Energy and gas exchange in urban areas – Experience from Helsinki

Training course/workshop on

EddyUH: a software for eddy covariance flux calculations

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Outline

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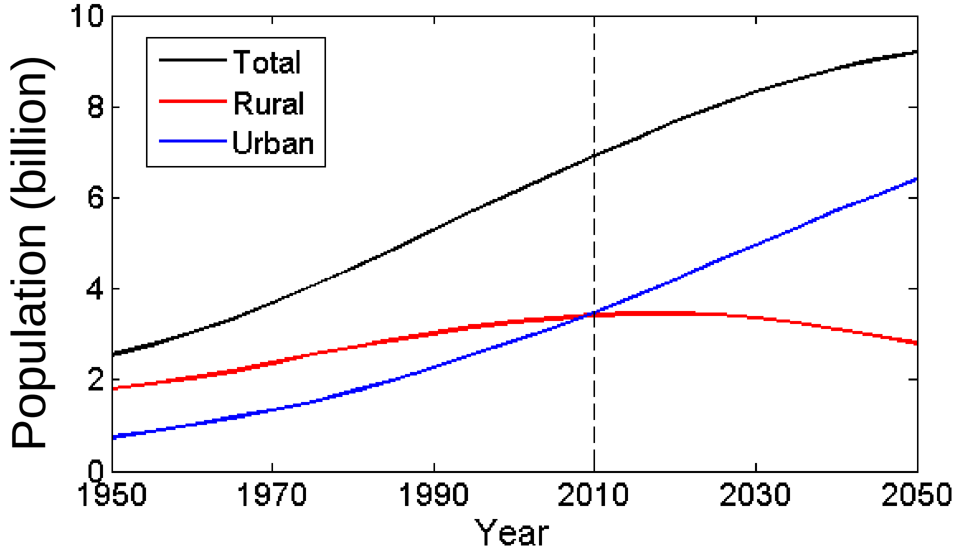
2. Differences between urban and non-urban EC measurements
3. Urban energy, water and CO_2 budgets
4. Urban heat island
5. Urban EC measurements in Helsinki
6. EddyUH URBAN

1. Introduction

Urban areas are challenging for EC measurements

BUT their importance drives the increasing number of measurements

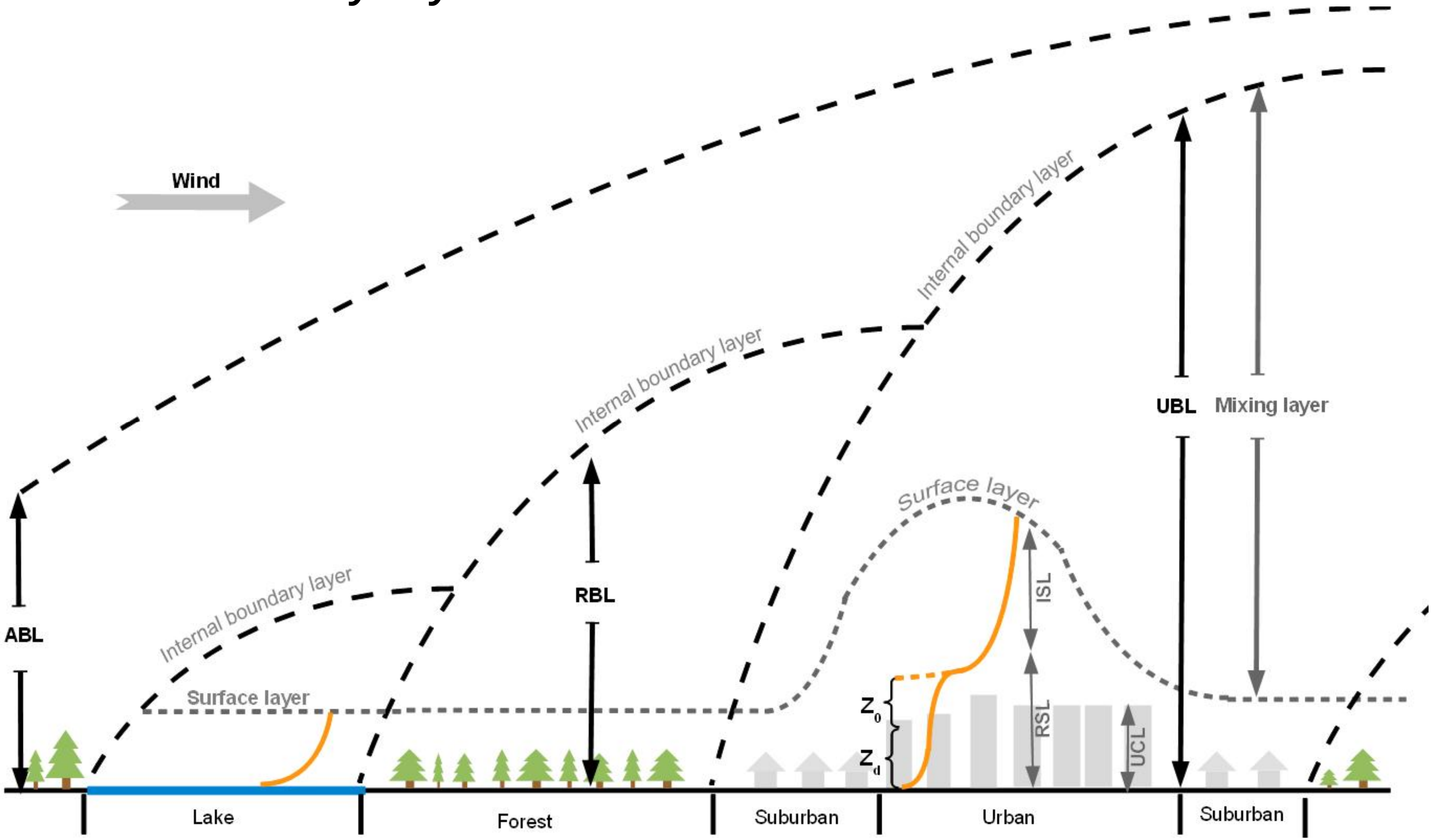


Urban EC measurement sites

- 28 active sites
- cover 22 cities
- Europe and North-America covered well

(Urban flux network, Jan 2013)

Urban boundary layer



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ABL – atmospheric boundary layer, RBL – rural BL, UBL– urban BL,
ISL– inertial sublayer, RSL– roughness sublayer, UCL– urban canopy layer

2. Differences between urban and non-urban EC measurements

1) Mounting of instruments more difficult
    - above roughness sublayer (RSL) but within surface layer
    - flow distortion due to surrounding buildings and tower structure
    - point sources vs. local scale sources (below)

304 S. Kotthaus, C.S.B. Grimmond / Atmospheric Environment 57 (2012) 301–316

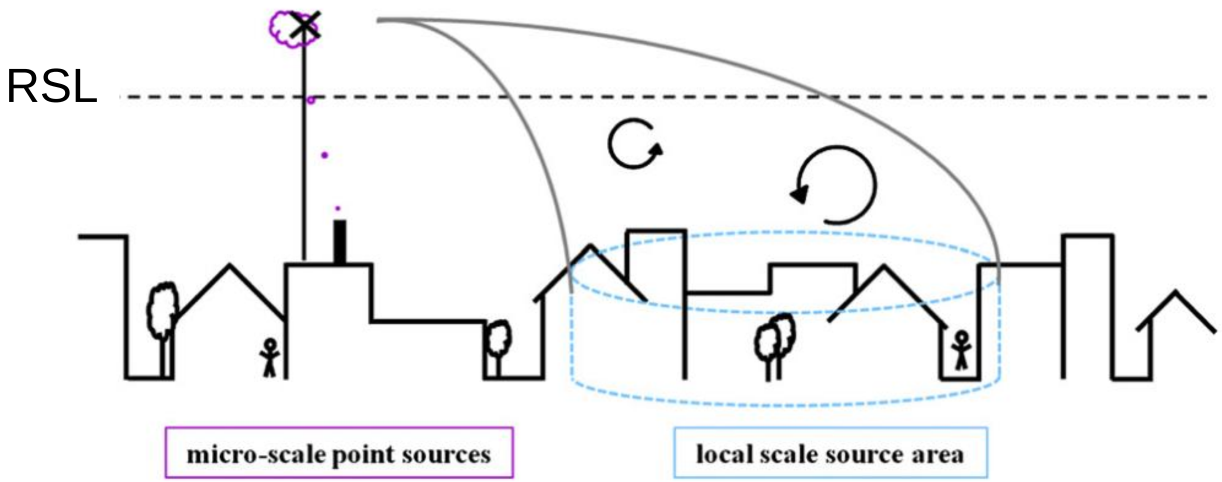


Fig. 2. Schematic of urban canopy indicating local scale source area and micro-scale point source influencing eddy covariance measurements above blending height z_r.

2) Increased surface roughness

- momentum transport stronger
- z_0 and z_d can be calculated from building dimensions

3) Anthropogenic emissions: sensible and latent heat, CO_2, particles...

4) Different surface covers

- impervious surfaces (paved) → less evaporation → more sensible heat
- less vegetation → less CO_2 uptake
- generally very heterogeneous → footprint models do not work

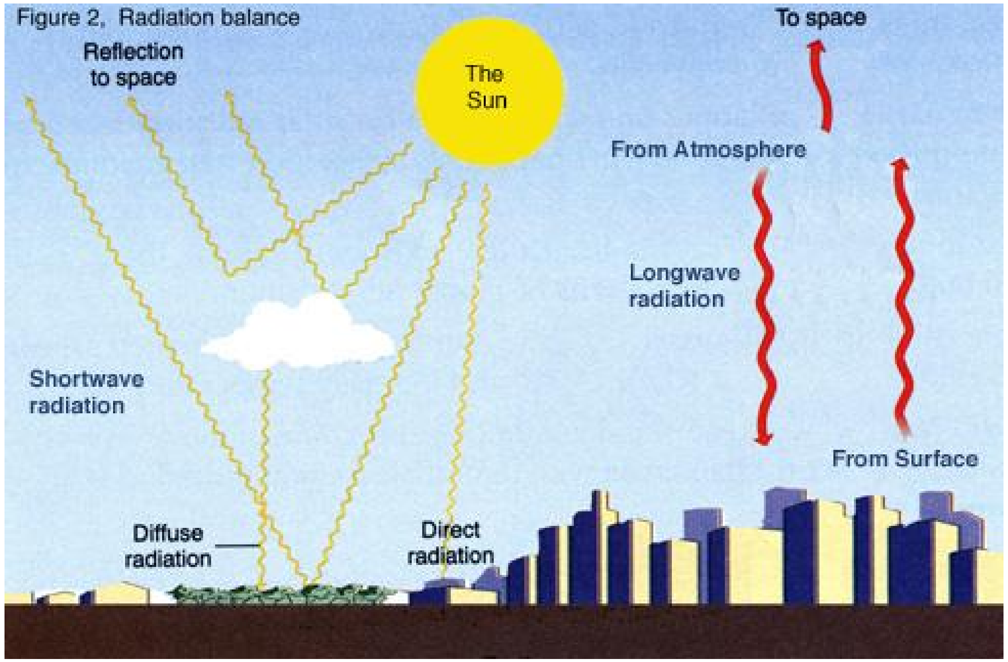
→ more unstable stratification, high BL, large CO_2 emissions

3. Urban energy, water and CO_2 budgets

Radiation balance is altered due to

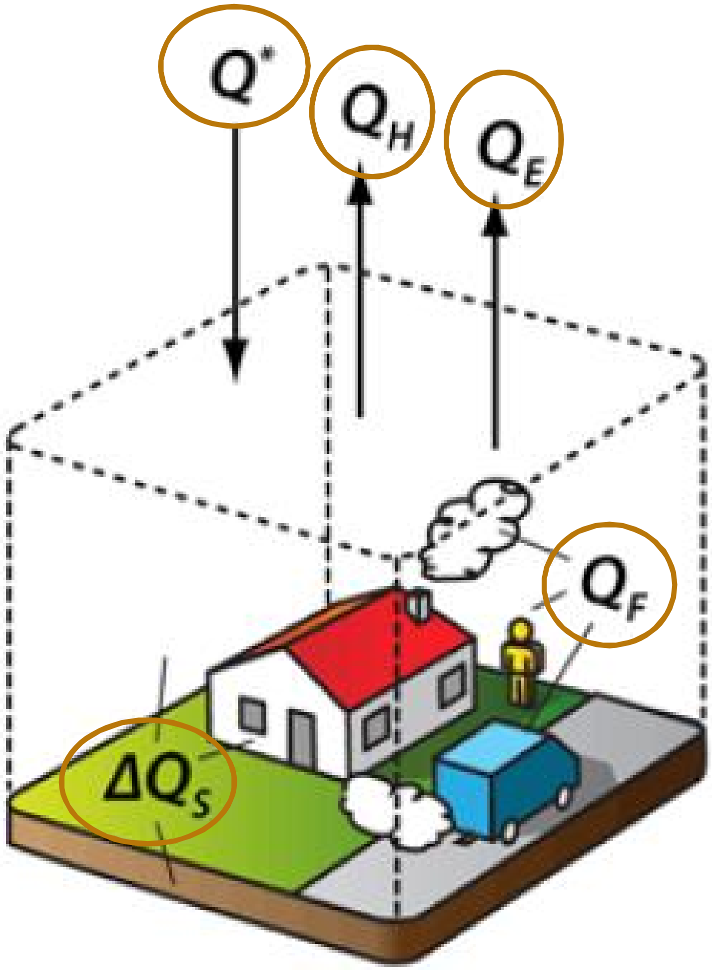
- Pollutants in the air
- Altered albedo

$$Q^* = \underbrace{K\downarrow + K\uparrow}_{\text{Incoming and outgoing shortwave radiation}} + \underbrace{L\downarrow + L\uparrow}_{\text{Incoming and outgoing longwave radiation}}$$



http://www.ruf.rice.edu/~sass/Policy%20Stuff/Fig%202%20alt%20Rad%20Diag.jpg

Energy balance



Grimmond and Christen 2012

Sensible heat

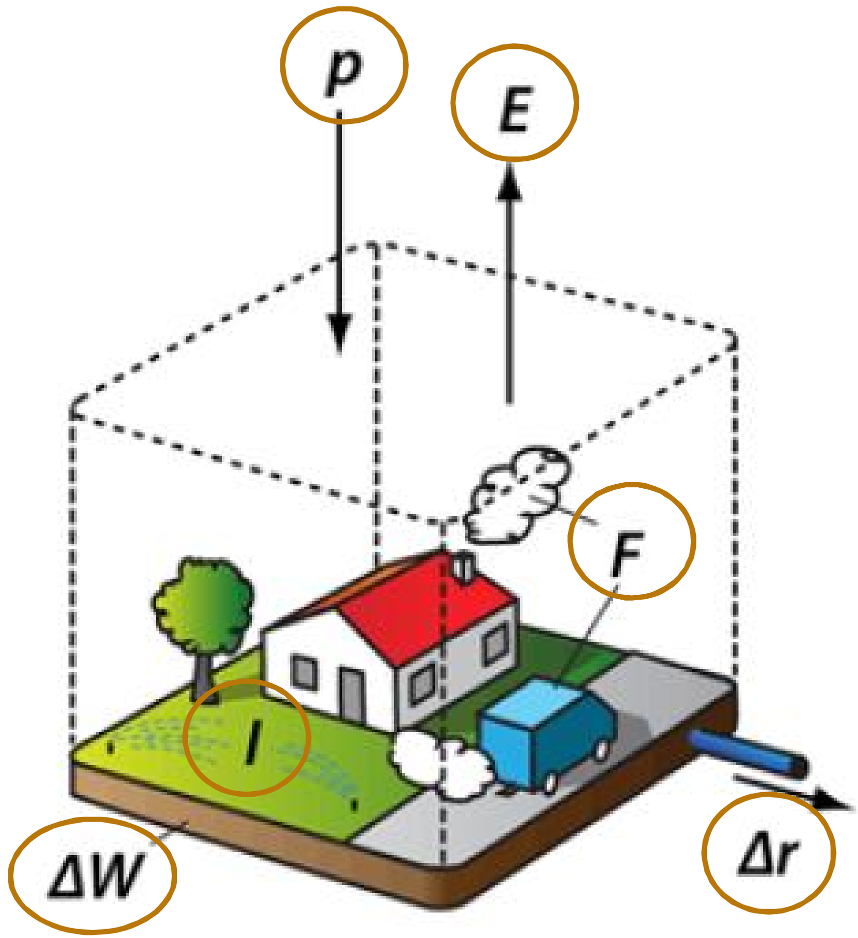
$$Q^* + Q_F = Q_H + Q_E + \Delta Q_S$$

Antrhopogenic heat (buildings, cars, humans)

Latent heat (evaporation)

Heat storage change

Water balance



Grimmond and Christen 2012

$$p + F + I = E + \Delta W + \Delta r$$

Precipitation

Anthropogenic

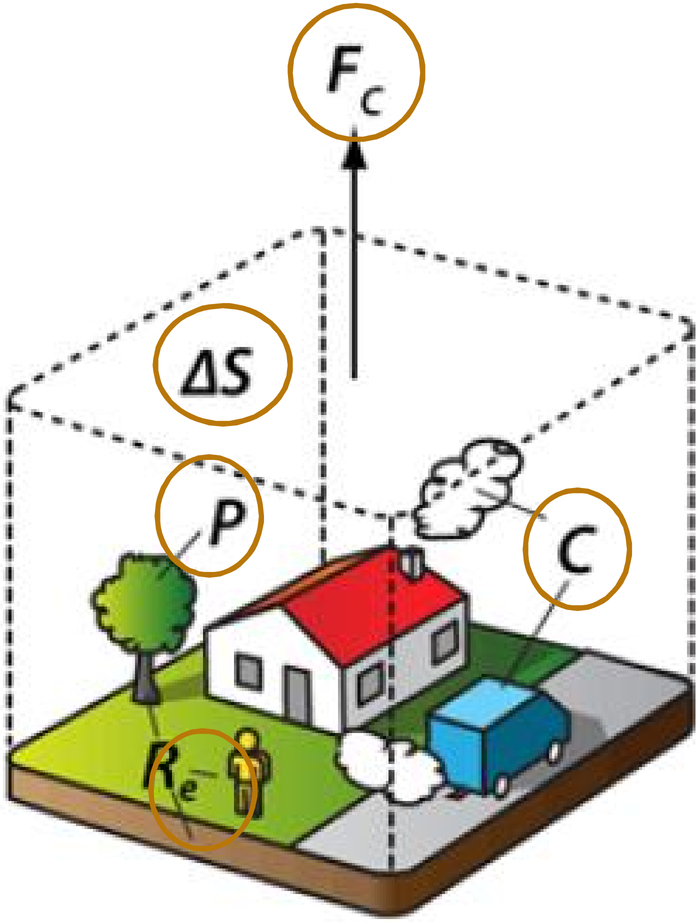
Irrigation

Evaporation

storage change in soils

Run-off

CO_2 balance



Grimmond and Christen 2012

$$F_c + \Delta S = C + R_e - P$$

Net CO_2 flux

Photosynthetic uptake

Storage change

Combustion emission

Respiration emission

4. Urban heat island

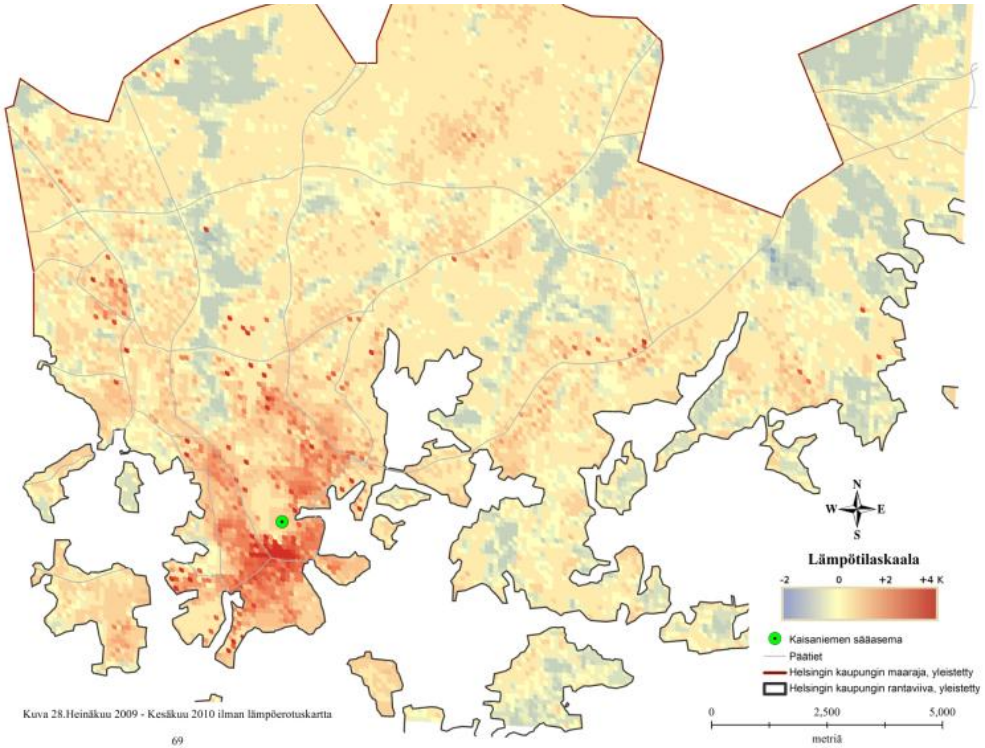
Temperatures in urban areas higher than in the surrounding areas (especially at night)

BECAUSE of

- Anthropogenic heat emissions
- Surface cover changes

Air temperature deviation from areal mean

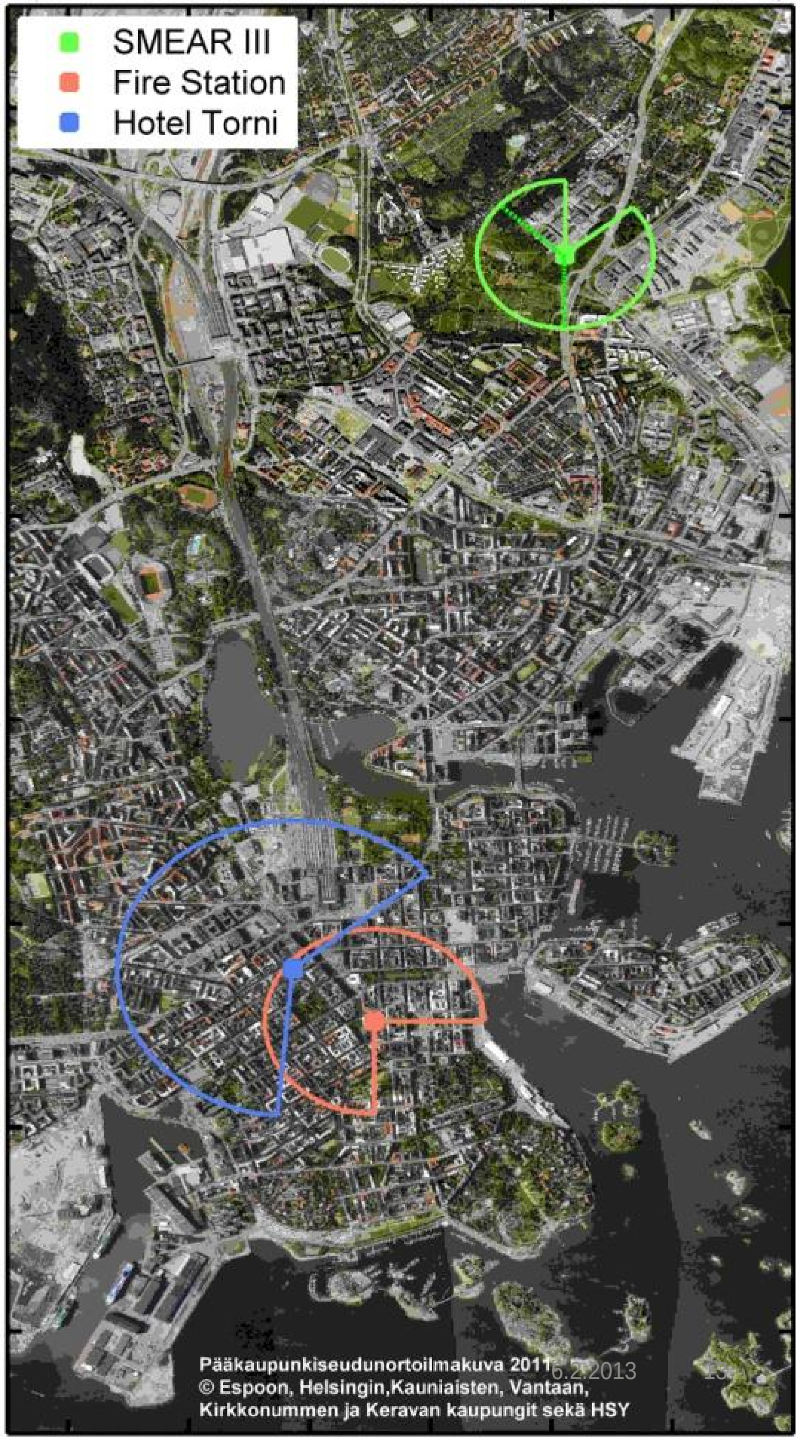
July2009 - June2010 (Achim Drebs)



5. Urban EC measurements in Helsinki

SMEAR III, semiurban, 2005

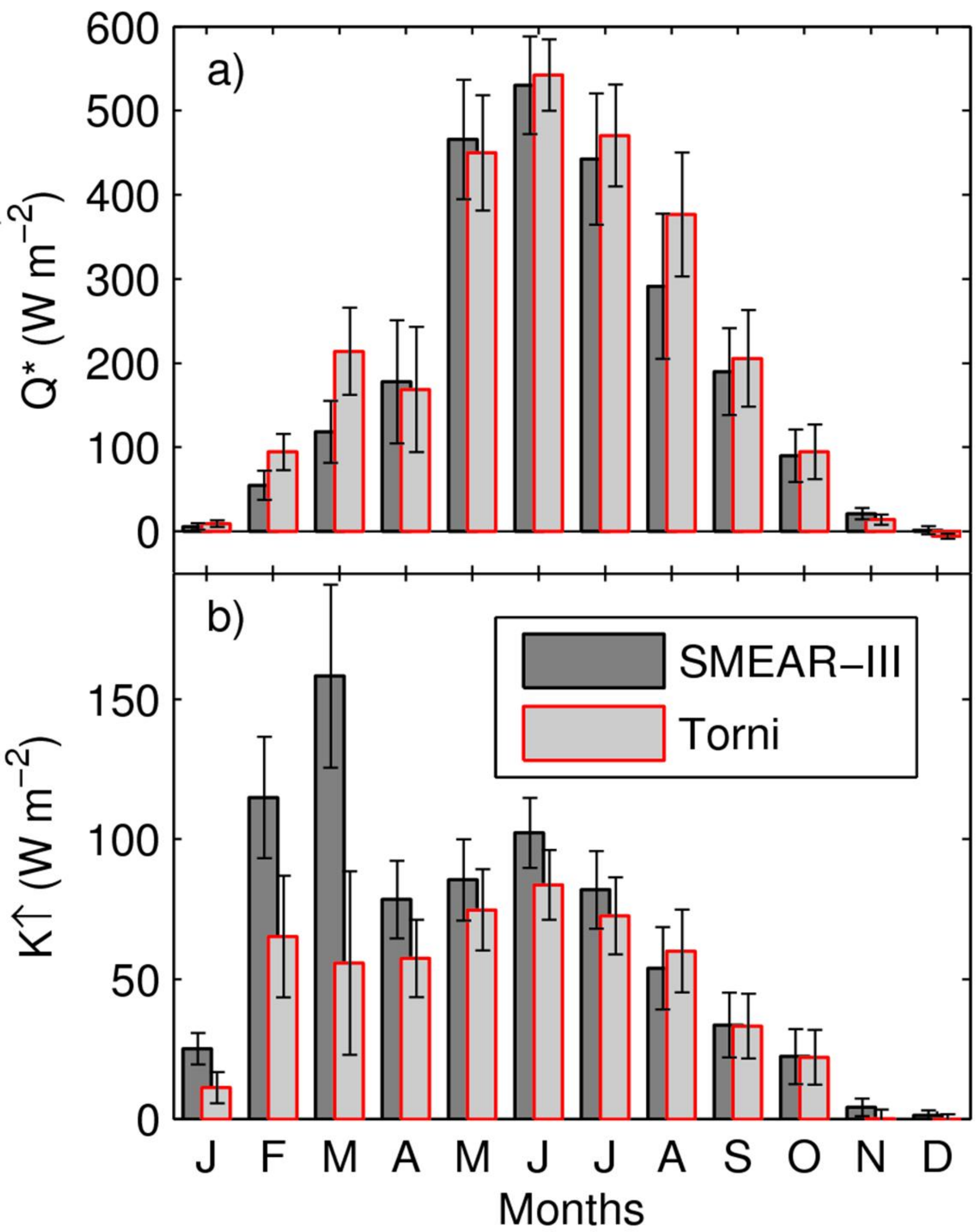
Hotel Torni, urban, 2010



Nordbo et al., 2012b

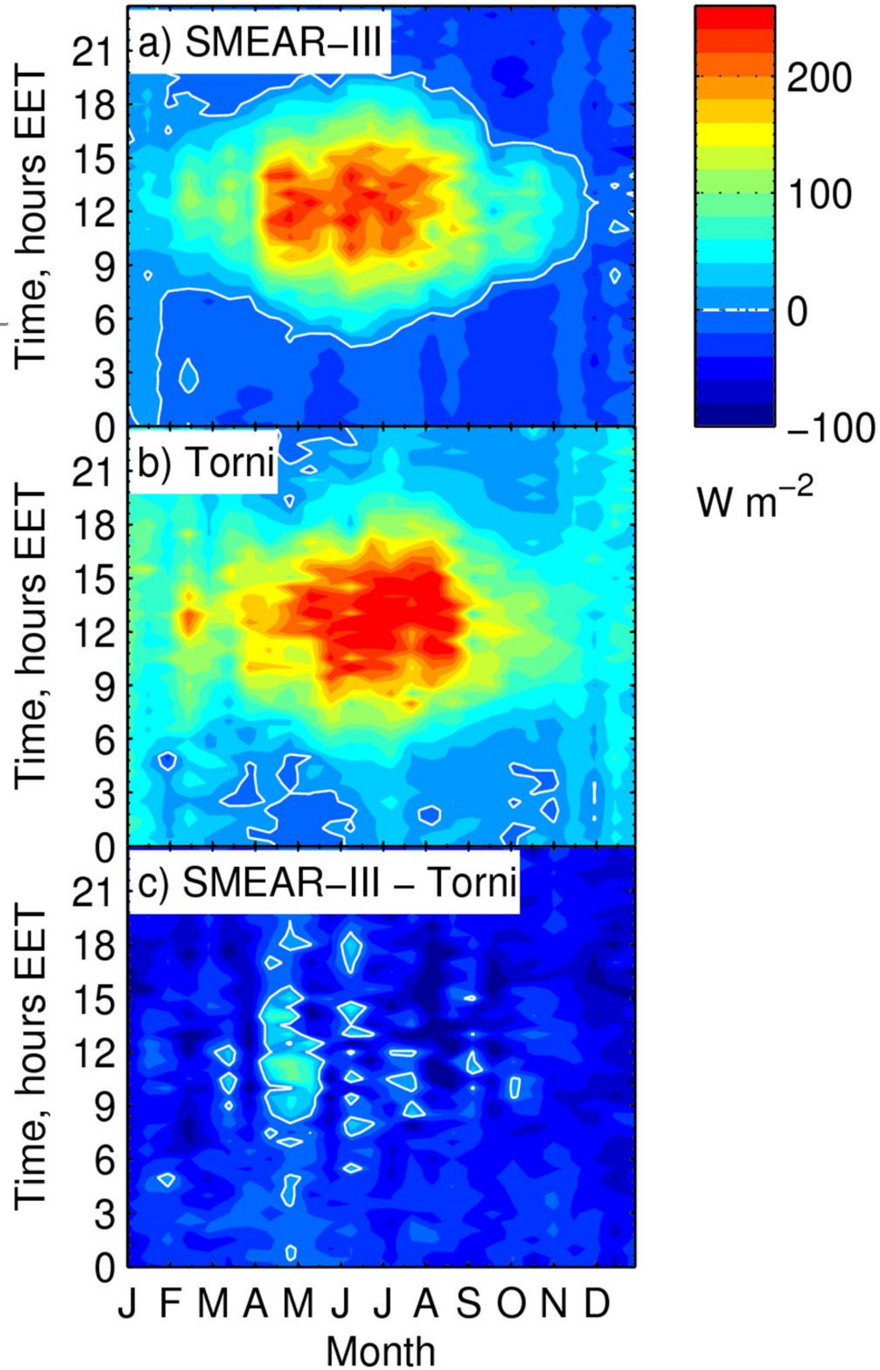
Monthly net all-wave radiation, and upwelling shortwave radiation in 2011

(Wood et al. 2013)



Mean sensible heat flux for each 30-min period for each month of 2011

(Wood et al. 2013)

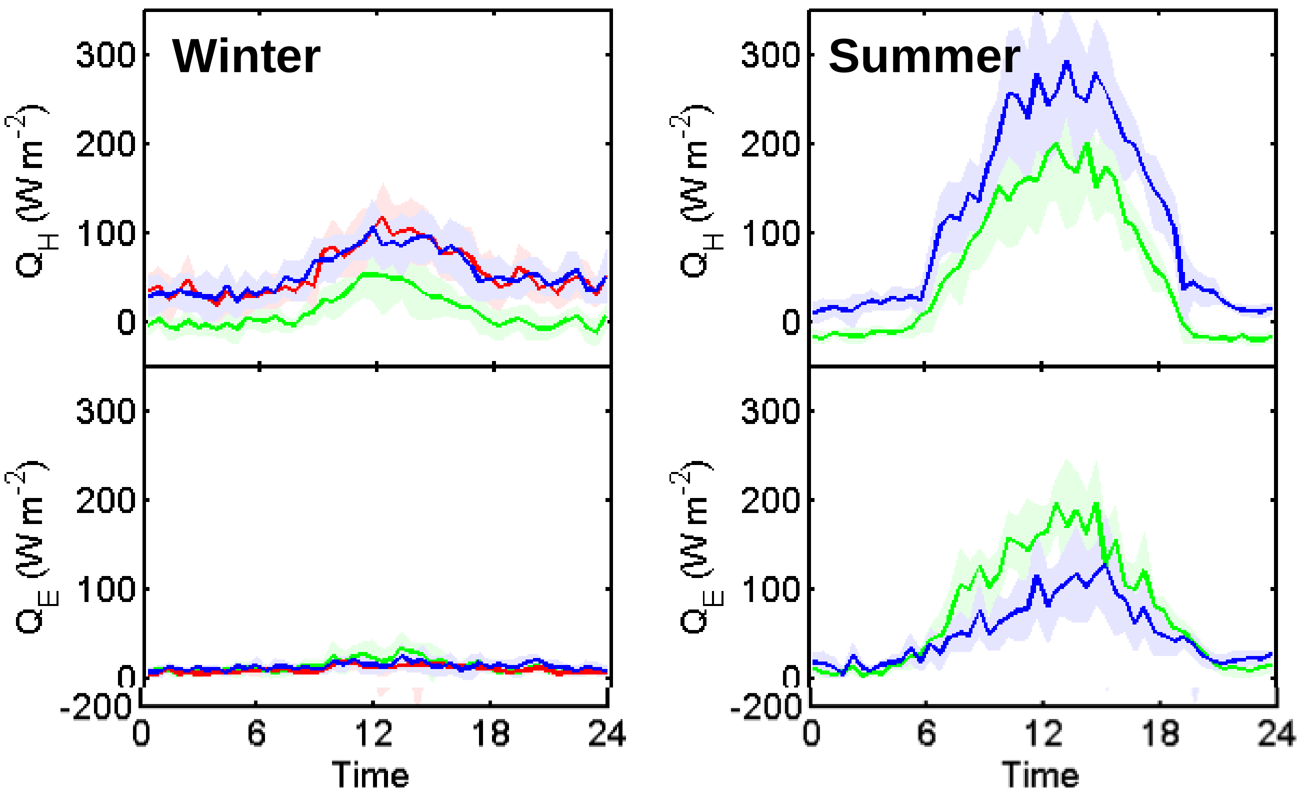


Mean diurnal courses of sensible and latent heat fluxes

SMEAR III

Hotel Torni

Fire Station



Evaporation is 30% lower downtown compared with Kumpula!

→ higher risk of flooding due to smaller evaporation and impervious surfaces!

“Floods are the most severe climate threat in Helsinki”

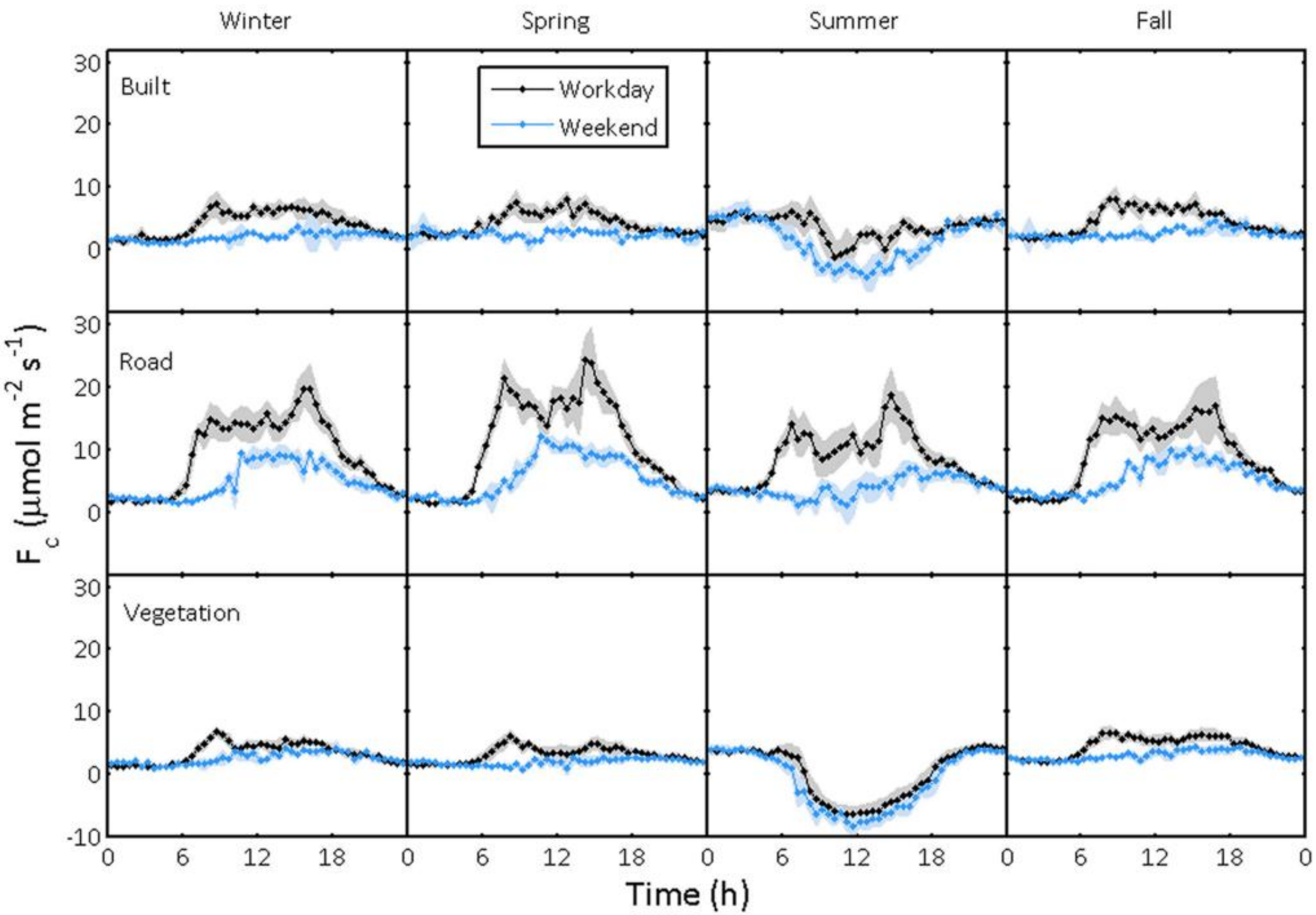
Tulvat Helsingin vakavin ilmastouhka

HS.fi Helsinki 18.1.2012 31

Merivesi tulvi puistokäytävälle Helsingin Tokoinrannassa 4. tammikuuta.

CO$_2$ fluxes in Kumpula

(Järvi et al. 2012)



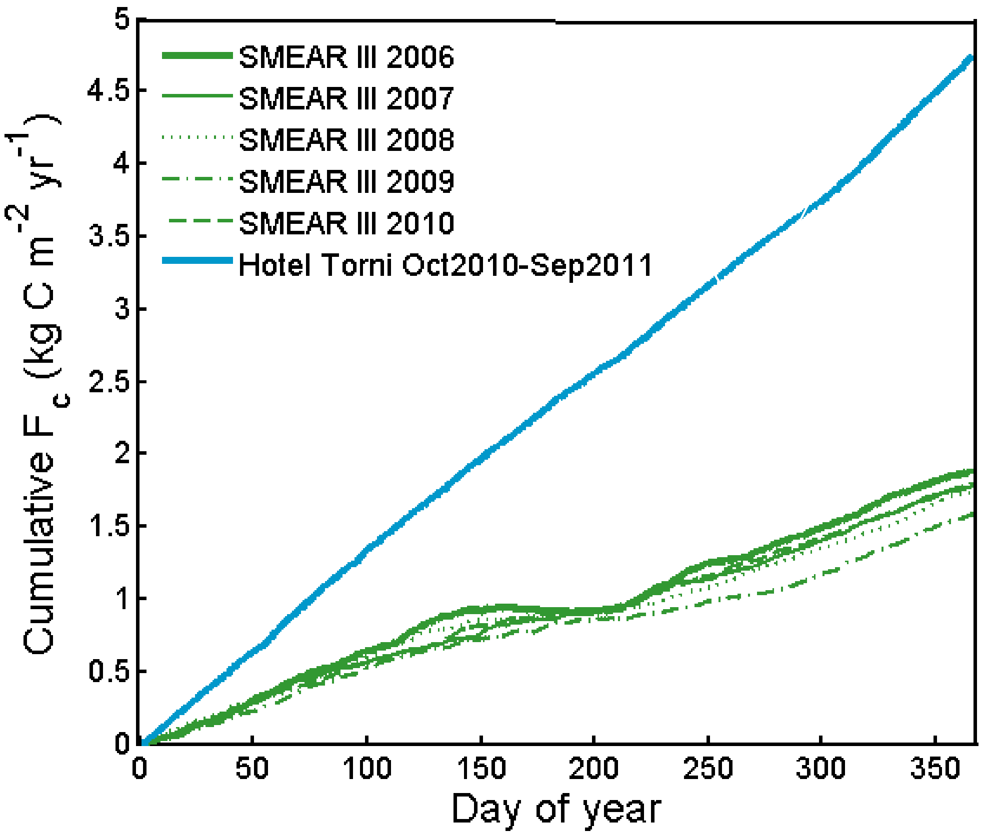
Annual CO_2 emissions from Kumpula and downtown Helsinki

Kumpula:1760 g C m^{-2}

Downtown: 4740 g C m^{-2}

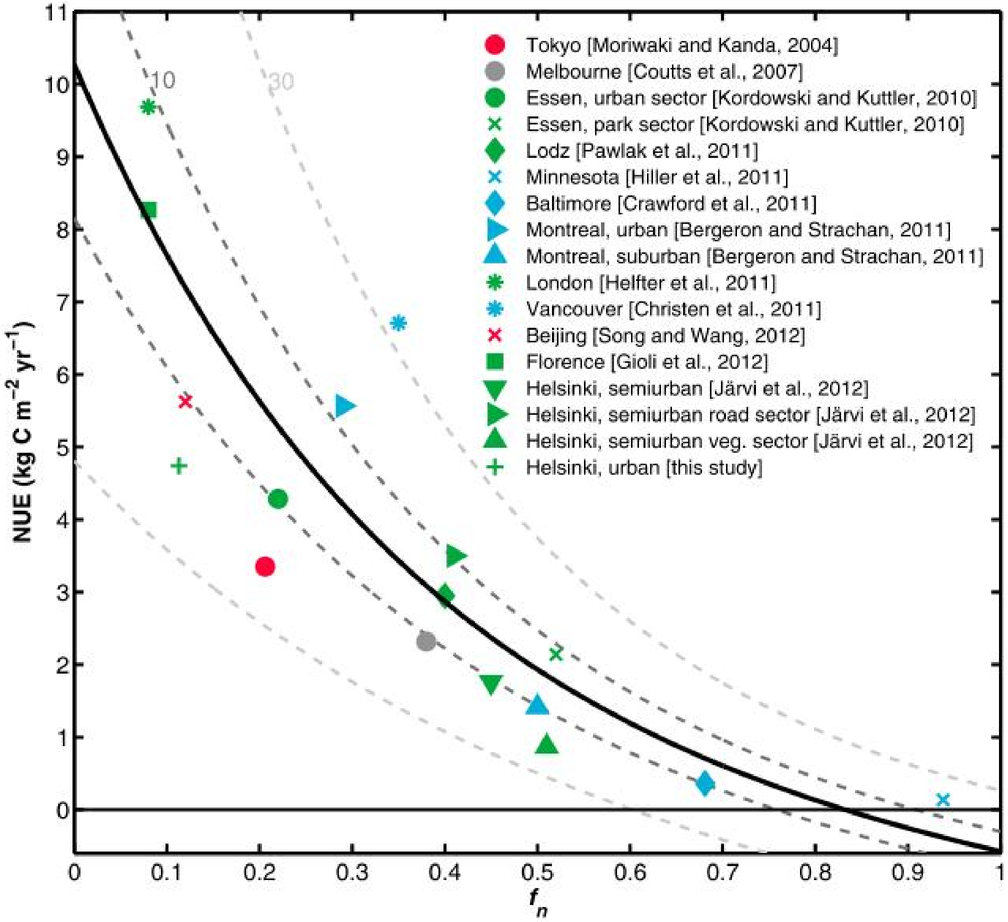
Finnish boreal forest: -209 g C m^{-2}

Finnish wetland: 43 g C m^{-2}



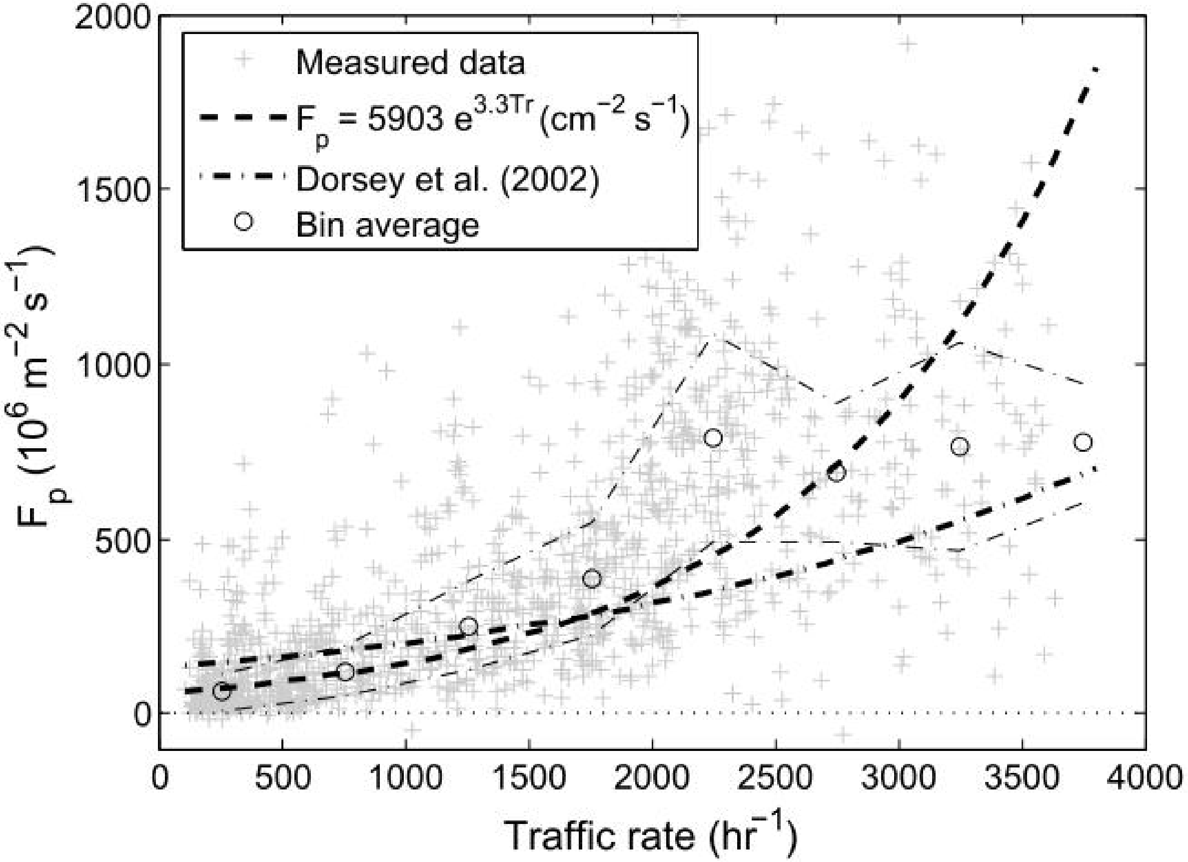
Nordbo, PhD Thesis, 2012; Järvi et al. 2012; Nordbo et al. 2012c

Net urban exchange (NUE) depends strongly on the fraction of natural areas (f_n) in cities



Nordbo et al., 2012c

Particle flux at SMEAR III follows traffic rate



Järvi et al. 2009b

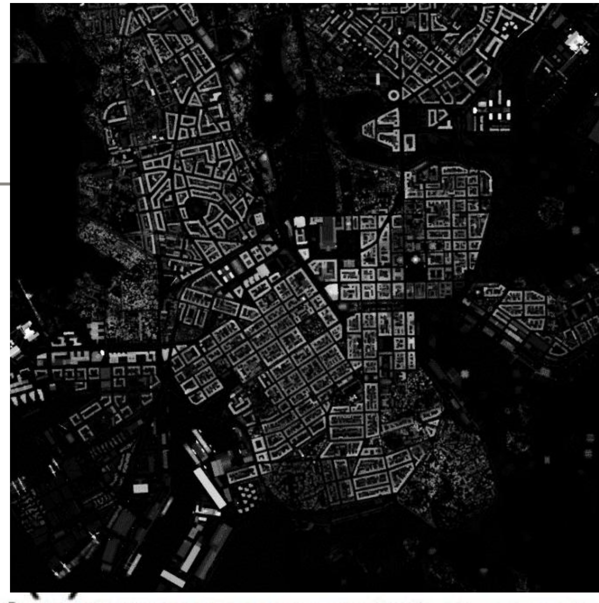
6. EddyUH URBAN

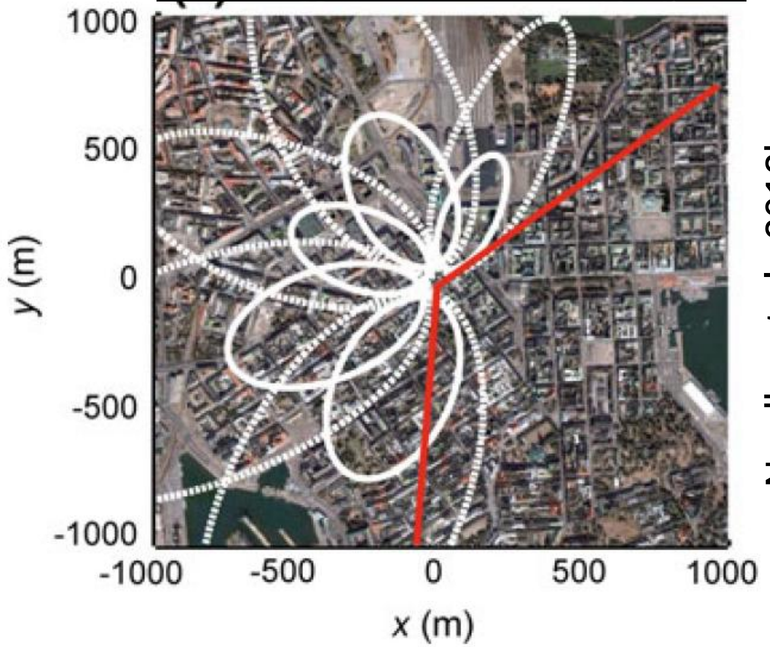
under development

- Calculates
  - z_0 and z_d for each 30-min period based on a building morphology map (right)
  - Flux footprints

    (Korrman and Meixner, 2001)
  - Land cover for each 30-min period

  (based on footprints and land cover map)





Nordbo et al., 2012b

Thanks!

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