Spatial comparison of the perception of urban heat islands and thermal comfort zones with participative *in situ* measurements and remote sensing data

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Abstract:

According to the IPCC, current climate change is likely to increase the intensity and frequency of extreme events (Core Writing Team, R.K. Pachauri and L.A. Meyer, 2014). This is particularly true for heat waves, the severity of which has increased in Europe in recent decades. In addition, the increase in temperatures due to global climate change is amplified by the urban heat island (UHI) effect. The UHI is characterized by a temperature difference between an urban area and rural environments. In general, urban air temperatures are higher than in rural areas, especially at night. This phenomenon is widely analysed and is one of the major themes of urban climatology, particularly in terms of its impact on human health. Heat can create heat stress and lead to risks of sunstroke, dehydration, hyperthermia and heat stroke. In France, the 2003, 2006 and 2015 heat waves caused 19490, 1388 and 3275 deaths respectively according to the International Disaster Database EM-DAT. During the 2003 heat wave in Paris, excess mortality was 141% higher than in a standard summer and 80% higher in Lyon, the second largest French urban area (Laaidi et al., 2012; Vandentorren et al., 2006). In addition, an increase in surface UCI of about 0.5°C may have caused a doubling of mortality (Dousset et al., 2011). Victims were mainly identified in large urban areas.

In the UHI research community, these UHIs can be quantified in different ways. For air temperature measurement, fixed measurements are most often used. However, urban measurement networks are generally not dense enough to accurately characterize processes (Keeratikasikorn and Bonafoni, 2018). Mobile measurement can then be used by operating by transect, but it will not be continuous over time, unlike a network of stations (Liu et al., 2017). Surface temperatures are most often measured by remote sensing using satellites. Under optimal conditions for measuring surface temperature (no cloud cover, no advection), the latter is often a few degrees higher than the air temperature. Finally, more qualitative measures of UHI measurement can be used by asking users about their thermal feelings and their practice of the place, for example through questionnaires, interviews or mental maps. In addition, the participation of users in the process makes it possible to mobilize and raise awareness about the phenomenon of thermal discomfort.

Thus, the purpose of this study is to compare three different ways of acquiring outside thermal data on the Lyon urban area in order to transcribe it from a spatial and cartographic point of view. Indeed, two types of abstraction are used in this study: polygons obtained by mental thermal maps and surface temperatures by remote sensing and points obtained by mobile measurements. These spatial information representations are determined by the tools used in the data acquisition and were not deliberately chosen. In addition, the perception of thermal gradients is compared to the measured data.

The first way is a subjective method of abstracting the spatial distribution of temperature in urban environments, which are then compared with two quantitative methods. The aim is to produce outside thermal mental maps for volunteers so that they represent the hottest areas of the agglomeration. When producing thermal mental maps, the participants are in the meeting room, just before to do the mobile measurements. It is based on Lyon blank maps targeted on city center. On this map, only the two rivers and the main streets are displayed. An aerial imagery map at the same scale is provided to help volunteers draw thermal maps. The volunteers are free to express their thermal perception using the provided pencils, with their own level of detail to describe an area. The process used for moving from the thermal perception to its representation as spatial information has been by drawing polygons only. No participants used lines or points. Thus, no interpolation has been needed. This understanding reflects both the individual's experience within this space and his or her value judgment of the place. The objective of using mental maps is to compare the perception of their thermal atmosphere in Lyon with quantitative measurements carried out in parallel in the field and by remote sensing. As a result, a map summarizing the perception of the distribution of temperatures during a hot day in Lyon based on the mental maps provided by the participants is obtained after georeferencing, digitization, quantification and standardization (fig. 1).

The second means of information retrieval is based on participatory or citizen measurements. They represent a democratization of science and an opening of the public to environmental issues. The main goal of this approach is to build large databases based on volunteers, with unprecedented spatial and temporal accuracy, using a specific methodology (Cohn, 2008; Silvertown, 2009). Volunteers were equipped with air and humidity temperature sensors and GPS. These sensors make it possible to instantly measure the temperature and humidity of the air and to associate them precisely with a location. The measurements are then corrected to take into account the rise or fall in daily temperatures during the campaigns. Typically, measurement campaigns take place over half a day. As part of this study, 20 measurement campaigns were carried out over 18 days. For example, 16 volunteers participated in the campaign of 03 July 2018, which provided a temporary network of 879 surveys in the Lyon city centre (fig. 1).

The last means of spatializing air temperature is based on surface temperatures from the Landsat 8 satellite (fig. 1). The single channel method has been selected (Renard et al., 2019). This involves calculating spectral radiance, brightness temperature, emissivity using NDVI thresholds and removing atmospheric effects occurring between the Earth's surface and the satellite sensor using appropriate functions. These four means of temperature assessment are spatially compared with each other using a GIS. The Pearson correlation coefficient (R), the mean square of errors (MCE) and the root-mean-square error (RMSE) are used to assess the adequacy of the measures.

Comparison of thermal mental maps with surface temperatures reveals a wide range of RMSEs and Rs from 0.05 to 0.83. The same is true for thermal mental maps compared to mobile measurements: some campaigns have a strong match (e. g. 26 June 2018; R = 0.70) and others have no correlation at all (e. g. 20 April 2017; R = 0.07) or even a negative correlation (e. g. 39 May 2017; R = -0.24). These results are not really surprising because from our field experiences, the measured thermal gradients can be much more changing than the imagination might suggest: constantly hot or cold areas in a rather uniform way, independent of time and type of weather. In addition, some results are counter-intuitive. In hot weather, some streets without vegetation but with a very low sky view factor may remain much cooler than parks with fountains located a few hundred metres away, exposed to the sun for most of the day. The sky view factor has been calculated using a GIS and LiDAR data.

In conclusion, the initial results of this study show that the perception of Lyon's inhabitants of hot and cold areas broadly corresponds to the areas identified with Landsat. However, in situ participatory measures reveal that strong local gradients exist and vary much more rapidly than participants expected. Some results are even counter-intuitive, with incised streets remaining cooler than parks. Secondly, while the mapping of the UHIs could be solved by massive participatory air temperature measurement campaigns, the same cannot be said for the spatialization of thermal comfort zones, which requires, in particular, obtaining sunshine and wind speed. Finally, these maps can be used by town planners to identify thermally unfavourable areas with a view to redeveloping them, but also by residents, particularly vulnerable people, to inform them of the areas to be used preferentially in the event of high heat.

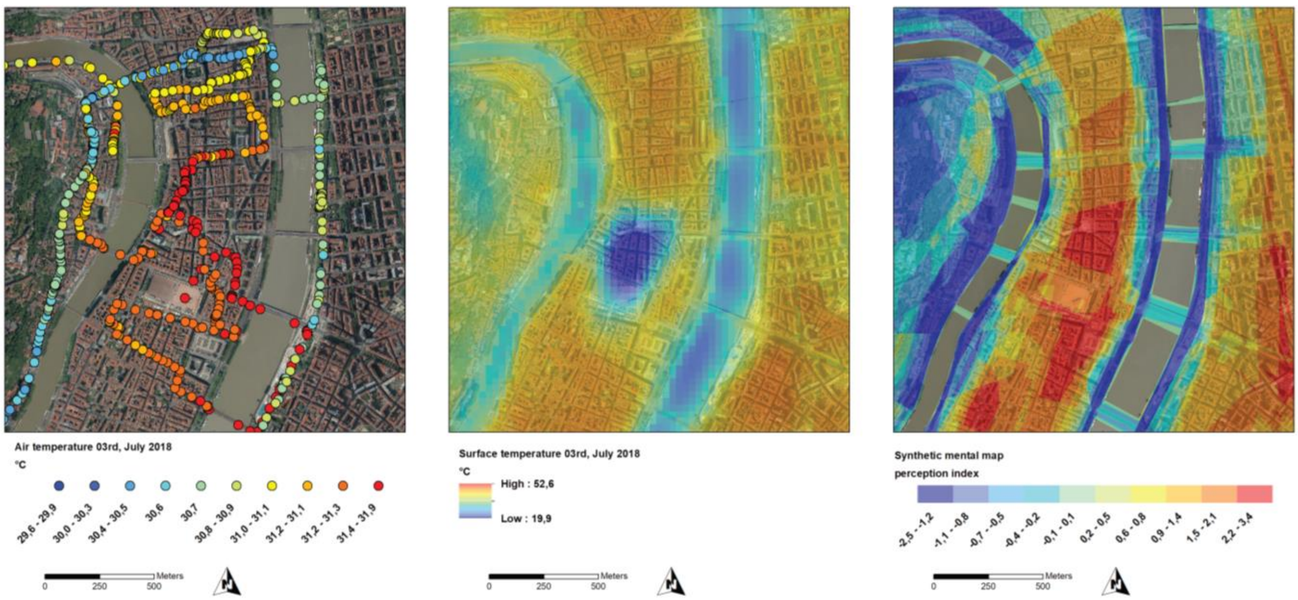

Figure 1. Mobile measurements of 03rd, July 2018 (points - left), surface temperatures of 03rd July 2018 (polygons - center) and synthetic mental map (polygons - right)