The variation of air and surface temperatures in London within a 1km grid using vehicle-transect and ASTER data

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Abstract: Urbanisation can modify the local climate, increasing the temperature of cities compared to rural areas. This phenomenon is known as the Urban Heat Island (UHI), and this paper introduces a methodology to investigate the spatial variability of air and surface temperatures across London. In particular, this study aims to investigate if a widely used spatial resolution (1 km) is appropriate for heat-related health risk studies. Data from vehicle-transect and ASTER thermal images were overlaid on a reference grid of 1 km, used by UHI simulation models. The results showed higher variability of air temperature within some specific modelled grid cells in the city centre, while surface temperatures presented higher variability in the London borders. This investigation suggests that LST has larger variation levels and more grid cells with sub-grid variation above 1ºC compared to air temperature measurements.

INTRODUCTION

Urban surfaces and human activities affect the climate of cities [1]. The Urban Heat Island (UHI) is a phenomenon whereby these factors lead to an urban-rural air temperature difference [2]. Many urban climate studies seek to quantify the UHI effects on heat-related health risk [3]. However, climate modelling and remote sensing mostly provide outputs with spatial resolutions of kilometres to preserve higher temporal resolution. Few studies have examined how much the temperature varies within different spatial resolutions to determine if commonly used spatial resolutions are appropriate to interpret the UHI heat exposure. Currently, studies investigating the effects of UHI on population health [3-9] and energy use [10] have been made with support of 1 km grids using both modelled air temperature [5] and land surface temperature [7] analyses. Air temperature (AT) and land surface temperature (LST) are important parameters to identify areas with elevated health risk [5,7]; a statistically significant increase in mortality risk has been demonstrated in areas with a 1 ºC increase in LST in France during the 2003 heatwave [6], while the relationship between AT and mortality is well established [3,4]. In the remote sensing field, for instance, there are weather-related mortality studies classifying areas with elevated risk using LST instead of AT [7,9].

The spatial variability of temperature plays an important role in the diagnosis of heat exposure zones, affecting directly the vulnerable population (including the elderly, people with limited mobility and pre-existing medical conditions). It has been shown that even modest exposure to heat leads to an increased mortality risk in temperate climates [3], caused by many factors, such as hyperthermia and heat stroke [6].

Different methods have been used to explore intra-urban temperature variability, such as fixed and mobile meteorological stations, vehicle-traverses, orbital and airborne remote sensing, and climate modelling. Across London, 68 measuring stations (micro data-loggers on lampposts) were arranged in eight transects to monitor the hourly variation of the air temperature from August 1999–July 2000 [12]. In the Greater Manchester (UK), a ground-based and airborne transects were used to measure at sub-kilometre scale the spatial variation of the air and surface temperatures during the summers of 2007 and 2008 [13]. In Birmingham (UK), remotely sensed MODerate resolution Imaging Spectroradiometer (MODIS) images were used to quantify the potential heat health risk areas [7]. Advanced Very High Resolution Radiometer (AVHRR) scenes from 1996 to 2006 were used to quantify the spatial variability of LST during the summer in London [14]. In Madrid, Airborne Hyperspectral Scanner (AHS) imagery were upscaled from 4 m to 10 different spatial resolutions of surface temperature and they concluded that spatial resolutions higher than 50 m are the most appropriate to estimate UHI at local level [15]. In London, a 1 km grid of air modelled temperature was used in conjunction with indoor temperatures, population counts and age data to estimate the spatial variation in the mortality from heat exposure during hot weather [5].

As part of ongoing research, there is a need to understand how spatial resolution of AT and LST may alter estimates of the risk of mortality to building occupants due to overheating in dwellings. Therefore, this study aims to investigate the degree of local temperature variation within the 1 km temperature grids used previously to estimate the spatial variability of AT and LST across London. The research hypothesis is that the variation within 1 km grid cells may be significant, with important consequences for heat-related health risk studies.

DATA AND METHODS

Dataset provided by the LUCID project

LUCID (the development of a Local Urban Climate model and its application to the Intelligent Design of cities) was a research project funded by the UK Engineering and Physical Sciences Research Council (EPSRC) between 2007 and 2010 [16]. The project developed tools to estimate London's climate and its impact on comfort, health and energy use. For this study, the LUCID project provided the following datasets: 1 km grid of modelled air temperature, vehicle-traverse measurements and satellite thermal images. An hourly modelled grid of air temperature was developed by The Met Office Unified Model for London (LondUM) from May to August 2006. This LondUM modelled grid was used in this study as the 1 km Reference Grid (RG).

Car transects provided air temperature measurements of London, between 8th and 30th of August 2008, in a total of eight routes (Table 1) distributed in two traverses (from north to south and east to west). During the transects the weather conditions were mostly half cloudy (4 oktas) and weak wind (5 m/s). The equipment, UMA THERMAL (developed by Energy Monitoring Company) with a thermistor probe, was attached to the car side, 1 m above the ground. A GPS (Global Positioning System) recorded the vehicle locations. Equipment calibration was performed in a Design Environmental Temperature and Humidity Chamber (Delta 335-70H model) and the equipment presented an accuracy of ±0.14 °C, from -10 °C to 40 °C.

TABLE 1: CAR TRANSECT AND ASTER IMAGES INFORMATION

		Date	Start time (GMT)[a]	End time (GMT)[a]	Count
CAR TRANSECTS - AIR TEMPERATURE	**T01** (N-S)	08/08/08	12:29:30	14:48:40	7.751
	T02 (S-N)	16/08/08	14:45:35	17:55:27	11.393
	T03 (S-N)	23/08/08	14:18:53	17:57:40	13.128
	T04 (E-W)	09/08/08	12:51:50	14:28:33	5.804
	T05 (E-W)	16/08/08	11:47:42	13:50:50	7.377
	T06 (E-W)	23/08/08	11:19:11	13:29:07	7.797
	T07 (E-W)	30/08/08	11:49:17	15:46:59	7.063
	T08 (E-W)	30/08/08	21:21:51	23:01:46	5.996
ASTER - LAND SURFACE TEMPERATURE	**12th July 2006**	12/07/06	21:45	21:45	17.818
	28th July 2006	28/07/06	21:45	21:45	17.818

[a.] *Greenwich Mean Time*

The ASTER (Advanced Spaceborne's Thermal Emission and Reflection Radiometer) sensor on-board Terra has 14 bands, 3 Visible and NearInfraRed (VNIR), 6 Short-Wave InfraRed (SWIR) and 5 Thermal InfraRed (TIR); with spatial resolutions of 15m, 30m and 90m respectively. To monitor the Earth, Terra has a sun-synchronous orbit, an orbit-period around 90 min and a revisit-time about 2 weeks. Two thermal night images with cloud cover of approximately 3% were acquired on July 12th and 28th 2006 at 21:45 to examine the LST spatial variability over the vehicle-traverse routes. The ASTER data products, including surface kinetic temperature (AST08), surface spectral emissivity (AST05) and digital elevation model (DEM) were obtained from NASA. Data processing, including orthorectification using a Digital Elevation Model (DEM), was performed using ENVI 4.3 [17] and both scenes were re-projected to the British National Grid reference system. Through Planck's Law, LST was defined using a temperature-emissivity separation (TES) algorithm, AST05, were used to scale the measured sensor radiances after correction for atmospheric effects [18].

Dataset fitting

Reference grid cells were overlaid on the car vehicle-transect routes and the grid cells with the same spatial location were selected. All vehicle-transect measurements within each grid cell were selected and spatially joined to the RG using ArcGIS 10.3 software [19]. The same procedure was repeated for the ASTER LST pixels (Fig. 1). AT and LST measurements, from the different sources were analysed within each grid cell for the difference between maximum and minimum temperature values found at the sub-km level.

Table 1 presents the travel information, such as day, duration, and quantity of measurements (count) about the vehicle transect and the ASTER images.

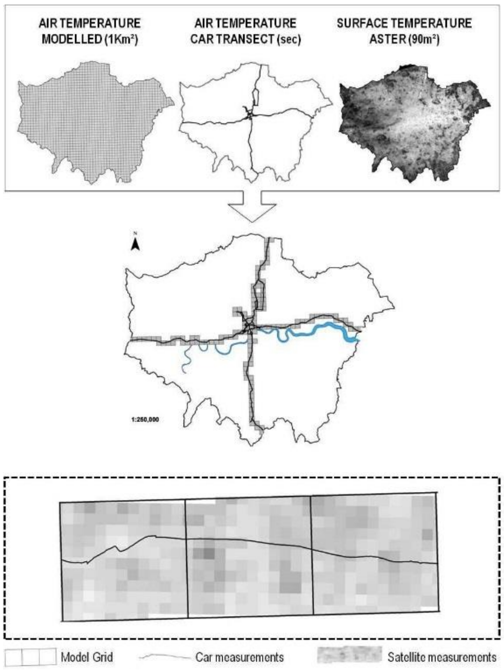

Figure 1: Combination of the reference grid, LST, and car transect routes. Source: [20]

RESULTS AND DISCUSSION

A statistical test (Q-Q-plot) showed that AT and LST temperatures are not normally distributed within grid cells. Therefore, initial investigations were only focused on extreme values inside the grid cells, analysing the worst case scenario of the temperature variability. Ongoing research will investigate the best way to characterise the variability within a grid considering the properties of the distribution.

Fig. 2 and 3 show ASTER images on 28th July 2008 and on 12th July 2008, respectively. According to [6], areas with an increased LST of 1ºC had a significantly increased mortality risk during the 2003 heatwave in France. Using this 1ºC as a useful initial indicator of significant temperature differences for health risk, the temperature variability within each grid cell was analysed. The LST at sub-km level showed variation higher than 1ºC on all grid cells in the two ASTER images, starting with 2ºC and reaching up 15ºC (Fig. 3). The grid cells with the lowest LST difference (2-5ºC) were concentrated in the city centre, while outer London had greater LST variation (5-10ºC).

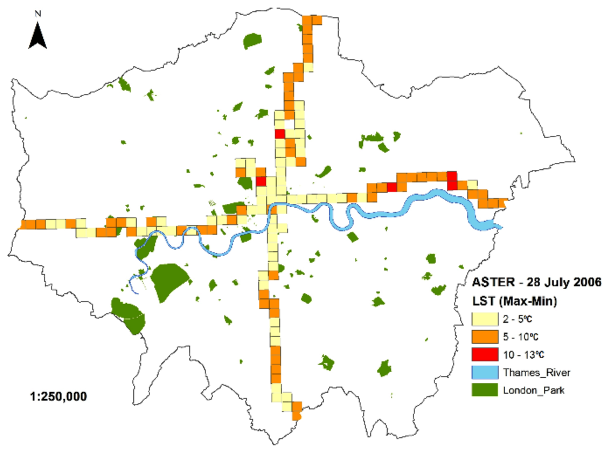

Figure 2: LST range from ASTER on 28th July 2006.

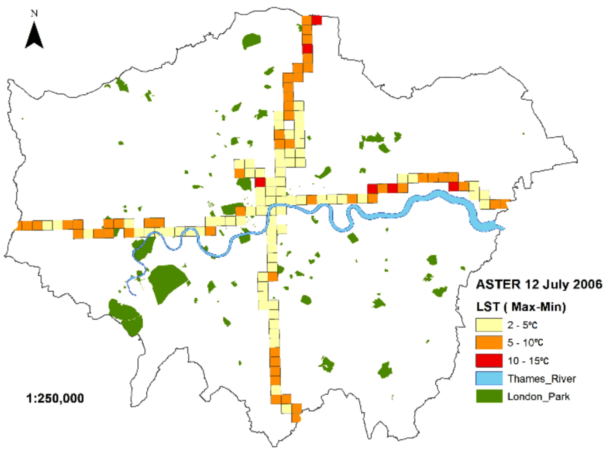

Figure 3: LST range from ASTER on 12th July 2006.

Between the eight transects, two car transects were selected to show daytime and night time air temperature differences. Fig. 4 and 5 present the ranges of temperature differences within grid cells for car transects 02 and 08, respectively. It can be seen that in both car transects there were more grid cells with AT difference lower than 1ºC then greater than 1ºC. The daytime transect indicated greater amount of grid cells with AT difference 1ºC or higher compared to the night time transect, reaching up 4ºC. The city centre has a high density of tall building that generate shadows on the street, which may cause some lower AT recordings over the route and generating higher AT variability during the day. The largest AT variations detected by the car transect 08 is also mostly concentrated in the city centre. This nocturnal variability found in the city centre might be caused by the late heat emission release from urban surfaces that force the AT to keep warmer in areas with intense concentration of impervious surfaces. Inside the black square dashed (Fig. 5), the grid cell in red, with 2-3ºC AT range, can be explained by the proximity with the Hyde Park, the largest green area in the central London.

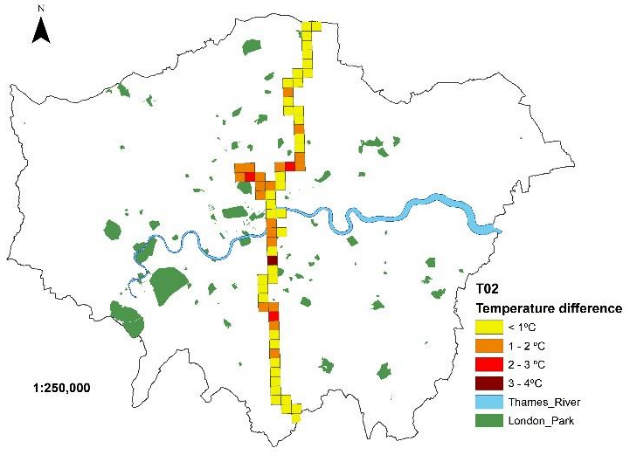

Figure 4: Air temperature difference from Car Transect 02.

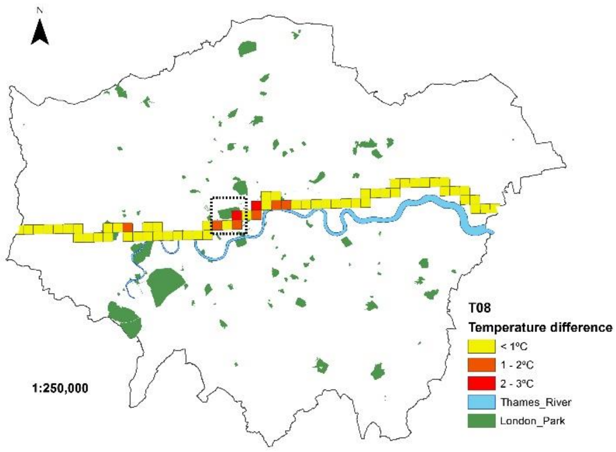

Figure 5: Air temperature difference from Car Transect 08.

The spatial trends in sub-grid temperature variation differed between LST and AT, and AT grid cells had much smaller variability overall. Spatial trends may be due to the amount of impervious surfaces concentrated in the city centre leads to warmer LST for the whole central area, causing lower sub-grid variability. However, in the city borders, compared to the city centre, there are cooler surfaces (e.g. green areas) and lower density of impervious surfaces, creating a mixed land cover and making the sub-grid variation of LST larger.

CONCLUSION

This study presented an initial analysis of the extent to which AT and LST vary within 1 km grid squares across London to investigate whether temperature variation at the local scale should be explored using higher resolution data sources. The results indicated that LST has more grid cells with variation higher than 1ºC and range levels larger than the AT grid cells. In those AT grid cells that showed temperature difference above 1ºC, further investigations will examine the impact of this variability on heat mortality estimates. For LST, a satellite image with spatial resolution higher than 1km should be used or, in order to preserve the temporal resolution, apply a downscaling technique to better estimate the LST variation.

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