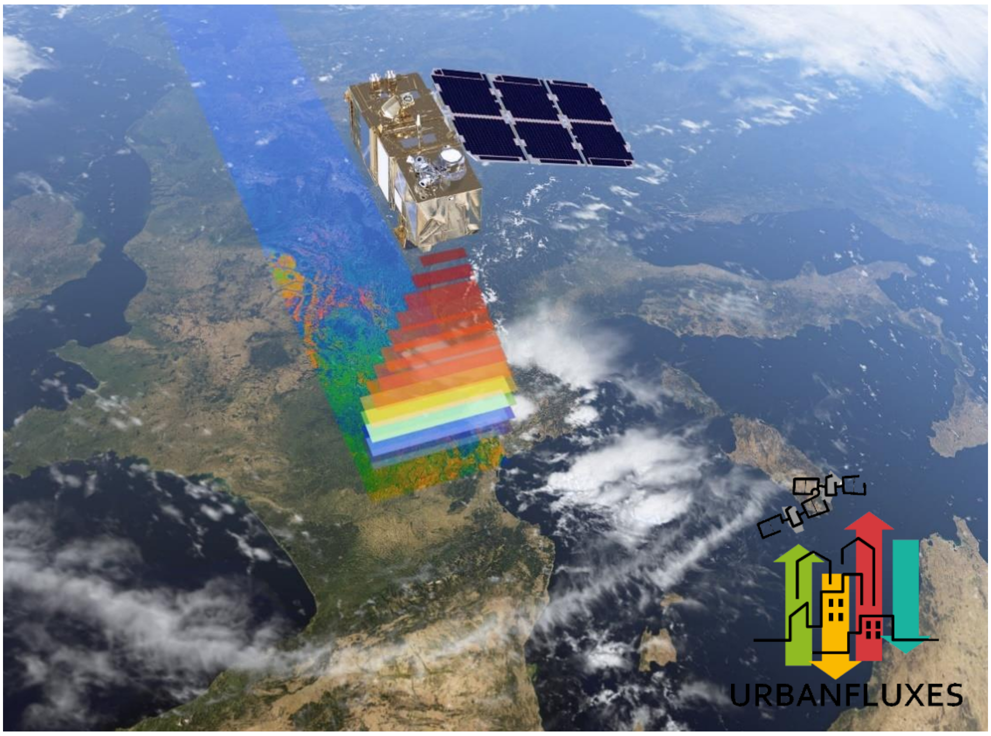
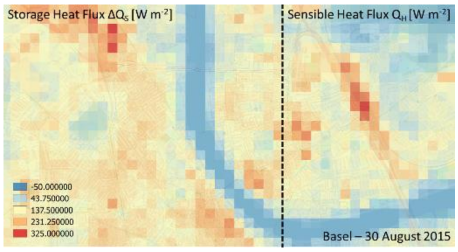


URBANFLUXES Newsletter

September 2016

URBAN ANTHROPOGENIC HEAT FLUX FROM EARTH OBSERVATION SATELLITES

IN THIS ISSUE



Main Achievements and Upcoming Activities

URBANFLUXES has successfully completed one and a half years of life. The first set of urban heat fluxes from satellites is true and the team is working hard on making the method sustainable and trustworthy for the estimation of anthropogenic heat flux.

Page 3

Measurements Networks

In URBANFLUXES we are too ambitious to try estimating the urban heat fluxes from satellite observations combined with standard meteorological measurements. In-situ Wireless Sensors Networks (WSN) for such measurements are operational in London, Basel and Heraklion for URBANFLUXES.

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Editorial

by Nektarios Chrysoulakis

URBANFLUXES is one of the five projects funded by H2020-Space call on new ideas for Earth-relevant space applications (H2020-EO-1-2014). It is a joint effort of eight European Organizations, aiming to introduce novel ideas on anthropogenic heat flux observation from space. URBANFLUXES generates new Earth Observation (EO) opportunities of benefit to climate change mitigation/adaptation and civil protection and enables the development of operational services in the field of urban environmental monitoring and energy efficiency in cities.

URBANFLUXES advances the current knowledge of the impact of urban energy budget on urban heat island development and consequently on energy consumption. It 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 the urban heat fluxes in cities.

An important milestone for URBANFLUXES was the 16th of February 2016, for two reasons: a successful Review Meeting held in Reading, UK; and the launch of Copernicus Sentinel-3A. Sentinel-3 series are multi-instrument missions capable of measuring, among others, the land surface temperature with high accuracy and reliability. Sentinel-3 is very important to URBANFLUXES, as it will provide daily observations of the urban surface temperature, a key parameter formulating the gradients that govern the long-wave radiation flux, the rate of heat storage in buildings, as well as the turbulent heat exchanges between the urban surface and the atmosphere.

This issue of the URBANFLUXES Newsletter presents the progress and the main achievements of the project during the six-month period after the 1st Review Meeting. Details on the in-situ measuring station networks in London, Basel and Heraklion are presented, along with a short description of the project's approach on turbulent heat fluxes estimation. Finally, an update on the project's publications and relevant events is given.

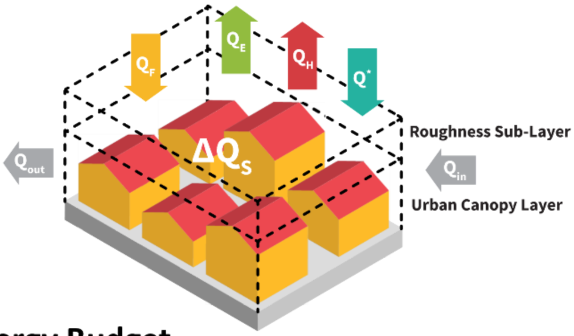
Project Overview

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 (ΔQ_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.

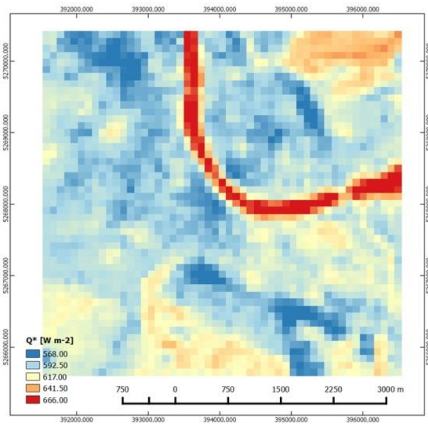
Main Achievements so far

The URBANFLUXES 2nd Progress Meeting held in Reading, on February 17, 2016, to discuss the outcomes of the 1st URBANFLUXES Review Meeting and to define the work plan for the first semester of 2016. Besides, these meetings, two Management Board internet meetings were held to guarantee the smooth progress of the project actives and to resolve any technical or administrative problems. Furthermore, two Technical internet meetings were organized to ensure the proper integration of the outcomes of different Work Packages. The operation of the URBANFLUXES web-server supported the communication and the data exchange among the partners. Besides this web-server the 1st Newsletter was dispatched to more than 3.000 recipients via a dedicated e-mailing campaign, reporting on the progress of the project, facilitating the communication with both the scientific and the planning communities and acting as the mean for the broader dissemination of the project outcomes. The communication with the potential users was further supported by the presentation of the main achievements of the first phase of the project in several conferences and workshops.

1st URBANFLUXES Review Meeting.

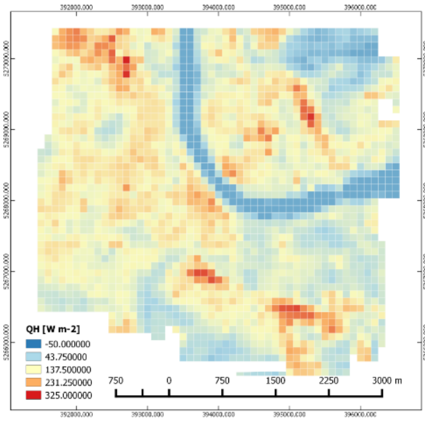
The Wireless Sensor Networks, as well as the Eddy Covariance and Scintilometers are fully operational at all case study cities. The measurements are made available via the URBANFLUXES web-site. Furthermore, the databases containing satellite-derived urban surface morphology and cover characteristics, for the three case study cities are updated with detailed information. Fractions of roofs, walls and paved areas are available. Detailed mapping of the vegetation phenology dynamics during the period from 2010 to 2016 is also included. All maps are made available via the URBANFLUXES web-site, in line with the H2020 Open Data Pilot requirements.

Especially for the urban heat fluxes, the main project outcomes concern spatial distributions of the net all-wave radiation, of the net change in heat storage, as well as of the turbulent sensible and latent heat fluxes, for Basel and central London, for selected weekdays and weekends of 2015. Examples of heat fluxes mapping for the city of Basel are given below: The first image presents the spatial distribution of the net all-wave radiation in the city of Basel. The spatial distribution obtains its maximum values (over 600 W m^{-2}) over the river surface, due to the lower albedo of the water.



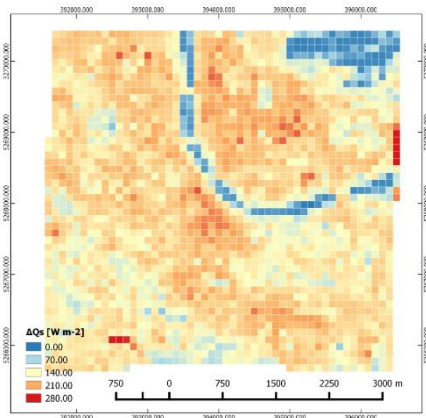
Net all-wave radiation (Q*) in W m^{-2}, on 30 August 2015 at 11:16 local time covering the central part of Basel, Switzerland

The second image presents the spatial distribution of the turbulent sensible heat flux in the city of Basel. The spatial pattern follows the one of transpiring and impervious surfaces. The highest sensible heat fluxes are found in the most densely built-up regions with high surface temperatures and missing vegetation. Industrial areas particularly show high fluxes up to 300 W m^{-2} and more.



Sensible heat flux (Q_H) in W m^{-2} on 30 August 2015 at 11:16 local time covering the central part of Basel, Switzerland.

The third image shows the spatial distribution of the net change in heat storage. The spatial pattern is affected by urban morphology and surface temperatures. The highest ΔQ_S is found in the central parts of the city. This is the densest part of Basel, with the warmest surface temperatures at this time. Cooler areas, with lower building density such as parks and open water, show lower ΔQ_S.

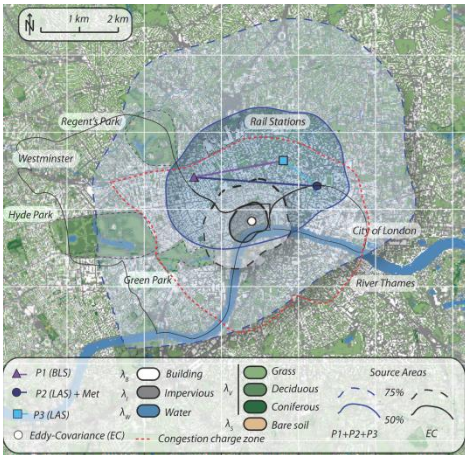


Storage heat flux (ΔQ_S) in W m^{-2} on 30 August 2015 at 11:16 local time covering the central part of Basel, Switzerland.

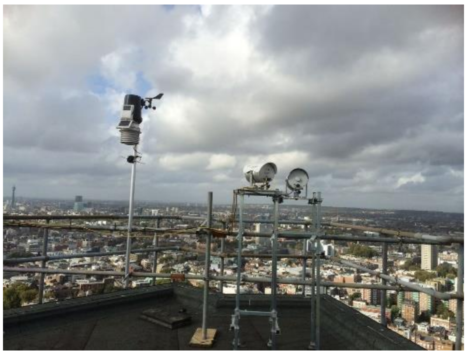
Finally, impendent estimates of the anthropogenic heat flux, based on non Remote Sensing approaches were done for all URBANFLUXES case study cities. These estimates are being used to evaluate the EO-based anthropogenic heat flux calculations, the most important outcome of the final step of the first phase of the project.

LONDON MEASUREMENTS NETWORKS

Eddy covariance equipment mounted on a tower in central London. The sonic anemometer points to the left of the image with the infra-red gas analyser sitting in the centre. At the highest point is an automatic weather station. To the right, are a series of radiometers measuring various wavelengths of radiation from the atmosphere and the surface.



Location of instruments measuring turbulent sensible heat flux in central London. The sonic or eddy-covariance (EC) system (top figure) and three scintillometers (P1, P2, P3, bottom figure). The shaded contours are annual average source area weightings for EC (black) and scintillometers (blue).



Part of two scintillometer systems located in central London for paths P2 and P3 (figure above) with an automatic weather station to the left. The BT tower (triangle on figure above) can be seen to the far left of the photo. The left scinitllometer is pointing towards the BT tower, whereas the right hand one is pointing towards the IMU (blue square on figure above) which is one of the taller buildings that can be seen through the legs if the stand supporting the scintillometers.

Measurements Networks

by Sue Grimmond, Christian Feigenwinter and Nektarios Spyridakis

London

In London, a range of observations are being undertaken within the URBANFLUXES project. These include using two different techniques to measure in-situ the turbulent sensible heat fluxes: *eddy covariance* and *scintillometry*.

Eddy Covariance

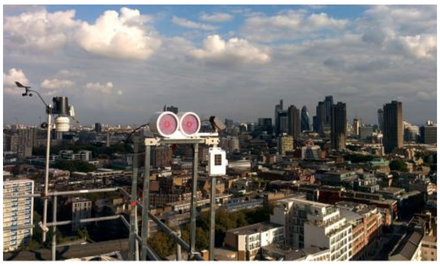
The more common and widely used approach of eddy covariance (EC) requires a sonic anemometer thermometer system (top figure). This rapidly measures wind movement in 3 dimensions separately: the wind coming towards an object, the wind at right angles to that, and air moving vertically. At the same time, air temperature is measured, using the speed of sound. When this instrument (commonly referred to as a sonic), has a fast response gas analyser located close by, then the variations in concentration of that gas can also be measured at the same time. To measure the turbulent latent heat flux, or evaporative flux, the variations of water vapour are measured with an infrared gas analyser (Figure 1) that can detect rapid variations in the concentration of humidity. As atmospheric pressure and temperature variations influence moisture, these need to be taken into account at the same time. Using the variations of vertical velocity, which are corrected for flow over the surface (or roughness elements e.g. buildings and trees) to ensure the 3-dimensions are in a standard coordinate system, and variations of temperature, then the turbulent sensible heat flux (Q_H) can be determined using the eddy covariance technique. The measurements are made at 10 times per second or faster and the fluxes are calculated from variations of the mean over periods of 30 minutes.

A sonic needs to be sited high above the surface to ensure that individual surface objects are not distorting the flow. Typically, in an area with large roughness elements, the sensor should be at least two times the mean height of the roughness elements above the surface. Ideally, the instrument should be three to four times the height of the buildings and trees. There are several very practical constraints associated with this, including: the instrument needs to be securely mounted on something that will not move in the wind but is porous (e.g. a mast or a pole), the area upwind needs to have similar conditions (or fetch), and the boundary layer needs to be sufficiently deep that the instruments are still responding to the surface.

Obviously, over a year the wind comes from many directions and thus the surface area upwind affecting the measurements varies (middle figure). There are two different ways that can be dealt with. Either the site needs to be uniform in all directions (this is extremely hard to find in any city) or variations in wind direction need to be accounted for. In the latter case, if there are similar surface cover over large upwind sectors, data can be stratified by these wind directions and analysed. The area influencing the measurements, is upwind of the sensor location and is approximately elliptical in shape (for an individual 30 min period). The centre is aligned with the mean wind direction, the width varies with the variation in wind direction, and the distance upwind varies with the strength of the wind. The area is affected by atmospheric stability (the mixing) of the atmosphere too. The probable location and size of these areas can be calculated using source area models. Using the results of these model the surface characteristics for an individual 30 min period can be determined. These can then be used to relate the surface observations to remotely sensed observations which are constrained by pixel size.

Scintillometry

The second method we are using to measure the turbulent sensible heat flux *in situ* in London is scintillometry (page 4, bottom figure). In contrast to the sonic, the transmitter of the scintillometer measures light rather than sound and the receiver is separated by 2-5 km rather than 0.1 m. The scintillometer receiver measures the variations in light intensity that are received and from that the turbulent nature of the atmosphere along the path can be determined. The source areas for these observations, because of the long path length between the transmitter and receiver, are larger than for the sonic but also vary with wind conditions and atmospheric stability (page 4, middle figure). Again, the measurements use rapid sampling, but the long measurement path length allows the fluxes to be determined for 1 min to longer time intervals (e.g. 30 mins to be consistent with the sonic).



Michael Cliffe part of the scintillometer systems (black circle in middle figure of page 4).

Barbican part of the scintillometer systems (blue square in middle figure of page 4).

Acknowledgements: The sites in the London area are kindly provided by King's College London, Barbican Estate, City of London, Borough of Islington, and BT. The vast number of people who help setup and maintain the instruments and data processing are gratefully acknowledged, especially Kjell zum Berge, Will Morrison, Ben Crawford, Andy Gabey, Simone Kotthaus, Christoph Kent, Elliott Warren, and Ting Sun. Additional support from NERC ClearfLo, NERC TRUC, EUf7 BRIDGE, EUf7 emBRACE, King's College London and University of Reading are appreciated.

Basel

The Meteorology, Climatology, and Remote Sensing Lab (MCR-Lab) of the University of Basel carries out long-term urban meteorological measurements in the city of Basel.

BKLI and BAES flux towers

A 18 m tall tower is mounted on the flat roof top of the 20 m high MCR building (BKLI) since 2003. The neighborhood of the site is mainly characterized by the inner ring street Klingelbergstrasse to the east with heavy traffic, oriented along the 200°/20° axis, as well as by residential buildings enclosing green backyards, to the west. Tall university buildings are located around 250 m to the north and the northeast of the site.

BKLI flux tower from south.

Top of BKLI flux tower with instrumentation for turbulent fluxes of momentum, sensible and latent heat and CO_2, radiation, wind and wind direction (Right). Close up to the BKLI radiation sensor (Left).

The urban flux tower at Basel Aeschenplatz (BAES , 270.6 m a.s.l.) is in operation since June 2009. It is the second long-term flux station in Basel besides the site at the Klingelbergstrasse which is located about 1.6 km to the northwest. Measurements take part on top of the 'Turmhaus', Basel's first so called high-rise building built of concrete, constructed in 1930 right on eastern border of the Aeschenplatz.

Mean annual source areas (footprints) of BKLI (Klingelbergstrasse) and BAES (Aeschenplatz) flux towers in Basel.

BAES Instrumentation: Campbell Scientific CSAT Sonic (left) and LiCOR-7500 IRGA (Infrared Gas Analyzer).

BLER meteo station

The meteorological site Lange Erlen (BLER) is located 7 km outside of the city center of Basel in a groundwater protection area. The station is located at the exit of the valley of the Wiese towards the upper rhine valley and thus is affected by a mountain-valley wind system. The station serves as a rural/suburban reference station (e.g. for characterizing the UHI intensity). Profiles of air temperature, humidity and wind velocity as well as wind direction are measured at the 10 m high tower as well as soil heat flux and a soil temperature profile. Since 2008 turbulent sensible heat flux is measured at BLER, too.

BLER flux tower (10 m), suburban/rural reference station (right) and

Wireless Sensor Network

This network was established in 2015 in the frame of the URBANFLUXES project with the aim to provide a spatial estimation of characteristic air temperature and humidity, wind velocity and wind direction. Surface temperature is also measured at selected site for validation of satellite derived Land Surface Temperatures (LST).

All measurements currently carried out by the research group are online:

The high temporal but low spatial resolution of in-situ (eddy covariance) measurements is the direct opposite to the high spatial but low temporal resolution of satellite images. Both together however complement one another to a highly comprehensive dataset used for the purposes of the URBANFLUXES project. In situ measurements are indispensable for the validation of satellite derived surface temperatures and heat fluxes. In detail, the amount of sensible and latent heat fluxes derived from satellite overpasses can be compared with measured fluxes in the source area of the flux towers (page 5, bottom figure). Broadband albedo derived from satellite are compared with albedo measurements from flux towers. If comparing albedo measurements, it has to be considered that the field of view (FOV) of a downward looking sensor mounted at a flux tower is different from what is seen from satellite. The following figure (the fisheye picture) shows a considerable amount of walls is in the FOV of the sensor, which is not the case for the satellite FOV.

Downward looking fisheye from flux tower BAES

Acknowledgements: The investments to install, operate and maintain flux towers in urban environments are often highly underestimated. A lot of manpower, instrumentation and other hardware is necessary to ensure the high data quality of such measurements. We therefore acknowledge all former scientists, technicians and students that were involved in this task in the University of Basel. Currently the MCR team is represented by: Eberhard Parlow (head of the research group), Roland Vogt (senior researcher), Christian Feigenwinter (scientist), H.-R. Rüegg (technician), Andi Wicki, Michael Schmutz, Robert Spirig (PhD students), Mihail Rüttimann, Iris Feigenwinter, Regula Keller (student assistants). The support from former projects EUf7 BRIDGE, BUBBLE, BASTA and REKLIP is appreciated.

Heraklion

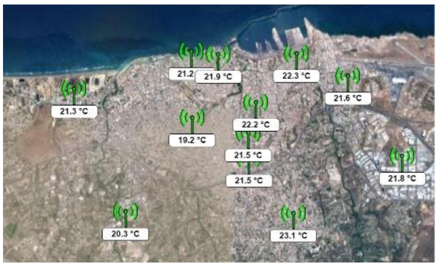
Meteorological Network

The Remote Sensing Lab (rslab.gr) of the Foundation for Research and Technology Hellas (FORTH) has developed a WSN of meteorological stations, covering the urban area of the Municipality of Heraklion, Crete.

Nektarios Spyridakis explains the functionality of a typical station of the Heraklion WSN to representatives from the City Authorities during the Communities of Practice Meeting, hosted by the Region of Crete, in December 2015.

The Heraklion WSN consists of 20 autonomous stations in permanent locations in the city, mounted above the urban canopy. The parameters measured by each station are: air temperature, relative humidity, wind speed, wind direction, surface temperature and solar radiation. Many additional meteorological parameters can be calculated based on these measurements, such as wind gust, dew point, vapor pressure, etc.

Station ID	Location	T	WS	ST	SR
		RH	WD		
UF-Her-01	Temporary Location	●	●	●	
UF-Her-02	Industrial Area	●	●	●	
UF-Her-03	Highway Bridge	●	●	●	
UF-Her-04	FORTH - IACM	●	●		
UF-Her-05	City Centre	●	●	●	
UF-Her-06	Temporary Location	●	●	●	
UF-Her-07	Western City Limits	●	●		
UF-Her-08	Heavy Traffic	●	●		
UF-Her-09	Temporary Location	●		●	
UF-Her-10	Southern City Limits	●			
UF-Her-11	Open Market	●		●	
UF-Her-12	Temporary Location	●		●	
UF-Her-13	Harbour Area	●	●		●
UF-Her-14	Temporary Location	●		●	
UF-Her-15	Temporary Location	●			
UF-Her-16	Airport Area	●			
UF-Her-17	Water Reservoir	●			
UF-Her-18	Heavy Traffic	●			
UF-Her-19	Temporary Location	●			
UF-Her-20	Densely Populated	●	●	●	



Location of the WSN in Heraklion through the web application presenting in real time the measurements. Here is air temperature for 20 September 2016, 13:10 local time.

Eddy Covariance

A new piece of high precision scientific equipment was recently acquired, measuring even minimal wind mass displacement in three dimensions, ambient temperature and atmospheric pressure, as well as CO_2 and H_2O fluxes.

The new EC just being tested at FORTH.

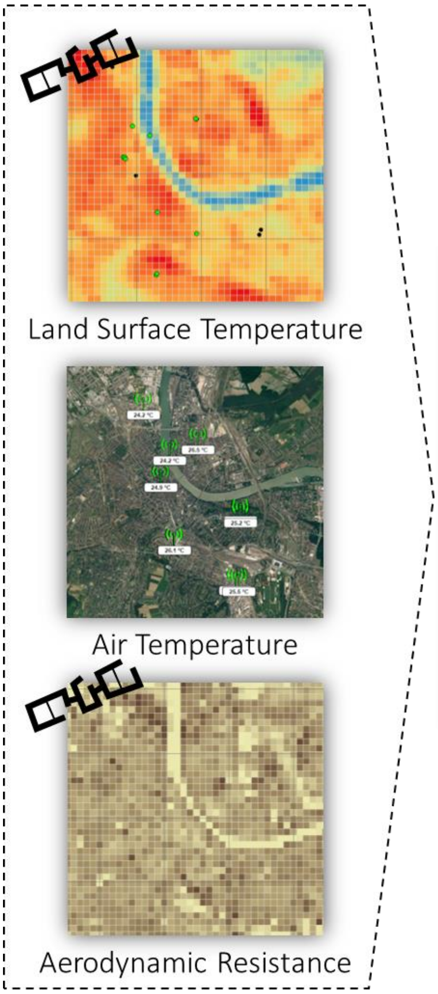
The EC instrument has been installed in a central location of the city of Heraklion, at an approximate height of 20 m above ground (approximately 10 m above the higher building in this area).

All measurements currently are available online:

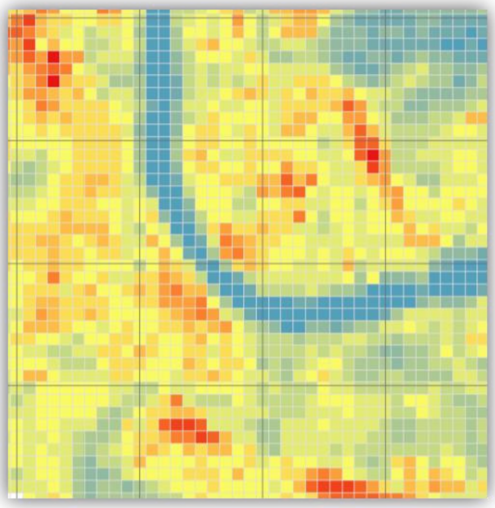
Acknowledgements: The meteorological network was came to reality thanks to the effort of the rslab.gr personnel and specially John Latzanakis' handcraftsmanship and Mr. Nikos Manioudakis' administration work. The city authorities provided the official permission for installing the equipment in municipality buildings and for this we especially want to thank Mrs. Spanoudakis, Mr. Papamattheakis, Mr. Archavlis, Mr. Patinakis, Mr. Aleksandrakis and Mr. Tsagkarakis (Municipal Authorities) for kind offering access to municipality buildings, special vehicles and infrastructure.

Turbulent Heat Fluxes from Satellites

by Christian Feigenwinter and Zina Mitraka



The turbulent heat fluxes of sensible (Q_H) and latent (Q_E) heat are strongly modified by the properties of the urban surface, the three- dimensional geometry of the city, the high roughness, the amount of impervious surfaces, the complexity of the distribution of source/sink and injections of heat and water into the urban atmosphere by human activities (traffic, heating, waste management, etc.). Thus, the spatial variability of urban terrain complicates their estimation. The existence of various surface types and different exposures to solar radiation in a complex surface geometry can lead to significant variations in heat fluxes over short distances.


Sensible Heat Flux (Q_H)

One of the main advantages of using satellite sensors is capturing the spatial variability of parameters. For example, to estimate the sensible heat flux over a city, the co-called *Aerodynamic Resistance Method* uses a simple relation between the density of air, the specific heat of the air at constant pressure, the surface temperature, the air temperature and the aerodynamic resistance.

Satellite thermal sensors measuring the radiation emitted from the urban surfaces are used to estimate the spatial distribution of the surface temperature. A combination of different satellite measurements provide insights on the estimation of the aerodynamic resistance. The spatial distribution of air temperature and humidity are derived from the in-situ WSN of meteorological stations in URBANFLUXES case studies.

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

European Geosciences Union General Assembly | 17 – 22 April 2016, Vienna, Austria

ESA Living Planet Symposium 2016 |9 – 13 May, Prague, Czech Republic

4th International Conference on Countermeasures to Urban Heat Island |30 May – 1 June 2016, Singapore

10th GEO European Projects Workshop | 31 May – 2 June 2016, Berlin, Germany

European Space Solutions |30 May – 3 June 2016, Hague, Netherlands

36th EARSeL Symposium | 20 – 24 June 2016, Bonn, Germany

IGARSS 2016 | 10 – 15 July 2016, Beijing, China

Upcoming

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

Recent Publications

Chrysoulakis, N., Esch, T., Gastellu-Etchegorry, J. P., Grimmond, C. S. B., Parlow, E., Lindberg, F., … Mitraka, Z. (2015). A novel approach for anthropogenic heat flux estimation from space. In *36th International Symposium on remote Sensing of Environment (ISRSE), 11-15 May, Berlin, Germany*.

Chrysoulakis, N., Esch, T., Grimmond, C. S. B., Parlow, E., Lindberg, F., Frate, D., … Feigenwinter, C. (2015). A novel approach for anthropogenic heat flux estimation from space. In *9th International Conference on Urban Climate (ICUC9), 20-24 July, Toulouse, France*.

Chrysoulakis, N., Heldens, W., Gastellu-Etchegorry, J.-P., Grimmond, S., Feigenwinter, C., Lindberg, F., … Olofson, F. (2015). Urban Energy Budget Estimation from Sentinels: The URBANFLUXES Project. In *Mapping Urban Areas from Space Conference, Frascati, Italy, 4-5 November*.

Heldens, W., Del Frate, F., Lindberg, F., Mitraka, Z., Latini, D., Chrysoulakis, N., & Esch, T. (2015). Mapping urban surface characteristics for urban energy flux modelling. In *Mapping Urban Areas from Space Conference, Frascati, Italy, 4-5 November*.

Landier L, Al Bitar A, Gregoire T, Lauret N, Yin T, Gastellu-Etchegorry JP, Aubert S, Mitraka Z, Chrysoulakis N, Feigenwinter, Parlow E, Heldens W, KC, L. F. (2015). Modeling parameters and remote sensing acquisition of urban canopies. In *9th International Conference on Urban Climate (ICUC9), 20-24 July, Toulouse, France*.

Lindberg, F., Grimmond, C. S. B., & Martilli, A. (2015). Sunlit fractions on urban facets – Impact of spatial resolution and approach. *Urban Climate*, *12*, 65–84. http://doi.org/10.1016/j.uclim.2014.11.006

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Project coordinator
Dr. Nektarios Chrysoulakis

e-mail: zedd2@iacm.forth.gr,
Tel.: +30 2810 391762,
Fax: +30 2810 391761

100 Nikolaou Plastira str.
Vassilika Vouton, Heraklion, Crete
GR 700 13, Greece

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