ANNUAL SPATIO-TEMPORAL VARIABILITY OF TOULOUSE URBAN HEAT ISLAND

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Abstract

During the CAPITOUL field campaign, the temperature was measured at 27 sites over Toulouse sampling different Urban Climate Zones (UCZ). The comparison of the sites for the different seasons revealed some variation of the behaviour between UCZs. Then, the differences of temperature have been analyzed in relation with the incoming solar radiation and the anthropogenic heat releases. Even with cloudy nighttime conditions, some strong urban heat island events are observed associated with large anthropogenic heat releases.

Key words: Urban Heat Island, Urban Climate Zone, Anthropogenic heat releases

1. INTRODUCTION

Since Oke (1982) has described the physics of the Urban Heat Island (UHI) formation, a large consensus has been established on the key function of the heat storage in the building material in the development of the UHI. However, most of the studies have generally focused on the UHI, in temperate climate cities, during the summertime when the anthropogenic heat flux is at its lowest values. This paper focuses on the UHI of Toulouse where the CAPITOUL field project (Masson et al., 2008) has been conducted during one year. In this study, the measurements of a network of 27 stations are analyzed, first, to describe the temperature behavior of some Urban Climate Zones proposed by Oke (2006) and, second, to evaluate the relation between the UHI development and the anthropogenic heat releases.

2. METHODS

2.1. Measurements

Toulouse is located in the south-west of France and has a circular pattern of a 20 km diameter. The population is 871 000 inhabitants. The prevailing winds in Toulouse are from west to north-west and from south-east. During the CAPITOUL field campaign, a network of 27 temperature stations has been deployed over the agglomeration (Figure 1) during a one year period from February 2004 to February 2005. The chosen sites covered a wide range of urban climate zones (UCZ) described in Oke (2006). In the center of the city, the sites MIC and MNP fit in UCZ 2, then UCZ 3 is sampled by sites like BON or MIN, UCZ 4 by sites like THI or LAB, UCZ 5 by sites like UNI or VIL, UCZ 6 by sites like BL2 or FRA and UCZ 7 by MON. Twenty-one sites (UCZ 2, 3, 4 and 5) were instrumented at 6 m above the ground on electrical pylons like in Pigeon et al. (2006). For sites in UCZ 2 or 3, it was considered from results of Nakamura and Oke (1988) that the measurements of temperature at 6 m were representative of the temperature at 2 m from the ground. Then, for UCZs 4 and 5, two sites were instrumented at 2 levels, one at 2 m and the other at 6 m. A Student statistical test on the temperature difference between the two levels was applied and the conclusion was that neither during the day nor during the night, the difference was significant. Consequently, the measurements at 6 m in these UCZs were considered to be representative of the temperature at 2 m. In sites classified as UCZ 6 and 7, the measurements were made at 2 m. In this paper, a focus is set on three sites BON, BL2 and MON which are compared to the site MIC. Site MIC is located in the old core of Toulouse and classifies as UCZ 2 where a high built-up ratio is observed, the buildings are typically 3-5 storey and the aspect ratio is about 2. Site BON corresponds to UCZ 3 with a medium density and typical buildings of 1-2 storey. The site BL2 is the typical station taken as a reference in many UHI studies since it is an airport site. Finally, site MON, is located in a agricultural area about 10 km from the center of Toulouse and fits in UCZ 7. During the field campaign, the MNP site was also equipped with a complete surface energy balance measurements system (Masson et al., 2008) where the incoming radiation (solar and infrared) was measured. The anthropogenic heat flux (Q_F) has also been inventoried for the whole agglomeration (Pigeon et al., 2007).

2.2. Post Processing of measurements

In this study the choice has been made to evaluate the UHI with the differences of daily extremes between the stations rather than on the synchronous temperature difference since it is more representative of the climate felt at one site. Consequently, for each stations, the daily maximum occurring during daytime (T_x) and the daily minimum occurring during the night or early morning (T_N) temperatures have been extracted. Then, the difference with the reference station MIC has been computed. For an analysis of the relation between the differences in minimum temperature (Δ T_N) and the incoming solar radiation or Q_F, only the events with wind speed lower than 3 m s⁻¹ and no rain during the day and the night have been selected. Then, for the nighttime, cloudy and clear events have been separated by comparing the measured infrared incoming radiation at the MNP site with $0.7 \times \sigma \times T_a^4$ where σ is the Stefan-Boltzmann constant, T_a is the air temperature measured at the top of the tower. The factor 0.7 is a good approximation for the emissivity of a clear sky. If the sky is cloudy, its emissivity will be closer to 1 (depending on the cloud type) and the infrared incoming radiation higher than $0.7 \times \sigma \times T_a^4$. A threshold of 40 W m⁻² has been taken to separate the clear and cloudy events.

3. RESULTS



Figure 1: Map of the measurement stations network

3.1. Comparison between the sites

The differences in $T_x (\Delta T_x)$ and $T_N (\Delta T_N)$ between the 3 sites and MIC have been plotted for summer (months of June, July and August) and winter (months of December, January and February) season on Figure 2. For each case, a density histogram is presented with a step of temperature difference of 0.25 K. At first sight for BON, there is not a significant difference between the distribution of ΔT_x and ΔT_N , both generally range between -1 and 1 K. A closer look enables to see that during summer, the difference during daytime (ΔT_x) tends to be negative (BON warmer than MIC) whereas it is the opposite during the night (ΔT_N). In winter, there is a wider distribution of nighttime difference than the daytime difference. For BL2, it can be observed for both seasons, that there are higher frequencies of the highest temperature differences during nighttime (ΔT_N) than during daytime. During nighttime, the highest event are between 2 and 3 K depending on the season whereas there is almost none event higher than 2K during daytime and the frequencies of events between 1.5 and 2 K are quite low. The same behavior concerning the daytime and nighttime differences is observed for the site MON. For both seasons and both T_x and T_N , MON presents higher differences with MIC than BL2 which records higher differences than BON. This result is quite consistent with the urbanization around the sites. The highest differences for MON are about 2 K for T_x and up to 5 K for the T_N .

3.2. Relation with incoming radiation and anthropogenic heat flux

The relation of ΔT_N with the measured incoming radiation and anthropogenic heat flux are presented in Figure 3 for the three sites BON, BL2 and MON. For the summer period (first line of graphics), only the relation between ΔT_N and the incoming solar radiation is presented since Q_F is rather low and constant in Toulouse during this period (Pigeon et al., 2007). It can be seen that for BL2 and MON, the higher the solar incoming radiation, the higher the difference of the minimum temperature. This relation is more pronounced for clear conditions for which ΔT_N is generally higher. During the winter period, the relations between ΔT_N and the incoming solar radiation (second line of graphics of Figure 3) and ΔT_N and Q_F (third line of graphics of Figure 3) are studied. Again, for BL2 and MON, the higher the incoming solar radiation, the higher the difference of the minimum temperature. The same dependency is observed between ΔT_N and Q_F for both sites and it is more pronounced for MON. Looking more carefully at the nighttime cloudy conditions (black points), 3 events of ΔT_N higher than 2 K are observed for BL2 and 4 for MON. For those events, there is a wide range of incoming solar radiation during the day but on the other hand, Q_F values are among the highest. Another interesting point can be noticed when looking closer at the relation between ΔT_N and the solar incoming radiation for BL2. For incoming radiation lower than 100 W m², there is a very good linear relationship between the 2 parameters which is not followed for the 4 highest values of incoming solar radiation. Indeed, these 4 events correspond to wind coming from south-east to south for which BL2 site is downwind of the city. For MON site, the linear relationship between ΔT_N and the incoming solar radiation is observed for the whole range of conditions since this site, to the north-east of Toulouse, is never downwind of the city.

4. CONCLUSION

This study is based on the measurements collected during the CAPITOUL field program conducted in Toulouse over a year period between 2004 and 2005. The observations included temperature measurements inside the streets of the city and around the agglomeration but also surface energy balance measurements in a dense urban



Figure 2: Histograms of the temperature difference between the reference site MIC and the sites BON (column 2), BL2 (column 3) and MON (column 4). The differences are computed with the daytime maximum temperature for the summer season (line 2) and the winter season (line 3) and with the nighttime minimum temperature for the summer season (line 4) and the winter season (line 5).¹ T_x is the daytime maximum temperature; ² JJA stands the months of June, July and August; ³ DJF stands for the months of December, January and February, ⁴ T_N is the nighttime minimum temperature.

area. The Urban Heat Island has been assessed by comparing the maximum and minimum daily temperature between 3 sites corresponding respectively to Urban Climate Zone (UCZ) 3, 6 and 7 (Oke, 2006) with an UCZ 2 reference site. The UCZ 2 is generally warmer than the other sites, and the maximum difference can reach 5 K with the UCZ 7 site for minimum temperature. But, it was noticed for the maximum temperature that the UCZ 3 could be warmer during summertime when there is a large insolation. Whereas, there is no significant seasonal variation of the minimum temperatures difference, UCZ 6 and 7 sites are cooler than the UCZ 2 during summertime than during wintertime. Finally, during wintertime, the minimum temperatures difference linearly increases with the anthropogenic heat flux for UCZ 6 and UCZ 7 and events of significant temperature difference can be observed with cloudy conditions when the anthropogenic heat flux is high. These interesting cases of wintertime UHI associated with high values of anthropogenic heat flux could now be analyzed with numerical modeling. Sensitivity studies could be conducted to demonstrate the relative influence of anthropogenic heat flux and heat storage during wintertime.



Figure 3: Scatterplots of minimum temperature difference with the reference site MIC for sites BON (column 1), BL2 (column 2) and MON (column 3) and the daily incoming solar radiation during summer (line 2), the daily incoming solar radiation during winter (line 3) and the daily anthropogenic heat flux (line 4) during winter.

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