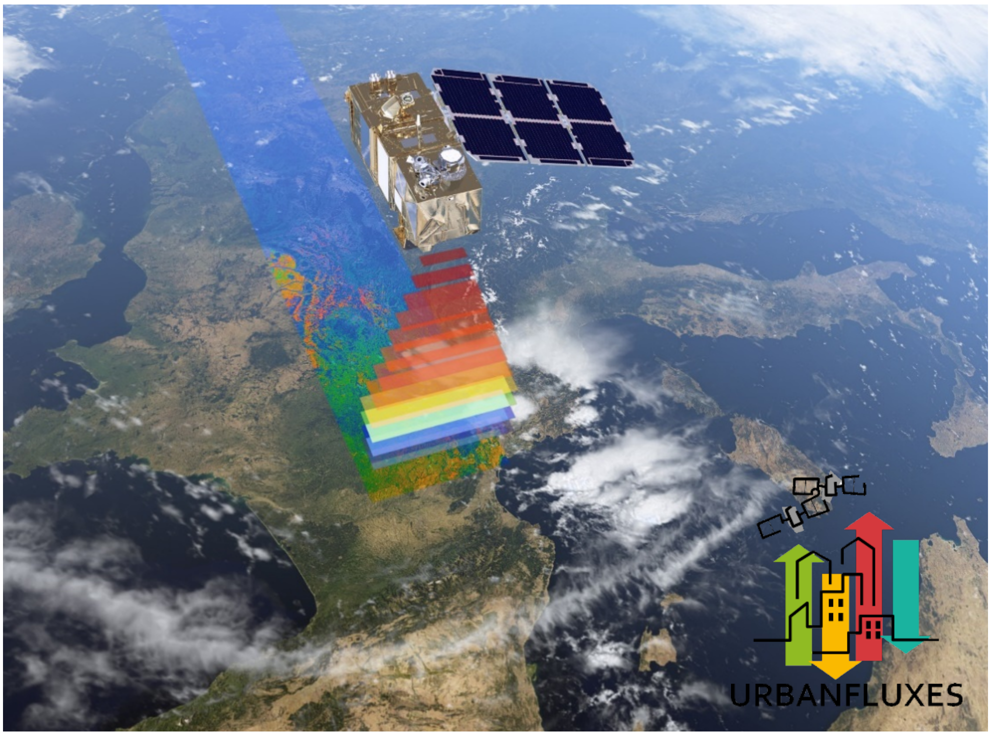



# URBANFLUXES Newsletter

January 2017

URBAN ANTHROPOGENIC HEAT FLUX FROM EARTH OBSERVATION SATELLITES

# Editorial

by Nektarios Chrysoulakis

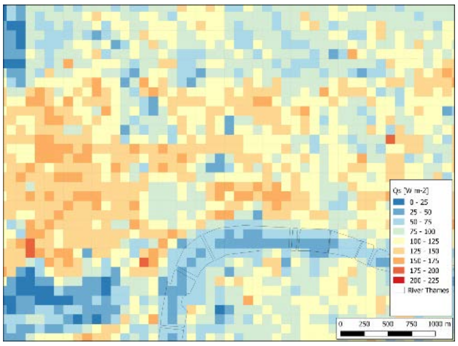
URBANFLUXES (URBan ANthropogenic heat FLUX from Earth observation Satellites) is a joint project of eight European Organizations, funded under the Horizon 2020 Framework Programme of the European Commission. It aims to introduce novel ideas on anthropogenic heat flux observation from space; thereby generating new Earth Observation (EO) opportunities of benefit to climate change mitigation/adaptation and civil protection, as well as enabling the development of operational services in the field of urban environmental monitoring and energy efficiency in cities.

URBANFLUXES is expected to lead to the development of tools and strategies to mitigate this impact, improving thermal comfort and energy efficiency in cities. The project exploits the improved data quality, coverage and revisit times of the current EO missions, which can reveal novel scientific insights for the detection and monitoring of the spatial distribution of heat fluxes in cities.

In the second semester of 2016, an important milestone for URBANFLUXES was the finalization and validation of the EO-based methods for the estimation of the net all-wave radiation, the net change in heat storage, as well as the turbulent sensible and latent heat fluxes in the three URBANFLUXES case studies (London, Basel and Heraklion). In the beginning of 2017, it is expected to conclude the methodology for anthropogenic heat flux estimation, based on the above EO-derived urban energy budget components. Furthermore, the adaptation of the whole URBANFLUXES methodology to Copernicus Sentinels synergies, towards producing time series of anthropogenic heat flux maps, is expected within the first semester of 2017.

The 3rd issue of the URBANFLUXES Newsletter presents the progress and the main achievements of the project during the last semester of 2016. In this issue, a detailed description of the activities related to the EO-based estimation of the net flow of heat stored within the urban volume in the three URBANFLUXES case studies is presented. Furthermore, the combined use of EO and DART model to monitor the urban net radiative budget is discussed. Finally, an update on the project's presentations in the main past and upcoming relevant events is given.

## IN THIS ISSUE



### Storage heat flux using Earth Observation and geodata

One essential part of the energy balance is the amount of energy stored in and released from the urban environment. In URBANFLUXES we estimate the net flow of heat stored within the urban volume (net storage heat flux - $\Delta Q_S$) using EO data.

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### Urban net radiative budget with the DART model

In URBANFLUXES we use the DART model (Direct Anisotropic Radiative Transfer), to simulate the net radiation budget, by radiative transfer modeling in the atmosphere and 3D urban and natural landscapes.

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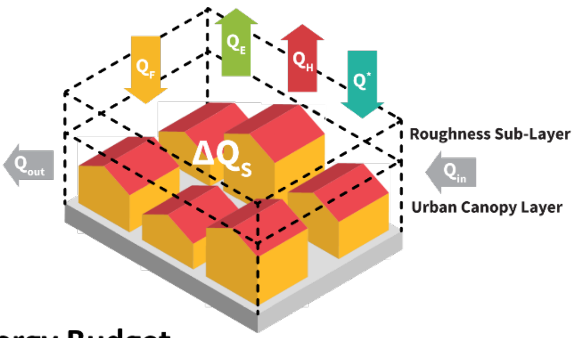
# Project Overview

The anthropogenic heat flux ($Q_F$) is the heat flux resulting from vehicular emissions, space heating and cooling of buildings, industrial processing and the metabolic heat release by people. Both urban planning and Earth system science communities need spatially disaggregated $Q_F$ data, at local (neighbourhood, or areas larger than the order of 100 m x 100 m) and city scales. Such information is practically impossible to derive by point in-situ fluxes measurements, while satellite remote sensing is a valuable tool for estimating Urban Energy Budget (UEB) parameters exploiting EO data. While the estimation of $Q_F$ spatial patterns by current EO systems is a scientific challenge, the major challenge lies on the innovative exploitation of the Copernicus Sentinels synergistic observations to estimate the spatiotemporal patterns of $Q_F$ and all other UEB fluxes.

URBANFLUXES investigating the potential of EO to retrieve $Q_F$, supported by standard meteorological measurements. The main research question addresses whether EO is able to provide reliable estimates of QF for the time of the satellite acquisition. URBANFLUXES answers this question by investigating the potential of EO to retrieve $Q_F$ spatial patterns, by developing a method capable of deriving $Q_F$ from current and future EO systems. URBANFLUXES aims to develop an EO-based methodology easily transferable to any urban area and capable of providing $Q_F$ benchmark data for different applications. URBANFLUXES is expected to increase the value of EO data for scientific analyses and future emerging applications (such as urban planning and local/regional level climate change mitigation/adaptation), by exploiting the improved data quality, coverage and revisit times of the Copernicus Sentinels data. To this end, the specific objectives of the project are:

**Anthropogenic Heat Flux ($Q_F$)**

Energy balance residual approach




**Urban Surface Energy Budget**

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

where $\Delta Q_A = Q_{in} - Q_{out}$ and S represents all other sources and sinks

**Sensible Heat Flux ($Q_H$) – Latent Heat Flux ($Q_E$)**

Adjusted Aerodynamic Resistance Method for EO data

**Net all-wave Radiation Flux ($Q^*$)**

Discrete Anisotropic Radiative Transfer (DART) approach

**Heat Storage Flux ($\Delta Q_S$)**

Element Surface Temperature Method

- to improve the accuracy of the radiation balance spatial distribution calculation;
- to develop EO-based methods to estimate the flux of heat storage in the urban fabric, as well as the turbulent sensible and latent heat fluxes at local scale;
- to employ energy budget closure to estimate the anthropogenic heat flux patterns;
- to specify and analyse the uncertainties associated with the derived products;
- to evaluate the products by comparisons with $Q_F$ estimations by independent methods;
- to improve the understanding of the impact of $Q_F$ on urban climate; and to communicate this understanding to the urban planning community, which will in turn lead to a better understanding of what new knowledge is needed on the ground;
- to exploit Sentinels 2 and 3 synergistic observations to retrieve UEB fluxes at the local scale, with the frequency of the Sentinel 3 series acquisitions;
- to standardise the resulting products and, by organizing an effective dissemination mechanism, to enhance their use by urban planners and decision makers in cities, as well as by EO scientists, Earth system modellers and urban climatologists.

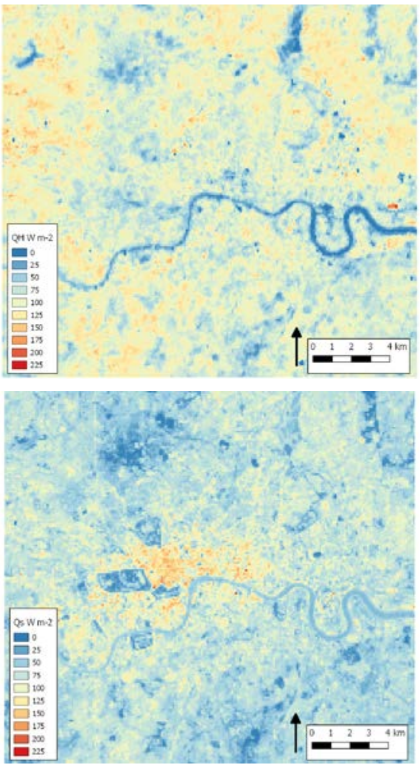
# Main URBANFLUXES Achievements so far

The Eddy Covariance system in the centre of Heraklion.

In the last semester of 2016, a new Eddy Covariance system has been installed on the roof of a high building in the centre of Heraklion. The sensor is mounted on a 10 meter telescopic mast in order to reach the appropriate height over the urban canopy layer and measure a blended, spatially averaged signal. This way the measurements are representative of a wide area around the sensor (footprint) that is estimated to cover a significant part of the city centre. The EC system along with the Wireless Sensor Network in Heraklion makes this case study also complete for the implementation and evaluation of the URBANFLUXES methodology.

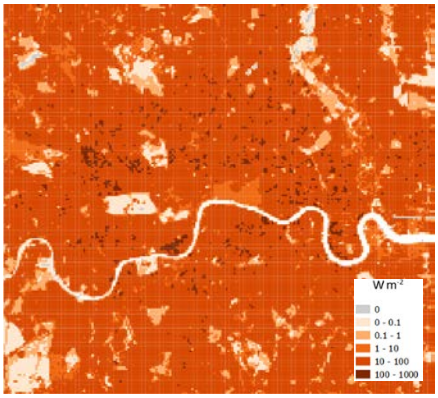
Long-term turbulent heat flux source area (November 2016 - January 2017) of the Heraklion Eddy Covariance measurements.

Furthermore, there have been improvements of the methods for EO-derived turbulent ($Q_H$, $Q_E$) and storage ($\Delta Q_S$) heat fluxes, as well as the net all-wave radiation ($Q^*$) based on the evaluation performed using in-situ EC, meteorological measurements and alternative modelling approaches. EO-derived fluxes have been estimated for wide areas in all case studies and multiple dates of available and clear satellite images. The methods have been adjusted in order to be uniform for all case studies according to the range of different land cover types and morphology. Examples of heat fluxes mapping for the city of London are given below: The first image presents the spatial distribution of the sensible heat flux ($Q_H$). Lowest $Q_H$ is calculated above the river and in vegetated areas. Lower $Q_H$ (up to 100 W $m^{-2}$) is also found in central London where surface temperature is reduced. Highest $Q_H$ (up to 200 W $m^{-2}$) is found generally outside of the central city core. In the second image the storage heat flux ($\Delta Q_S$) is presented, where the highest $\Delta Q_S$ (up to 200 W $m^{-2}$) is found inside the central city core where the building density is the highest.



Sensible ($Q_H$) and storage ($\Delta Q_S$) heat flux in W $m^{-2}$ over London on 2 October 2015 at 11:16 (CET).

Independent estimates of the anthropogenic heat flux ($Q_F$), based on non- remote sensing approaches were performed for all URBANFLUXES case study cities. These estimates are being used to evaluate the EO-based anthropogenic heat flux calculations. An example for London is given below. High $Q_F$ (~100 W $m^{-2}$) generally occurs when buildings dominate the land cover fraction.




Anthropogenic heat flux ($Q_F$) in W $m^{-2}$ over central London on 2 October 2015 at 11:10 (CET).

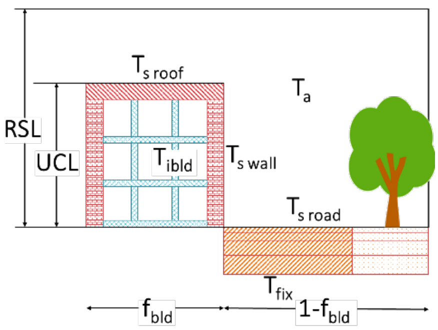
Concerning the evolution of the project, the 3rd URBANFLUXES Progress Meeting has been conducted in the facilities of DLR, in Oberpfaffenhofen – Wessling, in September 2016. Many important issues of the project have been discussed and some unclear point in methodology have been successfully clarified. Moreover, two Management Board and two Technical internet Meetings were held to guarantee the smooth progress of the project actives and to resolve any technical or administrative problems.

Finally, the communication and dissemination of the project outcomes were efficiently implemented using all the relevant tools such as the URBANFLUXES web-server, web-site and Newsletter. The communication with the potential users and scientific community was further supported by the presentation of the main achievements of the project in several conferences and workshops, as well as by a second round of Communities of Practice meetings that was held in project's case studies.

# Storage heat flux using Earth Observation and geodata

by Fredrik Lindberg

The city with its building environment, human activities, access of impervious surfaces among other things affects the energy balance and the interaction with the above atmosphere. One essential part of the energy balance is the amount of energy stored in and released from the urban environment. The storage heat flux of an urban canopy is approximately 2 - 6 times larger than for non-urban canopies. The net storage heat flux ($\Delta Q_S$) is the net flow of heat stored within the urban volume, i.e. the air, trees, buildings, ground, etc. In urban areas, the net heat stored in the canopy is a relatively large fraction of the net all-wave radiation ($Q^*$). Directly evaluating $\Delta Q_S$ in the urban canopy is very difficult. Therefore, a common way is to adapt various modelling approaches to estimate $\Delta Q_S$ within the urban environment.




Schematic representation of the elements used to estimate $\Delta Q_S$. Surface temperatures $T_S$, internal building temperature $T_{ibld}$, and air temperature $T_a$ are used. The fraction of surface covered by buildings is denoted fbld. (adapted from Offerle et al. 2005).

In the URBANFLUXES project, $\Delta Q_S$ is estimated using the Element Surface Temperature Method (ESTM) which reduces the three-dimensional urban volume to four 1-d elements (i.e. building roofs, walls, and internal mass and ground (road, vegetation, etc)). The heat storage for each element is then derived by estimating the rate of temperature change through each facet based on material properties and thicknesses of each facet. The rationale for using the ESTM scheme is that is has the possibility to be forced with EO and geodata which makes it suitable for the URBANFLUXES project.

To be able to use the ESTM scheme, the following input information is required:

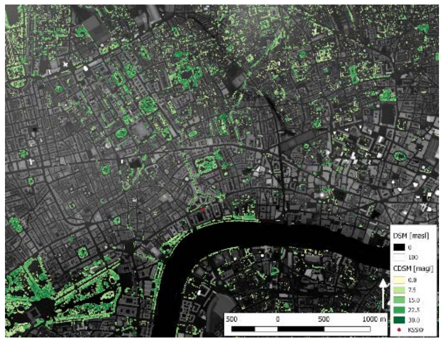
1. Fraction for each element
2. Material properties and thickness for each element
3. Temperature change over time for each element.

Previous sensitivity analysis of the ESTM scheme, i.e. how separate model input parameters affect the calculated change in heat storage, identified that the fraction of wall facet and material are two input variables that are important for a reasonable estimation of $\Delta Q_S$. Therefore, efforts to get these parameters correct are very important.

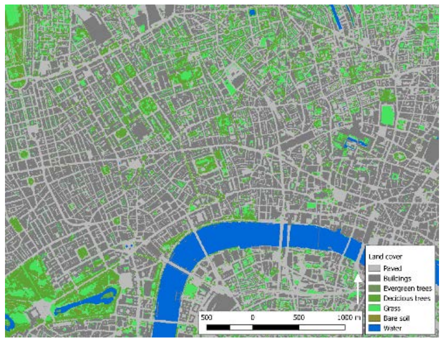
## Input information

The morphology of the urban surface is, as mentioned, an essential parameter for running the ESTM scheme. This information is derived from high resolution digital surface models (DSMs) of ground and building heights. 3D information of vegetation (trees and bushes) is also needed to estimate the vegetation volume and the heat it can store. These datasets can be derived from either secondary geodata or primary remotely sensed information such as LiDAR (Light Detection And Ranging). Detailed 3D geographical data for urban areas is becoming more widely available. Techniques such as aircraft mounted LiDAR make it possible to derive very high resolution DSMs that describe urban setting for buildings as well as vegetation.

As different land surface covers have different thermal properties, EO derived land cover information is also required. In the URBANFLUXES project we make use of land cover information divided up in seven classes according to the figure below.

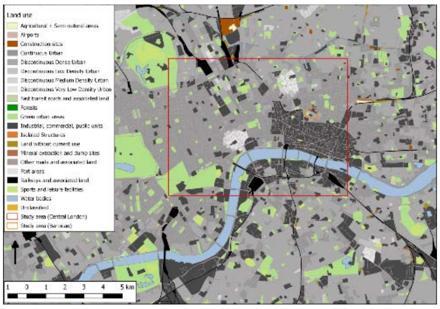


A building and ground DSM overlaid with a vegetation canopy DSM (CDSM) over the central parts of London. The pixel resolution is 1 m x 1 m. Location of Eddy Covariance tower (KSSW) is included. The surface models are derived from LiDAR data.

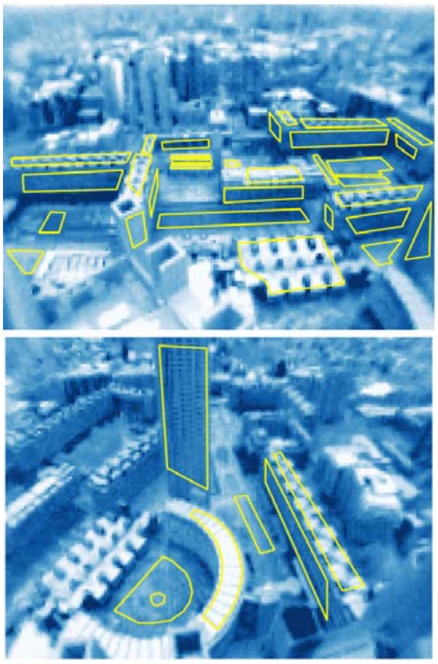


Land cover in central London (pixel resolution: 4 m x 4 m).

Since the type of materials used in the urban environment also is an essential information needed to obtain accurate estimations of net heat storage using the ESTM model, a further more detailed categorization of impervious surfaces (paved and buildings) has been made. Three different categories of impervious ground surfaces and five different building categories are included. These can differ between each of the case study areas (London, Basel and Heraklion). The Urban Atlas land use information in conjunction with Google street map and local knowledge has been utilized for this categorization. By manually categorizing each land use class in Urban Atlas based on the three impervious and five building types, respectively, detailed information of the resulting material properties is derived. As shown from Google maps, building types and structures can differ a lot between the different case study areas.



The Urban Atlas land uses classes in central London with the extent of the central London study area shown in previous figures marked by the red box. The smaller Barbican area within this area is marked by an orange polygon.



Barbican study area IR cameras images sampled north (upper) and west (lower). Yellow polygons are surfaces where brightness temperatures have been derived.

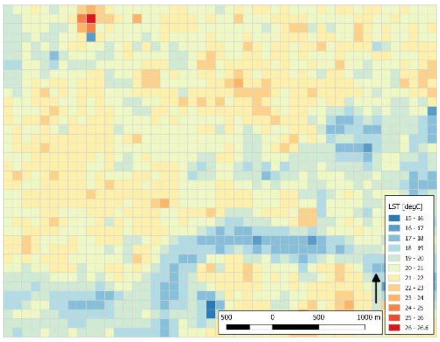
Furthermore, meteorological forcing data is needed as well as EO derived land surface temperature (LST). The meteorological forcing data is mainly derived from the eddy covariance (EC) observation towers and the sensor network installed in all three cities as shown in previous URBANFLUXES newsletters.

Snapshots of two images from Google street view showing typical buildings in Heraklion (top) and London (bottom).

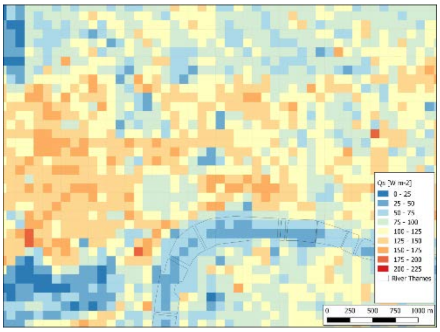
## Spatial information of net storage heat flux

Here, results from the central parts of London on the 2nd of October 2015 at 11 am covering are shown. The land surface temperature pattern shows that $T_{LST}$ is foremost controlled by the land cover variations and material differences. This could be seen in areas such as water bodies (e.g. River Thames) and extensive green areas such as Hype Park located in the south-west corner of the study area. There is also a tendency to lower $T_{LST}$ with higher building density, e.g. the eastern parts of the study area. Some outliers in $T_{LST}$ are also identified, for example the roof of Euston train station in the north-west part of the study area. This could probably be explained both by material and extensive exposure to sunlight.

The spatial variations of net heat storage show a pattern strongly influenced by urban morphology, materials and land surface temperature. In the ESTM scheme, outliers with high $\Delta Q_S$ can be identified. This is an artefact of errors introduced in the ground and building DSMs where some surfaces (e.g. glass roofs) disrupts the LiDAR signal during data acquisition resulting in 'holes' in the dataset. This leads to an overestimation of wall area which in turn produces unreasonable high values of $\Delta Q_S$. The ESTM-scheme is a dynamic approach where changes in parameters such as materials and urban morphology etc. affect $\Delta Q_S$. However, it also makes the model more sensitive to changes.



Aggregated land surface temperature (2 October 2015 at 10:59 (GMT), Landsat 8) over central London at 100 m x 100 m resolution.



Heat storage flux ($\Delta Q_S$) over central London on 2 October 2015 at 10:59 (GMT) calculated with the ESTM scheme. Pixel resolution is 100 m x 100 m and values are 30 min averages.

## Conclusions and future activities

As mentioned earlier observation and evaluation of $\Delta Q_S$ in urban areas are very difficult. Hence, evaluations between different modelling approaches are common. Evaluation between ESTM and other models such as the objective hysteresis model (OHM) show reasonable similar results but different spatial pattern is evident since the input parameters are more extensive and detailed in the ESTM scheme. Also, ESTM can be related to both EO and geodata products when deriving $\Delta Q_S$. Therefore, we conclude that ESTM is the most suitable method for deriving $\Delta Q_S$ within the URBANFLUXES project. For the remaining time of the project efforts to improve the estimation of $\Delta Q_S$ will continue. Items such as wall temperatures and improved geodata will add more information to the modelling. Furthermore, setting up the ESTM to be run using downscaled Sentinel 3 land surface temperatures will also be implemented.

# Surveying the urban net radiative budget with Earth observation satellites and DART model

by Jean-Philippe Gastellu-Etchegorry and Lucas Landier

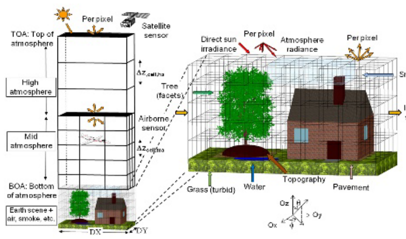
Our society is more and more concerned with the survey and management of the urban climate. Hence, EO satellites, as the Copernicus Sentinel series, are expected to become essential tools, because they observe cities continuously in different spectral domains with high spatial resolution. The climate of large cities is largely determined by their energy budget, including the net radiative budget ($Q^*$) and non-radiative terms as the sensible, latent and anthropogenic ($Q_F$) heat fluxes.

$Q^*$ is equal to the incoming solar radiation and atmosphere thermal emission, minus the outgoing reflected solar radiation and urban surface thermal emission. This major term of the energy budget is the most directly linked to EO satellites radiative signal. Its strong variations in time and space explain the interest of EO satellites. However, deriving urban $Q^*$ maps from EO satellites images is not straightforward since urban reflectance and thermal emission have a very anisotropic behavior which is mostly due to the urban three dimensional (3-D) architecture and distribution of urban material optical property (OP). It is a constraint, because EO satellites have a unique viewing direction. In addition, they work with a few spectral bands, whereas $Q^*$ is an integral over the whole spectral domain and over the whole hemisphere. The variability of urban architectures is an additional difficulty. The situation would be much simpler if the urban radiation behavior was isotropic because the EO satellite mono-directional signal could be accurately extrapolated to all the directions necessary to compute $Q^*$. However, this "isotropic" behavior is unrealistic and leads to erroneous assessments of $Q^*$, and therefore $Q_F$.

Models (i.e. remote sensing models) that simulate EO satellites data are potentially essential tools to account for the urban anisotropic and spatially heterogeneous radiative behavior provided they simulate images with a physical approach and also account for the 3-D architecture of urban surfaces, including vegetation. Scientists devote considerable effort to develop such models.

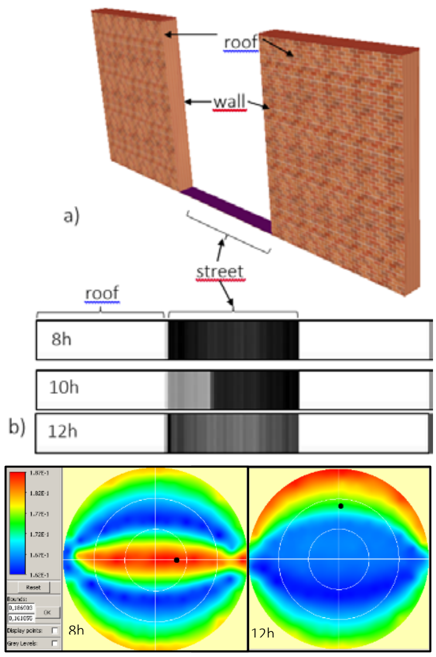
In this project, we use the DART (Direct Anisotropic Radiative Transfer) model. As far as we know, it is the only model to simulate the two radiative terms of interest in this project (i.e., $Q^*$ and EO satellite images) with accurate radiative transfer modeling in the atmosphere and 3-D urban and natural landscapes for any visible and thermal infrared bands.

DART (www.cesbio.ups-tlse.fr/dart) was patented in 2003. Its accuracy, functionalities and computer efficiency are continuously improved. During this project, it was improved to deal with spatially variable OP per urban element (*i.e.*, building, street, etc.) and large urban 3-D databases that map urban elements, each one being represented with facets.




DART cell matrix of the Earth / Atmosphere system. The atmosphere has three vertical levels: upper (i.e., just layers), mid (i.e., cells of any size) and lower atmosphere (i.e., same cell size as the land surface).

In addition, we developed a processing chain that calibrates DART with EO satellite images: the iterative comparison of these images gives an OP map per urban element at the spatial resolution of the considered EO satellite image. The procedure is iterative to account for the so-called multiple scattering mechanisms (i.e., a satellite pixel value depends on the optical properties of the elements in and outside the pixel).

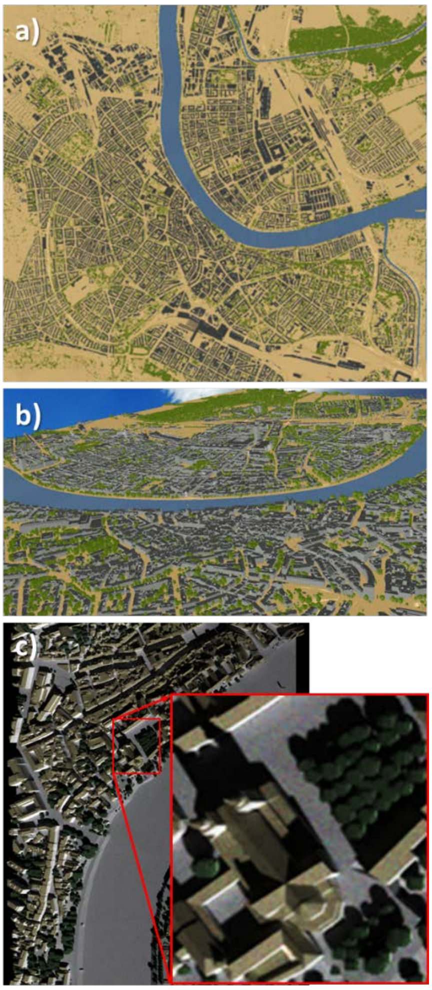



Anisotropy of the radiation scattered and emitted by a schematic urban canopy. a) The canyon: a street between two buildings with equal height and horizontal roofs. b) Nadir images at 8h, 10h and 12h, local time. c) 2-D distribution of directional reflectance as a function of zenith and azimuth angles of upward directions

The processing chain works with all visible and thermal infrared bands of the EO satellite image. It has 6 major stages:

1. The urban database (city of Basel in the following figure) is input into DART.

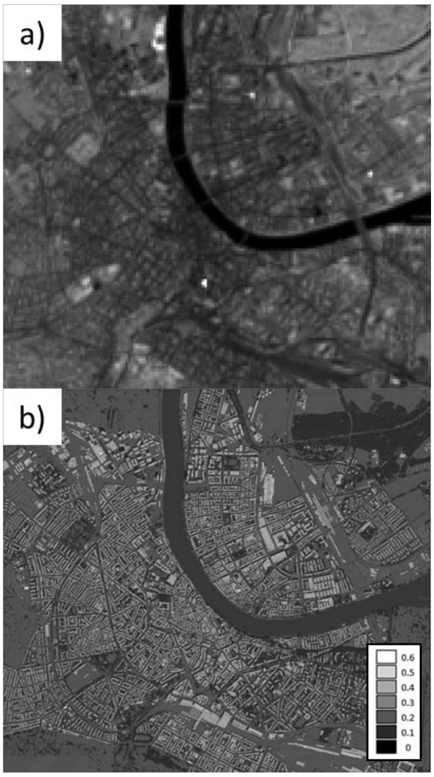
2. DART simulates the urban image for all spectral bands at high spatial resolution (e.g., 2.5m) for the atmosphere and illumination conditions of the EO satellite image. For the first iteration, the simulation is achieved with spatially constant OP per type of urban element.



City of Basel: Nadir (a) and oblique (b) view of the DART mock-up. c) DART simulated image.

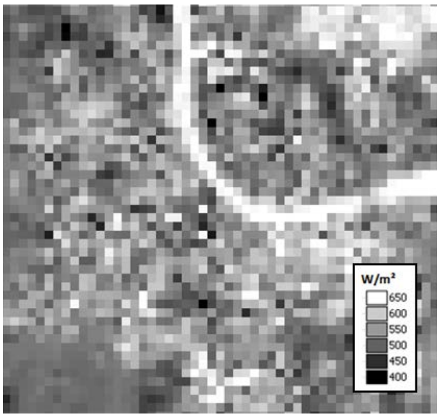
3. DART spectral images are georeferenced and spatially resampled to the EO satellite coordinate system and spatial resolution, respectively.
4. DART and EO satellite spectral images are pixel-wise compared to get improved OP maps per urban element, using the area of the urban elements within each satellite pixel. This information is derived from the urban database. Until the DART and EO satellite images fit, the procedure starts again from stage 2.
5. DART simulates the angular spectral radiative flux along directions that sample the upper hemisphere.
6. Short $Q^*_{short}$ and long $Q^*_{long}$ wave exitance maps are computed as a double integral over the spectrum and the upper hemisphere. The albedo map is derived from the short wave exitance map.

$Q^* = Q^*_{short} + Q^*_{long}$ is spatially resampled at the required spatial resolution. The following figure shows the Basel $Q^*$ map on August 30, 2015, at 100 m x 100 m resolution grid (URBANFLUXES output grid size).



City of Basel: a) Landsat-8 atmospherically corrected reflectance image at 864 nm and 30 m x 30 m spatial resolution. b) DART simulated reflectance image at 2.5 m x 2.5 m spatial resolution, for the same conditions

Results are very encouraging. However, the observed similarity of DART and EO satellite images does not prove that $Q^*$ is perfectly accurate. Indeed, different roof and street OP can lead to the same EO satellite signal. This multiplicity of solutions can arise from satellite image geometric inaccuracy (< 1 pixel), urban change (e.g., new building) relative to the urban database, etc. The processing chain being now sufficiently operational to process series of EO satellite images, new validation tests of $Q^*$ become possible such as cross-analysis of the temporal evolution of urban OP and EO satellite signal, per satellite pixel. Using URBANFLUXES radiation measurements and time series of OP maps from previously processed EO satellite images will undoubtedly improve the accuracy of OP maps, and consequently $Q^*$, the energy budget and $Q_F$.



City of Basel: Q* map on October 30, 2015, at 100 m x 100 m grid, derived from Landsat-8 satellite image.

Presently, $Q^*$ and urban OP maps are being calculated for each available EO satellite image using the DART model. This derivation of OP maps from EO satellites is a new approach to get time series of $Q^*$ urban maps on any time basis using the 3-D DART model. It opens new opportunities to survey the urban energy budget and consequently urban anthropogenic heat fluxes with EO satellites.

# Events

URBANFLUXES is present in several conferences and events. Follow us on your preferred social network (*ResearchGate, Twitter, Google+, LinkedIn*) to get instant updates on events related to URBANFLUXES.

**Past**

SPIE Remote Sensing 2016|26 - 29 September 2016, Edinburgh, UK (Invited)
United Nations Habitat III |17 - 20 October 2016, Quito, Equador
GEO-XIII Plenary and Exhibition| 7 -10 November 2016, St. Petersburg, Russian Federation
AGU Fall Meeting |12- 16 December 2016, San Francisco, USA

**Upcoming**

Joint Urban Remote Sensing Event 2017 (JURSE17) | 6 - 8 March 2017 | Dubai, United Arab Emirates
10th EARSeL SIG Imaging Spectroscopy Workshop | 19 - 21 April 2017 | Zurich, Switzerland
European Geosciences Union General Assembly 2017 | 23 - 28 April 2017, Vienna, Austria
37th International Symposium on Remote Sensing of Environment (ISRSE-37) | 8 - 12 May 2017, Tshwane, South Africa

*All publications are available through the project's web-site: www.urbanfluxes.eu.*

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