Effect of the Urbanization of Metro Manila on the Climate of Selected Urban and Rural Areas using WRFV3.4.1

Edgar Vallar[1,*], Jervie Oliveros[2], Maria Cecilia Galvez[1], and Gerry Bagtasa[3]

[1] *Environment And RemoTe sensing researcH (EARTH) Group, Physics Department, De La Salle University, Manila, Philippines*
[2] *Physics Department, Technological University of the Philippines, Manila, Philippines*
[3] *Institute of Environmental Science & Meteorology (IESM), University of the Philippines, Quezon City, Philippines*
**Corresponding Author: edgar.vallar@dlsu.edu.ph*

Abstract: The development of residential, commercial and business establishments in Metro Manila have increased due to a rapid growth of urban population producing an urban heat island (UHI) effect. UHI can be observed in the decrease of the diurnal temperature range (DTR) which is the difference between the maximum temperature (daytime) to the minimum temperature (nighttime). This work studied the effects of the UHI of Metro Manila on the meteorological conditions of nearby areas using the Weather Research and Forecasting model version 3.4.1 (WRFV3.4.1). WRFV3.4.1 is a mesoscale numerical weather prediction model that was used to determine the temperature (DTR, maximum and minimum) of selected urban and rural areas up to 100km North and 100km South of Metro Manila at 25km steps from the year 2000 up to year 2010. Results showed that the urbanization of Metro Manila does not affect (the trend is not statistically significant at p=0.05) the DTR of the surrounding areas for the study period. Although Metro Manila is developing even more during the study period, this period does not include the time when Metro Manila was just starting to urbanize. Long term (30 years or more) data might help to yield more refined information.

Key Words: urbanization; diurnal temperature range; urban heat island; WRFV3.4.1; numerical weather prediction

1. Introduction

Metro Manila is considered as one of the top five largest urban areas in the world, having an estimated population of 21,951,000 as of 2012 and a land area of 1,425 km^2 (0.48% of total land area of the Philippines) (Demograpia World Urban Areas: 8th Annual Edition, 2012). Metro Manila's estimated population growth rate annually is 1.1% (Ragrario J.M., 2003). Due to rapid growth of urban population, the demand for housing continues to rise. The higher demands of housing in urban areas bring changes in land use. Vegetation areas are transformed to high rise buildings, commercial establishments and roads.

Urbanization leads to less evaporation, higher surface temperatures, larger sensible heat fluxes, and a deeper boundary layer (Taha H. 1997; Sugawara & Narita, 2008). These modified atmospheric conditions lead to less water vapor, more water vapor mixing in the boundary layer and less convective available potential energy for triggering initiation of convection and rainfall formation (Zhang et al., 2009).

This study will focus on the characterization of the effect of the urbanization of Metro Manila on the temperature (DTR, maximum and minimum) of selected urban and rural areas located from 25km up to 100km from Lawton (Manila) using the Weather Research and Forecasting Version 3.4.1. (WRFV3.4.1) mesoscale numerical weather prediction model.

Trends will be investigated using the Mann–Kendall Test (M–K test) and Sen's Slope Estimator.

2. DATA AND METHODS

This section presents the domain used in the study, the WRFV3.4.1 calculations, and the statistical methods used in analyzing the data.

2.1. Domain

The domain of the simulation includes the selected urban and rural areas listed in Table 1. Groupings are based on their geographic locations and distances from Lawton. The USGS 24 Classification Land Use Category Index (LU) was used to identify urban and rural areas. A land use index (LU) of 1 means an urban area, LU=3 an irrigated cropland and pasture and LU=6 croplands and woodlands. Climate classification was also incorporated in the table to have an idea of the climate type of the selected area. The Modified Coronas Climate Classification (MCC) was used. A Type I climate is characterized by a distinct dry and a wet season; dry from November to April and wet during the rest of the year. For a Type II, there is no dry season and maximum rainfall during November to December. On the other hand, in Type III, the seasons are not very pronounced having a relatively dry period from November to April and wet for the rest of the year. Finally, Type IV places have rainfall more or less evenly distributed throughout the year. Most of the sites selected in this work are Type I. Tagaytay (50km South), Infanta (75km South), Lucena (100km South), and Dingalan (100km East) have been classified as a separate group since the characteristics of their locations do not seem to match their assigned classification.

Table 1. Selected sites with corresponding land use index (LU) and climate type (MCC).

Sites	Location	LU	MCC
MM	Quezon City	1	I
	Manila	1	I
	Pasig	1	I
25km S	Muntinlupa	3	I
	Gen. Trias	3	I
25km N	Sta. Maria	3	I
	Bulacan	3	I
25km E	Cogeo	3	I
50km S	Gen. Aguinaldo	6	I
	Calamba	3	I
	*Tagaytay	6	I
50km N	Angeles	3	I
50km W	Mariveles	3	I
75km N	Gapan	3	I
75km S	Lipa	2	I
	Luisiana (L)	6	III
	*Infanta	6	II
75km W	Olongapo	3	I
100km S	San Pablo	6	I
	Sn. Juan	6	I
	*Lucena	6	II
100km N	Cabanatuan	3	III
100km E	*Dingalan	6	II

* excluded and considered as another one group

2.2. Meteorological data

The study utilized the January 2000 up to December 2010 National Center for Environmental Prediction (NCEP) Final (FNL) grib1 operational global analysis data with 1.0x1.0 degree grids prepared every six hours. This product is from the Global Data Assimilation System (GDAS), which continuously collects observational data from the Global Telecommunications System (GTS) and other sources.

2.3. WRF process

WRFV3.4.1 was used in the study. The model generates the topographical features of the domain, rewrites the meteorological data into an intermediate data file format and interpolates the meteorological parameters for the selected domain.

2.4. Statistical method

2.4.1 Mann–Kendall test (M–K test)

Data was analyzed using the Mann–Kendall Test (M–K test). This method identifies trends in a time data series (Karpouzos et al., 2010; Chen et al., 2011). It is a rank–based procedure and is therefore resistant to the effect of extreme values in the data and deviations from a linear relationship (Hirsch et al., 1992). This generally measures the correlation between two variables. The M–K rank correlation coefficient (Kendall's τ) is applicable in cases when the data values (X_i) of a time series can be assumed to obey the model

$$\sum X_i = f(t) + \Sigma_i \qquad \text{(Eq. 2.1)}$$

where *f(t)* is a continuous monotonic increasing or decreasing function of time and the residuals Σ_i can be assumed to be from the same distribution with zero mean. It is assumed that the variance of the distribution is constant in time.

The Kendall's rank correlation measures the strength of monotonic association between the two vectors (*X* and *Y*). In case there are no ties in the *X* and *Y* variables, the Kendall's rank correlation coefficient τ is defined as:

$$\tau = \frac{N-M}{D} \quad \text{(Eq. 2.2)}$$

or

$$\tau = \frac{S}{D} \quad \text{(Eq. 2.3)}$$

where *N* represents the number of concordant pairs and *M* represents the number of discordant pairs. *S* is the Kendall score given by:

$$S = \sum_{i>1} sign(X_j - X_i) sign(Y_j - Y_i) \quad \text{(Eq. 2.4)}$$

where sign denotes the sign (or signum) function and *D* is the maximum possible value of *S* (Tonkaz & Cetin., 2007; Karpouzos et al., 2010). If the agreement and disagreement between the two rankings is perfect, the coefficient has value of 1 and –1, respectively. If *X* and *Y* are independent, the value of Kendall τ coefficient is approximately zero.

To identify a statistically significant trend, the *Z* value is used to evaluate the result of the M–K test. This statistic is used to test the null hypothesis (*Ho*) such that no trend exists. The standardized test statistic *Z* is given by (Tonkaz & Cetin., 2007; Karpouzos et al., 2010):

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & if\ S < 1 \end{cases} \quad \text{(Eq. 2.5)}$$

A positive *Z* indicates an increasing trend in the time–series, while a negative *Z* indicates a decreasing trend. If the probability (*p*) value is less than the confidence level (α=0.05), the null hypothesis (H_o) will be rejected and therefore accepts the alternative hypothesis (H_1).

2.4.2 Sen's slope estimator

The main purpose of the Sen's slope is to quantify the change in the magnitude of the trend per unit time (Karpouzos et al., 2010). The Sen's method can be used in cases where the trend can be assumed to be linear. This means that *f(t)* in Equation (2.1) can be described as

$$f(t) = Qt + B \quad \text{(Eq. 2.6)}$$

where *Q* is the slope and *B* is a constant.

To derive *Q*, the slope of all data pairs must be calculated first using

$$Q_i = \frac{x_j - y_k}{j-k}, i = 1, 2, \ldots. N, j > k \quad \text{(Eq. 2.7)}$$

If there are *n* values of X_j in the time series, this yields $N = n(n-1)/2$ slope estimates Q_i. The Sen's estimator of slope is the median of these *N* values of Q_i. The *N* values of Q_i are ranked from the smallest to the largest and the Sen's estimator is (Drápela & Drápelova, 2011)

$$Q_i = Q_{\left[\frac{(N+1)}{2}\right]}, \text{if } N \text{ is odd}$$

or (Eq. 2.8)

$$Q_i = \frac{1}{2}(Q_{\left[\frac{(N)}{2}\right]} + Q_{[(N+2)/2]}, if\ N\ is\ even$$

The computed positive and negative slopes represent the slope of increasing and decreasing trend, respectively.

3. RESULTS AND DISCUSSION

This work investigated the effect of urbanization on temperature [minimum temperature (Tmin), maximum temperature (Tmax) and diurnal temperature range (DTR)] for the years 2000–2010 for the sites selected. The maximum temperature is the temperature generated by WRF V3.4.1 every 06UTC or 2:00 PM PST (Philippine Standard Time). The minimum temperature is the temperature processed by the model every 21UTC or 5:00 AM PST. The diurnal temperature range (DTR) is the difference between the maximum and the minimum temperature. The urban heat island (UHI) effect exists once the Tmax or Tmin of an urban area is greater than that for a rural area (Li & Chen, 2009). Aside from this, analysis of the trends in DTR is also essential in indicating the presence of UHI.

3.1. Tmax

Fig. 1 shows the variation of Tmax for the selected sites. Tmax ranges from 23 °C to 35 °C. The average Tmax of Metro Manila (about 31 ˚C) is larger than the Tmax of all the other sites selected except for

Angeles City (about 31.5 ˚C) which represents the 50km North dataset. The average Tmax of North sites are higher compared to their counterpart equidistant places (South, West and East). The estimated difference between the averages (for 11yrs.) of Tmax of Metro Manila and the North sites (except 50km N), South sites, East (Cogeo) and West is 0.83 ˚C, 1.73 ˚C, 1.5 ˚C and 2.3 ˚C, respectively.

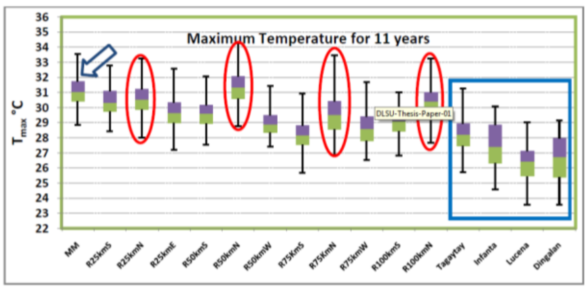

Fig. 1. Spatial variation of Tmax for the period 2000–2010.

3.2. Tmin

The Tmin of the selected sites for the period 2000–2010 is plotted in Fig. 2. Metro Manila has the highest average Tmin. The other sites have an average Tmin that is lower by about 0.4 °C to 2.4 °C than that for Metro Manila.

All of the factors that might alter the weather such as wind systems, ENSO, and many more are included in the results. Thus, this suggests that the urbanization of Metro Manila is affecting its' minimum temperature.

It can also be seen from Fig. 2 that places South of Manila recorded the highest average minimum temperature compared with North sites except 75km South (dotted red circle).

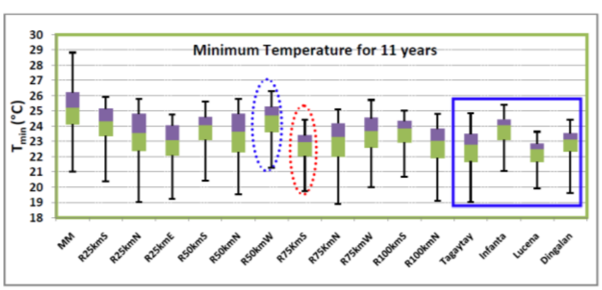

Fig. 2. Spatial variation of Tmin for the period 2000–2010.

3.3. DTR

The Tmax and Tmin results revealed the occurrence of UHI and the effect of urbanization on temperature. Fig. 3 plots the monthly average DTR for the period 2000–2010. Most of the high and low peaks of DTR happened during the summer season and southwest monsoon, respectively. Only 25km (North, South and East) were included in the DTR graph.

Decreasing trends were measured for Metro Manila, 25km North, 25km South and 25km East of Manila. A decreasing DTR means that either the Tmin is increasing (at a faster rate compared to Tmax) or the Tmax is decreasing (approaching Tmin). Both cases mean that there is not much difference between Tmax and Tmin values or the temperature at 5AM PST (Tmin) is close to the temperature at 2PM PST (Tmax). However, the closeness of the magnitude of the slopes indicates that it is not possible to identify which direction is most affected by the urbanization of Metro Manila.

The decreasing rate of DTR of Metro Manila is another evidence (aside from Tmin (urban) > Tmin (selected sites)) of the occurrence of UHI in Metro Manila.

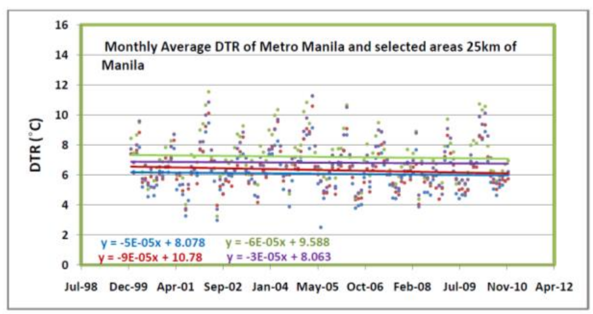

Fig. 3. DTR (˚C) of Metro Manila (blue), 25km South (red), 25km North (green) and 25km East (violet) of Manila. Decreasing rate is largest at 25km South.

3.4. Trend analysis using Mann–Kendall test and Sen's slope estimator

Trend analysis was done using the Mann–Kendall test. A result is significant when $p \leq 0.05$ (two tailed). In the Mann–Kendall test, the correlation between two vectors, such as time and a weather parameter (e.g., rainfall, temperature), was measured using the Kendall tau (τ) or M–K rank correlation coefficient whose value ranges from –1 to 1. If the computed value of τ is –1, this means that the disagreement between the two vectors is perfect. A τ of +1 means perfect agreement. The value of Sen's slope gives the rate of the trend while the sign tells whether the trend is increasing (+) or decreasing (–).

Figs. 4 and 5 give the Sen's slope results for Tmax and Tmin. It shows an increasing trend (positive slope) of Tmin and Tmax for all selected places except for the Tmax of 75km West of Manila. The value of the slopes of Tmax range from –0.001 °C/yr to 0.002 °C/yr while 0.001°C/yr to 0.003°C/yr is for Tmin.

Fig. 6 shows a decreasing (negative slope) trend for DTR. DTR is computed from Tmax–Tmin and the minimum temperature increases at a faster rate than the maximum temperature. Thus, the difference between Tmax and Tmin decreases yielding a negative slope/trend. This is the same as the result of Karl, T. R. et al., 1991. This means that all the selected locations are experiencing urban growth and land use change. In particular, the areas 25km South, 50km South (Calamba and Gen. Aguinaldo) and 75 km West of Manila are having a larger rate (more negative) while the other places have almost the same rate as Metro Manila. Lower rates are found for 25km East (represented by Cogeo) and 100km South (represented by San Pablo, Laguna and San Juan, Batangas). Although the Sen's slope has these results (Figs. 4–6), the p–values for Tmax, Tmin, and DTR show that the trends are statistically not significant (see Table 2) for the study period in this work.

Fig. 4. Tmax trends.

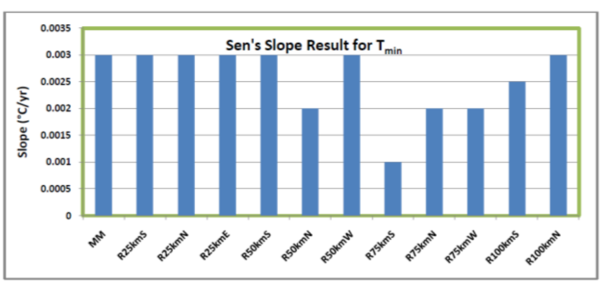

Fig. 5. Tmin trends.

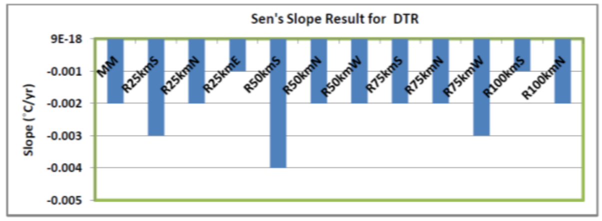

Fig. 6. DTR trends.

Table 2. Mann–Kendall results for Tmin, Tmax and DTR for the period 2000–2010.

Mann Kendall test and Sens Slope estimate on 11 years Minimum Temperature (T_{min})

	MM	R25kmS	R25kmN	R25kmE	R50kmS	R50kmN	R50kmW	R75kmS	R75kmN	R75kmW	R100kmS	R100kmN
Kendall's Tau (τ)	0.076	0.077	0.048	0.060	0.089	0.043	0.091	0.043	0.049	0.047	0.075	0.067
p-value(two-tailed)	0.202	0.197	0.421	0.312	0.184	0.461	0.120	0.469	0.410	0.427	0.214	0.256
Sen's Slope (Q)	0.003	0.003	0.003	0.003	0.003	0.002	0.003	0.001	0.002	0.002	0.0025	0.003

Mann Kendall test and Sens Slope estimate on 11 years Maximum Temperature (T_{max})

	MM	R25kmS	R25kmN	R25kmE	R50kmS	R50kmN	R50kmW	R75kmS	R75kmN	R75knW	R100kmS	R100kmN
Kendall's Tau (τ)	0.056	0.021	0.035	0.049	0.01	0.046	0.038	0.019	0.020	-0.031	0.054	0.046
p-value(two-tailed)	0.353	0.721	0.558	0.402	0.871	0.431	0.521	0.752	0.735	0.601	0.365	0.439
Sen's Slope (Q)	0.002	0.001	0.001	0.002	0.0004	0.002	0.001	0.00079	0.00098	-0.001	0.002	0.002

Mann Kendall test and Sens Slope estimate on 11 years Diurnal Temperature Range (DTR)

	MM	R25kmS	R25kmN	R25kmE	R50kmS	R50kmN	R50kmW	R75kmS	R75kmS	R75kmS	R100kmS	R100kmN
Kendall's Tau (τ)	-0.033	-0.068	-0.038	-0.026	-0.062	-0.032	-0.040	-0.018	-0.027	-0.037	-0.015	-0.040
p-value(two-tailed)	0.572	0.259	0.542	0.655	0.291	0.593	0.497	0.684	0.645	0.530	0.805	0.499
Sen's Slope (Q)	-0.002	-0.003	-0.002	-0.001	-0.004	-0.002	-0.002	-0.002	-0.002	-0.003	-0.001	-0.002

CONCLUSIONS

This work successfully utilized the Weather Research and Forecasting (WRF) model to investigate the effect of the urbanization of Metro Manila on the temperature (DTR, maximum and minimum) of selected urban and rural areas up to 100km North and 100km South of Metro Manila at 25km steps from the year 2000 up to year 2010.

Compared to the selected areas, Metro Manila attained the highest average Tmin during the study period. At 5:00AM PST, Metro Manila is warmer than all the selected areas in this study. This is due to the UHI intensity. UHI intensity is affected by land modification and population increases. This, in turn, can alter the energy budget and weather of the urban cities like Metro Manila.

Comparing rural areas, 25km, 50km and 100km South obtained high morning temperature (Tmin) while 25km up to 100km North obtained high noontime temperature (Tmax). Thus, the warming of Metro Manila extends only up to areas within 25km of Manila which is supported by the result of the DTR trend.

The difference in the temperature of Metro Manila from the selected sites are around 0.4 °C to

2.4°C and 0.83°C to 2.3°C for Tmin and Tmax, respectively. One reason for this is the number of commercial and residential buildings that are scattered inside Manila. Buildings increase surface roughness as a result of reducing the rate of ventilation in urban areas. Evapotranspiration by plants is a major cooling process for the land surface and the atmosphere. Transforming vegetation into high rise buildings in Metro Manila results to less evapotranspiration process, large sensible heat and warmed environment.

Thus, this Tmax differences between Metro Manila and the other selected sites along with the warming morning temperature are the effects of urbanization and it indicates the presence of an urban heat island. However, statistically speaking, it was observed that over the time period of study (2000–2010), the DTR values of Metro Manila and the selected sites were not affected by the urbanization of Metro Manila. A longer time period (30 years or more) may be necessary to have more conclusive results especially since Metro Manila was already urbanized during the study period although it is still expanding.

ACKNOWLEDGMENTS

The researchers would like to thank the support of Department of Science and Technology–Science Education Institute (DOST–SEI), Commission on Higher Education (CHED), DLSU–URCO and the DLSU Science Foundation for the study grants and the research grants utilized in this work.

REFERENCES

Chen, J., Li, Q., Niu, J., and Sun, L. (2011). Regional Climate change and local urbanization effects on weather variables in Southeast China. Stoch Environ Res Risk Assess 25, 555–565, doi: 10.1007/s00477–010–0421–0.

Demograpia, World Urban Area: 8th Annual Edition, 2012.

Drápela, K., and Drápelová, I. (2011). Application of Mann–Kendal test and Sen's slope estimation for trend detection in deposition data from Bílý kříž (Beskydy Mts., The Czech Republic) 1997–2010," Beskydy, 4(2), 133–146.

Hirsch, R., Helsel, D., Cohn, T., and Gilroy, E. (1992). Statistical analysis of hydrologic data. in Handbook of Hydrology. McGraw–Hill, New York, 17.1–17.55.

Karl, T. R., Kukla, G., Razuvayev, V., Changery, M. J., Quayle, R. G., Heim, R., Jr., Easterling, D. R., Fu, C. B. (1991). Global warming: evidence for asymmetric diurnal temperature change. Geophys. Res. Lett., 18, 2253–2256.

Karpouzos, D., Kavalieratou, S., Babajimopouls, C. (2010). Trend Analysis of Precipitation Data in Pieria Region (Greece). European Water, 30, 31–40.

Li, Q., and Chen, J. (2009). Investigation of Urbanization effect on climate change in south china by WRF model. EGU General Assembly 2009, Vienna, Austria, April, 19–24, 2009.

Ragrario, J. M. (2003). Urban Slums Report: The Case of Metro Manila. Report presented in "Understanding Slums: Case Studies for the Global Report on Human Settlements," a report prepared with the funding of UN-Habitat and produced by the Development Planning Unit of the University College London.

Sugawara, H., and Narita, K. (2008). Roughness length for heat over an urban canopy. Theor. Appl. Climatol. doi:10.1007/s00704–008–0007–7.

Tonkaz, T., and Cetin, M. (2007). Effect of urbanization and land–use type on monthly extreme temperatures in a developing semi–arid region, Turkey. Journal of Arid Environments, 68, 143–158.

Taha, H. (1997). Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat. Energy and Buildings, 25, 99–103.

Zhang, C., Chen, F., Miao, S., Li Q., Xia, X., and Xuan, C. (2009). Impacts of urban expansion and future green planting on summer precipitation in the Beijing metropolitan area. Journal of Geophysical Research, 114, D02116, doi:10.1029/2008JD010328.