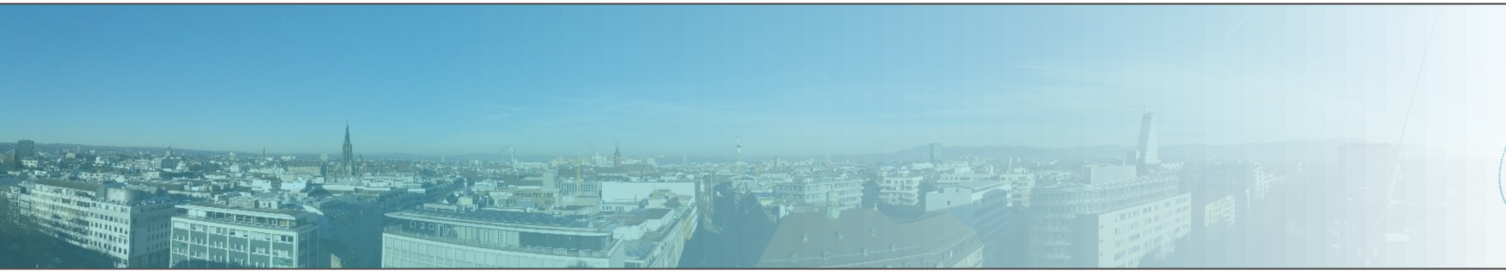

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Urban carbon dioxide Flux Monitoring using Eddy Covariance and Earth Observation

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

First results from diFUME project

Stavros Stagakis

Postdoc, ATM

24.11.2020

Current Studies in Physical Geography and Atmospheric Sciences

Fall Term 2020

mcr meteorology climatology remote sensing

University of Basel

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 836443

Contents

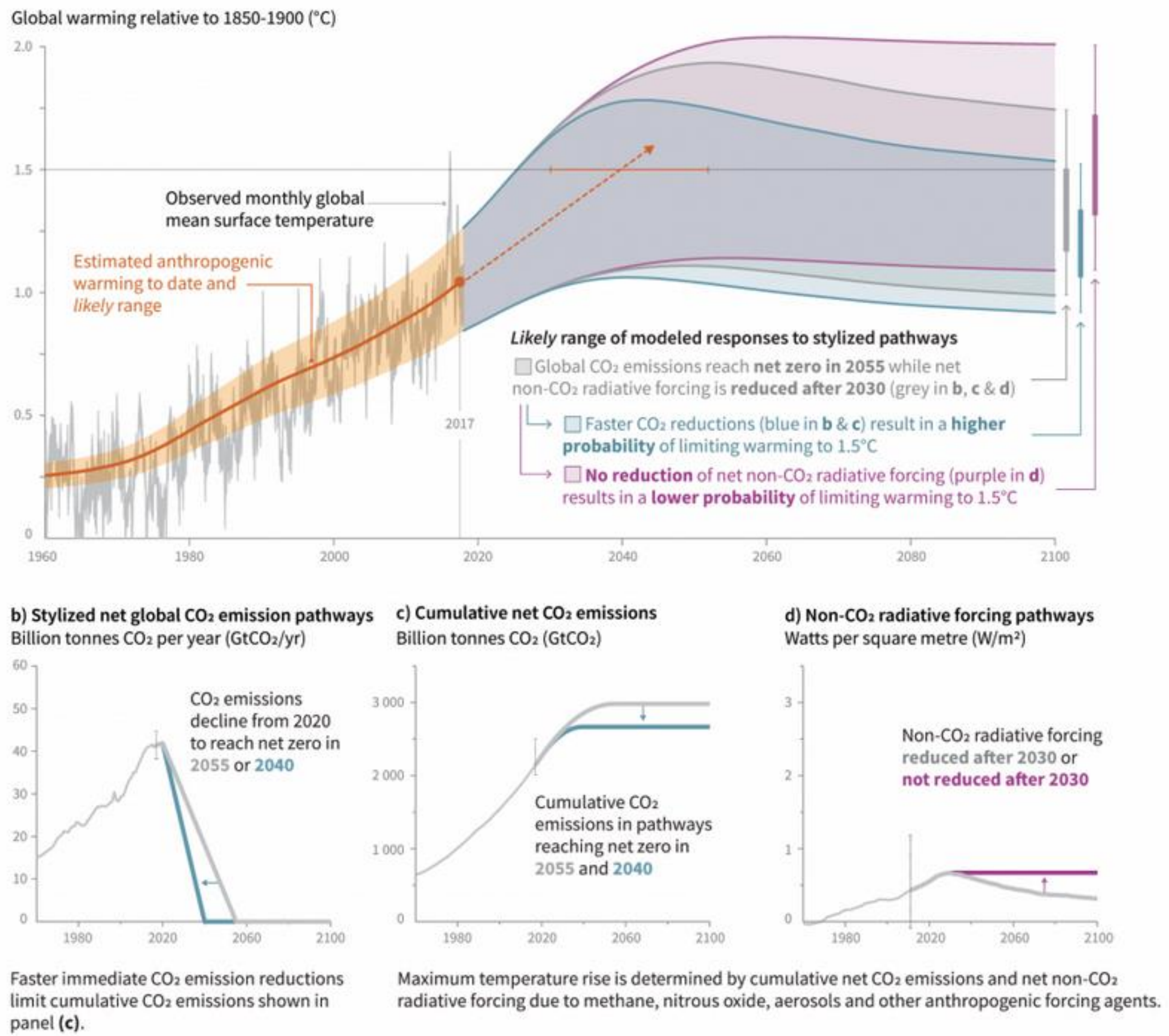
Introduction

Paris Agreement, 2015:

- global temperature rise < 2 ^{o}C
- limit temperature rise to 1.5 ^{o}C

IPCC Special Report, 2018:

- global warming is likely to reach 1.5°C between 2030 - 2052 if it continues to increase at the current rate.
- 1.5 $^{\circ}$C goal requires rapid and far-reaching transitions in energy, land, urban, infrastructure (including transport and buildings), and industrial systems.



IPCC, Special Report, 2018

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“Cities Are Where the Climate Battle Will Largely Be Won or Lost”

António Guterres, UN Secretary-General

C40 World Mayors Summit, 2019

Introduction

Urban Areas:

- **55 %** (4.2 billion) of world population lives in cities, projected to increase to **68 %** (6.7 billion) by 2050

UN, 2018

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

Canadell et al., 2009

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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.

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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

Introduction

Vertical fluxes

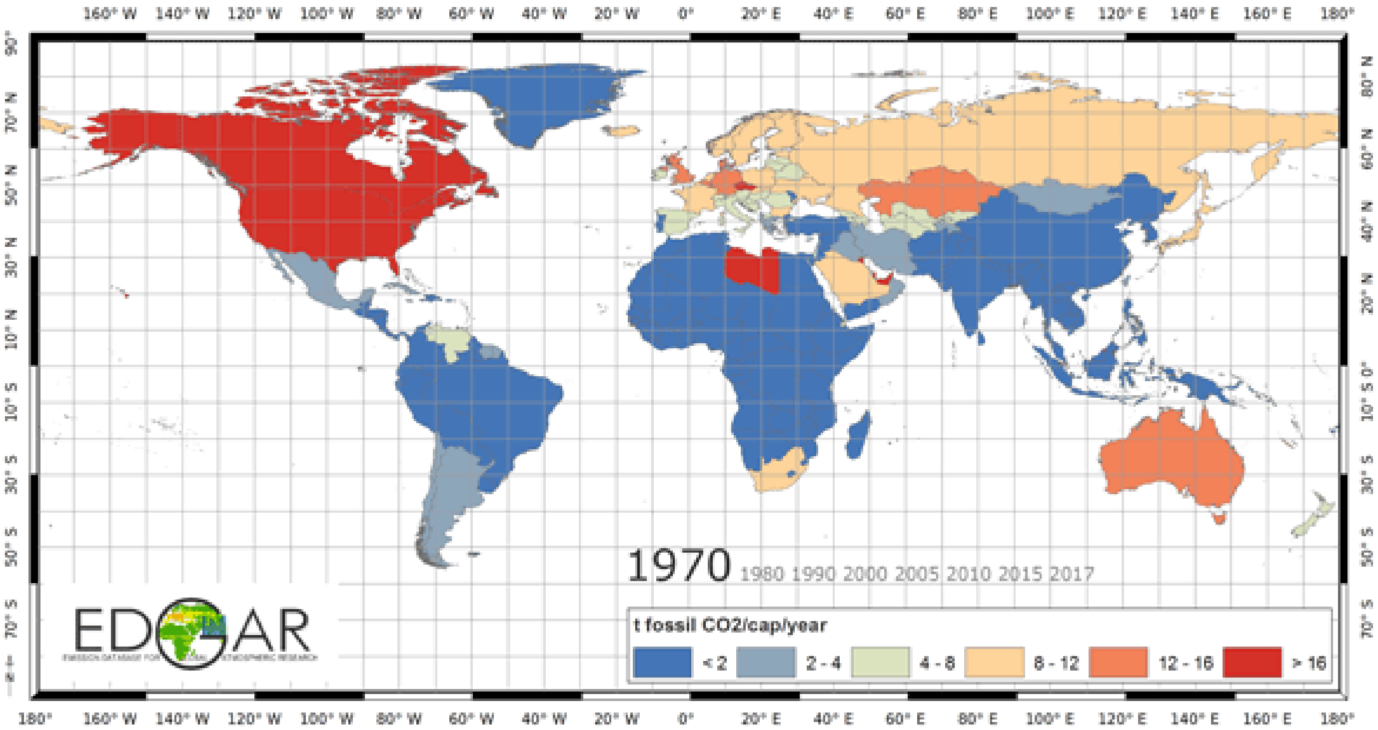
Processes:

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

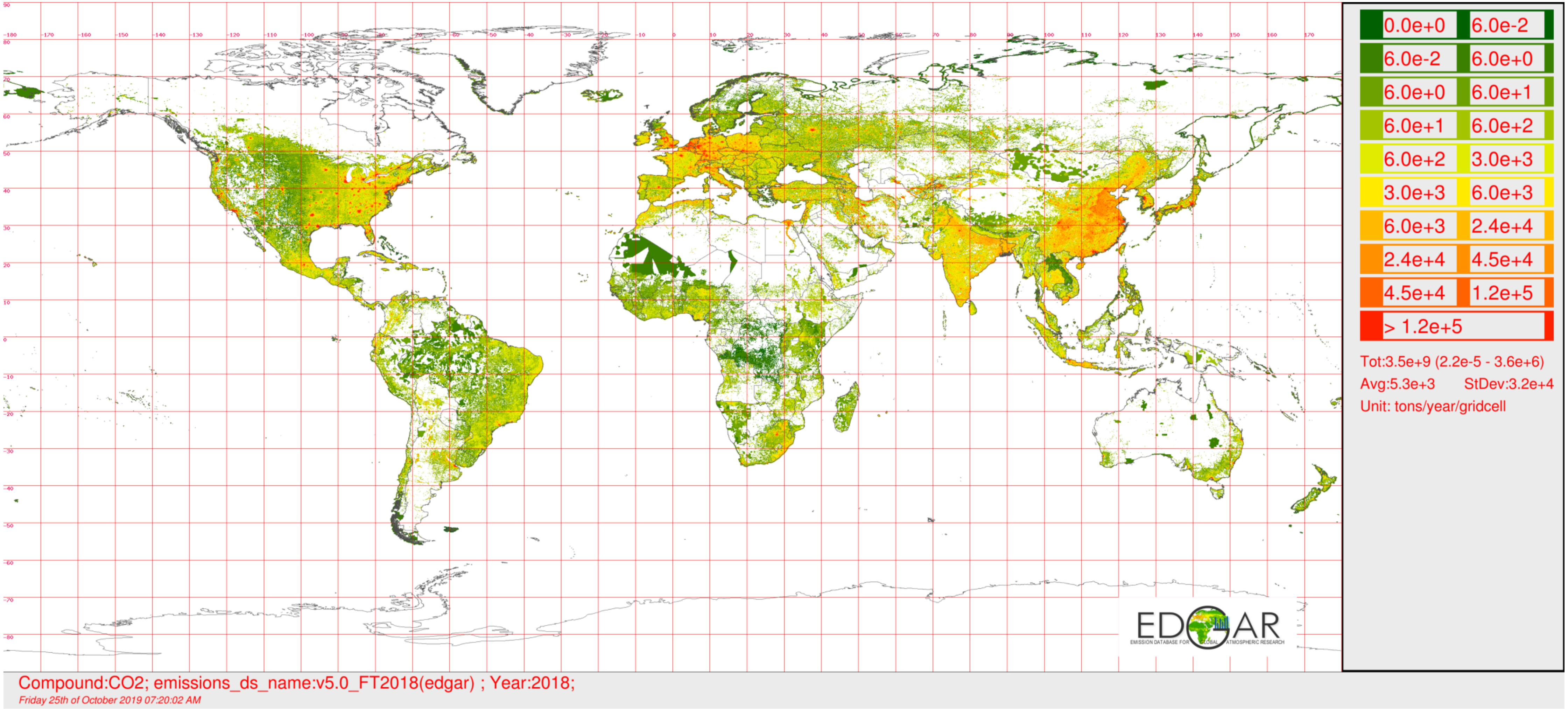
Monitoring CO_2 Fluxes in Cities

Inventory or bottom-up approaches (indirect)

- Fuel and electricity consumption data-statistics and emission factors
- Restricted spatial and temporal scales
- Downscaled using proxies (e.g. population density, land cover types)
- Data/methodology consistency issues



Monitoring CO_2 Fluxes in Cities



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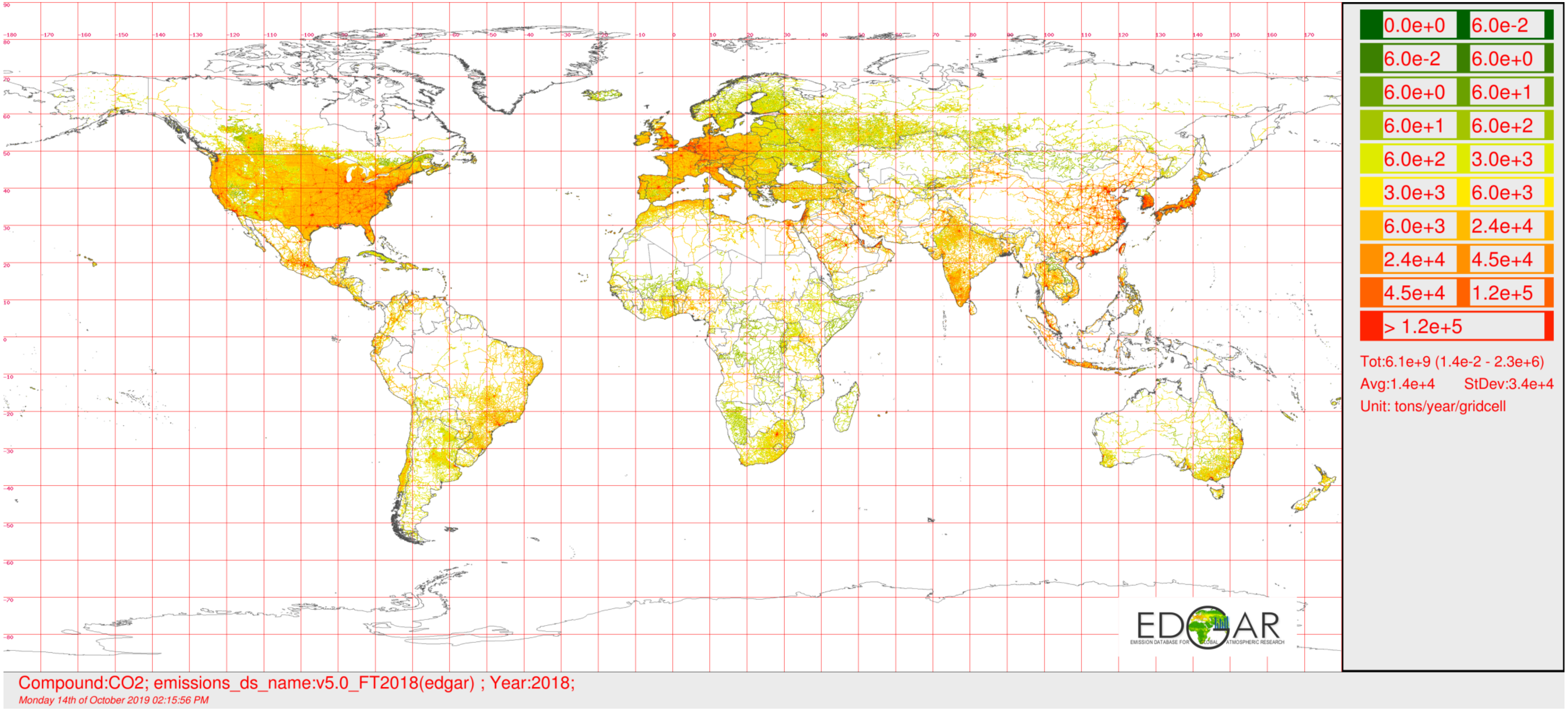
Monitoring CO_2 Fluxes in Cities



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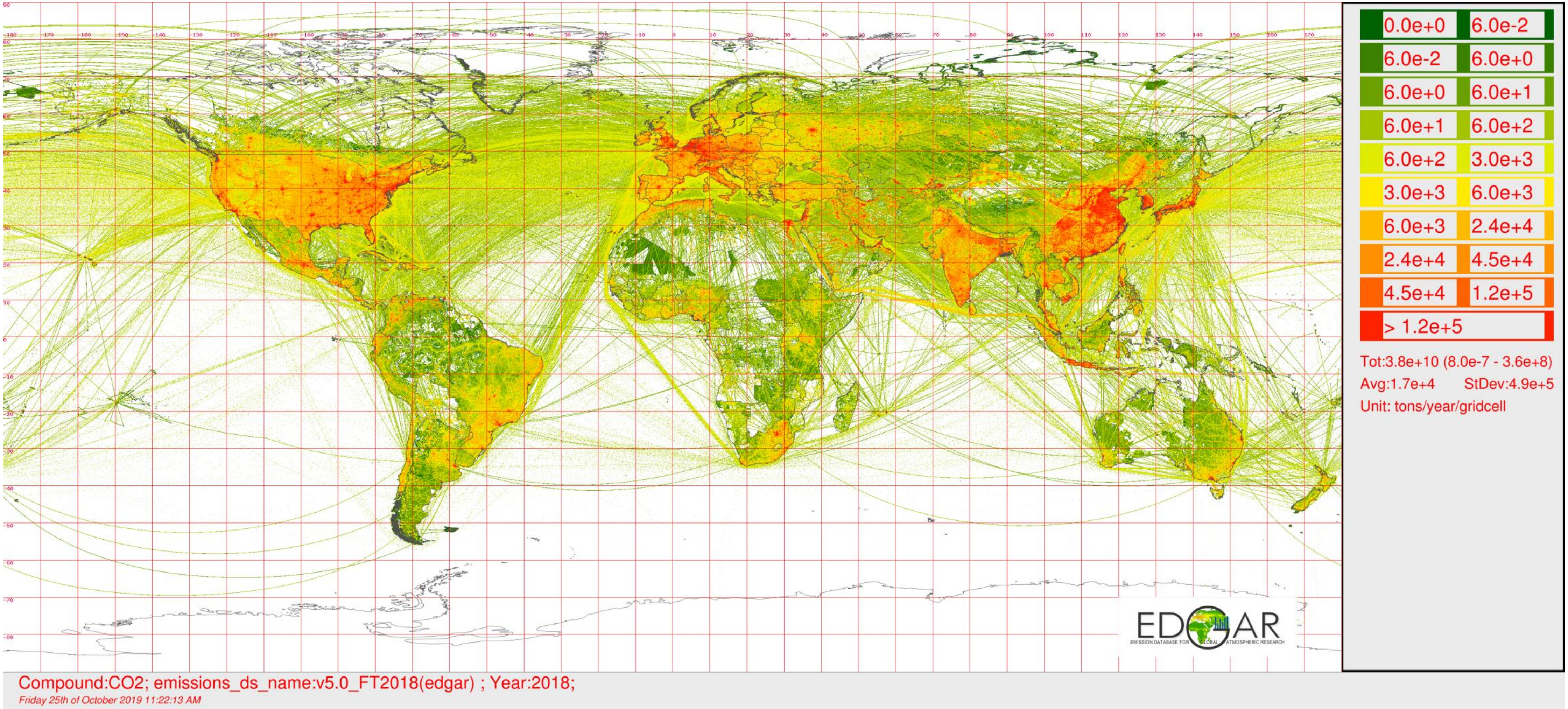
Monitoring CO_2 Fluxes in Cities



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Monitoring CO_2 Fluxes in Cities

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

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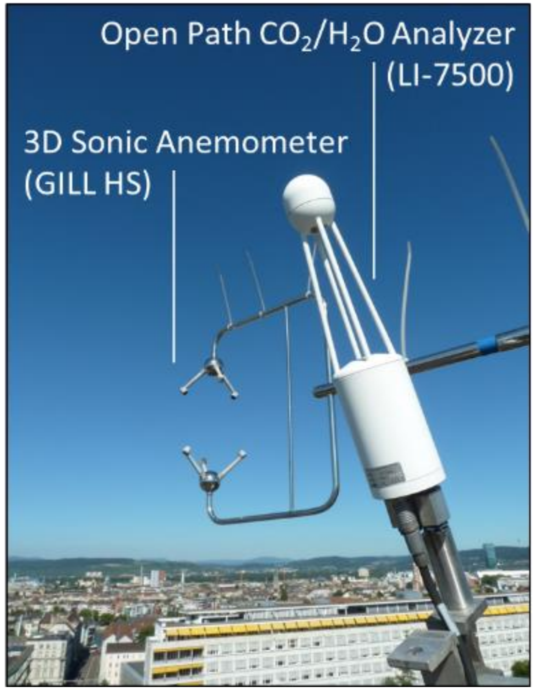
Eddy Covariance

- Direct CO_2 flux (*Fc*) estimations at local scale
- Variable measurement footprint (sources/sinks)



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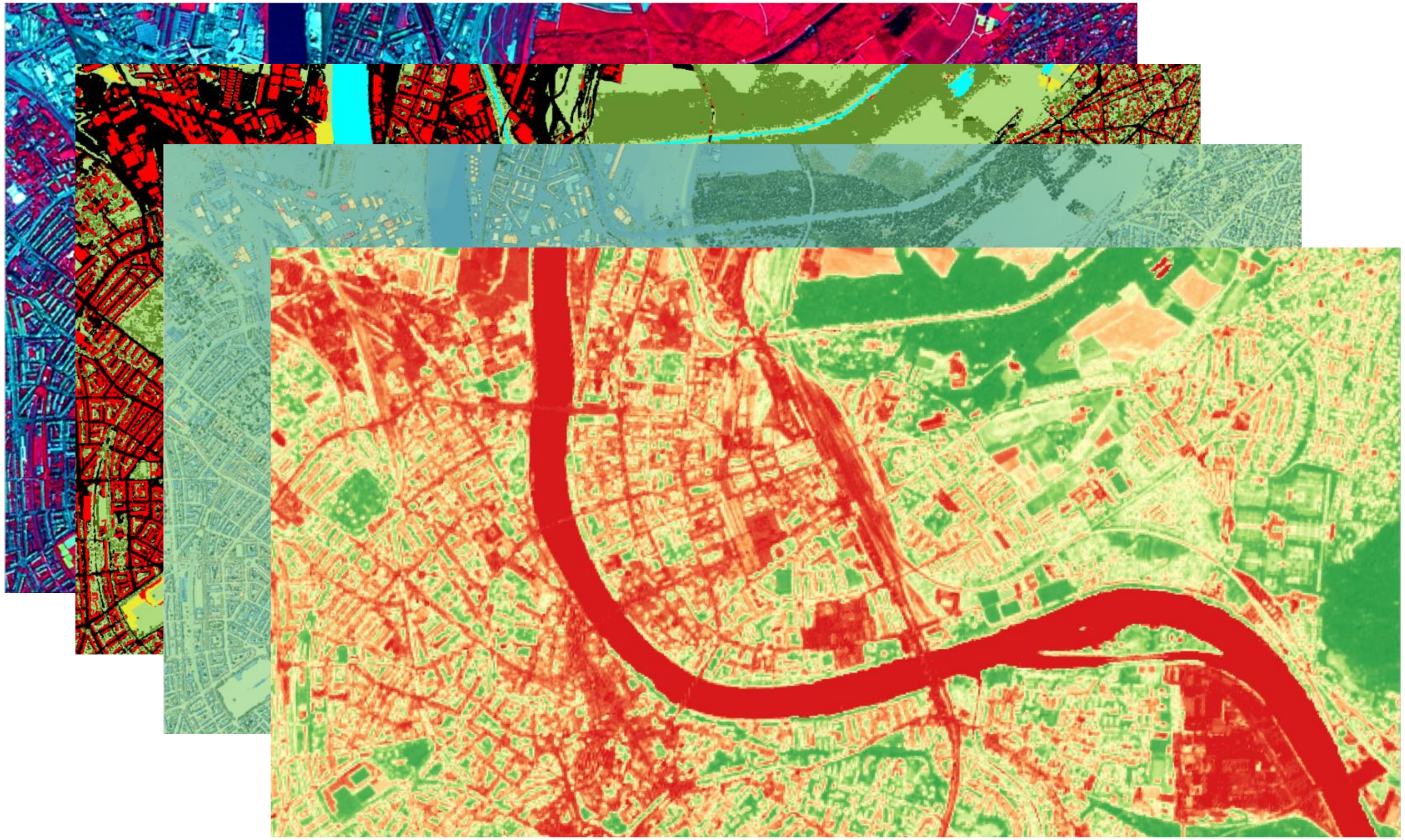
Earth Observation

Current capabilities:

- Urban cover
- Urban morphology
- Biophysical/biochemical parameters

Multiple spatial scales

Trade-off spatial - temporal



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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.

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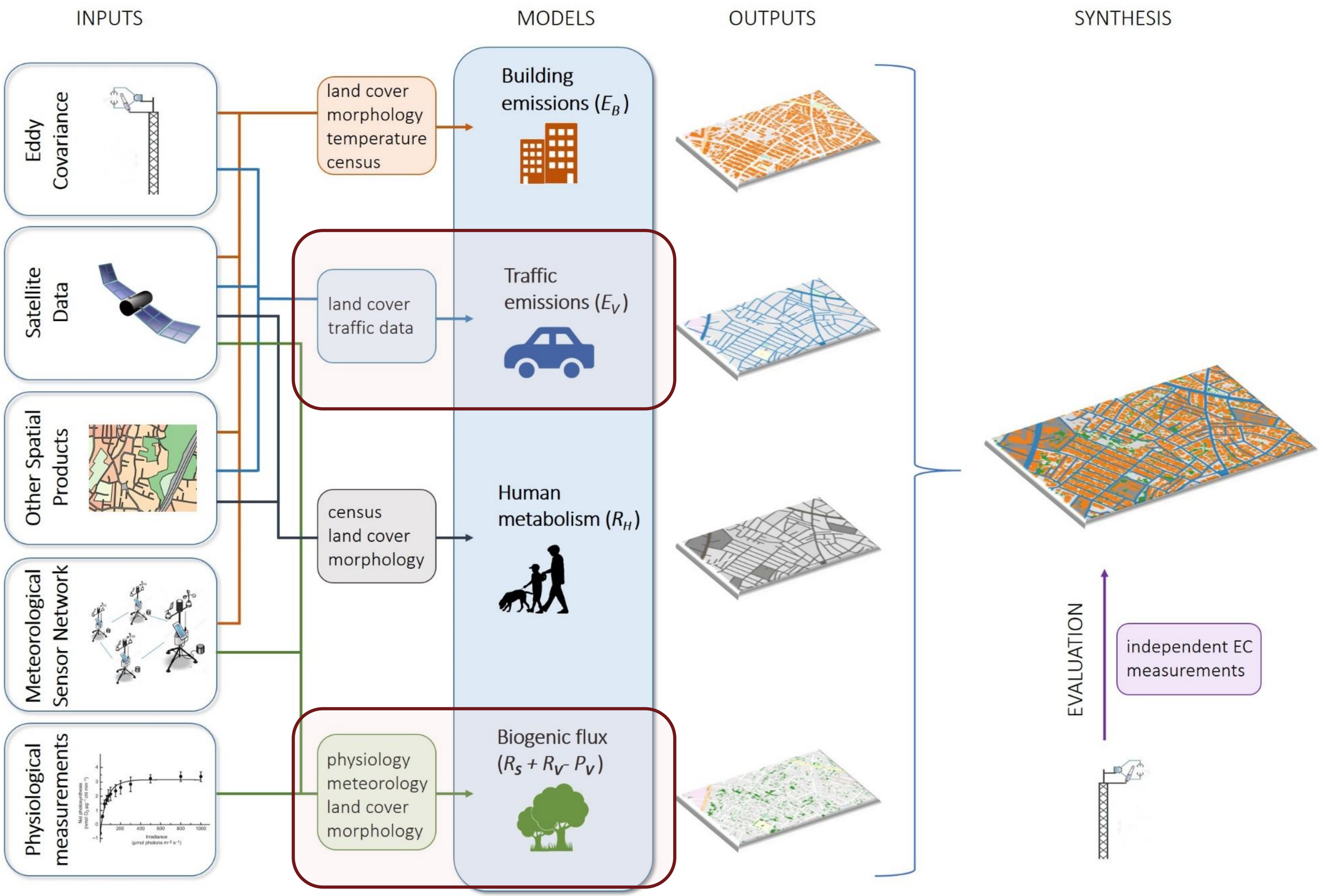
Methodology

Methodology



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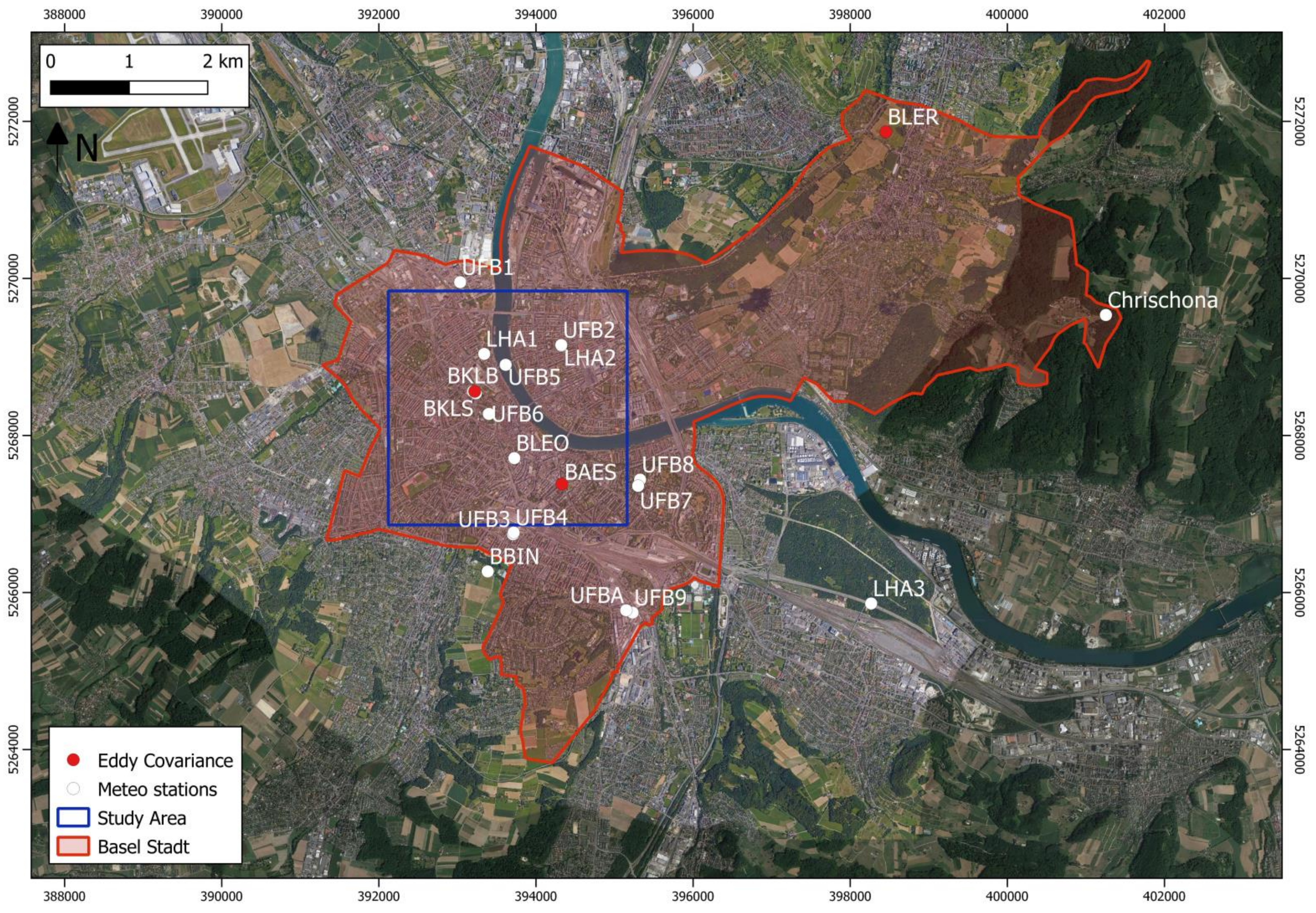
Eddy Covariance

3 Eddy Covariance stations:

- BKLI (urban 15 years)
- BAES (urban 10 years)
- BLER (grassland 8(1) years)

15 meteorological stations

- UCL stations
- Street level stations
- Rural stations



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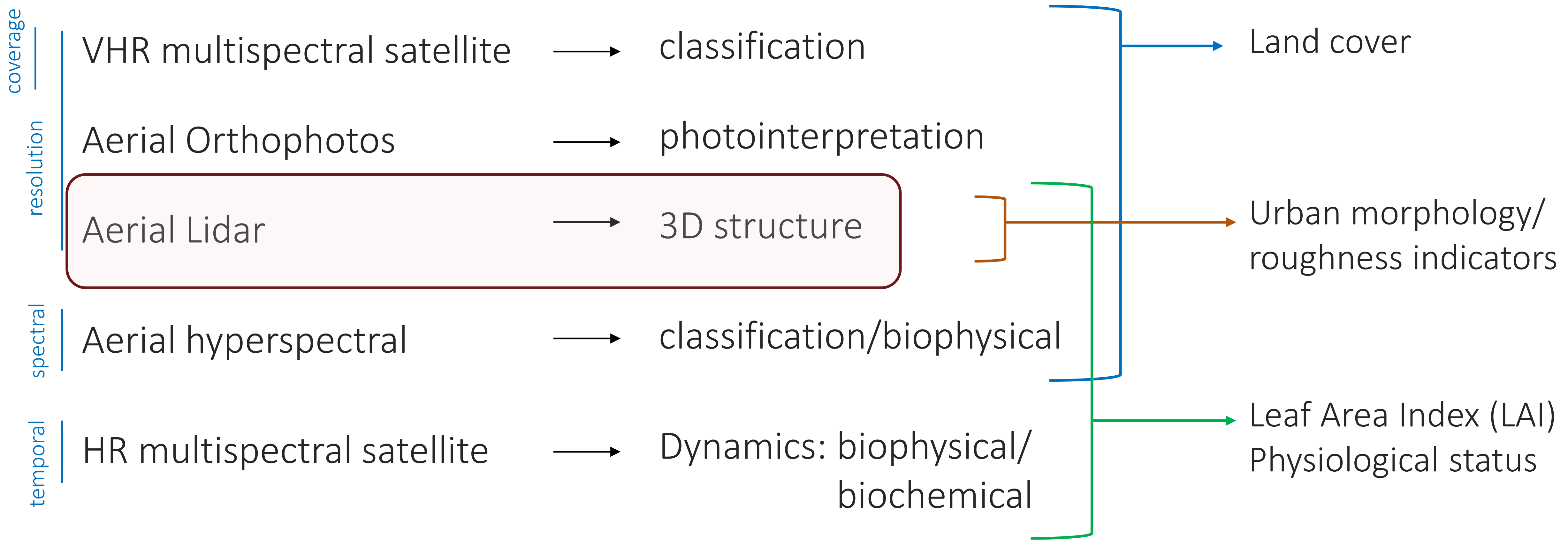
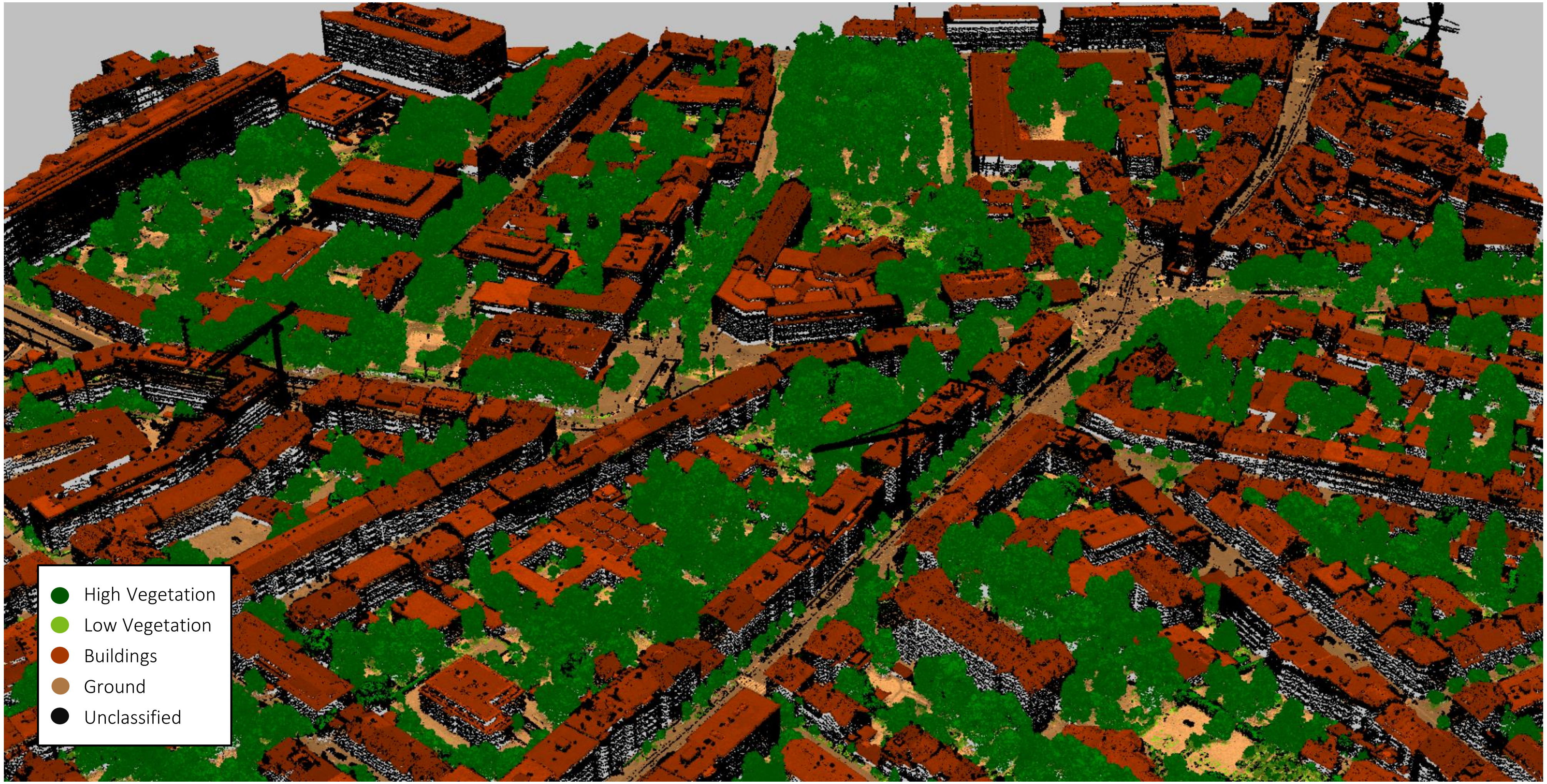
Earth Observation



Aerial LiDAR Data



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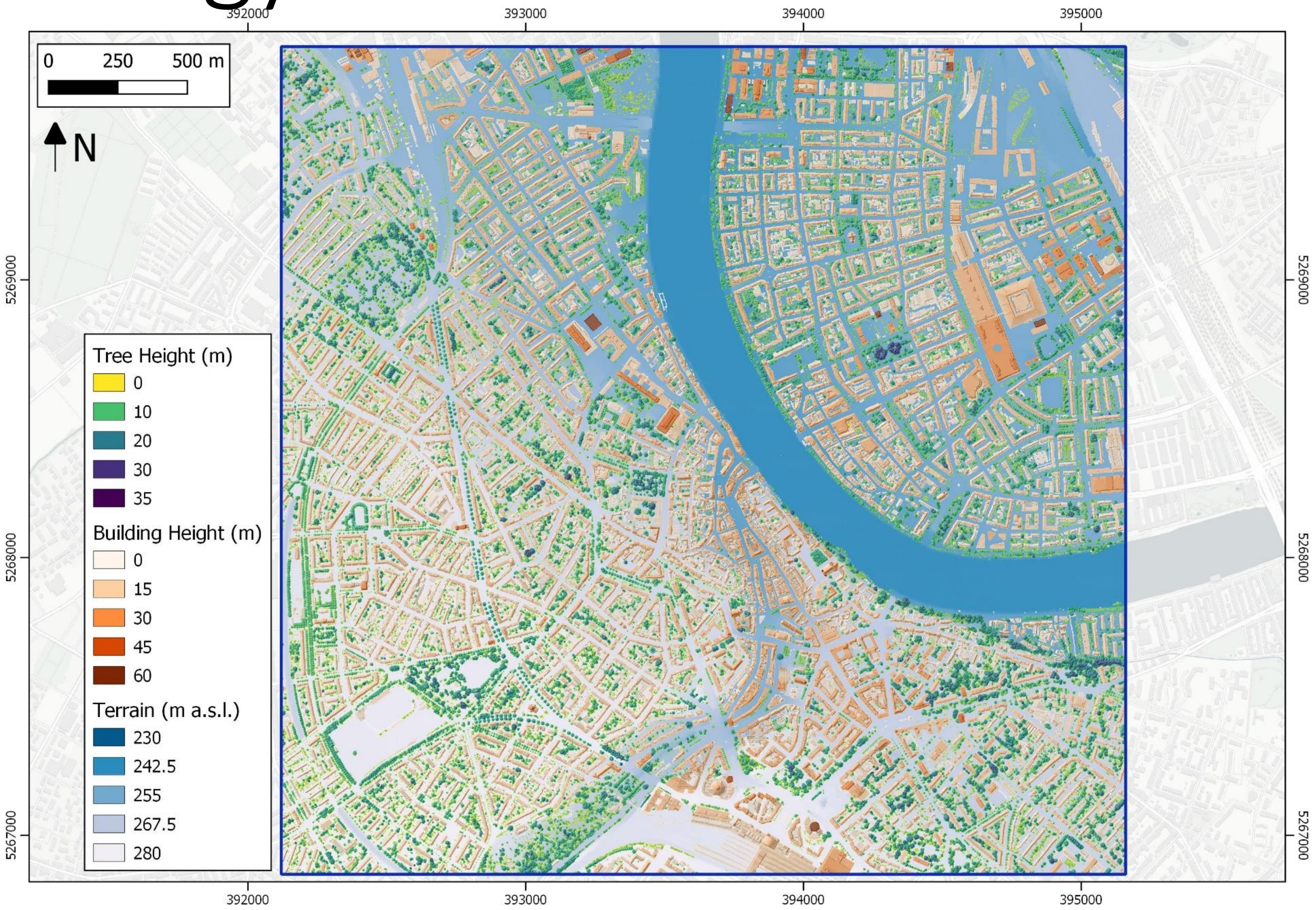
Urban Morphology

- Digital Terrain Model
- Digital Surface Model
  - Building Height
  - Tree Height
- Resolution 1 m



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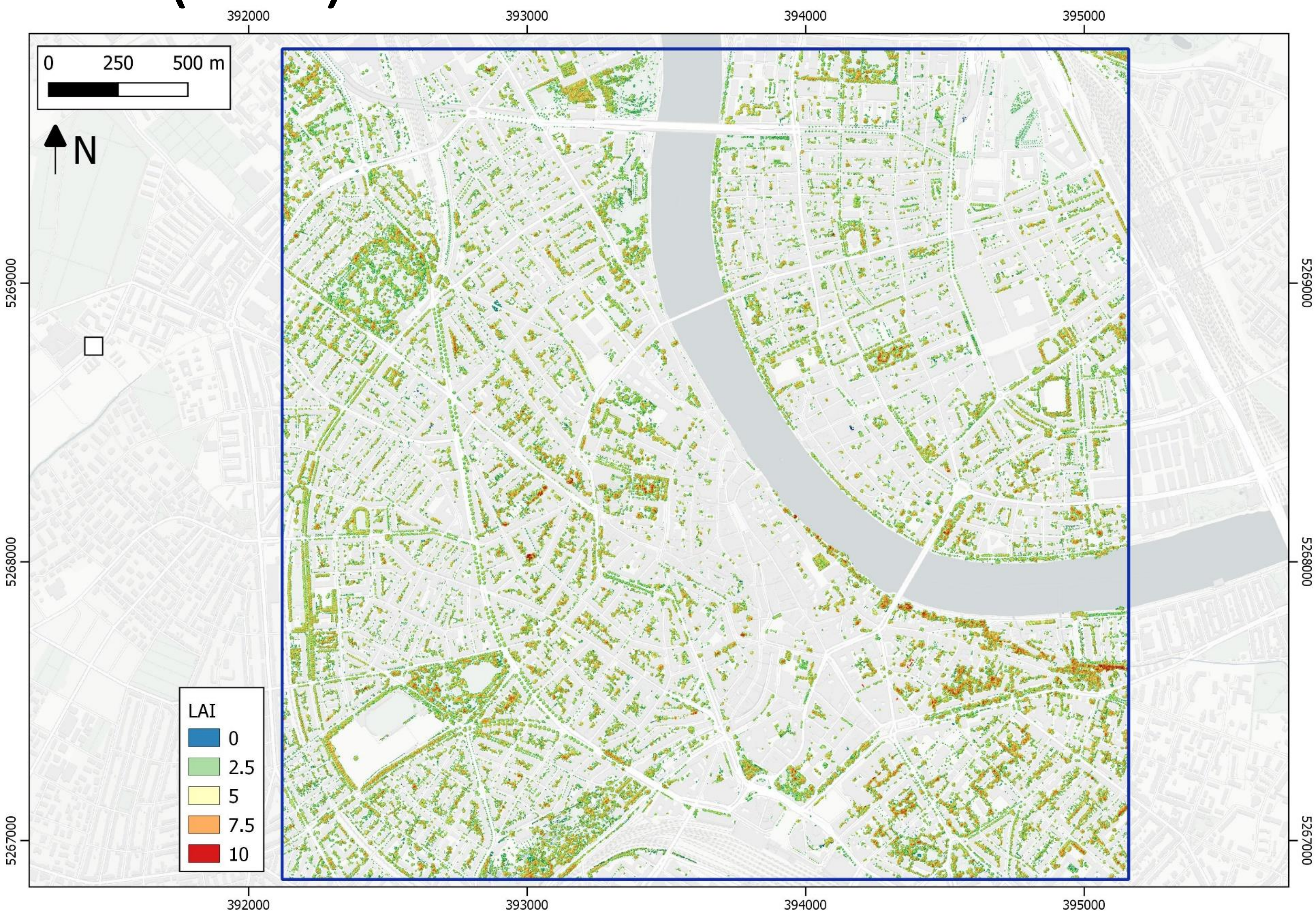
Leaf Area Index (LAI)

- Beer-Lambert law approach for discrete-return LiDAR (Solberg et al. 2006):

$$L_e = -\beta \, ln(R_g/R_t)$$

R_g: ground returns
R_t: total returns
β: constant, set to 2

- Estimated in 1 m resolution



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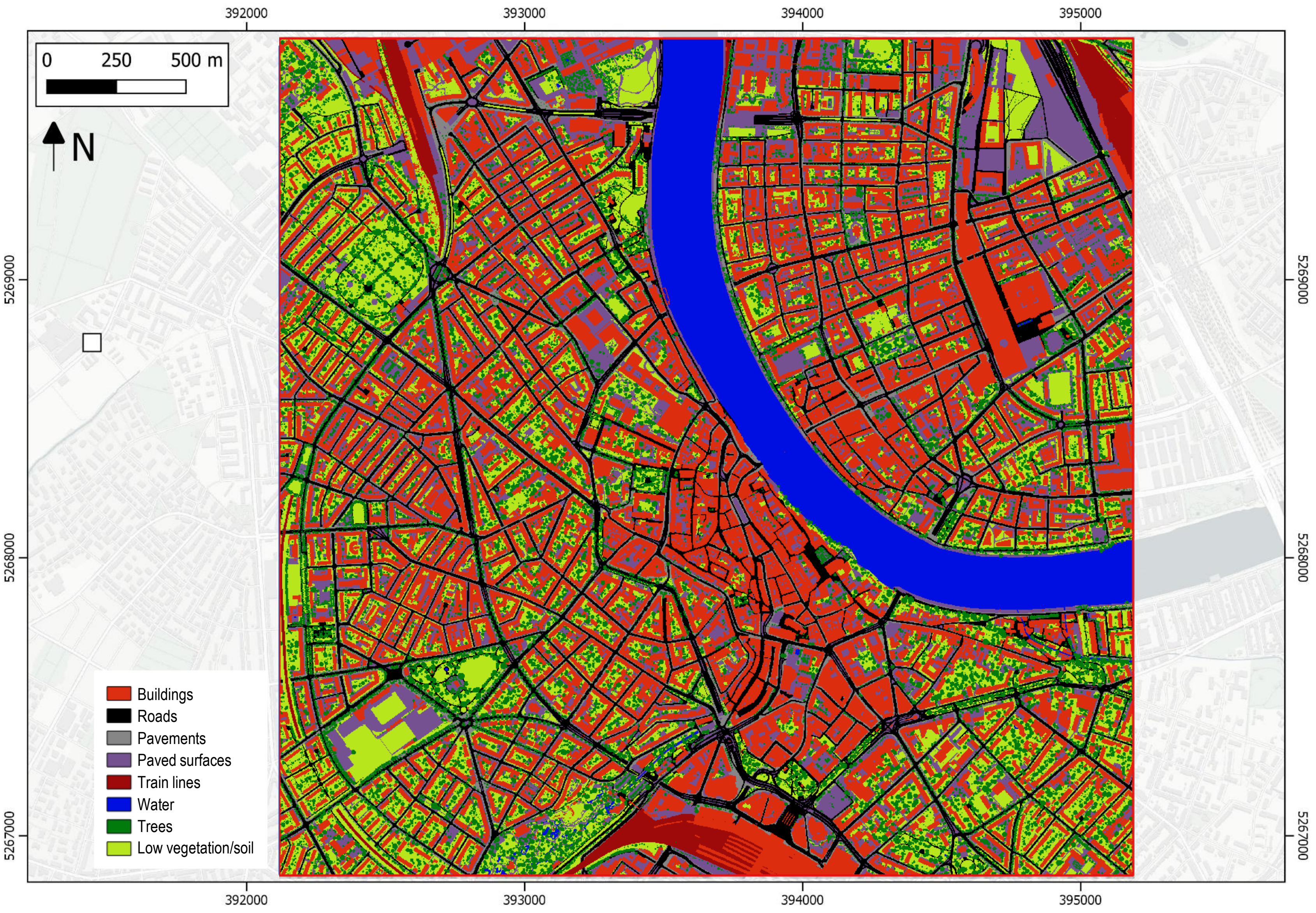
Land Cover

- Official survey of Basel-Stadt (http://www.gva.bs.ch)
- Lidar data

	Study area	BKLI 400 m radius	BAES 400 m radius
Buildings	31.9	38.0	35.8
Paved	21.6	20.8	20.5
Trees	12.2	14.2	15.2
Grass-Soil	22.8	24.4	27.0
Water	6.5	0.1	0.0
Main roads	4.3	4.7	5.3
Tempo 30	6.6	7.1	6.7
Other road	3.4	1.4	1.5



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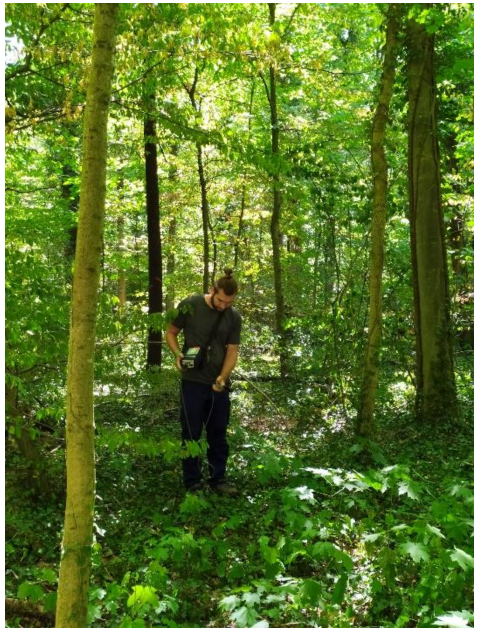
Physiological *in-situ* measurements

- Leaf photosynthesis
  - A_{max}, A-PAR, A-T_{air}
- Leaf respiration
  - R_{leaf}, R-T
- Soil respiration
  - R_{soil}, ϑ, T_{soil}
- Soil Organic Carbon content
- Leaf Area Index (LAI)



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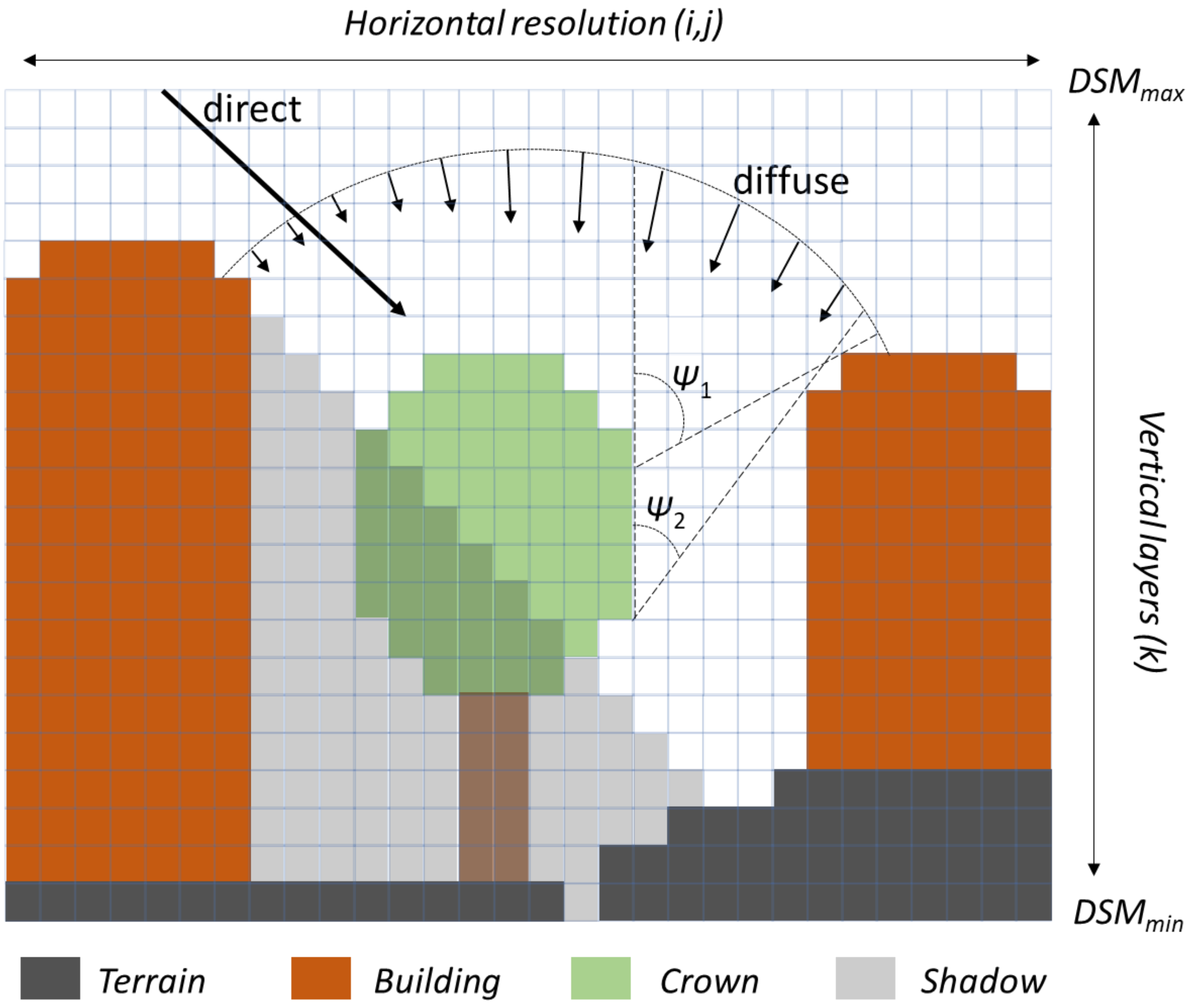
Urban Canopy Photosynthesis Model

- UCL expressed as 3D voxel grid
- Direct radiation modelling according to a ray tracing algorithm (Amanatides & Woo, 1987)
- Diffuse radiation modelling according to Sky View Factors (SVFs) per horizontal level and direction (Lindberg & Grimmond, 2011)
- 30 min step, 5 m resolution (horizontal & vertical)



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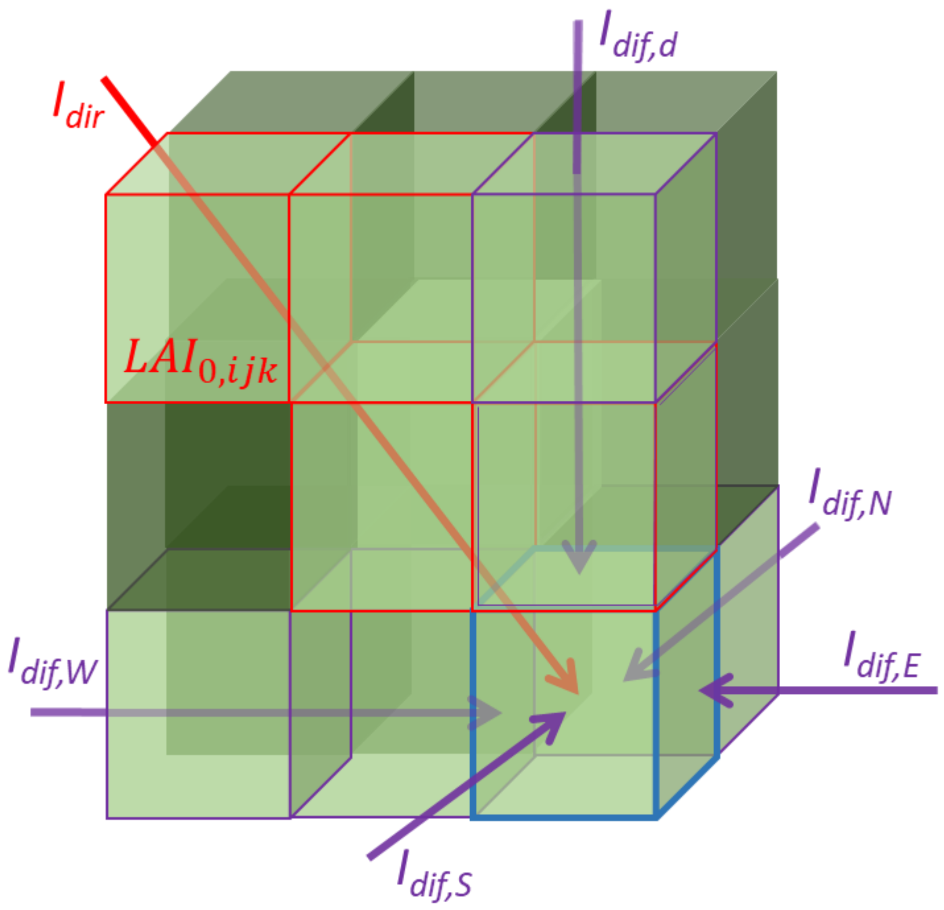
Urban Canopy Photosynthesis Model

- Beer-Lambert law for radiation reduction inside the canopy (Campbell and Norman, 1998)
- Fractions of the sunlit and shaded LAI per voxel

$$LAI_{sun,ijk} = \frac{1}{k_b} * e^{-k_b LAI_{0,ijk}} * \left(1 - e^{-k_b LAI_{ijk}}\right) * Sh_{ijk}$$

- Leaf photosynthesis based on PAR (Ögren and Evans 1993), temperature (June et al. 2004), VPD (Leuning 1995) and θ per voxel
- Canopy photosynthesis: sum of all horizontal layers

$$P_{V,ij} = \sum_{k=1}^{n} (A_{gross,I_{sun},ijk} * LAI_{sun,ijk} + A_{gross,I_{shade},ijk} * LAI_{shade,ijk})$$



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Results

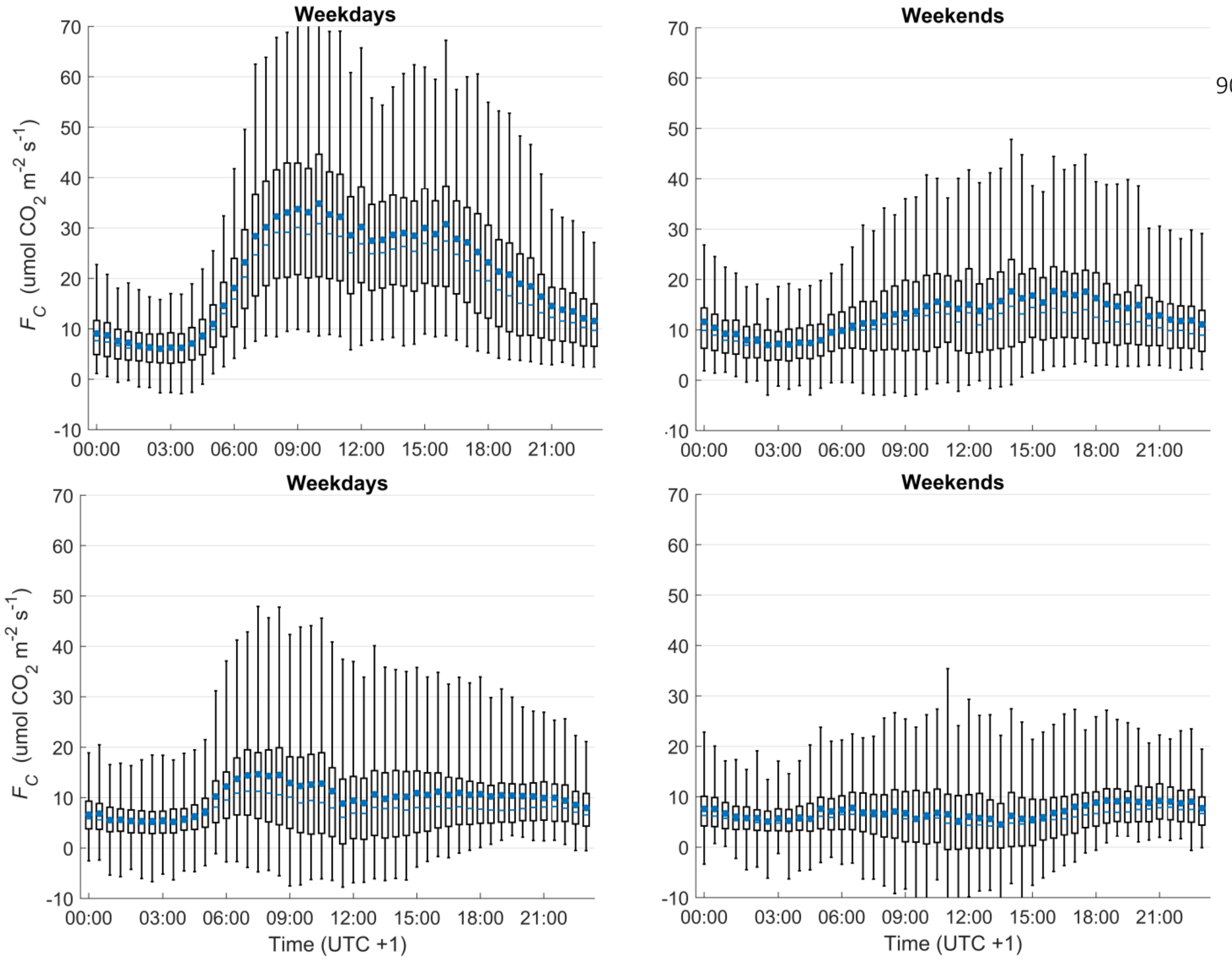
Anthopogenic fluxes

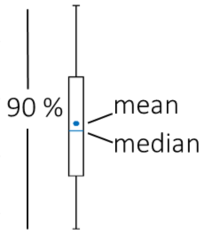
Eddy Covariance

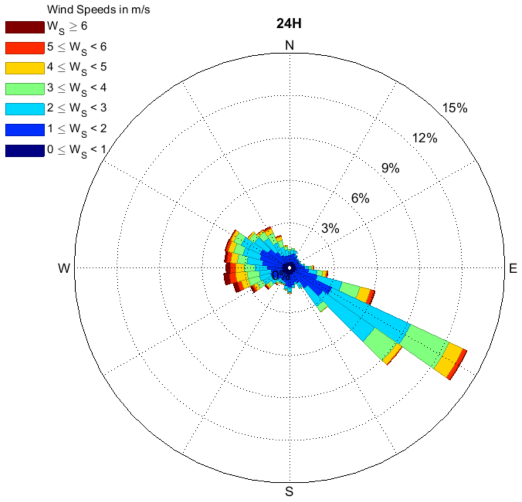
BKLI station (15 years)

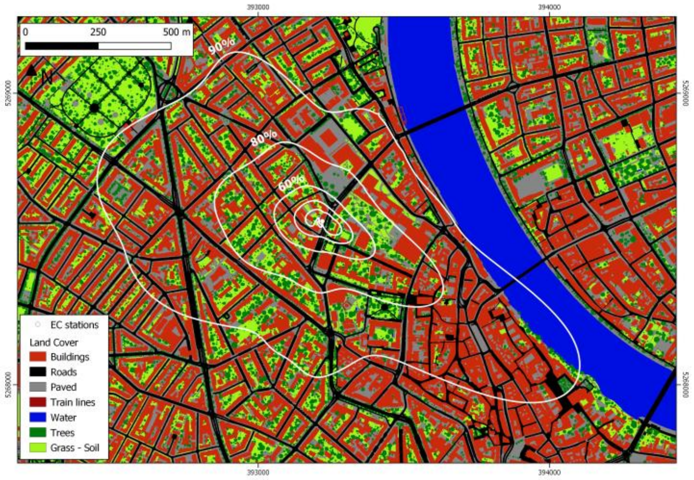
East

West









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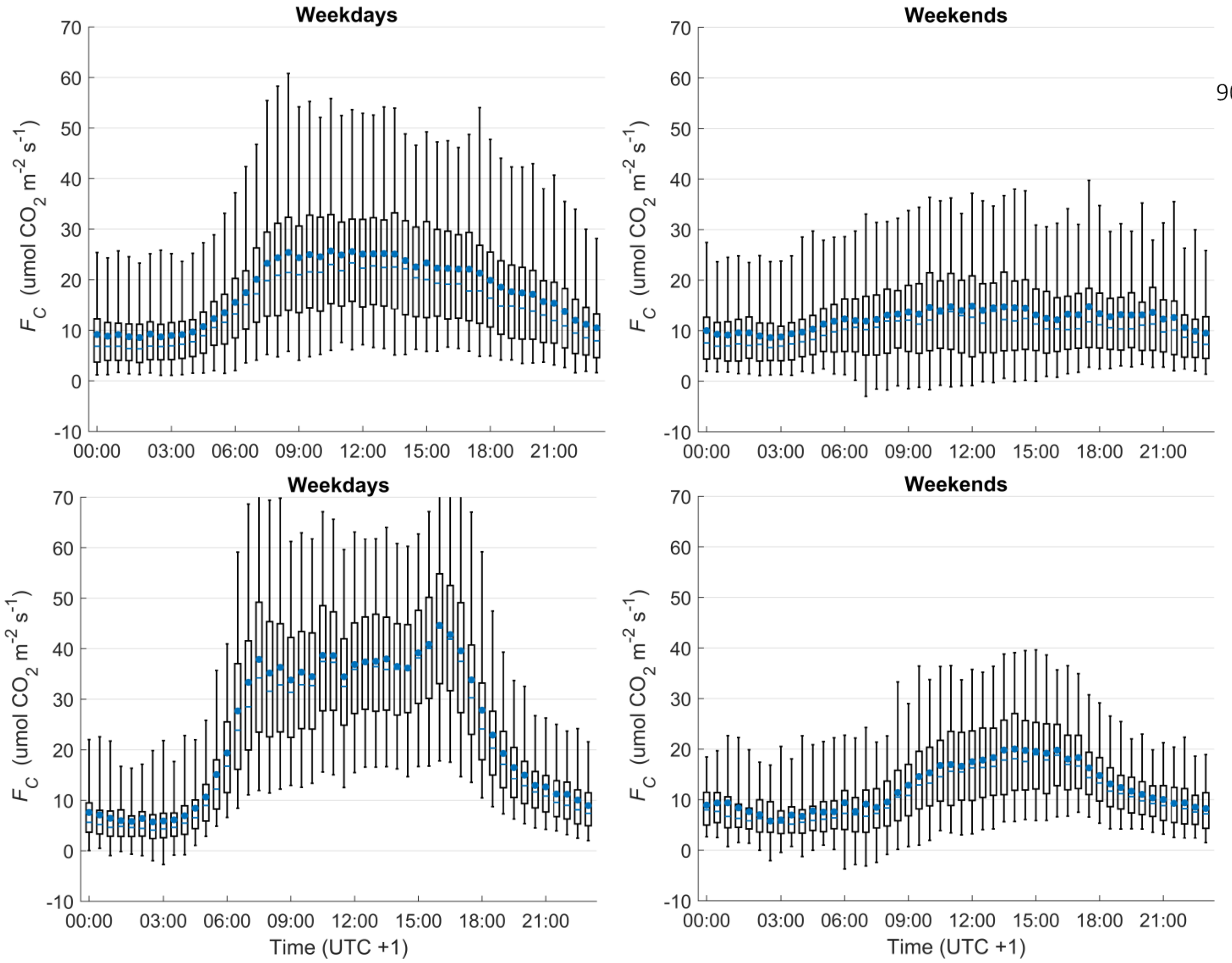
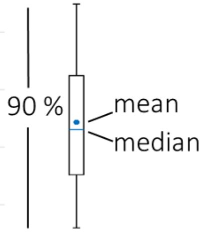
Eddy Covariance

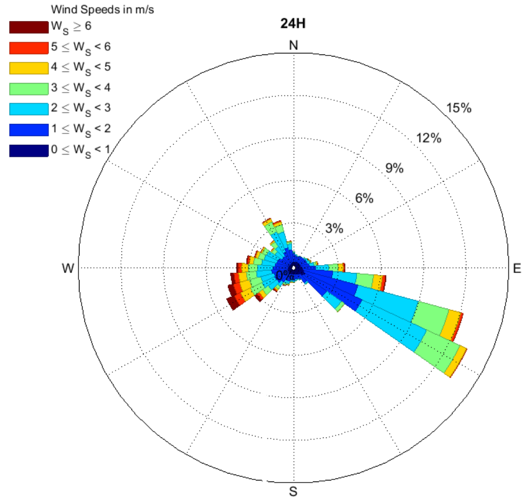
BAES station (10 years)

East

West







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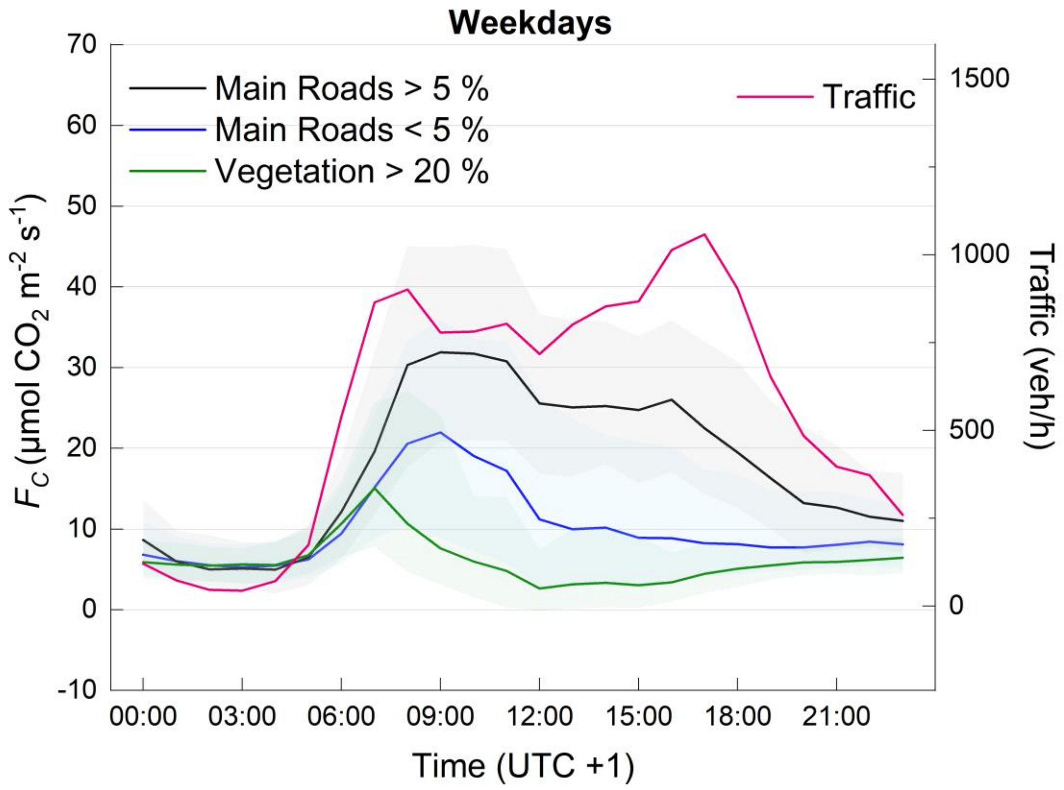
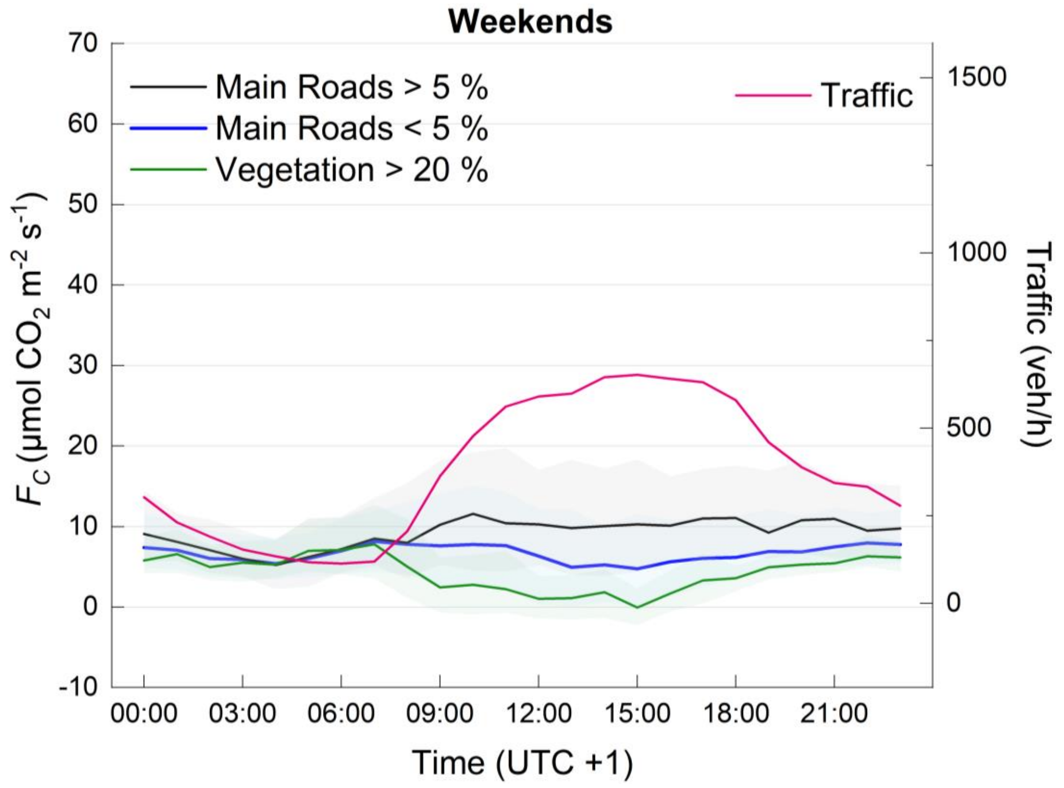
Eddy Covariance – Land Cover

BKLI station





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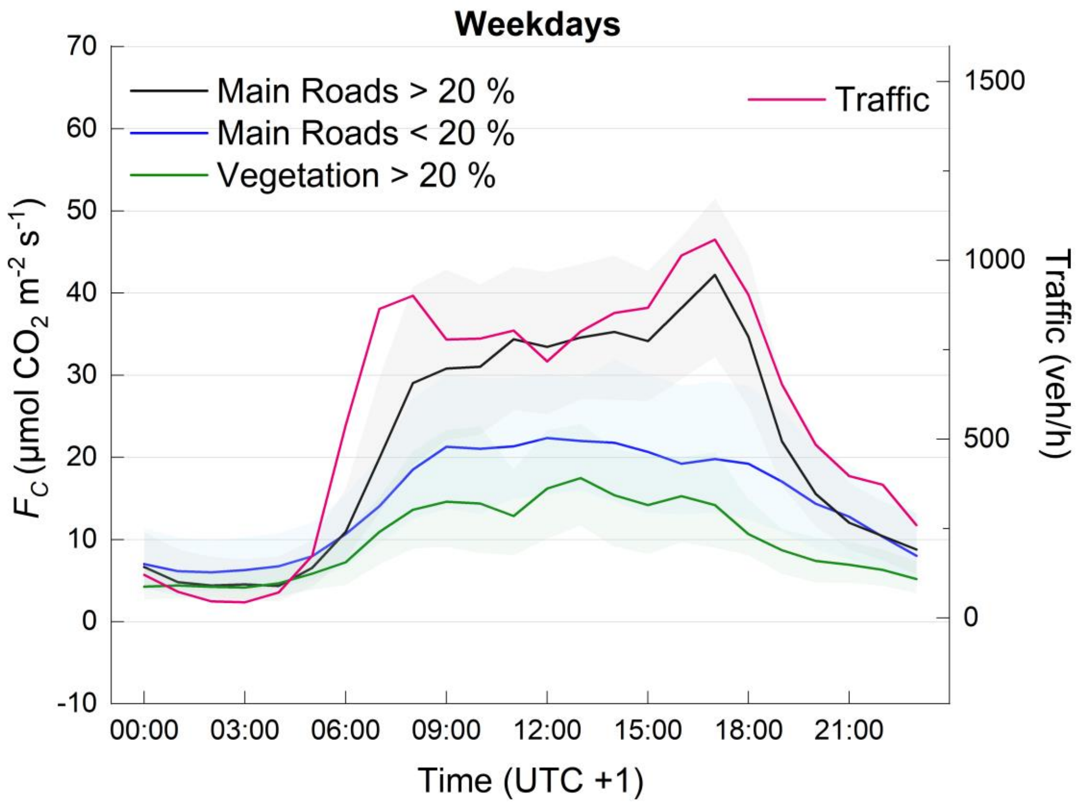
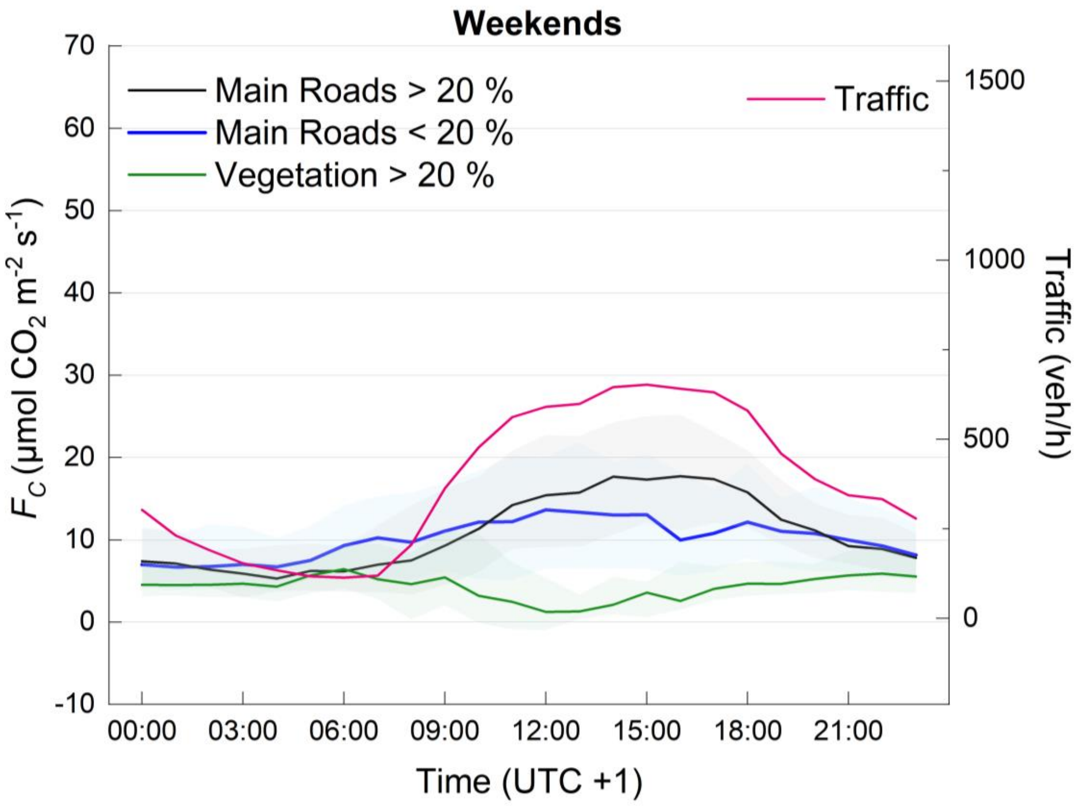
Eddy Covariance – Land Cover

BAES station





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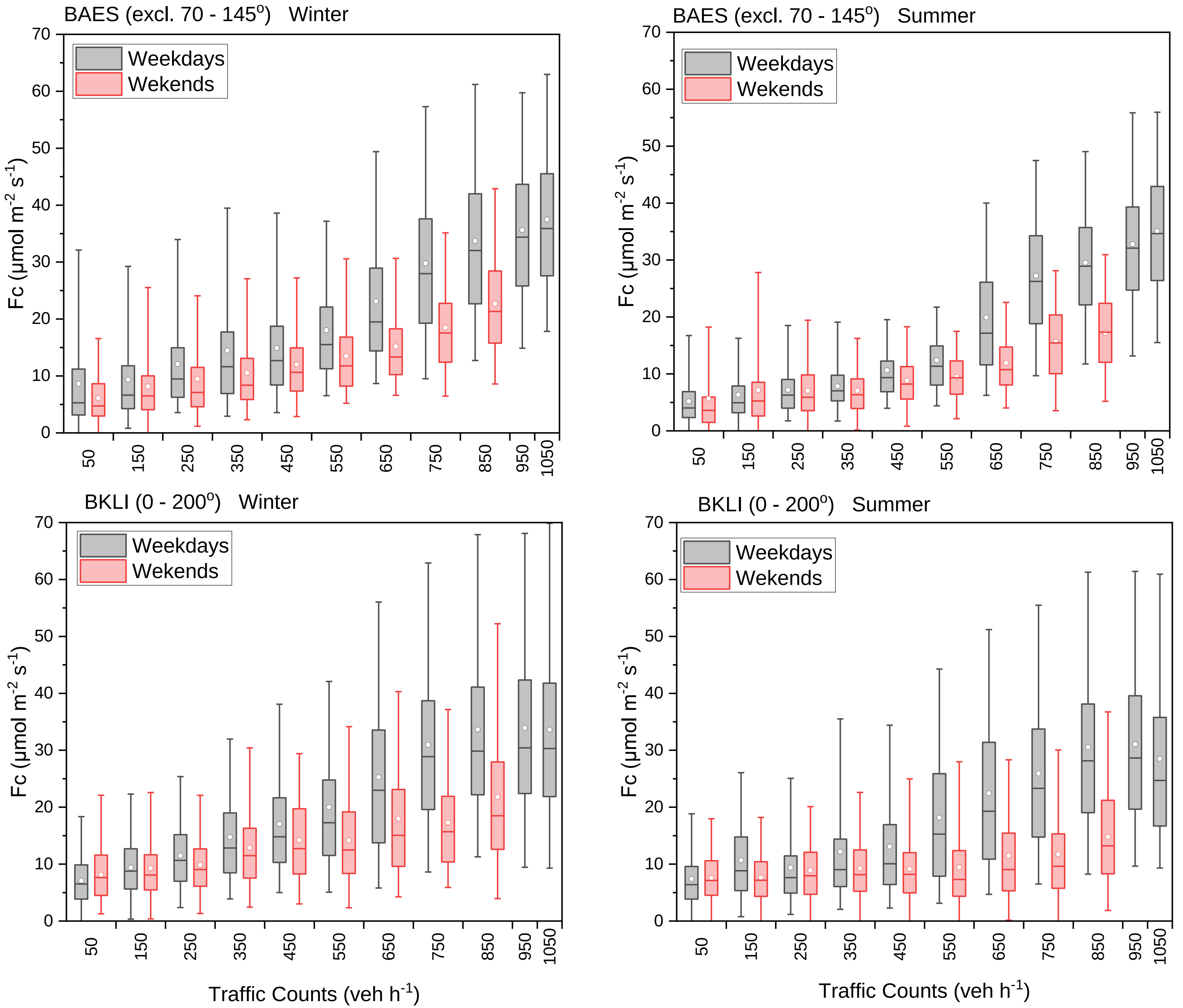
Eddy Covariance - Traffic

Different trends for weekdays – weekends indicate that traffic counts are not enough to explain Fc variability

The correlations are more clear in BAES due to the higher road fraction in Fc footprint

The winter space heating effect is clearer in BAES

Traffic counts have significant effect on Fc over 350 – 450 veh h^{-1} (clearer for BAES)



Results

Biogenic fluxes

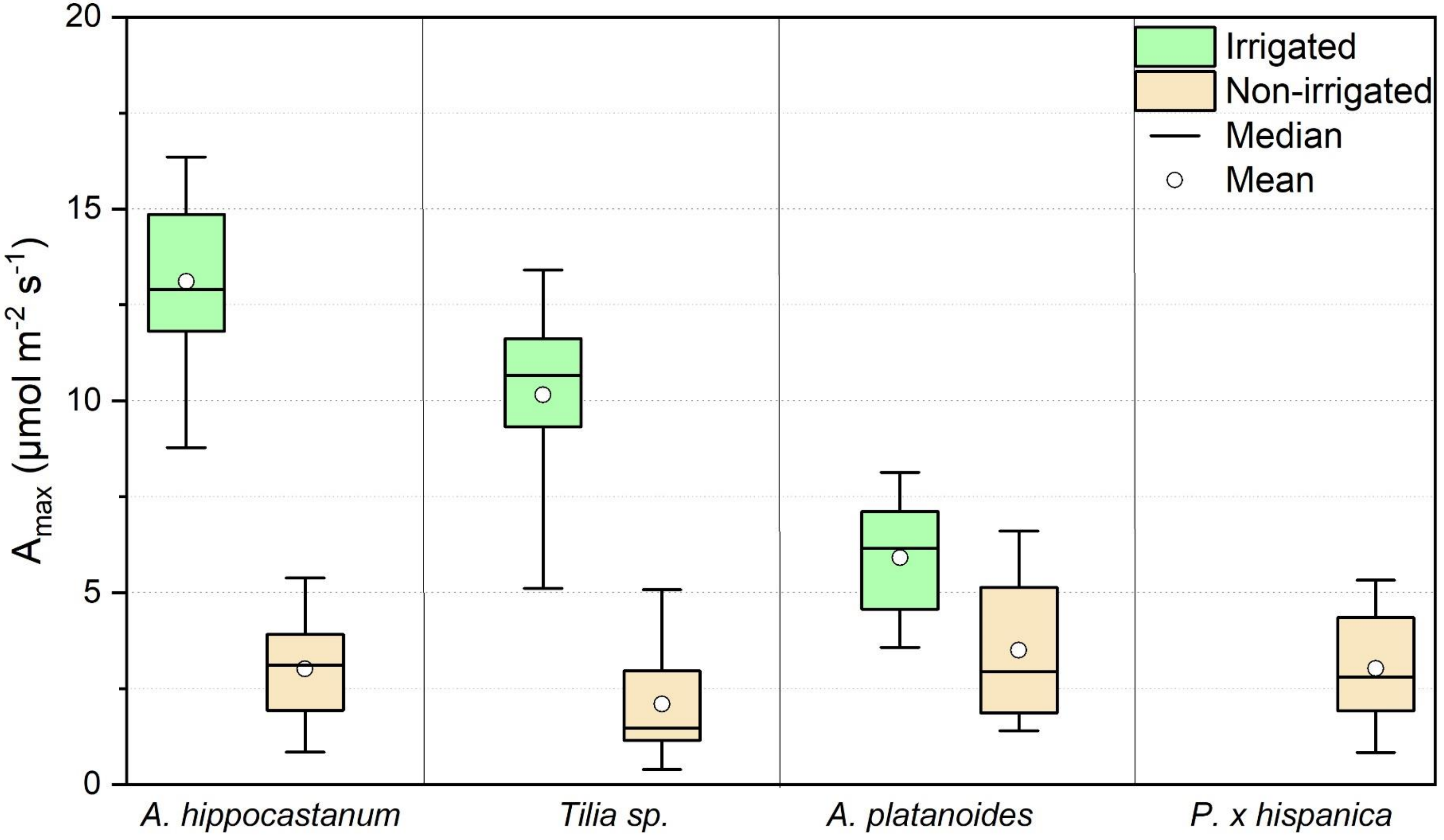
Field measurements

Extreme variability in photosynthetic rates between irrigated and non-irrigated areas and across trees - species

Higher A_{max} during morning measurements (lower temperature, water saving strategies)

Only parks are regularly irrigated, street trees are probably constantly under water limiting conditions

Lift campaign 23 – 25 July 2020



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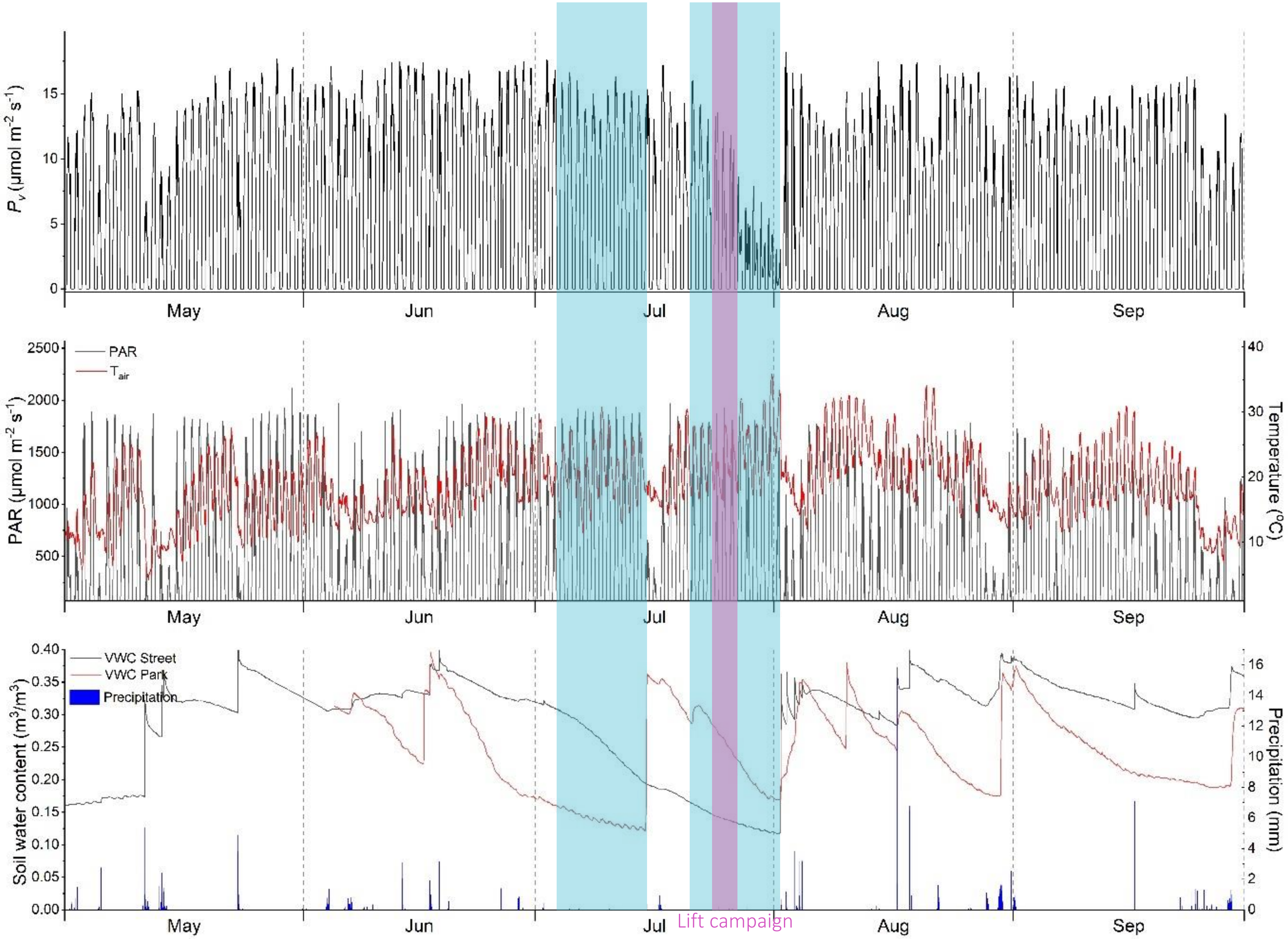
Photosynthesis model



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Canopy Photosynthesis model

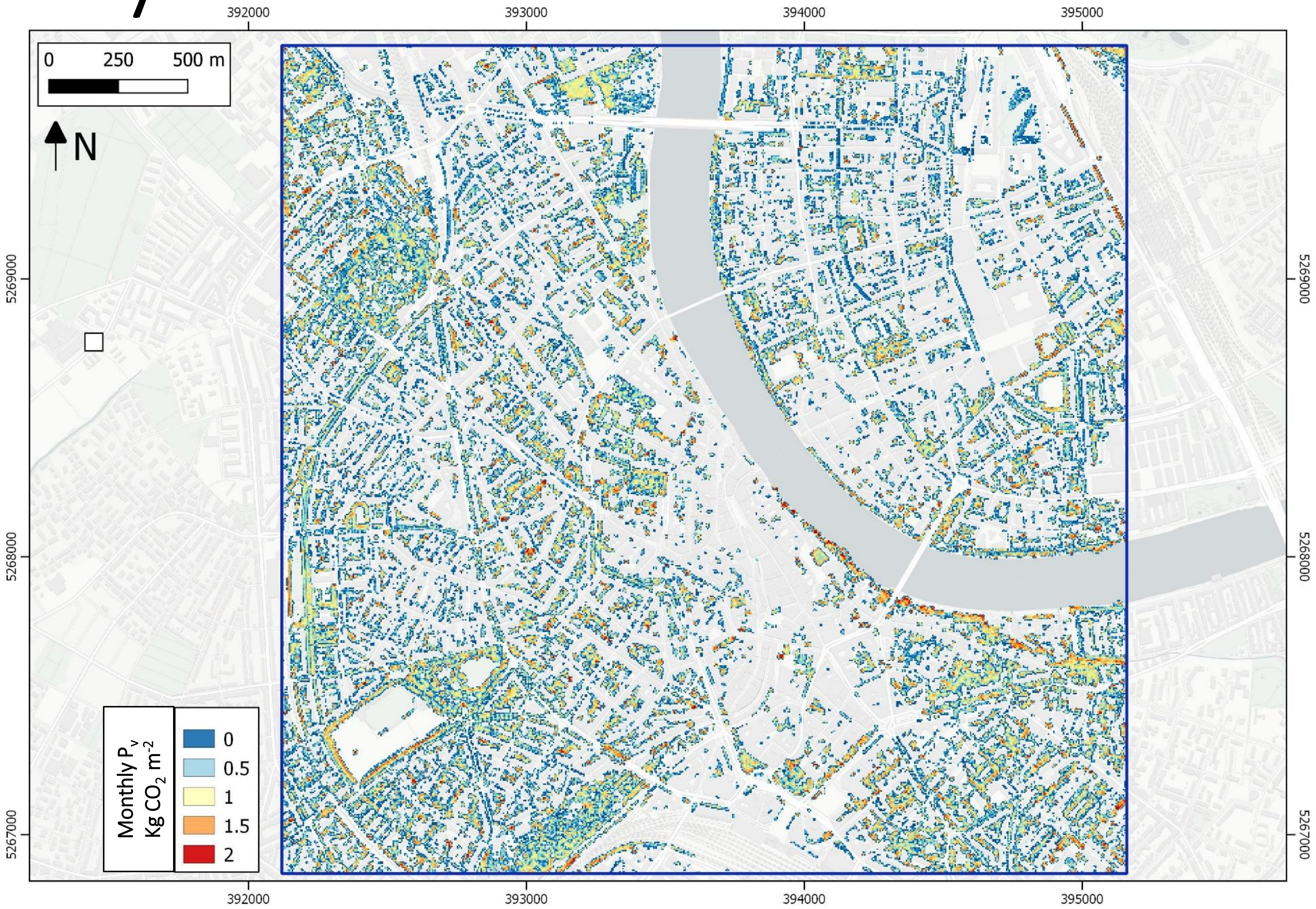
Open areas seem more productive

Mean monthly gross sequestration:

- 0.55 kg CO_2 m^{-2}

Balance in BKLI:

1.28 kg CO_2 m^{-2}



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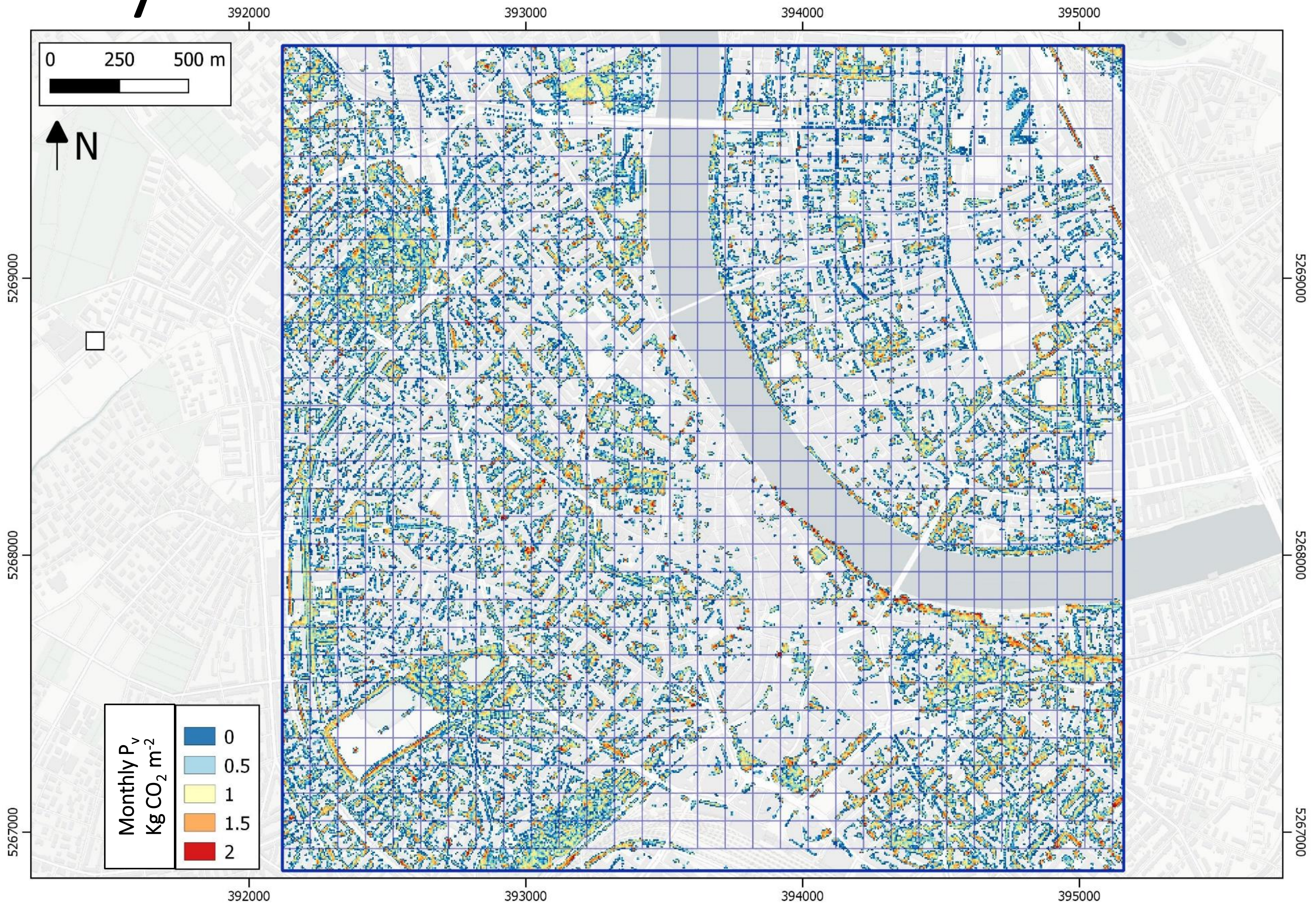

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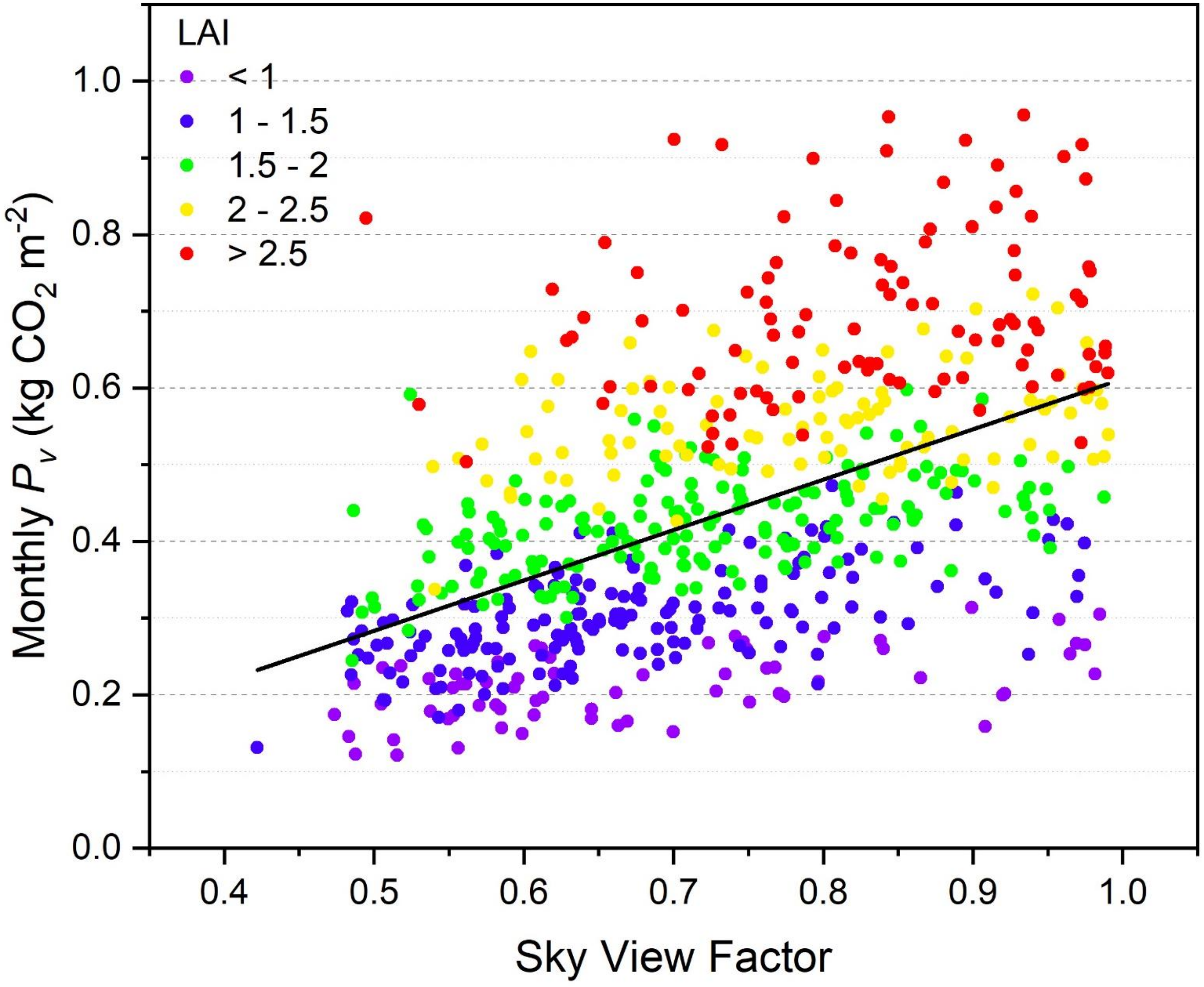
Canopy Photosynthesis model

100 m grid spatial analysis

P_v spatial variability is related to LAI and Sky View Factor

Urban morphology suppresses carbon sequestration by reducing light availability to plant canopies



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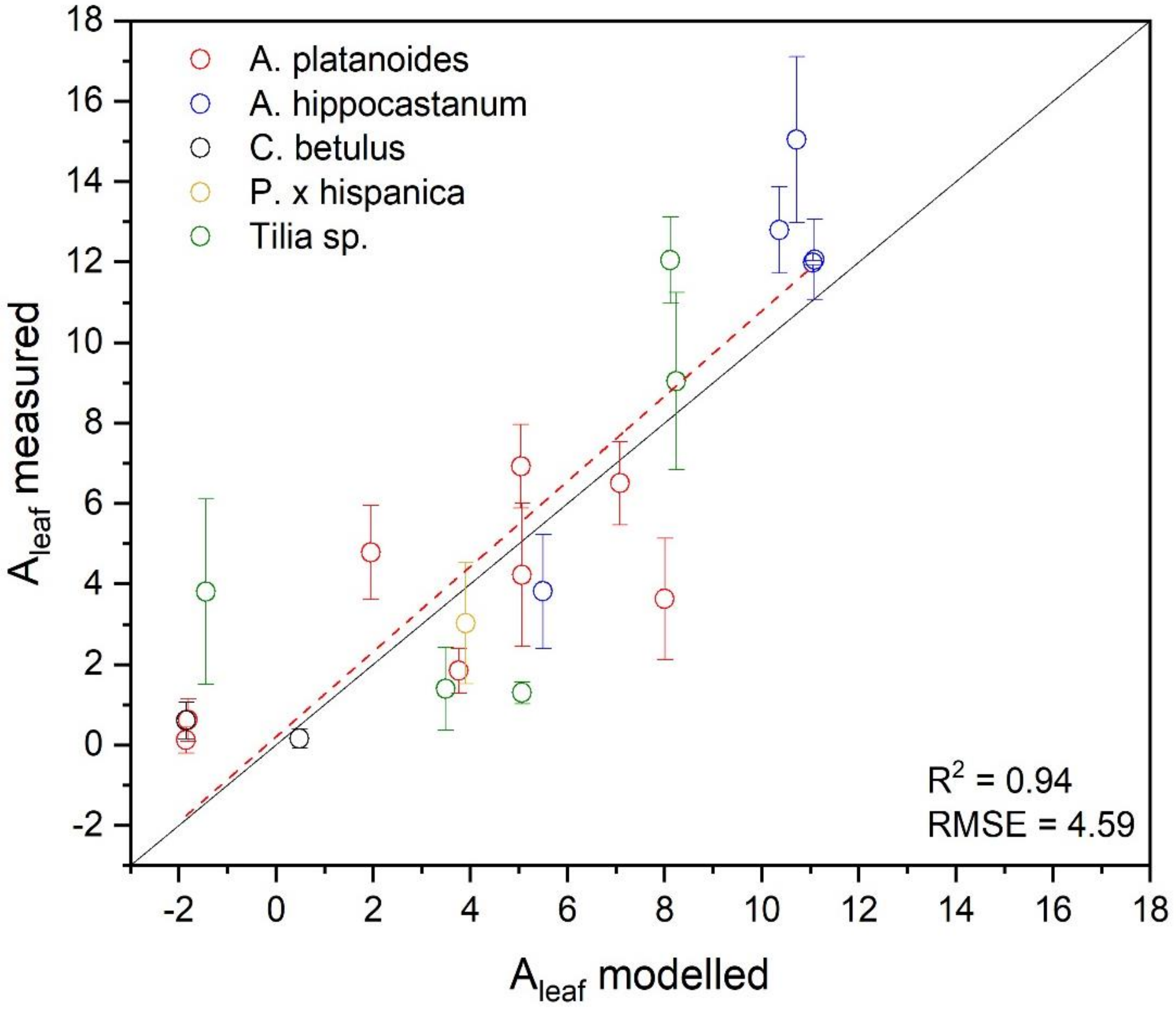
Leaf level model evaluation

Evaluation at leaf scale for all measurements of the lift campaign (23 – 25 July 2020)

Model run on T_{air} and VPD observed by the BKLI station during the lift measurements and ϑ was measured at soil surface near the root of each tree (soil surface)

Canopy scale evaluation planned for next year



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Conclusions

anthropogenic

- Vehicle traffic emissions is a significant controlling factor of F_C at both urban Basel sites and also the reason of the higher emissions measured in BAES station.
- Correlations between F_C and traffic counts are not straight-forward since other sources/sinks are always present.
- Traffic congestion may be more related to F_C than vehicle counts.

biogenic

- Photosynthetic rates (A_{max}) are extremely variable according to irrigation management at least during drought periods.
- Street trees are highly vulnerable to water stress.
- Carbon sequestration during drought conditions can be significantly reduced.
- Photosynthesis can potentially offset urban emissions up to 30 % during summer months.
- Sky view factor is an important urban attribute affecting canopy photosynthesis.

Next Steps

anthropogenic

- Investigation of clear relationships between traffic measurements and EC-measured F_C
- Determine the building heating emissions during winter according to air temperature, building volume and building type
- Modelling of emissions from human metabolism

biogenic

- Tree species classification using hyperspectral aerial imagery – Species-specific A_{max}
- LAI temporal variability according to Sentinel-2 imagery
- Include understorey vegetation and grasses in the biogenic models
- Model evaluation with Eddy Covariance (temporary installation) in an urban green area (summer 2021)

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Acknowledgements

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Thank you for your attention!

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