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URBANFLUXES

URBAN ANTHROPOGENIC HEAT FLUX FROM EARTH OBSERVATION SATELLITES

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1 INTRODUCTION

1.1 Purpose of the document

This document provides the proceedings of URBANFLUXES Demonstration Event 1 that took place on 6 December 2017 in London. This demonstration event aimed to inform scientists of the results of the URBANFLUXES project and to discuss the findings.

1.2 Project overview

H2020-Space project URBANFLUXES (URBan ANthrpogenic heat FLUX from Earth observation Satellites) aimed to advance the current knowledge of the impacts of Urban Energy Budget (UEB) fluxes on the urban heat island effect and consequently on energy consumption in cities. URBANFLUXES investigated the potential of Copernicus Sentinels to retrieve the anthropogenic heat flux Q_F, as a key component of the UEB.

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. In URBANFLUXES, the anthropogenic heat flux is estimated as a residual of UEB. The energy balance residual approach (Offerle et al. 2005, Pigeon et al. 2007) was used (Equation 1).

$$Q^* + Q_F = Q_H + Q_E + \Delta Q_S + \Delta Q_A + S \quad (W\ m^{-2}) \qquad (1)$$

Therefore, other UEB components, such as the net all-wave radiation, the net change in heat storage and the turbulent sensible and latent heat fluxes, are independently estimated from Earth Observation (EO). Although a rather straightforward method when the rest of the UEB components are known, its primary drawback is the accumulation of estimation errors of each energy budget flux in Q_F, and the error of having neglected any unmeasured terms.

The European Space Agency (ESA) launched new Earth Observation satellites in 2015, 2016 and 2017. The URBANFLUXES project exploits observations from Copernicus Sentinels 2 and 3, which provide improved data quality, coverage and revisit times and increase the value of EO data for scientific work and future emerging applications. A major challenge for the Earth Observation (EO) community is the innovative exploitation of the Copernicus Sentinels synergistic observations to estimate the spatiotemporal patterns of Q_F and all other Urban Energy Budget (UEB) fluxes.

1.3 Definitions and acronyms

3D	Three Dimensional
ARUP	Arup Group Limited, a multinational professional services firm headquartered in London
AMCR	Adaptive Multiple Contribution Retrieval of optical properties
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer, a device on board the Terra satellite
CESBIO	Centre d'Etudes Spatiales de la BIOsphère/ Center for the Study of the Biosphere from Space, located in Toulouse, France
CoP	Community of Practice
DART	Discrete Anisotropic Radiative Transfer, a model run by Cesbio that simulates measurements of passive and active satellite/plane sensors, as well as the radiative budget, for urban and natural landscapes
DLR	Deutsches Zentrum für Luft- und Raumfahrt/ German Aerospace Center
EC	Eddy Covariance
EO	Earth Observation
ESA	European Space Agency
ESTM	Element Surface Temperature Method, a model to calculate the storage heat flux
EU	European Union
FORTH	Foundation for Research & Technology – Hellas, Heraklion, Crete
GEO-K	A spin-off company of the Tor Vergata University of Rome to make the know-how developed by the University's Earth Observation Laboratory available in the form of user-oriented applications.
GIS	Geographical Information System, software for making maps
GLA	Greater London Authority
H2020	Horizon 2020 Research programme of the European Union (2014 to 2020)
INFRAS AG	Swiss research organization situated in Zurich and Berne
Landsat	The Landsat Program is a series of Earth-observing satellites from the United States, providing Earth images since 1972
LCCP	London Climate Change Partnership
LIDAR	LIght Detection And Ranging, a surveying method that measures distance to a target by illuminating that target with a pulsed laser light, and measuring the reflected pulses with a sensor

LUCY	Large scale Urban Consumption of energY (LUCY). A model that calculates anthropogenic heat fluxes for cities around the world
LU/LC	Land Use/Land Cover
MCR Lab	Meteorologie, Klimatologie und Fernerkundung, micrometeorological research unit of the University of Basel
MODIS	Moderate-resolution Imaging Spectroradiometer, a device on board the Terra and Aqua satellites from NASA
MoH	Municipality of Heraklion
NDVI	Normalized Difference Vegetation Index, a graphical indicator that can be used to analyse remote sensing measurements, and assess whether the target being observed contains live green vegetation or not.
NGO	Non- Governmental Organization
PDF	Portable Document Format
PMV	Predicted Mean Vote, a way to measure subjective heat stress
Q	Question
Q*	net all-wave radiation flux
ΔQ_A	net advected flux ($\Delta Q_A = Q_{in} - Q_{out}$)
Q_E	turbulent latent heat flux
Q_F	anthropogenic heat flux
Q_H	turbulent sensible heat flux
ΔQ_S	net change in heat storage within the volume (including the flux into the ground)
RoC	Region of Crete
S	all the other sources and sinks
SMS	short message service, a service to receive short messages via GSM
SPOT	Satellite Pour l'Observation de la Terre
SUEWS	Surface Urban Energy and Water Balance Scheme, a model to simulate the urban radiation, energy and water balances using meteorological variables and information about the surface cover
SVF	Sky View Factor
TPH	Tropical and Health Institute
UBL	Urban Boundary Layer
UEB	Urban Energy Budget
UHI	Urban Heat Island
UK	United Kingdom
UniBas	University of Basel
UoG	University of Gothenburg

UoR	University of Reading
URBANFLUXES	URBan ANthropogenic heat FLUX from Earth observation Satellites
W/m_2	Watts per square metre; a unit of energy
WP	Work Package
WUR	Wageningen University and Research

2 SETUP OF DEMONSTRATION MEETING 1

The demonstration meeting was held on Wednesday 6 December 2017 (08.30-14.00) at the Blue Finn Venue, 110 Southwark Street, London. The demonstration event presented the methodology to estimate anthropogenic heat flux (Q_F) in urban areas using Earth Observation data.

Figure 1: Blue Fin Venue

2.1 Programme

The programme consisted of a presentation of the work packages and an open discussion.

09:00	–	09:30	Overview of the URBANFLUXES project	FORTH - Chrysoulakis
09:30	–	09:45	WP3: Data preparation - lessons learned	DLR – Marconcini
09:45	–	10:00	WP4: DART model development – lessons learned	CESBIO – Landier
10:00	–	10:15	WP5: Heat storage – lessons learned	UoG - Lindberg
10:15	–	10:30	WP6: Latent and sensible heat and in situ measurements	UNIBAS - Feigenwinter
10:30	–	11:00	Discussion: uncertainties WP3 - WP6 & how to reduce them	All
11:00	–	11:30	Break	
11:30	–	12:00	WP7: Calculating Q_F – how far did UF take us to our goal	UoR - Grimmond
12:00	–	12:30	WP8: Operationalization of Remote Sensing maps	FORTH - Mitraka
12:30	–	13:00	Discussion on WP7-WP8: feasibility of UF method	All

2.2 Participants

Invitations were sent to the full contacts list of the URBANFLUXES project. Furthermore, for the scientific meeting invitations were sent out to the institutions of which the URBANFLUXES partners were a part. A total of 31 participants subscribed for Demonstration meeting 1.

surname	*first name*	*affiliation*	*country*
Ajmal	Tahmina	University of Bedfordshire	United Kingdom
Aldred	Freya	Met Office	United Kingdom
Chrysoulakis	Nektarios	Foundation for Research and Technology - Hellas	Greece
Del Frate	Fabio	GEO-K	Italy
Feigenwinter	Christian	University of Basel	Switzerland
Fleiss	Steven	Royal Borough of Greenwich	United Kingdom
Gawuc	Lech	Warsaw University of Technology	Poland
Grimmond	Sue	University of Reading	United Kingdom
Guo	Helen J.W	Sutton Borough	United Kingdom
Hatziyanni	Eleni	Region of Crete	Greece
Hsu	Shih-Che	UCL Energy Institute	United Kingdom
Iannitto	Giuseppe	GEO-K	Italy
Kanawka	Krzysztof	Blue Dot Solutions	Poland
Klostermann	Judith	Wageningen Research	Netherlands
Landier	Lucas	CESBIO	France
Lazuhina	Sabine	Astrosat	United Kingdom
Lietzke	Björn	Statistisches Amt Kanton Basel-Stadt	Switzerland
Lindberg	Fredrik	University of Gothenburg	Sweden
Macintyre	Helen	Public Health England	United Kingdom
Maranesi	Marcello	GEO-K	Italy
Marconcini	Mattia	German Aerospace Center - DLR	Germany
Mitraka	Zina	Foundation for Research and Technology Hellas	Greece
Parlow	Eberhard	University Basel	Switzerland
Schneider dos Santos	Rochelle	UCL - Bartlett	United Kingdom
Siegrist	Franziska	Frasuk - Umwelt & Kommunikation, Basel	Switzerland
Stagakis	Stavros	Foundation for Research and Technology - Hellas	Greece
Start	Ged	Astrosat	United Kingdom
Thompson	Ross	Public Health England	United Kingdom

Turner	Briony	Space4Climate group	United Kingdom
Wynne	John	FFORM	United Kingdom
Xing	Yangang	Cardiff University	United Kingdom

3 PRESENTATIONS, QUESTIONS AND COMMENTS

3.1 Overview of the URBANFLUXES project (FORTH – N. Chrysoulakis)

Cities heat up faster than their surroundings and the number of heat waves will increase due to climate change. This will impact human health in cities. The anthropogenic heat Q_F, which is the amount of heat added to cities by human activities, cannot be derived via direct measurements. To increase knowledge about these phenomena, URBANFLUXES investigates the urban energy budget with the following equation of the urban energy fluxes:

$$Q^{*}+Q_F = Q_H + Q_E + \Delta Q_S + \Delta Q_A + S \quad .$$

The approach is to calculate all the turbulent heat fluxes and calculate Q_F as a result. We used ground measurements and satellite data, and calculated every factor with different models and then deducted the Q_F.

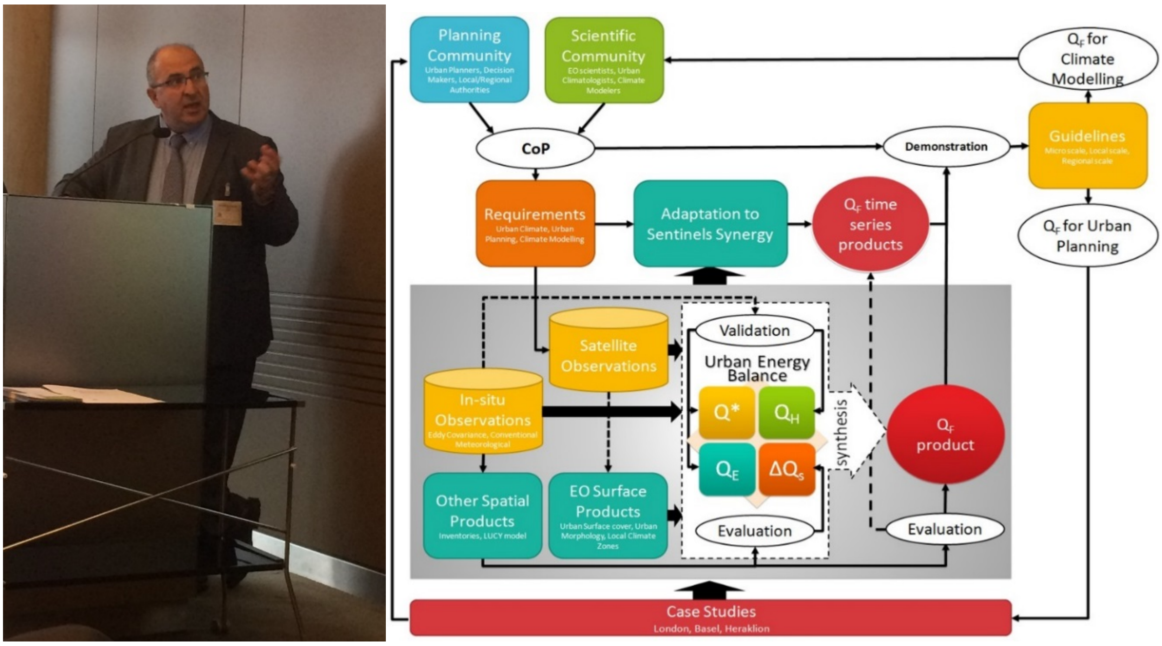

Figure 2: Nektarios Chrysoulakis presenting the URBANFLUXES approach

We installed in situ measurement devices in Heraklion and used existing measurement infrastructure from London and Basel where we also have data for several decades from Eddy Covariance towers. We used urban morphology maps to calculate the roughness and the sky view factor. Furthermore we used land cover maps. We started with fine scale data and then aggregated them to a 100x100 meter grid in the final products. We collected spectral libraries to know which materials are used in Basel and London while for Heraklion we built a new database for the materials. We used ASTER Earth Observation data for the surface temperature.

We used algorithms to downscale information to the levels we needed. We used the DART model to calculate the net radiation, and this is also calibrated with measured data. And we derived the albedo with the same model. This leads to a map of the net radiation on a 100 m grid. Heat storage is measured and calculated with the ESTM model. For this we need the building materials. Materials as seen by satellites depend on land use and materials of walls, roofs, and impervious surfaces. These data combined give the heat storage map. It was calibrated with different models such as ESTM. Then the turbulent heat fluxes (sensible heat and latent heat) are calculated with the ARM model. They were calibrated with Eddy Covariance tower measurements. Most important are variations in land surface temperature and roughness. Our results for Q_F underestimate the anthropogenic heat, which is likely due to underestimation of the sensible heat fluxes but the values are well correlated with the presence of buildings. Main achievements of URBANFLUXES:

- EO-based estimation of all UEB fluxes and exploitation of Copernicus Sentinels in Earth System Science and urban planning.
- Advancement of the current knowledge of the impacts of UEB fluxes on UHI and hence on urban climate and energy consumption.
- Development of tools capable of supporting strategies to mitigate these effects, improving thermal comfort and energy efficiency.
- Development of tools for monitoring and valuation of the implementation of climate change mitigation technologies, including NBS.
- Support the development of Sentinels-based downstream services towards informing policy-making.

3.2 WP3: Data preparation - lessons learned (DLR – M. Marconcini)

DLR prepared all remote sensing data for use in the other work packages. The spatial distribution of the urban energy budget is difficult to obtain with direct ground measurements so we wanted to use Earth Observation data for larger energy budget maps. In this project it took some time before the Earth Observation community and the urban meteorology scientists understood each other but after a while it worked well. WP3 provided biophysical parameters in time series because temperature varies over time. Sentinel data were not available at the start of the project. We started with using Landsat 5, 7 and 8 data because of accessibility of the data. These are three of the same satellites from the USA. Some of the data were damaged with stripes. Landsat provides a very broad coverage of spectral bands. We also used MODIS and ASTER data and later on also the data from the new EU Sentinel satellites. Not every pixel is at exactly the same location so we had to modify the datasets. An example of surface reflectance is shown: the earth surface is visible as well as the atmosphere is in between and for this we need to do atmospheric corrections: masking out the clouds. Then we used

Normalized Difference Vegetation Index (NDVI) to show where the vegetation is. The land surface temperature is well validated. And we used the leaf area index, and aerosol optical thickness. We used LIDAR images for morphology parameters. We also received data from GLA.

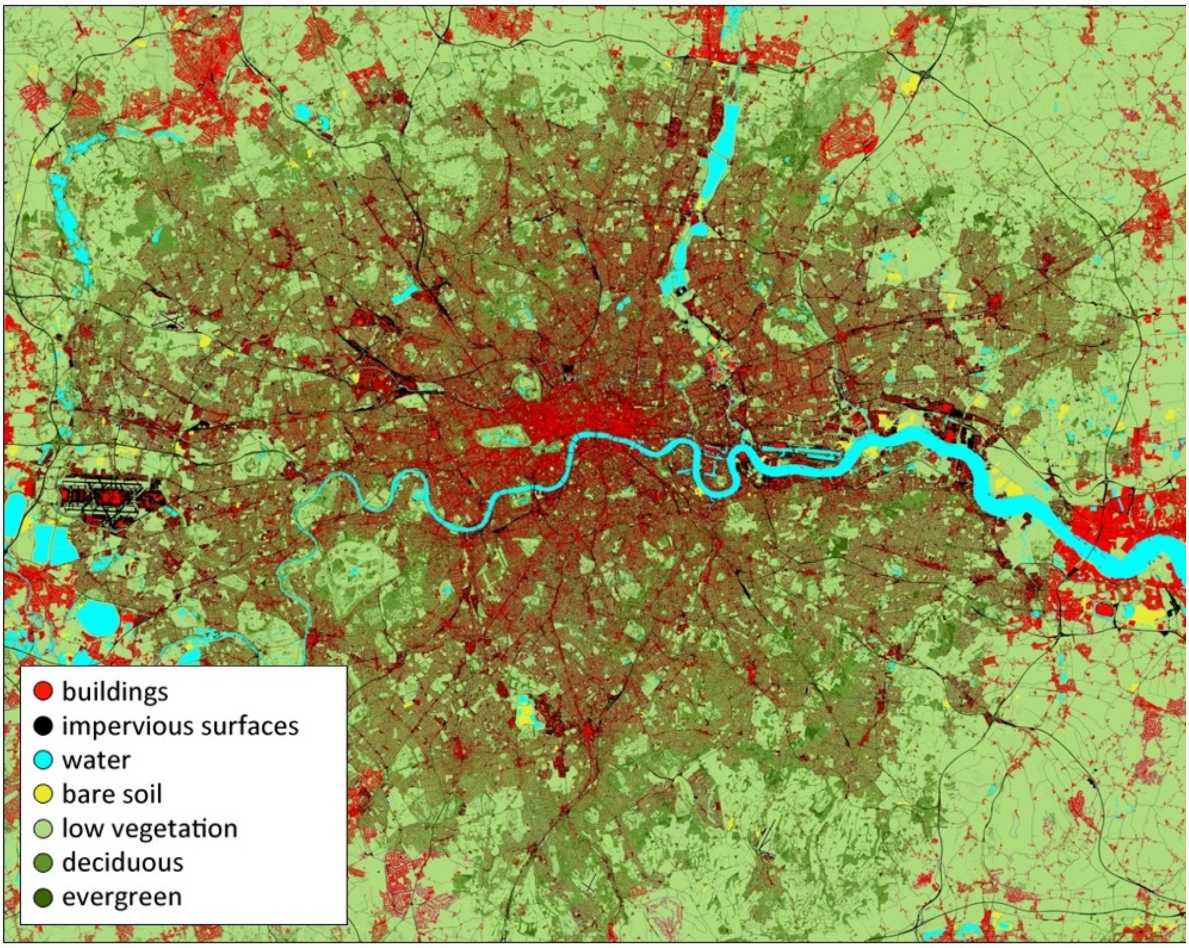

Figure 3: Land cover map of London

For Basel it was more difficult because the area of interest overlaps three countries and so three datasets needed to be calibrated. For the effect of buildings on wind, we needed the sky view factor (how much of the sky view is limited by buildings and trees; this is a measure for heat trapping). We also made land cover maps: agriculture is a class of land use but for the modelling we just needed low vegetation. We used SPOT data and advanced algorithms to calculate maps. It is important to have maps at the moments of maximum and minimum NDVI. Finally we had reliable land cover maps. ASTER data were used to calibrate downscaling outputs of WP8. ASTER has multiple bands so it provides high reliability of acquisitions. Unfortunately it offered few observations of the test sites but enough for calculating surface emissivity and surface kinetic temperature. Contrails are visible in the acquisitions. All these data were necessary for the calculation of the different energy budget terms. Concluding: it was a success to learn how to cooperate between the scientific communities. Earth Observation data can be of real support and enhance transferability of methods to any city. Now it is still a challenge to transfer the methods from USA data to Sentinel data.

Q: how about Sentinel 3?

Sentinel 3 has data with 1 km resolution but they should be used more and a second Sentinel 3 will soon be launched so it will acquire more acquisitions per day.

3.3 WP4: DART model development – lessons learned (CESBIO – L. Landier)

The challenges for WP4 were a simulation of the net radiance Q* to have time series and an estimation of irradiance and this for all the spectral bands. The DART model takes several inputs such as a 3D model of cities, the distinction between water and land and an atmospheric model. It can also use local data e.g. from flux towers. However, it still missed all the optical properties of the materials in a city, and we tried to model that as well. We used all input data from the partners and simulated different kinds of images. We simulated satellite images to compare the two images.

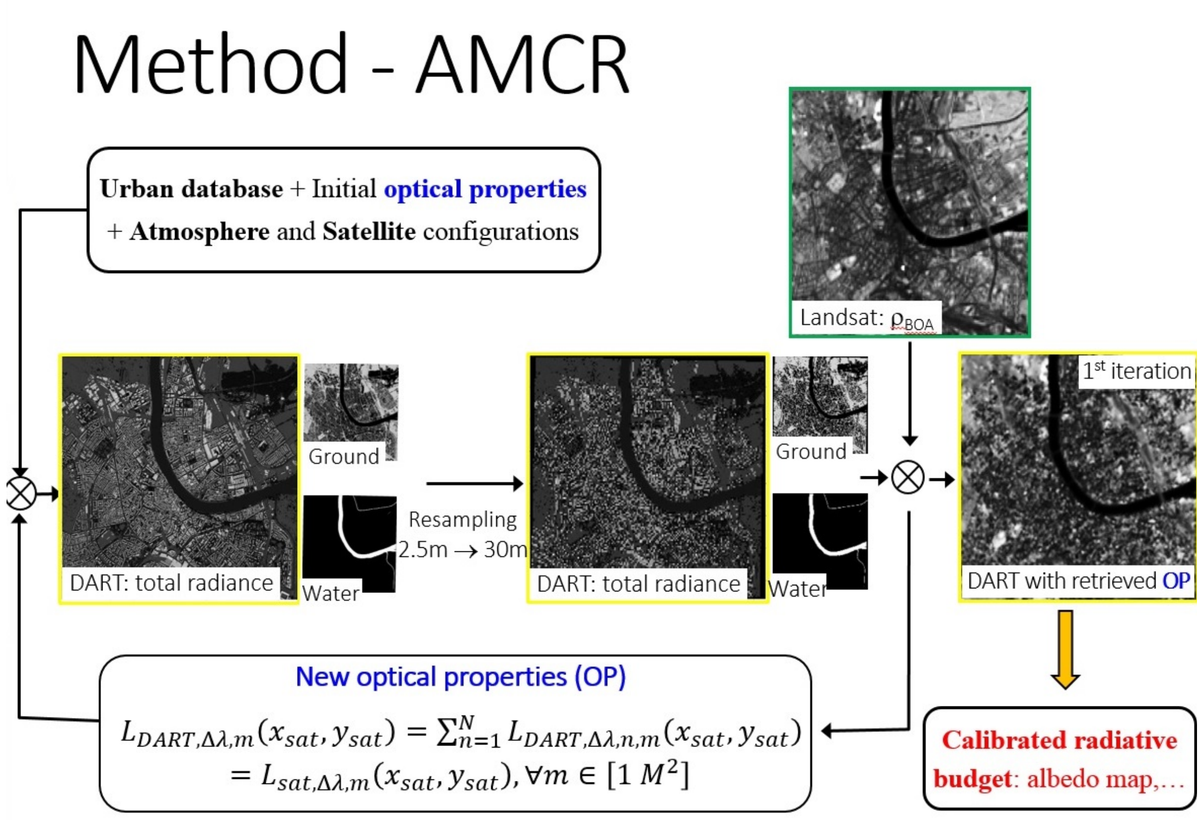

Figure 4: AMCR method: Adaptive Multiple Contribution Retrieval of optical properties

The total modelling exercise comprised several steps. In a first calibration we compared groups of pixels with the different materials data, and depending on the amount of materials we took more pixels to calculate. We went through different steps of calibration adding different materials. We did a pixel by pixel comparison and then a second order estimation. It allowed us to use groups of pixels instead after calibration. After the second calibration the vegetation still was different, because vegetation is sensitive to different optical properties and a third iteration was used to further improve the model. The performance graphs show that with each step the model gets more precise. The result we used to calculate the radiative budget of the different cities. It takes computation time and we needed time series, so we had to simplify. We assumed some pixels would stay the same such as roofs; we sampled the different angles of light and made a look up table and used that for faster calculations. This works fine for all short wave calculations; now it takes only one minute to calculate a map. We used tower data to calculate Q* maps for all the scenes. We made a few hundred scenes for Basel and London. There are only a few outliers, but overall we had good results on Q* to serve the partners in the project. For Heraklion there were no flux tower data for calibration but we assume that it is good too. Conclusion: if we have all the 3D data and atmosphere data and Earth Observation data we can calculate Q* for every city. Additional iterations are needed though for each new city to get the vegetation and material properties right. This means a time investment at first but after that it can be calculated fast. If you need a larger area later it is easy to add.

Q: Does DART work for different seasons?

Yes, for all seasons the data were good.

3.4 WP5: Heat storage – lessons learned (UoG - F. Lindberg)

WP5 aimed to calculate the heat storage fluxes Q_S. We used the Elements Surface Temperature Measurement (ESTM) model. The model estimates conduction of energy through materials such as walls and roofs as well as the ground which is aggregated in one facet. We needed the properties of all materials, how much energy they could store, how fast will they conduct heat and the volume of material present. We also included internal walls inside the buildings. We need different temperatures: outside and inside the building. We used EO data, Google street view combined with the Urban Atlas data to get roof and wall materials. We also used data about land cover and urban geometry to derive ground materials and building volume, respectively. All this information was aggregated to a 100m grid. To see how well the model performed we evaluated it on mono-material sites such as asphalt and long grass surfaces with very satisfactory results. 3D surfaces such as forest and an urban volume in Gothenburg, Sweden was also tested with satisfactory outcomes. One challenge using the ESTM model is that it requires to be running continuously, even for times of which we do not have the satellite images so we need to extrapolate datasets over time. We simulated the temperature development for the days of the data acquisitions and the days in between as well. For nights we estimates cooling rates to extrapolate forcing data for the model. Every material has different properties, for example asphalt shows quick cooling in the beginning and cooling slows down later. For a forest the cooling peak is much less. We defined three phases of cooling as presented from earlier research. Data and model results were compared. As an example we show Q_S for London, where you have a high volume of high rise buildings. We see high ΔQ_S in high rise areas while much smaller values in park areas. Summary: we have reasonable results for day and night. The challenge still is to propagate the forcing data for the whole period we want to investigate as satellite data is momentarily in time. It is important to get the correct input data such as materials. Another challenge is that satellites see roofs and ground whereas information for walls are difficult to derive.

ΔQ_S on a clear summer day,

2016

19th of July

11 am

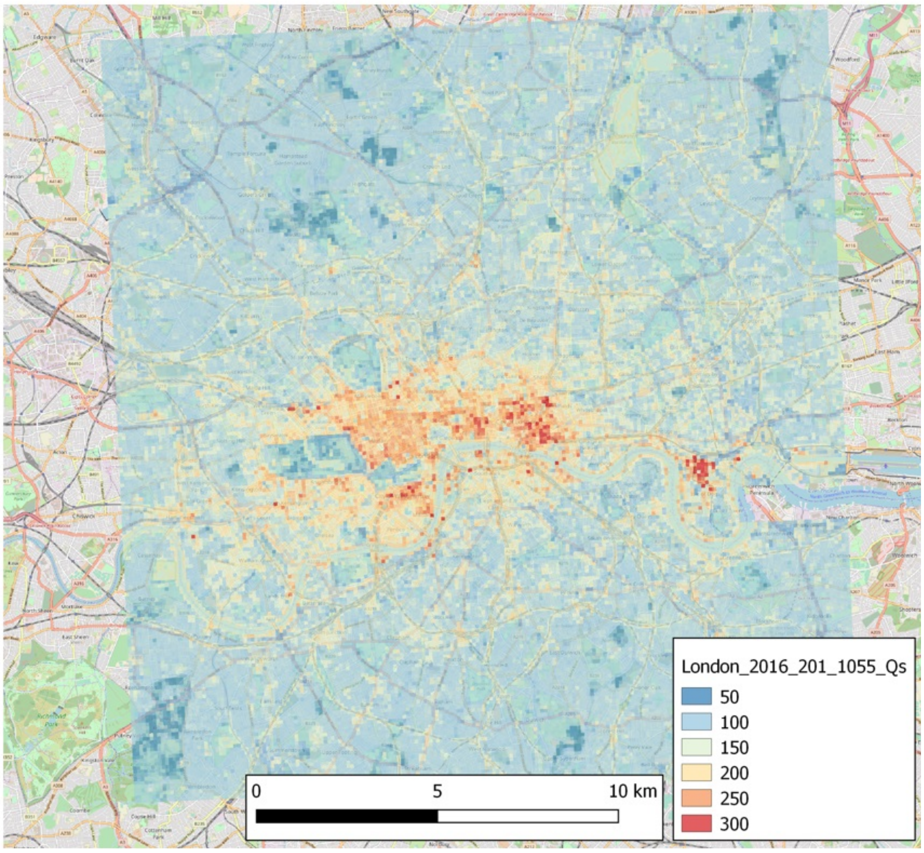

Figure 5: Storage heat flux in London

3.5 WP6: Latent and sensible heat and in situ measurements (UNIBAS – C. Feigenwinter)

WP6 covered latent and sensible heat flux calculations and local measurements. The urban energy balance is more complex than rural areas because of buildings and the human input Q_F. We used the aerodynamic resistance method (ARM) which is about the difference between surface and air temperature, and the water vapour saturation deficit for latent heat. Low resistance leads to high fluxes and vice versa. We have in situ measurements for several parameters such as short wave radiation, air temperature, humidity in different locations and three Eddy Covariance towers and we also use data from Earth Observation. Roughness parameters are used. We had data for all seasons and different times of day, more than one thousand scenes were processed for the three cities. The flux towers have different instruments for measuring direct radiation and air temperature. We have continuous measurements in Basel, Heraklion and London which are accessible via the URBANFLUXES website. The data can be downloaded. Other data are available on request.

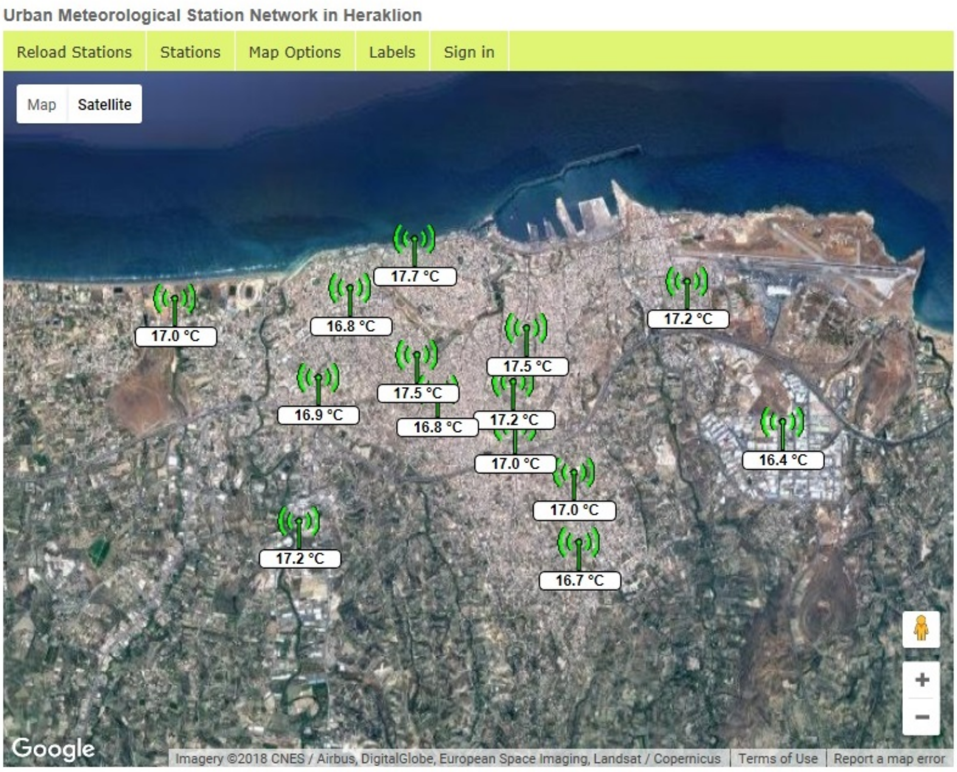

Figure 6: Meteorological station network in Heraklion

The sensible heat fluxes were highest in the summer, both for sensible and latent heat flux. Hotspots are the city centres and impervious surfaces. We find medium fluxes for dense built up areas and low heat fluxes in green areas. Water bodies evaporate year round. There are moderate sensible heat fluxes for low vegetation. The latent heat flux is highest in the forest and lowest in the city. The latent heat measurements are very different in two location so we should be careful with the measurements. The sensible heat flux of London is higher than in Basel.

The data show that we underestimate sensible heat fluxes in de 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. This pattern of underestimation of sensible heat is the same for all cities. In the winter the underestimation is more problematic because of lower values, which makes the error percentage higher. Eddy Covariance measurements show a high variation over time, and the overpass of the satellite is only a few times per day, so if we compare measured values with modelled fluxes we have to keep that in mind. Why do we underestimate the modelled fluxes? We see a large variation in Eddy Covariance measurement data; Eddy Covariance has already 15% uncertainty, and cities are heterogeneous. There also is uncertainty in the aerodynamic resistance; we do not know how good our extrapolation to the whole city is. For good Eddy Covariance measurements you need a homogeneous environment, so we have collect our data above the buildings. In Basel the instruments are at 18m while the buildings are 20m. In London we take measurements at .2m above mean height. So the data come from the upper part of the roughness area. We also want to extrapolate to a larger area, to know an average for a neighbourhood and not just for one building. It proved to be problematic to validate Earth Observation data with local measurements and we have only a limited number of local measurements.

Q: What is the accuracy of remote sensing measurements?

The most important data coming from Remote Sensing is Land Surface Temperature (LST). A tower measures only at the point of tower and the uncertainty of Earth Observation data is +/- 1-2 degrees. If we change LST in the model with 1 Kelvin, it causes a change of 50 Watts per m2 so its accuracy has quite an impact. All components are estimated and every factor has an amount of uncertainty, but all factors of the Urban Energy Budget use LST data and if that is uncertain, this is already a big problem. In the future we will have better resolution acquisitions, now we had to downscale.

3.6 WP7: Methods to determine Anthropogenic Heat Fluxes (Q_F) (UoR – S. Grimmond)

Q_F is a measure for the waste heat discharge by human activities: human metabolism, transport and buildings. Q_F cannot be measured directly but there are several different methods to calculate it. A top down method starts with urban energy consumption, which is then attributed to locations. A bottom up method starts at individual buildings, and assumes use of appliances for heating, cooling and so on. The same detailed approach is used for traffic and human metabolism. Bottom up methods are mostly focused on one of these three factors (buildings, traffic, humans) but the models are not yet combined.

Observational approaches are constrained by the amounts of measurements which are needed. The anthropogenic heat is very variable in time and space. In the longer term the average goes down because warm days and cool days smooth each other out. All work packages of URBANFLUXES were efforts to get us ready for the Q_F, but all measurements and calculations have uncertainties and the residual Q_F will have the greatest error. In URBANFLUXES we used six different methods, and there are always errors associated with them. What do we have the greatest confidence in? An overview of available methods:

- An Agent Based Model (ABM).
- Scintillometry, an observation based method with Eddy Covariance towers on Barbican and KCL looking over London, that allows us to look at buildings.
- GQF, a combined top-down and bottom-up method, that uses a large amount of different datasets which are available for London but not in many other cities.
- LQF, a top down approach that is similar to GQF but uses less data.
- SUEWS, a model which uses data on land use, temperature and population.
- An Earth Observation method which is both observation and model based.

Each method has advantages and disadvantages. If we use ground measurements the outcomes depend on where they are measured and results need to be extrapolated over the city. Earth Observation provides data for a whole city. Scintillometry provides data at a one minute timescale, while Earth Observation provides data only at the time of an overpass (1-4 times per day), and this has to be at a moment when there are no clouds present, so EO data acquisition is difficult for London. For modelling methods there still are many data needs and for Earth Observation there also are big data needs. Nothing is perfect.

Our evaluation of the different methods shows that SUEWS is working well in showing seasonal and spatial patterns.

With the scintillometry method we produced an estimate for London. We can see variability over the seasons as well as a diurnal pattern. Human behaviour also differs over weekdays and weekends. We see an increase of Q_F in rush hours, and it comes down in the afternoon. In London most anthropogenic heat is produced in the winter time because of heating of buildings. The central business district shows increased heating.

With the GQF and LQF methods we can also model Q_F fluxes. GQF needs far more data than LQF. Tutorials were made the URBANFLUXES project to use these methods. The method was used to map the different components such as heat from buildings and transport and to look at typical days compared to holidays. Also a manual was made for spatial and temporal mapping with LQF. This model provides less detail while less data are needed.

The Agent Based Modelling started with modelled behaviour of humans through the day: in a borough 180000 people are living; during the night they sleep, in the morning they go to work, then they go to lunch, after work they go shopping and they move back home in the evening. A school child has a different pattern than a grown up. Households can have different sizes and these are also modelled. Then we look at all appliances such as TVs and cooking, and then the total energy use of cooling, heating and using appliances is calculated. Then total use per home can be calculated, the same for workplaces, and finally an anthropogenic heat production is aggregated for a neighbourhood. The agent based method is often limited by data availability.

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. This can be extrapolated to a day with models. We do not get a diurnal pattern but we can get outputs for a year and for a whole city.

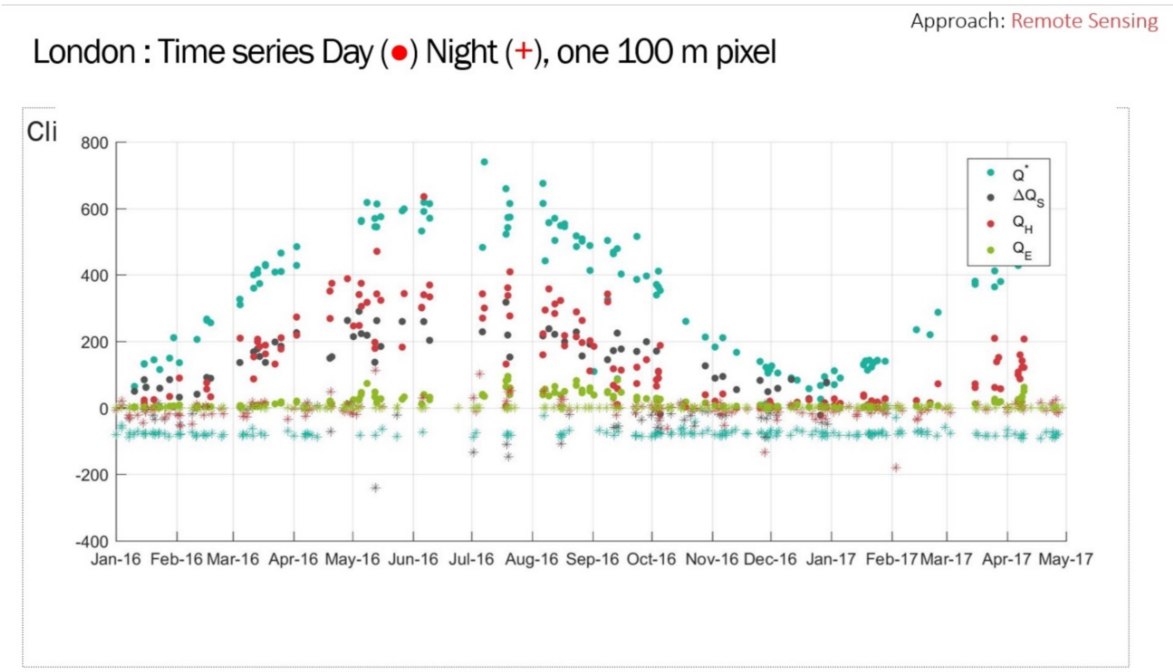

Figure 7: Energy fluxes for London : Time series Day (●) Night (*),obtained with Remote Sensing method

Concluding: all techniques are data intensive. We made a variety of tools available and we made sure each method can be used by others. Tutorials can be found on the URBANFLUXES website and data and models are downloadable. We are happy to discuss further uses with you.

Q: For the agent base method, what data are needed?

Data must be available of time and activity for cohorts of people. We created the age structures. Energy use data are based on survey data what people were doing during their day.

Q: How do methods compare about how high Q_F is?

Which one is the most truthful: we think GQF is the best because it is constrained by real data, so it is as correct as it can be; 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.

3.7 WP8: Operationalization of Remote Sensing maps (FORTH – Z. Mitraka)

The aim of WP8 was to use data from WP3 and flux models to produce time series of energy components. Copernicus is an ambitious programme of the European Space Agency (ESA). EU Sentinels are designed to provide data for the Copernicus program. There are many missions with different purposes giving us good revisit times and good resolution of data. Sentinel 1 has a small spatial scale. Sentinel 2 is comparable to Landsat, using a multispectral instrument with a very good spatial resolution and 5 days revisit times. Sentinel 3 is a multi-instrument satellite with better spectral resolution and revisit times twice per day with two satellites, but a low spatial resolution of 1 km. Sentinels allow us to produce better time series. We made examples for the three cities every ten days. There was an issue with cloud cover, so we needed to mask out those pixels from the analysis.

We made land cover maps with 2,5 meters resolution, and this was upscaled to 100m resolution because of the project goals. We worked on better precision of the materials maps in all cities. We used a method to upgrade Sentinel 2 20m resolution images to 2m resolution maps; it was a lot of work to classify materials in the city. On a land cover map the buildings were isolated and one type of material was connected to each building. Then the vegetation cover was separately done with an NDVI based method. We have three classes of vegetation in the project: deciduous, evergreen and low vegetation. This method shows the seasonal variation such as loss of leaves and dry vegetation.

We use land cover maps and spectral libraries to get high resolution emissivity maps. For London we had the SLUM a spectral library for building materials. With this we could plot the emissivity values. For Basel we had material maps, and there were some additional materials compared to SLUM so we estimated how much of each material was there. The mean value was assigned to a class of material. For vegetation we did another exercise with other spectral libraries for high grass, low grass, trees etc. For the emissivity of soil and water we used ASTER and MODIS spectral libraries. So we have emissivity maps as a product.

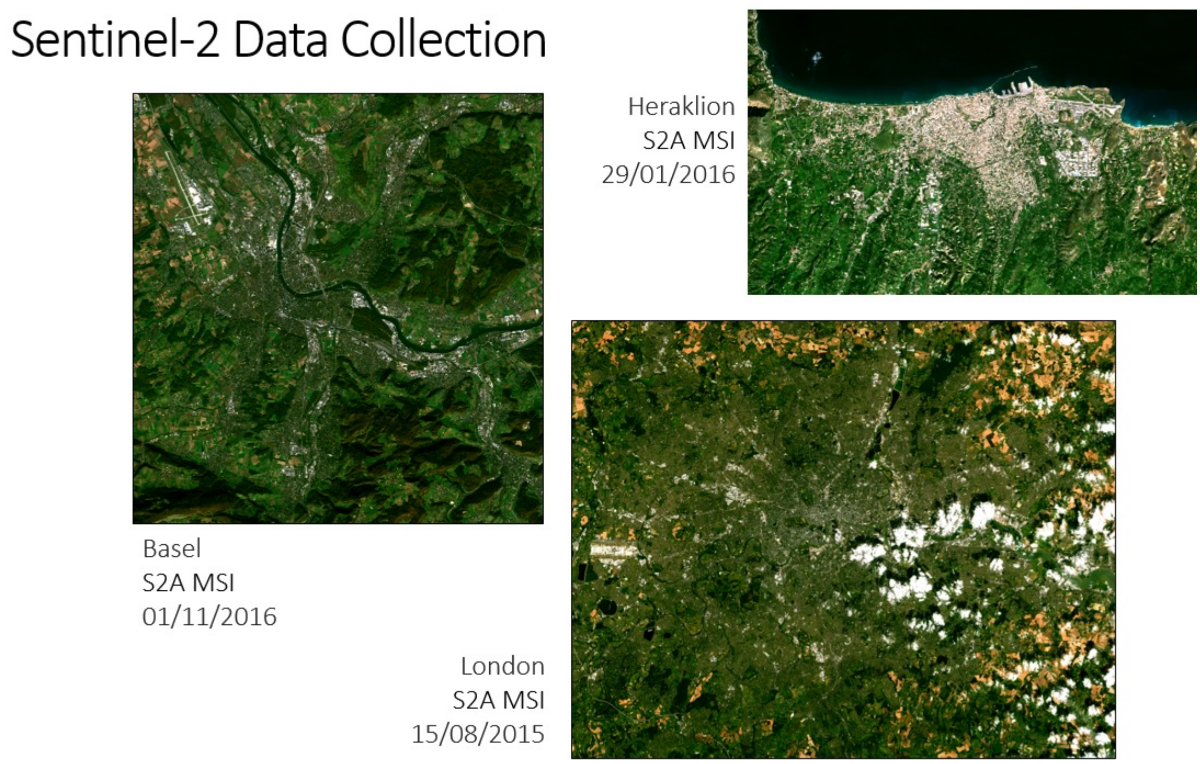

Figure 8: Examples of Sentinel 2 data for the three case study cities

Land surface temperature (LST) data were available at 1km resolution and we needed a downscaling to a 100m grid. LST downscaling algorithms were used to do the downscaling. A test was done to compare the downscaled product with the ASTER product and it was looking quite good. Uncertainty analysis showed that most uncertainty comes from the emissivity product namely 3% uncertainty in urban areas, such as the industrial area of Heraklion which has highest variation in materials. Overall there was 1,6 degrees of uncertainty for LST. In the validation of sites we found 3 degrees of error for Basel time series and 1,5 degrees for London time series.

Conclusions: Sentinels combined with NASA can provide a wealth of data with acceptable validity.

Q: How do you use LST from other satellites?

We do not use LST of other satellites, we use surface cover data: land cover in detail. We update that from other satellites. This is combined with low resolution LST data of Sentinels. In the future we can also look at satellites images of walls and high vegetation; this might narrow the errors.

Q: Do you cluster materials manually or automated?

We used base maps with a high resolution, these were manually corrected for errors and we used the peak of vegetation, we isolated the buildings and used spectral algorithms and connected data to a spectral library and finally matched it with satellite images.

Q: you use satellites because they acquire data often. Why not use the Advanced Very High Resolution Radiometer (AVHRR) of NOAA satellites as well?

Yes, we could use them to get more acquisitions. We wanted to use Sentinel 3 and it was launched later than we expected. The acquisition time of NOAA is the same as MODIS and the error is higher. So for downscaling it was problematic.

Q: What is dual view mode for satellites?

This means that there are two lenses, nadir and oblique, which capture data at the same moment so we can do a better correction for the atmospheric effect. It takes 1 minute for the images to overlap.

Q: The frequency of data acquisition is less in winter and in summer you have more cloud issues?

Yes we have to cope with that in the data. We have holes in the images but at least for the other areas you have the data. We have more night time acquisitions for London, and 400 for Heraklion.

Q: For which years do you have data?

Sentinel 3 is up since November 2016. We focused on 2016 and 2017. All Q_F calculations are for this period. We could go back in time as was suggested before. So these years were investigated in WP8 but in other work packages MODIS was also used because the Sentinels were delayed in data provision. We started with other data and then translated the method to the Sentinels.

Q: You used in situ data for a whole year?

Yes, we used data all through 2016 and a few months into 2017. For London we also looked at 2017.

3.8 Discussion on uncertainties and feasibility of the URBANFLUXES method

Q: How did you do the validation?

We were not validating it pixel by pixel but we did a three by three weighted validation. We used LST skin surface and the tower measurements at 20m. LST is the outgoing long wave radiation. The sensor with a fisheye lens sees a lot of walls that the satellite does not see, so it is difficult to compare.

Q: When is the final report?

We produce the final draft by the end of this year, and we have the final review in January. So the final report can be expected end of February. All data will be public at the end of this year. Measurements will continue after the project.

Q: Are there any spin off projects out of this? What are target issues?

We could try that in environment or space calls. The main issue is to be able to produce earth observation services for cities. We will discuss in the afternoon presentation how capturing dynamic data with new satellites can be done. And the use of other methods will be presented. We also want to map changes in land use, which is relevant for London but in Heraklion there is not much change in buildings due to the crisis.

Q: Could you also use the new US satellite Ecostress?

The question still is: will they cover the US only or the whole globe; this is not clear yet but if it is the globe then it is very useful. It will be launched in 2018. DLR wants to attach another sensor as well as Japan so more data will be available. Our main objective was to explore methods to make data and maps available.