BARCELONA URBAN HEAT ISLAND CHARACTERIZATION AND MODELING

Author information

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ABSTRACT

Cities tend to present higher temperatures than their surrounding areas. This difference in temperature is called Urban Heat Island (UHI). Nowadays, most of the cities are about 2 ºC warmer than surrounding rural areas and, areas with high urban density can easily reach about 5-7ºC more. Depending on the latitude, this effect can cause different kinds of associated problems or no problems at all. In colder climates it may produce some benefits and energy savings while in regions like Barcelona it may cause negative impacts during the warmer weeks of summer. Among other negative impacts, we can encounter: quality loss of the public space, increase in energy consumption for cooling devices, improvement of environmental conditions for non-native species and health risks for vulnerable population segments.

The present study aims to identify and model the UHI in Barcelona through different sources of information: land use, weather data, remote sensing data and urban morphology.

The identification process has been done with two approaches: using weather data from 12 official meteorological stations and retrieving the Land Surface Temperature from Landsat 8 with a mono-window algorithm. These two datasets have been used afterwards to validate or correlate the model output.

In the modeling part, the ADMS 5 Temperature & Humidity tool has been used to model the UHI effect in Barcelona. This tool is being developed by CERC as a part of the main dispersion model of the ADMS 5 which is widely used in air quality assessment. The T&H module uses land use parameters and meteorological data to estimate air surface temperature.

The present study is a step forward for understanding the UHI in Barcelona and a starting point to present usable tools to model and predict the UHI effects in cooling policies as well as test multiple scenarios of climate change.

Fig 1. Area of study. The municipality of Barcelona inside the Metropolitan Area of Barcelona.

OBJECTIVE

The final objective is to develope a decision making tool to test multiple scenarios of climate change as well as to evaluate if the different cooling policies of the local government may have a real impact in the UHI reduction and therefore, in the wellness of the citizens. In order to do so, the characterization of the phenomena is needed in first place to justify the study itself but also to compare and validate the outcome of the model.

The area of study is the municipality of Barcelona although some data is used also in the region of the Metropolitan Area of Barcelona.

METHODS

A. Characterization
B. Model

A.1. Meteorological data from the 12 official stations in the region of Barcelona has been analyzed.
The following chart shows the differences between the observed temperatures on site and upwind. It can be observed that the urban stations have higher temperatures downstream than upwind.

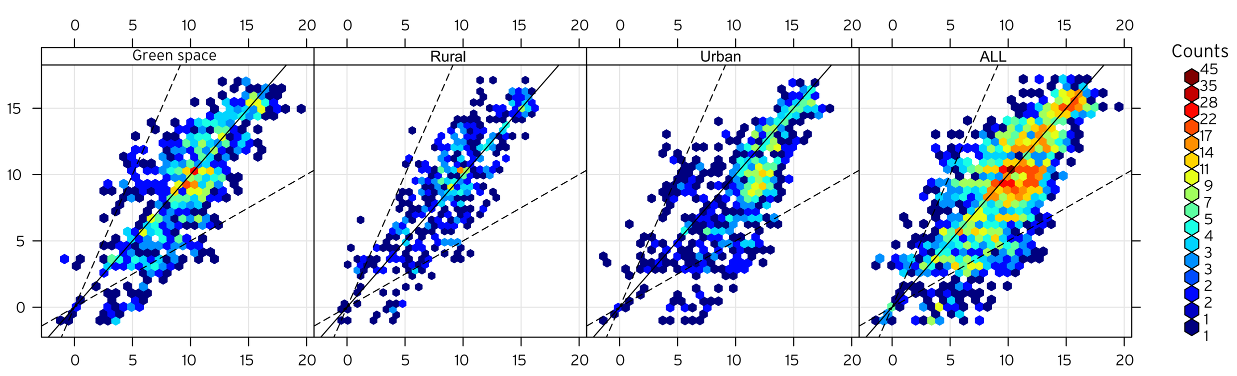

Fig 2. Frequency scatter plot. Upwind Vs downstream temperature from days 11 to 19 of 2015.

A.2. Remote sensing data. Retrieval of Land Surface Temperature. The methodology used is from Fei Wang *et al.* [1] and consists in a mono-window algorithm that retrieves the LST from thermal band 10 of Landsat 8. As it can be observed in Fig.6, the surface temperatures in rural and natural areas are way cooler than the ones inside the urban areas. Although LST and air temperature are of different nature, it has been proved that they have a strong correlation.

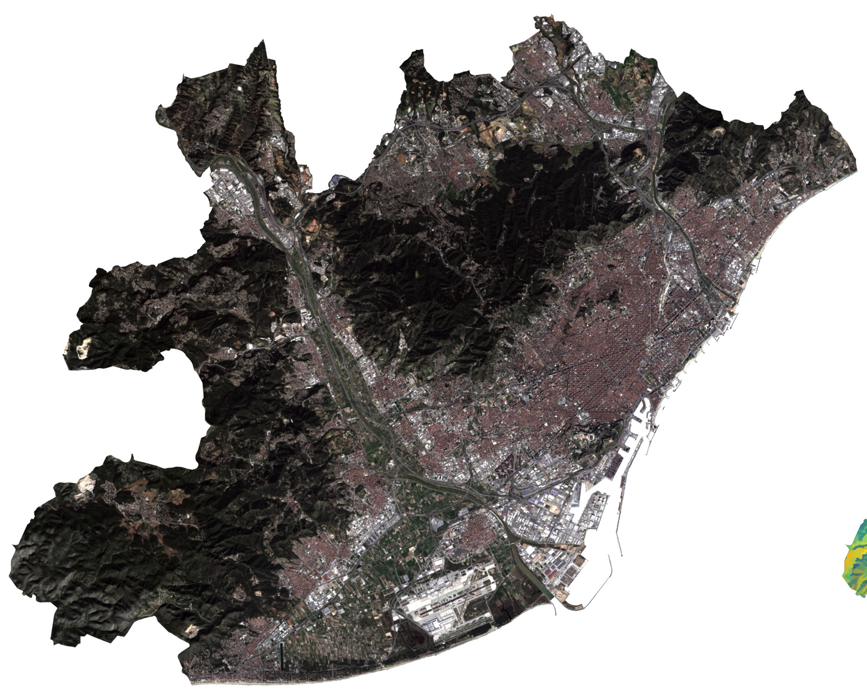

Fig 3. Pan sharpened RGB Landsat 8 composite of the Metropolitan Area of Barcelona.

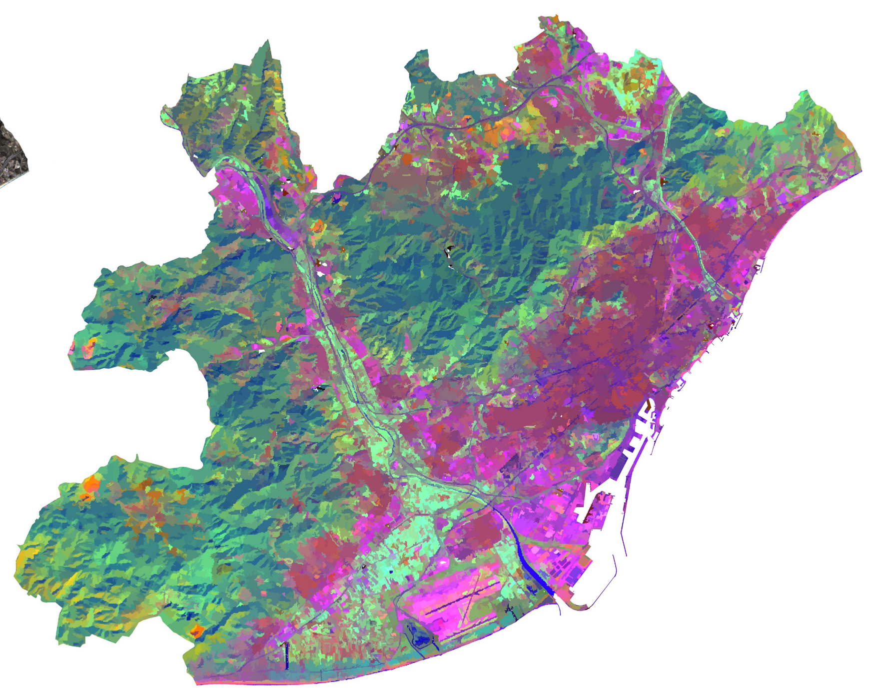

Fig 4. Segmented PCA of Landsat 8 bands 2 to 7 for the LST workflow.

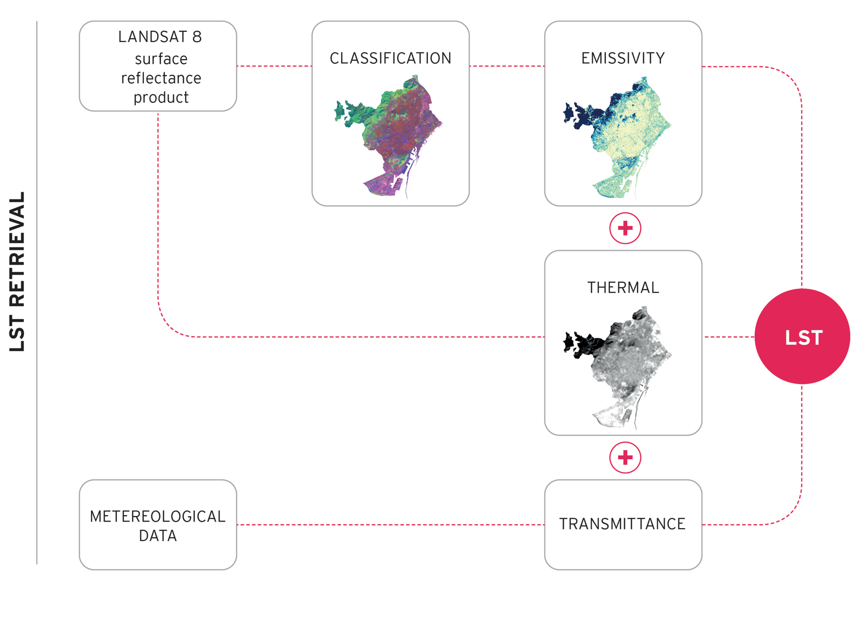

Fig 5. Summarized schema of the LST retrieval workflow.

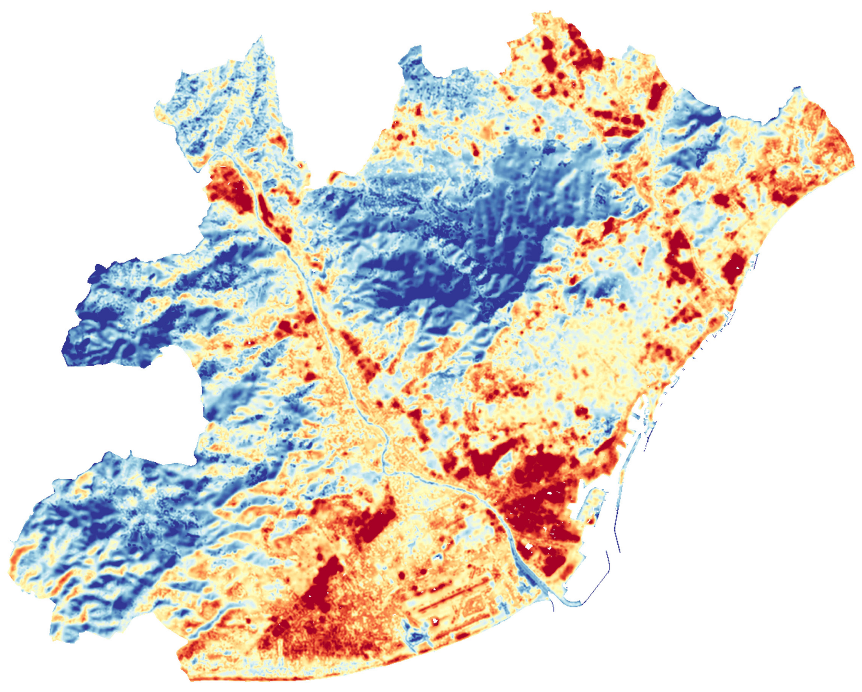

Fig 6. Land Surface Temperature of the Metropolitan Area of Barcelona retrieved from Landsat 8 using a mono-window algorithm.
Date: 2017-03-01.

Methods cont.

B. Model

The model uses land cover and morphology data to predict temperature and humidity values downstream from a known upwind temperature.

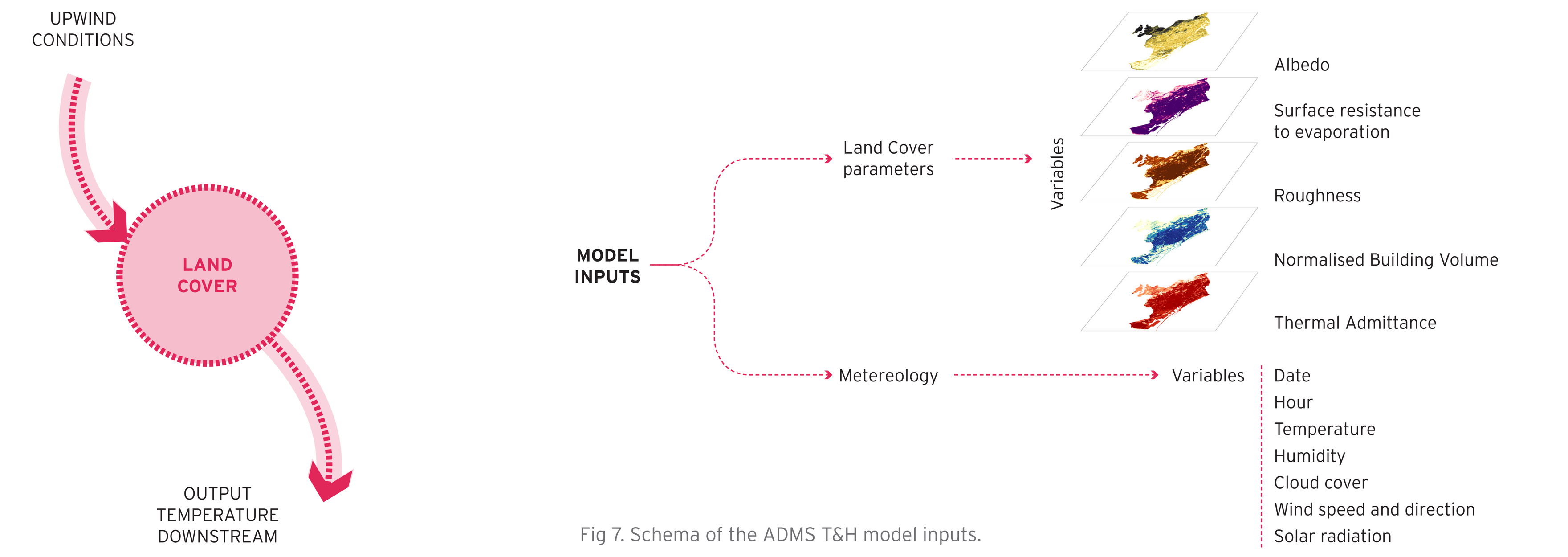

Fig 7. Schema of the ADMS T&H model inputs.

Inputs:

a) Land cover variables. These variables are introduced in the model using a rectangular grid with the weighted arithmetic mean of every variable for every cell. The model works with the following variables:

1. Albedo: retrieved from Landsat 7 and Landsat 8 using the Smith [2] normalization of the Liang [3] algorithm.
2. Surface resistance to evaporation: estimated with tabulated values provided by the model and a high resolution land cover map.
3. Roughness: estimated with tabulated values provided by the model and a high resolution land cover map.
4.Normalized building volume: calculated with a cadastral survey map and a 0.5 m Digital Surface Model from LIDAR data.
5. Thermal admittance: estimated with tabulated values provided by the model and a high resolution land cover map.

b) Meteorological data. This data is has been provided by the Catalan Meteorological Service (SMC) and consists in hourly results of 12 stations for the years 2011, 2013 and 2015. The model inputs are: time and date, temperature, humidity, cloud cover, solar radiation and wind speed and direction.

Fig 8. Input land cover variables for the model. From left to right: Albedo, Surface Resistance to Evaporation, Roughness, Thermal Admittance and Normalized Building Volume.

Output:

The model outputs a text file with the point coordinates of every cell in the grid and the following values:
- **Temperature:** the predicted temperature.
- **Temperature perturbation:** the temperature change caused by the land interactions
- **Humidity:** predicted humidity
- **Humidity perturbation:** the humidity change caused by the land interactions

The perturbations in temperature is what will be used to determine whether there is a UHI effect or not.

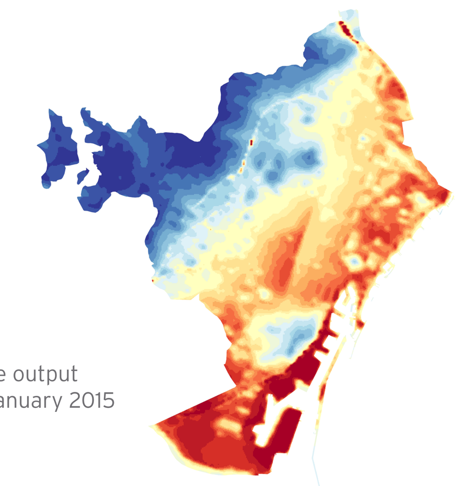

Fig 9. Interpolation of the output model values at 7th of January 2015 at 11:00 am.

RESULTS

Several weeks of 2011, 2013 and 2015 have been modeled and outputted from the model. As an example, the following tables show the comparison of modeled values and real measures from days 11 to 19 (winter) and days 192 to 200 (summer) of 2015. The measured values come from the 12 stations of the Catalan Meteorological Service.

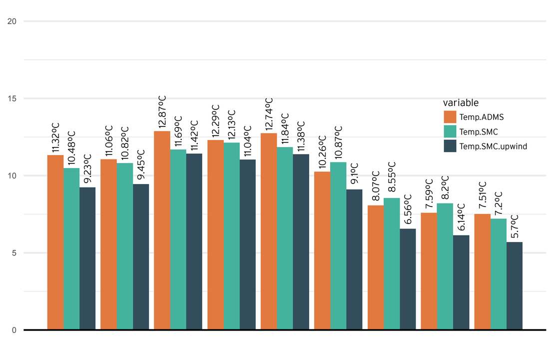

Fig 10. Average daily temperatures of model, downstream and upwind for a station inside the city. Winter period days 11 to 19 of 2015.

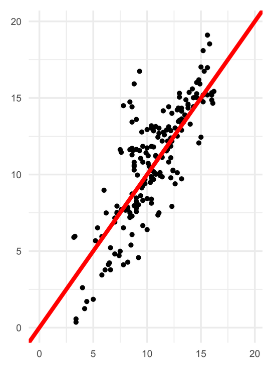

Fig 11. Scatter plot of measured Vs modeled temperatures for a station inside the city. Winter period days 11 to 19 of 2015.
R2 = 0.82

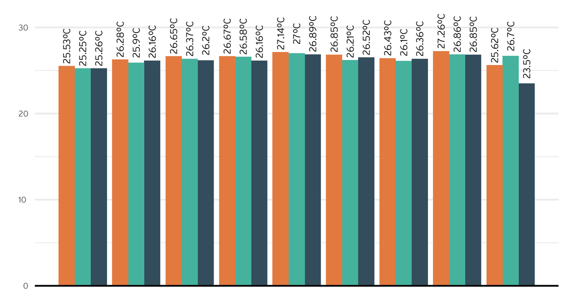

Fig 12. Average daily temperatures of model, downstream and upwind for a station inside the city. Summer period days 192 to 200 of 2015.

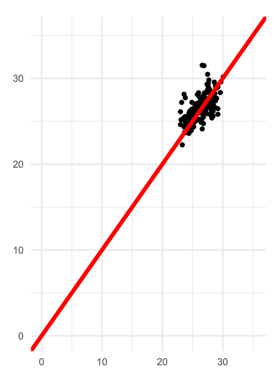

Fig 13. Scatter plot of measured Vs modeled temperatures for a station inside the city. Summer period days 192 to 200 of 2015.
R2 = 0.66

The model has also been compared against the LST (R^2=0.55). The residual differences from this analysis are shown in Fig 15.

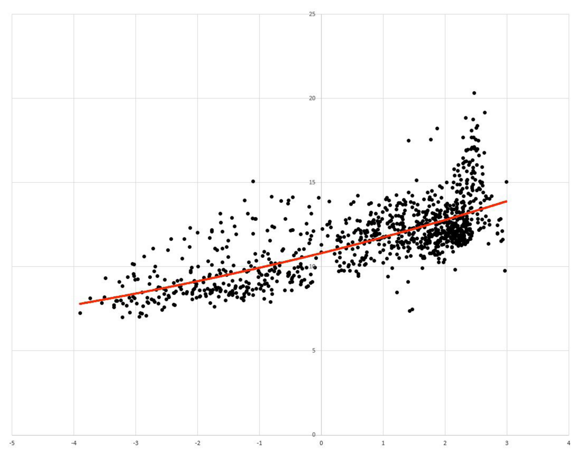

Fig 14. Scatter plot of the modeled temperature perturbations and the results of LST. R2 = 0.58

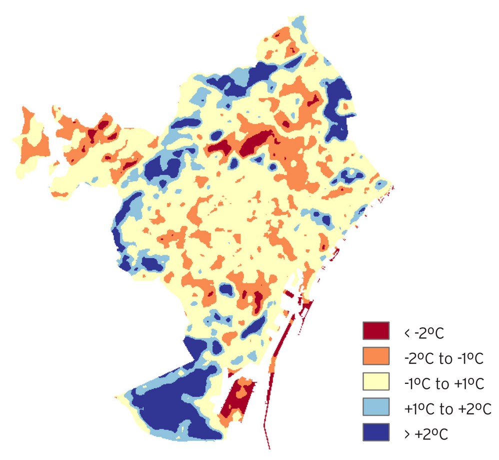

Fig 15. Residual map of the modeled values and the LST.

DISCUSSION

The analysis of LST and Meteorogical data show evidence of the UHI phenomena in Barcelona as shown in Fig.2. and Fig. 6.
The preliminary results show a good correlation between modeled temperatures and real measures for the 12 stations during winter (R^2=0.8). However, the summer correlations are lower (R^2=0.55). A further investigation is needed in order to calibrate the model for a full prediction in all periods.
The correlation between LST and Air temperature is higher in open spaces than at places very exposed or protected from the wind. LST is especially higher in industrial areas with lots of metallic covers. These differences are not of main concern since LST and Tair are known to differ, especially during winter and also due to changes in elevation and roughness [4].

ONGOING INVESTIGATION

At the moment, we are currently calibrating the model for a better results between the modeled and measured temperatures at stations.
The effect of anthropogenic heat has been recently added and this is a major change in the calibration and validation process.
Once validated, we will run the model using changes in the land cover values according to new urban planning projects.

References:

1. Wang, Fei; Qin, Zhihao; Song, Caiying; Tu, Lili; Karnieli, Arnon; Zhao, Shuhe. 2015. "An Improved Mono-Window Algorithm for Land Surface Temperature Retrieval from Landsat 8 Thermal Infrared Sensor Data." Remote Sens. 7, no. 4: 4268-4289.
2. Smith, R.B. 2010. "The heat budget of the earth's surface deduced from space"
3. Liang, S. 2000. "Narrowband to broadband conversions of land surface albedo I algorithms." Remote Sensing of Environment 76, 213-238.
4. Denis Mutiibwa; Scotty Strachan; Thomas Albright. 2015. "Land Surface Temperature and Surface Air Temperature in Complex Terrain." IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing (Volume: 8, Issue: 10, Oct. 2015)

Acknowledges:

1. Landsat data distributed by the Land Processes Distributed Active Archive Center (LP DAAC), located at USGS/EROS, Sioux Falls, SD. http://lpdaac.usgs.gov
2. ADMS 5 Temperature and Humidity 2015. Cambridge Environmental Consultants Ltd, 3 King's Parade, Cambridge.
3. Carslaw, D.C. and K. Ropkins, (2012). openair – an R package for air quality data analysis. Environmental Modelling & Software. Volume 27-28, pp.52-61.