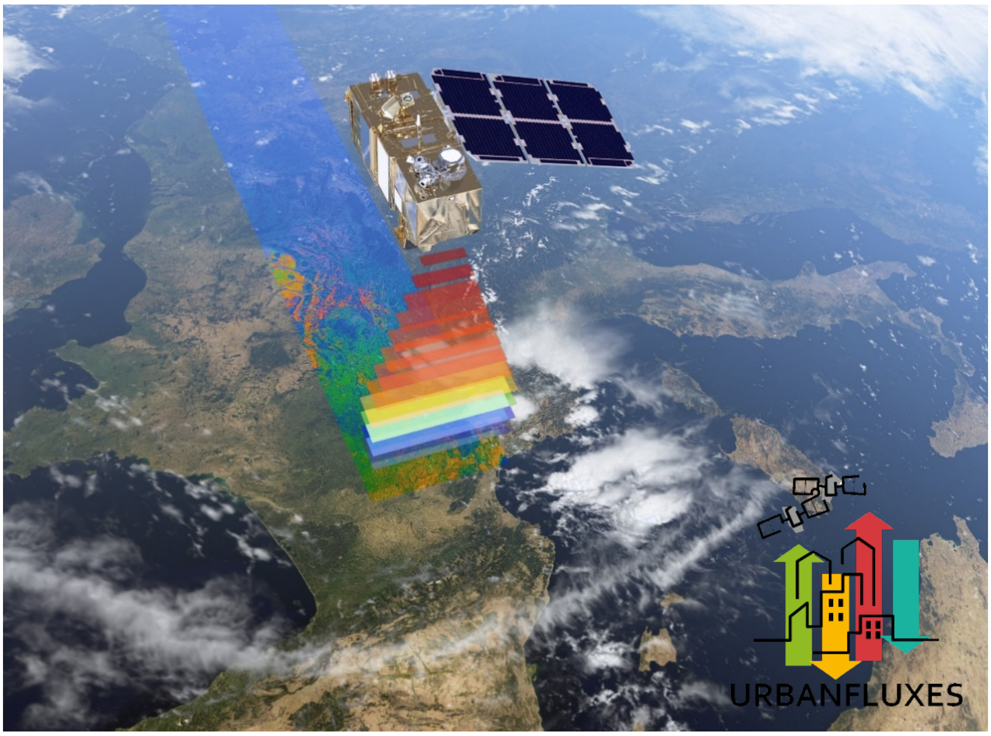


URBANFLUXES Newsletter

September 2017

URBAN ANTHROPOGENIC HEAT FLUX FROM EARTH OBSERVATION SATELLITES

Editorial

by Nektarios Chrysoulakis

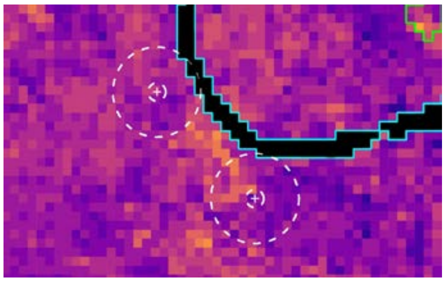
URBANFLUXES has entered its final stage, where adaptation of its method to Copernicus Sentinels synergy is scheduled. In this way, spatio-temporal patterns of Urban Energy Budget (UEB) components, including anthropogenic heat flux will be produced for the three study areas, London, Basel and Heraklion.

During the last eight months, the researching activities were focused on the analysis of time series of the different UEB components (net all-wave radiation, turbulent heat fluxes, heat storage in the urban web) that were derived during the second phase of the project. The objective of this analysis was to estimate the anthropogenic heat flux as a residual, by regressing the sum of the turbulent heat fluxes against the available energy (the radiation component minus the storage component). The resulted EO-derived anthropogenic heat flux was compared with independent model estimations, based on inventories. This comparison provided evidence on the accuracy of the approach and the means to fine-tune each step of the processing chain. Therefore, the URBANFLUXES approach became ready for adaptation to Sentinel 2/Sentinel 3 synergy, to be implemented during the final phase of the project.

An important milestone for URBANFLUXES was the completion of the second round of Communities of Practice (CoP) meetings; the last CoP meeting was held in Heraklion, in July 2017, with strong participation from both Municipality of Heraklion and Region of Crete. The successful second round of CoP meetings was very important for the project, since it prepared the ground for the two demonstration events, to be organized in London on December 6, 2017.

The 4th issue of the URBANFLUXES Newsletter presents the progress and the main achievements of the project during the first eight months of 2017. In this issue, a detailed description of the activities related to the EO-based estimation of the anthropogenic heat flux is presented. Furthermore, modelling results of the independent, inventories-based, anthropogenic heat flux estimation methods are provided. Finally, an update on the project's publications and the main past and upcoming relevant events is given.

IN THIS ISSUE



Anthropogenic heat flux using Earth Observation data

The ambitious aim of URBANFLUXES is to resolve UEB using Earth Observation data and simple meteorological measurements. The first attempt for the city of Basel is presented here.

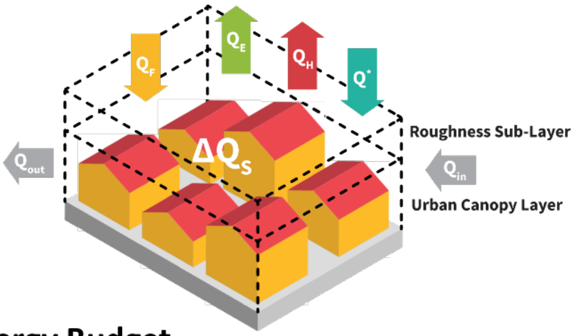
Modeling the anthropogenic heat flux

The anthropogenic heat flux is generally considered in terms of three sources: buildings, transport and metabolism. Sophisticated models developed from the URBANFLUXES team make estimations of Q_F for the three cities using combined approaches.

Project Overview

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 (ΔQ_S)

Element Surface Temperature Method

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 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.

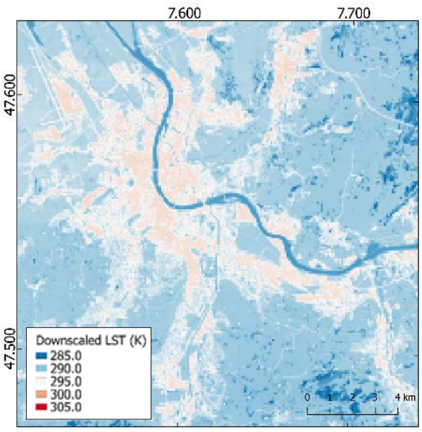
URBANFLUXES investigating the potential of EO to retrieve Q_F, supported by standard meteorological measurements. The main research question addresses whether EO is able to provide reliable estimates of Q_F for the time of the satellite acquisition. URBANFLUXES answers this question by investigating 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:

- 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 UEB 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

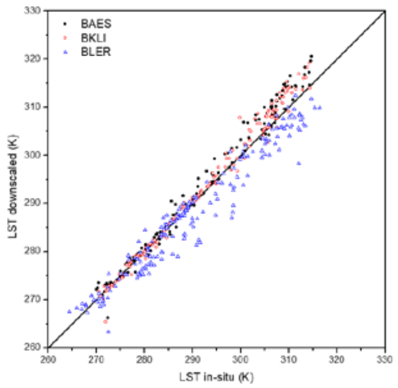
URBANFLUXES has entered its final year of implementation. During the first two years, an extended analysis of vast amount of satellite data took place. Sophisticated models were developed and applied and the first products of satellite-derived urban energy fluxes were available for London, Basel and Heraklion. During the last year, the effort is now concentrated on the combination of the component fluxes, to resolve UEB and to make the methodology applicable to Sentinels.

All the component fluxes have been estimated with the use of EO data and the team now tests UEB closure for the specific snapshots of satellite acquisition time. Results for the city of Basel are presented here, revealing the spatial pattern of the anthropogenic heat flux for the center of the city. The team now focuses on producing time series of downscaled Land Surface Temperature (LST) data from the synergy of Sentinel-2 and Sentinel-3.



Land Surface Temperature for the city of Basel, produced by downscaling 1 km original resolution to 100 m x 100 m.

The downscaling methodology is based on a spatial-spectral unmixing method. Surface cover information in high spatial resolution is used to downscale the low resolution thermal infrared satellite measurement (radiance) and estimate spectral emissivity in combination with information from spectral libraries. Combining the high resolution TIR and emissivity with atmospheric information in a split window algorithm provides LST in high spatial resolution. The evaluation of the downscaled LST products for the city of Basel using the tower-based in situ thermal radiation measurements has given promising results regarding the accuracy of the method.



Evaluation of the satellite downscaled Land Surface Temperature using the in-situ measurements of the three towers in the city of Basel.

The adapted to Sentinels synergy URBANFLUXES method is expected to produce time series maps of each of the UEB fluxes, including Q_F, for the three case study cities. This information will be valuable for achieving UEB closure. The methodology is highly automated and easily transferable to any urban area and capable of providing Q_F benchmark data for different applications and operational services. In this way, the URBANFLUXES approach will become capable of supporting sustainable urban planning strategies relevant to climate change mitigation and adaptation in cities, by taking into account the contribution of the anthropogenic heat.

View of the Greater London Authority city hall, where the 2nd CoP meeting took place

The second round of Communities of Practice (CoP) meetings took place in the first semester of 2017. On January 18, 2017 the second CoP was held in Basel and on February 14, 2017, in the Greater London Authority City Hall. The second CoP meeting of Heraklion was organized on July 14, 2017 in the Heraklion City Hall. Representatives of different public and private organizations of the three cities participated in the meetings.

Participants of the 2nd CoP meeting in Basel.

During the CoP meetings specific methods and data for the case studies were presented by the URBANFLUXES team along with the first results of the Q_F calculations. Discussion on the potential uses of the URBANFLUXES outputs in urban policy making followed after the meetings. The participants gave very positive feedback on the utility of URBANFLUXES data in their efforts for sustainable urban planning towards the goals for climate change mitigation and adaptation. Particularly for the case of Heraklion, the participants highlighted the significant contribution of URBANFLUXES on the environmental infrastructure of the city.

Nektarios Chrysoulakis explains UEB components to the meeting participants during the 2nd CoP in Heraklion

Anthropogenic heat emissions spatial pattern from satellites

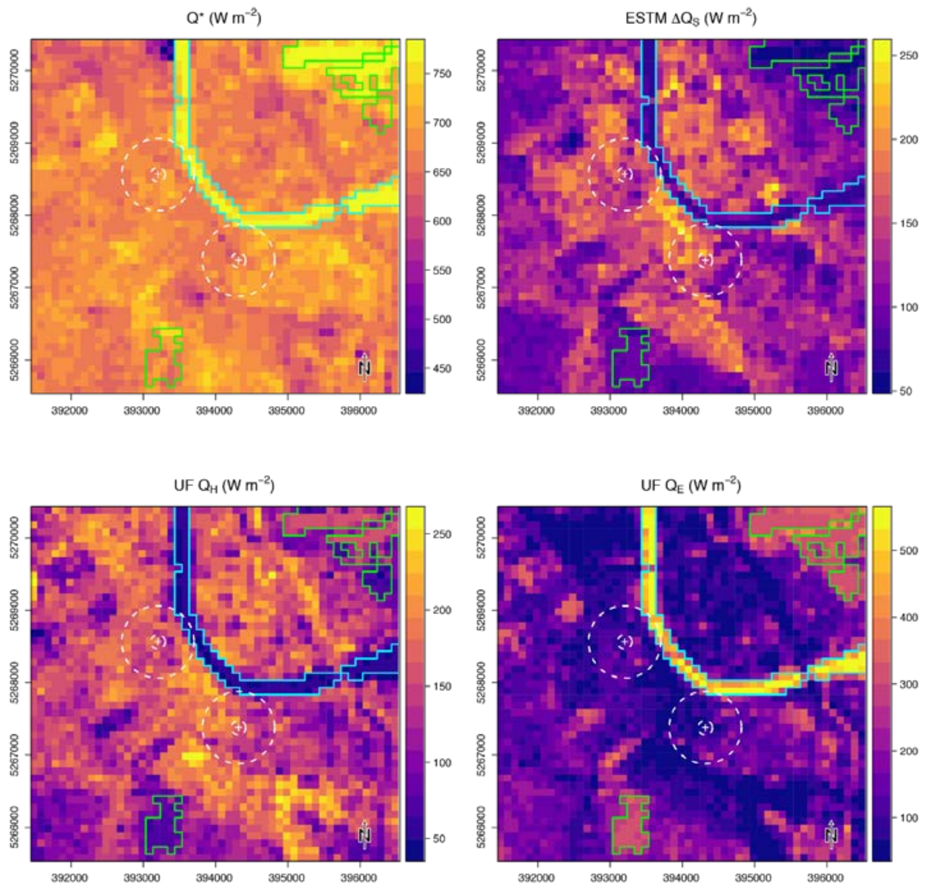
by Ben Crawford and Sue Grimmond

Intense concentrations of human activity inject large quantities of heat into the atmosphere above cities. Knowledge of spatial patterns of this heat (anthropogenic heat flux, Q_F) is useful to urban planners, public health officials, and meteorologists. In particular, this work explores how EO datasets can be used in innovative ways to assess spatial patterns of Q_F and identify emissions hot-spots.

Direct measurements of Q_F in cities are extremely difficult to obtain from the multitude of building, transportation, industrial, and human sources, therefore, the residual UEB approach is the basis of the URBANFLUXES project. The concept is that we can calculate Q_F on a pixel basis if all other surface UEB flux terms are determined:

$$Q^* + Q_F = Q_H + Q_E + \Delta Q_S \quad [\mathrm{W\ m^{-2}}] \ (1)$$

Here, we bring together modelled net all wave radiation (Q^*), turbulent sensible heat flux (Q_H), latent heat flux (Q_E), and storage heat flux (ΔQ_S) using EO surface temperature data to test this approach in Basel.



Modelled Q*, ΔQS, QH, and QE for 24th June 2016 at 11:05 UTC in central Basel. Note the colour scale is different for each figure. Predominantly vegetated (green) and water (blue) pixels are outlined.

Component fluxes

Before the residual Q_F is calculated, first the other terms of the surface energy balance are modelled. In these examples, Q^* is calculated using the Discrete Anisotropic Radiative Transfer (DART) model, ΔQ_S is calculated from the Element Surface Temperature Method (ESTM), and Q_H and Q_E are determined using the Aerodynamic Resistance Method (ARM). As of this writing, there are 12 daytime periods from 2016 with which to test the residual approach. The figures shown here are for an example period from 24th June 2016 at 11:05 UTC (the time of the MODIS satellite overpass).

The Q^* values shows relatively little spatial variation over the urban surfaces (i.e. non-water and non-park areas) and magnitudes range between 600-700 W m^{-2}. The ΔQ_S model shows spatial variability related to building density with highest values (up to 250 W m^{-2}) in densely built areas along the river. Q_H values exhibit similar spatial patterns and magnitudes to ΔQ_S while Q_E is relatively minor in urban areas (<150 W m^{-2}) with highest values in the water and vegetated pixels.

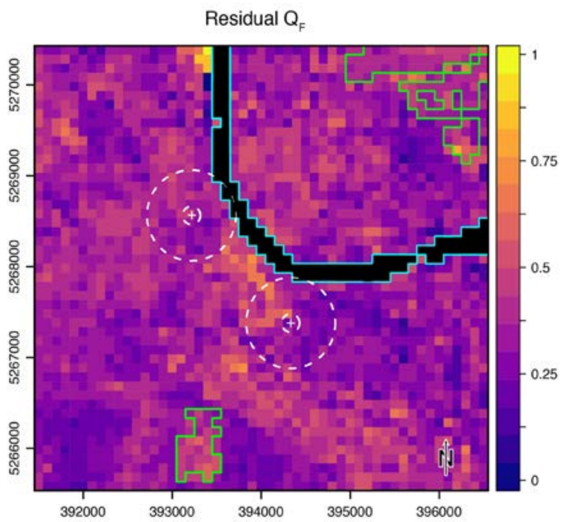
Spatial patterns of residual flux

With these UEB terms accounted for, the residual can then be calculated by solving for Q_F in Equation 1 on a pixel basis. The spatial pattern of Q_F determined from the residual method show clear patterns related to building density and other modelled component fluxes. Highest relative Q_F is found south of the river in the most densely built areas of the city. Independent Q_F models also confirm building sources are the dominant source of Q_F in the city centre of Basel. This information about spatial patterns of Q_F emissions has potential to inform public health officials, urban planners, and meteorologists about the state of the urban environment and atmosphere.

Plan for the project’s final stage

So far, this work has produced new results using EO datasets to calculate spatial patterns of Q_F in Basel. Expanding the analysis to London and Heraklion is a priority, as well as increasing our understanding of uncertainties in each of the component fluxes.

A drawback of a residual approach is that uncertainties from all the component fluxes are included in the residual calculation. This means the residual flux is extremely sensitive to assumptions, errors, and uncertainties in the input data. Enhanced understanding of these issues will help guide future research questions and applications. This work has also raised interesting questions about EO surface temperature datasets in cities, especially in areas with tall buildings and complicated 3D surface structure.



Relative spatial patterns of Q_F for central Basel scaled from 0 to 1 (unitless).

Modeling the anthropogenic heat emissions

by Ben Crawford, Andrew Gabey and Sue Grimmond

A variety of methods exists to model the anthropogenic heat emissions.

Top down Inventory uses energy consumption data from different spatial and temporal scales to create diurnal profiles. Data are normally at coarse resolution with results mapped to finer scales. This approach relies heavily on the availability and quality of data, as well as its relative temporal and spatial resolution. The energy consumption is often assumed to be equivalent to the sensible fraction of Q_F and energy efficiency of appliances is neglected.

UEB closure If measured data are available for all of the surface energy balance terms, then Q_F can be obtained as the residual. This approach employs direct measurements of radiation (e.g. via radiometers), Q_H and Q_E (e.g. eddy covariance, EC), and storage heat flux (e.g. based on surface temperatures of all components). However, such measurements are spatially limited and dependent on applicability of the underlying principles of all the instruments. Given the sensors used, and changing meteorological conditions, further complications arise as the size and shape of the area representative of the measurements varies (e.g. with local winds, stability). All sources of Q_F are included in the final results, which is advantageous, but the contributions of particular energy sectors cannot be isolated easily. Moreover, all measurement errors of the other instruments/fluxes accumulate in this term.

Bottom-up simulation To date, this approach has focused on the building energy component of Q_F. Building energy models simulate the energy consumption and heat rejection of buildings whilst considering the effect of street canyons and building occupancy. These models often also include the calculation of Q_H and Q_E.

Statistical relations with heating and cooling degree days. The consumption of energy is partly dependent on fluctuations in temperature, along with other meteorological factors. Multiple linear regression methods capture the effects of energy behaviour across seasons.

Direct measurement Eddy covariance observations have been used to measure plumes of $Q_{F,B}$ at the micro-scale. This approach, as with UEB closure methods, is challenging because meteorological factors (wind speed, direction, stability) cause shape and size of the source area of the measurement area to vary through time.

Air quality based The variations in carbon dioxide (concentrations or fluxes) can be used to infer the anthropogenic heat flux by investigating diurnal patterns coupled with emission factors related to heat. A wide variety of other atmospheric constituents could be used, but these are likely to be biased towards transport related sources.

Remote sensing data Given the wide variety of EO data sources the techniques vary. Night light data have been used both as indicator of population density but also of intensity of energy use. Infrared satellite images are used to analyse surface temperature urban heat islands, with attempts to determine Q_F. However, the different sources of anthropogenic heat flux cannot be analysed separately easily.

Combination approaches take advantage of a variety of data sources. For example, Narumi et al. (2009) determine all components using both large scale databases but also aspects of air quality data.

Despite the wide range of approaches available to determine Q_F, many urban land surface models ignore the term, use simple approaches to account for all components, or address some terms in detail, while ignoring others.

Two non-remote sensing approaches are adopted for modelling Q_F in URBANFLUXES, i.e. LQF and GQF.

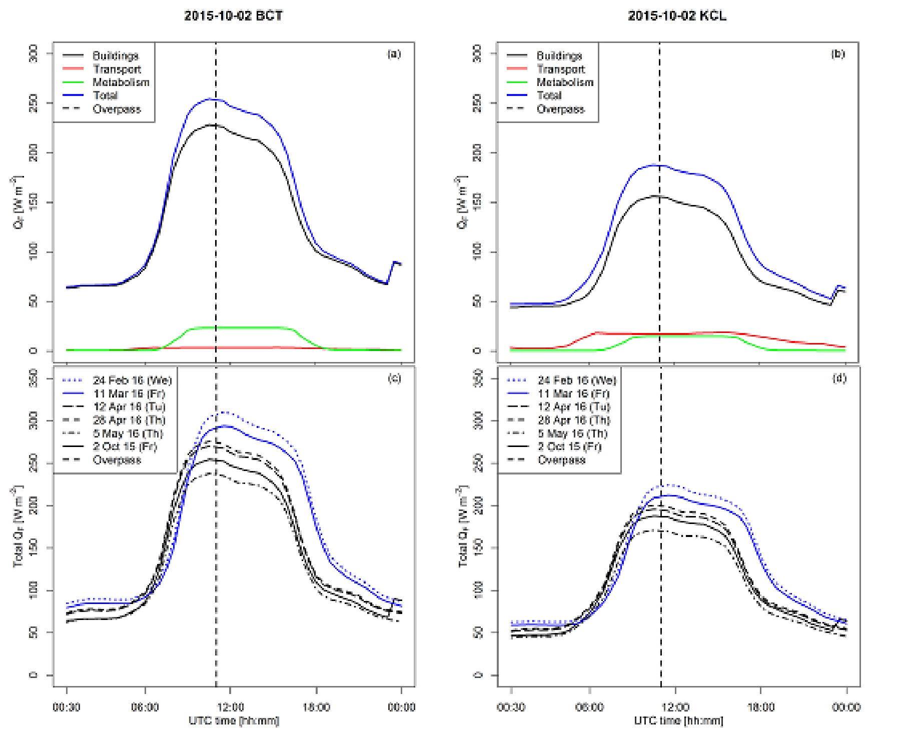
GQF is a modified version of the Iamarino et al. (2011) GreaterQF model. This is a top-down inventory approach that uses energy consumption data for both gas and electricity to determine buildings energy ($Q_{F,B}$) and various sources of transport data to calculate the contribution of transport energy ($Q_{F,T}$). The metabolism components ($Q_{F,M}$) are based on where people are expected to be at a particular time of day.

LQF is a modified version of the LUCY model (Allen et al., 2011 and Lindberg et al., 2013). This allows user-specified population density data for improved spatial resolution and uses general energy consumption modified by heating and cooling degree days.

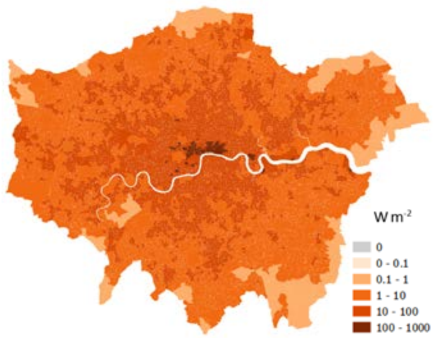
London (GQF)

GQF model results for the two London sites (BCT and KCL) on October 2, 2015 are shown for transport ($Q_{F,T}$), metabolism ($Q_{F,M}$) and buildings ($Q_{F,B}$) energy and the total Q_F is compared on the six overpass days. The summer overpasses have smaller $Q_{F,B}$ than those during February, which is substantially higher because of extra heating during the cold winter months. March and the autumn months also feature higher $Q_{F,B}$ as temperatures are cooler. In all cases, KCL Q_F contains a larger contribution from transport given there is more traffic in this area relative to the broader domain, but the total Q_F is substantially lower because less energy is consumed in buildings in this area. Metabolic Q_F contributions are comparable because estimated populations are similar.

Spatially distributed Q_F estimates show the variation in $Q_{F,T}$ between different areas on each overpass date in 2015 and 2016. Since Q_F is dominated by building energy use, the denser commercial and residential areas towards the centre of the city produce the greatest emission. Changes in the spatial distribution of Q_F are small between overpass days because each overpass takes place at approximately the same time on a weekday, and the bulk of the difference is caused by day-of-week variations in traffic and calendar date changes in building energy consumption.

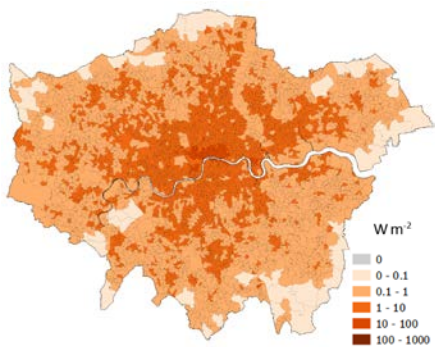


Total GQF anthropogenic heat flux and its main components that have (a) BCT and (b) KCL for the 2 October 2015 overpass day, and total QF for each overpass date at (c) BCT and (d) KCL. Satellite overpass time denoted by vertical dashed lines.

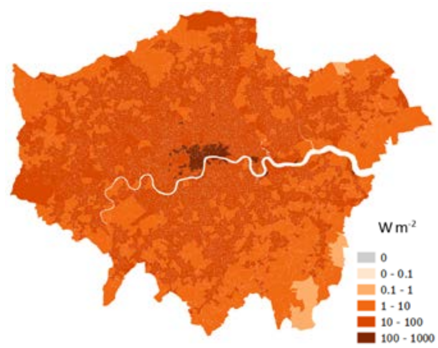


London building energy ($Q_{F,B}$) for October 2, 2015, 12:30 UTC

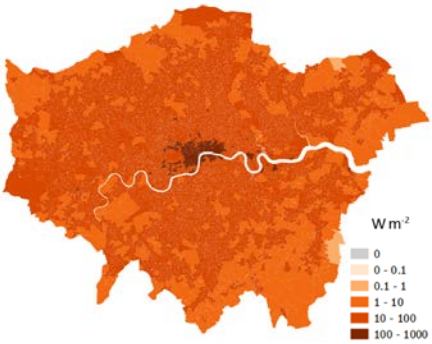
London transport energy ($Q_{F,T}$) for October 2, 2015, 12:30 UTC



London metabolism energy ($Q_{F,M}$) for October 2, 2015, 12:30 UTC



Total anthropogenic heat flux in Greater London (October 2, 2015). Time step used was 10:30-11:00 UTC to coincide with the satellite overpass.



Overall Q_F in Greater London, February 2, 2016

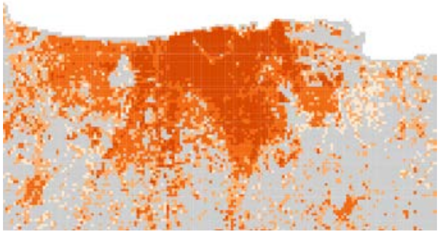

Overall Q_F in Greater London, March 11, 2016

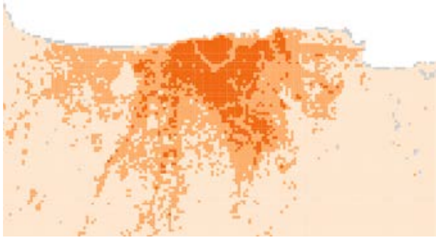

Overall Q_F in Greater London, April 12, 2016

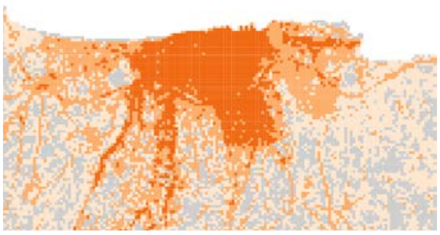

Overall Q_F in Greater London, May 5, 2016.

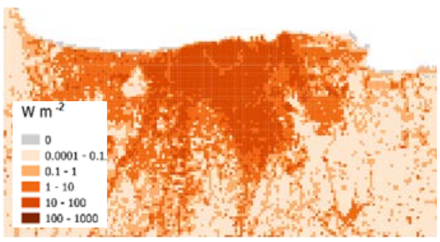
Heraklion (LQF)

The spatial distribution of overall Q_F does not vary much between the overpasses. Higher values are evident in general during summer months from air conditioning particularly along the coastline. Enhanced traffic activity during weekdays in the city centre cause higher $Q_{F,T}$. As the land cover surrounding Heraklion is classified as low vegetation, paved or grass, metabolic activity is attributed to it.


Heraklion building energy ($Q_{F,B}$) for January 24, 2015


Heraklion metabolism energy ($Q_{F,M}$) for January 16, 2015 (weekday)

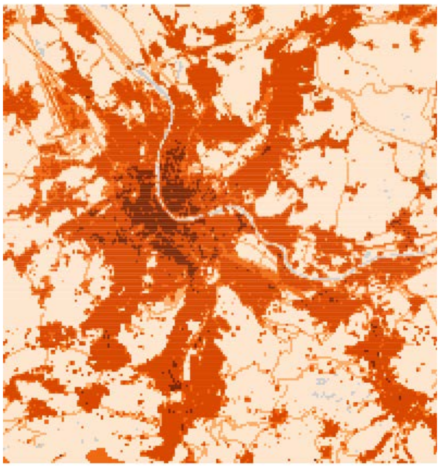

Heraklion transport energy ($Q_{F,T}$) for January 16, 2015



Overall Q_F in Heraklion, January 16, 2015

Basel (LQF)

Basel results are downscaled to 100 m x 100 m ROAs from coarse population spatial units. Metabolic emissions do not visibly vary between the overpasses because each is at the same time of day, $Q_{F,M}$ is shown only for the 2015-08-30 overpass. The higher population densities of central Basel and the outlying conurbations are visible, with zero emission on the river running through the city. Transport levels in LQF vary from weekend to weekday, with more areas showing enhanced values (darker shading) in central Basel on weekdays.


Overall Q_F in Basel for February 10, 2015

Conclusions

Three approaches are explored to calculate Q_F. These vary from the more complete GQF method to the more rapid SUEWS method. New elements have been developed for all three as part of this work. Specifically, each has been generalised to allow for greater ease of use and to enable new datasets to be used as/when they become available. The focus to date has been on London because of data availability, and sufficient data exists to produce LQF results for all three cities as a baseline product. Although a vast range of data sources are used to determine the Q_F via the three methods, there is no direct or true measure of Q_F. *A priori* GQF is expected to be closest to the “truth” because it is constrained by “real” energy uses and behaviours at particular time periods and spatial scales. However, there are number of the other constraints that need to be considered.

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

Joint Urban Remote Sensing Event 2017 (JURSE17) | 6 - 8 March 2017 | Dubai, United Arab Emirates

8th Japanese – German Meeting on Urban Climatology |25 - 29 March 2017 | Osaka, Japan

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

SPIE Remote Sensing 2017 | 11 - 14 September 2017 | Warsaw, Poland

Cities and Climate Conference 2017 | 19 - 21 September 2017 | Potsdam, Germany

Upcoming

URBANFLUXES Demonstration Events | 6 December 2017 | London, United Kingdom

Cities and Climate Change Science Conference (IPCC) | 5 - 7 March 2018 | Edmonton, Canada

European Geosciences Union General Assembly 2018 | 8 - 13 April 2018 | Vienna, Austria

10th International Conference on Urban Climate (ICUC10) | August 2018 | New York, United States

SPIE Remote Sensing 2018 | 10 - 13 September 2018 | Berlin, Germany

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

URBANFLUXES

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