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Cooling Effect of Urban Parks in the Metropolitan Region of Barcelona:
The sample of Viladecans, Gavà and Castelldefels urban continuous

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ABSTRACT: This study presents a multi-stage approach to quantify the cooling effect of urban parks in the metropolitan region of Barcelona from the Land Surface Temperature (LST) of Landsat-8 of a summer day. We quantified the cooling extent (Lmax) and intensity (ΔT) of seven parks in the conurbation of Viladecans, Gavà and Castelldefels through three analytical methods based on a multi-stage spatial subdivision of the urban surroundings. First results show ΔT of 1.25°C and 1.50°C in relation to the 0-100m and 100-300m concentric urban annuli respectively. The Lmax calculated by 10m-width concentric annuli registered 91.67m average with ΔT of 1.22°C. Last, 10m-width transversal sections to the park resulted in average ΔT of 2.21°C in industrial zones, 1.05°C in residential areas and 1.76°C adjacent to another park. Where the Lmax resulted in 109.00m average to northeast and 129.67m to southwest, with maximum 170m in the industrial zone and 310m in the another park’s area respectively. Conclusions discuss differences between methods applied and considerations to further replication in larger scale studies.

KEYWORDS: Global and Local Warming, Urban Heat Island, Cooling Effect of Green Spaces, Cool Island

1. INTRODUCTION

Urban parks play a fundamental role in climate change adaptation in cities. Commonly with the largest concentration of vegetation and unsealed surfaces in the cities, the parks increase humidity in the air and the shadow projected on the surfaces. Breaking the continuity of the Urban Heat Island effect (UHI), caused, in part, by the high absorption of direct sun-heat in the artificial surfaces [1]. Thus, parks register lower temperatures than the rest of urban spaces and generate a cooling effect that spreads to their surroundings creating a "cool island" effect [2].

The cooling effect of parks is quantified by the extent limit, which is the maximum distance reached by the cooling spread outside boundaries of the park; and the intensity, which is the difference in temperature between the park and a certain urban space in its near surroundings [2]. Divergences on the calculation of these cooling indicators are related to the scale of the study, the spatial distribution of the data and the method to register temperatures. There is a consensus on the calculation of the cooling intensity, but with slight differences on the spatial attribution of the temperature to the park and the one that represents the urban space. The cooling extent presents a lower consensus on its definition. Previous investigations pointed that the cooling extent of parks between 3 and 200ha size, is in the 50 to 300 meters (m) range, but larger parks go from 200 to 2000m. Whereas the cooling intensity registers values between 1 to 4°C during day and 2 to 5°C at night [3], with an average intensity between 0.94 and 1.15°C [4].

Previous studies are grouped in three general approaches. First, the survey of air temperature variations with weather stations and their relation to the distance to green spaces, limited to large-scale analysis and the need of interpolate information [5, 6]. Other studies performed field measurement campaigns with portable weather stations on routes that intersect parks and their surroundings, which is limited to specific cases [2, 7]. Second, studies that recur to numerical modelling and thermal simulation of parks and their surroundings, which allow higher number of cases and the assessment of hypothetical modifications to the current state of the spaces [8, 9]. Third, the remote sensing approaches, which has become one of the most frequent methods to obtain thermal and physical data of the territory. Particularly, the Land Surface Temperature (LST) has been applied to multiscale analysis of the UHI or in general urban climatology studies, due to the potential of the spatial continuity of the thermal data [10, 11].

2.2 Study area

In this study, we aboard the conurbation of Viladecans, Gavà and Castelldefels (VGC area) in the Metropolitan Region of Barcelona (41°20'16"N; 41°15'50"N; 1°55'29"E; 2°04'26"E). The area presents continuous and discontinuous urban fabric and industrial units (Figure 1). Castelldefels is mainly covered by discontinuous urban fabric; Gavà is predominantly agricultural and natural with industrial units as large as the urban fabric; and Viladecans is mainly covered by agricultural land.
The present work is part of a series of previous works that aim to quantify the microclimatic influence of the urban green spaces in the Metropolitan Region of Barcelona. First on the series, a study revealed differences of 4.28°C during day and 2.56°C at night in autumn between urban and rural areas LST [14]. Later, through measured air (T_a) and surface (T_s) temperature, a study registered that, during summer daytime, the Coll Favà Gardens with predominant paved surface and lower proportion of vegetation, registered 5.03°C and 9.91°C higher T_a and T_s respectively than the Central Park mostly covered by dense vegetation, both in the Sant Cugat del Vallès municipality [15]. Likewise, the integration of field measurements, remote sensing and thermal simulation in two parks of Barcelona, registered that Turó Park, with abundant vegetation and dense built-up context, reaches a cooling extent of 80m with a 2.89°C intensity. While, the Parc del Centre del Poblenou Park, with sparse vegetation and mid-dense built-up and wooded surroundings, registered 90m of extent and 2.75°C of intensity [16].

2. METHODOLOGY

In this context, here we adapted three remote sensing analytical methods to quantify the cooling effect of seven parks at different scale approaches. With the purpose of define basic criteria for replication in the metropolitan region of Barcelona. The seven cases selected for this study correspond to green areas identified as points of interest because of their landscape value and differences of urban context (Figure 1). The cases of study are: P. Riera de Sant Climent, Viladecans (PRC); P. Torrent Ballester, Viladecans (PTB); P. Torre Lluç, Gavà (PTL); Rambla de Gavà, Gavà (RG); P. de la Muntanyeta, Castelldefels (PM); P. dels Tellinaires, Castelldefels (PT); P. de la Plaça d’Asturias, Castelldefels (PPA).

2.1 LST retrieval

We retrieved LST from the Landsat-8 imagery of July 26 of 2018 acquired at 10:36 GTM+1 [17] and with the emissivity corrected algorithm [18]:

\[
\text{LST} = \frac{T_b}{1 + \lambda \times T_b/\alpha} \ln \epsilon \quad (1)
\]

where LST is in °C; \( T_b \) - at-sensor brightness temperature (°C) from thermal infrared one band (TIR\(S_1 \)); \( \lambda \) - wavelength value of TIR\(S_1 \) band (10.895µm); \( \alpha \) - surface radiation constant (1.4388×10^{-2} mK); \( \epsilon \) - surface emissivity estimated with the simplified NDVI threshold method [19] applying the emissivity values of [20].

2.2 Cooling effect indicators

The cooling effect is calculated by its extent and intensity. The cooling intensity (\( \Delta T \)) is the difference between the temperature of the parks (\( T_p \)) and the urban areas (\( T_u \)), calculated as \( T_p - T_u \) [2]. Cooling effect shows positive \( \Delta T \) values. The cooling extent limit (Lmax) is the maximum distance reached by the microclimatic influence of the park. Positive cooling effect implies lower temperatures near to the park and gradual increment according to more distance. In a fitted dataset of temperature of urban spaces ordered by distance to a park, the cooling effect generates a “cooling curve” [21, 22], which ends at the maximum \( \Delta T \) (\( \Delta T_{\text{max}} \)) and define the Lmax point (Figure 2).
2.3 Analytical methods

2.3.1 Delimitation of the surroundings by two concentric annuli

As first approach, we proposed a delimitation of the nearby surrounding areas by two concentric annuli for the cases of study. The aim of this division is to quantify the ΔT of each park, in relation to its particular context and make a first approach to identify potential ranges of distance of the Lmax.

Here, we generated two concentric annuli from zero to 100 meters (A1) and 100 to 300m (A2) away from each park. Then, we calculated the mean LST of each annulus and park individually, excluding pixels of the other parks within annulus of another park.

2.3.2 Quantifying the cooling effect through 10m-width concentric annuli

In a more detailed approach, we proposed a 10m-width concentric annuli to homogenize LST of the surroundings and quantify Lmax and ΔT of each park.

First, we created a 500m radius from the perimeter of the parks and divided it in 50 concentric 10m-width annuli. Then, we calculated mean LST for each park and annulus excluding LST pixels of parks and a six-degree polynomial curve fitting fixed fluctuations in the dataset of 51 LST values (park and 50 annuli). Here, we identified the Lmax at the end of the cooling curve and estimated ΔTmax with the Lmax point as T_U.

In this method, we excluded the Rambla de Gavà due to the narrowness of its section. Instead, we studied it with more detail in the following section.

2.3.3 Quantifying the cooling effect variations through transversal sections

Finally, we proposed transversal sections for a detailed analysis of ΔT and Lmax of the Rambla de Gavà. As complement to the 50 concentric annuli, we placed 10m-width transversal sections to the Rambla throughout its extension. It resulted in a 10m-cells grid, distributed in 59 rows that correspond to the transversal sections and 101 columns that are the clipped annuli, 50 to northeast, 50 to southwest and one of the Rambla. Then, we resampled the LST cells to 5m-pixels and calculated average LST of the 10m-cells grid. In this case, we obtained two LST datasets for each section: the northeast and southwest. Both with the LST of the Rambla as first value. Where we also performed the curve fitting and cooling indicators calculations in both orientations.

3. RESULTS

The entire VGC area registered 35.64°C mean LST, just artificial surfaces 36.69°C and the non-artificial 35.06°C (Figure 3). Particularly, artificial surfaces in the municipalities registered 35.41°C in Castelldefels, 37.15°C in Gavà and 38.02°C in Viladecans.

Figure 3: VGC area Landsat-8 LST of July 26 of 2018

The LST of the parks reflects the municipal variations, which decrease going from Viladecans to Castelldefels (Figure 4). In general, the parks resulted 1.08°C lower than the artificial surfaces of the conurbation. However, Viladecans registered the highest cooling effect and Castelldefels the lowest.

Figure 4: LST of the parks.

3.1 Cooling effect in the closest surroundings

The 0-100m (A1) and 100-300m (A2) annuli, indicate a 1.25°C and 1.50°C reduction of the parks in relation with these areas. In the particular results, annuli resulted in positive ΔT in all the cases (Figure 5).

Figure 5: Concentric annuli of 100 and 300m.

The A1 annulus registered the highest ΔT in the Parc Torre Lluch and the lowest in the Parc de la Plaça d’Asturias. While the A2 registered its highest ΔT also in the Parc Torre Lluch and the lowest in the Parc dels Tellinaires (Table 1).
3.2 Cooling effect by the 10m-width annuli

The quantification by 10m-width concentric annuli registered positive cooling effect in the six parks assessed in this stage. Parks resulted in average 91.67m Lmax and 1.22°C ΔT. The maximum Lmax correspond to the Parc Torrent Ballester and the minimum to the Parc de la Plaça d’Asturias (Figure 7).

Comparison of the fitted LST datasets of the parks, show the decreasing trend of the cooling effect of the parks from Viladecans to Castelldefels (Figure 7). Nevertheless, important differences are appreciable in the LST of the urban surroundings (Figure 6). Which are those that define the cooling potential of the parks. Particularly, the Parc dels Tellinaires and the Parc de la Plaça d’Asturias, with greener surroundings than the park, register the lower LST values which results in the lowest cooling Lmax and ΔT.

3.3 Cooling effect through transversal sections

The entire Rambla de Gavà registered an absolute mean LST of 37.10°C, the highest of the parks. Likewise, the divided Rambla by different urban contexts (Figures 8) registered a 2.21°C reduction in the industrial context, 1.05°C in the urban fabric and 1.76°C in the Parc Torre Lluch area.

The higher ΔT values in the A₂ annulus, imply an extended increase of the temperature beyond the 100m, where the Lmax point is reached (Figure 6). However, the Parc dels Tellinaires and the Parc de la Plaça d’Asturias, register their maximum ΔT in the A₁ area. Which imply that the cooling effect of the parks do not extents farther than 100m.

Table 1: LST of concentric annuli and ΔT.

<table>
<thead>
<tr>
<th>Park</th>
<th>LST Park</th>
<th>LST A₁</th>
<th>LST A₂</th>
<th>ΔT</th>
<th>ΔT A₁-P</th>
<th>ΔT A₂-P</th>
<th>ΔT A₂-A₁</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRSC</td>
<td>36.03</td>
<td>37.12</td>
<td>37.55</td>
<td>1.09</td>
<td>1.52</td>
<td>0.43</td>
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</tr>
<tr>
<td>PTB</td>
<td>36.27</td>
<td>37.97</td>
<td>38.24</td>
<td>1.70</td>
<td>1.97</td>
<td>0.28</td>
<td></td>
</tr>
<tr>
<td>PTL</td>
<td>35.77</td>
<td>37.92</td>
<td>37.99</td>
<td>2.15</td>
<td>2.22</td>
<td>0.07</td>
<td></td>
</tr>
<tr>
<td>RG</td>
<td>37.10</td>
<td>38.36</td>
<td>39.07</td>
<td>1.26</td>
<td>1.96</td>
<td>0.71</td>
<td></td>
</tr>
<tr>
<td>PM</td>
<td>34.65</td>
<td>35.82</td>
<td>36.18</td>
<td>1.17</td>
<td>1.53</td>
<td>0.36</td>
<td></td>
</tr>
<tr>
<td>PT</td>
<td>34.90</td>
<td>35.61</td>
<td>35.52</td>
<td>0.71</td>
<td>0.62</td>
<td>-0.08</td>
<td></td>
</tr>
<tr>
<td>PPA</td>
<td>34.39</td>
<td>35.05</td>
<td>35.04</td>
<td>0.66</td>
<td>0.65</td>
<td>-0.02</td>
<td></td>
</tr>
</tbody>
</table>

The entire Rambla de Gavà registered an absolute mean LST of 37.10°C, the highest of the parks. Likewise, the divided Rambla by different urban contexts (Figures 8) registered a 2.21°C reduction in the industrial context, 1.05°C in the urban fabric and 1.76°C in the Parc Torre Lluch area.
The Rambla registered differences of ΔT in relation to the orientations of the surroundings (Figure 10). In the industrial area, it registered 3.91°C ΔT to north and 0.51°C to south. In the Parc Torre Lluch area, a 1.48°C ΔT was registered to north and 2.03°C to south. Meanwhile, the urban fabric area registered a smaller variation with 1.16°C to north and 1.09°C to south.

The Lmax calculation for each transversal section, matched with the average LST reduction by type of urban context. The section 1 (Figure 11) registered a higher ΔT in the north sections with industrial units than in the south section with continuous urban fabric. Nevertheless, the extent resulted very close between both orientations. Meanwhile in the section 26 (Figure 12) corresponding to the urban fabric, values between northeast with discontinuous urban fabric and southwest with continuous urban fabric resulted very close. However, in this case, the Lmax registered a higher value in the discontinuous urban fabric.

Likewise, the section 59 (Figure 13), regarding to the Parc Torre Lluch area, registered the effect of the Rambla and the park together. Here, in the southwest, the intensity and extent registered higher values than the northeast with discontinuous urban fabric.

Last, the quantification of cooling effect of all the sections in both orientations results in a detailed spatial delimitation of the Lmax throughout all the Rambla (Figure 14). Average Lmax reached 109.00m to the northeast and 129.67m average to the southwest.

4 Conclusions
The three methods applied resulted in similar cooling potential of the parks. This multi-stage analysis, points that spatial analytical methods for measure the variations of temperature in the cities, are suitable to recognize the influence of the physical composition of the built environment.

The three methods are suitable for larger scales replication. However, the delimitation of the spaces through two concentric annuli allows a more generalized vision of the thermal environment, for which it results suitable for analyse a study area with a larger amount of data. Likewise, results on the first stage represent a general frame of the results of the other stages. In the other hand, the cooling extent calculation through transversal section is considered the more suitable to quantify influence of the built environment composition. As shown in the results, this method results in a detailed picture of the cooling
effect. However, processing the transversal sections demands several steps of spatial classification to analyse the data, and it is limited to particular cases.

The urban surroundings of the parks, registered more influence on the cooling effect than the LST of the parks. Particularly in this study area, the cooling effect resulted more related to the different variations of the temperature of the surrounding areas. Further research still necessary on this issue.

Higher temperatures in the urban context registered higher cooling effect. Nevertheless, higher LST in the closest urban spaces, cause a reduced cooling effect. This affirmation is related to the contention of the cooling, caused by the dense built spaces near to the park. In these cases, the parks cannot compensate the heat in their surroundings and their cooling effect is stopped.

Last, conclusions on the particular influence of the land cover classification are related to the observation that higher temperatures derive in higher cooling effect. Where the higher temperatures in the industrial units, resulted in the higher cooling intensity. As well as those in the discontinuous urban fabric with lower temperature. However, in the case of the Rambla, the continuous urban fabric caused a lower cooling effect than the discontinuous one, which is related to the detail of the analysis that reflects singularities of particular spaces.

Acknowledgements

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