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 $Q_F$. 
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 $Q_F$ spatial patterns at city scale and local scale;

› to specify and analyse the **uncertainties**;

› to **evaluate** the products comparing with independent methods;
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

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](image1)

![Building density of Basel based on GUF data (100 m grid)](image2)
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

(Mitraka et al. 2015)
Radiation balance (Q*)

DART: color composite reflectance image

Urban canyon

DARTEB: hourly wall temperature
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 $dT/dz = 0$)

(Source: Offerle et al., 2005)
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., Yu et al., 2008)

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

Parameters specific to land cover class
Turbulent Heat Fluxes ($Q_H$, $Q_E$)

- Aerodynamic Resistance Method (ARM)

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

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

From EO (WP 4 & 5)  
Measured in-situ

Aerodynamic resistance

Vapour pressures

Surface resistance
Depends on vegetation type, moisture conditions
Comparison with non-satellite

(Source: Iamarino et al. 2012)
The involvement of users
Visit URBANFLUXES website

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 EO as a tool to help inform policy-making.

› To develop EO-based services.