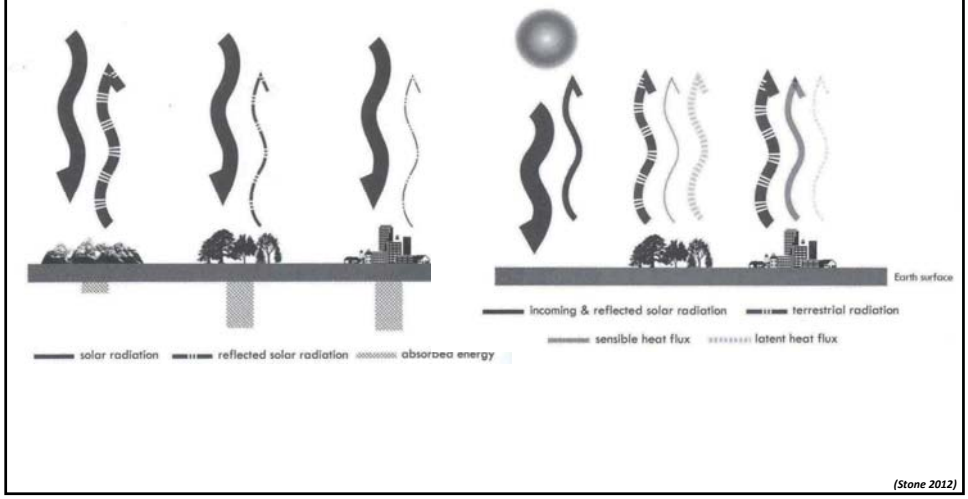
The exploitation of EO in UEB estimation

Nektarios Chrysoulakis
FORTH/IACM
N. Plastira 100, Vassilika Vouton, 70013, Heraklion
zedd2@iacm.forth.gr
http://rslab.gr

Outline

- Introduction
- Urban Energy Budget
- The contribution of EO
- URBANFLUXES
- Nature Based Solutions

Introduction



(Stone 2012)

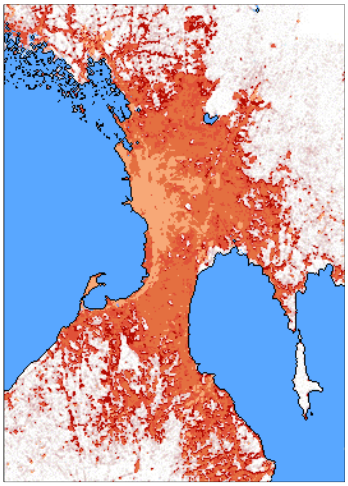
Introduction

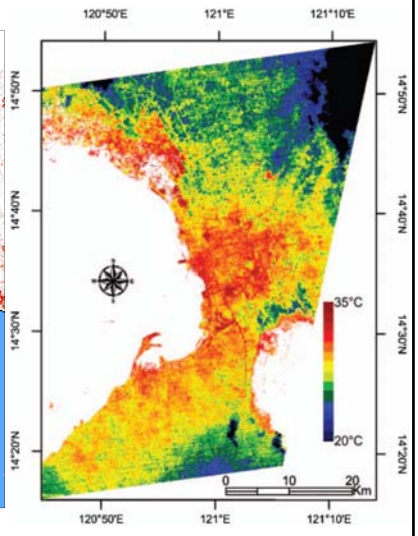
2010

2000

1990

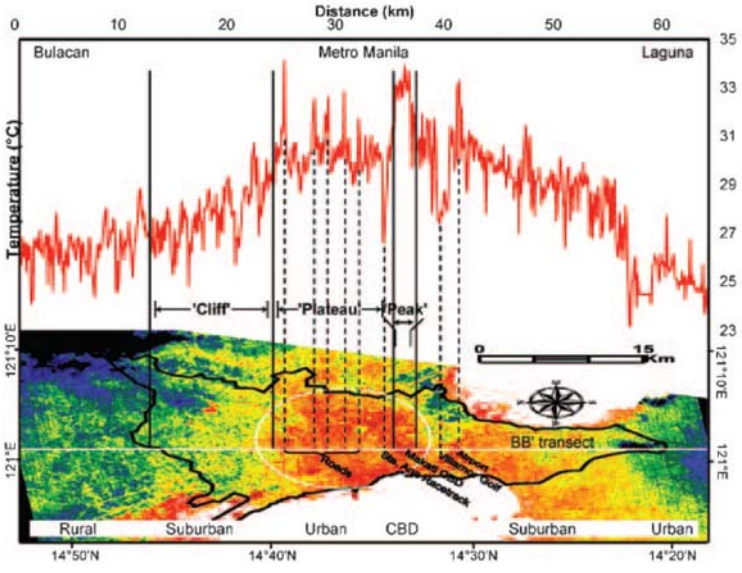
1975





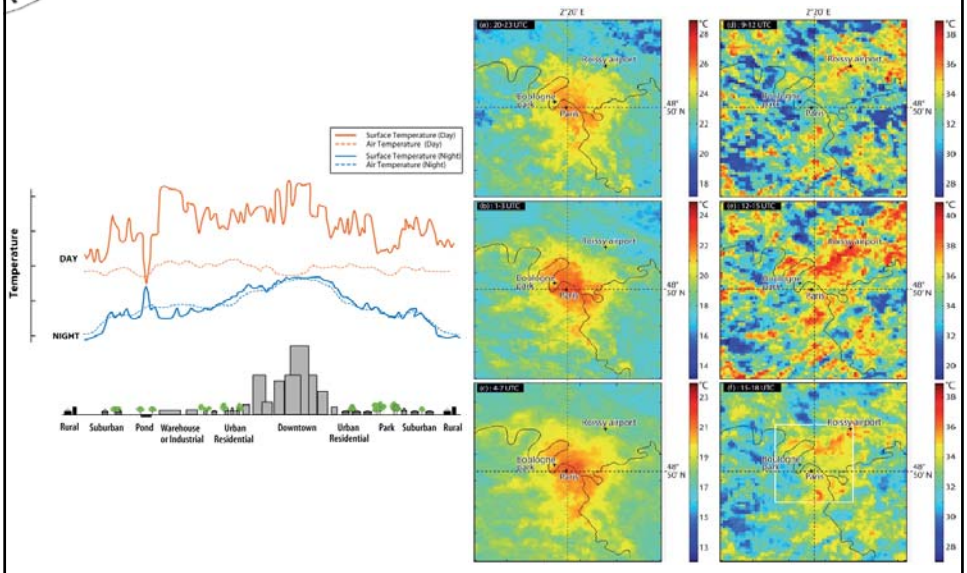
(Tiangco et al. 2008)

Introduction



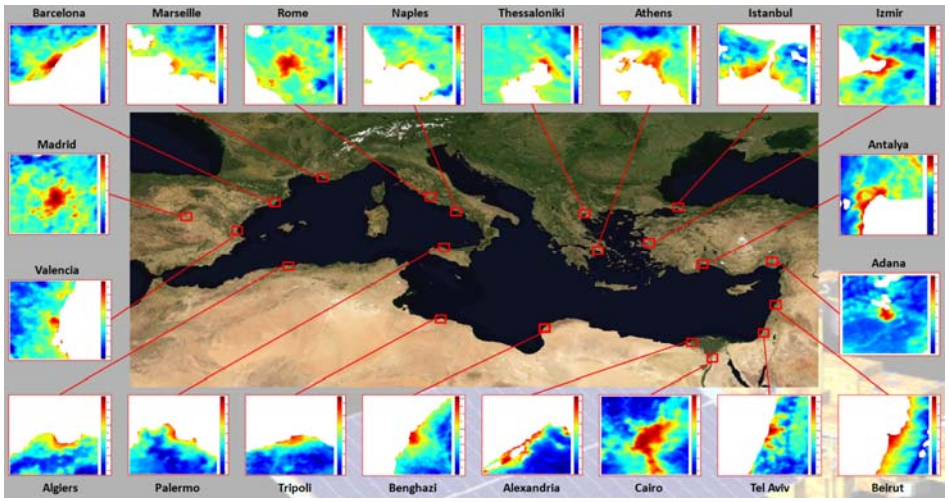
(Tiago et al. 2008)

Introduction



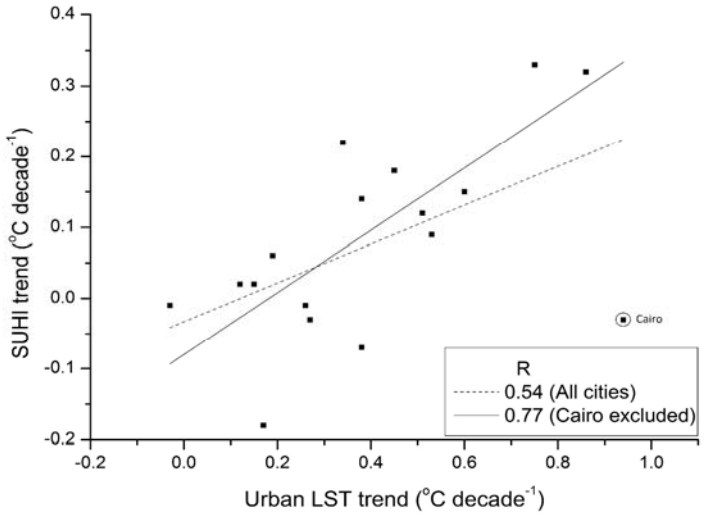
(Dousset et al. 2011)

Introduction



(Benas et al. 2016)

Introduction



(Benas et al. 2016)

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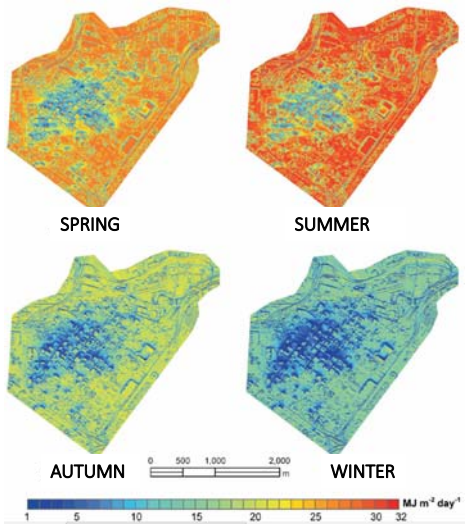
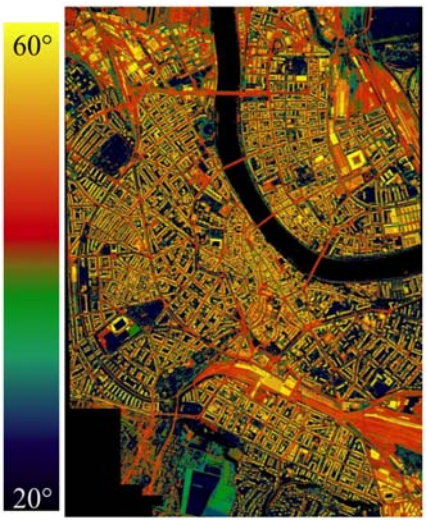


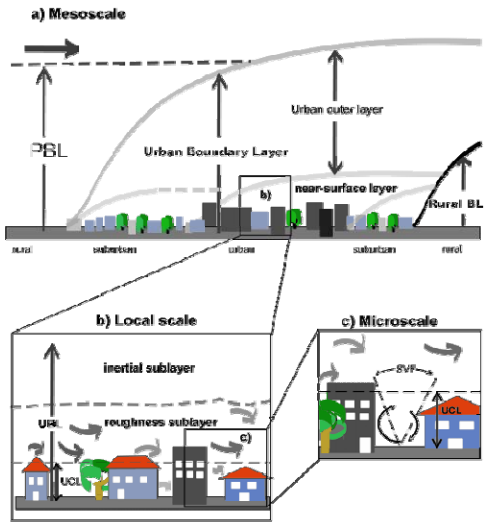
(Yu et al. 2009)



(Parlow et al. 2012)

Introduction

- Structure of the UBL.



Appropriate methods

- Measurements
- Models
- Satellite data

- Measurements
- Models
- Th-IR cameras
- Low altitude remote sensing

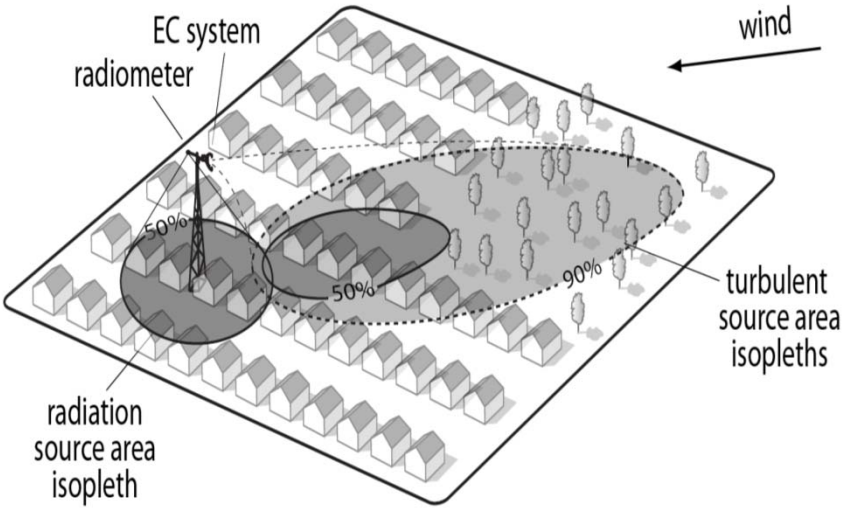
(Oke 1987)

Urban Energy Budget

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

- Q^*: Net all-wave radiation balance
- Q_F : Anthropogenic heat flux
- Q_H : Turbulent sensible heat flux
- Q_E : Turbulent latent heat flux
- ΔQ_S : Net change in heat storage
- $\Delta Q_A = Q_{in} - Q_{out}$: Advective heat flux
- S: All other sources and sinks

Urban Energy Budget

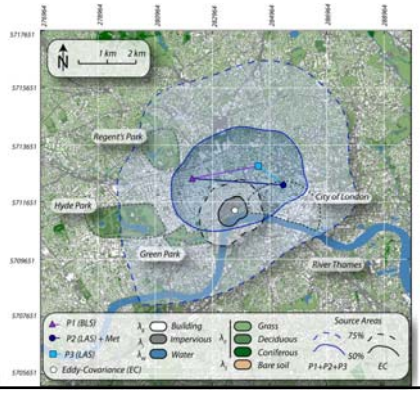


(Magliulo et al. 2014)

Urban Energy Budget

BTT
BT Tower

IMU
Michael Cliffe



BCT
Barbican

(Crawford et al. 2016)

Urban Energy Budget

Spalenring
1990 – 2002

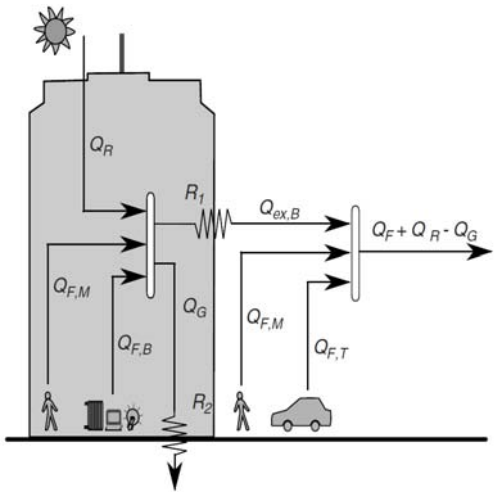
Klingelbergstrasse
Street side

Sperrstrasse
BUBBLE -2002

Klingelbergstrasse
Roof level since 2002

(Parlow 2015)

Urban Energy Budget



Sources

Q_R- short & long wave radiation received internally

$Q_{F,M}$ - metabolism
$Q_{F,T}$ – transport
$Q_{F,B}$ – buildings

Sinks

- Sensible heat
- Latent heat
- Waste water

Timing of heat release

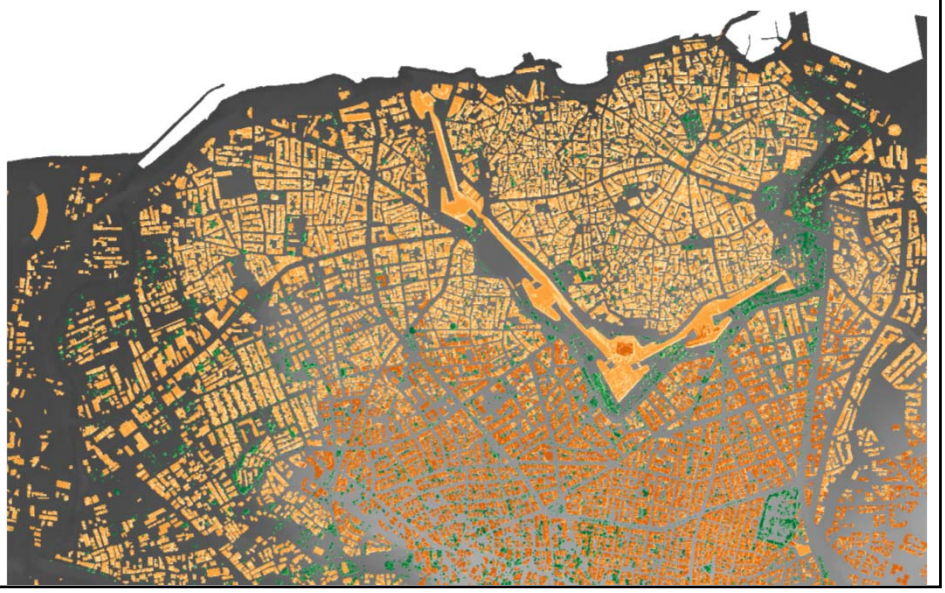
- Instantaneous
- Lagged

Location of heat release

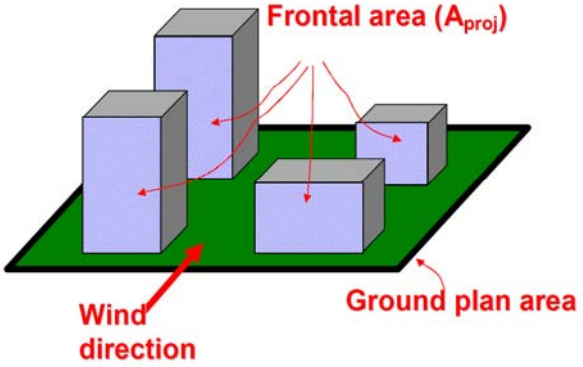
- Building openings: vents, windows
- Building materials: walls, roof
- Vehicles

(Iamarino et al. 2012)

The contribution of EO



The contribution of EO



$$\frac{z_d}{z_H} = 1 - \left\{ \frac{1 - \exp\left[-\left(c_{d1} 2\lambda_f\right)^{0.5} \right]}{\left(c_{d1} 2\lambda_f\right)^{0.5}} \right\} \qquad \frac{z_o}{z_H} = \left(1 - \frac{z_d}{z_H}\right) \exp\left(-k \frac{U}{u_*} + \psi_k \right)$$

(Burian et al. 2002)

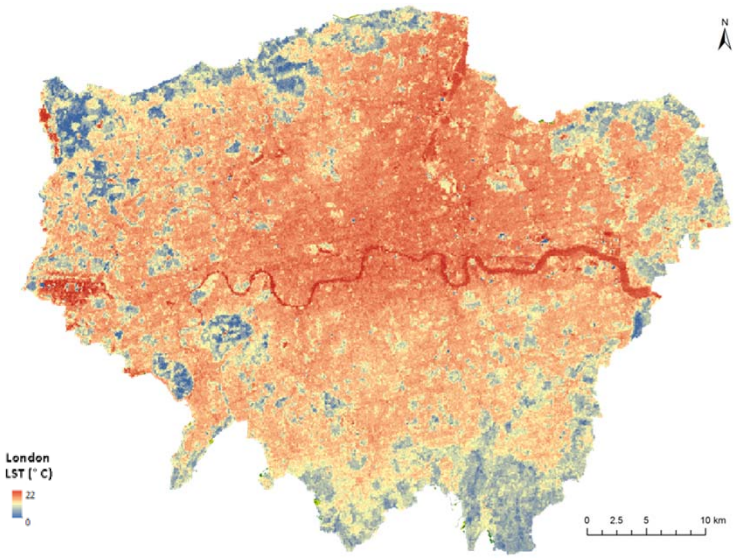
The contribution of EO

HyMap

(Esch et al. 2013)

The contribution of EO

The contribution of EO



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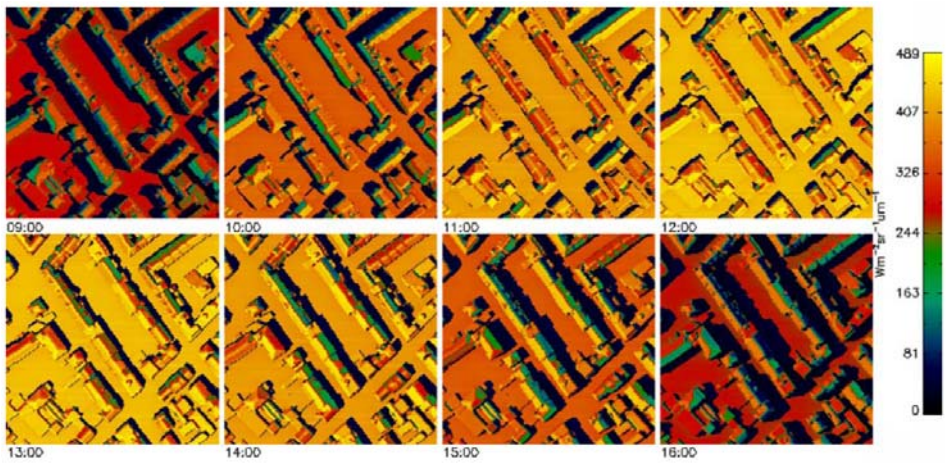


(Frey and Parlow 2009)

URBANFLUXES

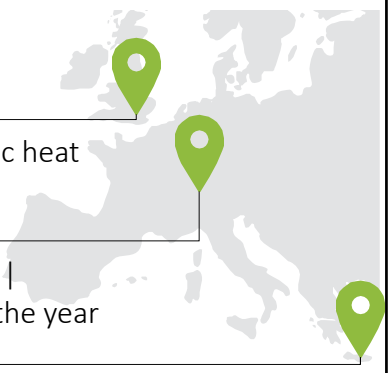
- Urban planning and Earth system science communities need **spatially disaggregated Q_F** .
- **Not possible** to derive it by *in-situ* flux measurements.
- The estimation of **Q_F spatial patterns** by current EO systems is a **challenge.**
- **Major challenge:** the innovative exploitation of the Copernicus Sentinels **synergistic observations** to estimate **Q_F spatiotemporal patterns**.

http://urbanfluxes.eu

URBANFLUXES

- to exploit EO to **improve the accuracy** of Q* and ΔQs calculation;
- to improve EO-based methods to **estimate** Q_H and Q_E and to **validate** them using flux measurement by EC, or scintillometry;
- to employ **energy budget closure** to estimate Q_F spatial patterns at city scale and local scale;
- to specify and analyse the **uncertainties**;
- to **evaluate** the products comparing with independent methods;
- To exploit **Sentinels 2/3 synergies** to retrieve UEB fluxes at the local scale, with the frequency of Sentinel 3 acquisitions.

URBANFLUXES

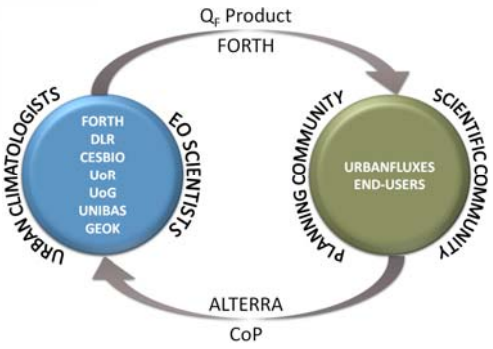


highly urbanized megacity | anthropogenic heat flux high throughout the year

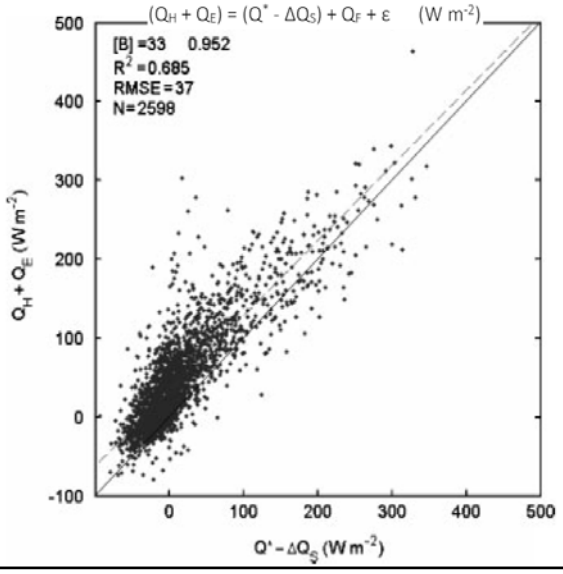
typical central European medium size city | anthropogenic heat flux high throughout the year

typical Mediterranean medium size city with dynamic urbanization process requires a substantial amount of energy for cooling

URBANFLUXES



URBANFLUXES



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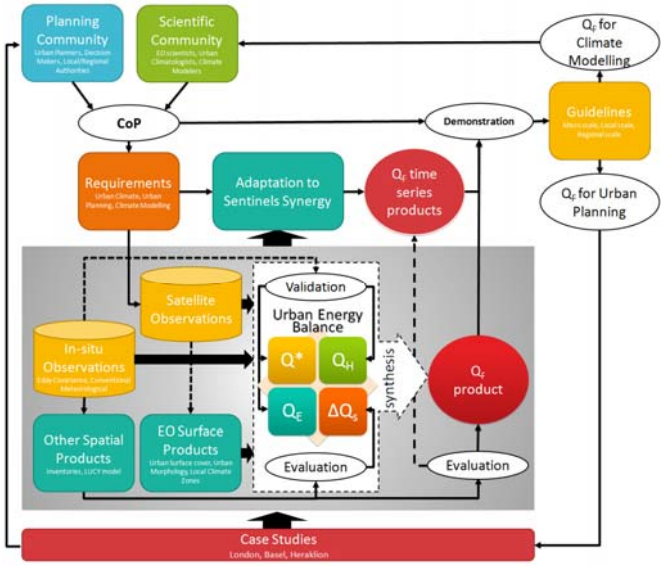
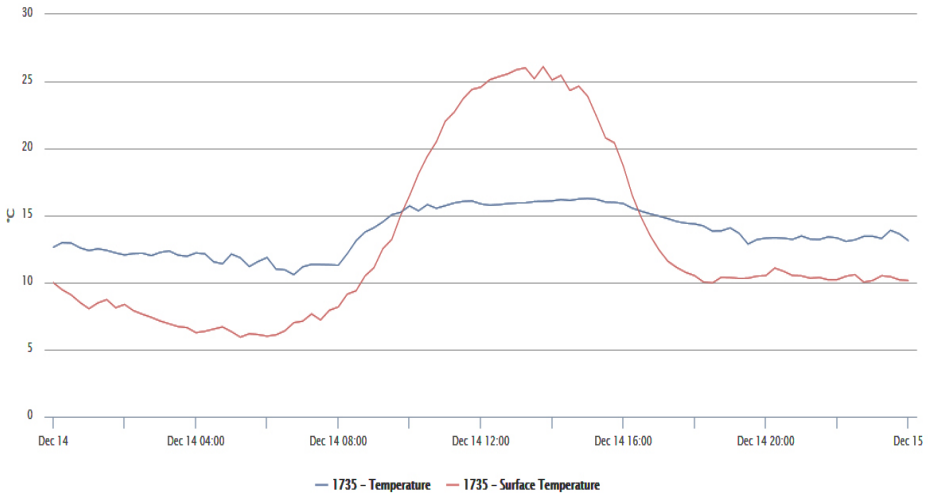


URBANFLUXES

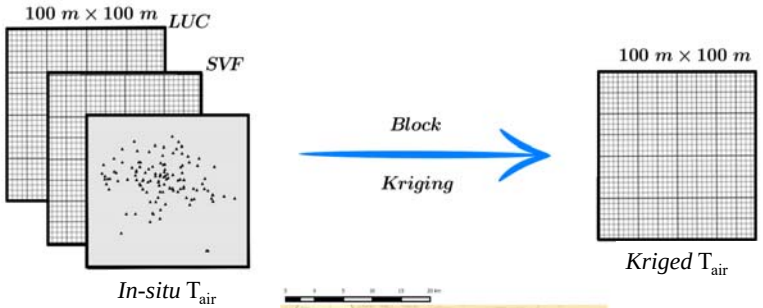
- High resolution measurements of:
  - ✓ Surface temperature
  - ✓ Soil moisture/temperature
  - ✓ Air temperature
  - ✓ Relative humidity
  - ✓ Wind vector

URBANFLUXES

URBANFLUXES

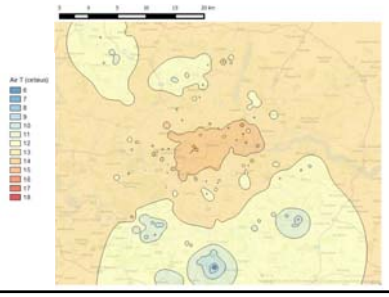


URBANFLUXES



In-situ T_{air}

Kriged T_{air}

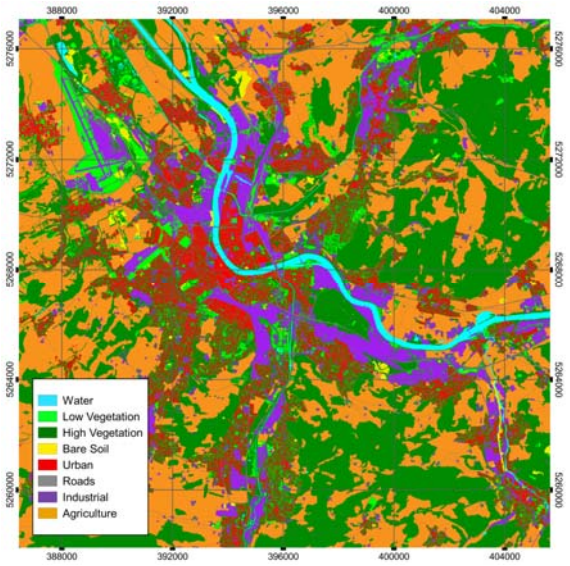


(Beloconi et al. 2016)

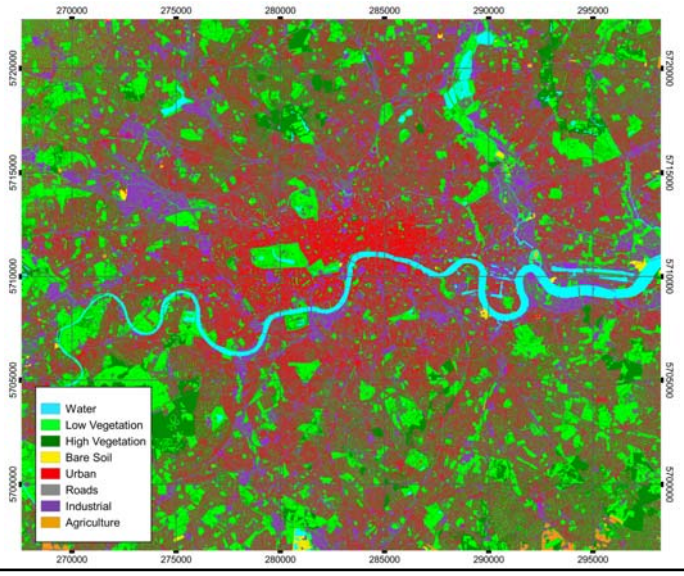
URBANFLUXES

- Independent for Q_E and Q_H
  - ✓ Eddy covariance from flux towers
  - ✓ Large-aperture scintillometers

URBANFLUXES

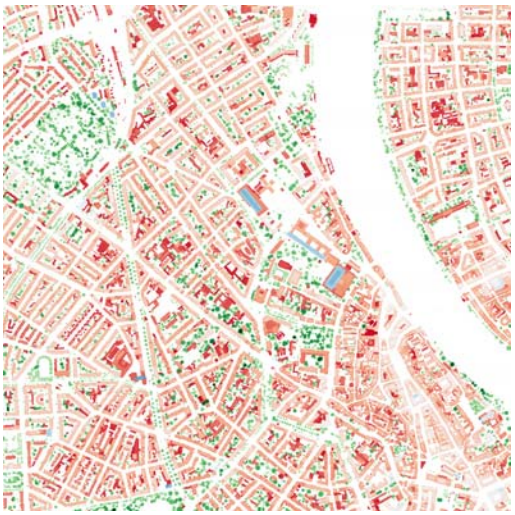


URBANFLUXES



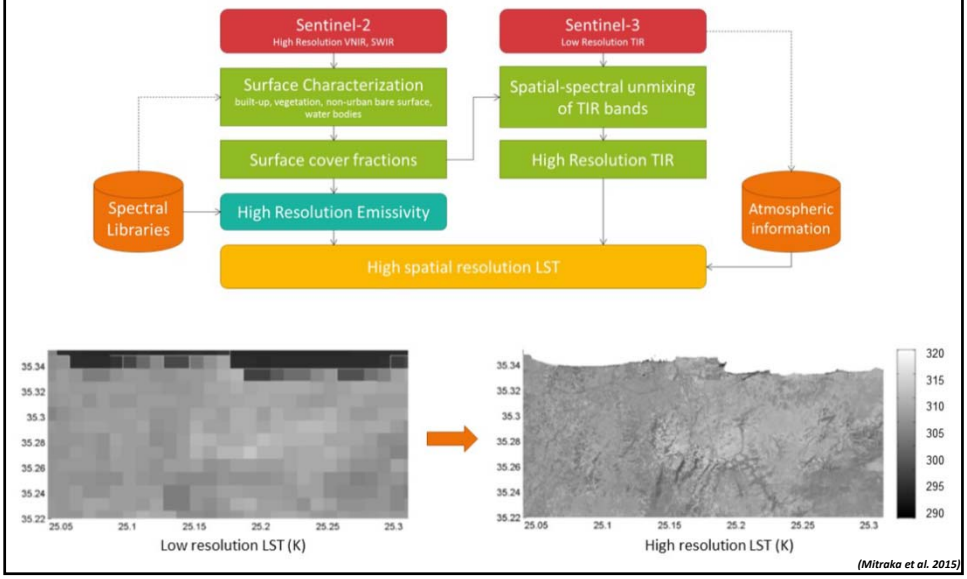
URBANFLUXES

- **Relevant parameters**: Sky View Factor (*SVF*), building & vegetation heights (z_H, $z_{H(SD)}$, $z_{H(max)}$), plan area index (λ_P), frontal area index (λ_F), zero displacement height (z_d) & roughnes length (z_0).



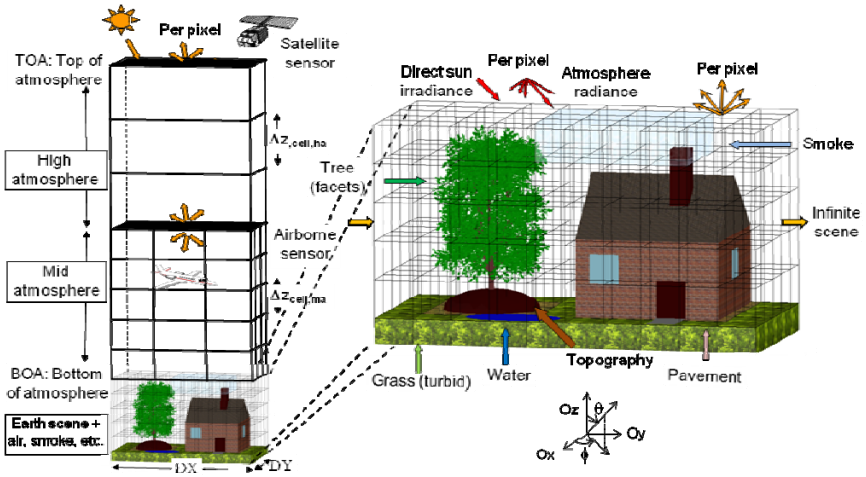
URBANFLUXES

URBANFLUXES



(Mitraka et al. 2015)

URBANFLUXES

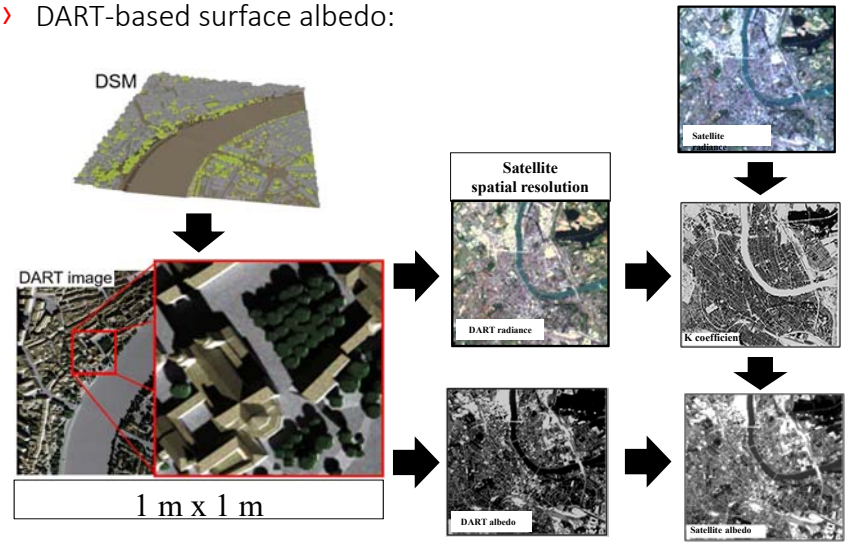


DART: simulates accurate urban satellite images (UV to TIR)

(Gastellau-Etchegorry et al. 2015)

URBANFLUXES

› DART-based surface albedo:



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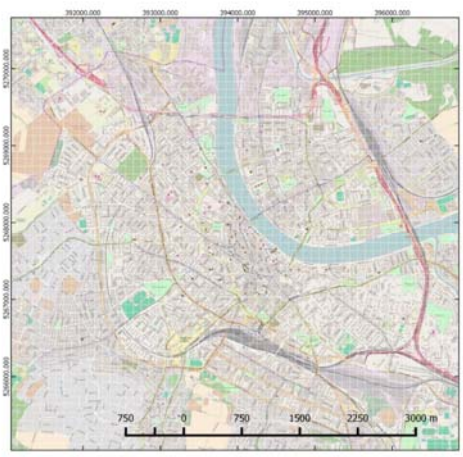
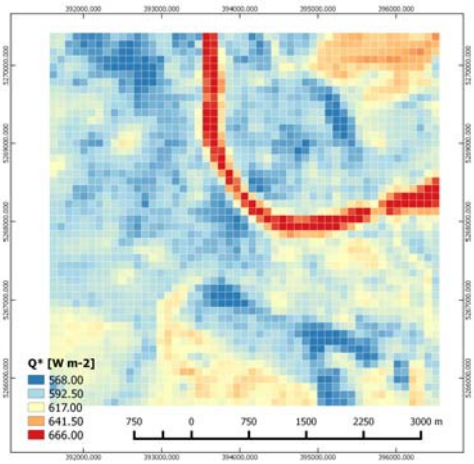


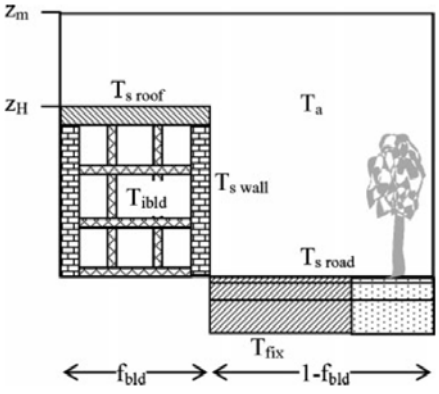


URBANFLUXES

- **ESTM** (Element Surface Temperature Method):
  - ✓ Based on facet areas.
  - ✓ Incorporates heat transfer through the different elements.
  - ✓ Estimated ΔQ_S represents unit plan area.

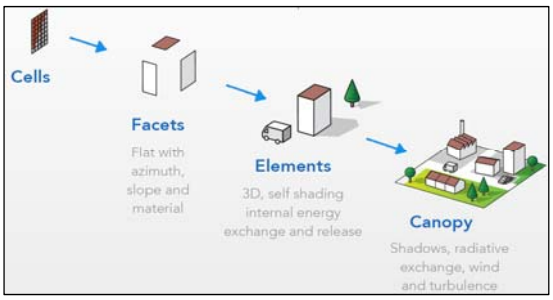
$$\Delta Q_S = \sum_i \frac{\Delta T_i}{\Delta t}(\rho C)_i \Delta x_i \lambda_{pi}$$

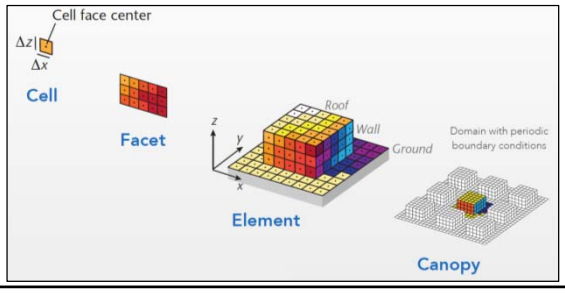
$$\rho C \frac{\partial T}{\partial t} = -\frac{\partial Q}{\partial x} = -\frac{\partial}{\partial x}\left(-k\frac{\partial T}{\partial x}\right)$$



(Offerle et al., 2005)

URBANFLUXES





(Christen 2015)

URBANFLUXES

Parameters:

- thermal properties (volumetric heat capacity, thermal conductivity) – ρC_i, k_i
- thicknesses for different element types – Δx_i
- element fractions – f_i
- morphology – z_h, H/W
- internal elements optical properties – λ_i, ε_i
- number of rooms per floor – n_{room}

Variables:

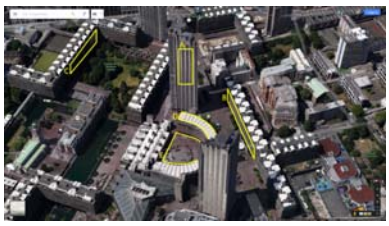
- surface temperatures – T_i
- outdoor air temperature – T_{oair}
- indoor air temperature – T_{iair}

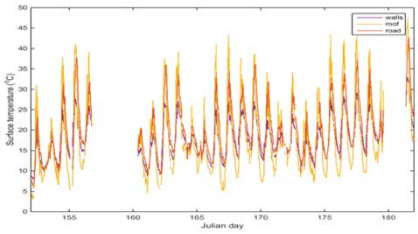
London

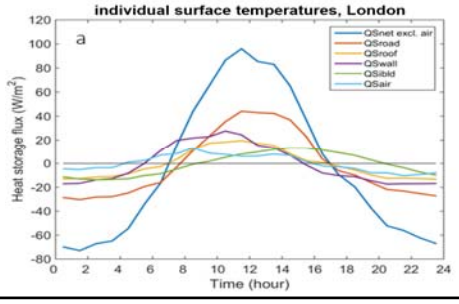
Element	Layer	Material	Δx (m)	k (W K^{-1} m^{-1})	ρC (MJ K^{-1} m^{-3})
roof	1	concrete [3]	0.2 †	0.5 [1]	0.84 [1]
	2	insulation †	0.1 †	0.03 [1]	0.056 [1]
	3	wood †	0.05 †	0.14 [1]	0.78 [1]
wall (N, E, S)	1-3	concrete & glass [2]	0.05 [1]	0.31 [1] ‡	0.877 [1] ‡
internal	1-3	concrete †	0.035 [2,4]	0.5 [1]	1.0 [1]
ground	1	brick clay [3]	0.1 †	0.65 [5,6]	1.5 [5,6]
	2	concrete †	0.1 †	0.93 [5,7]	1.5 [5,7]
	3-4	sand & gravel †	1.0/3.0 [7]	0.63 [5,7]	1.2 [5,7]

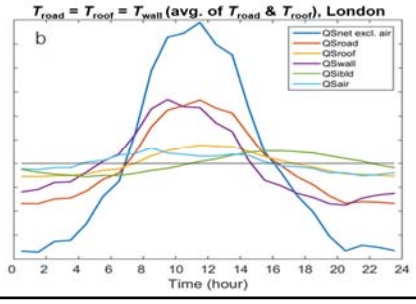
[1] Galezzi, 2010; [2] Behar, 2011; [3] Hogenhout, 2010; [4] Georgitsi, 2011; [5] Ashrae, 2013
[6] Mörtstedt and Hellsten, 1992; [7] Offerle et al., 2005; † estimation / guess; ‡ theoretical

URBANFLUXES

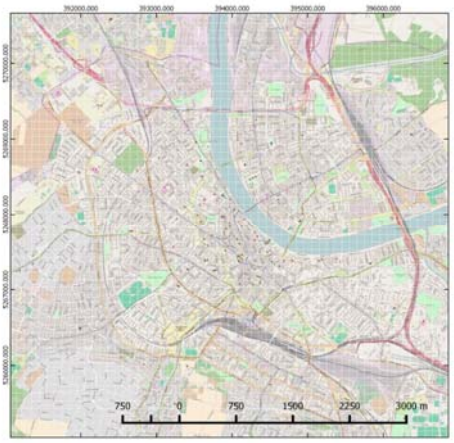


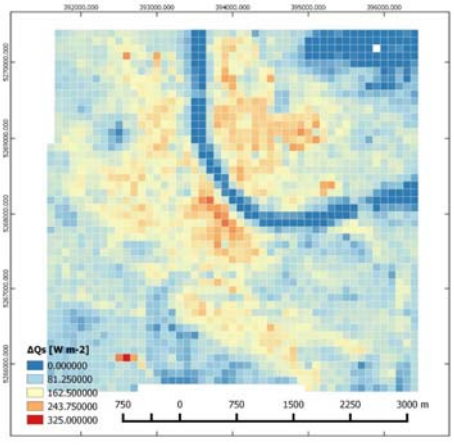






URBANFLUXES





URBANFLUXES

- **OHM** (Objective Hysteresis Model):
  - ✓ Contributions to ΔQ_S from multiple surface material types.
  - ✓ EO-derived dQ*/dt (e.g. Xu et al.,2008).

Q* and dQ*/dt measurements from EO

$$\Delta Q_s = \sum f_i a_{1,i} Q^* + f_i a_{2,i} \frac{dQ^*}{dt} + f_i a_{3,i}$$

Parameters specific to land cover class

(Grimmond anmd Oke 1991)

URBANFLUXES

- **ARM** (Aerodynamic Resistance Method)

Satellite-derived LST — Measured in-situ

$$Q_H = \rho c_P \frac{T_S - T_{air}}{r_a}$$

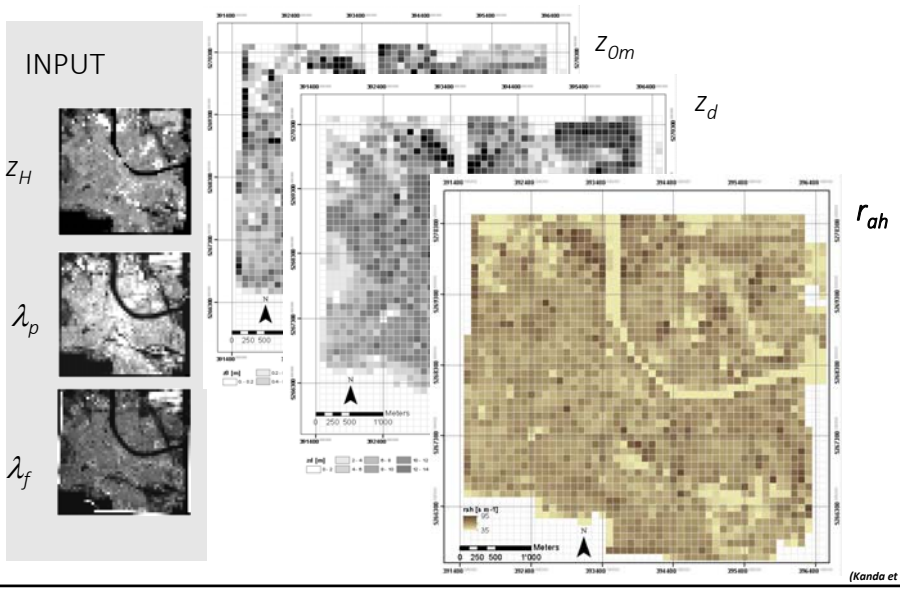
r_a ← Aerodynamic resistance

From T_{air} — Measured in-situ

$$Q_E = \rho c_P \frac{e_S - e_{air}}{\gamma(r_a + r_s)}$$

r_s ← **Surface resistance**
Depends on vegetation type, moisture conditions

URBANFLUXES



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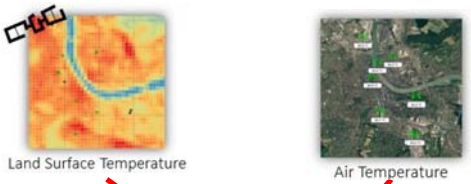
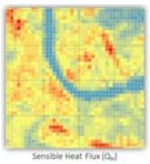

Land Surface Temperature

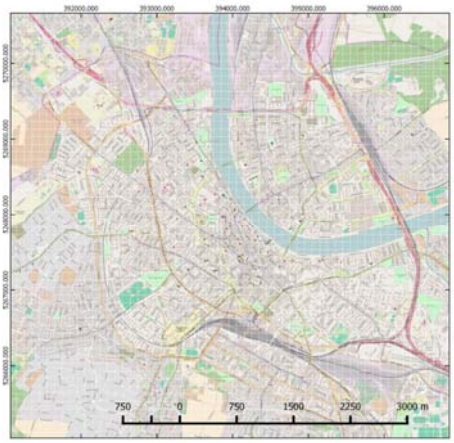
Air Temperature

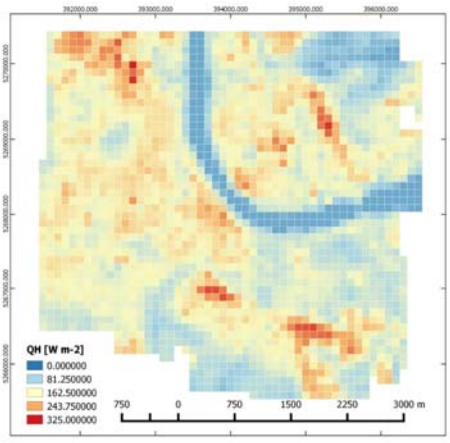


$$Q_H = \rho c_P \frac{T_S - T_{air}}{r_a}$$

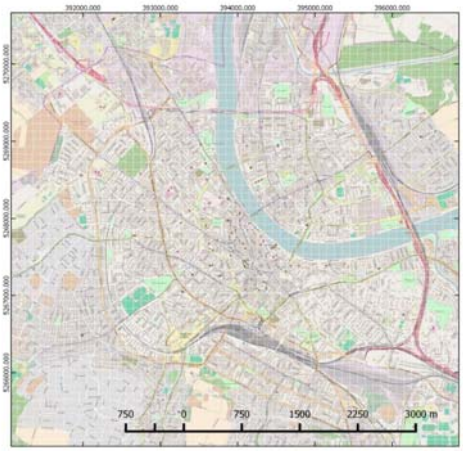

Aerodynamic Resistance

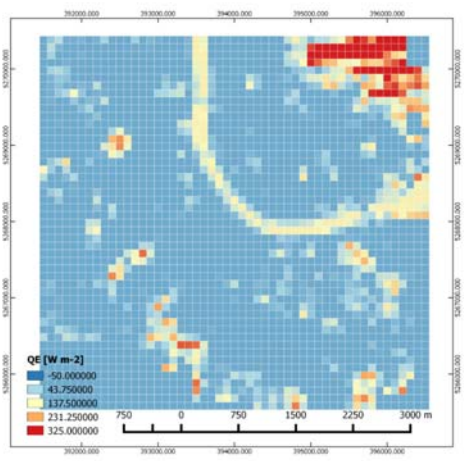
URBANFLUXES



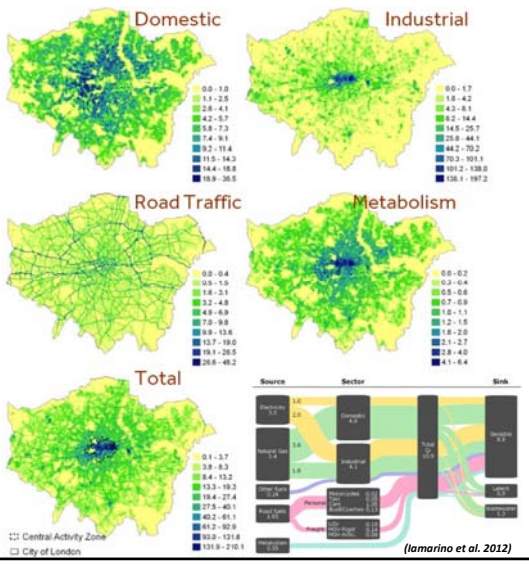


URBANFLUXES



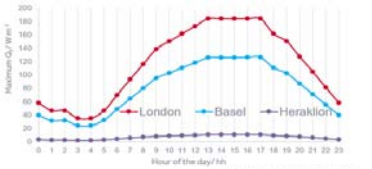


URBANFLUXES

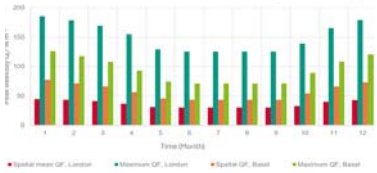


(Iamarino et al. 2012)

Q_F	Peak spatial mean W m^{-2}	Hour of peak spatial mean	Max. Q_F W m^{-2}	Area km^2
London	46.0	1700	185.2	1440
Heraklion	10.2	1700	10.5	17.4
Basel	76.9	1300	126.0	26.8



January Weekday



(Bhattacharya 2015)

URBANFLUXES

The vision:

- To advance the current knowledge of the **impacts** of Q_F **on UHI** and hence on urban climate and **energy consumption**.
- To support the **development of tools** and strategies to mitigate these effects, improving **thermal comfort** and **energy efficiency**.
- To support the establishment of EO as a tool to **help inform policy-making**.
- To develop **EO-based services**.

Nature Based Solutions

URBANFLUXES is expected to generate a **novel EO-based method** for estimation of UEB, enabling its integration into **applications and operational services**; as for example:

- develop **rules of thumb** for density and green space ratio;
- **distinguish** between insulated and non-insulated buildings/ neighbourhoods;
- **evaluate** the implementation of climate change **mitigation technologies** such as solar-screening, green-belting and carbon-cooling.

Nature Based Solutions

- **Nature Based Solutions (NBS)** are actions which are inspired by, supported by or copied from nature.
- Some involve using and enhancing **existing natural solutions** to challenges, while others are exploring more **novel solutions**, for example mimicking how non-human organisms and communities cope with environmental extremes.
- NBS are **energy and resource-efficient**, and **resilient** to change, but to be successful they must be adapted to local conditions.

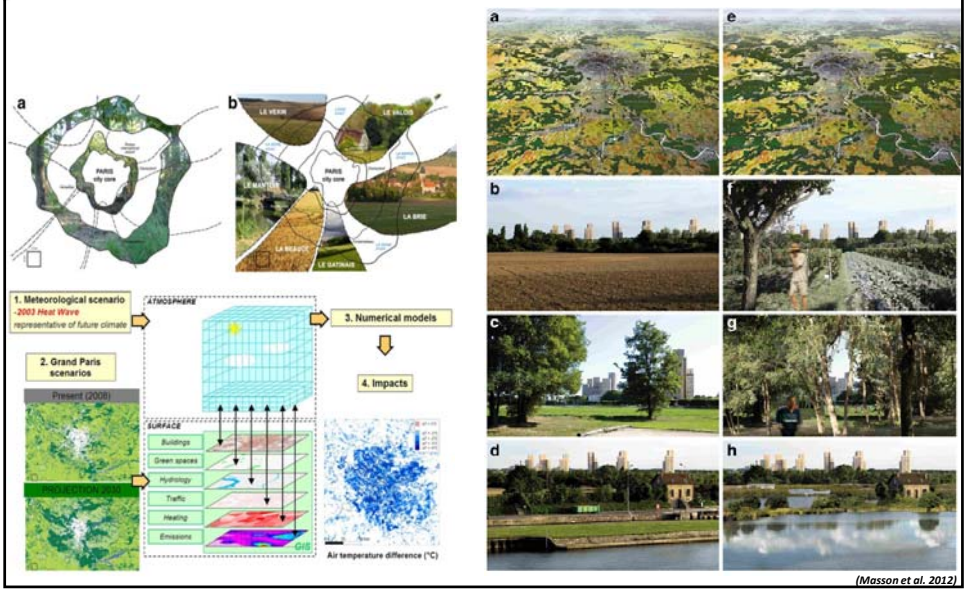
Nature Based Solutions

- **40 M€** in the H2020 WP 2016 - 2017 for NBS implementation.
- Need for **robust monitoring systems**.

Nature Based Solutions

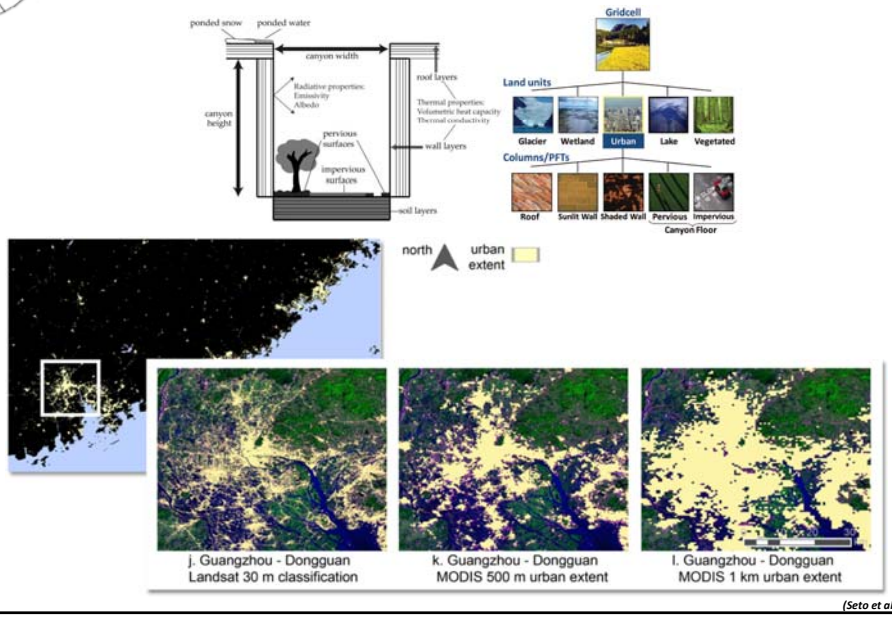
(Reuter 2011)

Nature Based Solutions



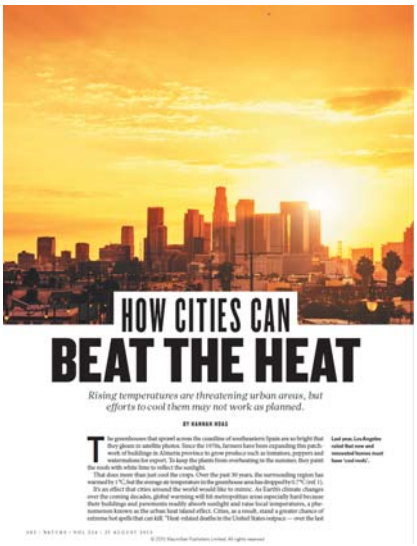
(Masson et al. 2012)

Nature Based Solutions



(Seto et al. 2012)

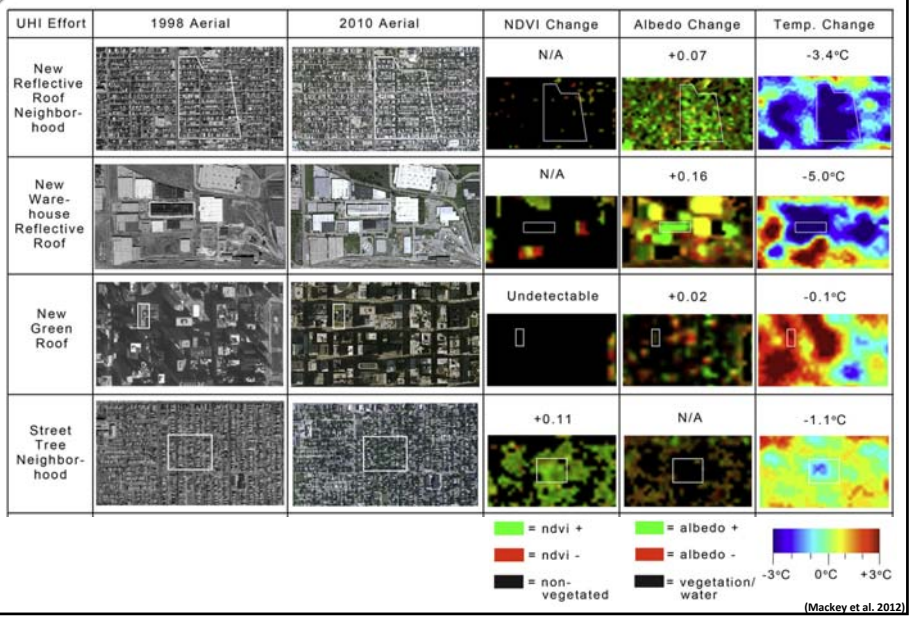
Nature Based Solutions



Nature Based Solutions

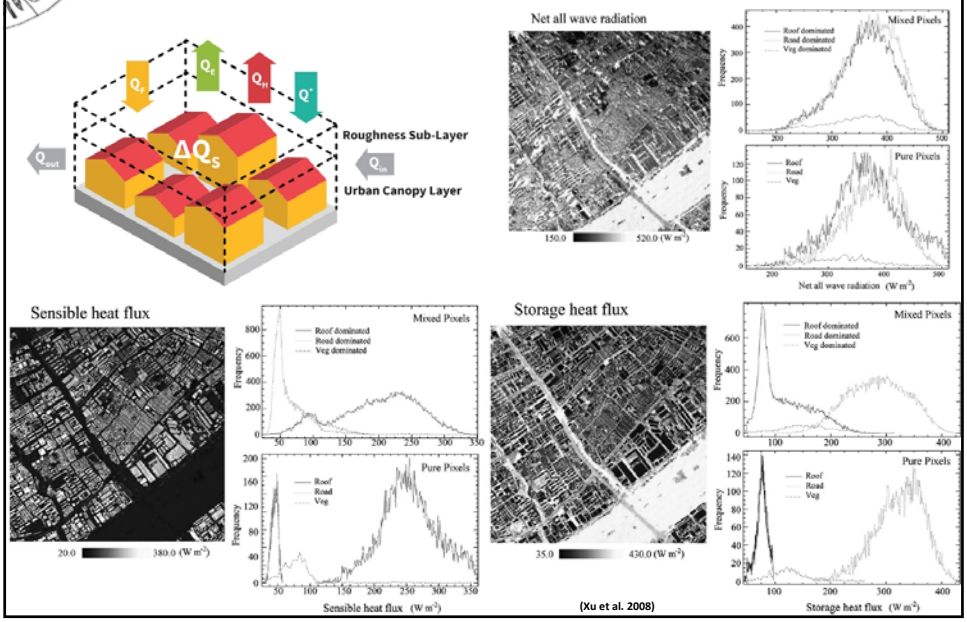
- The **evaluation** of the large scale implementation of NBS should be based on their **sustainability potential**, therefore on their environmental and socioeconomic benefits.
- To assess **environmental impact**, urban planners need to quantitatively estimate the **modification caused by NBS implementation to the UEWC fluxes**.
- Concerning UEW fluxes, NBS deployment can have an impact on the ambient temperature.
- No one knows **how much this approach can cool a whole city**, since only a **few simulations** have evaluated specific technologies, such as green roofs, at that scale.

Nature Based Solutions



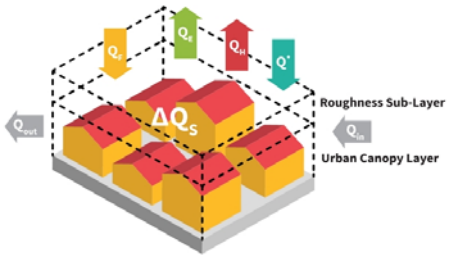
(Mackey et al. 2012)

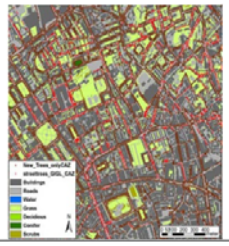
Nature Based Solutions



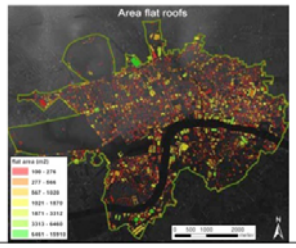
(Xu et al. 2008)

Nature Based Solutions

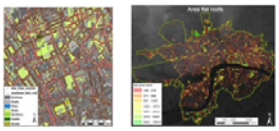




Add new street trees.

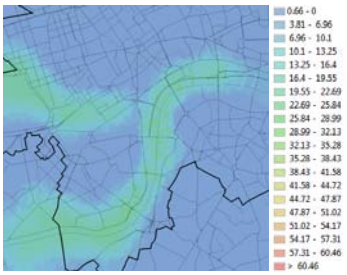


Add green roofs (varying slopes).

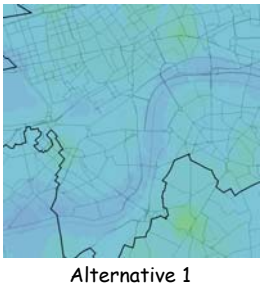


Implementation of both.

Nature Based Solutions

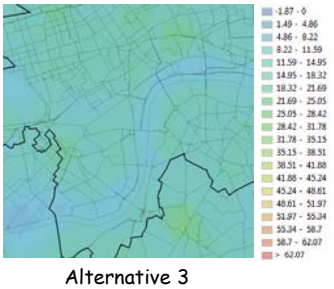


Base



Alternative 1

Alternative 2



Alternative 3

Nature Based Solutions

- The exploitation of EO for the **evaluation** of NBS implementation will lead to **new services** easily **transferable** to any city.
- Support the climate change **mitigation planning** at Municipality level.
- Support the **smart cities** concept towards building **resilience**.
- Support **sustainable planning strategies** to improve the **quality of life** in cities.
- RSLab in H2020: from **URBANFLUXES** to **ThinkNature.**

Thank you!

Nektarios Chrysoulakis

FORTH/IACM

N. Plastira 100, Vassilika Vouton,
70013, Heraklion

zedd2@iacm.forth.gr

http://rslab.gr