BIOCLIMATIC CHARACTERIZATION AND TREND ANALYSIS OF THE DISCOMFORT INDEX FOR PIRACICABA-SP

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Abstract

Some climatologic aspects of Piracicaba city, located in the São Paulo state, are here analyzed. It was used a dataset of 60 years (1943 – 2002) of daily temperature and relative humidity measured on the border region of the city that separate urban and rural areas. This climatologic dataset allowed compute and analyze the Discomfort Index, according to Bosen's methodology. Trend analysis was performed by using the sequential version of Mann-Kendall test and changing points were detected by Pettitt's test. The analyzed dataset - considering daily average data - allowed us classifying the bioclimatic of Piracicaba as bioclimatologically comfortable. However, important temporal changes were observed. The relative air humidity has been significantly changed since the end of 60's and apparent temperature has been significantly changed since the middle of 80's. Consequently, the DI value has been expressively changed since early of 80's.

Key-words*:* bioclimatology; Discomfort Index; Piracicaba city; climate changing; temporal evolution of apparent temperature and relative humidity.

Resumo

Caracterização bioclimática e evolução temporal do índice de desconforto para Piracicaba - SP

Neste trabalho alguns aspectos sobre a climatologia do município de Piracicaba, localizada no estado de SP, são analisados usando uma base de dados de 60 anos (1943 – 2002) de temperatura média diária e umidade relativa do ar, que foram medidos na periferia da área urbana. Esta base de dados climatológicos permitiu o cômputo e a análise do Índice de Desconforto, conforme a metodologia proposta por Bosen. Análise de tendência foi realizada usando-se uma versão sequencial do teste de Mann-Kendall e os pontos de alteração drástica foram detectados através do teste de Pettitt. Os dados analisados nos permitiu classificar o município de Piracicaba como bioclimatologicamente confortável. Contudo, expressivas mudanças temporais foram detectadas. Observou-se que a umidade relativa do ar tem sido significativamente alterada desde o final dos anos 60 e a temperatura aparente apontou drásticas alterações desde meados dos anos 80. Conseqüentemente, os valores do Índice de Desconforto têm sido expressivamente alterados desde o início dos anos 80.

Palavras-chave: bioclimatologia; Índice de Desconforto; município de Piracicaba; mudanças climáticas; evolução temporal da temperatura aparente e umidade relativa.

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GEOGRAFIA, Rio Claro, v. 31, n. 1, p. 151-167, jan./abr. 2006.

INTRODUCTION

The climate is one of the most important environmental factors that govern the physiology, biogeography, ecology and others biological characteristics of the living organisms over the Earth, including the man. Many climatologic factors can have strong influence over the life style of the living organisms. Two of them are temperature and humidity, which jointly can govern the comfort/discomfort sensation of the organisms (HEIDORN, 1998).

In tropical countries, most of the time cooling is necessary to maintain the body heat equilibrium, and in this case, considering that the temperature is often high, when the humidity is high as well, much of the lost heat is countered by an almost equal heat gain. Thus, the cooling of the body is minimal, leading to overheating. Researches on the effects of heat and humidity on humans have shown that the severity of heat disorders increases with age accordingly. Conditions which cause heat cramps in a 16-year old may cause heat exhaustion in a 40-year old and heat stroke in someone over 60 (HEIDORN, 1998).

Humans adjust to the demands of these conditions by way of the thermal regulatory system. This system balances heat production and loss. The thermal regulatory system of human body is minimally active when thermal conditions do not differ and it is more demanded in unfavorable situations. Cold stress can be generally be reduced by wearing appropriate clothing or finding shelter in wind-protected areas. Heat stress is more problematic because the direct physiological possibilities for adjustment are limited (SENATE DEPARTMENT OF URBAN DEVELOPMENT, no data).

Aiming to express how is the feeling of a person in an environment, in a scale ranging from very cold to very hot, some bioclimatic indexes has been used. These indexes are based on air temperature, air humidity, wind velocity, solar radiation, among others (KAKJSTEIN; VALIMONT, 1986). Normally, the two firsts are more used on the determination of such indexes (ASSIS; CAMARGO (2003), DEOSTHALI (1999), FERNÁNDEZ GARCÍA (2002), QUINTELA; GASPAR (1997)), considering that wind velocity and solar radiation are parameters very changeable and problematical to evaluate within urban places, and also considering that the heat stress is normally the main focus of scientific studies on the effects the climate of dense urban areas has on human health and well-being.

Even though there is scientific consensus about an ongoing global warming, there is no consensus about its cause and the urban expansion is normally considered one of the main causes that change the local climate. It is an established fact that the process of urbanization produces radical changes in atmosphere of a region, involving the radioactive, thermal, humidity and aerodynamic characteristics. The cities along the world are continually expanding due to the incessant influx of migrants from rural areas. In developing countries, particularly, a high rate of increase in population creates an additional factor aggravating the situation. This has resulted in urban problems of varied nature, underlining the importance of studies in urban climate (DEOSTHALI, 1999).

The difference in atmospheric conditions between the city and its surrounding areas includes a lower average wind velocity and higher temperatures. This can be described as a heat island. The climate in and around cities and other built up areas is altered in part due to modifications which humans make to the surface of the Earth during the urbanization process (DEOSTHALI, 1999). The surface is typically rougher and often drier in cities, as naturally vegetated surfaces are replaced by buildings and paved streets. Buildings along streets form urban street “canyons” that cause the urban surface, taking on a distinctly three-dimensional character.

These changes affect the absorption and reflection of solar radiation, the surface temperature, the evaporation rates, storage of heat and the turbulence and wind climates of cities. It also can drastically alter the conditions of the near-surface atmosphere. Human activities in cities also produce emissions of heat, water vapor and pollutants which directly modify the temperature, humidity, visibility and air quality in the atmosphere above cities (LEMONICK, 2001). On slightly larger scales, urbanization can also leads to changes in precipitation above and downwind of urban areas. In fact, urbanization alters just about every element of climate and weather in the atmosphere above the city, and sometimes downwind of the city.

Although cities themselves form a very small fraction of the Earth's surface area, the world's population has become increasingly urbanized and it is now affected by urban climates. Moreover, cities are important sites for greenhouse gas emissions because of the high energy required by urban residents and their activities. These emissions extend the (indirect) influence of cities on climate to much larger scales. Locally altered urban climates that have existed for many years may provide with some insight into how is the reaction to large scale climate change and this makes the study of urban climates increasingly important (VOOGT; OKE, 2003).

The Piracicaba city, a town located in São Paulo State, Brazil, has 1,368.37 km^2 area, 531,987 inhabitants, according to Seade Foundation (FUNDAÇÃO SISTEMA ESTADUAL DE ANÁLISE DE DADOS, 2005) and it is an important agro-industrial and agro-technological center of the São Paulo State, with a large predominance of sugar-cane cultivation areas and many agro-industries (sugar-cane processing industries (SPAROVEK; COSTA, 2004). Since the 1940's, the city has been experimenting an expressive human population increasing (currently the population is near 10 times bigger than the population on the early 1940's). The population has becoming more and more urbanized. The figure 1 shows that in the 1940's the urban population was near 46% and currently near 96% of them are living in urban settlements. This clearly results in a significant expansion of the urban area of the city, as presented in figure 2.

The goal of this paper is to characterize the bioclimatology of the Piracicaba city (SP) and studying the temporal evolution of the human discomfort index over the last sixty years according to increasing of urban settlement.

Figure 1 - Temporal evolution of the percentage of urban population on the Piracicaba city (population in inhabitants * 10^3)

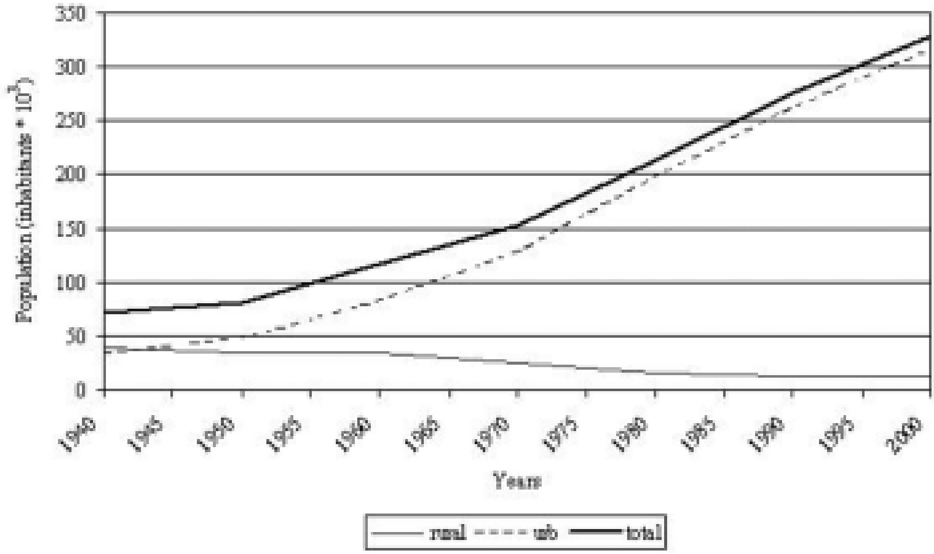
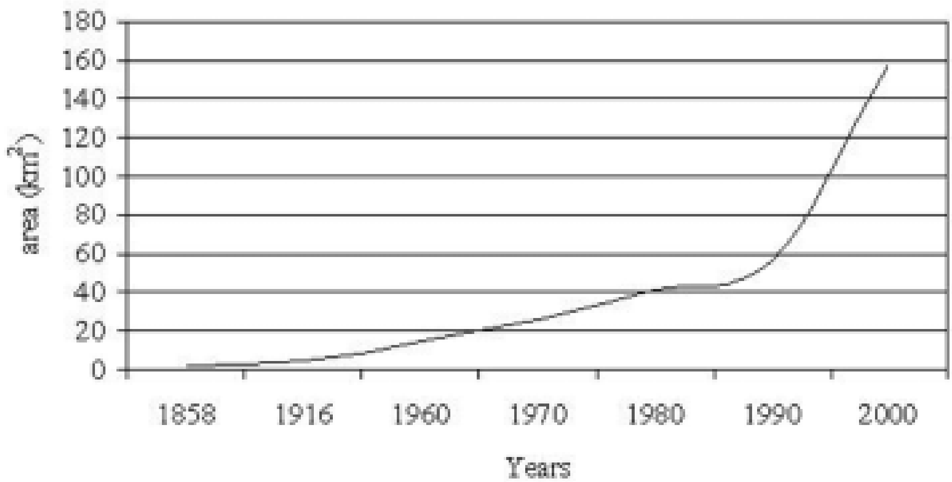


Figure 2 - Temporal evolution of the urban increasing of the Piracicaba city



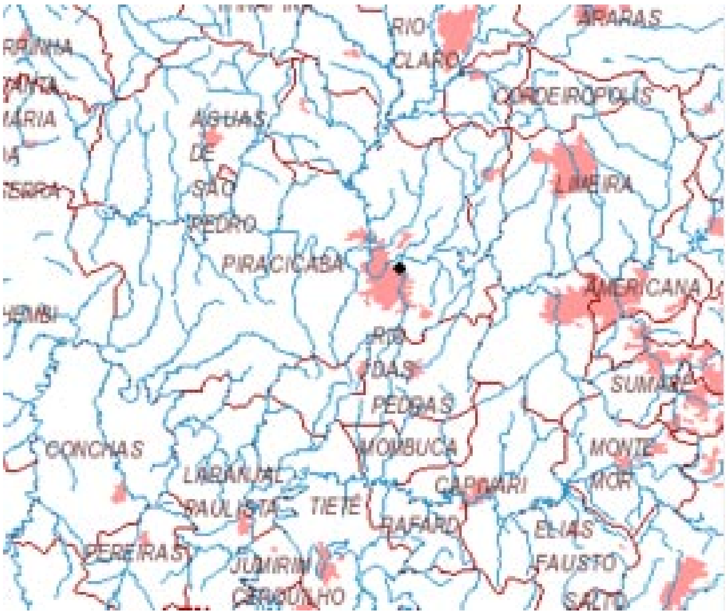
LOCATION AND ENVIRONMENTAL DESCRIPTION OF THE STUDY AREA

This study was carried out using a data set from Piracicaba city. The climatologic dataset used for this study was obtained from the Weather Station of “Escola Superior de Agricultura Luiz de Queiroz – ESALQ – University of São Paulo”. The geographic coordinates are: 22°42’30” South Latitude and 47°38’00” West Longitude, with 546m height above the sea level. The station is situated in the northern portion of the urban place of the Piracicaba city (Figures 3 and 4).

The annual average temperature is 21.6°C and the average annual rainfall is 1,230.0 mm. The climate is classified as Cwa according to Köeppen’s classification system (FERRAZ, 1996).

Figure 3 - Localization of the cities in the São Paulo state (largest map) and in the Brazilian territory (São Paulo city is the capital of São Paulo State)

Figure 4 - Location of the urban place of Piracicaba city and of the weather station (approximate scale: 1:1.000.000)



METHODS

The methodology used on this study was developed by J. F. Bosen and presented by Assis; Camargo (2003) and Quintela; Gaspar (1997). This index is utile for systematic assessment of the level of discomfort for hot climates (QUINTELA; GASPAR, 1997). The equation is:

$$D.I. = 0.55T_a + 0.2T_{po} + 5.28 \qquad (1)$$

Where:

D.I. – discomfort index.

T_a – Air temperature (°C) – average daily value.

T_{po} – dew point temperature.

The dew point temperature was calculated by using the Teten's equation (ASSIS; CAMARGO, 2003):

$$T_{po} = \frac{237.3 * \log\left(\frac{e_a}{6.10}\right)}{7.5 - \log\left(\frac{e_a}{6.10}\right)} \qquad (2)$$

Where:

e_a - vapor pressure (kPa).

T_{po} – the dew point temperature (ºC).

The vapor pressure was determined through the equation:

$$e_a = \frac{RH}{100} * e_a \tag{3}$$

Where:

e_s – Saturated vapor pressure (kPa).

RH – Relative humidity - average daily value (%).

The saturated vapor pressure was calculated using the Tetens' equation (VAN DAM et al., 1997):

$$e_s = 0.611 * \exp\left(\frac{17.27 * t_a}{t_a + 237.3}\right) \tag{4}$$

Where:

e_s –Saturated vapor pressure (kPa).

T_a – Air temperature (ºC) – average daily value.

This Discomfort Index (DI) was chosen due to the existence of categories ranging from no discomfort to strong discomfort. Meanwhile, aiming trend comparison, the "apparent temperature" (STEADMAN, 1984) was employed. This index is widely used, including the National Weather Service of the United States (YEE YAN; OLIVER, 1996) and in Germany for urban and regional plan (HÖPPE, 2000). Ignoring wind effects, the "apparent temperature" can be calculated by the following equation:

$$AT = -1.3 + 0.92T_a + 2.2e_a \tag{5}$$

The database of air temperature (average daily values) and air humidity (average daily values) were analyzed from 1943 to 2002 period.

In order to assess the temporal evolution of the discomfort index and statistically determining the trend of the climatologic data, the sequential version of Mann-Kendall test was applied (GOOSSENS; BERGER, 1986). To determine abrupt changes in the mean values the Pettit test was applied (DEMARÉE, 1990, MORAES et al., 1998). These non-parametric tests are widely used to assess temporal changes in meteorological parameters (CAVADIAS, 1992). To avoid incorrectly identification of trends the independence of the time series was verified by applying an Auto Correlation Function test before using statistical trend tests (YUE; WANG, 2002, YUE ET AL., 2002).

Additionally, in order to compare the results of Piracicaba city and some other cities located in the São Paulo State the average temperature was employed to perform statistical tests. The cities Campinas, Limeira, Jaú, Monte Alegre do Sul, Tatuí and Ubatuba, whose location is shown in Figure 3, were chosen because the availability of the climatologic dataset (monthly average temperatures longer than decades).

RESULTS AND DISCUSSION

Figure 5 shows the monthly average values of Discomfort Index for Piracicaba city. The mean annual amplitude is 5.6, ranging from the highest value (22.9) in February to the lowest (17.3) in July. According to Table 1, values lower than 21.0 indicate no discomfort, and such situation is observed for months April to October. From November to March the values indicate that less than half population feels discomfort (second interpretation class of Table 1).

Figure 5 - Monthly average values of Discomfort Index for Piracicaba city based on a daily dataset of 60 years of observation

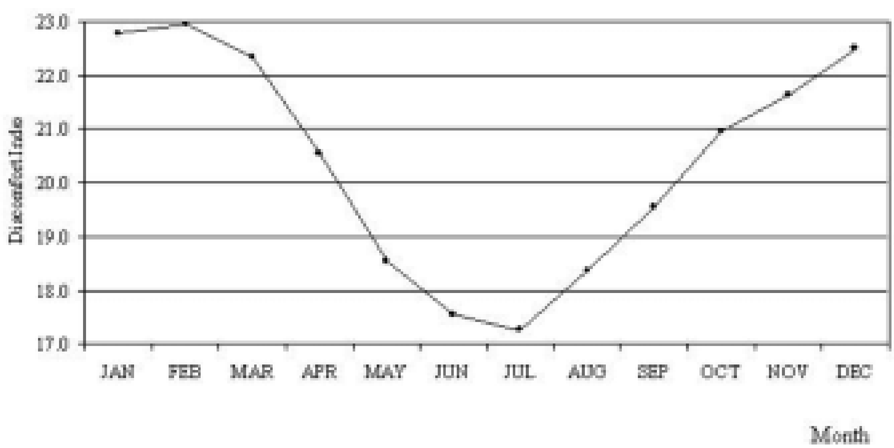


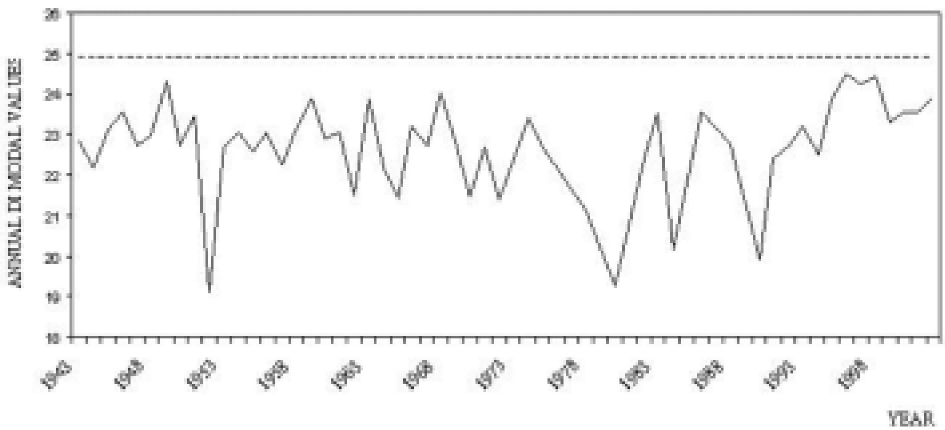
Table 1 - Interpretation categories for discomfort index (D.I.) according to range of values

Class	Range	Interpretation
1	≤ 21.0	No discomfort
2	21.1 - 24.9	Less than half population feels discomfort
3	25.0 - 27.9	More than half population feels discomfort
4	28.0 - 29.9	Most population feels discomfort and deterioration of psychophysical conditions
5	30.0 - 32.0	The whole population feels an heavy discomfort
6	≥ 32.1	Sanitary emergency due to the very strong discomfort which may cause heatstroke

Source: Eurometeo (http://www.eurometeo.com/english/read/doc_heat).

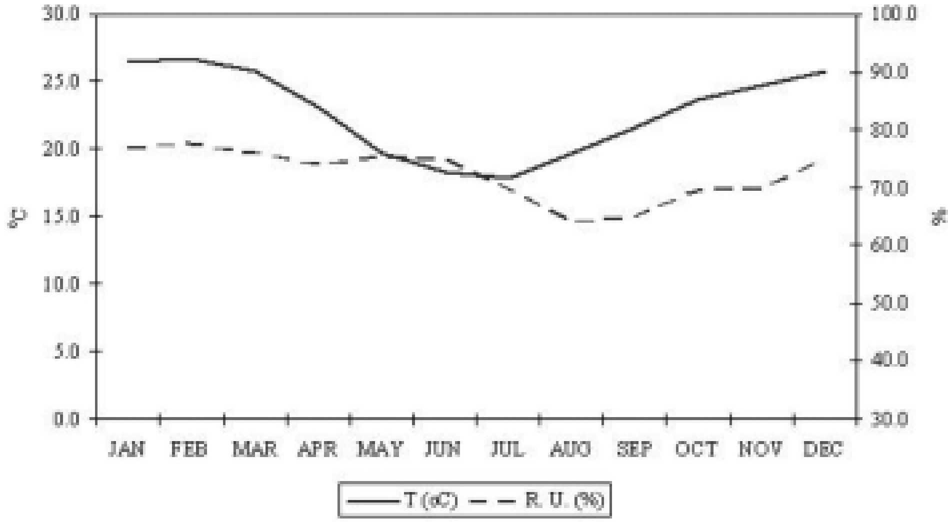
Although the Figure 5 was elaborated with average annual values and sometimes it might not precisely represents the actual bioclimatic conditions of the city, the Figure 6 shows the modal values occurring in each one of the studied year and indicates the climate in the Piracicaba is comfortable at most part of the studied years, with only four values situated in the “class 1” of the Table 1 and all the others situated in the “class 2”.

Figure 6 - Annual modal values of DI. The lower dash line represents the upper limit of the class 1 and the lower limit of class 2 of the Table 1. The higher dash line represents the upper limit of class 2 and lower limit of class 3 of the same Table



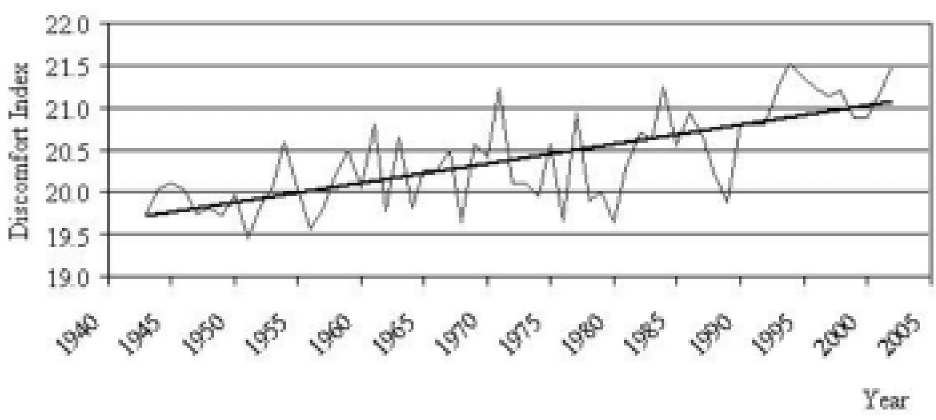
The seasonality of the apparent temperature and relative humidity are shown in Figure 7. It can be observed close similarity among the DI and temperature charts. The relative humidity presents slight variation along the year. However, it is in February that it gets the highest value, jointly with the temperature, resulting in the highest DI value, as shown in Figures 5. Considering the lowest values, it was observed that for the temperature the month was July and for relative humidity the month was August.

Figure 7 - Chart showing the seasonality of the average monthly temperature and monthly relative humidity



Nevertheless, although the DI values for Piracicaba city suggest that there is no discomfort or just a little discomfort, the data showed on Figure 8 show that an expressive change of such index it has been occurring since the 40's.

Figure 8 - Temporal evolution of the annual values of the Discomfort Index and the trend line generated



The Mann-Kendall's and Pettitt's tests show that the DI values were significantly altered in 1980 (Table 2 and Figure 9). For apparent temperature the effect was observed a little after (in 1982) and for relative humidity the effect was observed before (end of

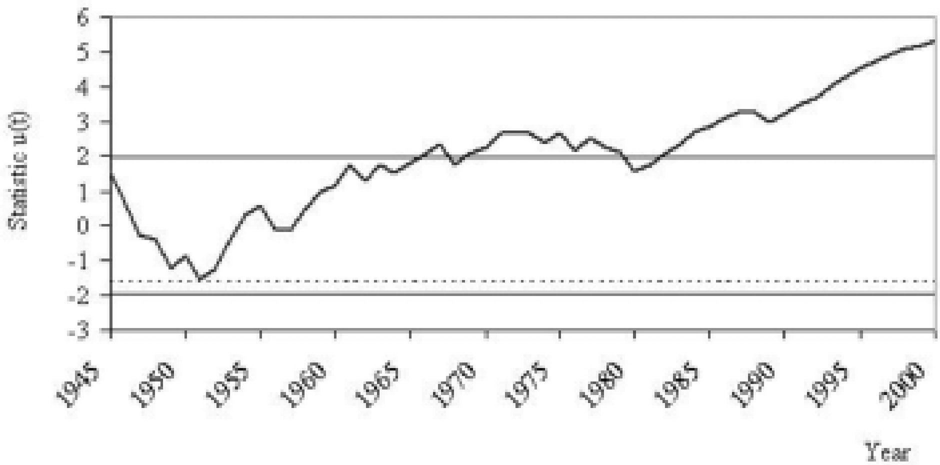
60's – Figures 10 and 11, respectively). The increase of relative humidity, with direct influence on the DI, has the same changing point as the increase of precipitation of the Piracicaba river basin, observed by Moraes et al. (1998).

Table 2 - Summarized results of statistical tests[(a)] for average, maximum and minimum temperatures (T_{aver}, T_{max} and T_{min} respectively), relative humidity, Discomfort Index and Aparent Temperature. The means before and after 1981 and its difference (D) were presented together, representing the changes in mean at the beginning of the 80's, where most of the changing point occurred

	Mann-Kendall	***Pettitt***	***Mean 1943-1980 1981-2002***
T_{aver}	T+1987	CP 1982 SL 0.0001	21.22 22.17 Δ= 0.97
T_{max}	T+1993	CP 1983 SL 0.0028	28.08 28.66 Δ= 0.58
T_{min}	T+1986	CP 1981 SL 0.0000	14.54 15.52 Δ = 0.62
Relative Humidity	T+1970	CP 1969 SL 0.0000	70.84 74.68 Δ = 3.84
Disconfort Index	T+1969	CP 1980 SL 0.0000	20.11 20.89 Δ = 0.78
Aparent Temperature	T +1983	CP 1981 SL 0.000	22.33 23.49 Δ = 1.16

[a] Trends; T+. upward significant (α<0.05); and year from which the trend is significant; Changing Point: CP=year; Significant Level: SL=value; D: difference between periods.

Figure 9 - Mann-Kendall sequential test applied to Discomfort Index



In order to complement such statistical tests, it was quantified the frequency of days whose value of Discomfort Index was higher than the lowest value of the class 3 (> 25.0 - Table 1), corresponding to more than half population feeling discomfort. For this purpose the DI index was calculated using the maximum daily temperature and the mean dew point temperature, once the relative humidity was only recorded as daily mean. Before 1983 the average number of days with DI > 25.0 was 120 and after 1983 the number of days increased to 158, meaning that after 1983 there are 38 additional days per year where more than half population feels discomfort.

As earlier mentioned, there are natural and anthropogenic causes that might explain such variation on the climatologic parameters and, consequently on the DI trends for Piracicaba city and region.

Among the natural causes, the sun is by far the most important driving force of the climate system (Beer et al., 2000). The Earth's climate response to a given forcing is strongly dependent on feedback mechanisms connected with clouds, water vapour, ice-cover, albedo, atmospheric and ocean circulation, etc. There are many other forcing factors besides solar forcing to be considered when discussing climate change. For example volcanic dust can reduce significantly the solar insolation leading generally to a cooling. Other possible causes of climate change are internal variations within the climate system itself which affect the global distribution of heat.

On this way, Lohele (2004), examining the global warming question through time-series analysis of geologic data (oxygen isotopes determined from sea floor sediments), suggests that 20th century warming trends are plausibly a continuation of past climate patterns. The author pointed out that the results are not precise enough to solve the attribution problem by partitioning warming into natural versus human-induced components. However, anywhere from a major portion to all of the warming of the 20th century could plausibly result from natural causes according to these results.

Regarding to human-induced change, derived mainly from the land cover change through the past centuries, it indicates that if the anthropogenic forces are not the responsible for such climate change, it certainly is an "intensifier" agent of this process, under two central ways: one cause linked to rural area and one linked to urbanization. Logically such two reasons are complementary themselves.

About the agricultural approach, according to Ferraz (1996) since middle of 60's has occurring in Piracicaba an expressive increasing of the cultivated area of sugar-cane on the region, while areas with natural remnant vegetation have been drastically diminished. Such land cover changes consequently started an alteration on patterns of albedo, where the sugar-cane reflects more than natural forest (Bloom, 1970). On this way, there is the beginning of a possible local climatologic change.

An another additional cause is the fact that the sugar-cane plant is a low plant and such culture means fields with poor roughness, once that the plants are all of same age and are uniformly tall. This situation permits an increasing of the wind speed. The employed "technology" for the sugar-cane harvest is still through of a previous burn of the sugar-cane fields with a posterior manual work (burning material becomes the manual work easier and such activity has been repeated since the 40's), with a little mechanically managed area. This implicates on the emission of great quantities of carbon dioxides and other greenhouse gases to atmosphere (Lara et al., 2001), although this emission not necessarily causes drastic local effects.

Under the urban approach, probably the most important cause of such detected DI evolution, it is important to mention that all urban area located near the weather station is already urbanized since long time ago (100 years at least), once this area is the main region that connects the highway connecting São Paulo and Piracicaba cities.

However, according to old local inhabitants, in 80's and 90's it was occurred a drastic alteration on the patterns of the civil construction and the average height of the buildings had increased. This urban alteration surely implicates in changing the regional air circulation, with consequently change on the air humidity. Obviously it is expected that the DI values in the central part of the urban area are stronger than its neighborhoods (GOMEZ et al., 1998).

Figure 10 - Mann-Kendall sequential test applied to Apparent Temperature

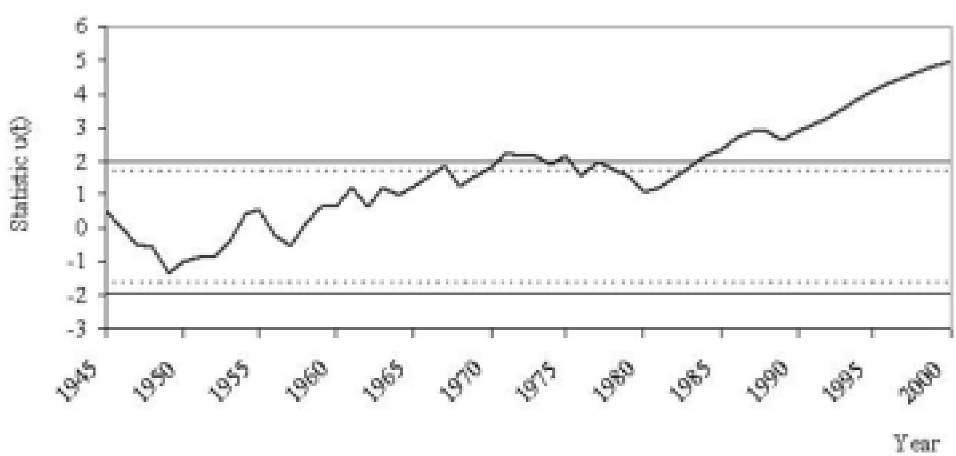
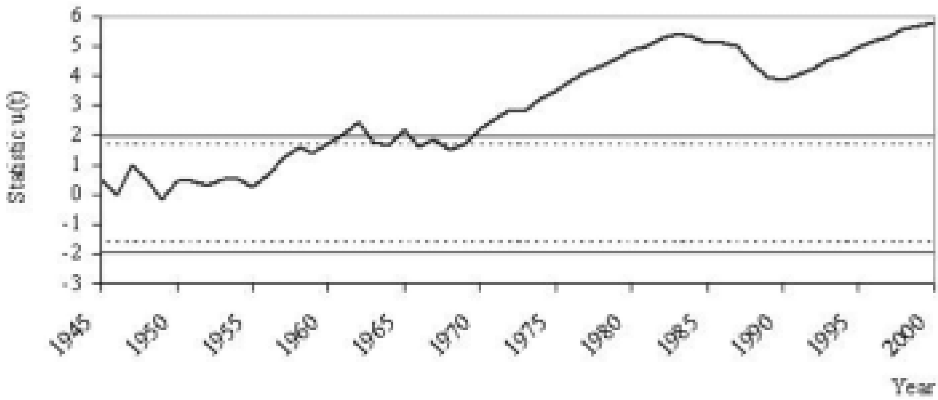


Figure 11 - Mann-Kendall sequential test applied to Relative Humidity



The reported alterations on this study are probably more related to land cover changes associated with regional and urban climate changes. There also is the high increasing of Piracicaba urban people as early showed in figures 1 and 2.

The population increasing normally brings many consequences. One of them is the increasing of the number of vehicles. Currently, the number of vehicles in Piracicaba is approximately 140,000 units, being predominantly automobiles (near 66%) and after by motorbikes (near 14%). Number of bus – a popular and alternative kind of transportation and with probable reduction on the pollutant emission, is only 0.66% (SILVA; LEITE, in press).

Table 3 presents the statistical tests performed by using temperature data, together with population, distance from the urban area (D_{urban}), distance from the center of the town (D_{center}) and distance from Piracicaba (D_{Pir}). The general results show a positive significant trend in all average temperatures becoming significant after the 70's but the changing points are different for each city. Excepted Tatuí and Ubatuba all other weather stations are near the borders of the cities, but the period of such data set is shorter and deeper comparisons are tricky. The nearest city from Piracicaba is Limeira and its trend became significant near the end of the 90's. This station is farther (2.01 Km) from the border of the urban area than the one in Piracicaba (800 meters), suggesting that important influence of the urbanization on the average temperature occurs in this last station.

Average temperature of Campinas, the biggest city of region, became significant at the end of the 90's (MELLO et al., 1994), similar to Piracicaba. Meanwhile, its changing point was 7 years later. The Campinas station is close to the city border like Piracicaba. On the other hand, the average temperature of Monte Alegre do Sul, became significant at the beginning of the 70's. This station is very close to the center of the city and even though it is a small city, probably buildings could cause an influence in this temperature.

Although the increasing of temperature over the planet has occurring since the last century (LEMONICK, 2001), due to natural and/or anthropogenic causes, and this actually implicates in a generalized increasing of the DI values along the planet, comparatively for the Pelotas city (located in Brazilian southern region), Assis; Camargo (2002), studied a DI dataset from 1967 to 2000 (calculated using same methodology described in present study) and pointed out that the DI values did not changed along the study period, showing a strong intra-annual variance and practically none evolution of the annual average values in the studied period.

On this way, it seems that there are regions along the planet whose such effect is more effective and others regions where is not. This certainly needs to further studies to be investigated with refined details. The interpolation of the spatialized values and generation of truly bioclimatologic maps, as that one elaborated by Svensson et al. (2003), should be a nice option.

CONCLUSIONS

Results obtained on this study permitted us classify the climate of the Piracicaba city as comfortable in half of the year. However, important changes and significant trends were detected, and such trends indicate an increasing of the Discomfort Index, that might become the city climate less comfortable.

For the two analyzed parameters considered on the computation, DI and apparent temperature, Man Kendall test showed that both parameters have been significantly altered since the early 80’s and the Relative Humidity has been significantly altered since the early 70’s.

As pointed out in literature, it is difficult affirm that the land use is the main cause of such increasing of the DI along the decades (how much is due to natural factors and how much is due to anthropogenic influences), but the close relation observed among the increasing of the annual values of ID and the land cover change on the Piracicaba city permit us stating that the land use change represents an important driving force that stimulates the regional climatic change.

The trend towards less comfortable condition is reinforced by the occurrence of 38 more days per year, after 1983, with more than half of the population felling discomfort. This represent around 10% of the year that can be considered as a significant change of the local climate.

ACKNOWLEDGEMENTS

The authors thanks the people of Weather Station of the “Escola Superior de Agricultura Luiz de Queiroz” (USP) by permission of use the meteorological dataset.

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Recebido em setembro de 2005
Revisado em outubro de 2005
Aceito em novembro de 2005