

Climatic changes in urban environments: trends and generations of heat islands in Presidente Prudente, Brazil

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Abstract – Presidente Prudente is located at São Paulo State (Brazil), has a population of approximately 200,000 inhabitants and in the structure of the city, there are intra-urban environments completely different from the point of view of soil occupancy, especially with regard to the density of constructions, arborization standards of roads and backyards, green areas, circulation of vehicles and people. This survey had the purpose of verifying the trend of thermal characteristics of the last 34 years and analyzing the intensity and shape of the urban heat island. The materials and techniques used to develop this study were: temperature data (minimum, average, maximum, and recorded at 9 pm) in the period from 1971 to 2005, collected in the Meteorological Station of Presidente Prudente (INMET). They were statistically treated, and the methodology to verify the intensity and shape of the urban heat island consisted of the definition of two transects, with mobile measurements, using digital thermometers, coupled to the side of two vehicles, totaling 120 points of air temperature collection. The results showed that the temperatures have suffered significant increase, especially with regard to the absolute minimum values and the records at nighttime. Heat islands of high magnitude were also identified, with maximum intensity of 9.6°C. The spatial variations occurred according to the types of soil occupancy and relief. This way, one concludes that in view of all the changes implemented in the natural environment, the energy balance has changed, coinciding with the global warming trend described by the IPCC published in 1994 and 2001.

Keywords – climatic changes; urban environments; urban climate; heat island; Presidente Prudente/Brasil.

Resumo – Presidente Prudente localiza-se no Estado de São Paulo (Brasil),

possui população aproximada de 200.000 habitantes e na estrutura da cidade, existem ambientes intra-urbanos completamente diferentes do ponto de vista da ocupação do solo, principalmente no que se refere à densidade de construções, verticalização, padrões de arborização de ruas e fundos de quintais, áreas verdes, circulação de veículos e pessoas e áreas com degradação ambiental. A presente pesquisa teve como objetivo verificar a tendência das características térmicas dos últimos 34 anos e analisar a intensidade e a forma da ilha de calor urbana em Presidente Prudente/SP. Os materiais e as técnicas empregados para o desenvolvimento deste estudo foram: os dados térmicos (mínimos, mínimos absolutos, médios, máximos e os registrados às 21 horas) do período de 1971 a 2005, coletados na Estação Meteorológica de Presidente Prudente (UNESP/INMET). Os mesmos foram tratados estatisticamente através do cálculo dos valores médios e da regressão linear simples. A metodologia para se verificar a intensidade e a forma da ilha de calor urbana consistiu na definição de dois transectos, com medidas móveis, utilizando-se de termômetros digitais, com os sensores presos a uma haste de madeira com 1,5m de comprimento, acoplados na lateral de dois veículos, totalizando 120 pontos de coletas de temperatura do ar. As medições foram efetuadas em julho de 2002 entre 20h e 20:45h. Os resultados mostraram que as temperaturas da cidade de Presidente Prudente têm sofrido aumento significativo, sobretudo no que se refere aos valores mínimos absolutos e os registrados no período noturno. Também foram identificadas ilhas de calor de alta magnitude, com intensidade máxima de 9,60C. As variações espaciais ocorreram de acordo com os tipos de ocupação do solo e características de relevo. Desta forma, conclui-se que diante de todas as transformações implementadas no meio natural, nestes últimos cinquenta anos, tenha alterado o balanço de energia, coincidindo com a tendência de aquecimento global descrita pelo Intergovernmental Panel on Climate Change publicado em 1994 e 2001.

Palavras-chave: mudanças climáticas; ambiente urbano; clima urbano; ilhas de calor; Presidente Prudente/Brasil.

INTRODUCTION

The fast and unorganized urbanization process that Brazil suffered after the 50s caused a substantial change in the original landscape of the natural environments. This change caused serious problems regarding urban environmental issues, like pollution of water bodies, thermal discomfort, atmospheric pollution among others.

Together with the relief and hydrography, the climate was one of the main abiotic elements and suffered with the anthropogenic derivations. The construction of the cities allowed modification of the energy balance, especially due to the substitution of the materials making up the natural landscape by those of human origin. These substitutions caused considerable changes in the characteristics of the main dynamic elements of the atmosphere, in addition to causing the emergence of a microclimate with very particular specificity.

The city's climate is therefore the result of the integration between the atmosphere and the urban environment built by man and the roughness of its location.

This way, studies on urban climates in Brazil have, decade after decade, obtained more and more highlight and need for understanding by experts, because it was believed that the transformation of spaces, releasing of tons of solid particles produced by man in urban environments, are contributing toward the global warming trend, as informed by the IPCC (2001).

Presidente Prudente gave the urban climate study a complex situation with regard to the soil occupancy and relief.

In this city, there is a diversity of significant uses with regard to soil occupancy, since the oldest towns (30s/40s) are densely built and have adequate quantity of tree vegetation in the roads and backyards.

The less ancient towns (50s/60s) and the more recent ones (as of the 70s), which are the great majority, have sparse constructions with lawns and disperse tree vegetation. The popular housing assemblies (low-income dwellers) are densely constructed. The city does not have a very diversified soil use, there being a predominance of domiciles to the detriment of other uses, such as industrial, commercial and services. The non-residential units (commerce, services and industry) represent 13% of the total, while residential units represent 87%.

The commercial and service use is predominantly located in the central area, with some subcenters spread through the urban network, but with relatively little circulation of vehicles and people, in comparison with the center.

The rural area near Presidente Prudente is characterized by the pastures and sparse tree vegetation, the soil being covered at all times of the year (Amorim, 2000).

With approximately 200,000 inhabitants, covering an area of 562 Km², there is a relief inserted in the Planalto Ocidental Paulista [São Paulo Western Plateau], and is basically formed by average, broad hills and long hillocks and spikes. The city is located on a spike dividing the waters, and the water system that drains the urban location is made up of small watercourses.

In the western part of the city, where it has grown the most, due political, economic issues and issues of relief, the dividing water surfaces have longer convex profiles, forming smoother topographic divides separated from each other by less narrow valleys, representing today about 80% of the urban network total. The eastern part has a well undulated relief and the roads outlined have strong slopes, exceptionally rendering the city's expansion difficult.

The roughness of the Presidente Prudente's relief favors the central area, since it is on a spike where most of the buildings with more than four stories are located and is very unfavorable in its outskirts, where the slope ruptures are sharper.

The climate of Presidente Prudente and region is the result of an alternating field of tropical and polar systems, but dominated by more or less continentalized,

tropical sea air masses (Sant'Anna Neto and Barrios, 1996).

The participation of the frontal systems, above all the cold fronts and RFPAs, together with the individualized systems, is the main factors responsible for rains in the region (about 70% of the annual average precipitation).

The rains associated to the cold fronts are observed during all seasons, with more expressive values during the entire summer, end of spring and beginning of fall.

While the rains associated with the individualized systems, especially the ZCAS (South Atlantic Convergence Zone) occurred during the summertime and end of spring. As ZCAS have their genesis connected along the subtropical jets at high levels, as well as the east of the semi-stationary hollows.

The rains associated with the CCMs (Mesoscale Convective Complexes) over the region occur mainly during nighttime, when all the ascending air from the water evaporating from the rivers Paraná and Paraguay cools and precipitates.

The participation of the inter-tropical systems does not have significant precipitation values for the municipality of Presidente Prudente and the region, but the systems play an important role in controlling the temperatures.

The action of the Tropical Atlantic system throughout the year brings to the region, during the winter, time stability due to the upper subsidence and some instability during the summer due to the basal warming that causes some convective cells.

The Continentalized Tropical Atlantic system has as characteristics the changes in thermal, hydric and barometric values of the Tropical Atlantic (TA) originating in the stationary Anticyclone of the South Atlantic. These changes are caused by the modifications suffered by the TA on advancing and remaining in the continent. One of its strong characteristics is the increase of thermal values.

The Tropical Continental system is one of the only ones with their geneses associated with the continent's interior. Originating in the Platina do Chaco lowland, this system mainly influences the high temperatures of the region.

Several studies have shown that the urban atmosphere has presented differences in relation to the rural atmosphere, especially with regard to temperature, with formation of heat islands. The various types of soil use and occupation, associated with the relief characteristics, cause changes in the environmental quality, which materialize in various ways and one of these has to do with the urban atmosphere.

The detection of heat islands in the urban environment can aid urban planning, to the extent in which the temperature rise causes the establishment of areas of less pressure, which in turn facilitates air circulation toward the hotter points and consequently transport of pollutants to these areas.

Studies of this nature in small and medium-size cities allow for effective actions in the territory's reordering, to the extent in which they do not reach unsustainable levels of growth, as in the big metropolitan cities.

This survey had the purpose of verifying the tendency of thermal characteristics of the last 34 years and analyzing the intensity and shape of the urban heat island

in Presidente Prudente/SP.

Inserted in the transformation context of the landscape, the production of space, substitution of natural materials by humans and global, regional and local warming, the city of Presidente Prudente becomes a good example of analysis and understanding with regard to climatic changes.

METHODOLOGICAL PROCEDURES

The urban climate study considered the internal structure of the Urban Climate System, integrating the ecological and urban, without disregarding the higher scales of the climate (Monteiro, 1976). The materials used to conduct this research were: the temperature data, especially with regard to the average of the maximum, medium and minimum values, the absolute minimum values, minimum and maximum temperature values of July and January and the records in the period of 9 pm.

These thermal data was gathered from the Meteorological Station of the Faculty of Science and Technology of Presidente Prudente (UNESP/INMET) in the period from 1971 to 2005.

From the data available, some statistical techniques were used, like calculation of the mean and simple linear regression, used to help in the general analysis and facilitate actual knowledge of the thermal changes for the city of Presidente Prudente.

In the data statistical treatment, the software Origin 7.5¹ and Excel² were used to formulate the following graphs shown in the body of the work.

- Trend of the mean temperature values;
- Trend of the mean minimum values;
- Trend of the mean maximum values;
- Mean representation of the minimum temperatures recorded in July and the mean of the maximum temperatures recorded in January
- Trend of the absolute minimum values;
- Trend for increase of the thermal mean for the period of 9 pm.

The methodological procedure for gathering air temperature data in Presidente Prudente consisted in the definition of two transects, with mobile measurements, using digital thermometers, with sensors fastened to a wooden rod with 1.5-m length, coupled to the side of two vehicles that left the outskirts (rural), passing through the center, arriving at the opposite side of the city.

The measurements were taken in 5 days in July 2002, between 8:00 pm and 8:45 pm, time in which the temperatures do not undergo rapid changes, due to the time difference between the first and last measurement (45 min). In transect 1, 42 temperature records were taken and 78 in transect 2 (Figure 1)

¹ Origin 7.5 is a registered trademark of NAG Software Partner.

² Excel is a registered trademark of Microsoft.

The gathering of data with vehicles requires that the time spent between measuring the initial point and final point of the itinerary does not exceed one hour, with a speed that should vary between 30 and 40Km/hr. This methodology was adapted based on the works of Oke and Maxwell (1975); Gomes and Garcia (1984); Johnson (1985); Pitton (1997).

The field survey was conducted in winter episodes, under synoptic conditions of low wind speed, favorable to the formation of heat islands.

The regional atmospheric systems acting on the days of field survey were analyzed through the synoptic maps of the surface available in the Brazilian navy site³ and of the Goes satellite images.⁴

To analyze the result, isothermal maps were elaborated, using the Software Surfer for Windows,⁵ thus allowing viewing of the temperature variation in different points of the city.

Thus, the research was developed from the methodological propositions presented by Monteiro (1976 and 1990), considering the spatial analysis that resulted from an intra-urban analysis to explain how the different geological and urban conditioning factors answer for the action of the atmospheric systems.

THE CLIMATE OF URBAN ENVIRONMENTS: AN EXAMPLE OF PRESIDENTE PRUDENTE/SP

All the anthropic derivations play a very important role in the changes of the main climatic elements. Perhaps, one of the main materializations of these derivations, regarding the climate, can be viewed directly from within the cities.

The cities, in addition to being the stage of constant social struggles, since the 17th century, is being regarded more and more as one of the main objects of study for atmospheric sciences.

Since the publication of the first works on urban climate, conducted in London by Evelyn (1661) and Howard (1833) up to the publication of the classical works of Landsberg and Chandler (1965), cited by Lombardo (1985), understanding the changes in urban environments becomes essential for studies aimed at greater verticalization of the constant local and regional atmospheric changes.

The cities, although they occupy great spatial extensions, are responsible for abrupt changes in the natural landscape. According to Amorim (2000), this modification can be materialized through different forms of pollution (water, soil, subsoil and air), as well as the changes in the morphology and structure of the urban environment, devastation of green areas, destruction and channeling of water bodies, among others.

In view of all these changes in the spatial assembly, caused by human

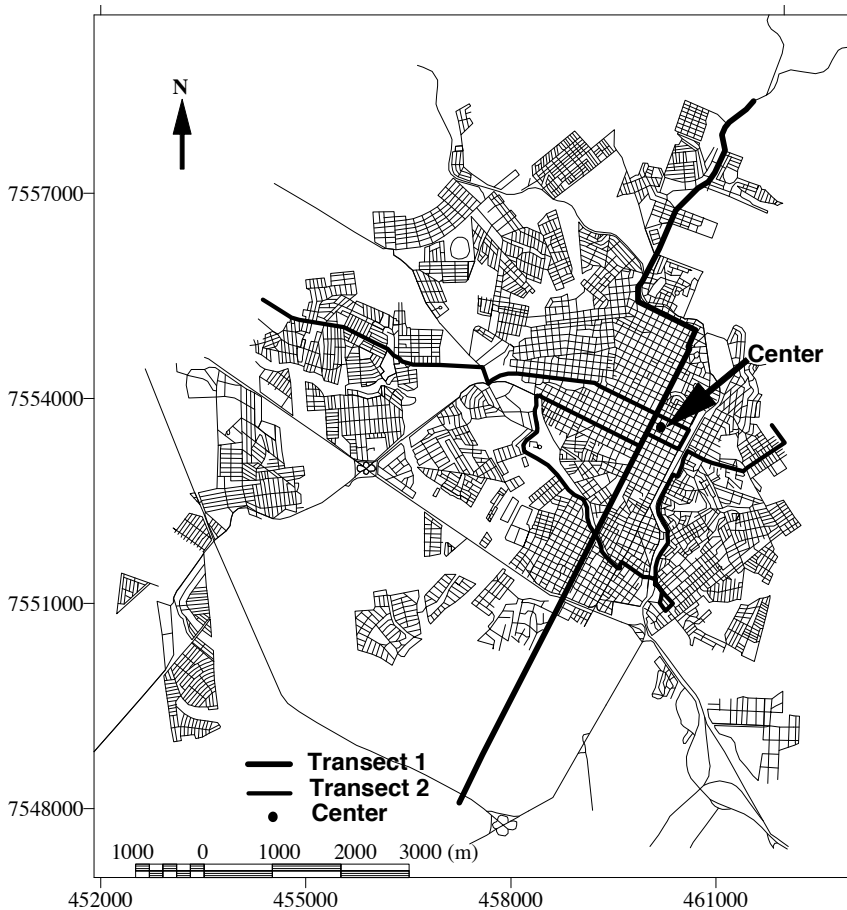
³ www.mar.mil.br.

⁴ <http://satelite.cptec.inpe.br/imagens/>.

⁵ Surfer is a registered trademark of Golden Software, Inc.

Figure 1. Presidente Prudente – Location of transects - 2002

Source: Topographical map of the municipal government of Presidente Prudente, 1995.



actions, a “new” local atmospheric formation begins, established by the change in the dynamical behavior of the atmospheric elements.

This way, Monteiro (1976), influenced by the General Theory of Systems by Ludwig von Bertalanffy of 1950, calls the interrelation between the elements of nature and man the Urban Climate System (UCS).

The proposal of this Urban Climate System model is subdivided into three channels of perception or into three subsystems, among them: Thermodynamic, (which will mention the quality of heat comfort in urban environments), the Physical-Chemical, (fundamental for the studies in large and medium-size cities, since it is in these types of environments that there is a greater quantity of particulate material dispersed in the atmosphere, expelled by the chimneys of factories and exhausts of automobiles, creating problem for air quality), and the Hydrometeorologic (subsystem responsible for “verifying” the meteoric impacts, that is, concentrated pluvial impacts or extreme pluvial events).

The channels of perception fundament an important understanding within the systemic perception that the urban climate is exclusively an open system. This, since it is open, is subject to changes of different orders and impacts, caused by the most varied triggering factors.

The importance of analyzing the urban climate within the perspective of the channels of perception can be justified by the fact that, although not a perfect model of analysis, it can encompass a good part of the interferences and characteristics of the local micro-climate.

This way, the urban climate can be understood as a large open system that covers the climate of a certain space and of its preexisting urbanization that, despite being the micro-climatic materialization of a spatial portion, is inserted in a macro-climate, being influenced by the different types of soil use and by the different social productions of space.

According to Amorim (2000), “the urbanization process changes the surface radiation balance due to substitution of natural materials by urban materials”, which has the capacity of capturing, absorbing and reflecting part of the electromagnetic radiation emitted by the sun.

The electromagnetic radiation's integration with the finished material ends up modifying its original wavelength, directly contributing toward increase in the local thermal values. In addition, it is in the urban environment that there is heat production by indirect actions, from human derivations.

Automobile engines, associated with heavy use of refrigeration machinery and acclimatization, is one of the main elements responsible for direct increase in the thermal values of large and medium-size urban centers.

The other forms that contribute toward warming in these environments are the various colors and types of materials used in the construction of buildings, houses and pavements of sidewalks of road, circulation of vehicles and people, high concentration rates of water and dust particles, and tons of pollutants generated by the burning of fossil fuels, etc.

Inserted in all this context of derivation and space production by human actions, the city of Presidente Prudente becomes a good example to study the characteristics of urban climate.

The city of Presidente Prudente, as well as any other of similar structural size, has countless urban environmental problems. Oftentimes, the genesis of these problems is related to the disorderly growth of the city itself, provided by a fragile environmental planning policy.

Urban space construction, in addition to changing the forms of relief and changing the directions, potentiality and quality of the water bodies, is able to cause impacts of different magnitudes in the main micro-climatic elements, reflecting, above all, in the air quality and thermal comfort. The change of thermal values in urban environments is the greatest proof that the use of countless material types and colors can cause changes in the energy balance.

Substitutions of natural material by urban materials, guaranteed by the

urbanization process, caused a change in the energy balance and consequently modification in the thermal characteristics of Presidente Prudente.

Analyzing the thermal behavior of the city, it is possible to note that the considerable modifications in the minimum thermal, absolute minimum, maximum mean values and in the records in the period of 9 pm in the time scale extends from 1971 to 2005.

TREND FOR INCREASES IN TEMPERATURES FOR THE CITY OF PRESIDENTE PRUDENTE

The increase of mean temperatures of the globe, without a shadow of doubt, is a cause of much concern to countless experts on the subject. The increase forecasted by IPCC ('994) for the global mean temperature between 1990 and 2100 will be varying between 1.4 to 5.8°C, reflecting directly in an increase in the level of the oceans from 0.09 to 0.88 meters.

According to Bessat (2003), the increase in temperatures would cause an increase in the values observed in the global hydrological cycle, that is, it would rain more at some points of the planet (creating risks for the society) and less at other points (causing problems like water scarcity).

Modification of the thermal values in the whole of Latin America is being regarded as one of the factors greatly responsible for the 20% reduction in glacier areas found in the Andes, according to IPCC (2001).

Thermal variations in the mean values are also observed in large, small and medium-size urban centers.

Analyzing the mean temperatures of the city of Presidente Prudente, recorded for the period from 1971 to 2005 in Figure 2, one sees that they have a tendency to increase.

This tendency serves as example in the understanding of new and strong evidences that majority of the warming (global, regional and local) observed in the last 50 – 60 years can be attributed to anthropic derivations, as explained by the IPCC (2001).

However, one does not know for sure if man is the sole and only agent responsible for all the thermal change in the planet, or if all the warming in the global, regional and local scales is linked to the natural cycles: of sunspots, effects of volcanic eruptions, etc. Nevertheless, what is perhaps one of the great problems of humanity is exposed.

Using some statistical techniques, like calculation of linear regression, it was possible to see that the increase in mean temperatures of the city of Presidente Prudente in the last 34 years was 1.5°C, which would give an increase of 0.44°C per decade (Table 1).

In addition to this visible increase in the mean values of the temperatures, one notes that the means of the minimum and maximum temperatures are being more and more modified (Figures 3 and 4).

The changes in the mean values of the minimum temperatures have

Table 1. Linear regression for the mean temperatures of Presidente Prudente

	VALUES OF Y LINE	1971	2005	TEMPERATURE INCREASE	DECADE INCREASE
TEMP.	T=-66,50183+0,04521.ANO	22,6	24,1	1,5	0,44

been much more significant compared to the mean values of the maximum temperatures. The mean of the minimum values, observed in the period from 1971 to 2005, have suffered an increase of 2°C, which represents an increase of 0.56°C each decade. While the thermal mean of the maximum values increased by only 1.1°C in the same period of analysis.

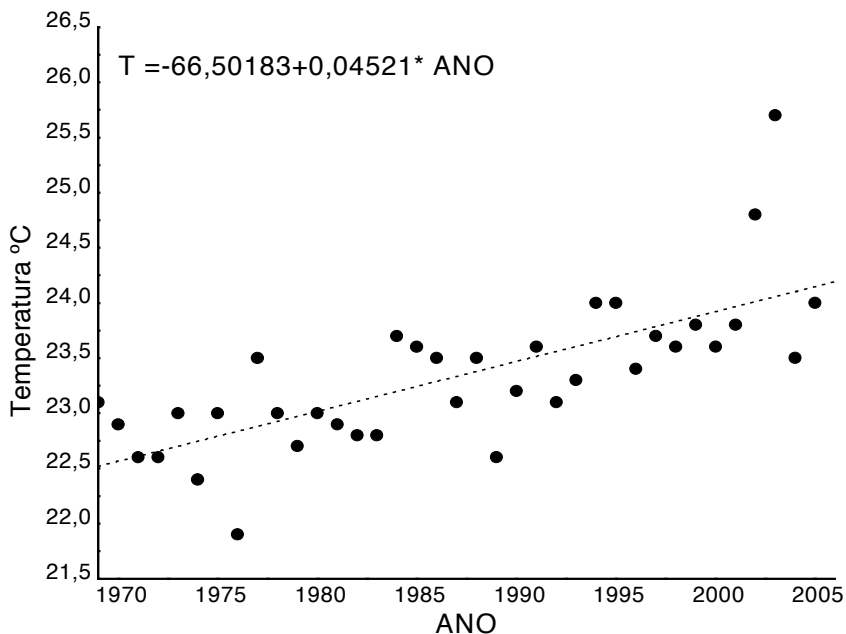
One can thus conclude that, although the mean of the maximum thermal values is increasing by approximately 0.3% for the last four decades, it is the mean of the minimum temperatures that is having the more significant values.

This fact ends up encouraging and evidencing the possible trends for positive changes in thermal values, generated within the large, small and medium-size urban centers in the last decades.

In view of all this trend, on analyzing the mean values of the maximum and minimum temperatures for the months of January and July, this trend became even more evident.

The importance of analyzing the thermal variations for these two months are

Figure 2. Trend of the mean values of temperature



linked to the fact that it is during these periods (January and July) that the highest and lowest thermal values in the year are observed.

The changes in mean values of the minimum temperatures for the month of July show that year after year the winter for the city of Presidente Prudente is becoming hotter, as can be seen in Figure 5 (A and B).

Figure 3. Trend of the mean minimum values

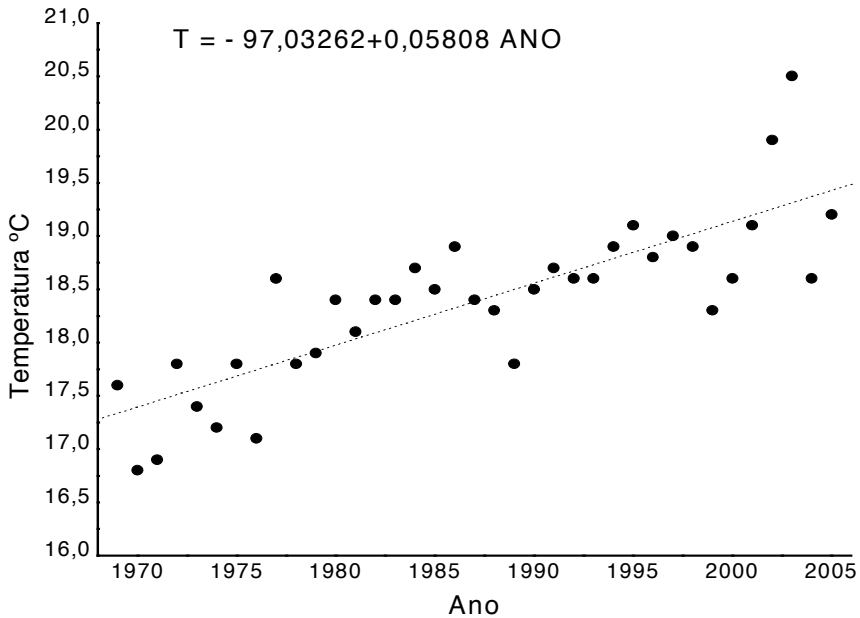
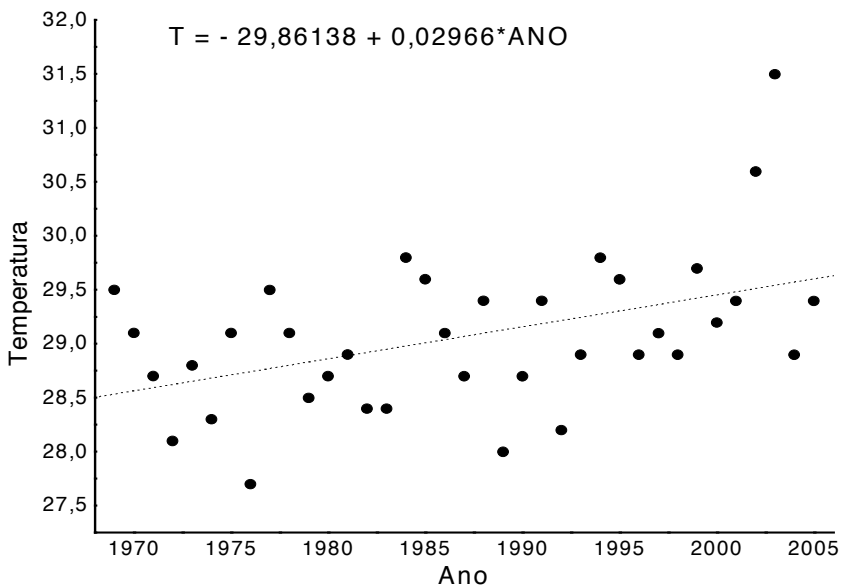


Figure 4. Trend of the mean maximum values



The changes in the minimum values during these times of the year do not mean exactly reduction of the polar flows, responsible for reducing the thermal values. It is very likely that increase of the minimum means can be directly associated with the “heat” generation produced by human activities within the city itself.

Calculation of the linear regression reveals that between 1971 and 2005, the minimum temperatures recorded in July (considered to be the coldest month) was 3.3°C, which would give approximately 0.95°C of increase each decade (Table 2).

In the same way that changes are observed in the minimum values during winter, it is possible to observe modifications in the maximum behavior of the temperatures recorded during the central season of summer, as can be seen in Figure 5.B.

During the entire time series (1971-2005), this temperature increased by approximately 1.7°C, which represented approximately 0.5°C each decade (Table 2).

On analyzing the absolute minimum temperatures of the city of Presidente Prudente, it was possible to note high changes in its thermal behavior. This temperature suffered an increase of approximately 3.5°C in the last 34 years, which would give approximately 1°C of increase each decade.

The graph of trend for increase in the absolute minimum values, shown by Figure 6, shows that during the start of the 70s and 80s, the lowest thermal values of the entire time series analysis were recorded. With highlight for the

Figure 5. Mean representation of the minimum temperatures recorded in July (A) and the mean of the maximum temperatures recorded in January (B)

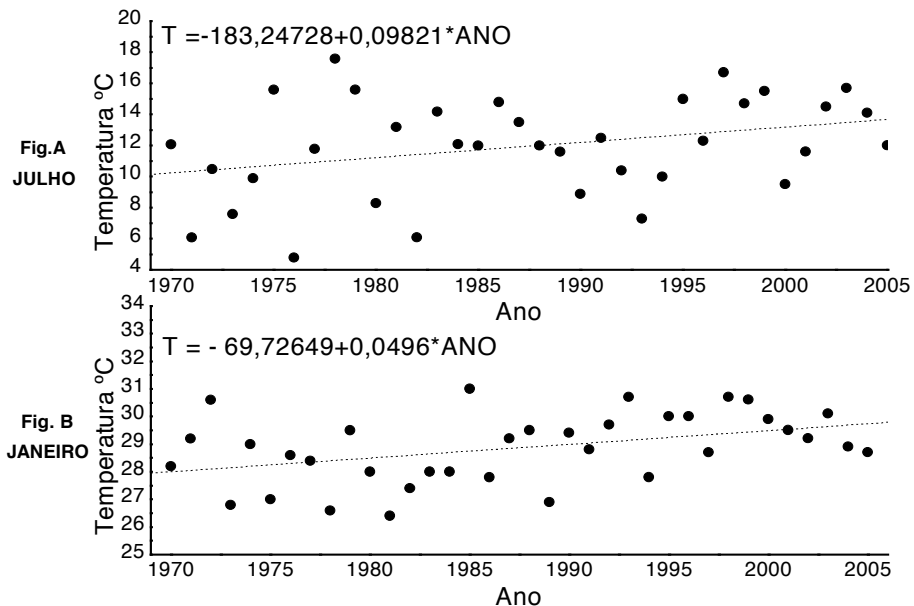


Table 2. Linear regression for the mean of minimum and maximum temperatures of Presidente Prudente

	VALUES OF Y LINE	1971	2005	TEMPERATURE INCREASE	DECADE INCREASE
TEMP. JULY	$T=183,24728+0,09821*ANO$	10,3	13,7	3,3	0,95
TEMP. JANUARY	$T= - 69,72649+0,0496*ANO$	28,0	29,7	1,7	0,48

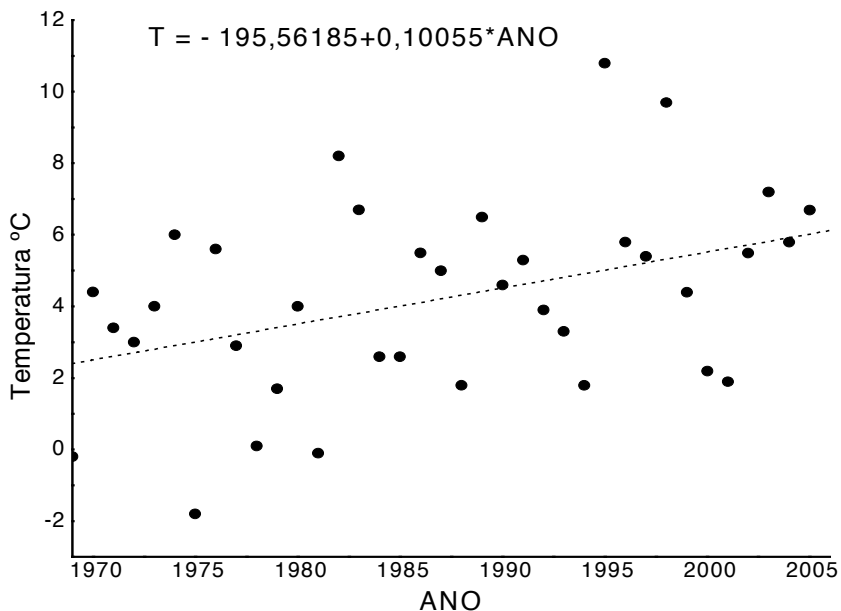
years of 1975 and 1981, being that in the first, the lowest absolute thermal value of the entire historical time series was recorded, with -1.8°C and the second with temperature of -0.1°C .

In the following decades, one notes that the absolute minimum values of the temperatures increased more and more.

The increase in absolute minimum temperatures, as shown in Figure 6, reflects the very high rates of soil impermeabilization, due to densely concentrated buildings, reducing the number of trees, expansion of urban network, in addition to tons of pollutants thrown in the atmosphere. These elements are able to retain heat during the day and slowly disperse it at night, interfering in the energy balance.

The increase in minimum temperatures implies in serious problems, since the low temperatures serve as natural control to eradicate small pests in agriculture. With reduction in the absolute minimum values, there will possibly be an increase

Figure 6. Trend of the absolute minimum values



of pests, creating economic and even environmental and social problems, since the need to control proliferation of these agents with the use of pesticides is increasing, which is harmful to the environment and human health.

Finally, one sees that the changes in the thermal values of the city of Presidente Prudente are not occurring in the minimum, mean, absolute maximum and minimum values alone. The warming process is also being significant in the temperatures recorded at nighttime, that is, at 9 pm.

The temperature at this time is extremely fundamental for the possible inferences that a global warming is possibly occurring.

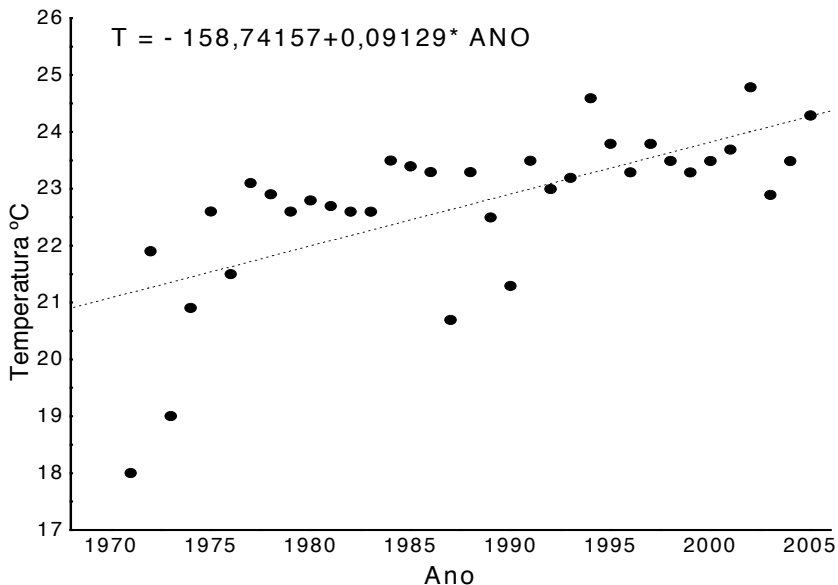
The temperatures at 9 pm in the city of Presidente Prudente has undergone positive changes of 3.1°C, which restates the idea by IPCC (2001) that nights are becoming hotter and hotter in the entire globe. (Figure 7).

The temperatures recorded at 9 pm in the city of Presidente Prudente in the last four decades underwent significant changes of approximately 0.9°C. Analyzing the graph of Figure 7, it becomes evident that the lowest mean temperatures of the entire time series were those of the first quarter of the 70s. This fact is not noted in the following years. This occurrence can be attributed to countless spatial changes suffered by the city itself, mainly with regard to substitution of natural materials by those of anthropic origin, in the last four or five decades.

HEAT ISLANDS UNDER 'IDEAL' CONDITIONS

The temperature data analysis involved the construction of isotherms for

Figure 7. Trend for increase of the thermal mean for the period of 9 pm



each survey. It was chosen to conduct take the temperature readings on clear nights with low wind speed, since they favor the formation of well developed heat islands.

In July 2002, in the southeastern region of Brazil, the cold fronts are weak to moderate and cause only increase in cloudiness and light rain. Considering the dry period in most of the Region, according to Climanálise (July/2002), the few rains were around the record mean and seven frontal systems were acting in the country, this number also within the record mean. These systems were rapidly displaced to the Southern and Southeastern Regions and three affected the extreme south of Bahia. On the field survey days, the region of Presidente Prudente was affected by the following atmospheric systems:

- on July 14, there was a Polar, due to the cold front located in the Atlantic Ocean and that was being tropicalized, allowing a new frontal system to penetrate the south of the country. The temperature at 9 pm at the Meteorological Station of Presidente Prudente was 16°C;

- on July 16, the polar was weakened and the temperature increased by 4.2°C in relation to the same time on July 14 (20.2°C) and a new frontal system hit the south of the country;

- on July 17, the cold front advanced over the Brazilian coast and the polar that was acting on the region of Presidente Prudente received a reinforcement, causing slight drop in temperature and southeast wind (18.9°C at 9 pm);

- on July 23, the region was under the action of a polar, since on the 22nd, a frontal system moved toward the coast, causing rains in the region, and stability was brought by the polar on the 23rd, with northeast winds (4m/s) and the temperature at 9 pm rose to 21.2°C;

- on July 25, a cold front interacted with the cyclogenesis that formed over the ocean, and the region of Presidente Prudente was under the action of the Tropical, with weak northeast winds and temperature of 22.6°C at 9 pm.

Figures 8, 9, 10, 11 and 12 show the temperature distribution in Presidente Prudente on July 14, 16, 17, 23 and 25, 2002. All the nights had a clear sky and low wind speed, with predominance of the east quadrant or under tranquil conditions (Table 3). This information was obtained from 8 to 9 pm at the Meteorological Station located at FCT/UNESP of Presidente Prudente, since the course of the first transect lasted about 33 minutes and the second about 45 minutes.

The temperature standard revealed by Figures 8, 9, 10, 11 and 12 made it possible to distinguish some recurrent characteristics which will be shown below.

The city usually generates heat islands with temperature increase from the rural area and towns less densely constructed toward the densely constructed towns and the center.

Table 3. Temperature, relative humidity, wind direction and speed data at the Meteorological Station of FCT/UNESP.

FCT/UNESP						
DAY	Hour	Temp (°C)	Relative Humidity (%)	Wind Direction	Wind Veloc. (m/s)	NEB
14/07	20:00	16	77	SE	0,5	0
	21:00	16	77	CL	0,0	0
16/07	20:00	20,0	59	CL	0,0	0
	21:00	20,2	54	CL	0,0	0
17/07	20:00	19,7	43	SE	1,0	0
	21:00	18,9	45	SE	3,0	0
23/07	20:00	21,4	77	NE	0,5	0
	21:00	21,2	78	E	4,0	0
25/07	20:00	23,8	51	NE	0,5	0
	21:00	22,6	53	CL	0,0	0

Source: Meteorological Station of FCT/UNESP – July/2002

Strong heat islands were observed on all the days, with amplitudes between the hottest and coldest point oscillating between 4.9°C and 9.6°C, as can be seen in Table 4. The amplitudes were less on days with slightly stronger winds (5.4°C on the 17th, with wind of 3.0m/s and 4.9°C on the 23rd, with wind of 4.0m/s).

In the majority of the heat island studies conducted at nighttime, the center of the island is well defined and often located in the center of the city with greater density of constructions or in the industrial districts.

In Presidente Prudente, however, at least two separate cells of the heat island were detected, which can be directly attributed to urban causes.

Firstly, a bigger cells was noted with hotter air located in the central area towards the north and south part of the city, where the older and densely constructed districts are located.

To the extent in which the constructions reduced, there was a temperature drop toward the rural area.

The second cell was located in the western part of the city, where there were two densely constructed housing assemblies. The temperatures in this cell, although high when compared to other points of the city, were 1°C to 2°C lower in relation to the center. Thus, besides the temperature being slightly lower than in the center of the city, its size was quite smaller in relation to the center and its surrounding.

The localization of higher temperatures proved to be directly related to the

Table 4. Maximum, minimum temperatures and thermal amplitude between the points

Temp.(°C)	14/07	16/07	17/07	23/07	25/07
Maximum	17,9	22,3	20,1	22,3	26,7
Minimum	11,9	14,8	14,7	17,4	17,1
Amplitude	6,0	7,5	5,4	4,9	9,6

Source: Field Work - 2002

density of constructions and excess night heat, attributed to release of heat stored during the day by the buildings.

Reduction in the construction density has a pronounced effect in breaking the continuity of higher temperature distribution.

Under tranquil conditions and wind speed of 0.5m/s, lower temperatures were observed between the cells of the western part and central area, even though inserted in the urban network.

The interval of the lower temperatures between the two main cells with higher temperatures was broken on July 17, due to the presence of weak southeast winds, between 1m/s at 8 pm and 3m/s at 9 pm. The air circulation was enough to homogenize the higher temperatures throughout the western part of the city, regardless of the density of the constructions. The heat produced in the more densely constructed area was distributed by the predominant southeast wind and only the rural area and districts located to the east of the center of the city had lower temperatures on this day.

Figure 8. Presidente Prudente: air temperature – 14.07.2002 – 8:00 pm

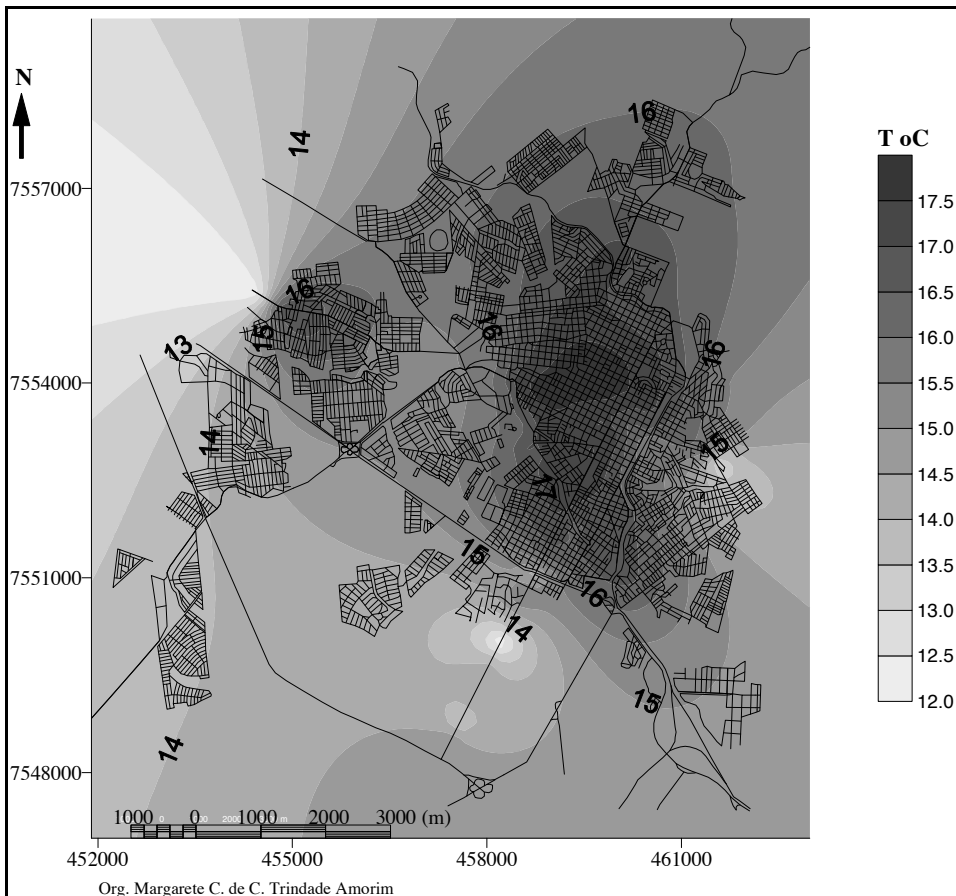
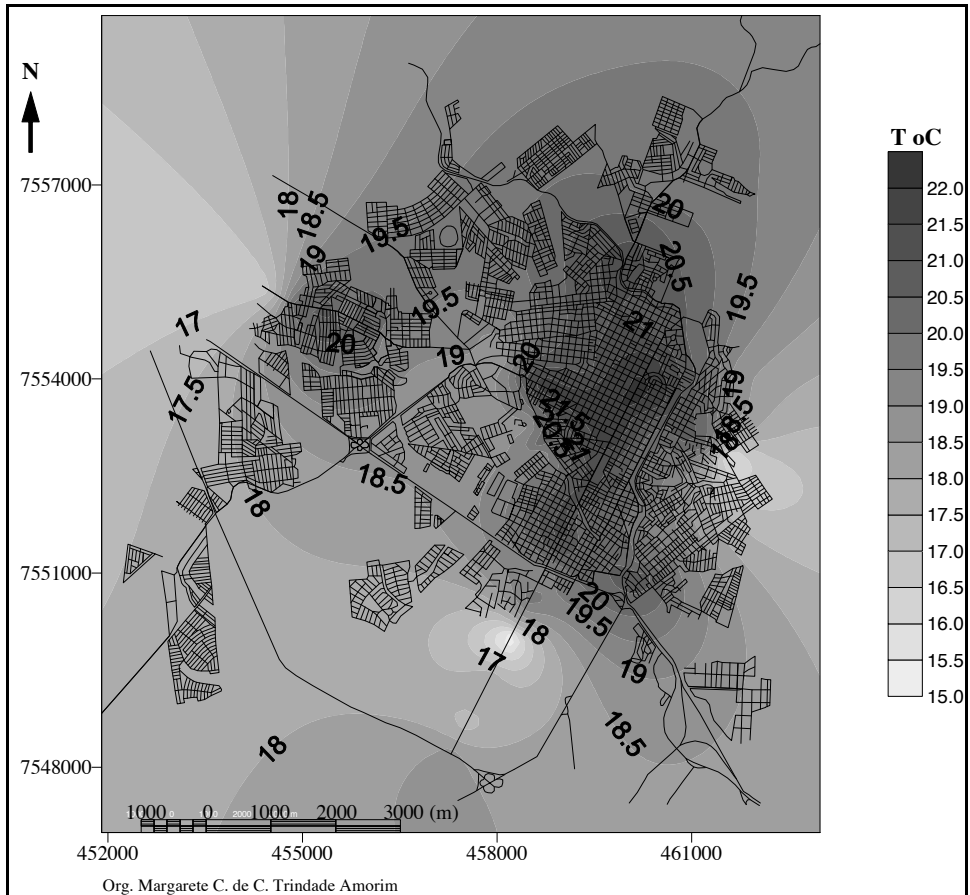


Figure 9. Presidente Prudente: air temperature – 16.07.02 – 8:00 pm



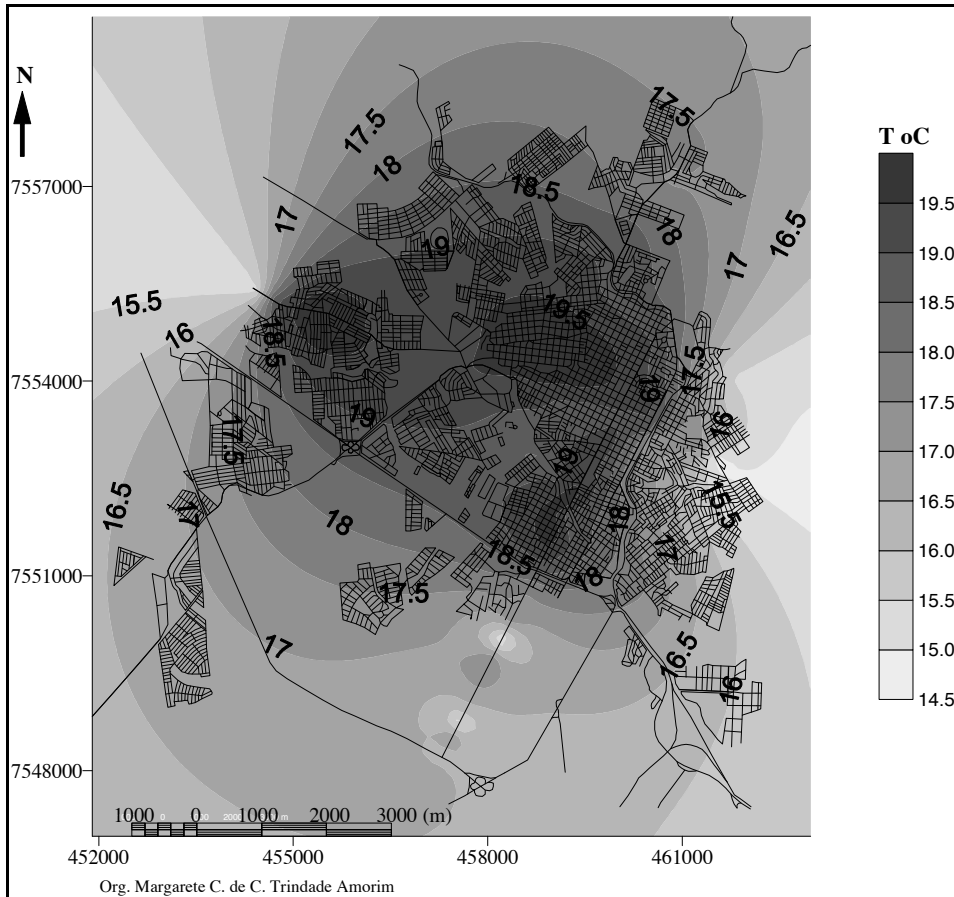
In all the days surveyed, the limits of the constructed areas toward the rural area clearly defined the heat island. However, the intra-urban areas with lower construction density were subject to higher temperatures due to breezes coming from the east quadrant, where the higher temperatures are located, usually at nighttime.

On nights without cloudiness, as in those observed in this study, in the rural environment, the bottom of the valleys favored the lower temperatures, as was seen in the southern, western and eastern part of the urban stain.

The isotherms shown in Figures 8, 9, 10, 11 and 12 explain the lower temperatures at the bottom of the valleys in the rural area.

Most of the brooks located in the urban environment were channeled. At nighttime, the points with lower altitudes did not “break” the main heat island found in the city. Even the Parque do Povo [People’s Park], where Córrego do Veado was channeled and the area was covered by low and tree vegetation, the heavy flow of vehicles and soil use in the avenues at the margin of the bottom of

Figure 10. Presidente Prudente: air temperature – 17.07.02 – 8:00 pm



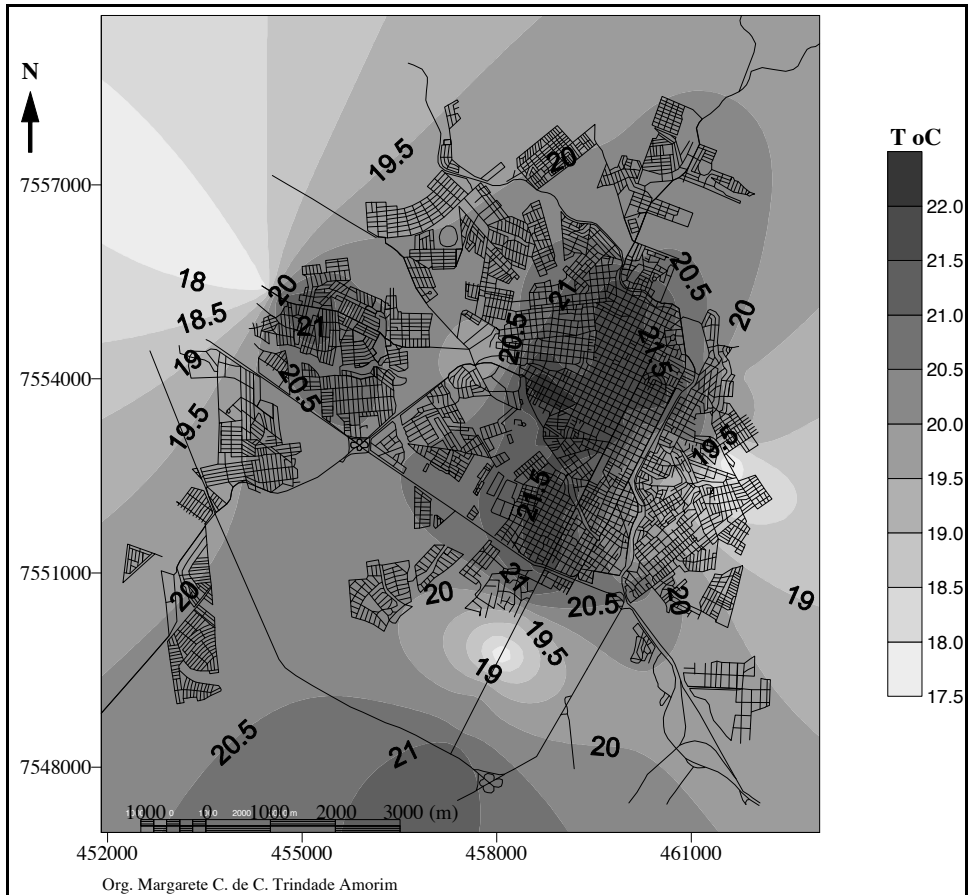
the valley (commercial and residential) caused the temperatures to remain high.

FINAL CONSIDERATIONS

The city of Presidente Prudente has been undergoing an increase in its temperature year after year, as was observed in the analyses made in the setoff this work.

The modifications of the minimum, absolute minimum, mean, maximum values and especially in the nighttime temperatures (recorded at 9 pm) restate a series of occurrences that unfolded throughout the history of the city of Presidente Prudente and shows a trend that, although observed for the city of Presidente Prudente, has been becoming increasingly common around the globe, the increase of nighttime temperatures. This fact, associated with countless others, ends up taking leading many experts to confirm the occurrence of changes in the global climate.

Figure 11. Presidente Prudente: air temperature – 23.07.02 – 8:00 pm



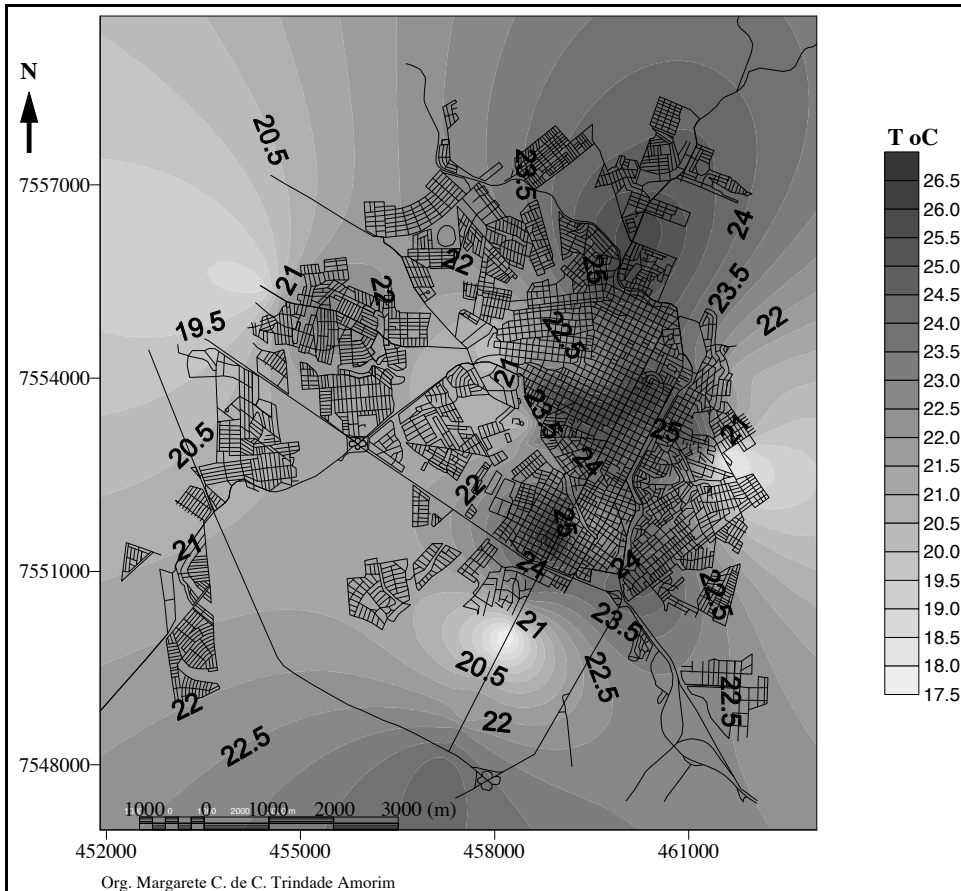
The changes in landscape and implementation of materials capable of retaining heat during the day and releasing it at night causes changes in the city's energy balance, as previously describe and well observed by Amorim (2000 and 2002) for the city of Presidente Prudente.

Modification of this energy balance is not something observed only in medium-size cities like Presidente Prudente. The same occurs in greater proportions in the world large metropolitan cities like São Paulo, described by Lombardo (1985) and possibly influencing the global warming observed in the last decades.

Therefore, to consider the changes undergone by the spaces, substitution of natural materials for those of human origin and changes in the energy balance is without doubt of utmost importance, but one must also take into consideration the natural processed unfolded in our galaxy before saying which are the factors responsible for the global climatic changes or global changes.

The intra-urban and rural variations shown in this study allows one to state

Figure 12. Presidente Prudente: air temperature – 25.07.02 – 8:00 pm



that the city has a set of microclimates.

These differences are especially pronounced under clear and tranquil conditions, when the various surfaces allow the development of their own microclimatic characteristics.

The differences in altitude in the rural environment were very representative, the lower temperatures being at the bottom of the valley. In the urban environment, the differences were linked to the construction density, since the “heat island” did not disappear at lower altitudes where there were brooks with closed channeling.

One thus recommends that the indiscriminate impermeabilization of the soil be stopped in new settlements, respecting the areas intended for greenery and protection of water sources, for the generation of higher temperatures to be reduced with the city’s growth.

Naturally, the tropical environment is capable of generating discomfort due

to the great amount of heat, increased by the growth of the cities. Therefore, on setting up new settlements, one must consider the climatic characteristics, avoiding generalized impermeabilization of the soil, use of improper materials in construction, felling of original vegetation without being concerned about leaving areas that can contribute toward reducing the high temperatures.

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