UEB estimation from Sentinels: The URBANFLUXES Project

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Introduction
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
- \( \Delta Q_A = Q_{in} - Q_{out} \): Adveotive 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 $\Delta Q_s$ 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;
- 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

LCZ3 – Compact low rise
High angle
Low level

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 ($\lambda_F$), Canyon aspect ratio ($\lambda_s$).

Digital surface model (DSM) of Basel

Building density of Basel based on GUF data (100 m grid)
Urban surface characteristics
Urban surface temperature

- High Resolution VNIR, SWIR
- Low Resolution TIR
- Surface Characterization
- Spatial-spectral unmixing of TIR bands
- Surface cover abundances
- High Resolution Emissivity
- High Resolution TIR
- Atmospheric information
- High spatial resolution LST
Urban surface temperature
**Urban surface albedo**

- **DART** simulates surface multispectral reflectance $\rho_{\text{DART}}(\lambda, x, y)$ and shortwave albedo $a_{\text{DART}}(x, y)$ for any satellite acquisition (date: $t_{\text{sat}}$; viewing geometry: $\Omega_v$; and atmospheric conditions: AOT, PW).

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

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

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

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

- Application for Landsat:

  - DSM
  - Landsat radiance
  - K coefficient
  - Landsat albedo
Radiation balance ($Q^*$)

DART: color composite reflectance image

Urban canyon

DARTEB: hourly wall temperature
Heat storage change (ΔQₛ)

**ESTM (Element Surface Temperature Method):**

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

\[
ΔQₛ = \sum_i \frac{ΔT_i}{Δt} (\rho C)_i Δx_i λ_{pi}
\]

\[
\rho C \frac{∂T}{∂t} = - \frac{∂Q}{∂x} = - \frac{∂}{∂x} \left( -k \frac{∂T}{∂x} \right)
\]

**Input data**
- Materials
  - Thermal conductivity
  - Volumetric heat capacity
- Physical arrangement of elements
  - View factors between elements
- Tₛ
- T_air inside and outside
- Soil temperature T_fix (where dT/dz = 0)
Heat storage change ($\Delta Q_s$)
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).

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

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

**ARM (Aerodynamic Resistance Method):**

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

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

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

- Aerodynamic resistance
- Vapour pressures
- Surface resistance
  - Depends on vegetation type, moisture conditions
Turbulent Heat Fluxes ($Q_H$, $Q_E$)

$r_{ah}$

$Q_H$
Comparison with non-satellite
The involvement of users

URBANFLUXES research team

Heraklion

London

Basel

Community of Practice

Q_f Product

FORTH

DLR

CESBIO

UoR

UoG

UNIBAS

GEOK

URBANFLUXES END-USERS

SCIENTIFIC COMMUNITY

PLANNING COMMUNITY

ALterra

CoP

EO SCIENTISTS

CLIMATOLOGISTS
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.