The Copernicus Sentinels for Urban Energy Fluxes

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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.

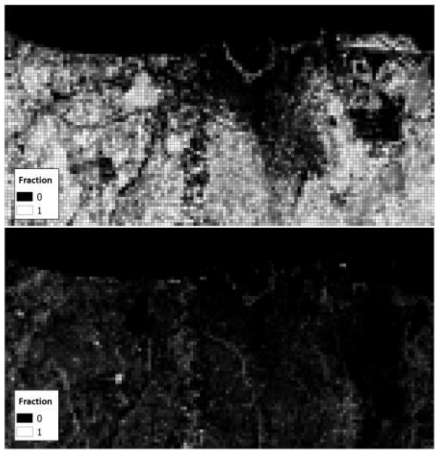
Image fusion techniques were used in URBANFLUXES, to further enhance the spatial resolution of Sentinel-2 to reach 2 m (using very high resolution WorldView-2 data). This allowed discrimination between some basic roofing materials. Knowing in detail the fraction of different roofing materials in the 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

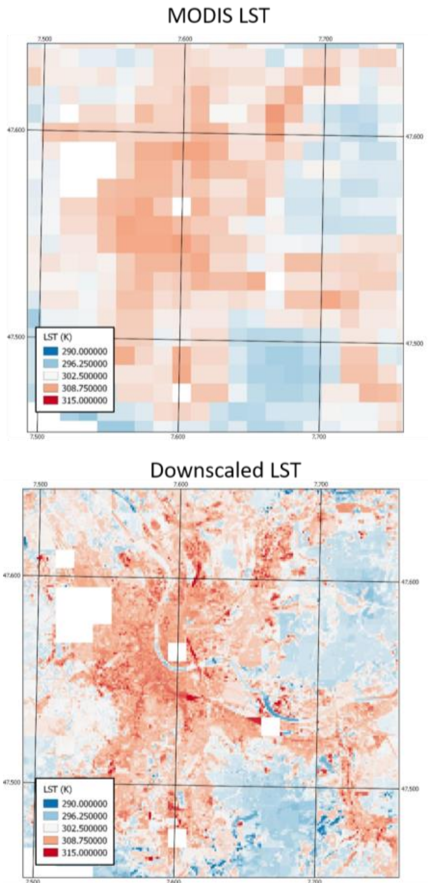
The VHR Classification image is used in order to estimate a static dataset of Class fractions in the same resolution with the NDVI-based vegetation fractions (i.e. 10 m for Sentinel-2, 30 m for Landsat). Then, these fractions are used as a baseline to adapt the NDVI-estimated vegetation fractions and 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.

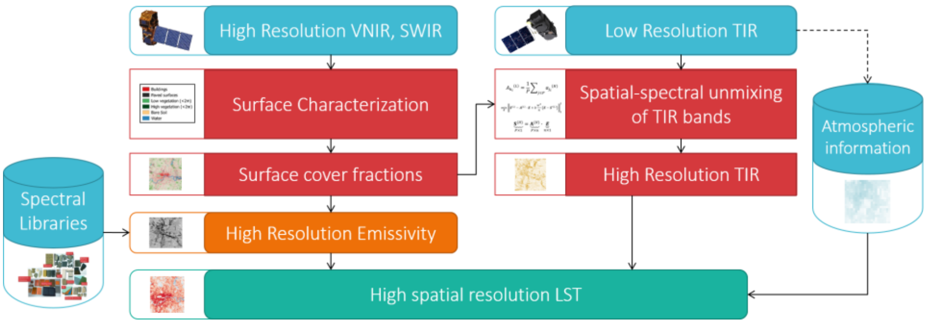
For all trees, it is assumed that the VHR Classification has captured the maximum tree growth. Changes that include the increase of deciduous or evergreen tree fractions over the baseline are neglected. Therefore, this algorithm will not capture the establishment of an urban park or the planting of new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

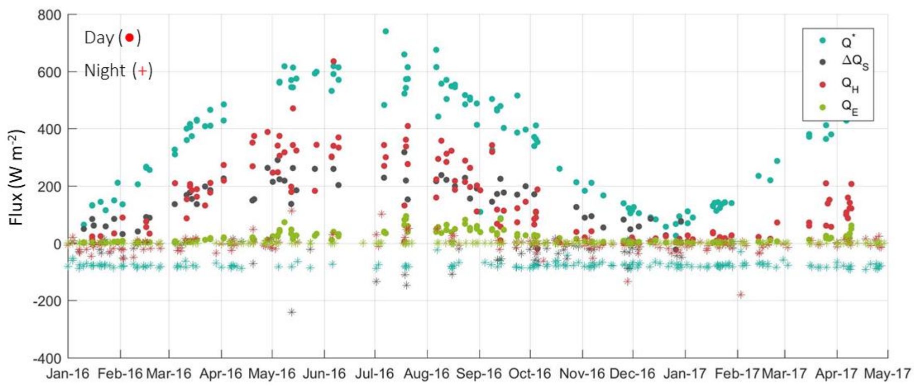
Spatial-spectral unmixing is then used to enhance the spatial resolution of the low resolution thermal bands. Each low resolution pixel is unmixed, using the contextual information of the neighbouring pixels in a moving window. The downscaling is performed in the radiance and the assumption is that the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