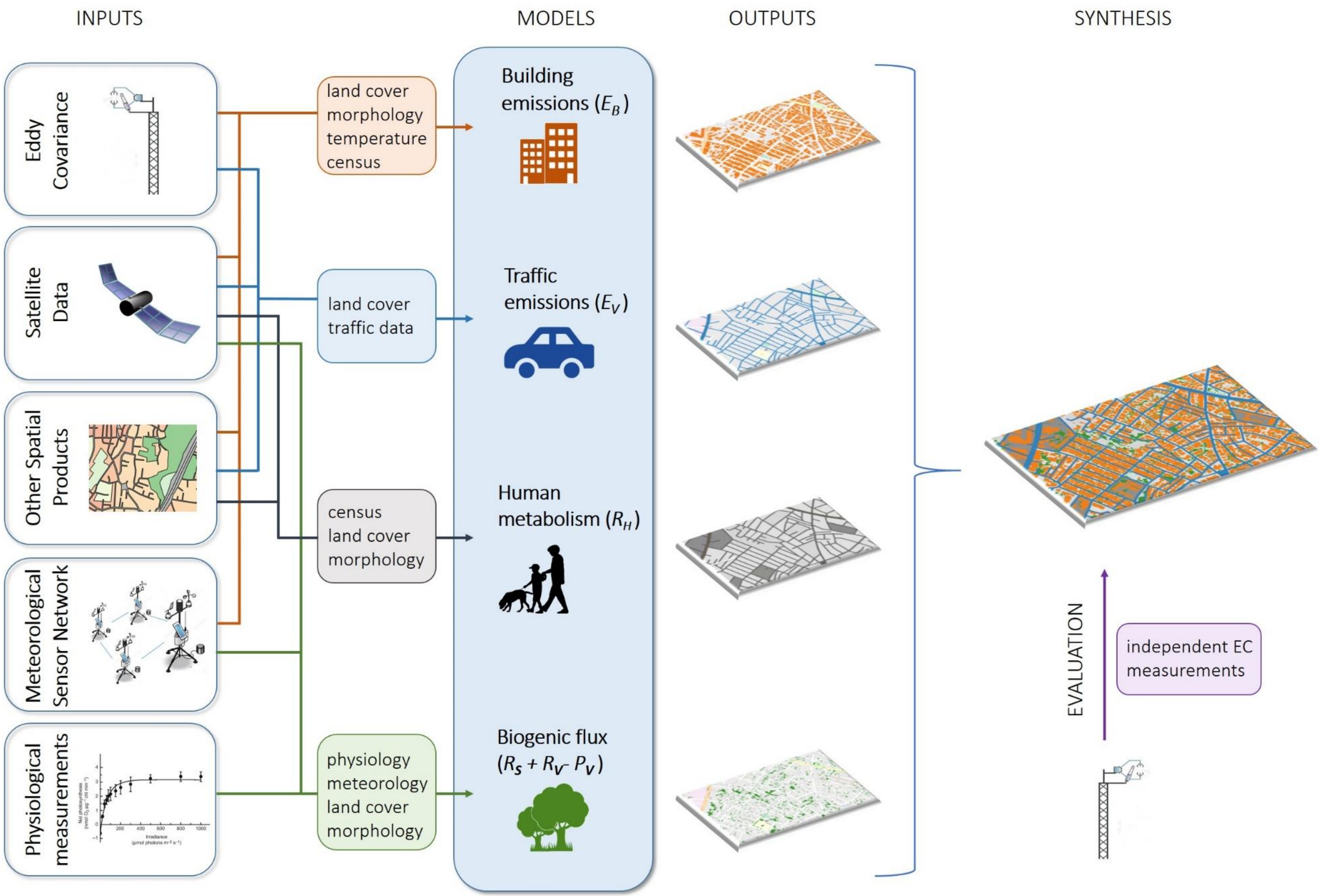
Scope

Develop a robust methodology for mapping and monitoring the urban CO_2 flux at high spatial and temporal scales, meaningful for urban design decisions (neighbourhood, block, or building scale)

- independent models for all the different components of the urban carbon cycle
- interdisciplinary perspective: combine EC with EO capabilities
- offer improved spatiotemporal urban CO_2 emissions' monitoring
- Evaluate the developed methodology using independent local scale EC-measured F_C.

Methodology

Methodology



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Eddy Covariance

› 3 EC stations (2 urban, 1 rural)

  – 15 years of measurements
  – F_C calculation in 30 min time-step
  – Quality flagging
  – Gap filling
  – Directional analysis (diverse typologies)
  – Detailed flux footprint estimation

Meteorological data

› 15 meteo stations

– Air temperature, precipitation, incoming radiation, soil temperature

- Gap filling
- temporal aggregation
- spatial interpolation

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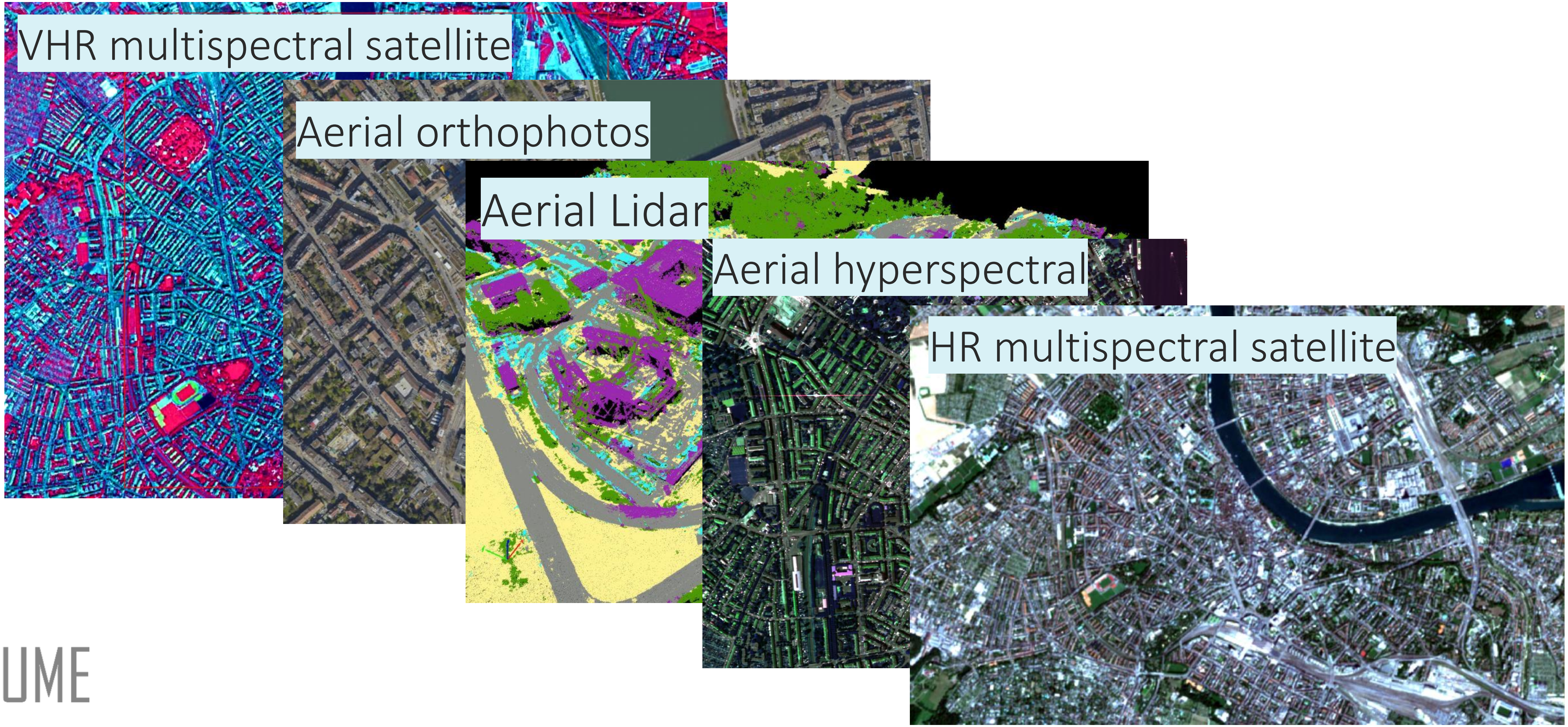
Earth Observation



Earth Observation

coverage / resolution	VHR multispectral satellite	→ classification	Land cover
resolution	Aerial Orthophotos	→ photointerpretation	
resolution	Aerial Lidar	→ 3D structure	Urban morphology/ roughness indicators
spectral	Aerial hyperspectral	→ classification/biophysical	
temporal	HR multispectral satellite	→ Dynamics: biophysical/ biochemical	Leaf Area Index (LAI) Physiological status

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Other spatial data

Physiological *in-situ* measurements

- Species-specific relations between biogenic processes (R_S, R_V,P_V) and site-specific abiotic parameters

  - Leaf photosynthesis responses to PAR
  - Leaf photosynthesis responses to temperature
  - Leaf respiration responses to temperature
  - Soil respiration responses to soil temperature
  - Soil respiration responses to soil water content

Models

Traffic emissions, E_V

Inputs:

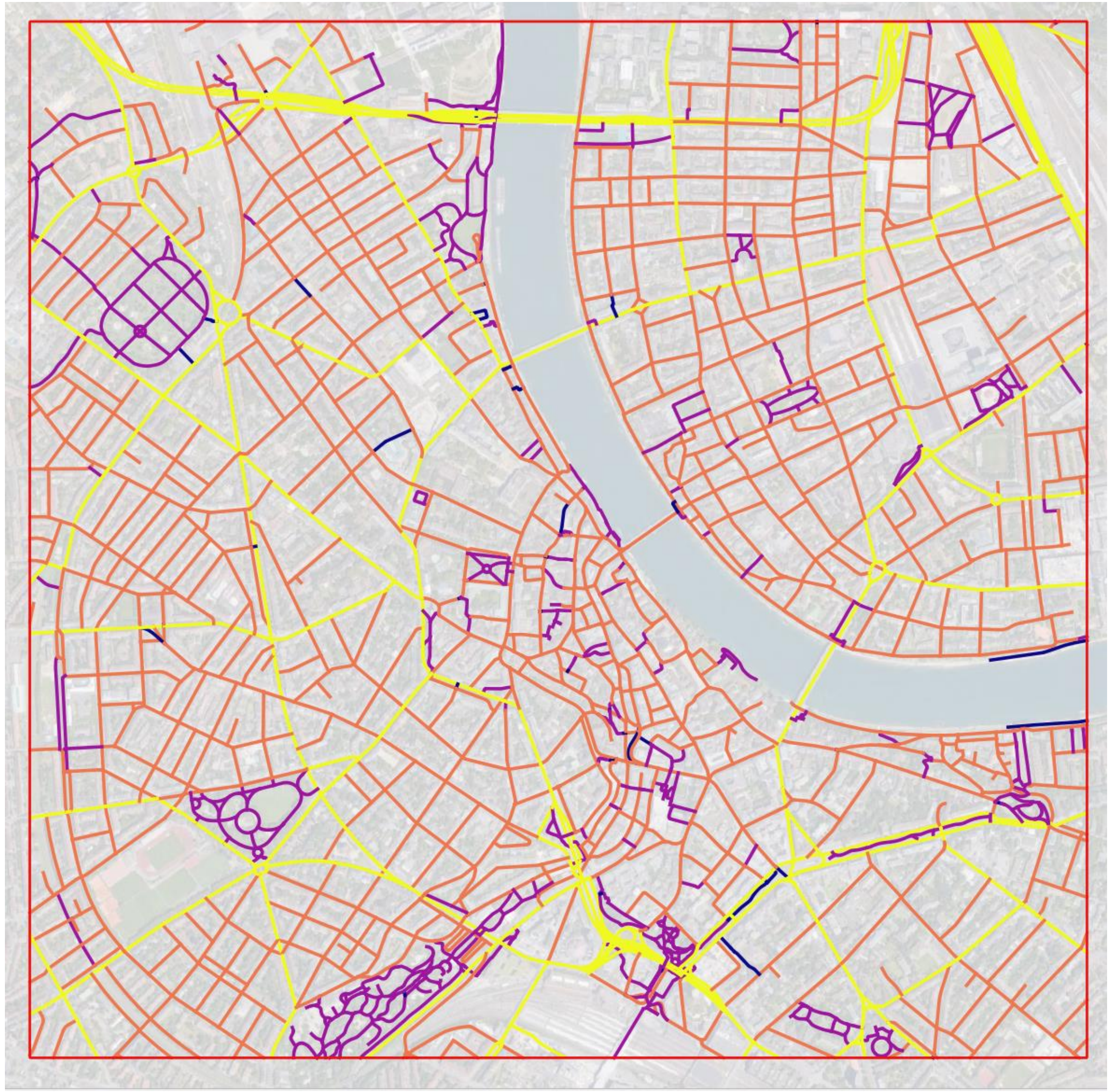
- EC data + source area modeling
- Traffic profiles (traffic counts)
- Road types
- Vehicle type statistics
- Traffic flow indicators (e.g. cross-sections, traffic light locations, terrain)

Method:

Hourly and type of day specific statistical models between measured F_C and source area weighted E_V controlling parameters (road types, traffic statistics, flow indicators).

Conditions:

- Only data during high T_{air} will be used ($E_B = 0$)
- Model residuals must equal $R_H + R_S + R_V - P_V$



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Building emissions, E_B

Inputs:

- EC data + source area modeling
- Temperature – Heating degree days (HDD)
- Building height
- Population density
- Land use

Method:

Statistical models (hourly) between measured F_C and source area weighted E_B controlling parameters (building volume, building type, population density, HDD).

Conditions:

- Model residuals must equal $E_V + R_H + R_S + R_V - P_V$
- Data with low source area weighted road fractions will be used to decrease E_V bias

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Human metabolism, R_H

Inputs:

- Population density
- Gender
- Age
- Weight (if available)
- Workforce
- time use statistics
- Land use

Method:

Bottom-up model based on per capita respiration rate (μmol CO_2 cap^{-1} s^{-1}) as a function of the spatiotemporal distribution of population characteristics and activities.

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Photosynthesis, P_V

Inputs:

- Land cover
- LAI dynamics
- Satellite stress indices
- Temperature
- Radiation
- Terrain/urban structure
- *In-situ* measurements

Method:

Process-based algorithms based on established interactions of photosynthesis with radiation and temperature, calibrated according to site- and species-specific measurements. Use of a multi-layer canopy integration model to scale-up leaf photosynthesis to plant canopies according to LAI. Dynamic monitoring of LAI and stress indicators using EO data.

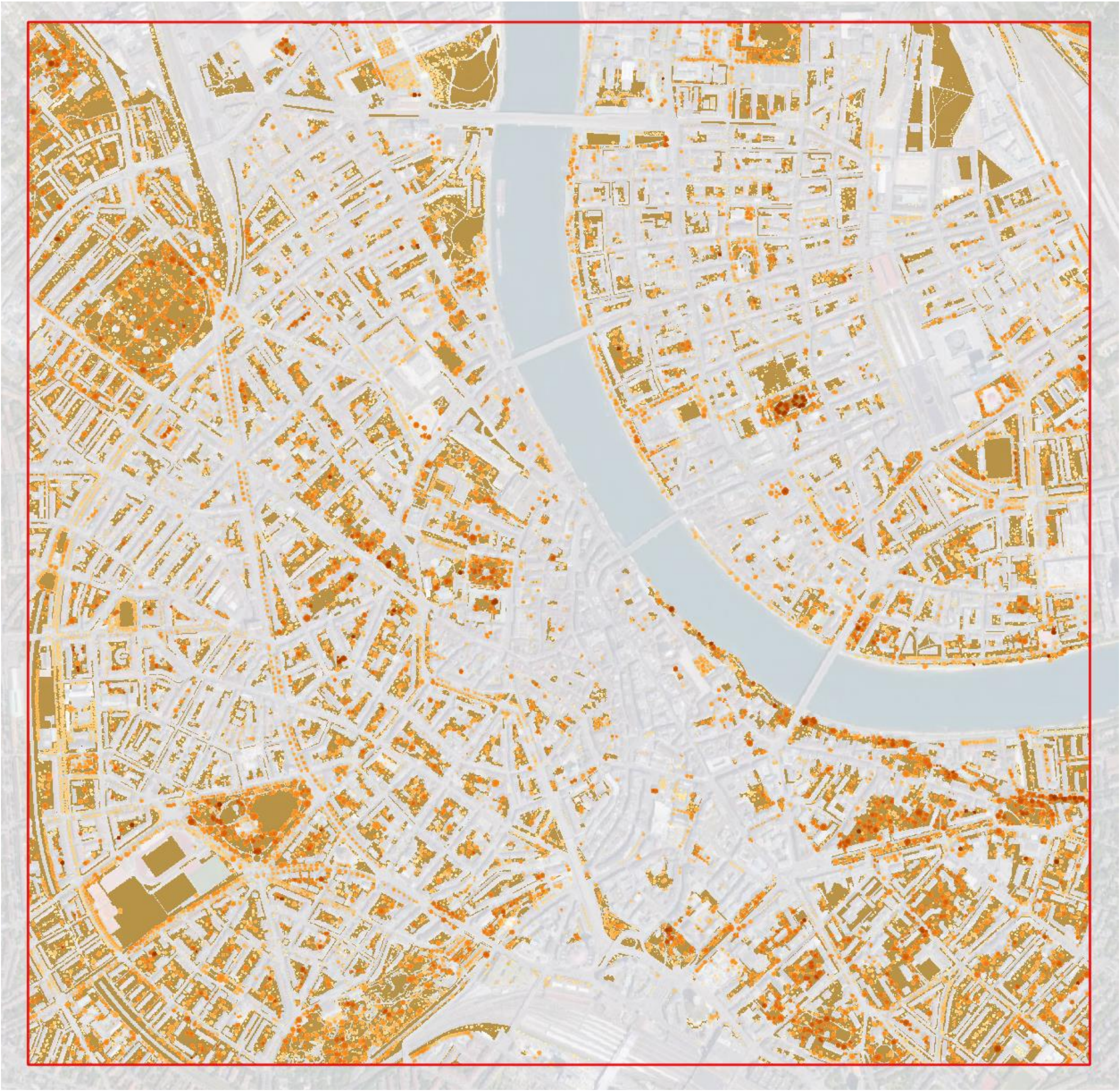
Plant Respiration, R_V

Inputs:

- Land cover
- LAI dynamics
- Tree height
- Satellite stress indices
- Temperature
- Terrain
- *In-situ* measurements

Method:

Process-based algorithms based on the interactions of plant respiration with temperature, calibrated according to site- and species-specific measurements. A 50% inhibition of dark respiration during light will be assumed. Use of a multi-layer canopy integration model to scale-up leaf respiration to plant canopies according to LAI. Dynamic monitoring of LAI using EO data.



Soil Respiration, R_S

Inputs:

- Land cover
- Temperature
- Precipitation
- Terrain
- *In-situ* measurements

Method:

Process-based algorithms based on the interactions of soil respiration with temperature and soil water content, calibrated according to site- and species-specific measurements.

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Synthesis

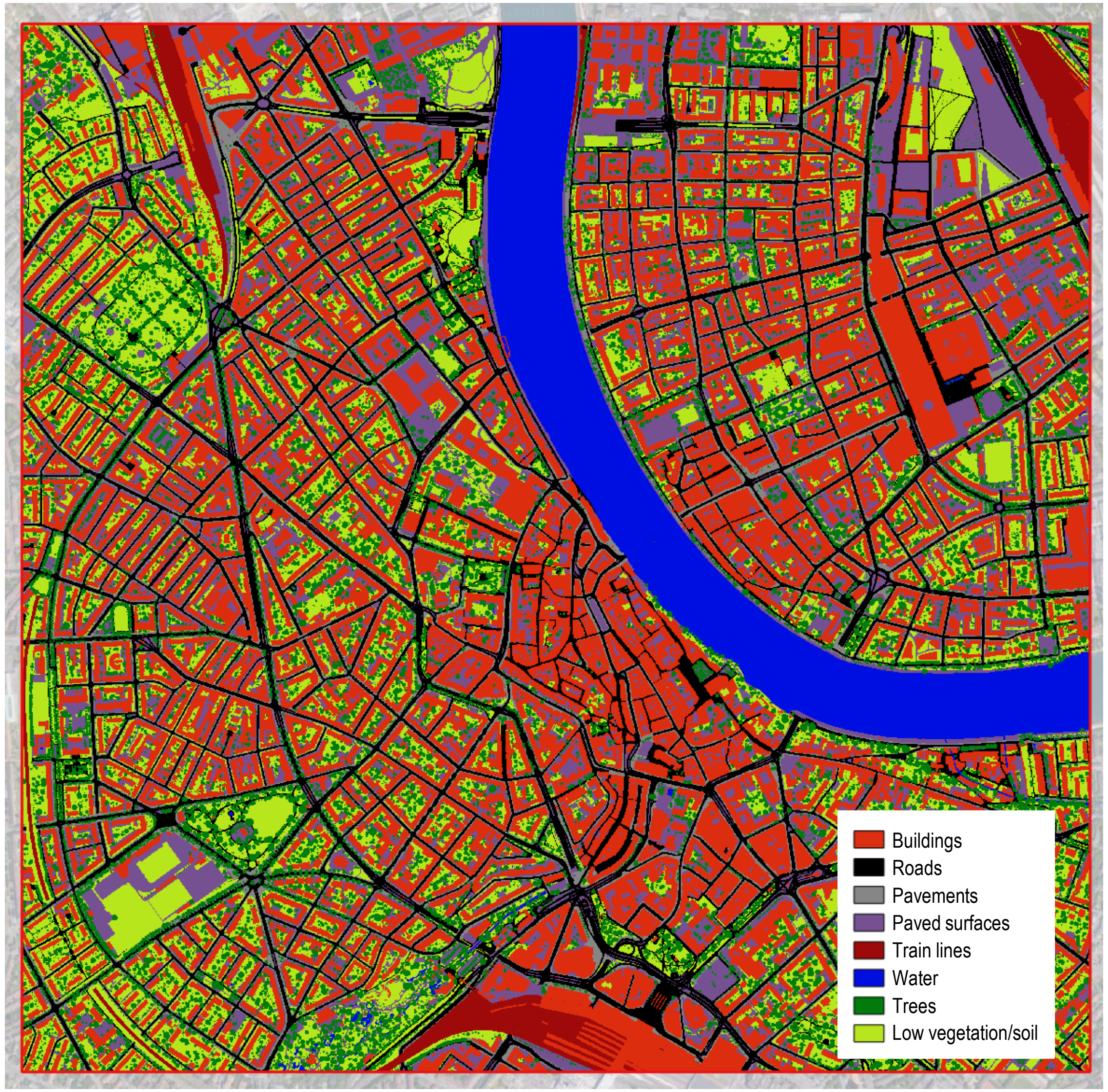
- Total F_C estimation
- Upscaling of models to city scale according to input geospatial parameters
- Evaluation locally using independent EC measurements
- Final model calibration – product optimization
- Definition of optimal spatial and temporal scales of F_C maps.

Preliminary results

Land Cover Classification

- Basel geodatabase
  - Land use
  - 3D model
  - Tree inventory

- Airborne Lidar
  - Tree height
  - Crown radius



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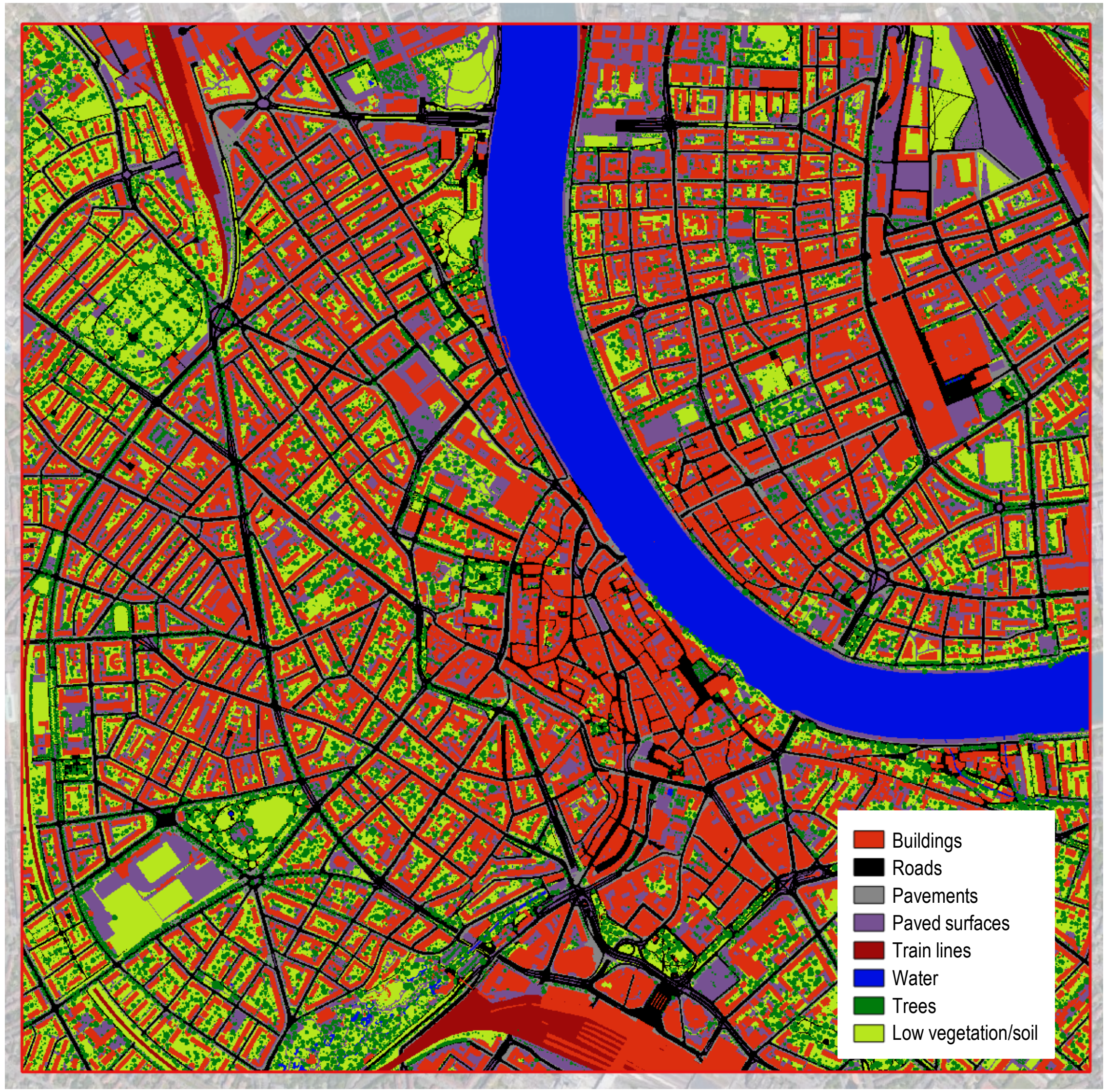
Land Cover Classification

Next steps:

- Hyperspectral aerial
  - Complete tree species classification
  - LAI estimation

- Geodatabase
  - Road types

- VHR multispectral satellite
  +
  Aerial orthophotos
  - Past situation



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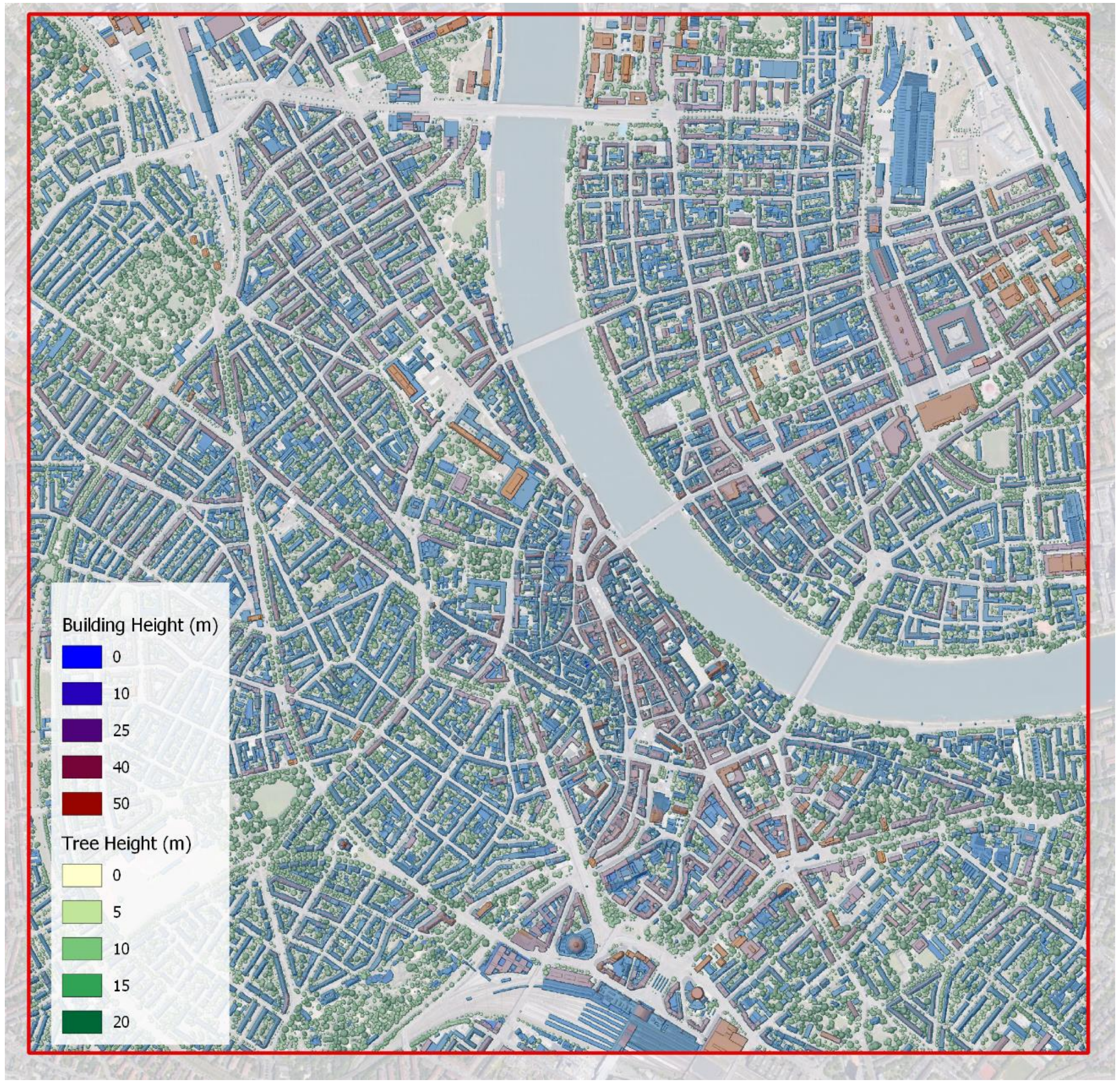
Urban Morphology

- Basel 3D model
  - Building structure
  - Terrain
- Aerial Lidar
  - Tree height
  - Crown radius



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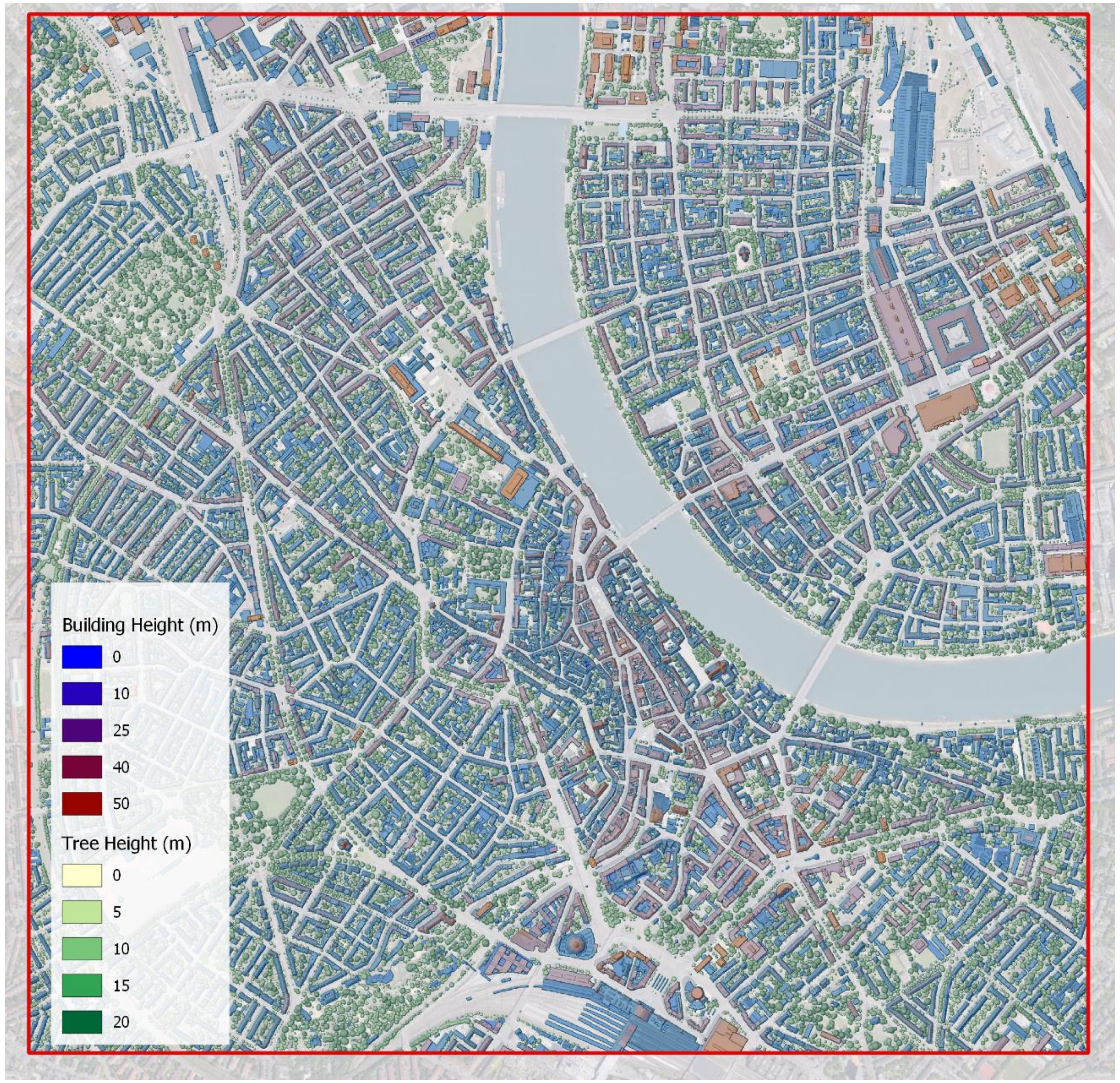
Urban Morphology

Next steps:

› Calculate roughness indicators

› Investigate morphology changes (past 3D models, VHR satellite imagery)



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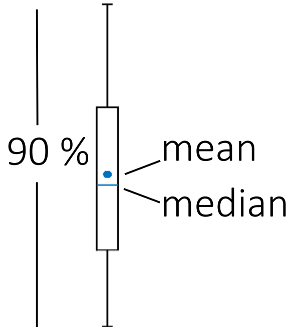
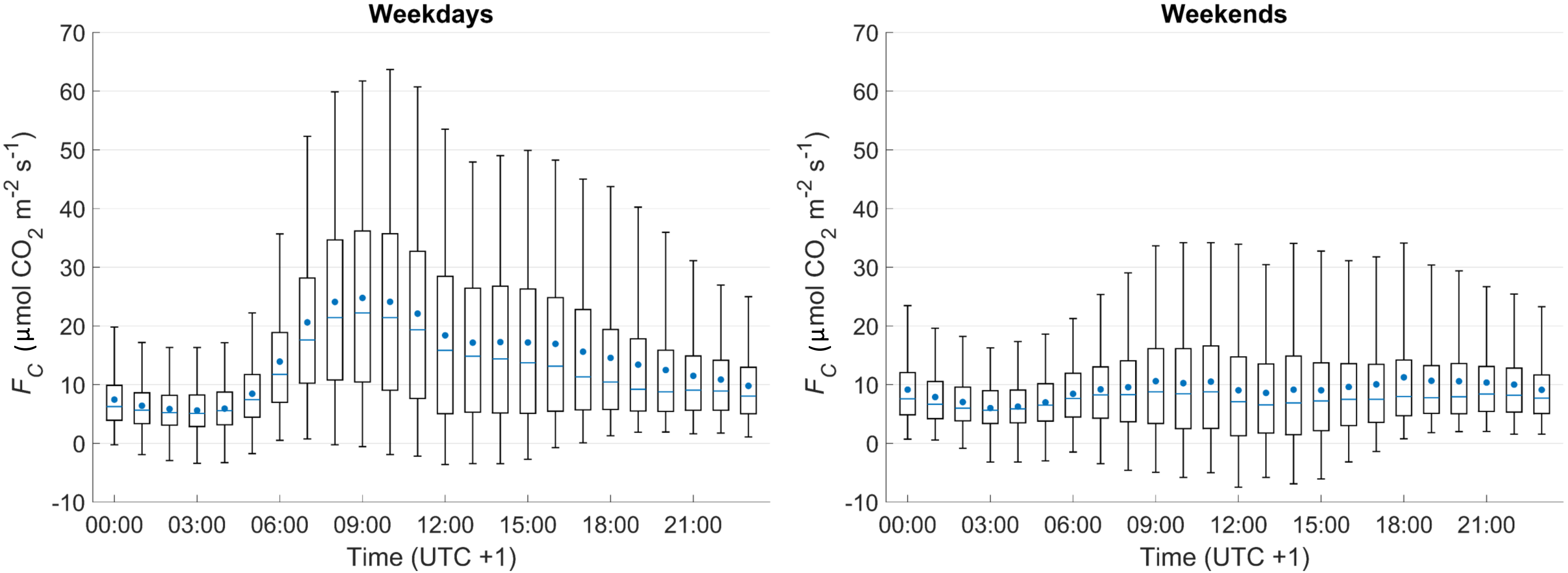
Eddy Covariance

BKLI station (15 years)





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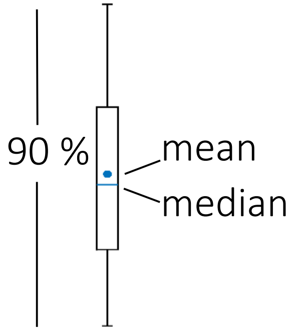

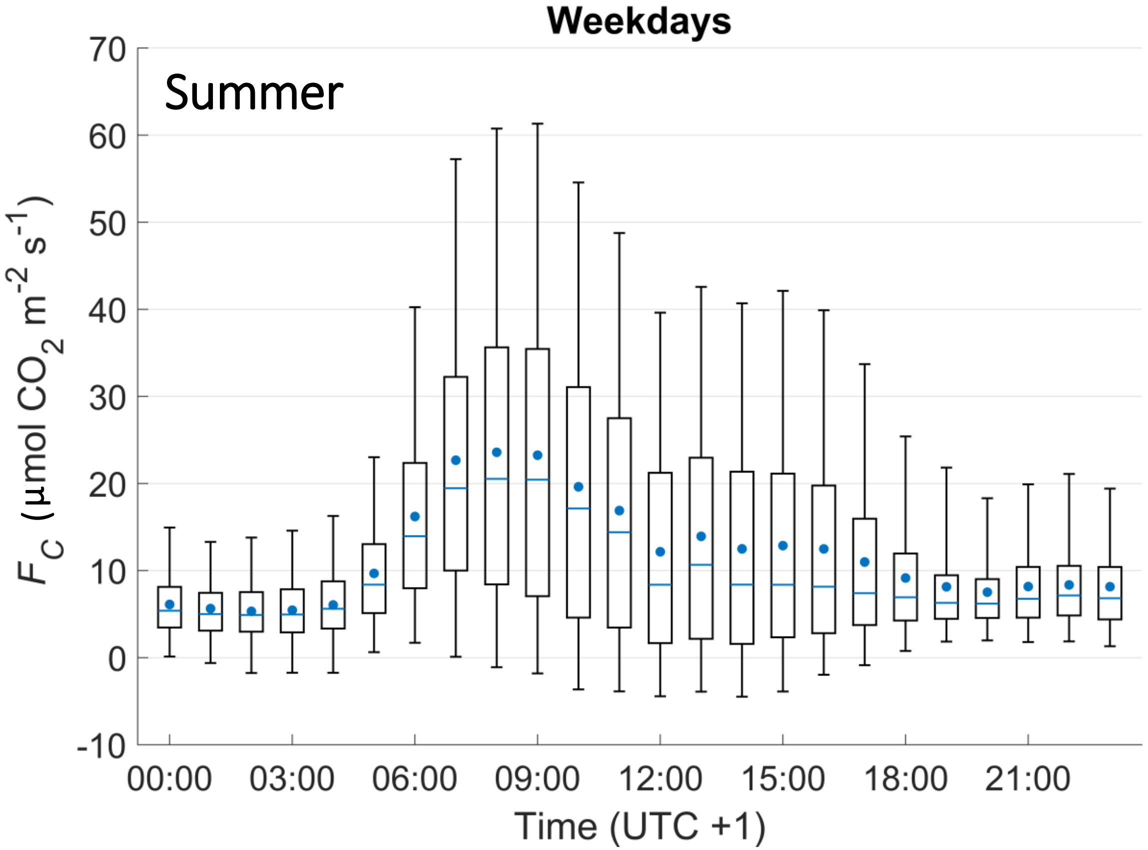

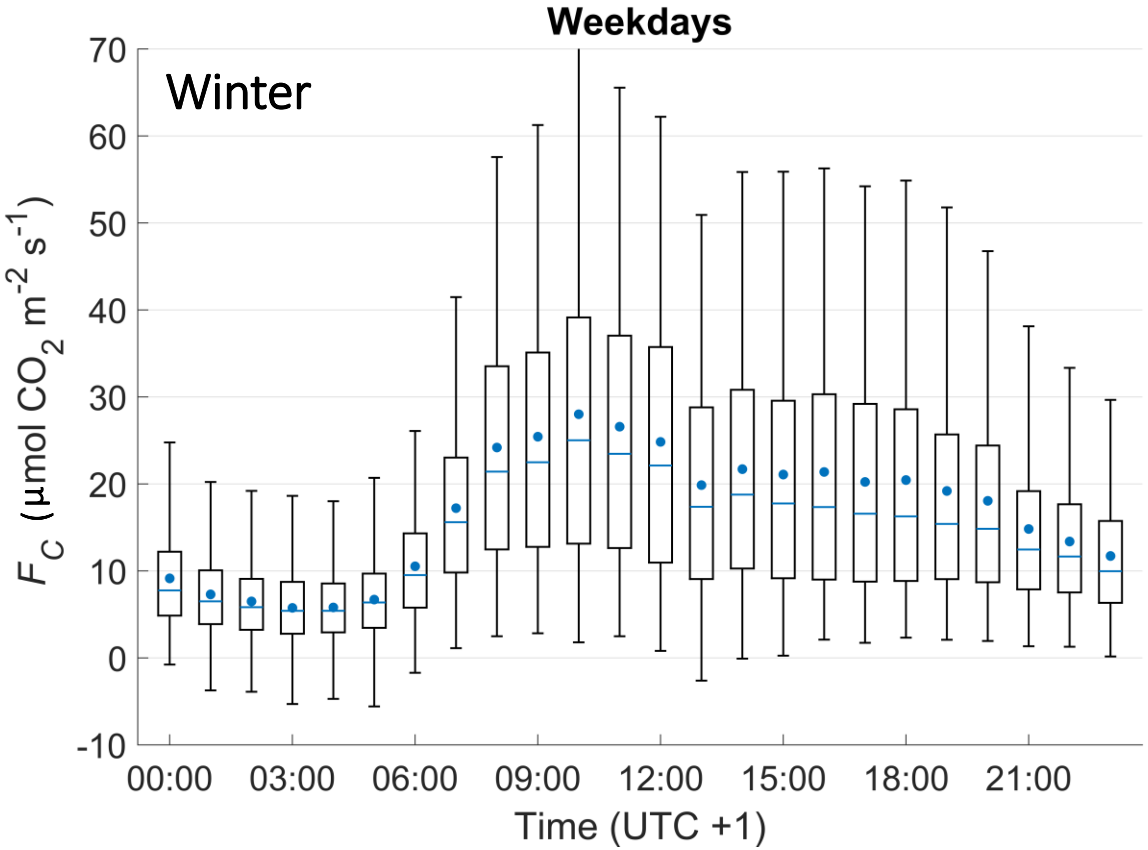

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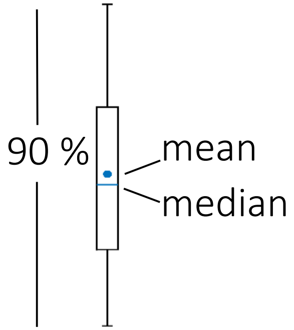

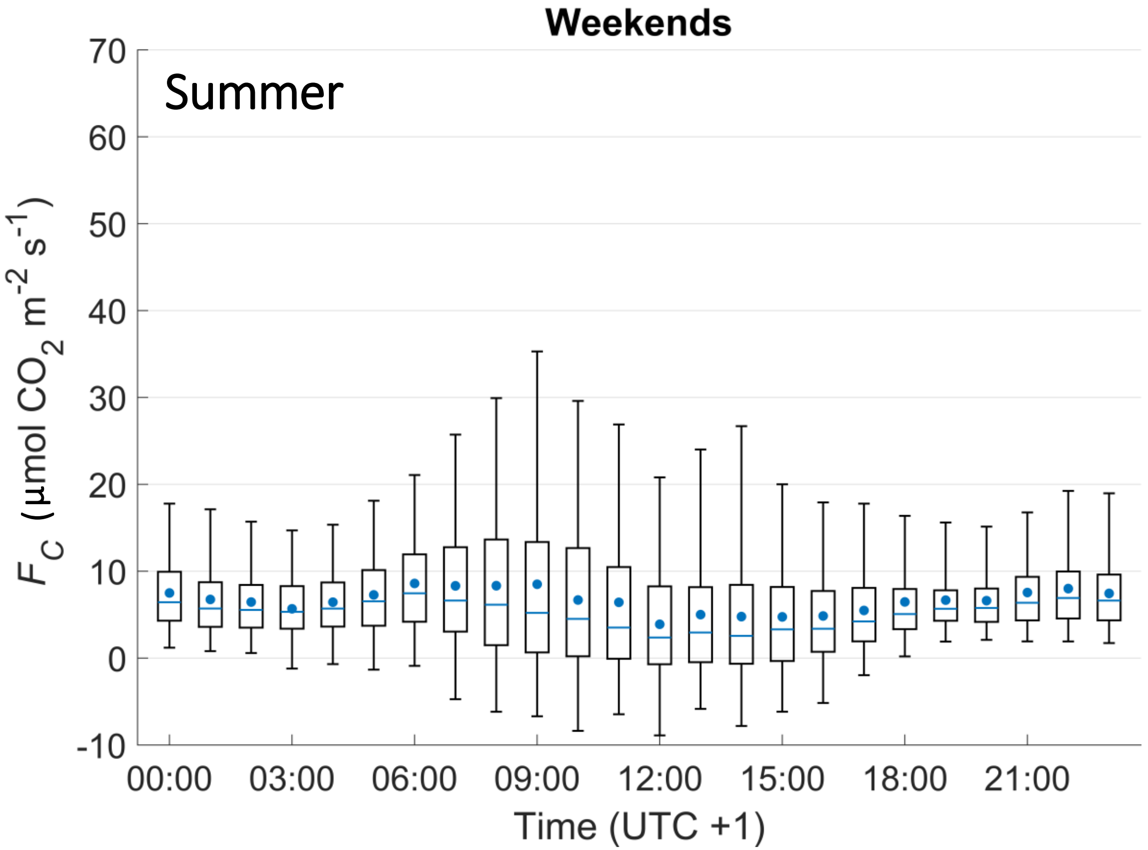

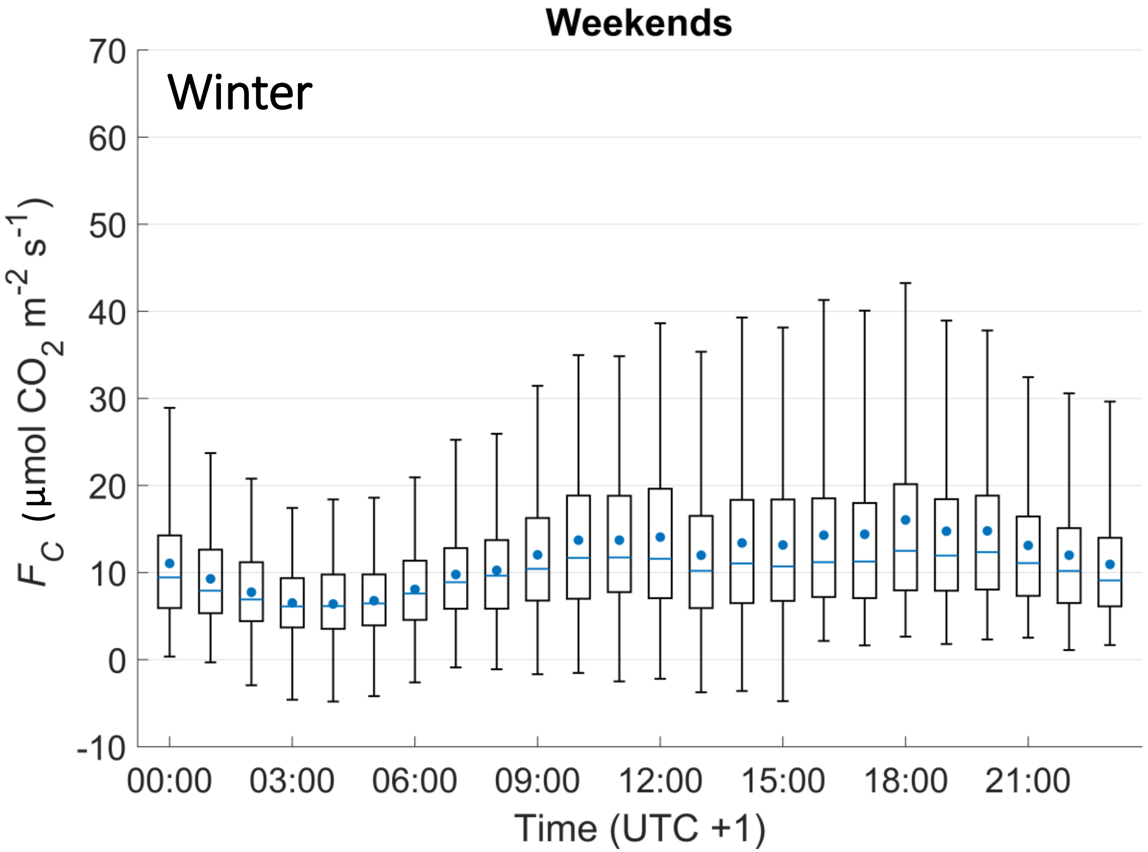

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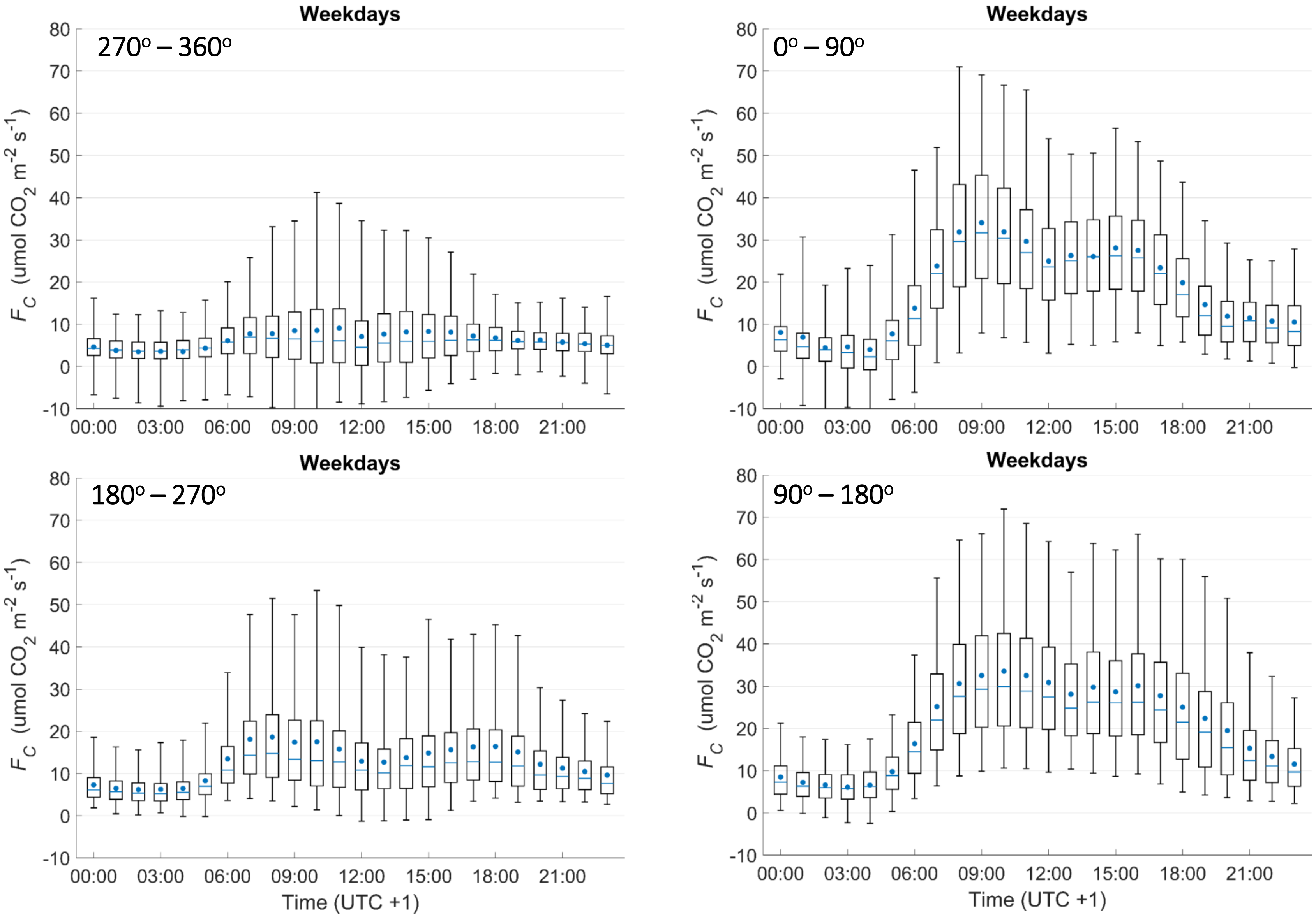

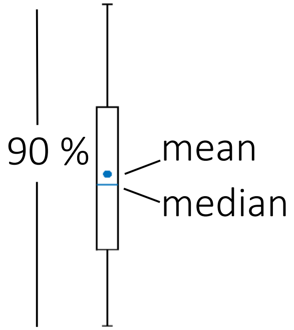

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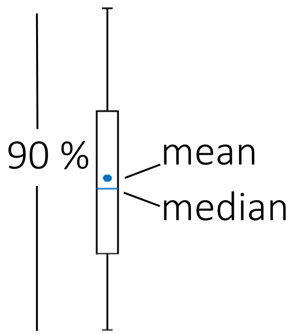
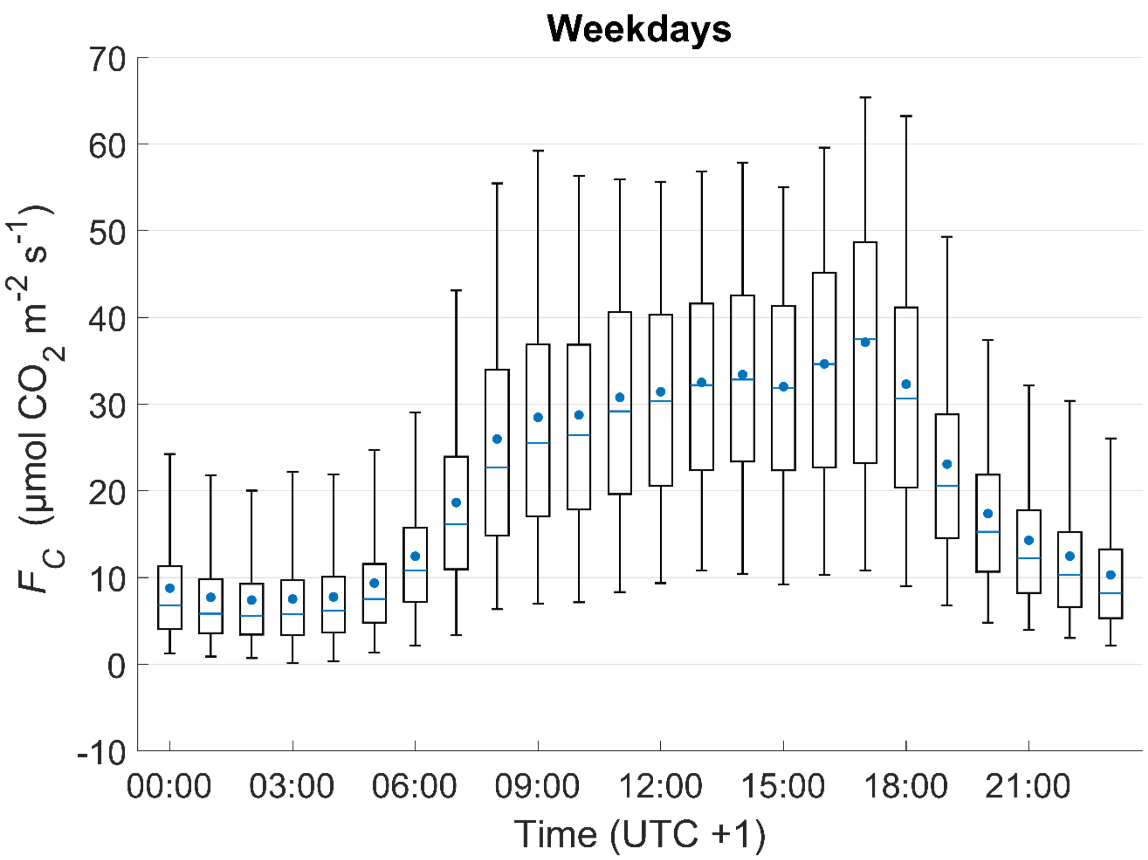
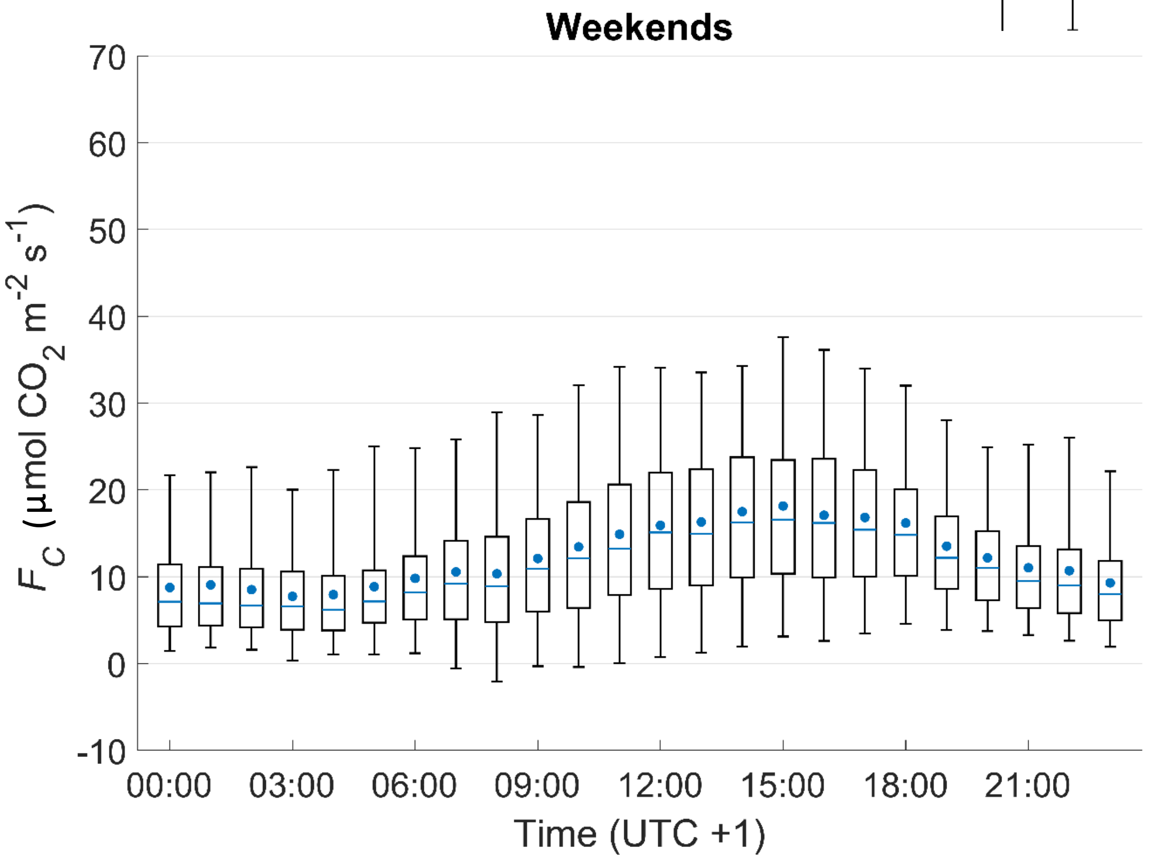


BAES station (10 years)





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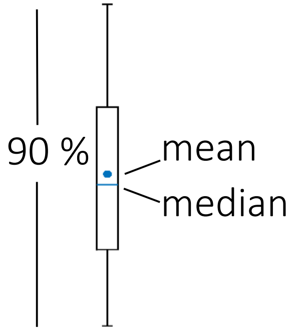

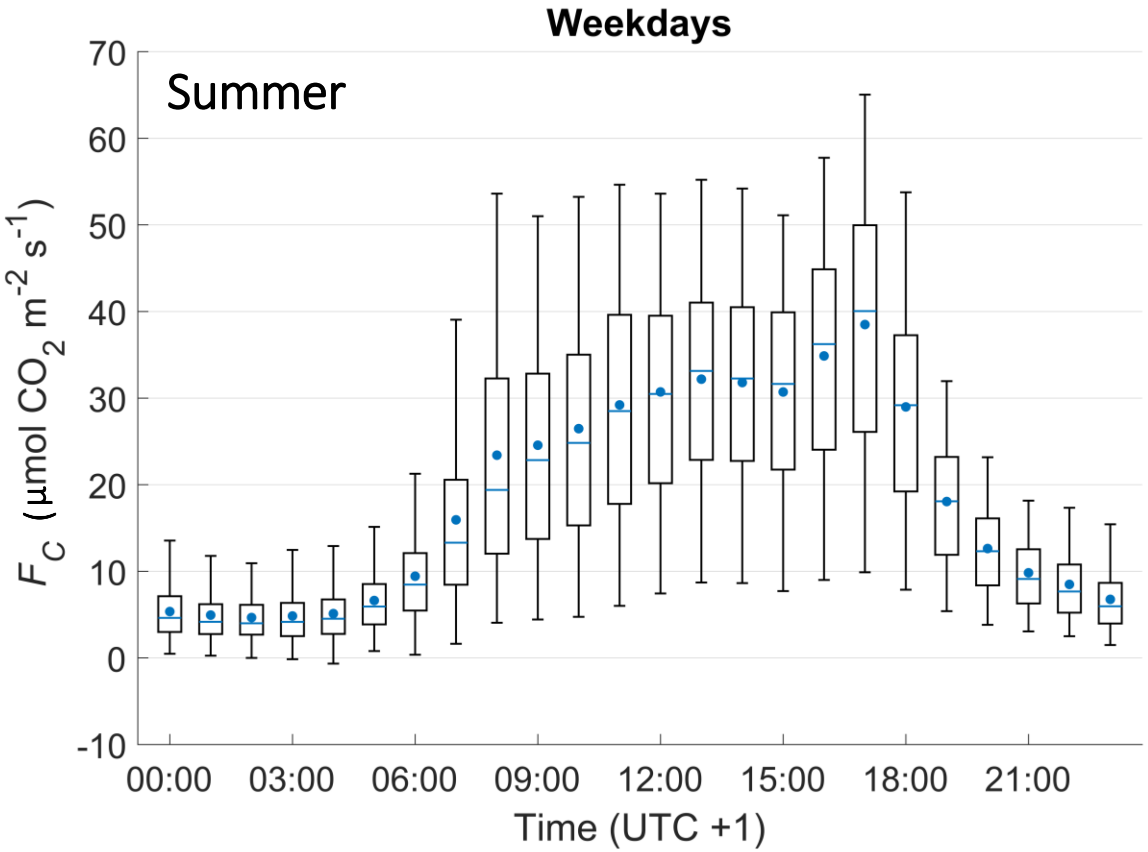

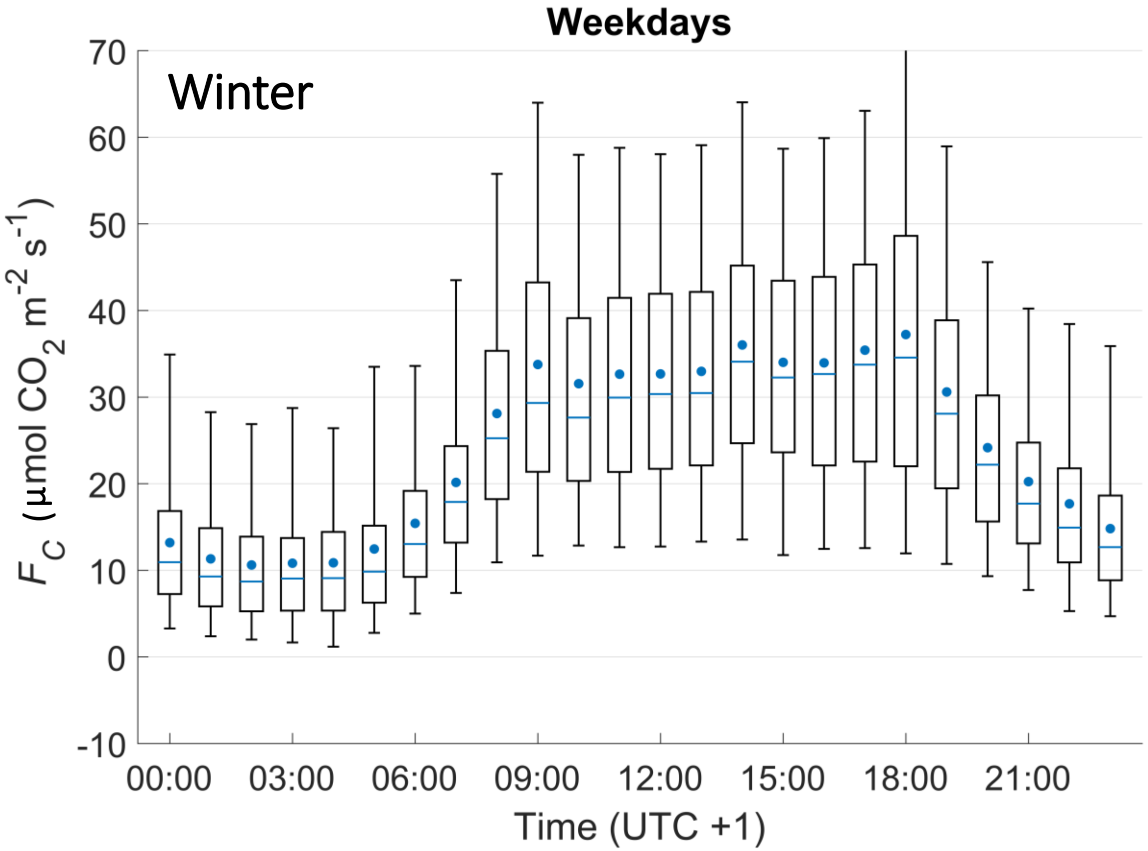

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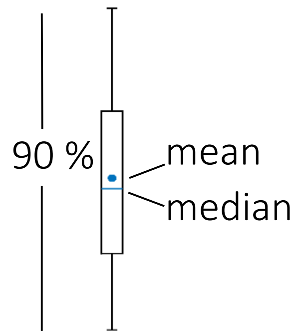

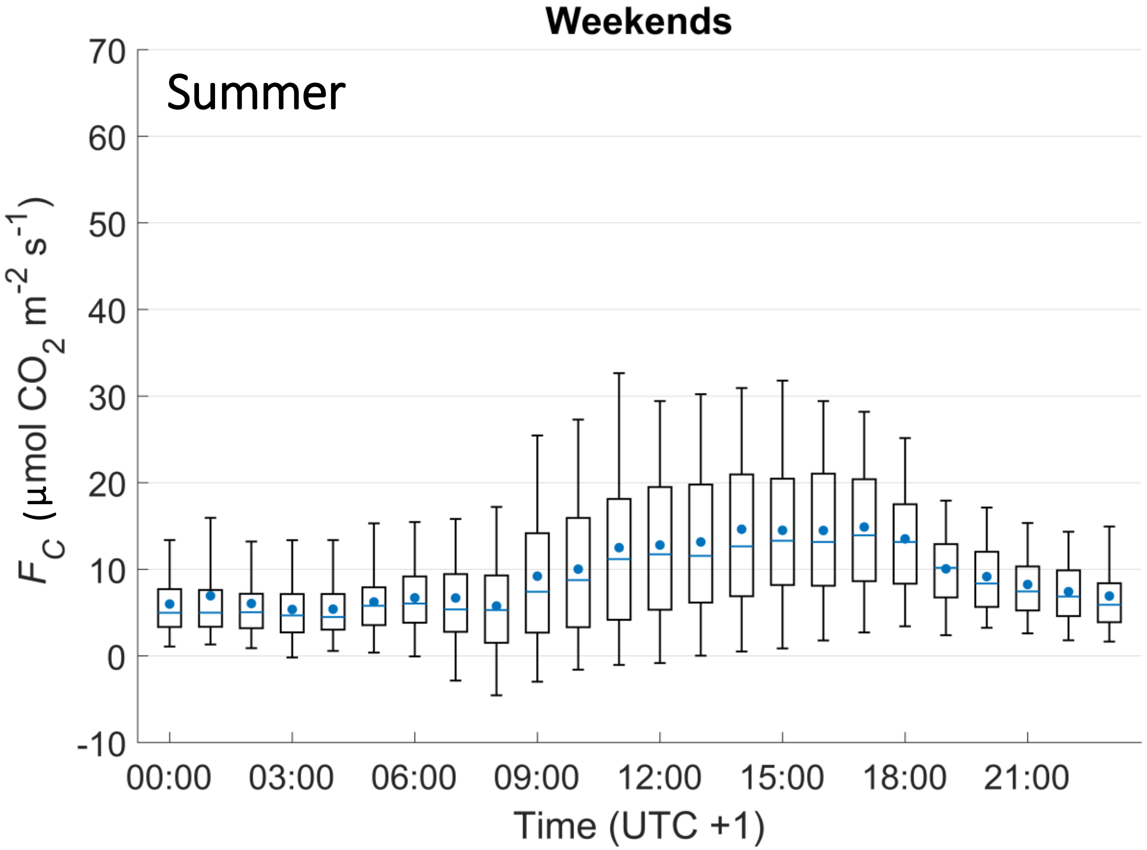

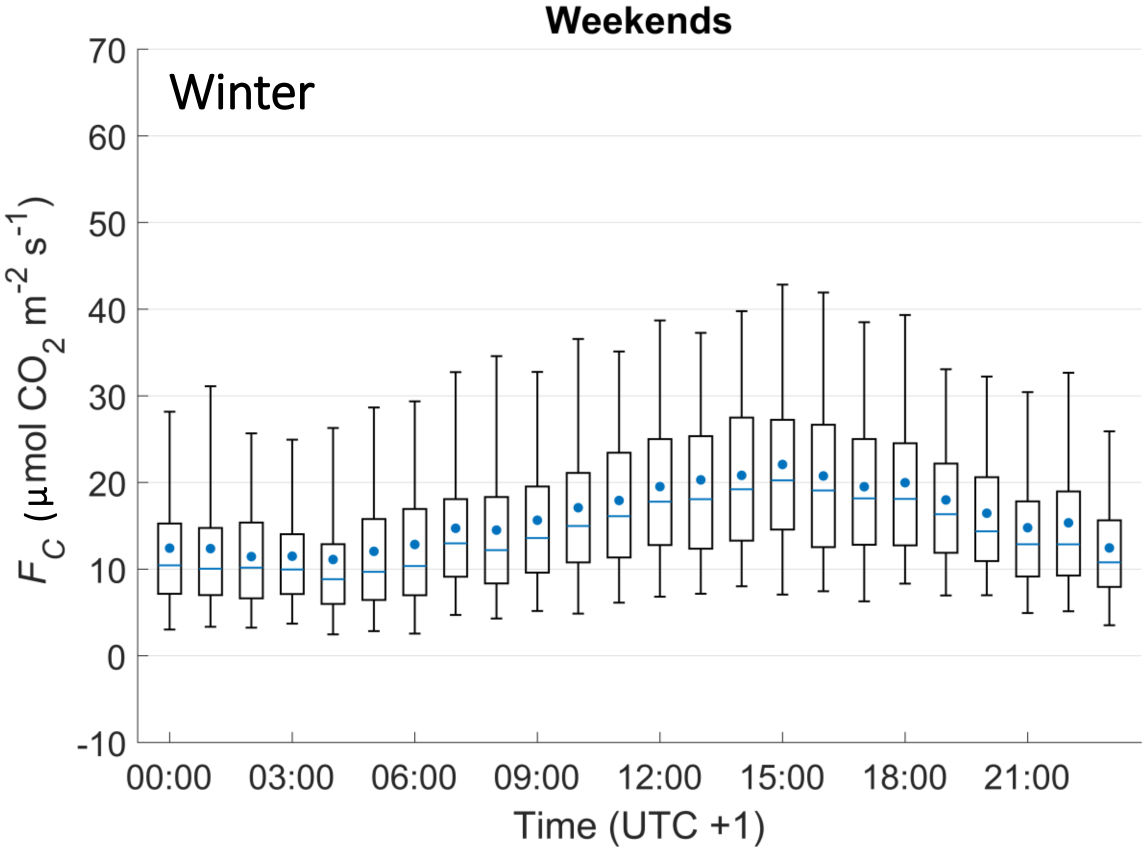

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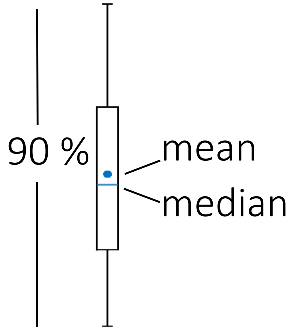
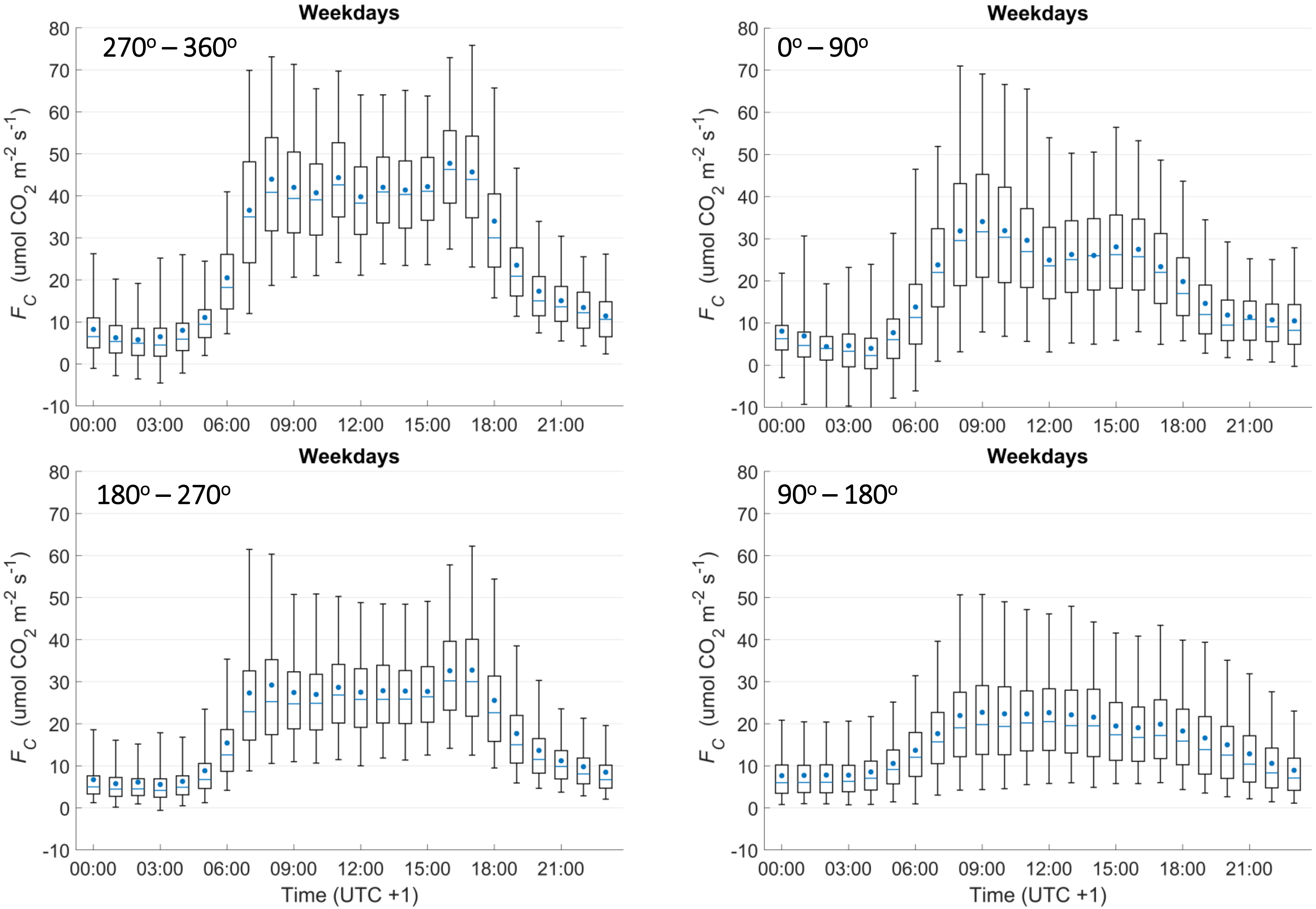
Eddy Covariance

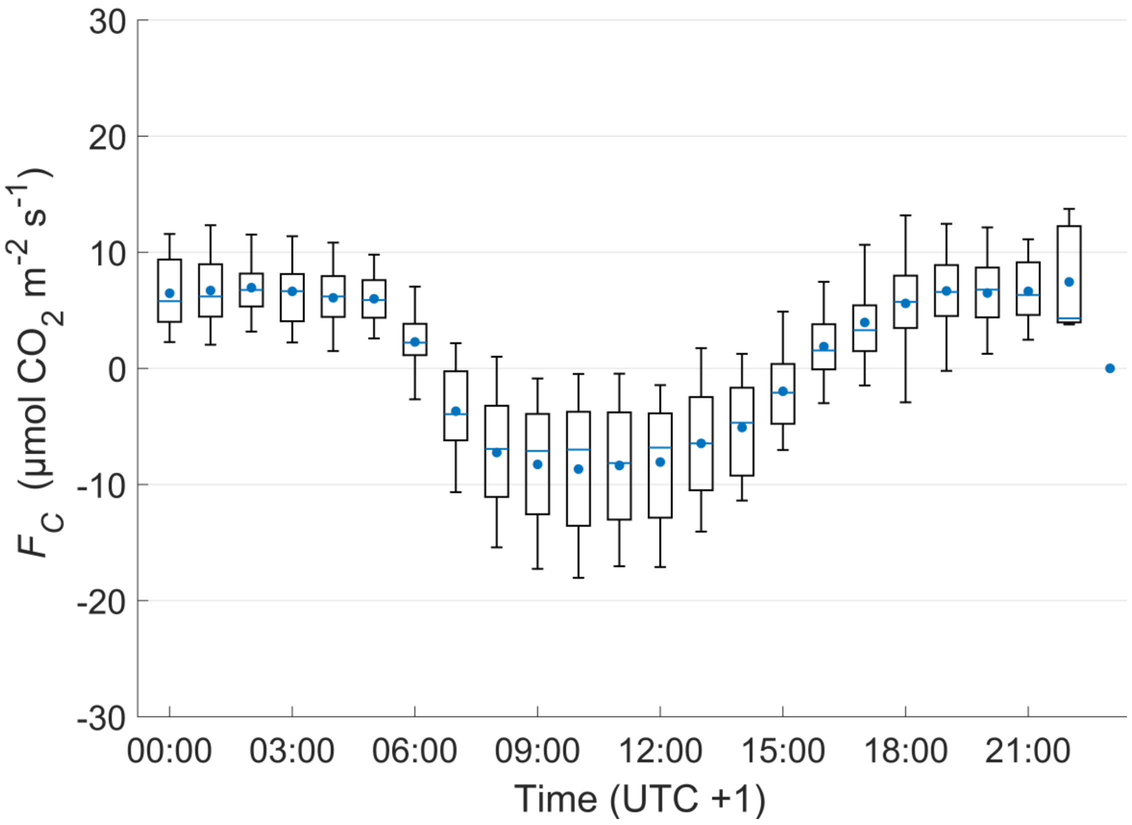


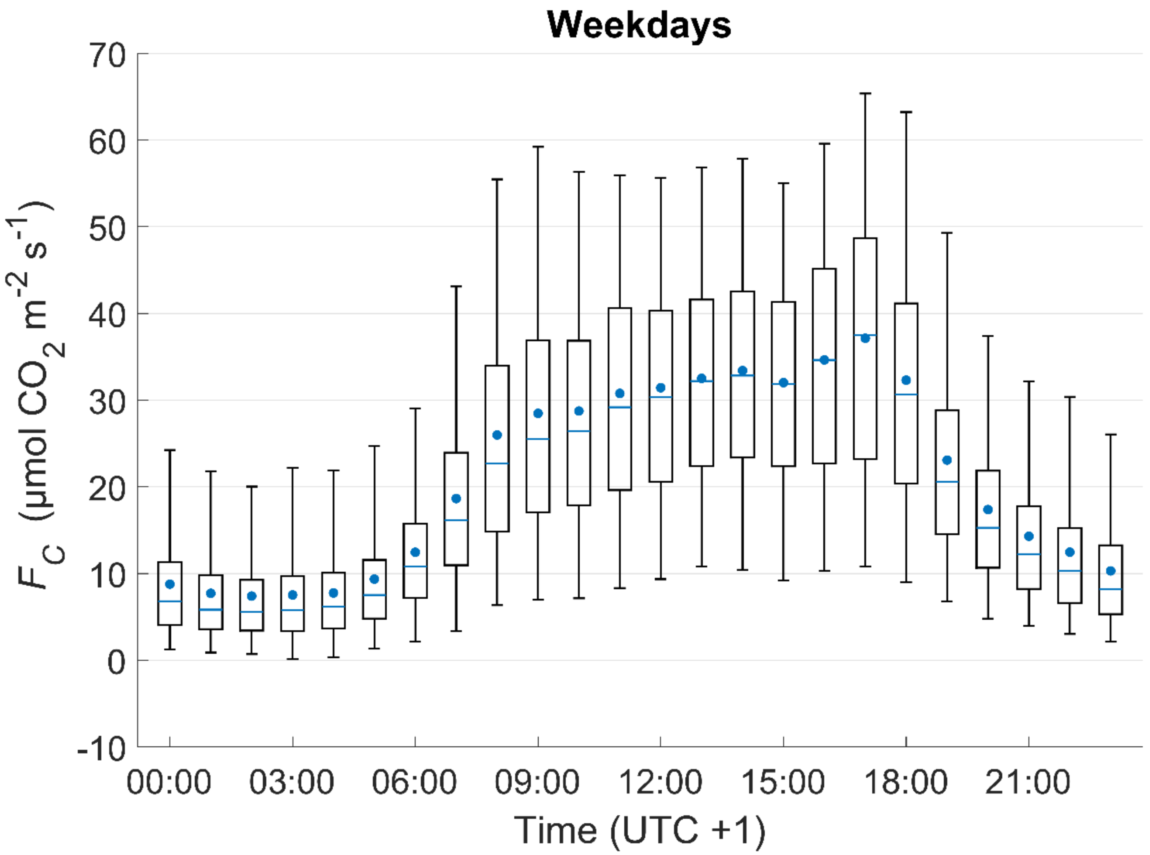
BAES station (10 years)



Eddy Covariance

BLER station (3 months)





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Acknowledgements

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Thank you for your attention!

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