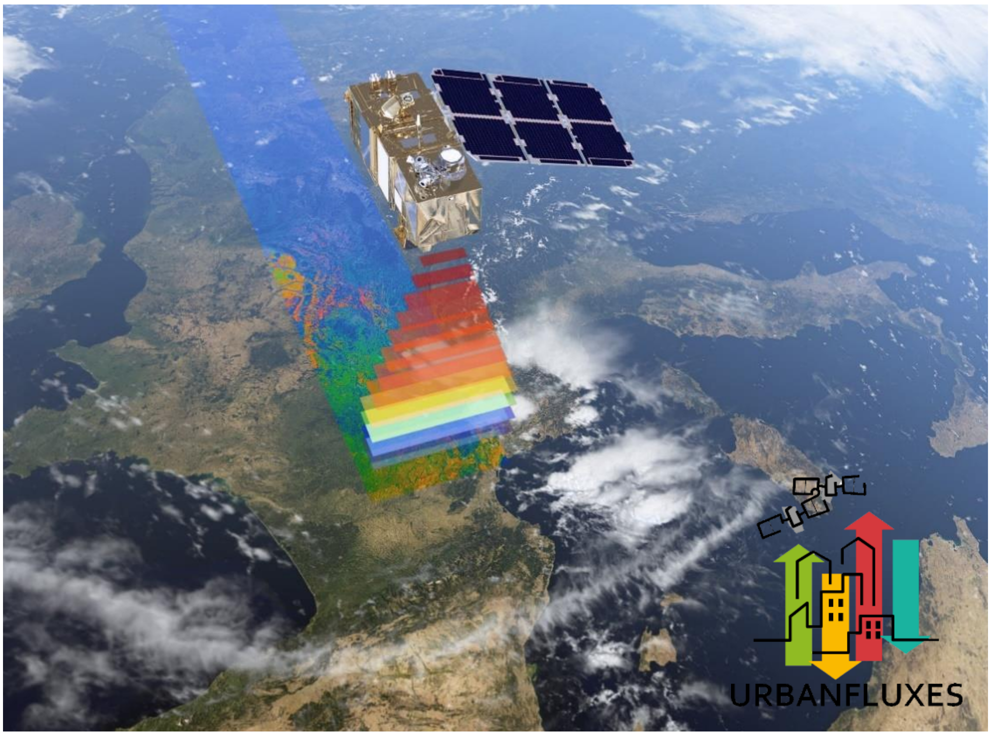

URBANFLUXES
Newsletter

December 2017

URBAN ANTHROPOGENIC HEAT FLUX FROM EARTH OBSERVATION SATELLITES

Editorial

by Nektarios Chrysoulakis

After a three-years period of intensive work towards meeting the ambitious scientific objectives that were set in the beginning of the project, URBANFLUXES is now concluded. It introduced novel ideas on how the different components of the Urban Energy Budget (UEB) can be observed from space, thereby generating new Earth Observation (EO) opportunities of benefit to climate change mitigation/ adaptation and civil protection.

URBANFLUXES gave the opportunity for a close collaborative interaction among the involved scientific teams, enabling cross-fertilizing the disciplines of EO and Urban Climate and produced high level research. The major challenge of the project was to develop methods capable of exploiting Copernicus Sentinel satellites' synergistic observations to estimate spatiotemporal patterns of the different UEB components, including the anthropogenic heat flux.

Under the assumption of limited advection, the project met its objectives by developing Sentinels-based synergistic approaches for estimating each UEB component separately, using also standard meteorological observations from the Wireless Sensors Networks that were deployed in the three case studies: London, Basel and Heraklion. In the general case however, the energy balance closure still remains challenging, leading to underestimations of the sensible heat flux and therefore of the anthropogenic heat flux. Therefore, beyond its important findings, URBANFLUXES has opened new research questions related to more robust EO-based estimation of the sensible heat flux in complex urban settings, as well as to EO products calibration using multiple Eddy Covariance observations.

The 5th issue of the URBANFLUXES Newsletter presents the concluding main achievements and the progress during the last semester of the project. In this period the research activities were focused on the adaptation of the URBANFLUXES method to Sentinels synergy and in this issue, a detailed description of this effort is presented. Furthermore, important milestones of the project were the two Demonstration Events that were organized in London in the beginning of December 2017 and their outcomes are summarized here. Finally, an update on the project's publications and conference presentations is given.

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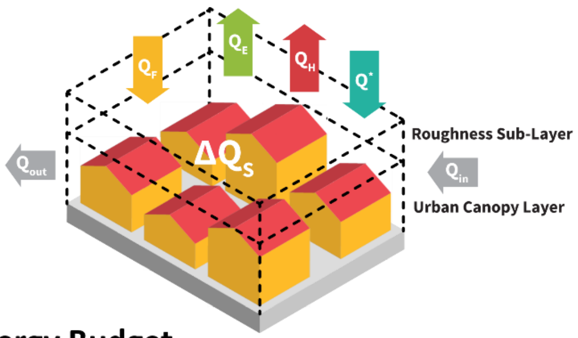
Energy balance residual approach



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

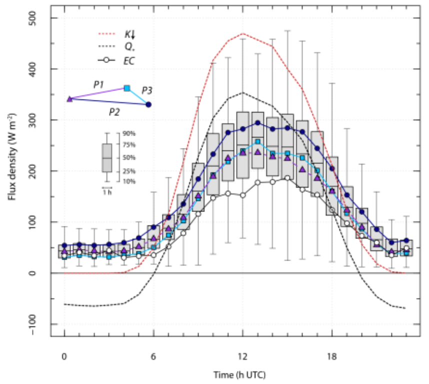
During the three years of URBANFLUXES project, the team advanced significantly the current knowledge of the UEB components estimation methods and assess their behaviour in space and time, as well as their impacts on the Urban Heat Island (UHI) and hence on urban climate and energy consumption.

Extended analyses of various methodologies and a vast amount of meteorological, micro-meteorological and geospatial (mainly EO-based) data took place in London, Basel and Heraklion. Sophisticated models were developed to derive the different urban energy fluxes. The final methodology for EO-based estimation of all UEB fluxes through the exploitation of Copernicus Sentinels is a valuable tool for Earth System Science and urban planning communities.

Online monitoring of in-situ meteorological and Eddy Covariance data of each case study through the URBANFLUXES web tools.

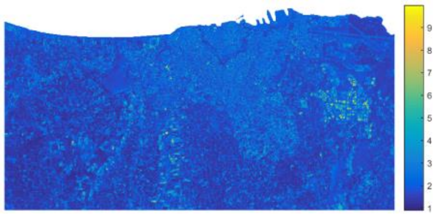
The URBANFLUXES tools are capable of supporting strategies to mitigate UHI effects, improving thermal comfort and energy efficiency in cities. Furthermore, the developed tools can be used for monitoring and evaluation of the implementation of climate change mitigation technologies, including Nature Based Solutions (NBS).

The method for deriving Q* using the DART model proved to work efficiently for Sentinels and can now be applied in any city, provided the necessary data (3D urban models & atmosphere data). The Element Surface Temperature Method (ESTM) is a dynamic and the most appropriate method when utilizing EO and geodata for deriving ΔQ_S. The Aerodynamic Resistance Method (ARM) is also a valuable technique for deriving turbulent heat fluxes using EO data combined with morphology and in-situ meteorology.



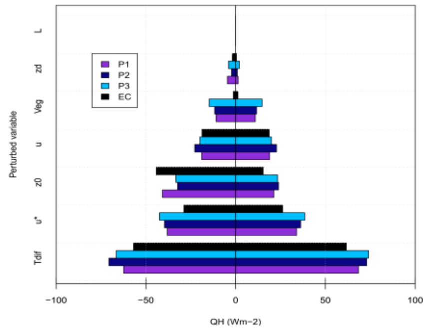
Diurnal patterns of in-situ measured energy fluxes for the centre of London using net radiometers, scintillometry and Eddy Covariance.

The challenges that have been recognized in the estimation of each UEB term are also very important for the future research. The sensitivity/accuracy of input parameters in each model have been proved crucial for the output accuracy. The temperature of surfaces not seen by the satellites, combined with the thermal anisotropy of the urban environments are factors that may introduce uncertainty in the flux models.



Uncertainty (K) map of downscaled LST product in Heraklion.

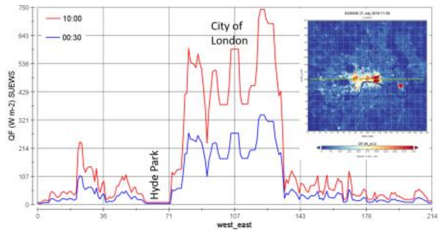
Sensible heat flux (Q_H) is a key component of the UEB and URBANFLUXES proved that the uncertainty imposed in its estimation is crucial for closing the energy balance and estimating Q_F from a residual approach. Uncertainties in the calculation of aerodynamic resistance and excess resistance due to extrapolation of measured air temperature, humidity and wind speed to the full area of interest can affect the Q_H estimation. However, the most important parameter is the difference between air temperature and surface temperature. ± 2 K perturbation in LST can impose ± 50 W m^{-2} variance on modeled Q_H.



Sensitivity of Q_H estimation to various input variables. The difference between surface and air temperature is the most important parameter in the model.

The anthropogenic heat flux has been estimated in URBANFLUXES using a variety of approaches. Bottom-up, top-down, simple parameterization and combined models have been integrated with in-situ UEB flux measurements and compared with the developed EO-based methodology. All of the techniques have uncertainties and most are data intensive. Attention is needed when comparing compatible spatial information. Areas with most intense anthropogenic heat emissions may be missed by a simple model, while emissions estimates are improved with more detailed information.

Anthropogenic heat emissions vary with human activity and population shifts during workdays lead to changes in the spatial structure of emissions. During URBANFLUXES, a variety of methods have been developed and are available for others to use through the integrated UMEP tool that is offered as an open source plugin in QGIS.



Spatial variations of Q_F in London during day and night of a summer day, estimated using SUEWS model.

The Copernicus Sentinels for Urban Energy Fluxes

by Zina Mitraka and Stavros Stagakis

Europe's Copernicus is the most ambitious EO programme to date. It will provide accurate, timely and easily accessible information to improve the management of the environment, understand and mitigate the effects of climate change and ensure civil security.

The European Space Agency (ESA) coordinates the delivery of data and is developing a new family of satellites, the Sentinels, specifically for the operational needs of Copernicus. Each Sentinel mission is based on a constellation of two satellites to fulfil revisit and coverage requirements, providing robust datasets for Copernicus services. These missions carry a range of technologies, such as radar and multi-spectral imaging instruments for land, ocean and atmospheric monitoring.

Urban materials

Sentinel-2 is a polar-orbiting, multispectral high-resolution imaging mission for land monitoring to provide, for example, imagery of vegetation, soil and water cover, inland waterways and coastal areas. Sentinel-2A was launched on 23 June 2015 and Sentinel-2B followed on 7 March 2017.

Sentinel-2 data are essential for URBANFLUXES. The enhanced spatial resolution compared to Landsat (10 m and 20 m) allows better discrimination in urban features (buildings and streets). The enhanced spectral resolution (13 visible and near-infrared and shortwave-infrared bands) allows discrimination between some urban materials and the high temporal resolution (twice per week) enhances the monitoring of the urban surface cover.

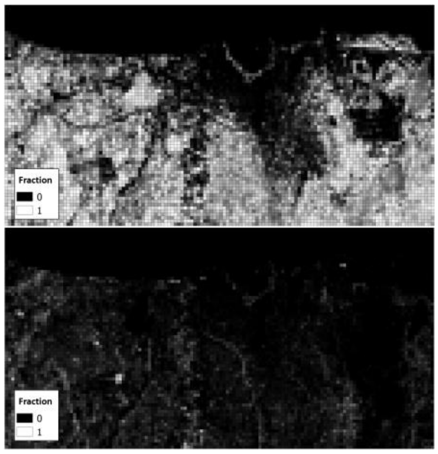
Image fusion techniques were used in URBANFLUXES, to further enhance the spatial resolution of Sentinel-2 to reach 2 m (using very high resolution WorldView-2 data). This allowed discrimination between some basic roofing materials. Knowing in detail the fraction of different roofing materials in the city is important when estimating the urban energy fluxes. Different materials not only have different optical properties, but thermal properties as well.

Roofing material classification using spectral library from fused Sentinel-2 and WorldView-2 imagery in Heraklion.

Vegetation cover changes

Vegetation cover presents dynamic changes both in space and time. In order to capture the changes in all three URBANFLUXES vegetation classes, an algorithm was developed that uses 10 m resolution Sentinel-2 NDVI, combined with the static URBANFLUXES Classification (2.5 m). In order to have a complete monitoring of vegetation changes for URBANFLUXES UEB time-series products, all available Sentinel-2 and Landsat-8 cloud-masked NDVI images were used. When Sentinel-2B becomes operational, there would be no need to integrate Landsat images in the methodology. Vegetation fractions are estimated by scaling NDVI using minimum (that correspond to base soil) and maximum (that correspond to 100% vegetation fraction) NDVI values.

Three different vegetation fraction images are produced in the same resolution as the NDVI image (10 m for Sentinel-2). These images however do not distinguish between the vegetation types and each of them contain the total vegetation of the study area. In order to separate the different vegetation types and fine-tune the estimated fractions with the rest of the URBANFLUXES land cover classes, the VHR Classification of the study area is used as a baseline.



Low Vegetation fraction in winter (upper image) and summer (lower image) in Heraklion

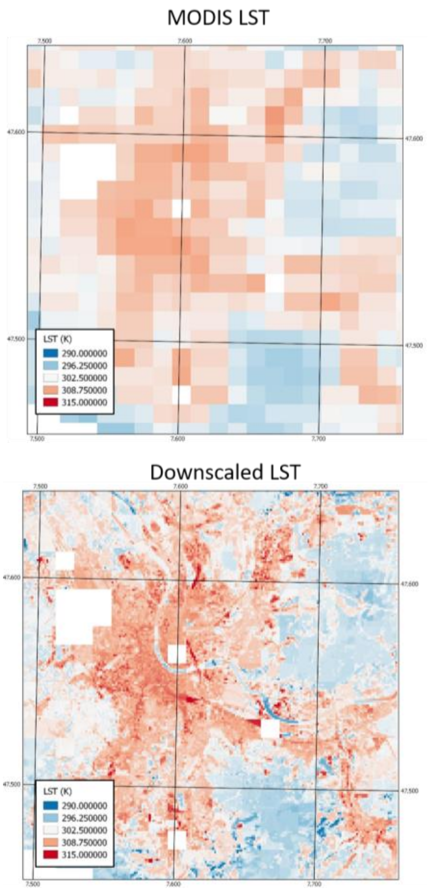
The VHR Classification image is used in order to estimate a static dataset of Class fractions in the same resolution with the NDVI-based vegetation fractions (i.e. 10 m for Sentinel-2, 30 m for Landsat). Then, these fractions are used as a baseline to adapt the NDVI-estimated vegetation fractions and produce updated fractions for the vegetation classes. Finally, the updated fractions are aggregated to the standard 100 m URBANFLUXES grid for each study area. The algorithm is predominately based on a series of logical assumptions. These assumptions are formulated as rules in order to reach the final products.

The main rules concerning the class interchangeability can be summarized as follows: Low vegetation class can change to bare soil class and vice versa. These changes are the most frequent during the annual growth cycle in natural and agricultural areas around the city. Deciduous Trees class can change to Dry Vegetation, Low Vegetation and Paved classes due to the leaf fall in winter. Evergreen trees class may change due to pruning or other types of interference to Bare Soil or Paved classes.

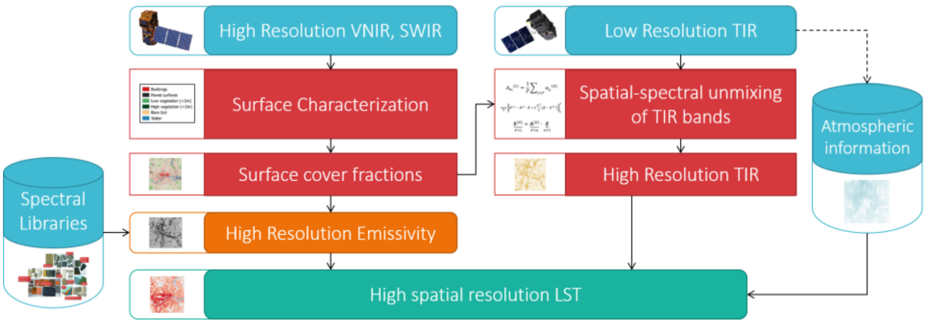
For all trees, it is assumed that the VHR Classification has captured the maximum tree growth. Changes that include the increase of deciduous or evergreen tree fractions over the baseline are neglected. Therefore, this algorithm will not capture the establishment of an urban park or the planting of new trees, but only their decrease.

Local Scale Land Surface Temperature

For the estimation of the urban energy fluxes, one of the most important parameters to consider is the Land Surface Temperature (LST). Although LST is routinely derived by satellite thermal infrared (TIR) observations, currently there is no space-borne sensor capable of providing frequent thermal imagery at sufficient spatial resolution for urban studies. Sentinel-3 is delivering TIR data twice per day (and in the future 4 times per day with the second satellite in orbit), but of 1 km spatial resolution. The same is for the NASA MODIS satellite. Thus, in URBANFLUXES we had to confront the trade-off between spatial and temporal resolution.



Comparison of MODIS LST product (1 km) with downscaled LST (100 m) for Basel at 2/8/2011.



Land Surface Temperature downscaling methodology

A synergistic method that unmixes the low-resolution TIR measurements using high spatial information on the surface cover for estimating high spatial resolution LST was applied.

The method is a multistep procedure. For the method to be applied information on the surface cover fractions is necessary. The surface cover fraction information is available in high spatial resolution from the Sentinel-2 and Landsat data, as described above.

Representative emissivity values are assigned to each of the cover types, using information derived from spectral libraries. Libraries like the ASTER Spectral library (https://speclib.jpl.nasa.gov/), the MODIS emissivity Library (https://icess.eri.ucsb.edu/modis/EMIS/html/em.html) and the Spectral Library of Impervious Urban Materials (http://www.met.reading.ac.uk/micromet/LUMA/SLUM.html) were used. The emissivity maps are the derived assuming a linear combination between the surface cover fractions and the representative emissivity values.

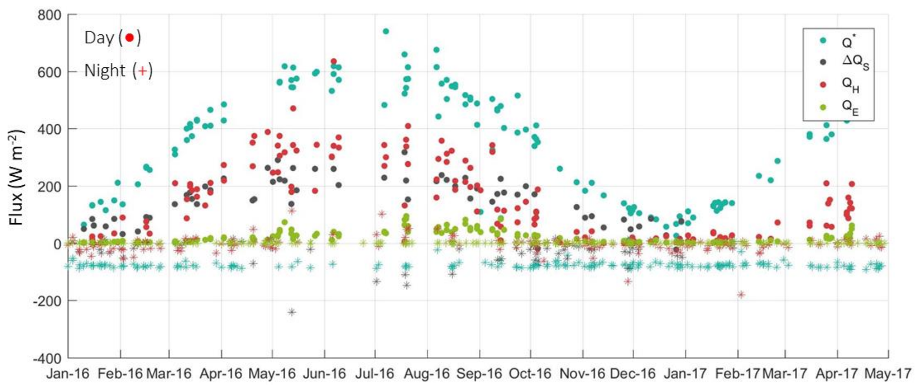
Spatial-spectral unmixing is then used to enhance the spatial resolution of the low resolution thermal bands. Each low resolution pixel is unmixed, using the contextual information of the neighbouring pixels in a moving window. The downscaling is performed in the radiance and the assumption is that the radiance of a low resolution TIR pixel is a combination of the individual radiances coming from different surface cover.

The high resolution TIR information is then combined with the high resolution emissivity maps, along with atmospheric information from other sources (satellite water vapour products) to retrieve the high resolution LST maps.

Urban Energy Fluxes Time-Series

The LST downscaling methodology was applied for time series of Sentinel-3 and MODIS data for the three case studies, for periods covering more than a calendar year (2016 and part of 2017). This in-theory allowed 6 LST maps per day. In practise, the time series is constrained from the cloud cover.

Daily LST products allowed the estimation of the urban energy fluxes through time for London, Basel and Heraklion. Monitoring the fluxes through time allows conclusions on the urban energy balance.



Time-series of Urban Energy Fluxes for an area in the centre of London from January 2016 to May 2017

The URBANFLUXES Demonstration Events

by Judith Klostermann

The URBANFLUXES project is drawing to a close, and it was time to present the results. Two demonstration meetings were held in the Blue Fin Venue in London in December 6, 2017.

Methods to obtain anthropogenic heat maps in cities

This first meeting was entitled 'Methods to obtain anthropogenic heat maps in cities' and aimed at informing scientists. The methods used in the different work packages were explained and the project results were discussed. URBANFLUXES wanted to use EO data for larger urban energy budget maps.

Nektarios Chrysoulakis presenting the main achievements of the URBANFLUXES project.

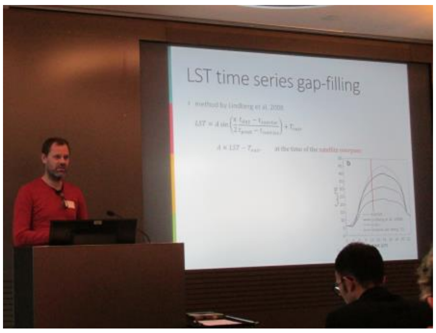
WP3 started with using Landsat 5, 7 and 8 data, MODIS and ASTER data and later on also the data from the new EU Sentinel satellites. All the data were necessary for the calculation of the different energy budget terms. For WP3 it was a success to learn how to cooperate between the scientific disciplines.

Mattia Marconcini explaining the difficulties in translating EO data into useful information for flux models.

The challenges for WP4 was a simulation of the net radiance Q* to have time series and an estimation of irradiance. After several iterations of the modelling exercise the results were quite good. If all the 3D data of a city, atmosphere data and EO data are available the model can now can calculate Q* for every city. Additional iterations are needed though for each new satellite acquisition to get the vegetation and material properties right.

Lucas Landier presenting the DART model for the estimation of Q*.

WP5 aimed to calculate the heat storage flux (ΔQ_S). The modelling showed high ΔQ_S in high rise areas, while in the values for parks for example are lower. In the end WP5 produced reasonable results for day and night. The challenge still is to propagate the measured data for the whole period under investigation. It is important to get the correct input data such as the building materials.

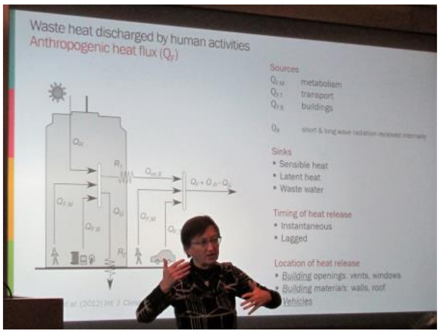


Fredrik Lindberg explaining the difficulties in time series gap filling for Land Surface Temperature.

WP6 covered latent and sensible heat flux calculations and local measurements. The sensible heat fluxes were highest in the summer, both for sensible and latent heat flux. Hotspots are the city centres and impervious surfaces. Calculations showed medium fluxes for dense built up areas and low heat fluxes in green areas. The sensible heat flux of London is higher than in Basel. The latent heat flux is highest in the forest and lowest in the city. The data show that we underestimate sensible heat fluxes in the models compared to the measurements. Latent heat is also underestimated but the values are low in the city so this is less of a problem for our calculations.

Christian Feigenwinter explaining the various products for turbulent heat fluxes.

WP7 used six different methods to calculate the anthropogenic heat fluxes Q_F. Q_F is a measure for the waste heat discharge by human activities: human metabolism, transport and buildings. With each method are associated errors and all techniques are data intensive. What do we have the greatest confidence in? The remote sensing method works with the different fluxes: sensible heat, latent heat, storage heat and so on and Q_F is finally calculated as a spatial map at one point in time. We think the GQF model is the best, because it is constrained by real data, but it cannot predict Q_F so it always uses past data. So, you could use GQF first and then use the SUEWS model for predicting future outcomes based on land use. The other methods are more constrained in time and space so it is hard to say how correct their outcomes are. The order of magnitude is OK but how to extrapolate this over time we cannot say. We made a variety of tools available and we made sure each method can be used by others.



Sue Grimmond explaining the waste heat discharge by human activities.

Finally, WP8 used EO data and flux models to produce time series of energy flux components. The data coming from different satellite sources and of different spatial resolution were upscaled or downscaled to a 100 m resolution to match the project goals. The conclusion was that European Sentinel satellites combined with observations from NASA satellites can provide a wealth of data with acceptable validity for energy flux estimations.

Zina Mitraka presenting the Copernicus Sentinels and how their data can be valuable for the fluxes estimation.

How can cities reduce urban heat problems and energy losses

The second demonstration meeting was also held in the Blue Fin Venue in London, in the afternoon. This meeting was entitled 'How can cities reduce urban heat problems and energy losses?' and aimed at informing practitioners. Participants were present from the three case study cities Basel, Heraklion and London. In different presentations the knowledge from URBANFLUXES researchers was extrapolated to suggestions for reducing heat in cities.

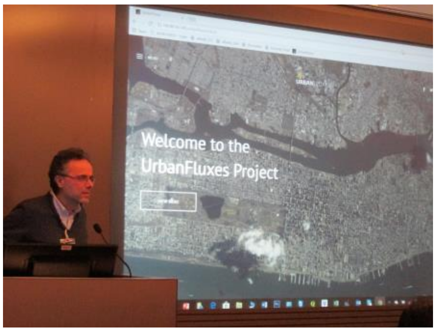
Eberhard Parlow started with an explanation that it is not so straightforward because many factors play a role, and in the end it is the total balance of incoming and outgoing energy that defines the ambient temperature. The income consists of solar radiation. The resulting heat can be reduced with shadowing, increased albedo, and reduced absorption of radiation. Shadowing by trees is very effective; and the tree roots can get enough water for evaporation. Evaporation cools a city, and this factor is called the latent heat flux. So vegetation can be used to increase the latent heat flux. The effect of green roofs, however, is questionable. If arid plants are used there is not much difference between green and gravel roofs. Only if a green roof is irrigated, it can make a difference; and irrigation is costly. Painting walls and roofs white increases the albedo so more heat reflects back into space. However, people prefer red roofs. Nowadays there are also innovative coatings with the same reflectivity in the visible spectrum (looking red), and in high wavelengths it is reflecting 80%.

Eberhard Parlow explaining the reasons for investing on solutions to combat the urban heat.

Fredrik Lindberg added that painting the walls white is not a solution. The reflection of white surfaces on people also has a heating effect, even if the walls themselves stay cooler. White roofs are good to increase thermal comfort but white walls and floors are not. Stone stores heat, which is based on storage capacity and conductivity of the material. Brick, stone and concrete have high values for both aspects. Considering different building materials may help to reduce the storage heat. Another factor is the amount of material: a building with a higher volume can store more heat. The city centre of London has many high rise buildings and much use of concrete and steel. Streets are also hotter: asphalt can store a lot of heat. If you have parks there is less storage. Today many new buildings have glass surfaces, which lets in the heat. Through glass even floors and inner walls can be heated up. Glazed buildings require more air conditioning. This fashion should be reconsidered by architects.

Finally, Sue Grimmond discussed how the anthropogenic heat emitted in cities can be reduced. There are three main sources of anthropogenic heat: buildings, transport and human metabolism. Buildings are the most important source, and insulation against both heat loss in winter and heat accumulation in summer can reduce the heat emissions from buildings.

Fabio Del Frate showed the app that was developed, summarizing the results of the URBANFLUXES project. The app is functional for phones, iPad and laptops. The main sections are background, technology and results. The app provides direct links to the ground measurements websites in Basel, London and Heraklion.



Fabio Del Frate presenting the URBANFLUXES App.

Events

URBANFLUXES will be present in several conferences and events after the termination of the project. You can still follow us on your preferred social network (*ResearchGate, Twitter, Google+, LinkedIn*) to get instant updates on events related to URBANFLUXES.

Past Past

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

Upcoming Upcoming

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

Latest Publications

2018 2018

Lindberg, F., Grimmond, C.S.B., Gabey, et al., 2018. Urban Multi-scale Environmental Predictor (UMEP): An integrated tool for city-based climate services. Environ. Model. Softw. 99, 70–87.

2017 2017

Kent, C.W., Grimmond, S., Gatey, D., 2017. Aerodynamic roughness parameters in cities: Inclusion of vegetation. J. Wind Eng. Ind. Aerodyn. 169, 168–176

Marconcini, M., Heldens, W., Del Frate, F., et al., 2017. EO-based products in support of urban heat fluxes estimation, in: 2017 Joint Urban Remote Sensing Event, JURSE 2017.

Chrysoulakis, N., Marconcini, M., Gastellu-Etchegorry, J.P., et al., 2017. ANthropogenic heat FLUX estimation from Space, in: 2017 Joint Urban Remote Sensing Event, JURSE 2017.

Wicki, A., Parlow, E., 2017. Multiple regression analysis for unmixing of surface temperature data in an urban environment. Remote Sens. 9.

Kent, C.W., Grimmond, S., Barlow, J., et al., 2017. Evaluation of Urban Local-Scale Aerodynamic Parameters: Implications for the Vertical Profile of Wind Speed and for Source Areas. Boundary-Layer Meteorol. 164, 215

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

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