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The Microclimatic Effect of Green Infrastructure (GI) in a Mediterranean City: The Case of the Urban Park of Ciutadella (Barcelona, Spain)

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Abstract. The use and promotion of green infrastructure (GI) is of great importance for improving urban climates and for helping cities to be more resilient and sustainable in the context of climate change. For this reason, the effect of urban parks on city climates is of great interest for research. In this study, temperature measurements were made during 14 nights in the winter and spring of 2015 in the largest park of the Mediterranean city of Barcelona, Spain: the Ciutadella Park. The analysis of the measurements made inside the park and in its adjacent urban environment has confirmed the existence of an urban cool island (UCI) with a maximum cooling intensity of 5.2°C (9.4°F) in winter, under anticyclonic situations preferably, and an average cooling intensity of 2.7°C (4.9°F). In the spring months, the urban cool island has an intensity under the average, with a maximum of 2.1°C (3.8°F).

Key Words. Urban Climate; Urban Cool Island; Weather Type.

INTRODUCTION

Promoting the use of green infrastructure (GI), such as gardens, parks, green surfaces, walls, and covers, is considered one of the best actions for improving the urban climate. GI serves mainly for decreasing the intensity of the urban heat islands (UHI), reducing the storage of heat in the buildings during the day, and improving the air quality (Alexandri and Jones 2008; Cameron et al. 2012; Zinzi and Agnoli 2012; Berardi et al. 2014; Manso and Castro-Gomes 2015; Brudermann and Sangkakool 2017). In the case of dense cities, such as Barcelona, Spain, GI can produce a clear beneficial effect in the above mentioned aspect and in public health (Baró et al. 2014; Amoly et al. 2014). It is well known that GI is an important tool for promoting ecosystem and human health in urban areas (Tzoulas et al. 2007). Several studies even suggest that living in urban areas with large green surfaces reduces mortality (Chen et al. 2014; Gascón et al. 2016). GI elements such as green roofs, urban forests, and porous-moist materials have great potential as a strategy for adapting urban ecosystems to the effects of climate change (Saiz et al. 2016). Both GI and all nature-based solutions are important for promoting climate resilience in urban areas (Raymond et al. 2017).

Urban parks and green spaces have the potential to provide thermally comfortable environments and help reduce vulnerability to heat stress (Brown et al. 2015). The effect of parks on nocturnal temperatures has been studied in several cities (Cheng and Wong 2006; Potcher et al. 2006; Chang et al. 2007; Zhang et al. 2013; Chang and Li 2014). The parks and green surfaces produce cool temperatures that mitigate heat islands (Georgi and Zafiriadis 2006; Bowler et al. 2010; Cao et al. 2010; Vidrih and Medved 2013; Armaghan et al. 2017). One of the greatest effects is the reduction of solar radiation input due to the trees. But the most fundamental process is evapotranspiration, which consumes solar energy and increases the transfer of latent heat to the atmosphere (Shishegar 2014). In Barcelona, only some projects have proved

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this cooling effect. The Barcelona Green Infrastructure and Biodiversity Plan 2020 (Parés et al. 2013) sets out a long-term plan of action in order to achieve green infrastructure, its connectivity, and the conservation of biodiversity. So it is very interesting from a scientific point of view, as well as for the improvement of urban climates, to further investigate the thermal effects of parks and the trees they contain (taking into account the effects of density, size, and species).

The municipality of Barcelona in the northeast of Spain is 102.2 km^2 and has a population of 1,604,555 inhabitants (2015), so its population density is very high at 15.706 inhabitants/km^2, and the urban green surface per capita is very low at 7.0 m^2 (Hernández 2017). In the urban continuum, except the peripheral zone, there are few parks. Only Ciutadella Park has a notable surface area of 31.1 ha. The high urban density of Barcelona produces some environmental problems: air pollution, dense traffic, noise, etc., as well as high temperatures at night in the central neighborhoods due to a frequently intense urban heat island. The UHI effect has been investigated in numerous Mediterranean cities (Moreno-García and Serra-Pardo 2016). An early study on the UHI intensity in Barcelona (Moreno-García 1994) showed that the average difference between urban and rural temperature was +1.4°C (2.52°F)(+2.9°C [5.22°F]) referring to the average daily minimum, while the maximum UHI intensity exceeded 8°C (14.4°F). The average UHI intensity was slightly greater during winter months. After the important urban transformation of the city due to the 1992 Olympic Games, a new study about the possible differences in the UHI of the pre- and the post-Olympic city was made (Martín-Vide et al. 2003). The analysis of the new measurements and results did not seem to lead to a significant variation in the intensity of its UHI, partly because of the population stability in the metropolitan area and the decrease in the population of the city itself. The new buildings constructed have tended to produce a more uniform behavior in the surface thermal field. A recent study of the UHI of Barcelona's metropolitan area based on temperature differences between urban and non-urban meteorological stations, urban transects, and the sky view factor has confirmed the high intensity of its UHI, with the core in the central neighborhood, depending on the weather types (Martín-Vide et al. 2015).

Another study has focused on the intensity of the UHI in Barcelona and its impact on the cooling demand of residential buildings (Salvati et al. 2017). The experimental analysis in this work is based on temperature data from rural and urban weather stations and field measurements at street level. The maximum average UHI intensity was found to be 2.8°C (5.04°F) in winter and 1.7°C (3.06°F) in summer, reaching 4.3°C (7.74°F) at street level.

The objective of this article is to improve the knowledge of the cool effect at night of the biggest park in the city of Barcelona. For this purpose, a pilot study recording temperatures inside and outside the park was carried out from December of 2014 to March of 2015. The recording period coincides approximately with the period of the year with a greater intensity of the heat island in Barcelona. The comparison of the values recorded inside and outside will give us a picture of the magnitude of the park's cooling effect. This effect depends mainly on the weather type, which has been studied for the nights analyzed.

METHODS

Study Area: the Ciutadella Park

Barcelona is located in the eastern Mediterranean coast of Spain and has a Mediterranean climate (Csa, Köppen type). The annual mean precipitation is 600 mm and the rainiest season is autumn. The mean temperature in July and August is 25°C (77°F) and 10°C (50°F) in January.

The Ciutadella historic park is located in the eastern part of Barcelona, close to the sea, between the new quarter of Vila Olímpica, built for the Olympic Games of 1992, the Ensanche, a central district of new construction from 19th century, and the downtown area (Figure 1). Its location corresponds to the place where Felipe V ordered the building of a great military citadel in the year 1715. In 1869, the general Prim ceded this space for the city with the condition that it was used as a public park. The slogan of the winning project to convert it into a public park was: *"The gardens are to the city what the lungs to the human body."* A zoo occupies half of the ground. The park includes differentiated areas such as a large central square with a monumental fountain (The Waterfall), a "great lake," a tree-lined walkway, and several ornamental gardens, among others. Some of the old military buildings and pavilions today house different public services.

The park has a considerable variety of trees and plant species. Among the most abundant tree species

Figure 1. Aerial image of the city of Barcelona with the location of Ciutadella Park (Source: Google Maps. Imágenes ©2018 Google, Data SIO, NOAA, U.S. Navy, NGA, GEBCO, TerraMetrics).

Figure 2. Surface types of Ciutadella Park and transect with measurements points (Source: Cartographic base ©Institut Cartogràfic i Geològic de Catalunya).

are the limes (*Tilia* × *hispánica, Tilia tomentosa,* and *Tilia* × *euchlora*), magnolias (*Magnolia grandiflora*), white poplars (*Populus alba* and *Populus alba* "Pyramidalis") and London planes (*Platanus* × *hispánica*). Around the lake are bald cypress (*Taxodium distichum*) and maidenhair trees (*Ginkgo biloba*). The pond named as the "great lake" has a surface area of 6,600 m^2, being the largest water sheet in the park, followed by that of the waterfall with approximately 2,000 m^2.

The park's plan is quasi-rectangular. In the area of the park where measurements have been made, it is possible to distinguish the following surface types, excluding the zoo: paved surface made of asphalt (4.3%), buildings (12.0%), dense tree cover over natural ground with grass (39.2%), disperse tree cover over natural ground with grass (24.5%), and water sheets (5.9%) (Figure 2). As can be seen in Figure 2, some wide paths cross the park (14.2%). These are light-colored, dirt paths.

Measurements

The field work is summarized in Table 1.

As it is well known, the technique of thermal transects consists of crossing the study area (the park) from a point of the periphery (the built space that surrounds the park) to an opposite one, recording temperatures. In previously selected points, air temperature (and sometimes air humidity) is recorded.

The transect can be seen in Figure 2. It begins outside the park to the north. After entering into the park it describes a zigzag path and leaves out of the park by the southeast. The observation points inside the park have been distributed covering the different types of surfaces. Some points have been added outside the park to evaluate the urban cool island.

The instrument, a digital thermo-hygrometer, has an environmental sensor. The measurements have to be taken with the sensor in motion or with the observer running, to guarantee an air flow through the sensor. The timetable of the measurements was in the previous hour of the closure of the park, at 20:00 (UTC), approximately 2 hours after sunset.

The comparison of extreme values recorded can be considered the intensity of the cooling

Table 1. Basics of the field work.

Measurements period: 14 nights (from December 2014 to March 2015)
Observation points: 33 points in total (28 inside the park and 5 outside)
Methodology: technique of thermic transects
Instrumentation: digital thermo-hygrometer with environmental sensor, model Hanna, HI9565

park effect. Finally, the weather maps of the 14 dates were analyzed synoptically. Each date was classified in one weather type.

RESULTS AND DISCUSSION

The maximum and minimum temperatures recorded along the transect during the 14 nights are summarized in Table 2. The maximum values of every night were measured outside the park and the minimum inside it, in its central-south sector. As usual for a Mediterranean city in front of the sea, winters are mild, and the values recorded are a good sample of this climatic characteristic. All the values are above the freezing point, between 6.8°C (44.2°F) and 15.1°C (59.2°F).

The differences between the recorded maximum and minimum temperatures give us the intensity of the cooling effect. It goes from 0.9°C (1.62°F) (23 March 2015) to 5.2°C (9.36°F) (21 December 2014). These values are explicit about the cooling effect of the Ciutadella Park, but it is interesting to highlight that in 5 out of 14 nights, the difference between the park and the peripheral built area is higher than 3.0°C (5.4°F), and in 3 out of 14 nights higher than 4.5°C (8.1°F). The differences recorded are quite similar to the intensity of the Barcelona urban heat island measured as a difference between the center of the city and its airport, 14 kilometers (8.7 miles) away (Moreno 1994; Martín-Vide et al. 2015). So we can say that the Ciutadella Park cooling effect almost balances the urban heat island in the park and its vicinity.

Table 2. Values of the maximum and minimum temperatures recorded and the intensity of UCI (Urban Cool Island) in the park and the surroundings.

Date	Tmax (°C)	Tmin(°C)	Intensity UCI (°C)
12/21/14	14.0	8.8	5.2
01/23/15	13.5	10.0	3.5
02/03/15	9.5	7.5	2.0
02/04/15	8.0	6.8	1.2
02/11/15	13.6	9.0	4.6
02/13/15	14.6	12.1	2.5
02/18/15	13.8	10.6	3.2
02/20/15	12.6	10.8	1.8
02/22/15	13.7	8.8	4.9
03/08/15	13.6	12.0	1.6
03/10/15	15.1	13.1	2.0
03/16/15	11.7	9.6	2.1
03/21/15	15.1	13.0	2.1
03/23/15	14.5	13.6	0.9

A specific classification of the intensity of the UCI produced by the Ciutadella Park can be distinguished in four categories: low, moderate, remarkable, and high, with the thresholds of Table 3.

Table 3. Number of nights with different levels of intensity of the cooling effect of Ciutadella Park in Barcelona.

Intensity UCI	Number of nights
Low ≤ 1.5°C	2
Moderate 1.6°C to 3.0°C	7
Remarkable 3.1°C to 4.5°C	2
High ≥ 4.5°C	3

50% of the studied nights had a moderate UCI due to the park (differences between the maximum temperature outside of the park and the minimum temperature were between 1.6 and 3.0°C [2.9 and 5.4°F]), and more than one third (35.7%) had a remarkable or a high UCI (differences higher than 3.0°C [5.4°F]). The remaining 14.3% of the nights had a low intensity UCI (differences lower than 1.6°C [2.9°F]).

Regarding the relationship between the weather type and the UCI, the results from the classification of the weather types of the 14 dates analyzed show in general terms that the anticyclonic situations present high differences between the interior of the park and the exterior, while situations of atmospheric instability, such as depressions and troughs, give rise to small differences. These results are consistent with the fact that the anticyclonic weather types enhance the urban heat island. When the wind is light or calm, and the sky is clear or with sparse clouds, the longwave radiation emission is very effective in open, non-built areas, such as rural areas or even large parks. The low pressure systems or the trough produce instable weather, wind, and sometimes rain with overcast skies, so the air is mixed, and a there is a limited cooling of

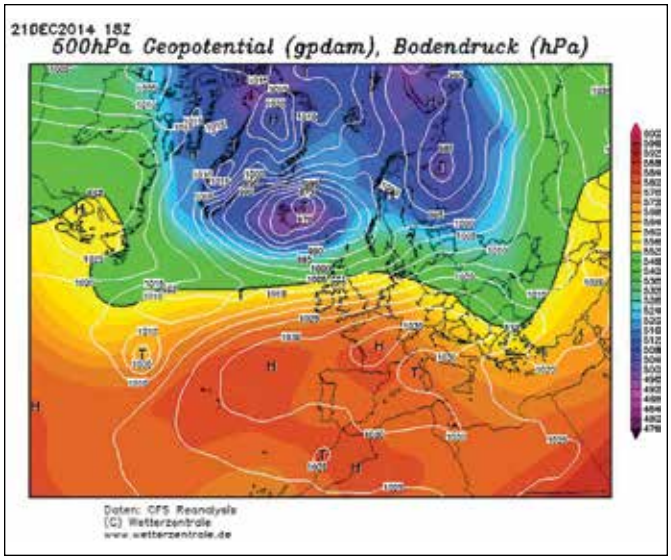

Figure 3. Surface pressure map and 500 hPa geopotential of 21 December 2014 (Source: ©www.wetterzentrale.de).

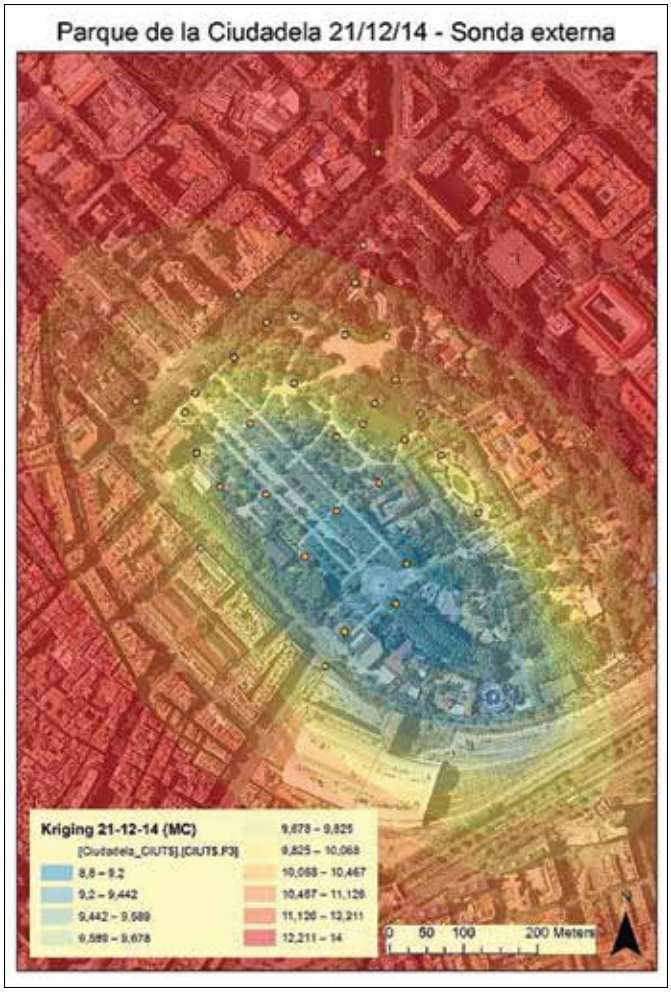

Figure 4. Isotherms map of Ciutadella Park on 21 December 2014 early in the night (Source: Cartographic base©Institut Cartogràfic i Geològic de Catalunya).

the non-built areas. The wind mixes the cool air of the park and the warm air outside of the park, so the temperature difference between them is almost null. Moreover, the overcast skies limit the cooling effect of the non-built areas.

As examples of the first group of nights (anticyclonic), the isotherm maps of the Ciutadella Park and its surroundings, together with surface pressure and 500 hPa maps, for 21 December 2014 and 11 February 2015 are presented in Figures 3 to 6. In the first case, a remarkable anticyclone dominated the Iberian Peninsula, France, North Africa, and the Atlantic and Mediterranean neighbors (Figure 3). In the second, the conditions from the south of Scandinavian to the Iberian Peninsula were anticyclonic (Figure 5). The intensity of the cooling effect of the park was 5.2°C (9.4°F) and 4.6°C (8.3°F), respectively, a high UCI in both cases. The isotherm maps (Figures 4 and 6) are very similar, with the lowest temperatures in the central-southwestern part of the park, coincident with the promenade named Los Tilos.

On the other hand, as examples of the second group of nights (instable weather), a clear low pressure had its center not far from Barcelona on 4 February 2015 (Figure 7), and on 20 February 2015 a trough with meridian axis was crossing the Iberian Peninsula (Figure 9). The isotherm maps of these cases show a low UCI, with 1.2°C (2.2°F) and 1.8°C (3.2°F), respectively (Figures 8 and 10). The lowest temperatures are located in different areas in the Forestier gardens at the front of the Catalan Parliament building and near the great lake. The maximum temperatures, instead, are located always in the streets of the exit north of the park, at the junction between Meridiana Ave. and Pujades St., which experience dense vehicle traffic.

CONCLUSION

The analysis of the differences between the temperatures inside of the largest park of Barcelona and its adjacent urban environment during 14 dates in the winter and spring of 2015 has confirmed the existence of a clear urban cool island. The maximum difference, or UCI intensity, was 5.2°C (9.4°F) in a night of December under anticyclonic weather conditions. The mean intensity was 2.7°C (4.9°F). In the spring months, the UCI is less intense. The intense UCI has its core usually located along the Los Tilos promenade, whereas the weak UCI has its core in the

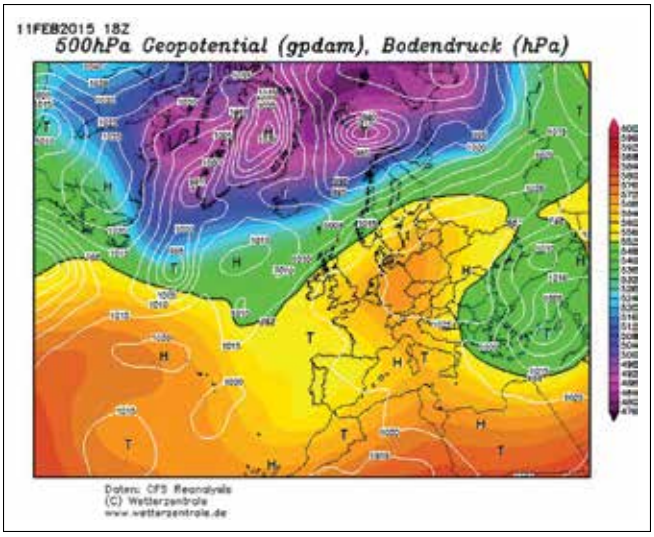

Figure 5. Surface pressure map and 500 hPa geopotential of 11 February 2015 (Source: ©www.wetterzentrale.de).

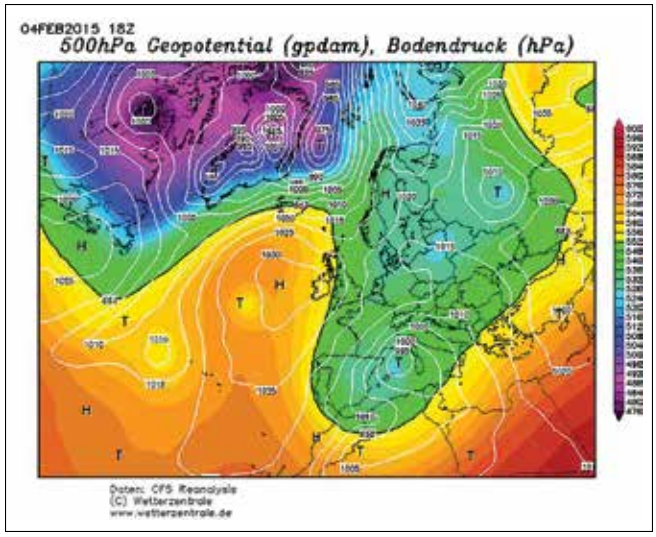

Figure 7. Surface pressure map and 500 hPa geopotential of 4 February 2015 (Source: ©www.wetterzentrale.de).

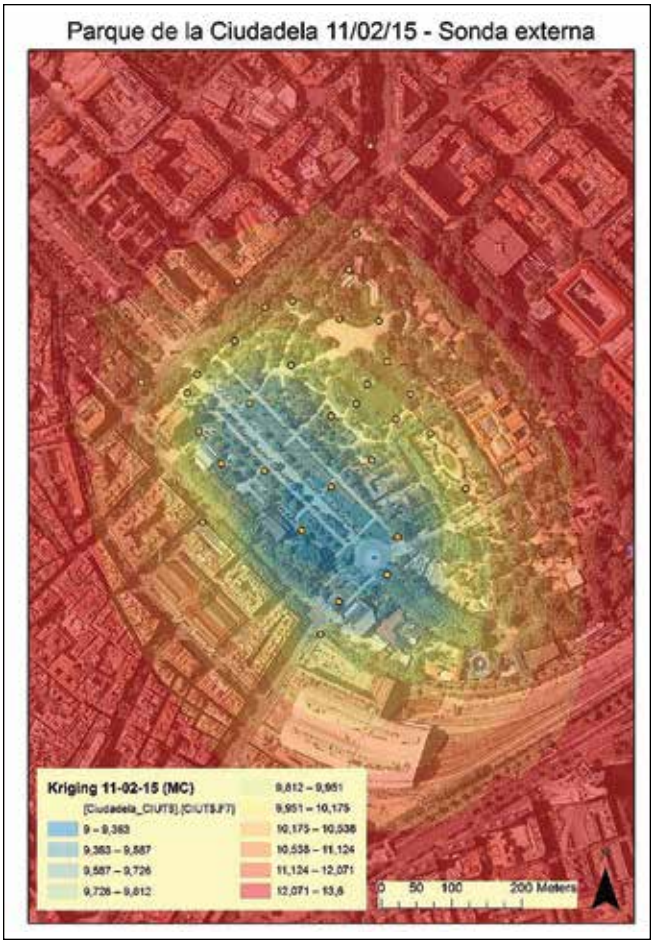

Figure 6. Isotherms map of Ciutadella Park on 11 February 2015 early in the night (Source: Cartographic base©Institut Cartogràfic i Geològic de Catalunya).

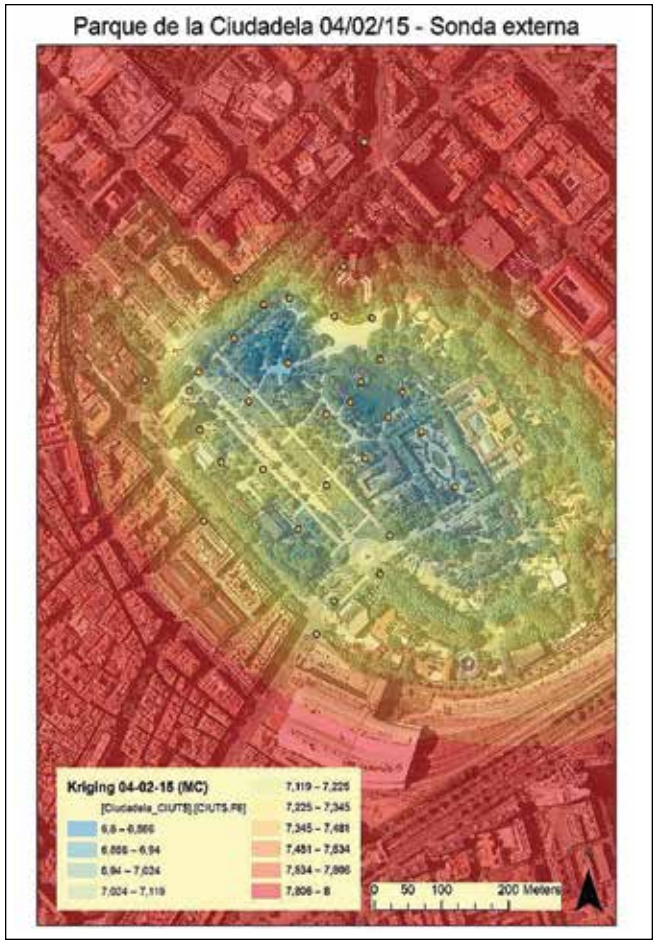

Figure 8. Isotherms map of Ciutadella Park on 4 February 2015 early in the night (Source: Cartographic base©Institut Cartogràfic i Geològic de Catalunya).

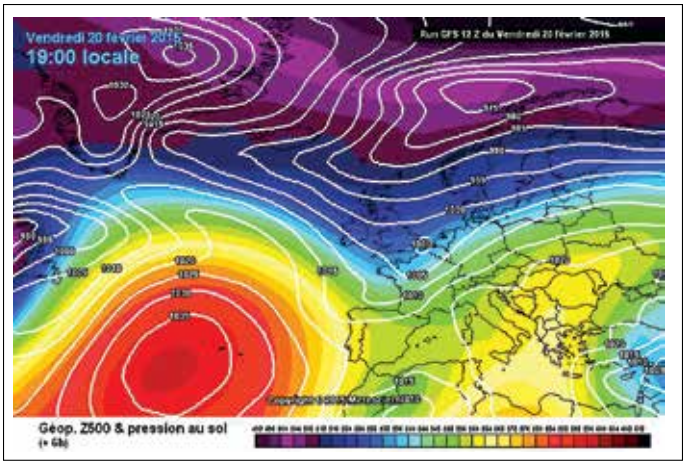

Figure 9. Surface pressure map and 500 hPa geopotential of 20 February 2015 (Source: Copyright©2015Meteociel.fr).

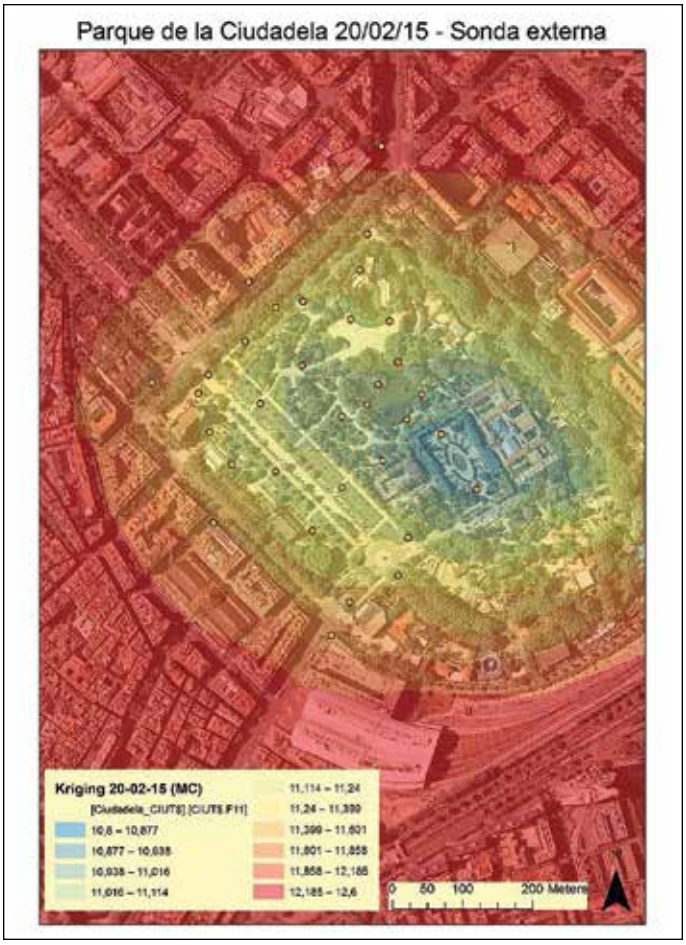

Figure 10. Isotherms map of Ciutadella Park on 20 February 2015 early in the night (Source: Cartographic base©Institut Cartogràfic i Geològic de Catalunya).

ornamental zone near the building of the Parliament. Although GI gives a low temperature, the lowest temperatures inside the park in every case are recorded over relatively open surfaces with not much vegetation, such as the Los Tilos promenade, which has a dirt surface as well the marked open space of the walk between two rows of deciduous trees.

The results obtained on the Ciutadella Park reveal that its UCI clears the UHI. GI is crucial for the control of the UHI of Barcelona and the improvement of its urban climate. Climate change is increasing the occurrence of heat waves. During these events, the urban heat island becomes a true meteorological risk for health, producing an increase of morbidity and mortality in aged people or people with chronical diseases (Martín-Vide 2016; Xu et al. 2016). The additional heating produced by the heat island aggravates the effects of the heat wave itself. In the downtown area of Barcelona, the annual mean number of tropical nights is higher than 90, and there are already about five torrid nights per year with a minimum temperature higher than 25°C (77°F). The use of GI such as green roofs/walls, small gardens, etc., can minimize the adverse effects of the heat excess at night and decrease air pollution.

Summing up, the use and promotion of other GI elements to help improve Barcelona's resilience and sustainability in the context of climate change is of great interest.

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Résumé. L'usage et la promotion des infrastructures vertes (IV) est d'une grande importance pour l'amélioration du climat urbain afin d'aider les villes à être plus résilientes et durables dans un contexte de changement climatique. Pour cette raison, l'incidence des parcs urbains sur le climat des villes est un sujet de recherche d'un grand intérêt. Pour cette étude, des mesures de la température furent effectuées durant quatorze nuits à l'hiver et au printemps 2015 dans un grand parc de la ville méditerranéenne de Barcelone, Espagne: le parc Ciutadella. L'analyse des données recueillies à l'intérieur du parc et dans son environnement urbain adjacent a confirmé l'existence d'un ilot de fraîcheur urbain (IFU) avec une intensité de rafraîchissement maximale de 5.2°C (9.4°F) en hiver sous des conditions anticycloniques de préférence et une intensité de rafraîchissement moyenne de 2.7°C (4.9°F). Durant les mois printaniers, l'ilot de fraîcheur urbain a montré une intensité inférieure à la moyenne avec un maximum de 2.1°C (3.8°F).

Zusammenfassung. Der Gebrauch und die Verbreitung von Grüner Infrastruktur (GI) ist von großer Bedeutung für die Verbesserung von urbanen Klimata und hilft den Städten im Kontext von Klimaveränderungen resilierend und nachhaltig zu sein. Aus diesem Grund sind die Auswirkungen von urbanen Parkanlagen auf das Stadtklima von großem Interesse für die Forschung. In dieser Studie wurden in einem großen Park in Barcelona, Spanien: dem Ciutadella Park in 14 Nächten im Winter und Frühling 2015 Temperaturmessungen vorgenommen. Die Analyse der Messungen innerhalb des Parks und seines angrenzenden urbanen Umfelds hat die Existenz einer urbanen kühlen Insel (UCI) mit einer maximalen Kühlungsintensität von 5.2°C (9.4°F) im Winter, vorzugsweise unter antizylonischen Situationen und einer durchschnittlichen Kühlungsintensität von 2.7°C (4.9°F) bestätigt. In den Frühlingsmonaten hatten die urbanen kühlen Inseln eine Intensität unter dem Durchschnitt, mit einem Maximum von 2.1°C (3.8°F).

Resumen. El uso y la promoción de la infraestructura verde (IG, por sus siglas en inglés) es de gran importancia para mejorar los climas urbanos y para ayudar a las ciudades a ser más resistentes y sostenibles en el contexto del cambio climático. Por esta razón, el efecto de los parques urbanos en los climas de la ciudad es de gran interés para la investigación. En este estudio, se realizaron mediciones de temperatura durante 14 noches en el invierno y la primavera de 2015 en un gran parque de la ciudad mediterránea de Barcelona, España: el Parque de la Ciutadella. El análisis de las mediciones realizadas dentro del parque y en su entorno urbano adyacente ha confirmado la existencia de una isla de enfriamiento urbano (UCI, por sus siglas en inglés) con una intensidad de enfriamiento máxima de 5.2°C (9.4°F) en invierno, preferiblemente en situaciones anticiclónicas, y una intensidad de enfriamiento promedio de 2.7°C (4.9°F). En los meses de primavera, la isla fría urbana tiene una intensidad inferior a la media, con un máximo de 2.1°C (3.8°F).