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A Linear Model for Moving Measurements Estimation in Urban Climate Studies

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Abstract: Problem statement: Several methods can be adopted to study the variations in urban climate. The mobile measurement method is one of them, involving information provided by moving measurements of air temperature, that are taken in points defined along pre-established routes and also data from fixed-point temperature recording stations. Because moving measurements are made in different times along the measurement process, adjustments must be made in order to adequately analyze the air temperature measurements. **Approach:** Mobile measurements were taken in an urban area and contextualized in the domain of some fixed-point temperature recording stations. Therefore, a linear model proposed to investigate and represent the variables that influence moving measurements estimation in the urban context. **Results:** All proposed variables in the linear model were considered relevant, because all coefficients of the determined model were non null. Also, the identified model presents a good fit to the field data, as indicated by the resulting coefficient of determination (R^2) that is 90.3%. **Conclusion/Recommendations:** The linear model described in this work is easy to apply, requiring few input variables. It is important to emphasize that the model was developed to estimate moving measurements as a function of fixed measurements and presents the potential to identify new input variables based on moving measurements, as shown by the fit among fixed and moving temperature measurements, in order to provide insight about other possible models of late time adjustment.

Key words: Late time adjustment, urban climate studies, air temperature, parameters estimation, temperature measurements, model presents, fixed-point temperature, mobile measurements, fixed-point temperature, interpolation methods, air temperature, area's morphology, model described

INTRODUCTION

Nowadays, many methodologies are adopted to study the variations in urban climate (Mirzaei and Haghighat, 2010; Oke, 2006). The data needed for these studies can be obtained from weather stations, fixed-point measurements, mobile transect measurements and remote sensing; also, can be inferred from mathematical models. In this way, several studies present mathematical models to estimate enviromental variables, such as the air temperature related ones (El-Nesr *et al*., 2010; Mota *et al*., 2011), rainfall characteristics (Thongwan *et al*., 2011; Danazumi *et al*., 2010), underground water characteristics (Rahnama-Rad *et al*., 2010) and solar radiation characteristics (Kudish and Evseev, 2007).

Mirzaei and Haghighat (2010) emphasize that data gathering in urban context present limitations and require and independent approach. They also report that only a limited number of parameters are actually registered in fixed and moving metering stations. This fact does not allow the estimation of all spatial

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dimensions in the desired urban area. So, approximations are usually employed to supply the data that corresponds to the inaccessible stations. The data must be gathered along a long period of time to minimize the influence of unpredictable errors. Mirzaei and Haghighat (2010) also conclude that data analysis is the sensible point about this approach. Even after sufficient data is available, consistent representations can not be based on simple correlations among just the measured temperatures and heat urban island characteristics, because there are a huge amount of external parameters that influence the heat island formation. Thus, the estimation of a model that composes temperatures relations becomes crucial.

More specifically, the mobile measurement method (Charabi and Bakhit, 2011; Murphy *et al*., 2007). Vicente-Serrano *et al*., 2005) is usually used to obtain a detailed horizontal distribution of climate variables. The methodology begins with the specification of the urban area under study and the points inside this area where the measurements will take place. After the study area is delimited and the measurement points are defined, the moving measurements of air temperature are made along pre-established routes that encompass all the measurement points. The main purpose of mobile transect measurements is to obtain detailed horizontal distributions of air temperatures in urban areas. To achieve this goal, sensors are mounted on a vehicle or carried by a person over a specific trajectory in an urban area, yielding mobile measurements that are combined with continuously recorded fixed-point measurements, in order to obtain reliable adjustment indexes using the correlation of both results. Beeson *et al*. (2005) reports the advantages of using moving transects in short routes, mainly because this situation permits data gathering from multiple points in a short period of time. However, over long trajectories, there may be a significant time difference between the first and last measurement. In these cases, interpolation methods can be applied to the climate measurements in order to account for the differences between times of day. In one hand, some authors have criticized the method due to the aforementioned time difference. On the other hand, others have successfully applied interpolation methods, like Kaiser and Faria (2001). that conducted a case study in the city of Bauru, state of São Paulo, Brazil, wherein they assessed the adjustment of late time caused by mobile measurements. Several authors use the transect-based mobile measurement method to produce a detailed horizontal distribution of air temperatures within urban areas. Some studies mount the instruments on automobiles or other vehicles (Sun *et al*., 2009; Pezzuto *et al*., 2006; Hedquist and Brazel, 2006; Vicente-Serrano *et al*., 2005); while in others the measurements are performed by a person on foot (Nagara *et al*., 1996). Lee and Sharples (2008) implemented two transects using automobiles and one using an aircraft.

In the present study, mobile measurements were taken with the instruments mounted on an automobile, for this enables a characterization of the urban heat island at a low cost and much higher measurement point density. Some fixed-point temperature recording stations were also distributed across the study area to provide supplemental data in addition to the mobile measurements.

MATERIALS AND METHODS

Studied area and measurement points: The study was conducted in the city of Campinas, located in the southwestern region of the state of São Paulo, Brazil, at the geographic coordinates: latitude 22°53'20”S, longitude 47°04'40”W, occupying a total area of 796.40 km2 (urban area of 388.90 km2 and rural area of 407.50 km2) and at a mean altitude of 680 meters. Its estimated population is 962996 people (City Secretariat of Planning, Urban Development and Environment, 2011).

The measurements were made using a portable digital thermometer (model TH-090 with type K thermocouple sensor) mounted on an automobile. The equipment was installed on the side of the vehicle, attached to a rod mounted on the car door, at an approximate height of 1.50 m above the ground. Air temperature readings were recorded by the driver/researcher.

The transect (Fig. 1) covered the entire study area. 18 mobile measurement points were defined over an approximately 20 km route, covering a diversified range of land usage. The trajectory was defined based on the most reasonable route to be taken considering the local traffic. Thus, the decisions about the route and the location of the measurement points were made to provide the best possible coverage of the area under study.

Eight fixed-point measurement stations were set up near the mobile measurement locations to enable late time adjustment. The fixed measurement points were used as references for late time adjustment. The criteria used to assign fixed points to each mobile point were proximity between the points and similarity in usage and occupation of the land around them. Figure 2 illustrates how the fixed and mobile points were grouped according to the study area's morphology and Table 1 describes these groupings location in the urban context of the studied area.

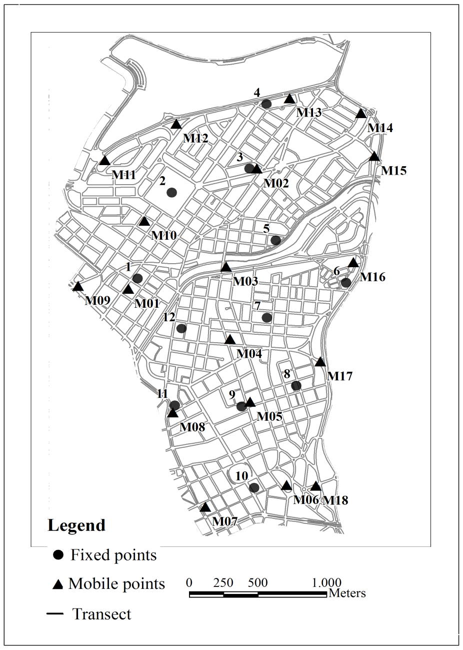

Fig. 1: Map of mobile points, fixed points and transect-study area

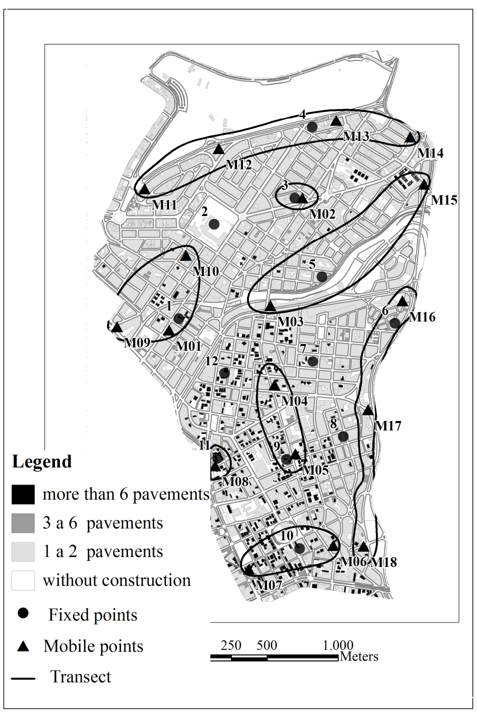

Fig. 2: Map of fixed and mobile point groupings according to proximity across area's morphology

Table 1: Description of fixed and mobile point grouping locations

Mobile points	Fixed point for adjustment	Surrounding area
01/09/10	01	Mixed-use area little vegetation, predominantly 1 or 2 story buildings, except for some
02	03	areas with 6+ story buildings
03/15	05	Predominantly residential area, 1 or 2 story buildings, near valley bottom region
04/05	09	Mixed-use
06/07	10	area, with 8-12
08	11	story buildings and some lower buildings
11/12 / 13/14	04	Predominantly residential area, 1-2 story buildings, near wooded area and body of water
16/17/18	06	Intense traffic corridor, predominantly commercial area 1-4 story buildings, except for some areas with 10+ story buildings, near valley bottom region

Mobile measurements data gathering: The mobile measurements were carried out in three shifts: 9:00 AM, 3:00 PM and 9:00 PM. Data were collected in two times a year, during the winter and summer. The winter data collections took place over seven days of measurements in late July and early August. In the summer, the data were collected in March, over nine days of measurements. During the data collection periods, there was no recorded precipitation and all days presented stable weather conditions.

Each circuit was initiated approximately forty minutes prior to each standard study time (for example, the 3 PM circuits commenced at 2: 20 PM) and the time and temperature at each reading were recorded at all selected measurement points. A quick stop (approximately 1 minute) was made for measurement recording at each point. Thus, each circuit was completed over a 1:15 to 1:40 hour period, depending on the conditions of local traffic and time of day.

The collected mobile measurement data must be adjusted to the reference daytimes adopted in the measurement shifts (9: 00 AM, 3: 00 PM and 9: 00 PM). Such adjustment is necessary because there may be a significant time interval between the first and last measurements in a certain circuit. Consequently, interpolation methods are needed to adjust the mobile measurements to the standard times. In this work, late time adjustment was performed using the multiple linear regression model described below.

Linear model for late time adjustment: Since temperature measurements must be estimated at the standard times, a multiple linear regression model, represented by Equation × was adopted for the late time adjustment to the standard times (9: 00 AM, 3: 00 PM and 9: 00 PM):

$$Y = \beta_0 + \beta 1X_1 + \beta 2X_2 + \beta 3X_3 + \beta 4X_4$$

Where:

Y = Mobile measurement temperature
X1 = Fixed-point temperature reading at standard time
X2 = Fixed-point temperature reading at same time as mobile point reading
X3 = Time difference between mobile point reading and standard time, in minutes
X4 = Binary variable, that is 1 for summer readings and 0 for winter readings

RESULTS

Model parameters estimation: The following regression equation defines the parameters obtained from the model regression, using the data from mobile and fixed points (Eq. 1):

$$Y = 2.68 + 0.47X_1 + 0.40X_2 + 0.01X3 + 0.70X4 \quad (1)$$

The regression analysis results are shown in Table 2-3. Table 2 presents the variance analysis and indicates that the regression was adequate (p = 0.000), rejecting the null hypothesis at the 5% significance level.

Validation: In order to validate the model, the temperature data acquired at July 29 was used, as shown in Table 4.

The adjusted mobile point times (Y) were obtained by applying the linear regression equation for the identified model (Eq. 2):

$$Y = 2.68 + 0.47X1 + 0.40X2 + 0.01X3 + 0.70X4 \quad (2)$$

Using the temperatures presented in Table 4, the mobile temperatures can be adjusted to standard times.

Table 2: Linear regression results

		Coefficient	P-value
Variable	Constant	2.68	0.000
Fixed-point temperature reading at Standard time	X_1	0.47	0.000
Fixed-point temperature reading at same time as mobile Point reading	X_2	0.40	0.000
Time difference between mobile point reading and standard time, in minutes;	X_3	0.01	0.000
Variable equal to 1 for summer readings and 0 for winter readings	X_4	0.70	0.000

Table 3: Variance analysis results

Source	DF	SS	MS	F	P-value
Regression	4	12806.7	3201.7	1753.23	0.000
Error	751	1371.4	1.8		
Total	755	14178.2			

Table 4: Fixed and mobile temperature results for July 29

Time	Fixed point 9 Air temperature (°C)	Mobile point 5 Air temperature (°C)
8:46 AM*	15.33	15.00
9:00 AM	15.41	
2:45 PM*	22.05	21.50
3:00 PM	21.76	
8:22 PM *	19.05	18.90
9:00 PM	18.90	

* Given that the fixed equipment recorded the temperatures at 10-min. intervals, the following approximation method was applied: for mobile measurement times ending in 1-5, the previous fixed measurement was used and for those ending in 6-9, the subsequent fixed measurement was used. Examples: 8: 46 AM (mobile) was correlated with 8:50 AM (fixed) and 2: 45 PM (mobile) was correlated with 2: 40 PM (fixed).

Equation 3-5 show the estimated mobile point temperature:

$$Y_{9AM} = 2.68+0.47^*(15.41) +0.4^*(15.33) +0.01^*(-14) +0.7^*(0) =15.91 \quad (3)$$

$$Y_{3PM} = 2.68+0.47^*(21.76) +0.4^*(22.05) +0.01^*(-15) +0.7^*(0) = 21.60 \quad (4)$$

$$Y_{9PM} = 2.68+0.47^*(18.9) +0.4^*(19.05) +0.01^*(-38) +0.7^*(0) =18.80 \quad (5)$$

A comparison between the mobile temperatures collected at point 5 and the standard-time temperature estimates for July 29 is shown in Fig. 3.

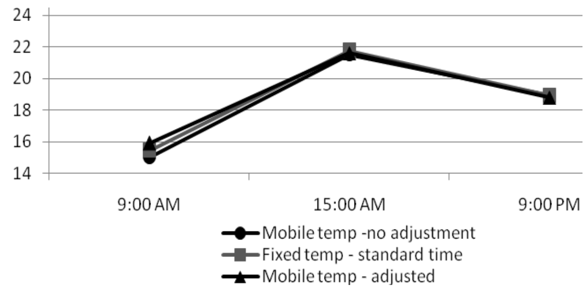

Fig. 3: Comparison between collected mobile temperatures and estimated temperatures- Point 5- July 29

DISCUSSION

Concerning the model, one can conclude that all of the variables influenced the regression line, for all of the obtained coefficients are different from zero. Also, the obtained coefficient of determination (R2) is 90.3%, indicating that the model presents a good fitness considering the available data.

Moreover, by applying the proposed adjustment methodology to the mobile measurements, it was possible to determine the horizontal distribution of air temperatures at the standard times (9, 3 and 9 PM) in the studied area during the collection period.

CONCLUSION

The model described in this work is easy to apply, requiring few input variables, assuming that the required parameters and variables are input correctly. Specifically, the variables that presented the best fit among fixed and moving measurements (and that corresponds to the proposed model inputs) are: the fixed-point temperature reading at a standard time, the fixed-point temperature reading at the same time as the mobile point reading and the time difference between mobile point reading and the standard time. On the other hand, it is important to highlight that data collection by the mobile measurement method must be carried out in strict compliance with the adequate criteria and methods, so that the same standards will apply to all measurement points.

The obtained results show a model with a good adjust between inputs and outputs; it is possible then to conclude that temperature readings can be taken in both levels (moving and fixed). That characteristic can be advantageously explored in the development of new models for lat time adjustment of moving measurements.

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