→ MAPPING URBAN AREAS FROM SPACE CONFERENCE

UEB estimation from Sentinels: The URBANFLUXES Project

Nektarios Chrysoulakis,
FORTH

http://urbanfluxes.eu

4–5 November 2015 | ESA–Esrin | Frascati, Rome (Italy)

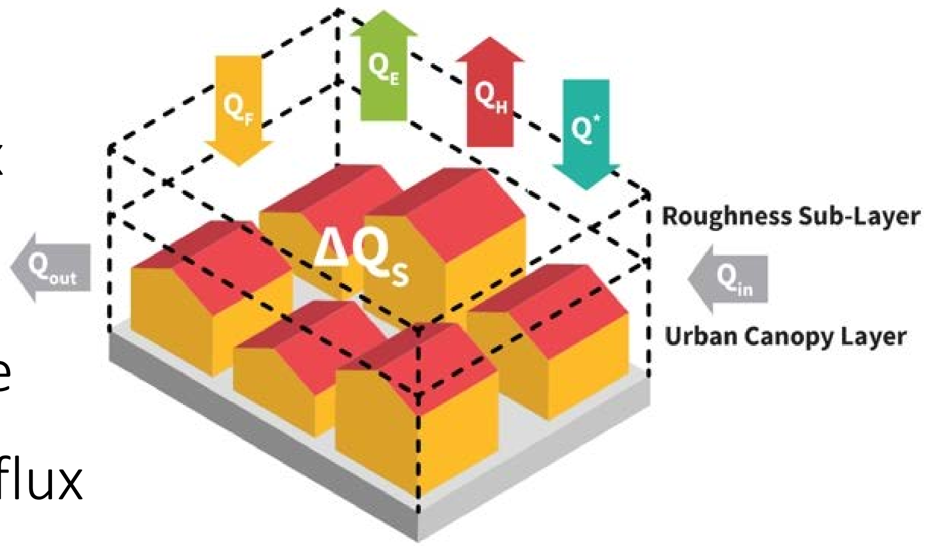
Introduction

URBANFLUXES

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
- ΔQ_S : Net change in heat storage
- $\Delta Q_A = Q_{in} - Q_{out}$: Advective heat flux
- *S:* All other sources and sinks



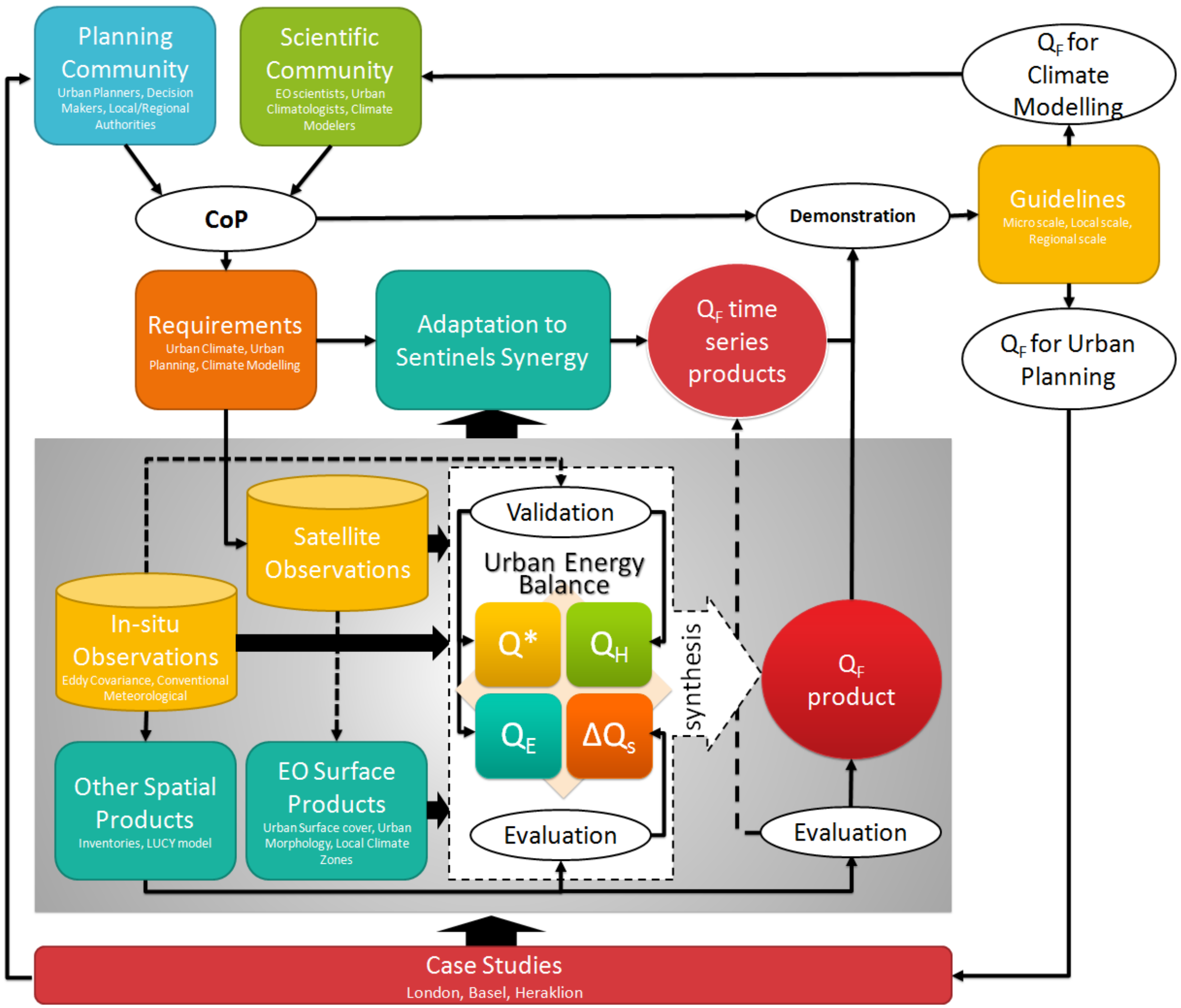
Why URBANFLUXES?

- 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.
- **Challenge:** the estimation of **Q_F spatial patterns** by current EO systems.
- **Major challenge:** the innovative exploitation of the Copernicus Sentinels **synergistic observations** to estimate **Q_F spatiotemporal patterns**.

The objectives

- 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.

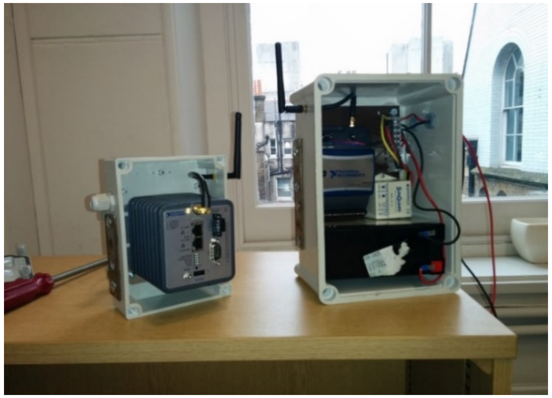
The approach

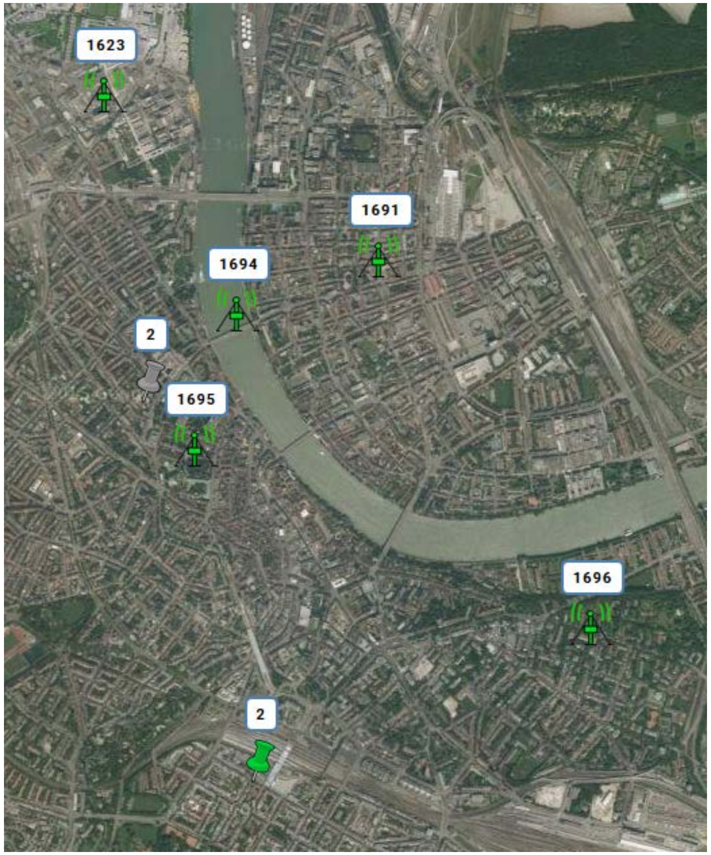


In-situ observations

- Wireless Sensors Networks:

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



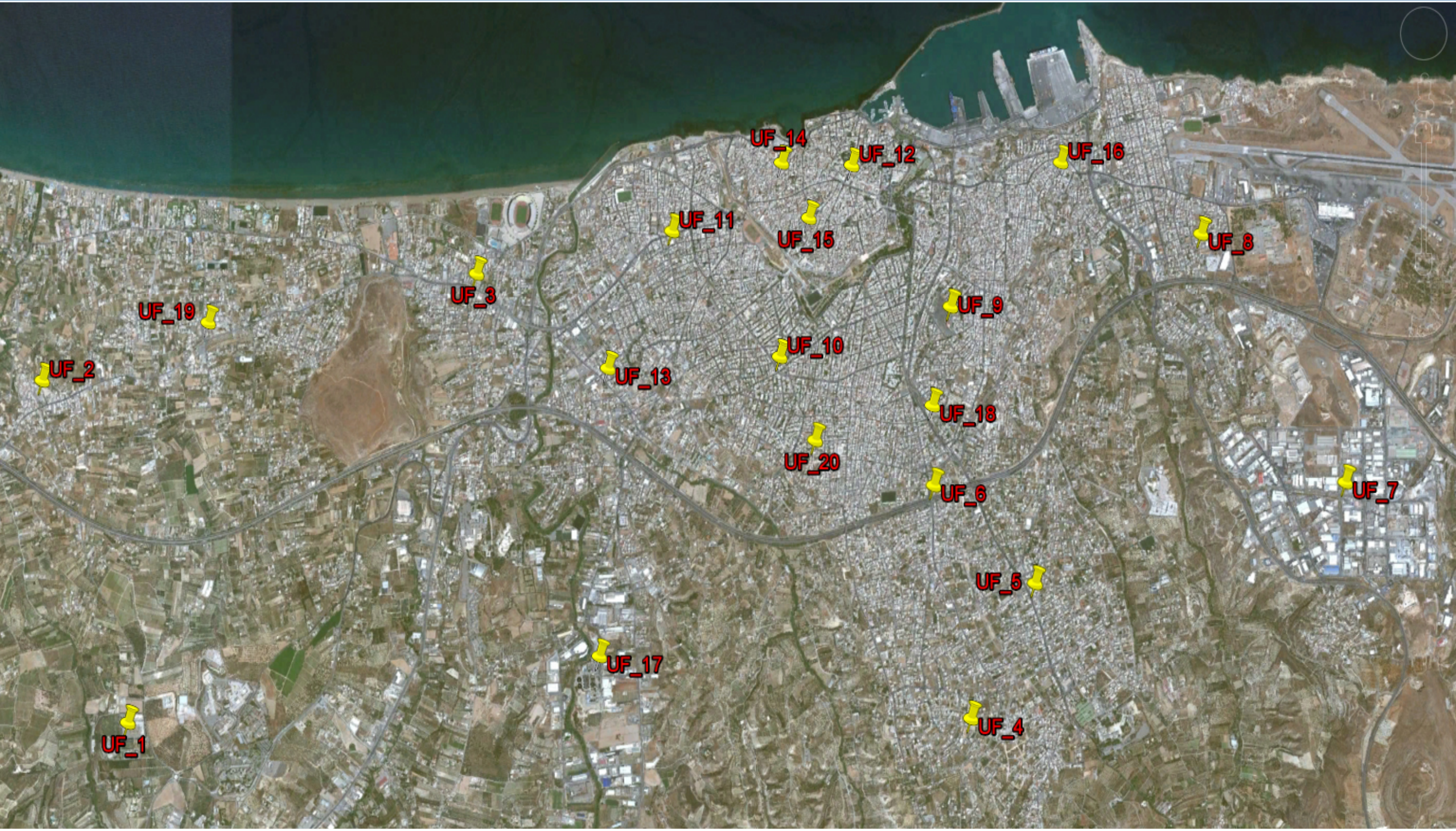


In-situ observations

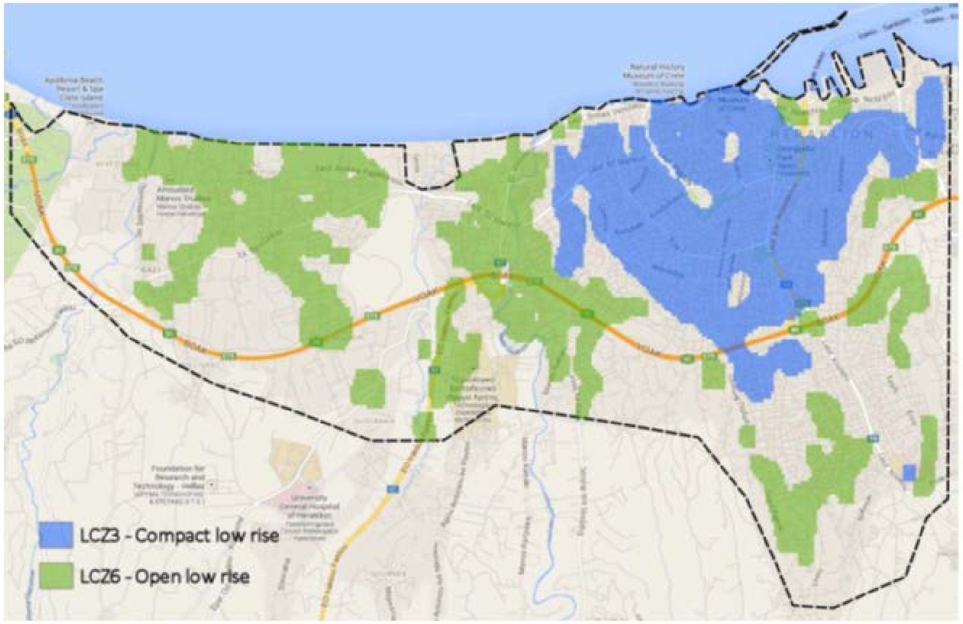
- Flux measurements:

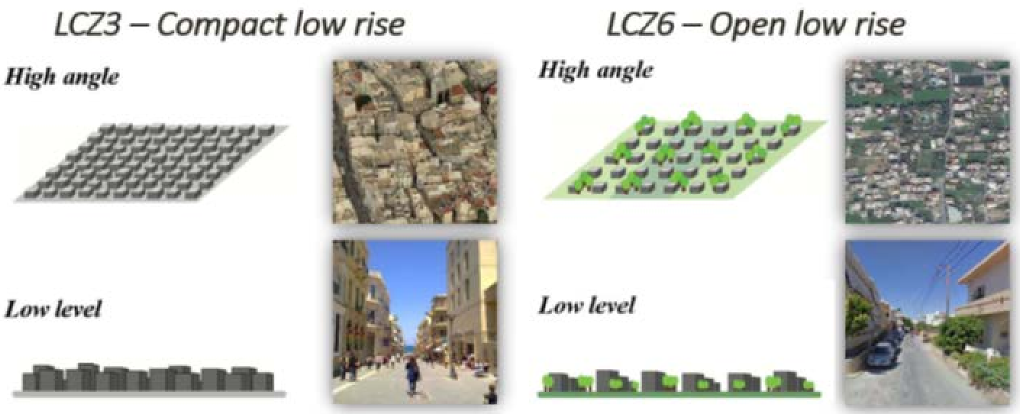
  Independent for Q_E and Q_H
  - Eddy covariance from flux towers
  - Large-aperture scintillometers

In-situ observations



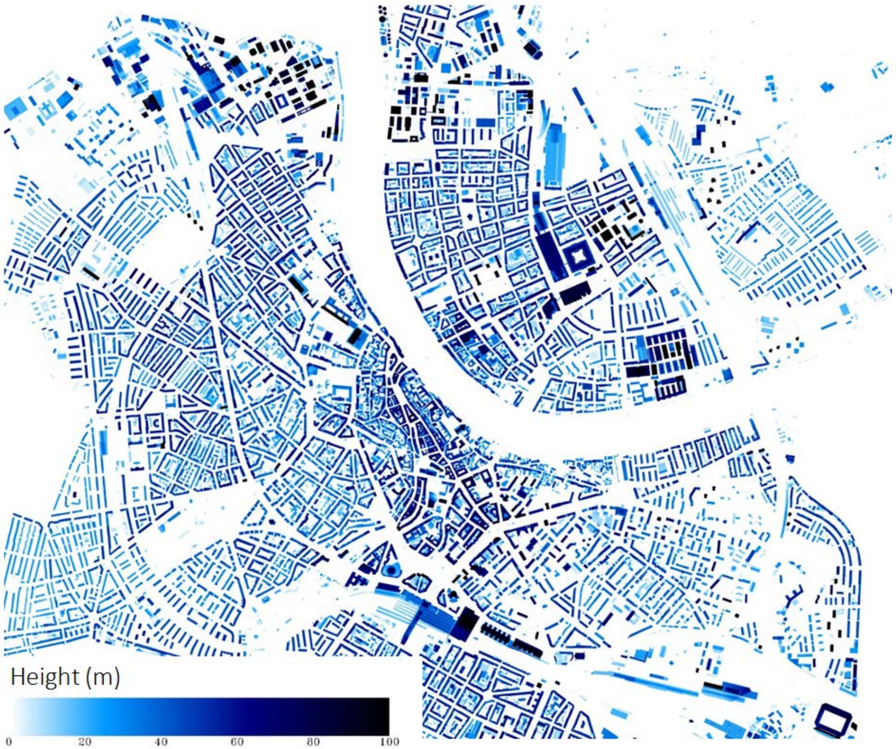
Local Climate Zones



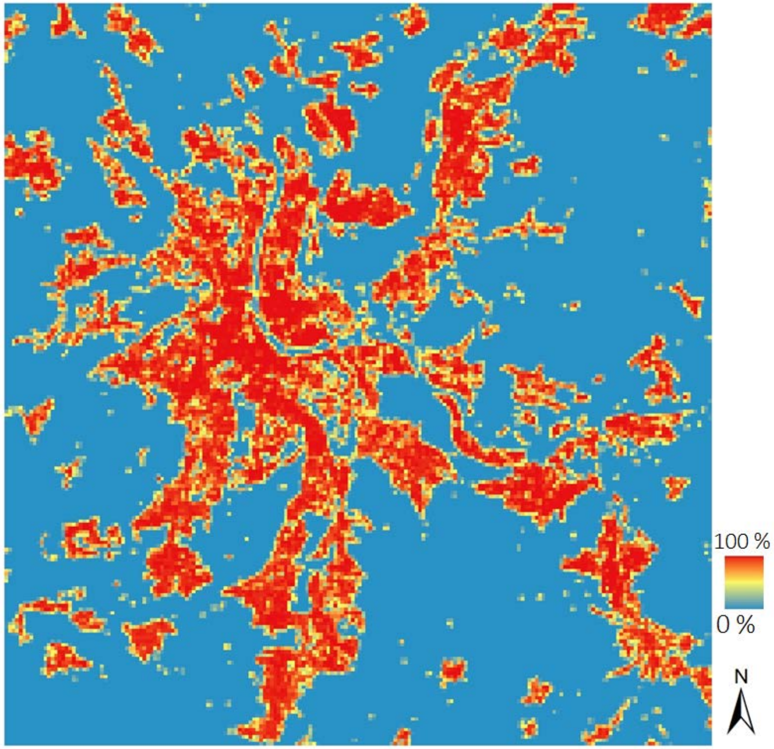


Urban morphology

- **Relevant parameters**: Sky View Factor (*SVF*), Building and vegetation heights (z_H, $z_{H(SD)}$, $z_{H(max)}$), Plan area index (λ_P), Frontal area index (λ_F), Canyon aspect ratio (λ_s).

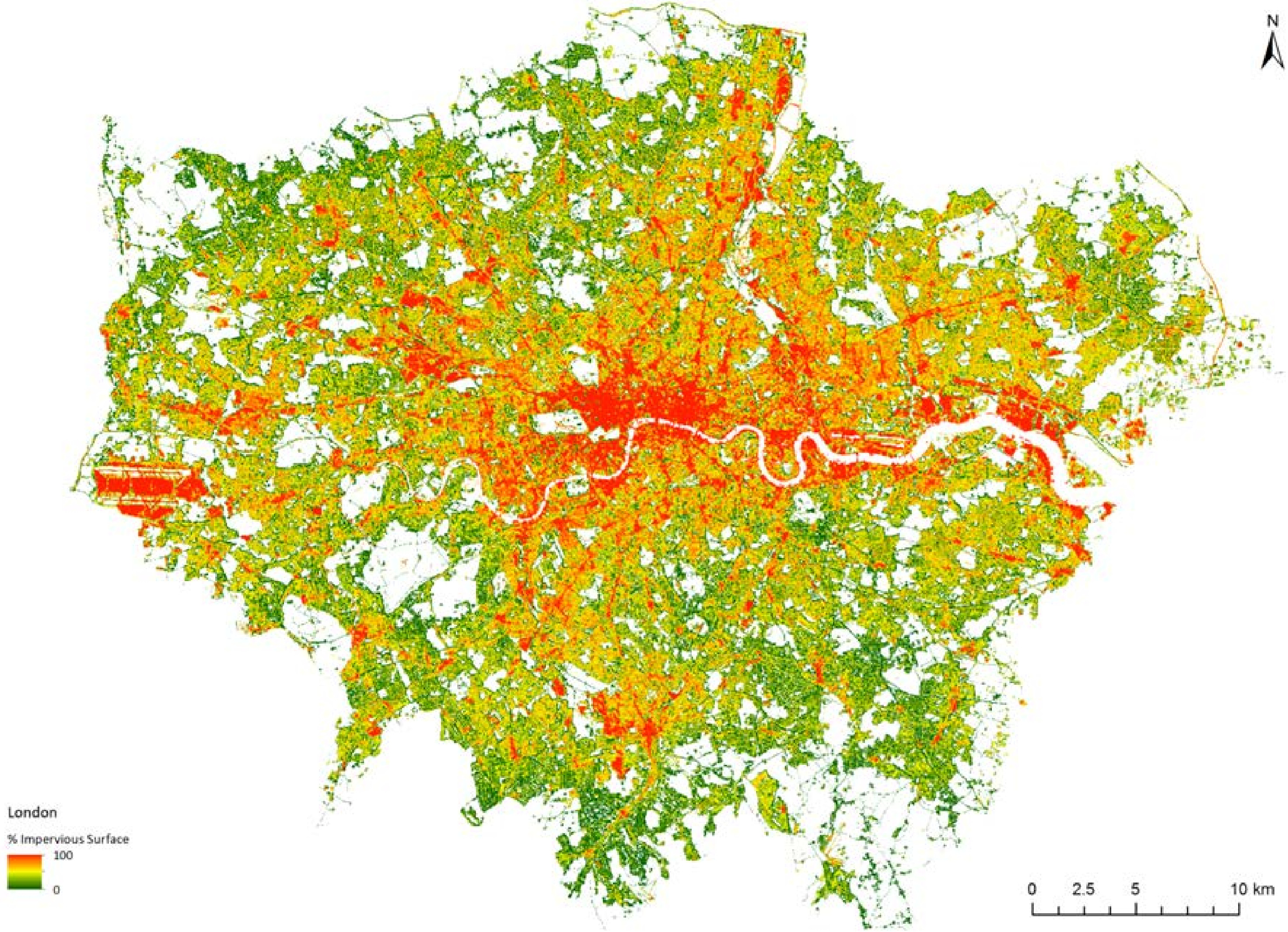


Digital surface model (DSM) of Basel

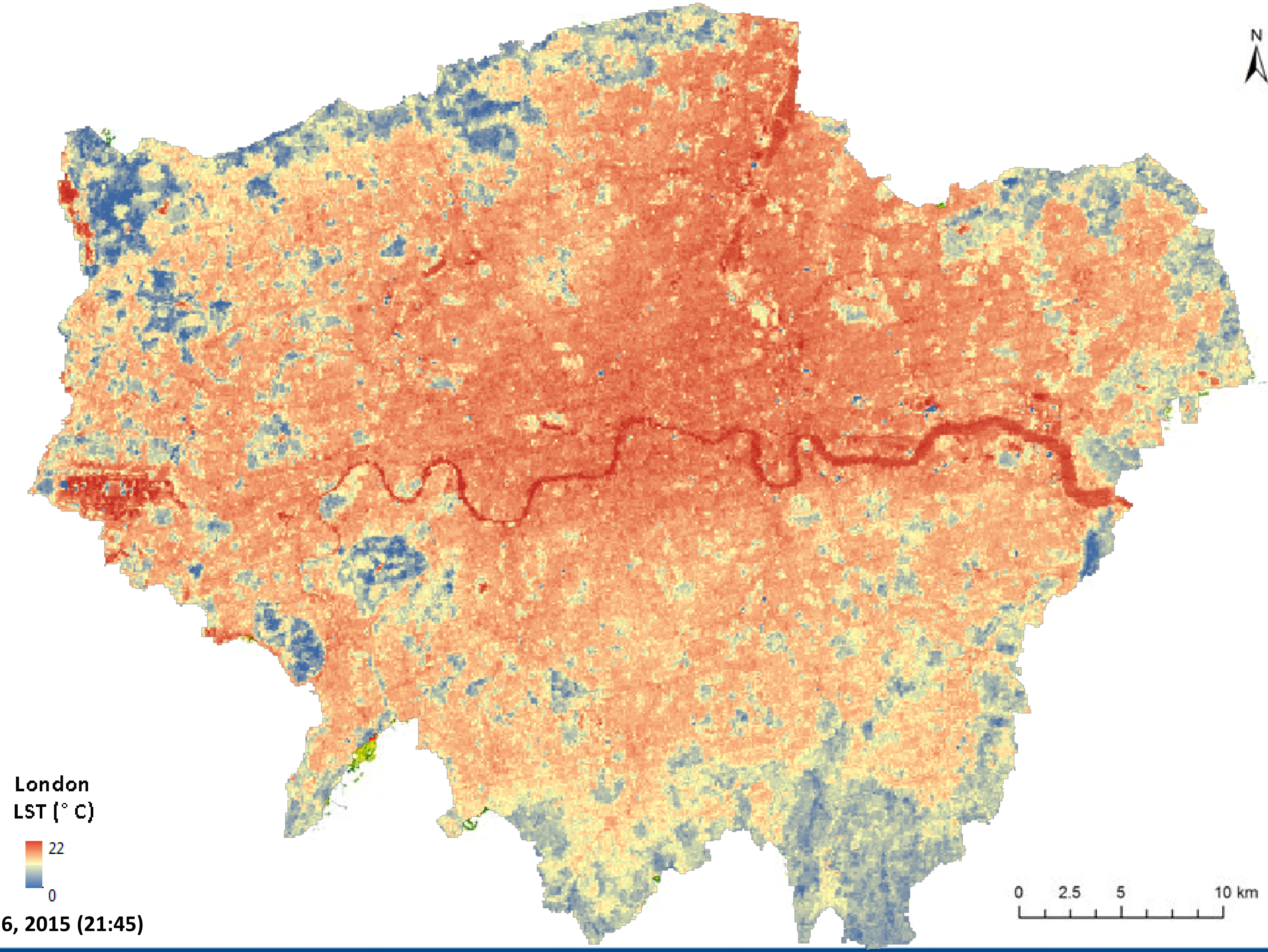


Building density of Basel based on GUF data (100 m grid)

Urban surface characteristics

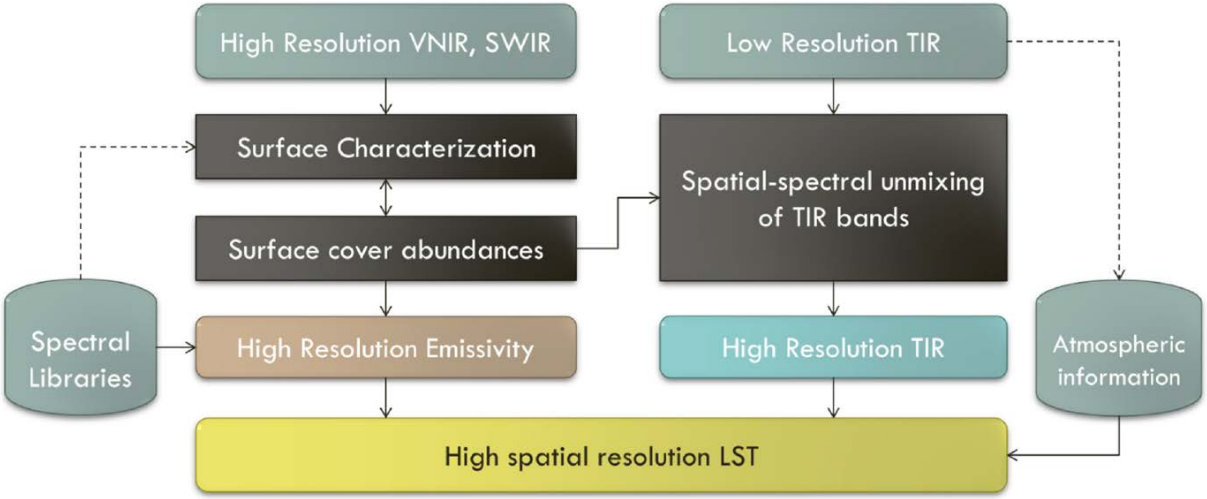


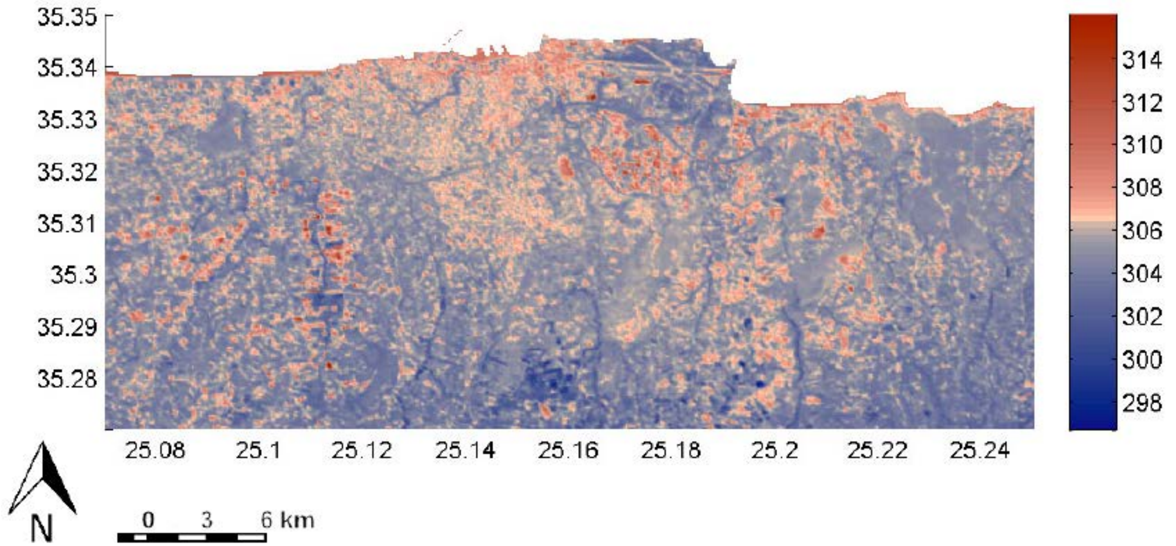
Urban surface temperature



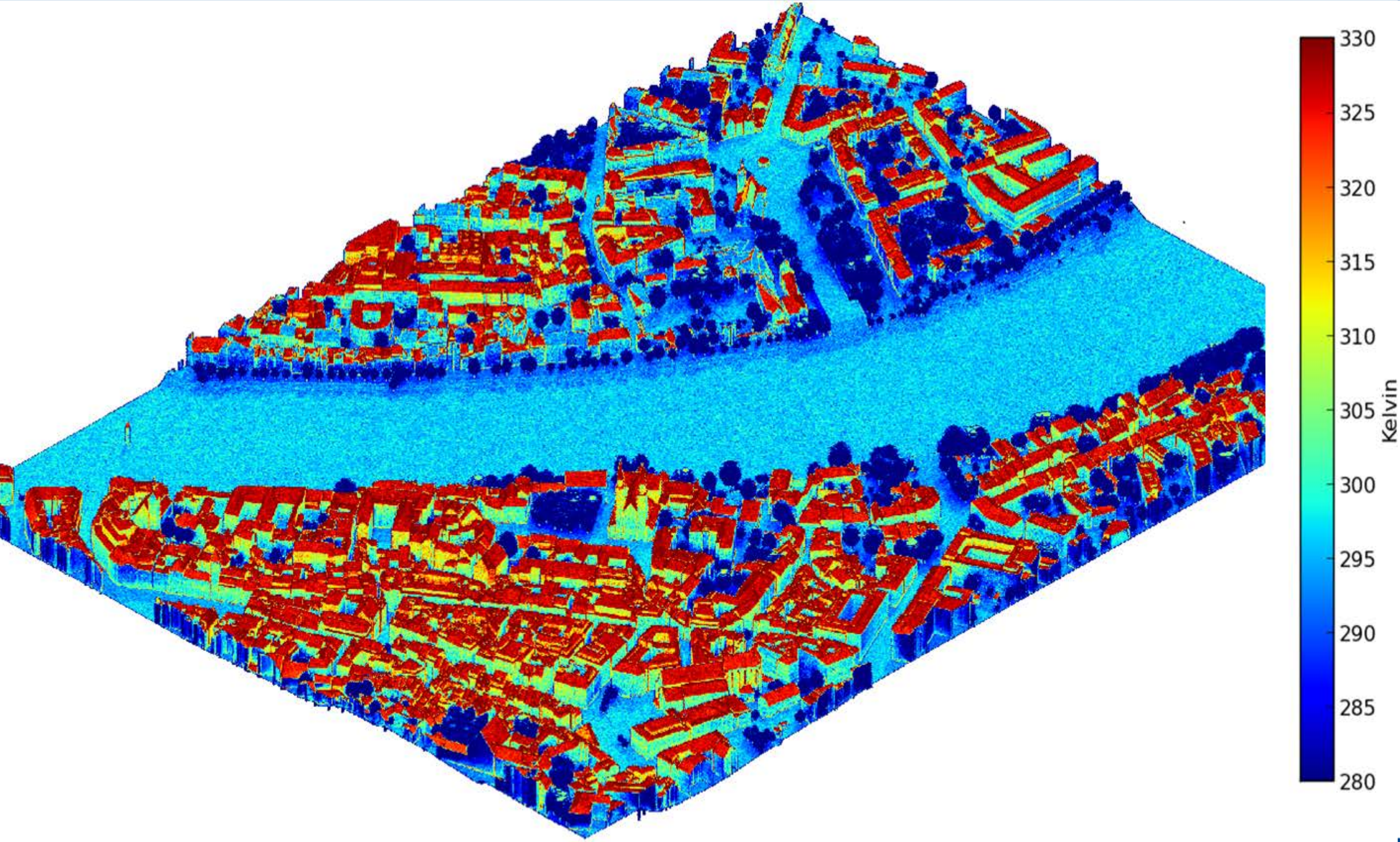
August 6, 2015 (21:45)

Urban surface temperature





Urban surface temperature



Urban surface albedo

- **DART** simulates surface multispectral reflectance $\boldsymbol{\rho}_{DART}(\lambda,x,y)$ and shortwave albedo $\mathbf{a}_{DART}(x,y)$ for any satellite acquisition (date: $\mathbf{t}_{sat}$; viewing geometry: Ω_v; and atmospheric conditions: **AOT**, **PW**).

- Simulated images are resampled to satellite resolution (x_{sat}, y_{sat}).

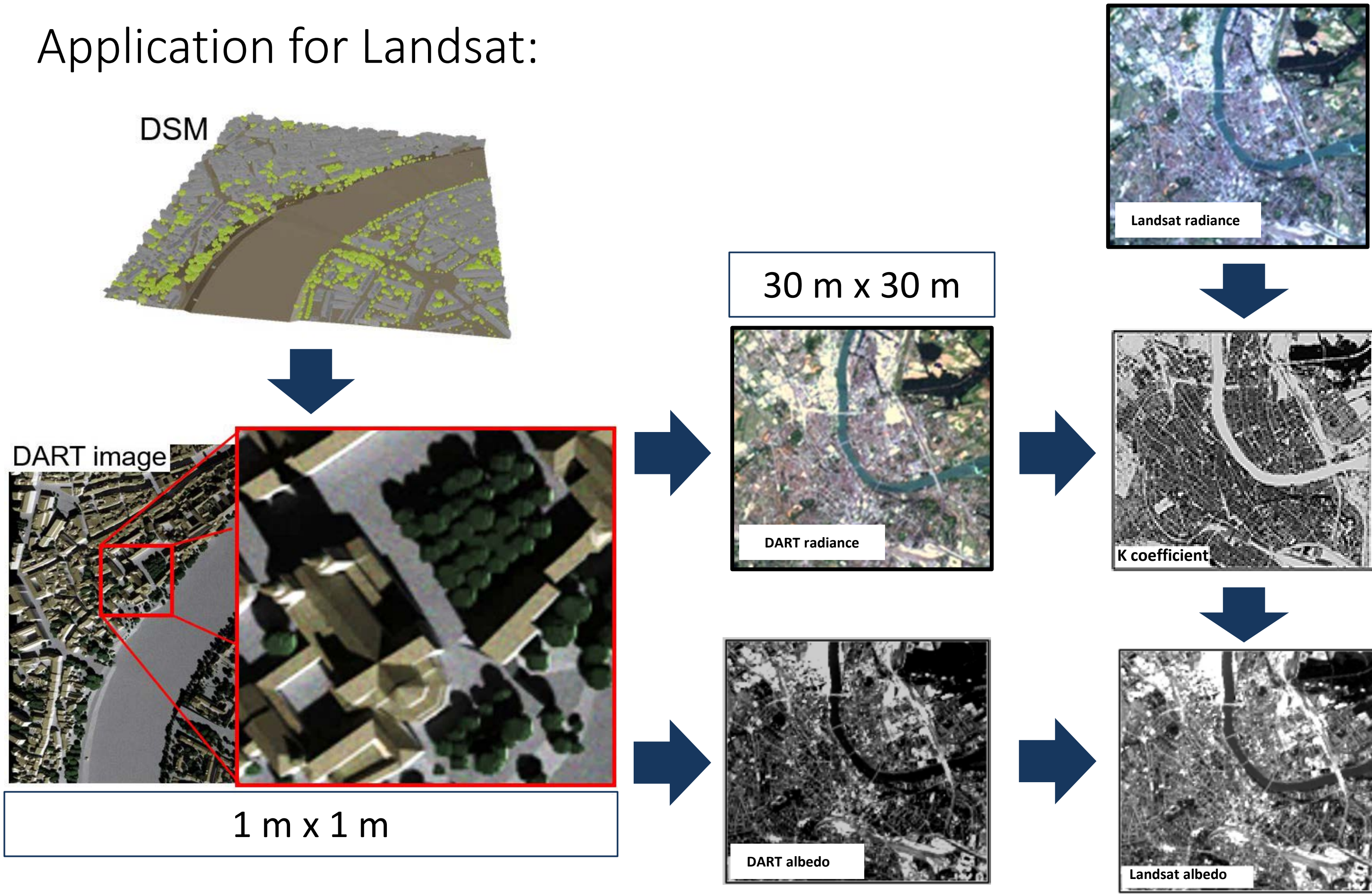
- The resampled reflectance image $\boldsymbol{\rho}_{DART}(\lambda,x_{sat},y_{sat})$ is calibrated with the atmospherically corrected satellite image $\boldsymbol{\rho}_{sat}(\lambda,x_{sat},y_{sat})$:

$$K(\lambda,x_{sat},y_{sat},t_{sat})=\frac{\rho_{sat}\,(\lambda,x_{sat},y_{sat},t_{sat},\Omega_s,\Omega_v,AOT,PW)}{\rho_{DART}\,(\lambda,x_{sat},y_{sat},t_{sat},\Omega_s,\Omega_v,AOT,PW)}$$

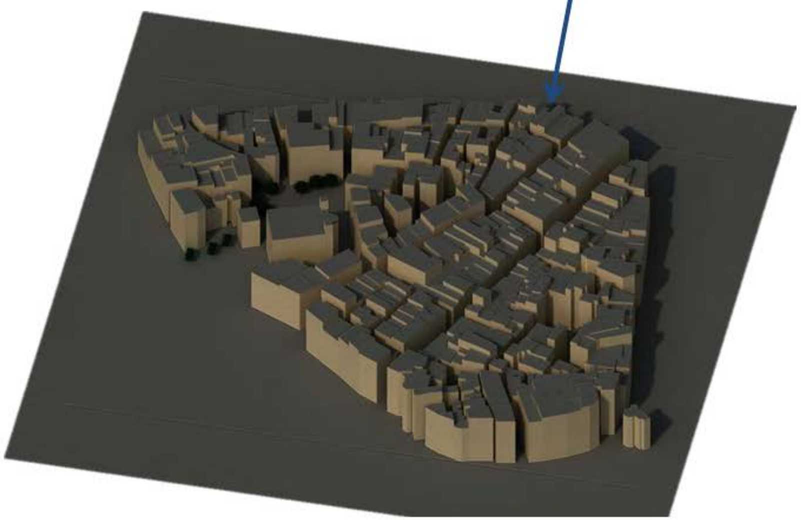
- Calibration of $\mathbf{a}_{DART}(x_{sat},y_{sat})$ with $K(\lambda,x_{sat},y_{sat},t_{sat})$ to derive the urban surface albedo for the satellite acquisition: $\mathbf{a}_{sat}(x_{sat},y_{sat})$.

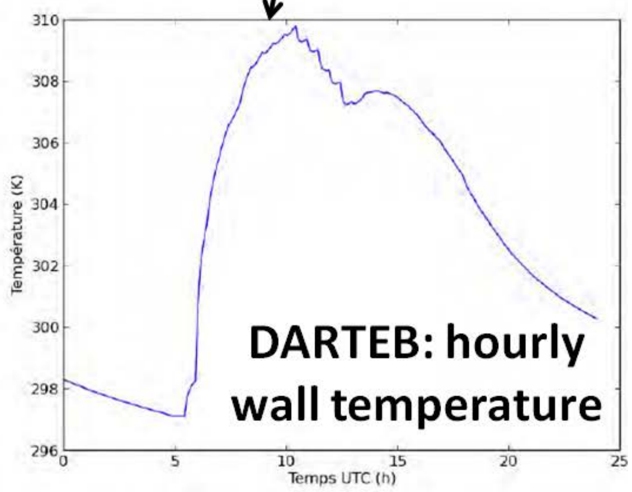
Urban surface albedo

- Application for Landsat:



Radiation balance (Q*)





DART: color composite reflectance image

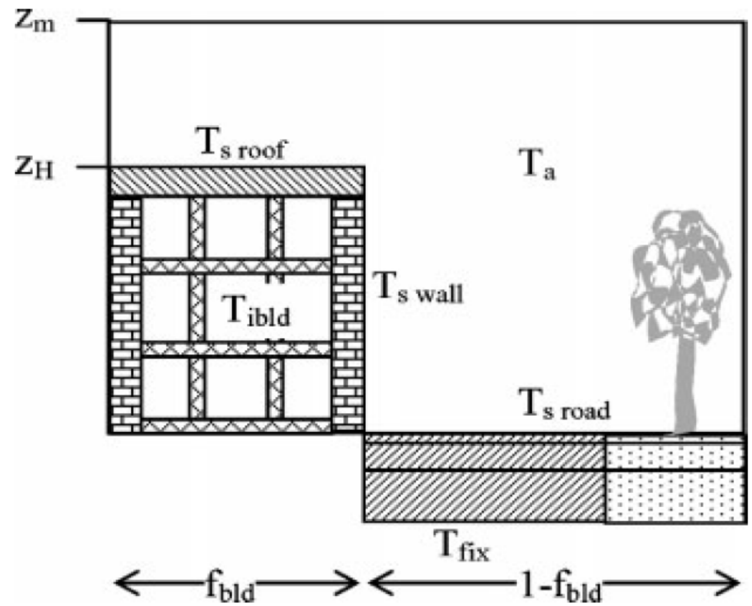
Heat storage change (ΔQ_s)

ESTM (Element Surface Temperature Method):

- Based on facet areas.
- Incorporates heat transfer through the different elements.
- Estimated ΔQ_S represents unit plan area.

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

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



Input data

Materials

Thermal conductivity

Volumetric heat capacity

Physical arrangement of elements

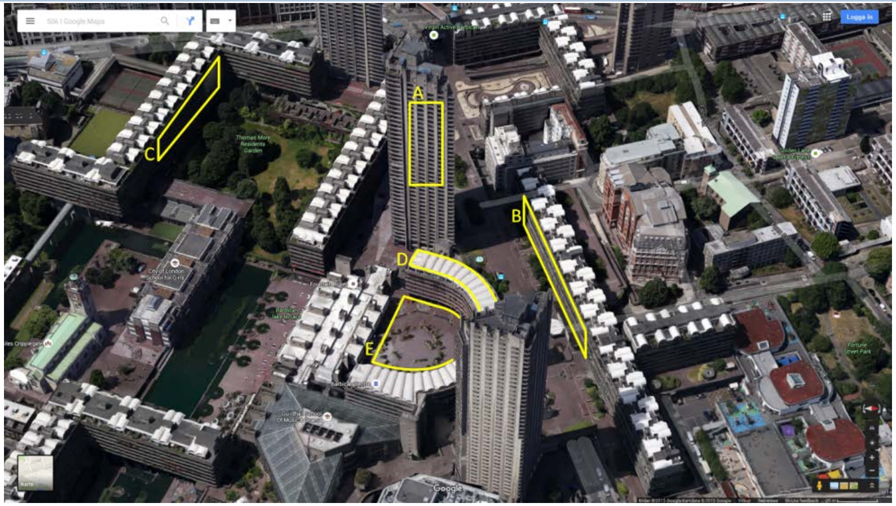
→ view factors between elements

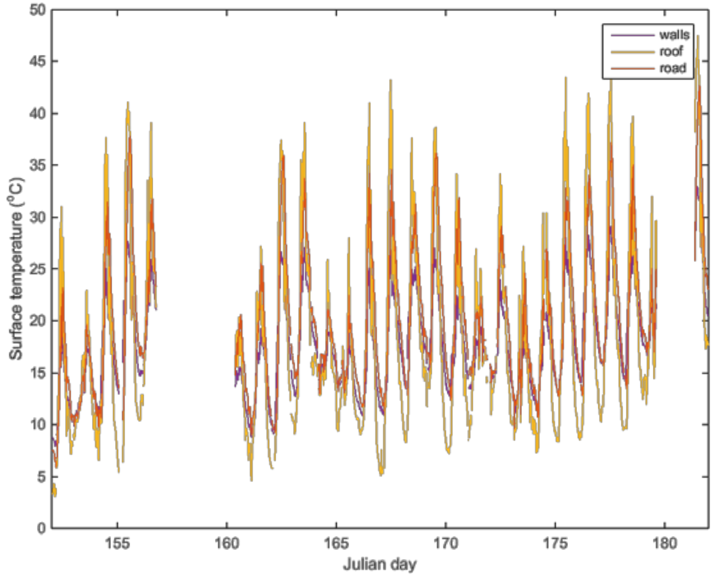
T_S

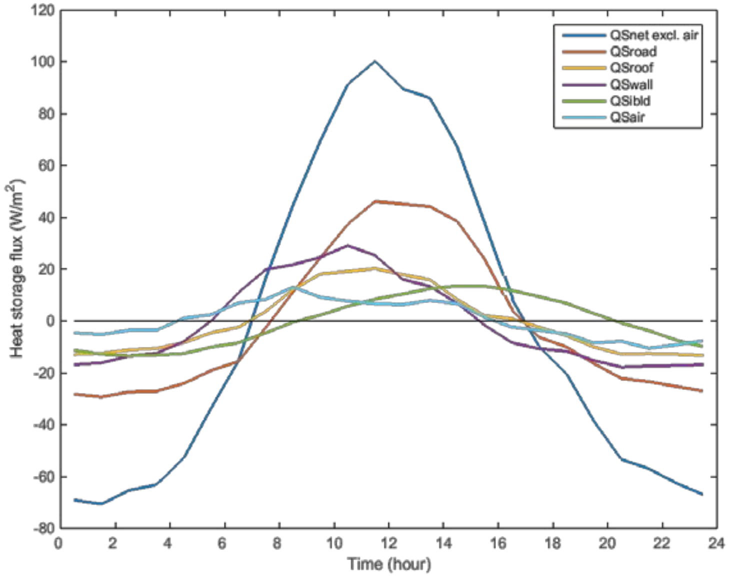
T_{air} inside and outside

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

Heat storage change (ΔQ_s)







Heat storage change (ΔQ_s)

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

Turbulent Heat Fluxes (Q_H , Q_E)

ARM (Aerodynamic Resistance Method):

From EO (*WP 4 & 5*)

Measured in-situ

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

Aerodynamic resistance

From EO (*WP 4 & 5*)

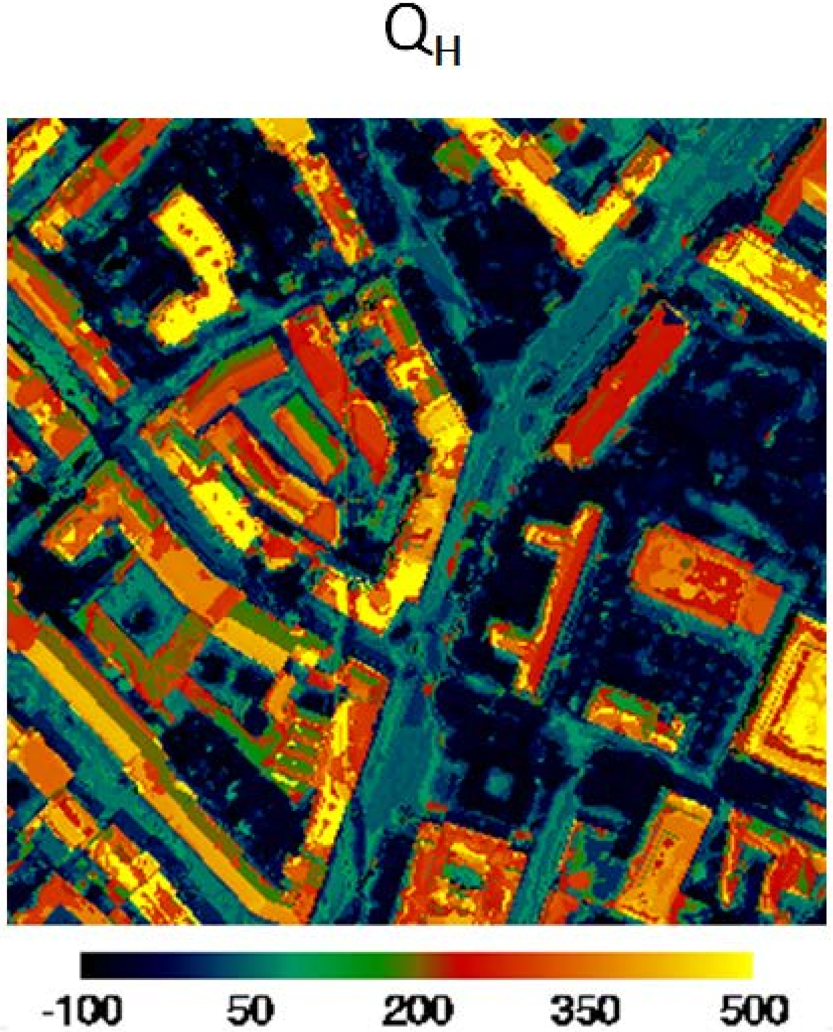
Measured in-situ

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

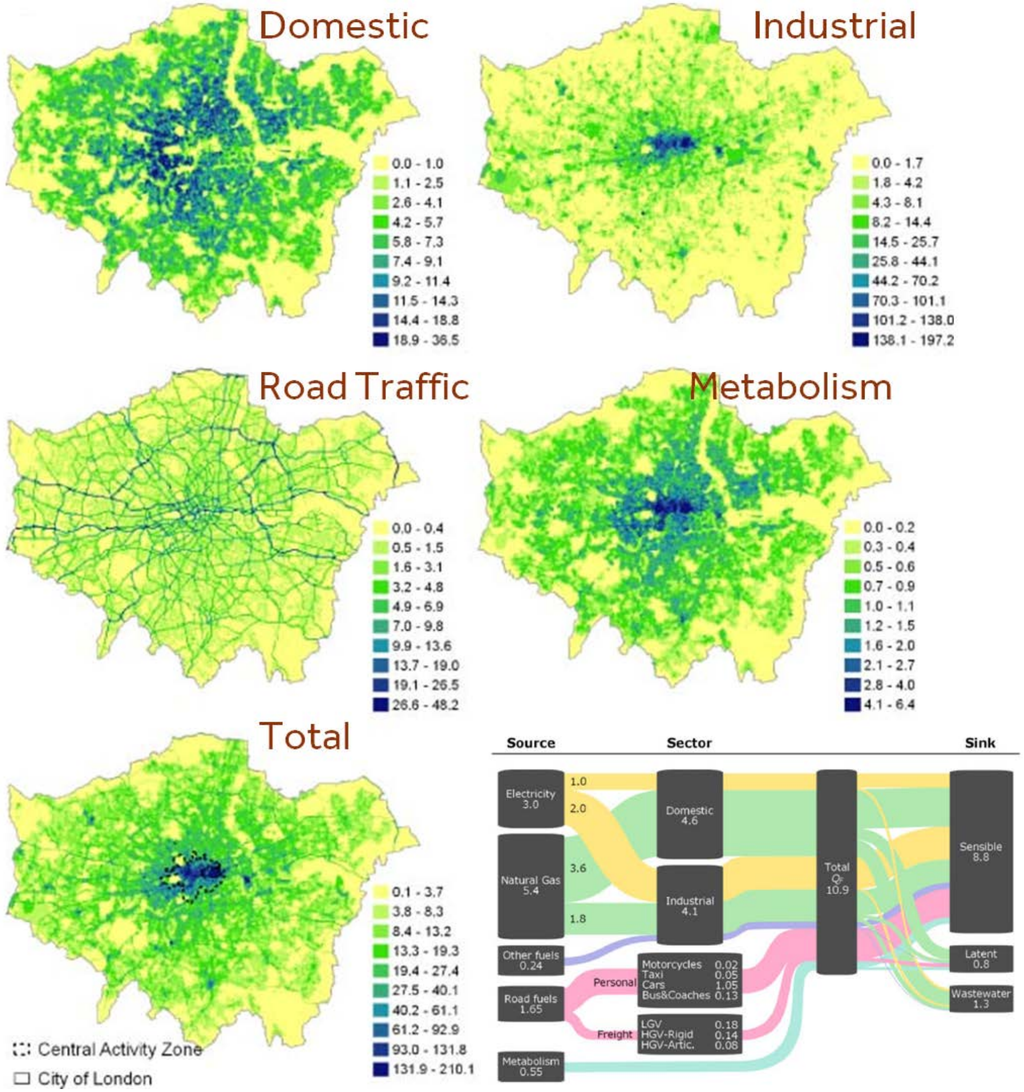
Vapour pressures

Surface resistance
Depends on vegetation type, moisture conditions

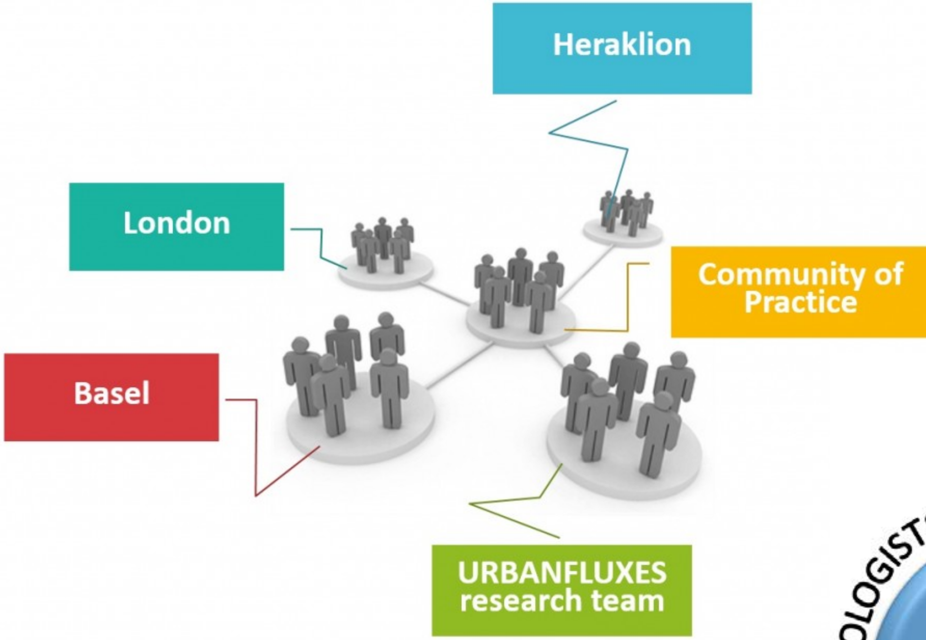
Turbulent Heat Fluxes (Q_H , Q_E)

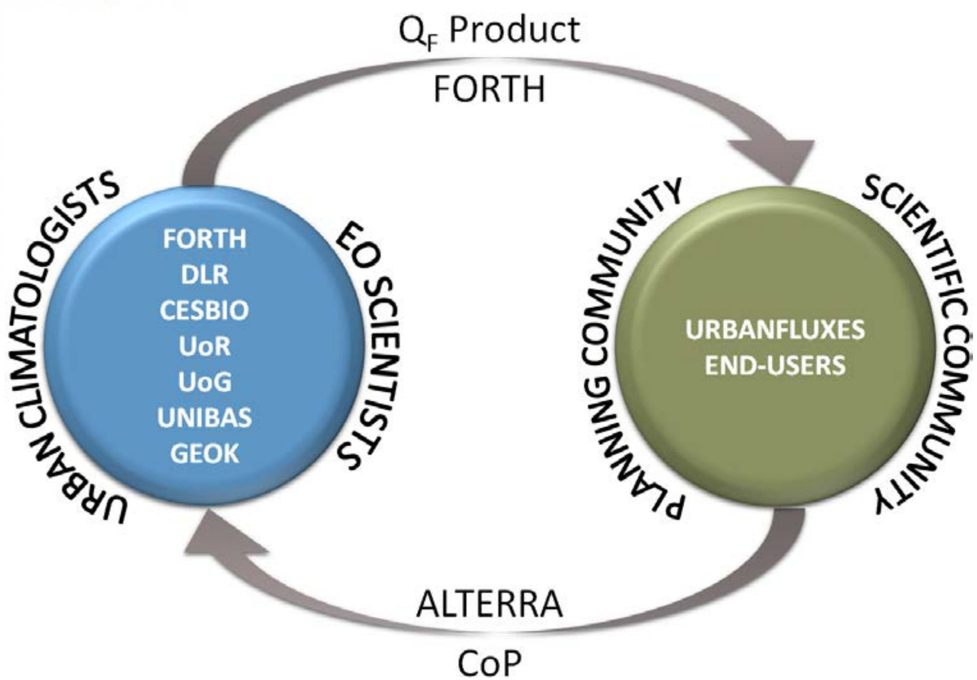


Comparison with non-satellite



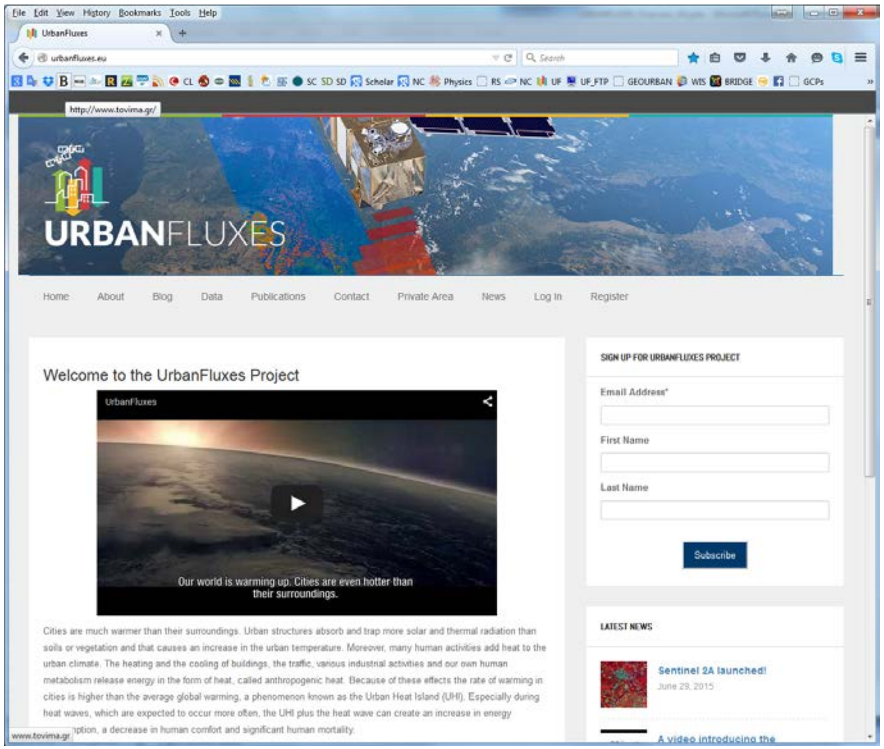
The involvement of users

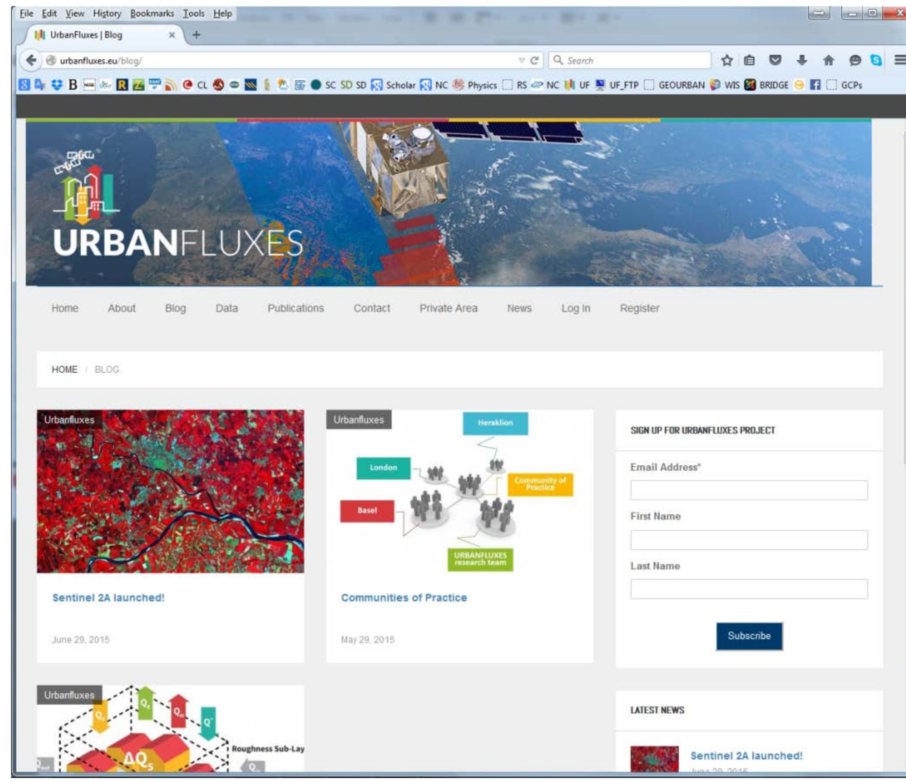




Visit URBANFLUXES web-site

- http://urbanfluxes.eu





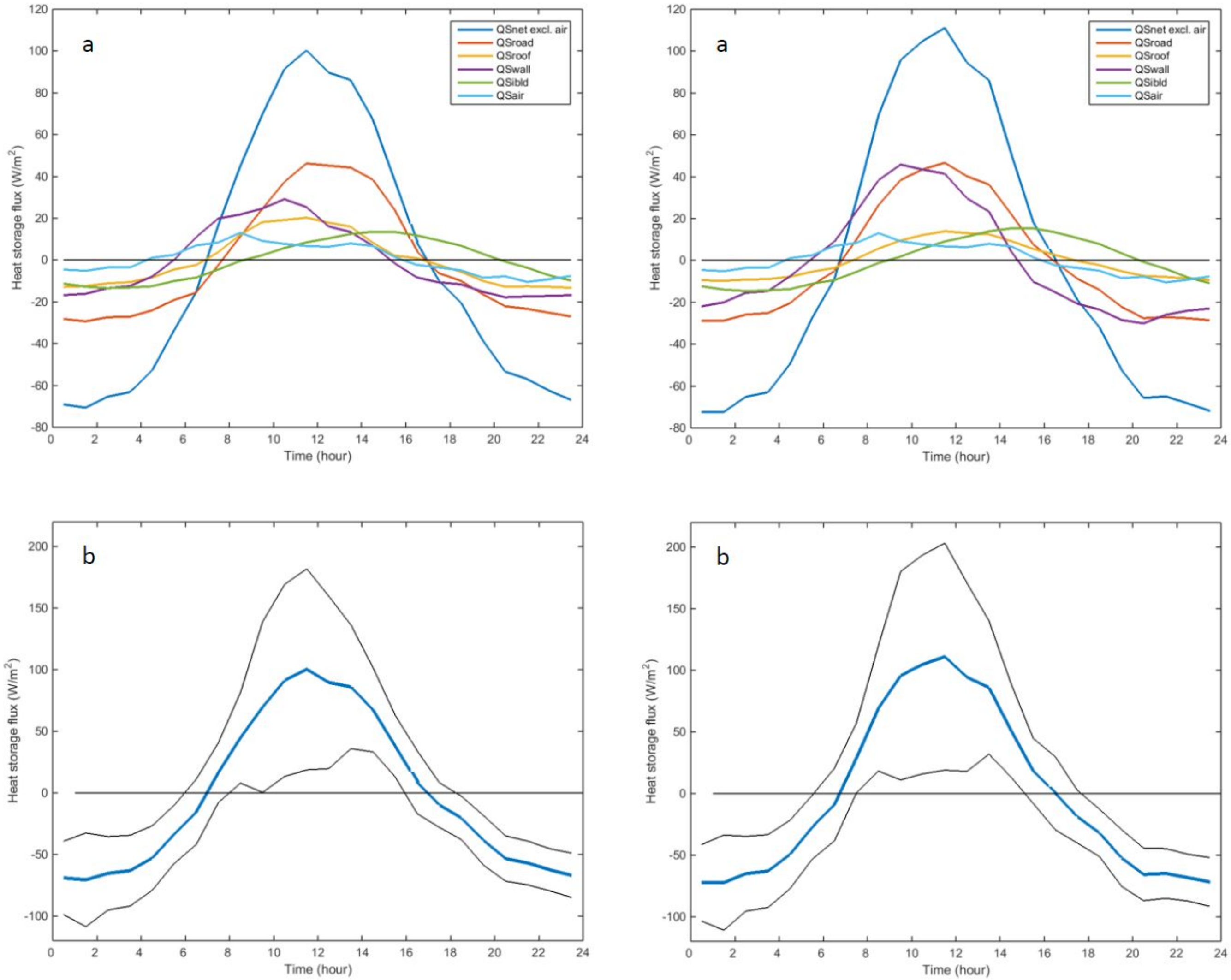
The vision

- 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 Sentinels as a tool to **help inform policy-making**.
- To develop **EO-based services**.

urban tep


THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION
HORIZON 2020

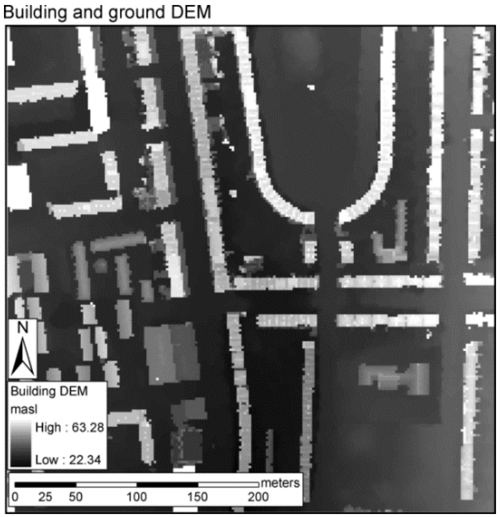
ESTM

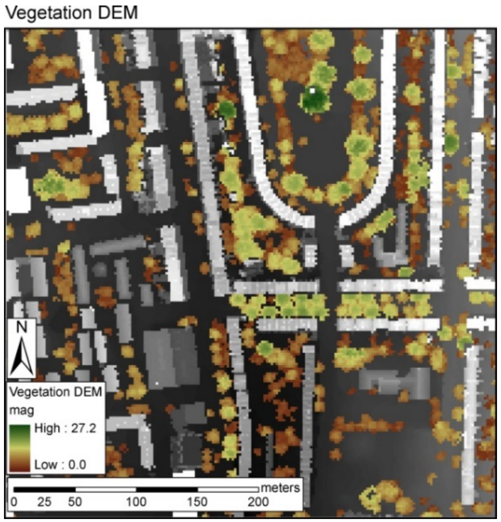


a
QSnet excl. air
QSroad
QSroof
QSwall
QSibld
QSair
Heat storage flux (W/m^2)
Time (hour)
b

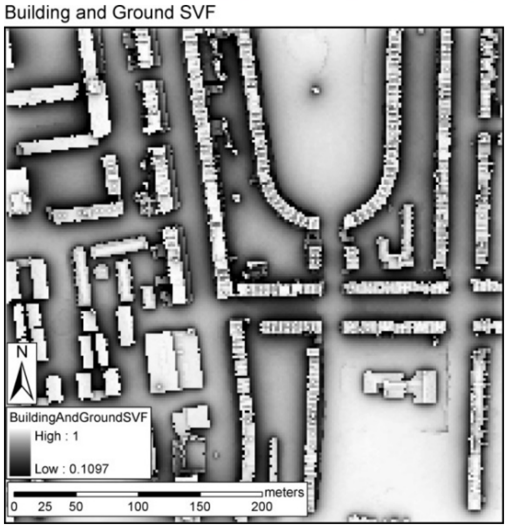
SVF

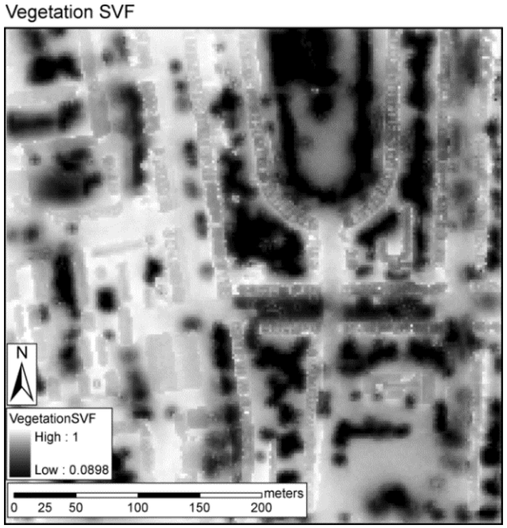
DEM:


Building and ground DEM
N
Building DEM
masl
High : 63.28
Low : 22.34
meters
0 25 50 100 150 200


Vegetation DEM
N
Vegetation DEM
mag
High : 27.2
Low : 0.0
meters
0 25 50 100 150 200

SVF:


Building and Ground SVF
N
BuildingAndGroundSVF
High : 1
Low : 0.1097
meters
0 25 50 100 150 200


Vegetation SVF
N
VegetationSVF
High : 1
Low : 0.0898
meters
0 25 50 100 150 200