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WINTER URBAN HEAT ISLAND MAGNITUDES OF MAJOR AUSTRALIAN CITIES

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ABSTRACT: This study seeks to determine the relative magnitude of the Urban Heat Island (UHI) effect in five major Australian cities during the winter season. To achieve this, the study considers three weather stations in each city: one in a high density urban area, one in a medium density urban area and one in a nearby very low density urban/rural area. For each station, temperature data were collected every 30 minutes over a three day period. The data where then plotted and maximum, minimum, and average temperature differences (and the times of those differences) were recorded. The data show that all of the cities investigated showed a strong winter heat island effect with the magnitude ranging from about 3ºC up to 8ºC. The largest temperature differences typically occurred near dawn (about 6 am) and overnight. It was also observed that during the day, the high and moderate density urban areas could have temperatures either higher or lower than the rural areas, a condition consistent with other global observations of the UHI effect.

Keywords: *UHI; Climate Change; Weather Stations; Daily Temperature*

1. INTRODUCTION

Globally, cities and urban populations are growing rapidly. As cities expand and develop, they become increasingly warm relative to surrounding areas. This phenomenon is known as the "urban heat island" (UHI) effect [1]-[2]. This temperature difference can lead to significant complications in urban areas including an increase in the magnitude and frequency of heat waves, an increase in urban pollution and energy use, and heat related illnesses and fatalities. These problems are likely to be exacerbated by global warming, which is likely to see Earth warm by an additional 2ºC or more by the end of this century [3].

The causes of this temperature difference between urban areas and adjacent and/or surrounding non-urban areas are multifaceted. These include: a high percentage of low albedo and impermeable surfaces (such as roads, footpaths and buildings); a loss of vegetation (which would normally help to cool the area via shading and evapotranspiration); the geometry of the urban landscape which creates a canyon effect that traps heat and prevents it from escaping; and higher mean pollution levels (than surrounding areas) which can also promote warming and/or trap heat [4]-[7].

As previously mentioned, UHIs can cause numerous problems in cities. These include both social and environmental impacts. In terms of social impacts, perhaps the most significant is a rise in heat related illnesses. Indeed many illnesses have been shown to be related to heat ranging from the relatively benign (e.g., heat rash) to the potentially fatal (e.g., heat stroke). These heat related illnesses are most dangerous for the young and old and those with compromised immune systems. In addition, those without access to cooling are also particularly susceptible, which can make this an environmental justice issue [8]-[9]. The environmental impacts of UHIs can also be significant and include an increase in energy demand in cities (predominantly as a result of increased demand for cooling energy), an increase in pollution (associated with the rise in energy use), and heightened chemical weathering rates [10].

The magnitude of UHIs vary from place to place and according to a variety of climatic and other factors. Observed UHIs magnitudes from around the world range from 0.4°C to as high as 14°C [11]-[12]. These values are strongly influenced by the degree of urbanization, the amount of greenspace, seasonality, time of day and other factors (so that, for example, the highest observed UHI values may have only occurred for a brief period of time on a single day during a particular season). According to current research, the highest UHI magnitudes occur overnight and during summer when conditions are clear and winds are low [13]-[18]. A limitation of most of the studies on the UHI phenomenon is a focus on only one city at a time. In addition, most studies focus on collecting data in summer alone. This limits our ability to compare the relative strength of the UHI phenomenon during winter and between cities.

To address these problems, this study considers the magnitude of the UHI in five Australian cities over a three day period in the winter of 2015. Data are considered in terms of urban density, city size, and geographic position within Australia. The results of this study will help to clarify the magnitude of UHIs in winter and what might be driving observed patterns in UHI intensity.

2. SITE DESCRIPTION AND METHODS

This study was undertaken in Australia's five largest cities, namely Adelaide, Brisbane, Melbourne, Perth and Sydney (Fig. 1). These cities were chosen because of their large populations and high urban densities. As of June 2014, the population, from largest to smallest of these cities was: Sydney with 4.8 million (density = 9,295 per km^2); Melbourne with 4.4 million (density = 14,105 per km^2); Brisbane with 2.3 million (density = 7,188 per km^2); Perth with 2.0 million (density = 3,112 per km^2) and Adelaide with 1.3 million (density = 1,814 per km^2).

In terms of average climate, Adelaide and Perth are classified as having hot dry summer or Mediterranean climates (Koppen classification of Csa), Melbourne is classified as having a temperate oceanic climate (Koppen classification of Cfb), and Brisbane and Sydney are classified as having warm temperate/humid subtropical climates (Koppen classification of Cfa).

The average annual rainfall for Adelaide is 545 mm and the average maximum and minimum temperatures are 22.3 ºC and 12.2 ºC, respectively. The average annual rainfall for Perth is 850 mm and the average maximum and minimum temperatures are 24.6 ºC and 18.7 ºC, respectively. The average annual rainfall for Melbourne is 650 mm and the average maximum and minimum temperatures are 19.9 ºC and 10.2 ºC, respectively. The average annual rainfall for Brisbane is 900 mm and the average maximum and minimum temperatures are 26.5 ºC and 16.3 ºC, respectively. The average annual rainfall for Sydney is 1200 mm and the average maximum and minimum temperatures are 21.7 ºC and 13.8 ºC, respectively.

In each city, three Bureau of Meteorology weather stations were selected. These included one in a high density part of the city (population density greater than 2,000 persons per km^2), one in a medium density part of the city (population density approximately 500 persons per km^2), and one in a low density part of the city or its surroundings (population density less than 50 persons per km^2) (Table 1). Stations were also selected to minimize elevation differences between them (as elevation can have a strong control on temperature independent of urbanization influences). Consequently, stations from all cities had elevation differences of less than 40 m except Melbourne where the maximum elevation difference was 100 m (Table 1). From these stations, temperature data were collected every 30 minutes over a period of three days in early August 2015.

Fig. 1 The locations of the five largest Australian cities that were sampled in this study.

Table 1. Weather station characteristics for the 15 locations included in this study.

Stations	Density	Elevation (m)	Lat.	Long.
Adelaide				
Noarlunga	High	55.0	-35.16	138.51
Adelaide	Medium	48.0	-34.92	138.62
Edinburgh	Low	16.5	-34.71	138.62
Brisbane				
Brisbane	High	8.1	-27.48	153.04
Archerfield	Medium	12.5	-27.57	153.01
Amberley	Low	24.2	-27.63	152.71
Melbourne				
Melbourne Olympic Park	High	7.5	-37.83	144.98
Viewbank	Medium	66.1	-37.74	145.10
Melbourne Airport	Low	113.4	-37.67	144.83
Perth				
Perth	High	24.9	-31.92	115.87
Pearce	Medium	40.0	-31.67	116.02
Jandakot	Low	30.0	-32.1	115.88
Sydney				
Observatory Hill	High	39.0	-33.86	151.21
Bankstown	Medium	6.5	-33.92	150.99
Richmond	Low	19.0	-33.6	150.78

For each city, temperature data were plotted on a single graph to compare temporal differences between stations. Then temperatures were compared across stations by subtracting the temperature from each station from that of the other two stations in the same city. This allowed for computations of average, maximum and minimum temperature differences (and the time that the maximum and minimum temperature difference occurred) between stations. Note: for the purposes of this study, night was classed as the hours between 6:00 pm and 6:00 am.

3. RESULTS AND DISCUSSION

Temperature data for each city and summary differences between stations are presented in Figs. 2-6 and Table 2. For Adelaide (Fig. 2), the temperatures for all three stations are very similar during the day while at night some separation becomes apparent. Generally speaking, the low urban density weather station shows the coolest nighttime temperatures, although at times it has temperatures similar to the medium urban density station. According to Table 2 the highest daytime temperature differences occur between the high and low urban density sites and equate to 3.7ºC and 4.3ºC for daytime and nighttime temperatures, respectively. The maximum temperature difference was observed at 9:00 pm.

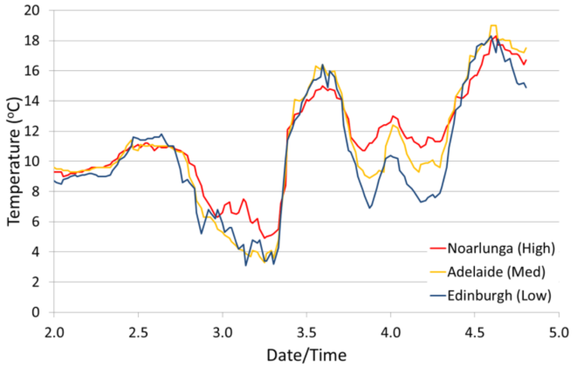

Fig. 2 Temperature comparison for three weather stations in Adelaide in the winter of 2015.

For Brisbane (Fig. 3) the separation between stations was much more pronounced. Here daytime temperatures remain similar but nighttime temperatures display a clear trend with the highest urban density site being the warmest and the low urban density site the coolest. The maximum daytime and nighttime temperature differences were both 9.1ºC which were recorded at 6:30 am and 4:30 am, respectively (Table 2).

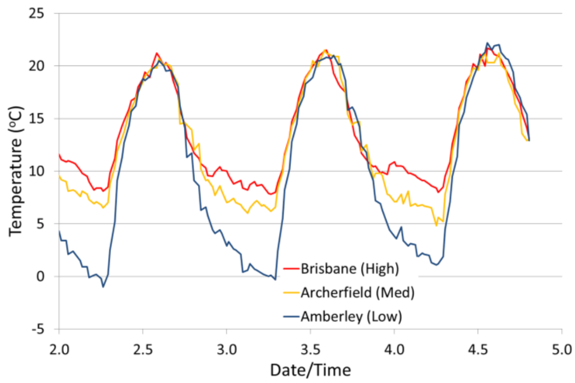

Fig. 3 Temperature comparison for three weather stations in Brisbane in the winter of 2015.

Melbourne temperature patterns are presented in Fig. 4. In Melbourne, the medium urban density and low urban density sites typically plot very close to one another and only clearly separate over one nighttime period (with the low density site showing cooler temperatures for this particular instance). Meanwhile, the high urban density site tends to plot higher that the other two sites, indicating it is warmer overnight but with similar daytime temperatures to the other two. The maximum daytime and nighttime temperature differences were 3.0°C and 2.7°C, respectively, with these occurring at 6:30 am and 1:30 am, respectively (Table 2).

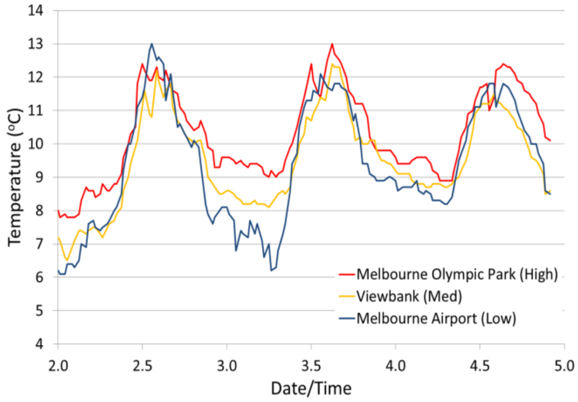

Fig. 4 Temperature comparison for three weather stations in Melbourne in the winter of 2015.

In Perth (Fig. 5) there is little separation between the three stations during the day or overnight. However, some minor nighttime temperature variations are apparent on one of the study nights. The maximum daytime and nighttime temperature differences are 3.7°C and 3.6°C, respectively (Table 2) and these occur at 7:00 am and 4:30 am, respectively.

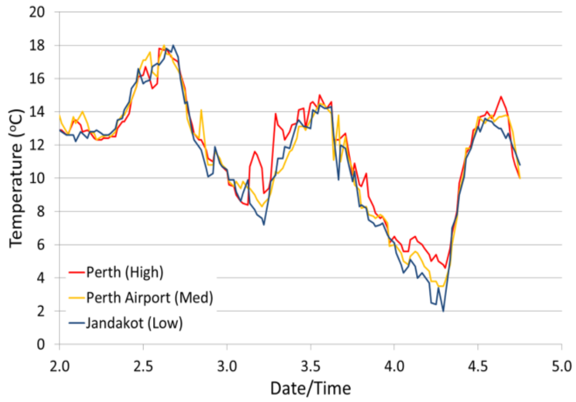

Fig. 5 Temperature comparison for three weather stations in Perth in the winter of 2015.

The final city investigated was Sydney and these data are presented in Fig. 6. Here very clear differences between stations can be observed, with the highest urban density site being warmest at night and the lowest urban density site being coolest at night. The medium urban density site plots in the middle of the other two. During the day, temperatures are generally similar for all sites, although there is some tendency for the high urban density site to be cooler than the other two sites during the hottest part of the day. According to Table 2, the maximum daytime temperature difference is 7.5°C and this occurs at 11:30 am while the maximum nighttime temperature difference is 8.0°C which occurs at 6:00 am.

The results of this study clearly show that there is an obvious and apparent winter UHI effect evident in all five major Australian cities. The UHI magnitude varied from a high of 9.1°C in Brisbane to a low of 2.6°C in Melbourne. In terms of the magnitude alone, Sydney and Brisbane displayed very similar patterns, exhibiting obvious differences between sites and high absolute temperature differences between sites. In contrast, Adelaide, Perth and Melbourne were similar to one another, exhibiting more similar temperatures throughout the day and comparatively minor absolute temperature differences.

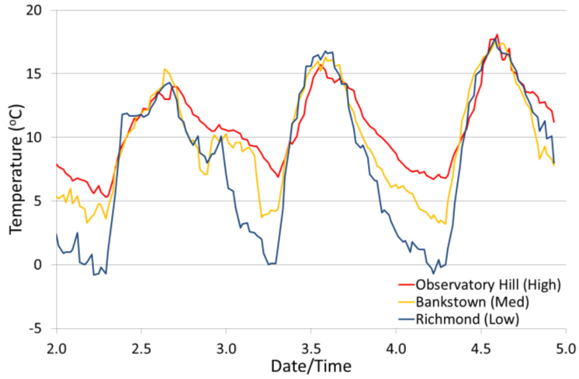

Fig. 6 Temperature comparison for three weather stations in Sydney in the winter of 2015.

For the five cities that were studied in this research the maximum temperature differences tended to occur either overnight or in the very early morning (around 6:00 am being the most common time). In most cases, the maximum daytime and nighttime temperature differences were similar to each other but occurred at similar times (again being very close to the segregation time between day and night as adopted in this study which was 6:00 am). Perhaps, then, it is more useful to say that the maximum temperature differences for all cities occurred during the coolest parts of the day while temperatures were mostly similar during the hottest parts of the day.

Table 2. Summary statistics for the comparisons between the high, medium and low urban density weather stations for each of the five largest cities in Australia.

	Day			Night		
Adelaide	**Avg**	**Max**	**Min**	**Avg**	**Max**	**Min**
High - Med	-0.25	1.70	-1.60	0.94	3.40	-0.80
High - Low	0.19	3.70	-1.90	1.69	4.30	-0.50
Med - Low	0.44	2.20	-0.90	0.75	2.60	-1.30
Brisbane						
High - Med	0.51	3.60	-2.60	1.55	3.80	-2.10
High - Low	1.84	9.10	-2.20	5.10	9.10	-2.30
Med - Low	1.33	7.50	-2.00	3.55	7.40	-2.70
Melbourne						
High - Med	0.76	1.70	-0.20	0.86	1.80	-0.20
High - Low	0.57	3.00	-1.10	1.33	2.60	0.30
Med - Low	-0.19	2.10	-2.20	0.46	1.60	-0.80
Perth						
High - Med	0.33	3.50	-1.70	0.28	2.70	-1.80
High - Low	0.43	3.70	-1.30	0.71	3.60	-1.50
Med - Low	0.10	3.90	-1.50	0.43	2.40	-1.00
Sydney						
High - Med	-0.01	3.60	-2.80	2.27	5.00	0.20
High - Low	0.74	7.50	-2.70	4.65	8.00	0.20
Med - Low	0.75	4.90	-2.70	2.38	6.70	-2.20

4. CONCLUSION

This study investigated 30-min temperature data for five Australian cities over a three day period in winter. Within each city three sites, representing high-, medium- and low-urban densities, were examined. All five cities exhibit evidence of the urban heat island phenomenon, with the high-density regions routinely recording the highest temperatures. This result was most pronounced for the more northerly cities of Brisbane and Sydney, but was also evident in the more southerly cities of Adelaide, Melbourne and Perth.

In all five cities, the maximum differences between high- and low-urban density settings were observed to occur in the coldest part of the day (overnight or early morning). In comparison, during the warmest time of the day, temperatures between sites tended to converge. These findings indicate that the urban heat island phenomenon is evident even during winter months but that the impacts reflect lower rates of overnight cooling. This suggests that the urban fabric is retaining heat more effectively than non-urban landscapes and may help to explain why summer temperatures in urban settings are often comparatively high. It is not just a matter of increased rates of energy capture during the daylight hours, but also retention of that energy overnight.

5. ACKNOWLEDGEMENTS

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