



# URBANFLUXES

URBAN ANTHROPOGENIC HEAT FLUX FROM EARTH  
OBSERVATION SATELLITES

A novel approach  
for anthropogenic heat flux  
estimation from space

Nektarios Chrysoulakis &  
the URBANFLUXES Team

<http://urbanfluxes.eu>

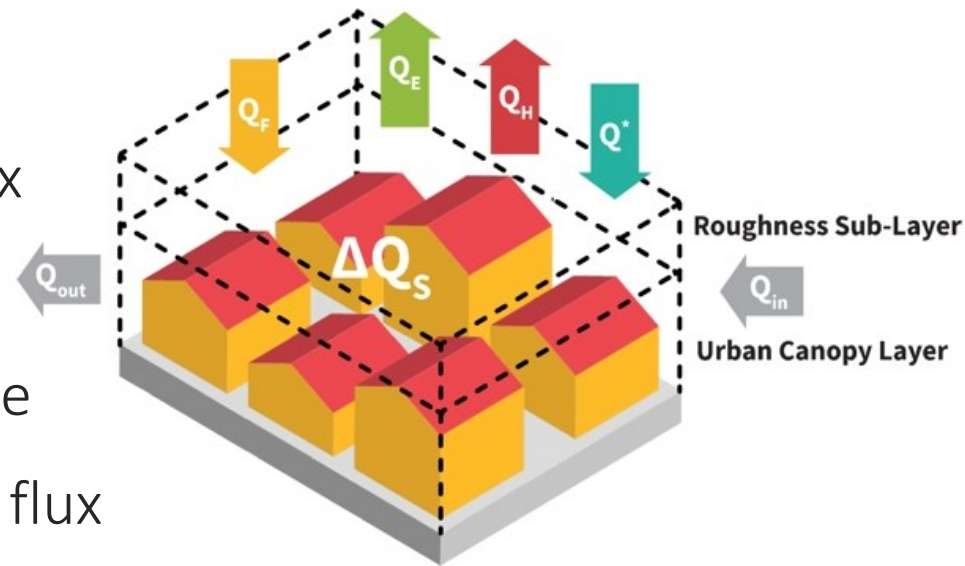
ICUC9, Toulouse,  
July 24, 2015



# Urban energy balance

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

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



# Why URBANFLUXES?

- › EO-1-2014: **New ideas** for Earth-relevant space applications
- › 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**.



**URBANFLUXES**

URBan ANthropogenic heat FLUX from Earth observation

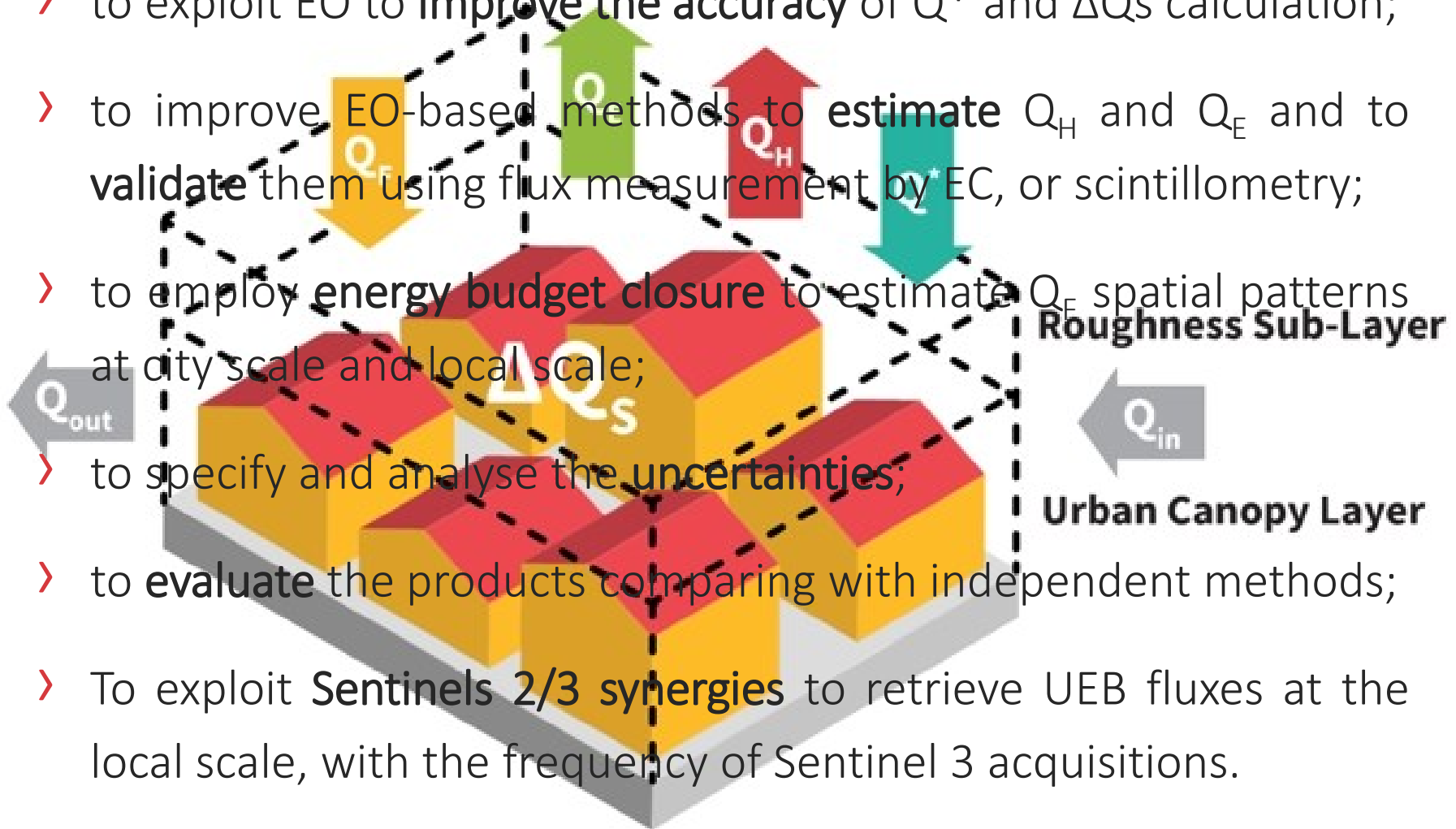
[urbanfluxes.eu](http://urbanfluxes.eu)

Funded under  
H20.1.2 on 2020

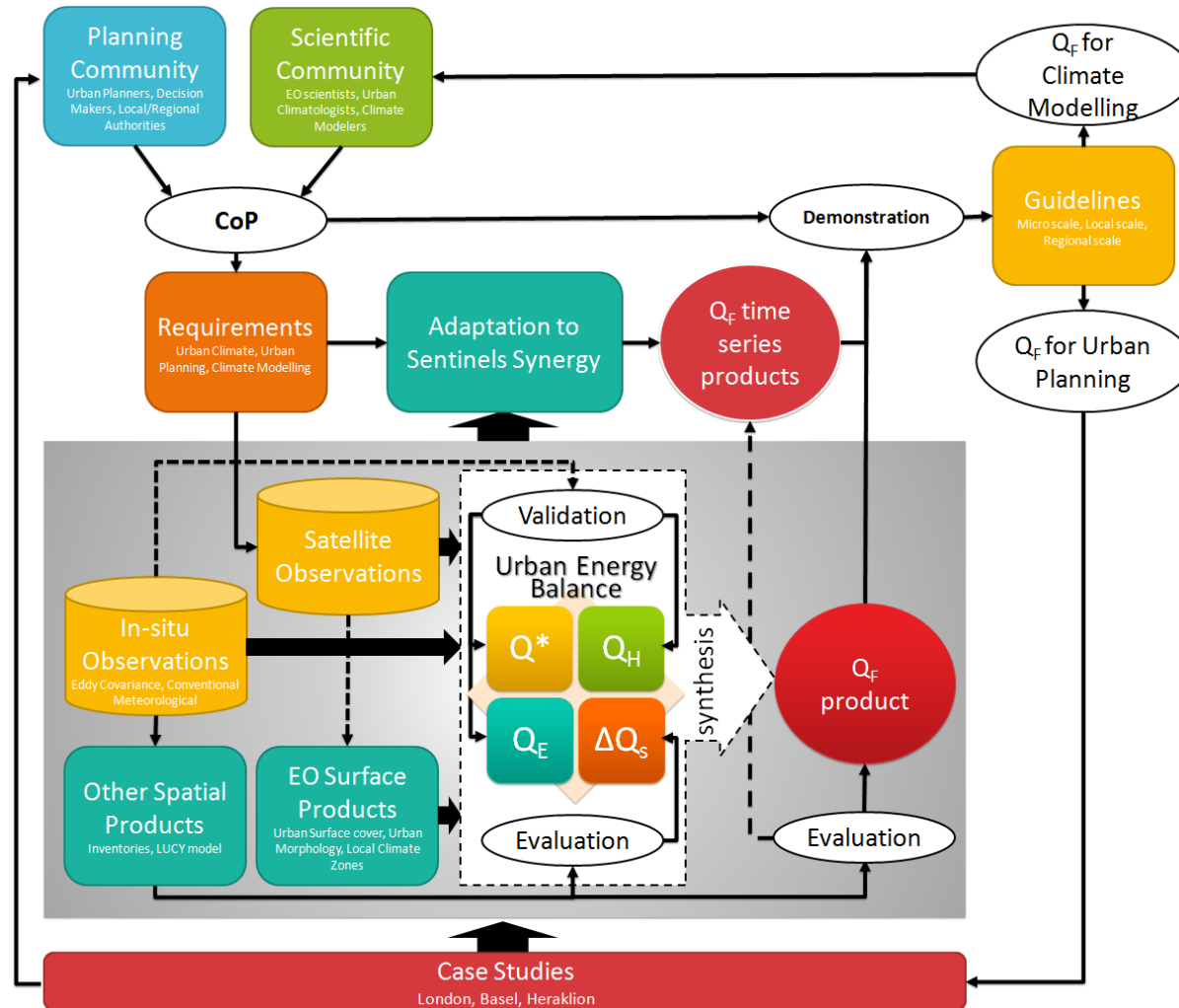


# The objectives

- > to exploit EO to improve the accuracy of  $Q^*$  and  $\Delta Q_s$  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  $Q_E$  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.



# The approach



# The approach

› In-situ measurements:

Wireless network for high spatial resolution measurements of:

Surface temperature

Air temperature

Relative humidity

Soil moisture/temperature





# The approach

› In-situ measurements:

Independent measurements of  $Q_E$  and  $Q_H$

Eddy covariance from flux towers

Large-aperture scintillometers



# Local Climate Zones



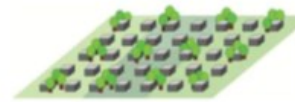
*LCZ3 – Compact low rise*

*LCZ6 – Open low rise*

*High angle*



*High angle*



*Low level*



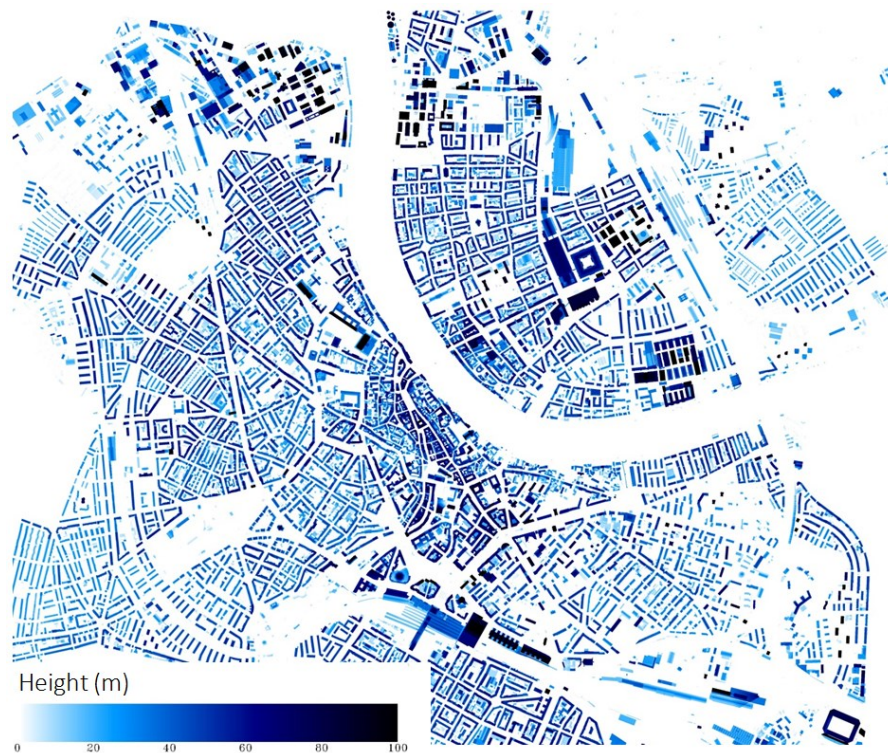
*Low level*



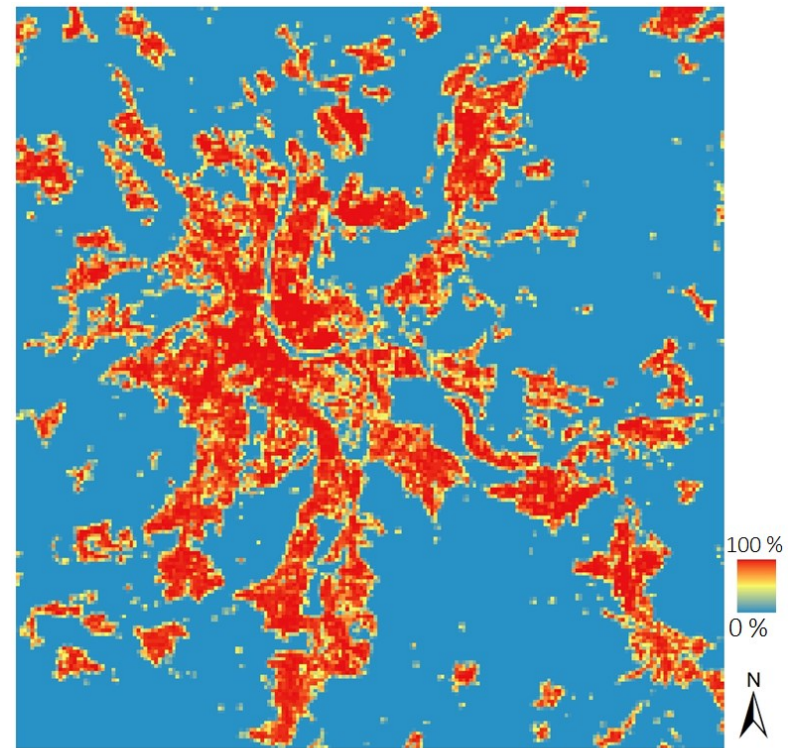


# Urban morphology

- › Relevant parameters: Sky View Factor (*SVF*), Building and vegetation heights ( $z_H$ ,  $z_{H(SD)}$ ,  $z_{H(max)}$ ), Plan area index ( $\lambda_P$ ), Frontal area index ( $\lambda_F$ )



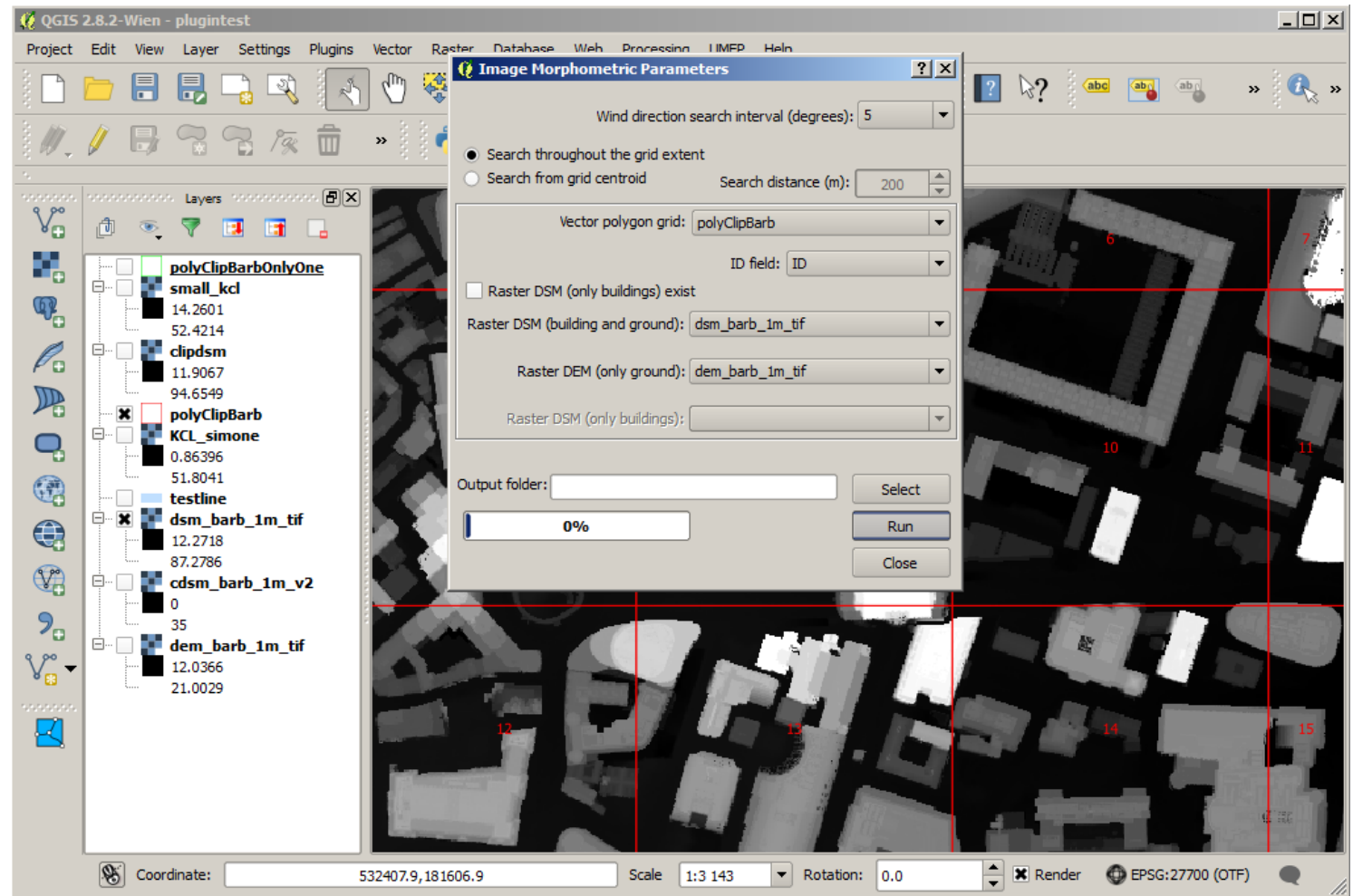
Digital surface model (DSM) of Basel



Building density of Basel based on GUF data (100 m grid)

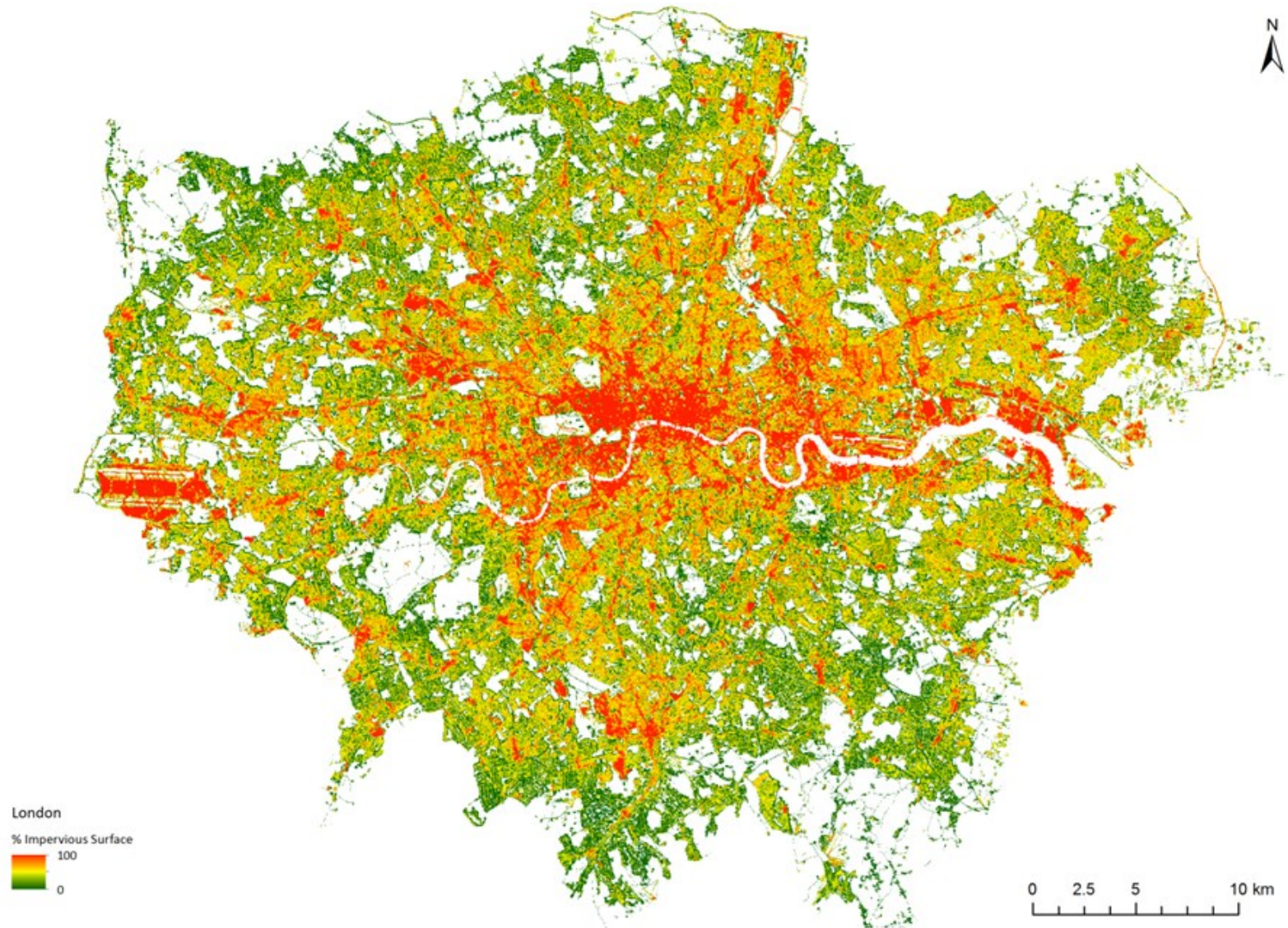
# Urban morphology

- › Urban Multi-scale Environmental Predictor (UMEP)



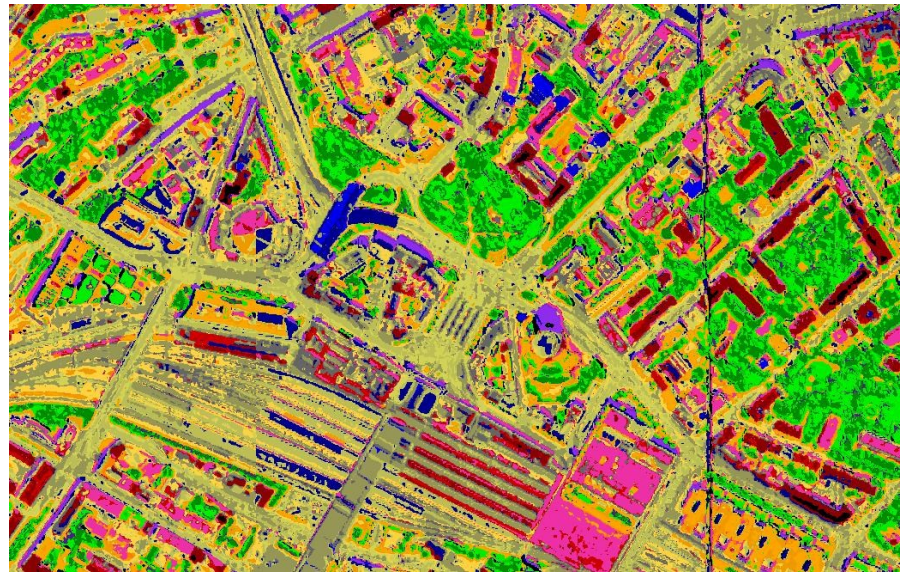


# Urban surface characteristics





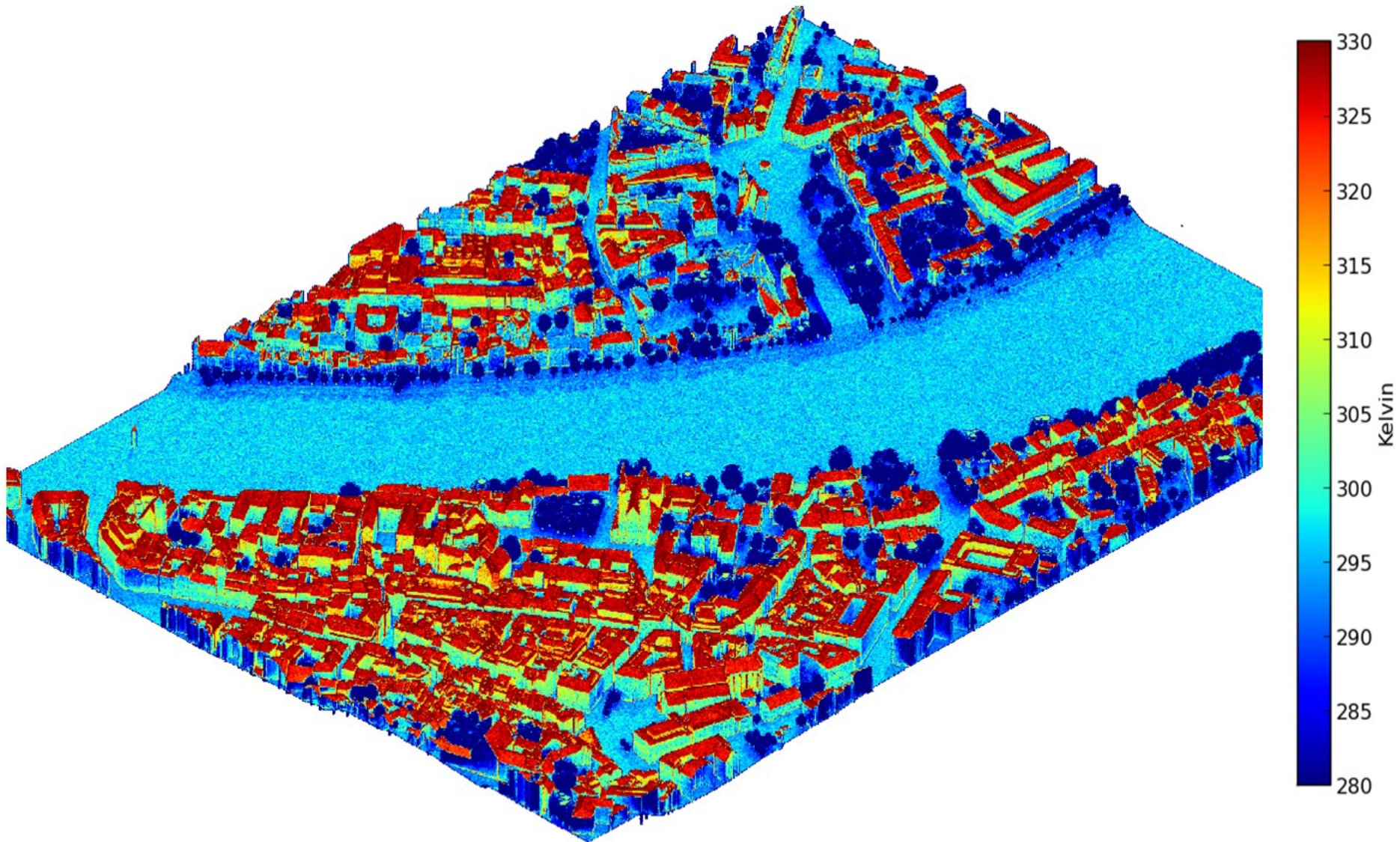
# Urban surface characteristics



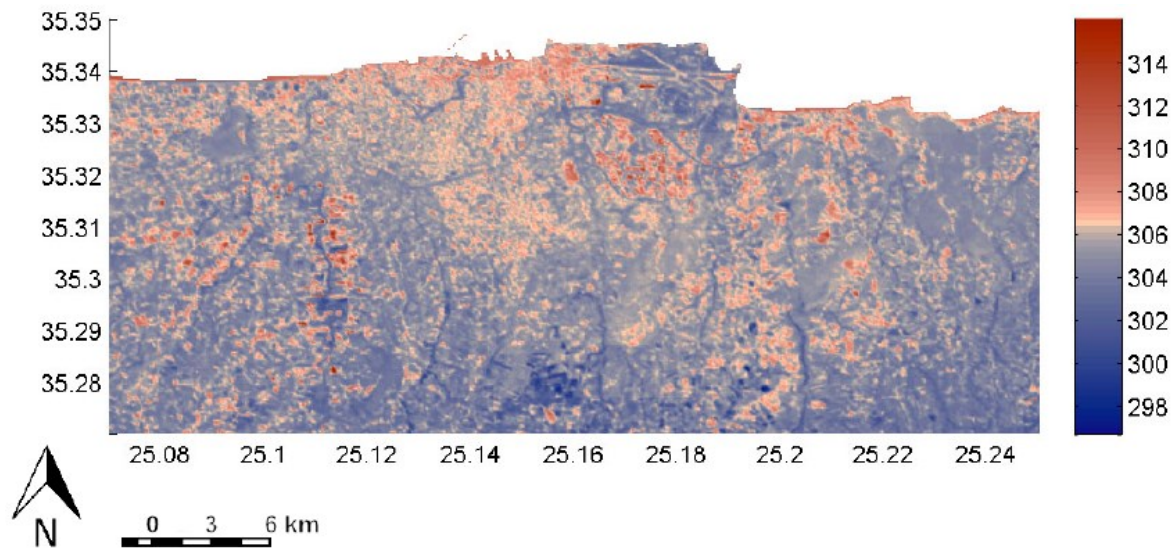
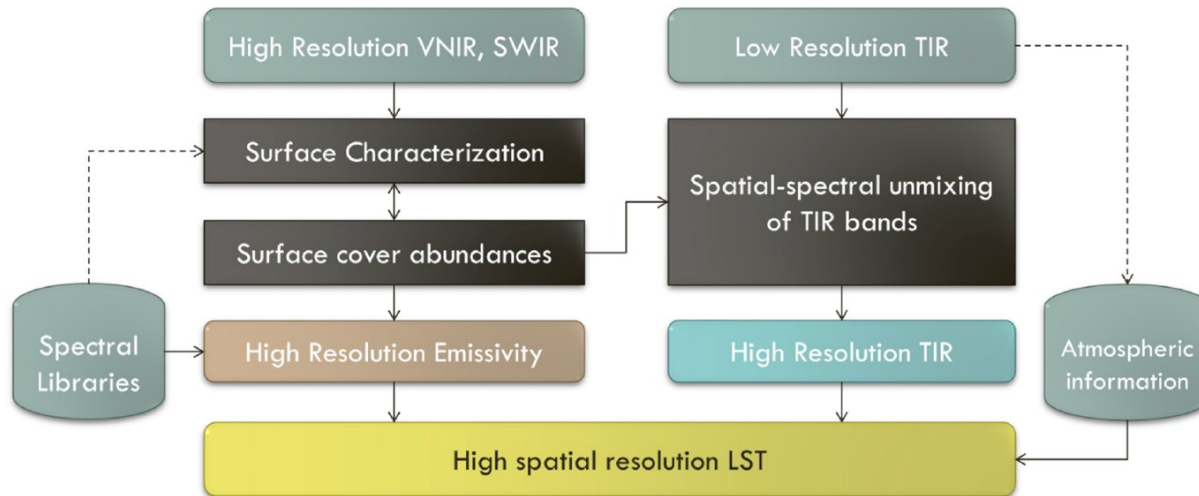
bright tiles	metal I	asphalt I	lawn/meadow	clay	gravel
red tiles	metal II	asphalt II	trees I	sandy soil	tar
dark red tiles	metal III	asphalt III	trees II	bare soil	concrete



# Urban surface characteristics

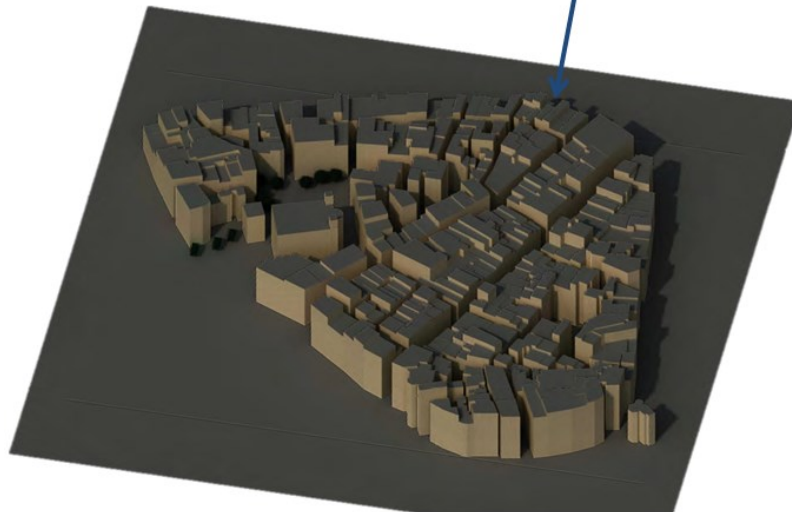


# Urban surface temperature

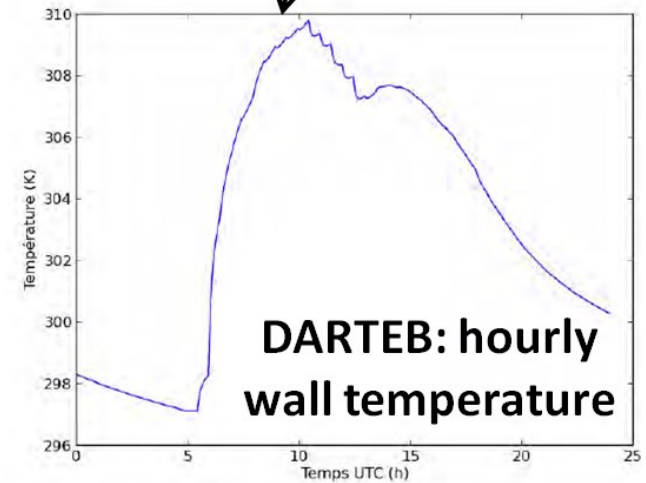




# Radiation balance ( $Q^*$ )



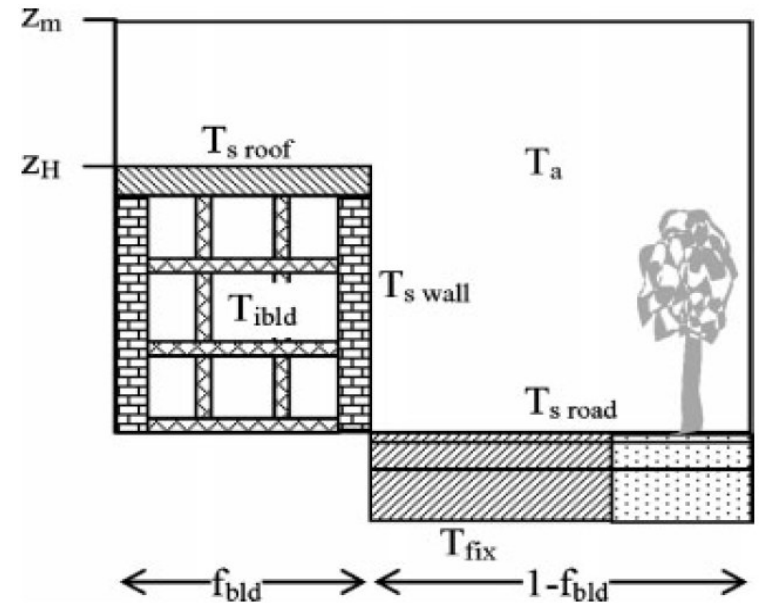
DART: color composite reflectance image



# Heat storage change ( $\Delta Q_s$ )

ESTM (Element Surface Temperature Method):

- › Based on facet areas.
- › Incorporates heat transfer between the different elements.
- › Estimated  $\Delta Q_s$  represents unit plan area.



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

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

## Input data

### Materials

Thermal conductivity

Volumetric heat capacity

### Physical arrangement of elements

→ view factors between elements

$T_s$

$T_{air}$  inside and outside

Soil temperature  $T_{fix}$  (where  $dT/dz = 0$ )



# Heat storage change ( $\Delta Q_s$ )

OHM (Objective Hysteresis Model):

- › Contributions to  $\Delta Q_s$  from multiple surface material types
- › EO-derived  $dQ^*/dt$  (e.g. Xu et al., 2008)

$Q^*$  and  $dQ^*/dt$  measurements from EO

$$\Delta Q_s = \sum \underbrace{f_i a_{1,i}}_{\text{Parameters specific to land cover class}} Q^* + \underbrace{f_i a_{2,i}}_{\text{Parameters specific to land cover class}} \frac{dQ^*}{dt} + \underbrace{f_i a_{3,i}}_{\text{Parameters specific to land cover class}}$$

Parameters specific to land cover class

# Turbulent Heat Fluxes ( $Q_H$ , $Q_E$ )

- > Aerodynamic Resistance Method (ARM)

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

From EO (WP 4 & 5) →  $T_S$

Measured in-situ →  $T_{air}$

← Aerodynamic resistance

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

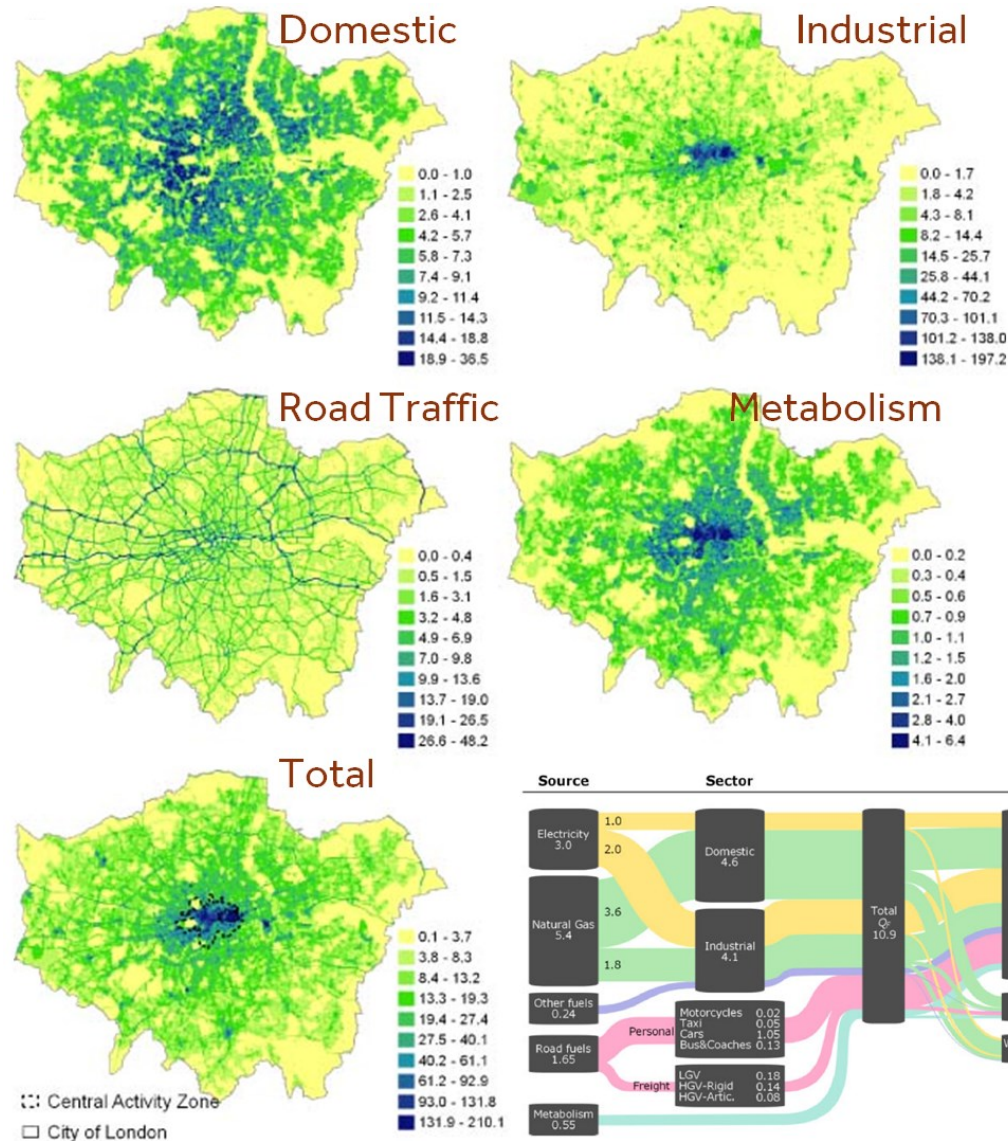
From EO (WP 4 & 5) →  $e_S$

Measured in-situ →  $e_{air}$

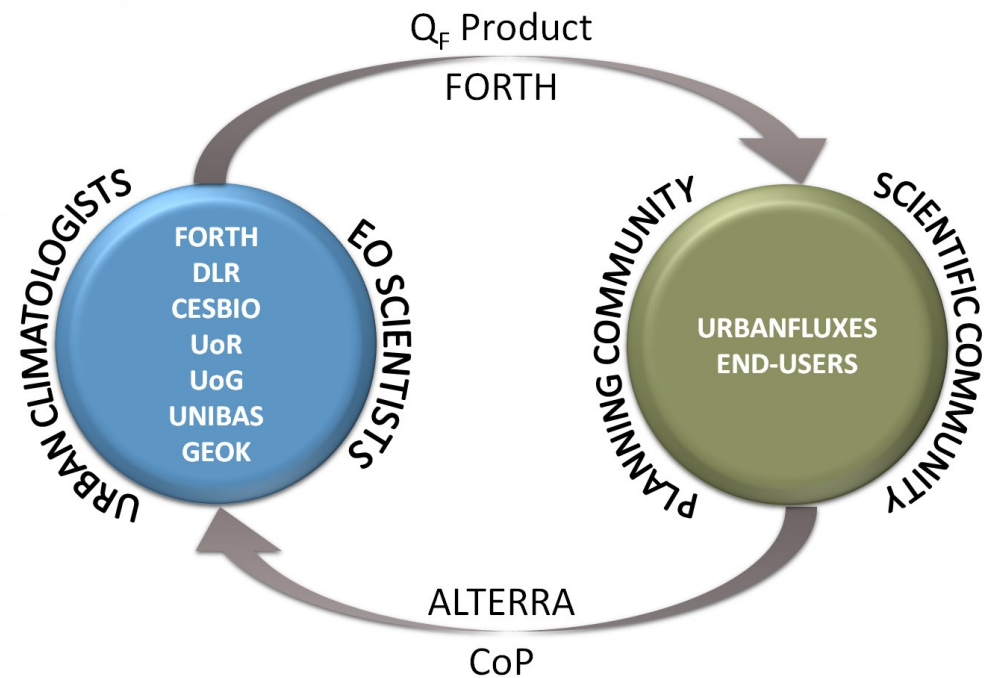
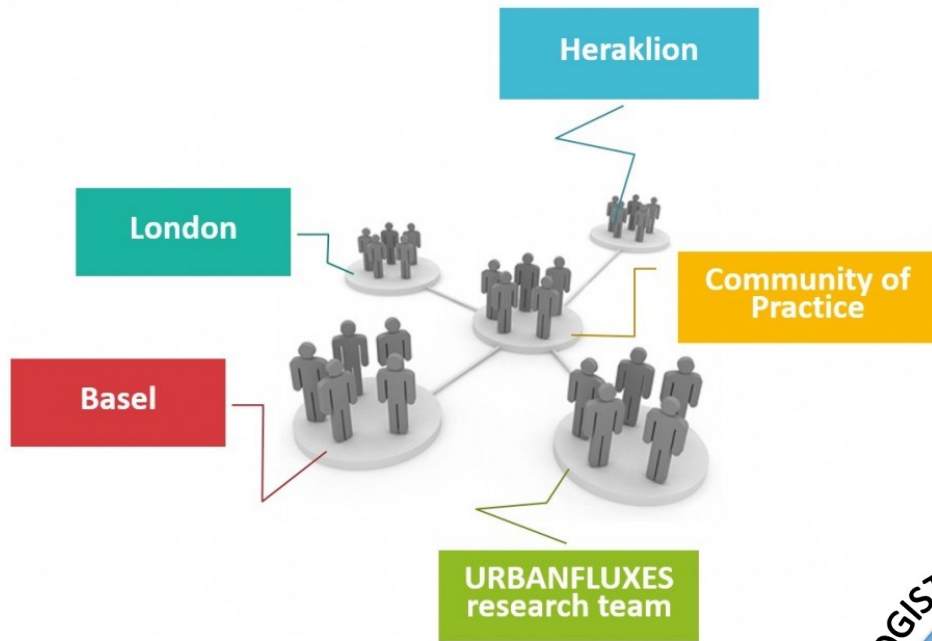
← Vapour pressures

← Surface resistance  
Depends on vegetation type, moisture conditions

# Comparison with non-satellite



# The involvement of users





# Visit URBANFLUXES web-site

> <http://urbanfluxes.eu>

The screenshot shows the main page of the UrbanFluxes website. At the top, there is a navigation menu with links for Home, About, Blog, Data, Publications, Contact, Private Area, News, Log In, and Register. The main content area features a large banner image of a satellite over a city. Below the banner, there is a video player with the text "Our world is warming up. Cities are even hotter than their surroundings." and a "Subscribe" button. To the right, there is a "SIGN UP FOR URBANFLUXES PROJECT" form with fields for Email Address, First Name, and Last Name. Below the form, there is a "LATEST NEWS" section with a link to "Sentinel 2A launched!" dated June 29, 2015.

The screenshot shows the blog page of the UrbanFluxes website. The navigation menu is the same as the homepage. The main content area features a large banner image of a satellite over a city. Below the banner, there is a "HOME / BLOG" section. The main content area is divided into three columns. The left column features a "Sentinel 2A launched!" article dated June 29, 2015. The middle column features a "Communities of Practice" article dated May 29, 2015, with a diagram showing the "URBANFLUXES research team" and "Community of Practice" in London and Basel. The right column features a "SIGN UP FOR URBANFLUXES PROJECT" form with fields for Email Address, First Name, and Last Name, and a "Subscribe" button. Below the form, there is a "LATEST NEWS" section with a link to "Sentinel 2A launched!" dated June 29, 2015.

# 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**.



THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION

HORIZON 2020

The logo for Horizon 2020 features a central globe of the Earth, which is the letter 'O' in the word 'HORIZON'. The globe is positioned above a curved horizon line that represents the Earth's surface. The background is a deep blue gradient with light rays emanating from behind the globe, creating a sense of depth and focus. The text 'HORIZON 2020' is written in a clean, white, sans-serif font across the middle of the image. Above it, the text 'THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION' is written in a smaller, white, sans-serif font.