

Evaluating the Performance of RegCM5 in Simulating the Near-Surface Air Temperature in Select Cities of Luzon, Philippines

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Abstract: The urbanization of a settlement can make its environment have higher temperatures compared to its nearby rural areas. This phenomenon is known as the urban heat island effect. One method of studying the urban heat island effect is through computer simulations, and in order to have accurate results, the performance of the computer simulation to be used needs to be evaluated. This study aims to evaluate the performance of the latest version of the Regional Climate Model (RegCM5) developed by the International Center for Theoretical Physics, in simulating the near-surface air temperature in six highly-urbanized cities in Luzon, Philippines: Angeles, Baguio, Manila, Olongapo, Pasay, and Quezon. Four simulations were run with two different datasets of initial conditions and boundary conditions (ICBC): EIN15 and CNRM-CM5, and two different horizontal resolutions: 16 km and 8 km. The results of the simulations were compared to weather station data from the Integrated Surface Dataset (ISD), maintained by the National Oceanic and Atmospheric Administration. Four evaluation statistics were computed: the mean bias (MB), mean absolute error (MAE), and root mean square error (RMSE) show the closeness of the simulation to observed data, and the index of agreement (IOA) shows how error-free a model prediction is. Results show among the four runs, the run using EIN15 as its ICBC with 8 km resolution performs the best, showing MB, MAE, and RMSE values below ± 2.0 °C, 2.0 °C, and ≤ 3.5 °C, respectively. Furthermore, the run exhibits high IOA (≥ 0.8) in all cities except Olongapo. The runs using CNRM-CM5 perform poorly in both resolutions, with most IOA values < 0.8 , which indicate that a finer resolution is needed in order for it to be more accurate.

Key Words: near-surface air temperature; RegCM5; urban heat islands; Luzon; Philippines

1. INTRODUCTION

The urbanization of a settlement greatly changes its environment. In an urban city, the artificial surfaces, the physical structures, and man-made processes contribute to the modification of the city's climate. One effect of urbanization can be seen in the urban heat island, the

phenomenon where urban areas have higher temperatures compared to nearby rural areas. Studies in over 400 cities worldwide have documented the urban heat island effect, with an average temperature of 4 °C to 5 °C more than their rural surroundings (Santamouris, 2020). The urban heat island effect is attributed to the modifications that urbanization makes to the energy balance of the area. Urban areas have different radiative,

thermal, moisture, and aerodynamic properties compared to their rural surroundings. This is due to the shapes of buildings, the materials used in buildings, the removal of plants and soil, and air pollution (Stewart and Oke, 2012). In addition to these urban modifications is anthropogenic heat, which is heat from man-made activities. Examples of anthropogenic heat include industrial processes, combustion of fuels in vehicles, and air-conditioning (Oke et al., 2017). All of these contribute to the heating of the city.

It is important to study the urban heat island effect as it is a threat to the health of the citizens in the city. High temperatures can cause discomfort (Bhati and Mohan, 2018), worsen ambient air quality, and increase morbidity and mortality (Khan, 2021). Vulnerable sectors such as the young, the old, and those who are lower middle class and below, are especially susceptible to the effects of urban heat islands. In addition, cities are continually expanding and new cities are being created as populations grow. In order for cities to be habitable, it needs to be resilient to disasters and extreme climate. There are development plans such as the United Nations' Sustainable Development Goals (SDGs), where one of the goals (SDG 11) is to "make cities and human settlements inclusive, safe, resilient and sustainable" (United Nations, 2015), and the National Economic and Development Authority's *AmBisyon Natin 2040*, whose goal is to have Filipinos "enjoy a strongly rooted, comfortable, and secure life" by 2040 (National Economic and Development Authority, 2016). Given the effects of urban heat islands on city resiliency and human health, as well as the intensification of these effects by climate change, it is important to study this phenomenon in order to understand it better and to learn how to mitigate it.

Previous studies have used simulations to study the urban heat island effect in the Philippines. Some studies used the Weather Research and Forecasting model (WRF). Bilang et al. (2022) simulated the air temperature and relative humidity of Metro Manila using WRF and an urban canopy model. They reported an urban heat island intensity of 8°C during the daytime, and 3°C during the nighttime. Places near bodies of water, such as Laguna Lake, showed lower air temperatures. They also showed that stagnant winds led to higher air temperatures. Oliveros et al. (2019) studied a total of 19 places in the Philippines with WRF to see if their urbanization efforts have had an effect on weather. They noted an urban heat island effect occurring, with a reported 0.4 °C to 2.4 °C minimum difference, and a 0.83

°C to 2.3 °C maximum difference between urban and rural areas of Metro Manila. They also noted that urbanization led to more rainfall, though this finding was not statistically significant.

Besides WRF, studies also use other tools to study the urban heat island effect. One study by Cortes et al. (2022) used ENVI-met, a three-dimensional computational fluid dynamics software model, to evaluate the effectiveness of urban heat mitigation strategies in Mandaue, Cebu. They found that adding more trees and using green roofs could decrease surface temperature by about 0.4 °C to 1.1 °C. Notably, based on the thermal comfort index, the authors concluded that people would still feel uncomfortable from the heat, despite employing mitigation strategies. Some studies use remote sensing and satellite data. Almadrones-Reyes and Dagamac (2022) used remote sensing technology to examine how land use has changed in Metro Manila from 2001 to 2019. Their results show a decrease in normalized difference vegetation index, as well as a 4 °C difference from 2001 to 2019. Purio et al. (2022) assessed the urban heat islands in Manila City using satellite and meteorological data. They report a 6 °C difference between the cold and hot parts of Manila. In addition, they note that areas with vegetation or bodies of water have lower surface temperature compared to residential areas, roadways, and commercial buildings.

While previous studies have used WRF and other tools to study the urban heat island effect in the Philippines, few have used the Regional Climate Model (RegCM), a limited area model for long-term regional climate simulation, developed by the Abdus Salam International Centre for Theoretical Physics. Thus, the goal of this paper is to determine the performance of RegCM5 in simulating near-surface air temperature in select cities of Metro Manila during the years 2015 to 2017.

2. METHODOLOGY

This study used the latest version of the Regional Climate Model, RegCM5, which is described in detail by Giorgi et al. (2023). Table 1 shows the physics schemes used in the study. These schemes, with the exception of the land surface model, were used because they are the default RegCM5 schemes. For the land surface model, the Community Land Model version 4.5 is chosen over the default, the Biosphere-Atmosphere Transfer Scheme, as the Community Land Model has a model for urban

energy balance and climate, which the default model lacks.

Table 1: Configuration of the RegCM5 physics schemes.

City	
Atmospheric radiation	Radiation scheme from the Community Climate Model version 3 (Kiehl et al., 1996)
Land surface model	Community Land Model version 4.5 (Oleson et al., 2013)
Planetary boundary layer	Based on Holtslag et al. (1990)
Cumulus convection	Based on Emanuel (1991)
Resolvable scale precipitation	Subgrid explicit moisture scheme (SUBEX) (Pal et al., 2000)

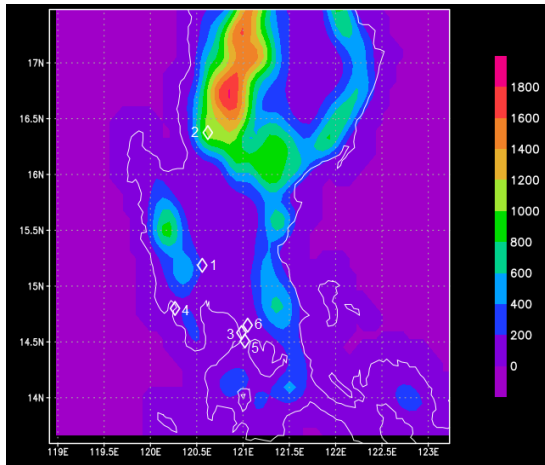


Fig. 1. The domain of the run, Luzon. Color represents elevation in meters. Places marked with a diamond are the stations used in model evaluation (listed in Table 3). The center is placed at a longitude of 121° and a latitude of 15.5°.

This study conducted simulations of Luzon over a four-year period, starting from 2014, January 2. A figure of the domain can be seen in Fig 1. The first year was considered as spin-up time and was ignored. Thus, only the three-year simulation period from 2015, January

1 to 2018, January 1 is considered for the data analysis. The simulation is set to output the results every 3 hours.

Four simulations were run. The first two simulations used the EIN15 dataset, a global atmospheric reanalysis by the European Centre for Medium-Range Weather Forecasts and described in Dee et al. (2011), for the initial conditions and boundary conditions (ICBC). The first run used a horizontal resolution of 16 km (28 by 30 grid cells), while the second run had double the resolution (8 km, 59 by 56 grid cells). The last two runs used the CNRM-CM5, a general circulation model as described in Voltaire et al. (2013), for the ICBC. As with the EIN15 runs, one was run with double the resolution of the other. A summary of the simulations run is in Table 2.

Table 2: A summary of the four simulations run in this study.

Run #	ICBC Dataset	Horizontal resolution (<i>ds</i>)
1	EIN15	16 km (28 × 30 grid cells)
2	EIN15	8 km (59 × 56 grid cells)
3	CNRM-CM5	16 km (28 × 30 grid cells)
4	CNRM-CM5	16 km (59 × 56 grid cells)

Table 3: Cities and their corresponding stations in the Integrated Surface Dataset (ISD) to be used in model evaluation.

#	City	ISD Station
1	Angeles, Pampanga	Clark International Airport
2	Baguio, Benguet	Baguio
3	Manila, Metro Manila	Manila
4	Olongapo, Zambales	Cubi Point
5	Pasay, Metro Manila	Ninoy Aquino International Airport (NAIA)
6	Quezon City, Metro Manila	Science Garden

To determine the performance of the simulation, an evaluation was performed. The evaluation procedure is adapted from Bilang et al. (2022). The results of the simulation was compared to weather data from the Integrated Surface Database (ISD). The ISD is maintained by the United States National Oceanic and Atmospheric Administration, and is readily available on their website

(<https://www.ncei.noaa.gov/products/land-based-station/integrated-surface-database>). Missing values were handled by replacing them with the mean of the data. The cities and their corresponding stations in the ISD to be used in the evaluation are listed in Table 3. These cities were chosen because they are all both highly-urbanized cities and have weather data available from the ISD.

Four performance statistics were computed using equations 1 to 5, where y_i is the modeled value, $y_{i,obs}$ is the observed value, and N is the number of data points. The mean bias (MB) is a measure of the model to overestimate or underestimate a variable (Carbonell et al., 2013), and is calculated by

$$MB = \frac{1}{N} \sum_{i=1}^N (y_i - y_{i,obs}). \quad (\text{Eq. 1})$$

The mean absolute error (MAE) is used to measure the closeness of the modeled and observed values (Arasa et al., 2016). It is calculated by

$$MAE = \frac{1}{N} \sum_{i=1}^N |y_i - y_{i,obs}|. \quad (\text{Eq. 2})$$

The root mean square error (RMSE) is similar to the MAE but more sensitive to large errors due to the squared term (Carbonell et al., 2013). It is calculated by

$$RMSE = \sqrt{\frac{\sum_{i=1}^N (y_i - y_{i,obs})^2}{N}}. \quad (\text{Eq. 3})$$

Lastly, the index of agreement (IOA), introduced by Willmott and Wicks (1980), shows how an error-free model predicts a variable. The index ranges between 0 and 1, with a value of 0 meaning no agreement between the model and observed data, and a value of 1 meaning a perfect match. It is computed as

$$IOA = 1 - \frac{\sum_{i=1}^N (y_i - y_{i,obs})^2}{\sum_{i=1}^N (|y_i - \bar{y}| + |y_{i,obs} - \bar{y}|)^2}, \quad (\text{Eq. 4})$$

where

$$\bar{y} = \frac{1}{N} \sum_{i=1}^N y_{i,obs}. \quad (\text{Eq. 5})$$

Before computing the statistics, the model values were first rounded to the nearest tenth in order to match the accuracy of the observed values from the ISD. The threshold for these values to determine if the model is performing well are given in Table 4, as adapted from Bilanz et al. (2022).

Table 4: Recommended values of statistical tests for near-surface air temperature.

Statistical parameter	Criteria
MB	$\leq \pm 2.0 \text{ }^\circ\text{C}$
MAE	$\leq 2.0 \text{ }^\circ\text{C}$
RMSE	$\leq 3.5 \text{ }^\circ\text{C}$
IOA	≥ 0.8

3. RESULTS AND DISCUSSION

Table 5 shows the evaluation results for the three stations inside Metro Manila: Manila, NAIA, and the Science Garden. All MB and RMSE values fall within the recommended values of $\leq \pm 2.0 \text{ }^\circ\text{C}$ and $\leq 3.5 \text{ }^\circ\text{C}$, respectively. Furthermore, all MAE values, besides the one for the CNRM-CM5 run with 16 km horizontal resolution, fall within the recommended value of $\leq \pm 2.0 \text{ }^\circ\text{C}$. Despite this, many runs show an IOA value < 0.8 , indicating a bad agreement between the simulation and observed data. A graph of the simulation data and observed data for Science Garden using CNRM-CM5 can be seen in Figure 2. With the lower grid cell resolution, the simulation was able to follow the trend of the observed data, but its oscillations were smaller than the observed data (Figure 2a). The finer resolution matches the large oscillations of the observed data more closely (Figure 2b).

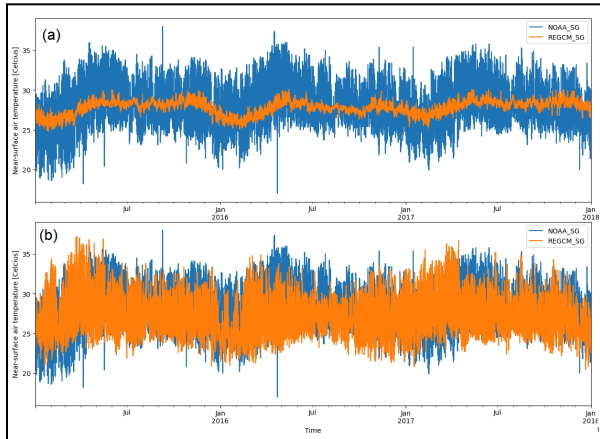


Fig. 2. Simulated data (orange) and observed data (blue) of the near-surface air temperature in the Science Garden, Quezon over time. The simulation used CNRM-CM5 with a horizontal resolution of (a) 16 km and (b) 8 km.

Table 5: Evaluation results for the three cities inside Metro Manila. Values that do not match the recommended values are underlined.

ICBC	ds [km]	MB [°C]	MAE [°C]	RMSE [°C]	IOA
<i>Manila</i>					
EIN15	16	-0.53	1.27	1.61	<u>0.78</u>
EIN15	8	0.90	1.45	1.84	0.85
CNRM-CM5	16	-0.73	1.63	2.09	<u>0.57</u>
CNRM-CM5	8	-0.38	1.87	2.33	<u>0.75</u>
<i>Ninoy Aquino International Airport, Pasay</i>					
EIN15	16	-0.59	1.24	1.55	0.88
EIN15	8	0.94	1.40	1.75	0.88
CNRM-CM5	16	-0.72	1.87	2.39	<u>0.52</u>
CNRM-CM5	8	-0.37	1.78	2.22	<u>0.79</u>
<i>Science Garden, Quezon</i>					
EIN15	16	-0.61	1.45	1.81	0.88
EIN15	8	0.57	1.33	1.70	0.91
CNRM-CM5	16	-0.10	<u>2.29</u>	2.77	<u>0.46</u>
CNRM-CM5	8	-0.75	1.95	2.44	0.81

Table 6 shows the evaluation results for the three stations outside of Metro Manila: Baguio, Clark, and Cubi Point. For Baguio, both CNRM-CM5 runs and the EIN15 run with 16 km resolution showed poor results. This may be because of the elevation of the city. Baguio is situated about 1,500 m above sea level. Also, while the other stations have roughly the same elevation in its surroundings, Baguio's surroundings have varying elevation, which can affect the simulation. The results also show that the 8 km runs have a lower MB, MAE, and RMSE, as well as a higher IOA, than the 16 km runs.

For Clark, the two EIN15 runs have evaluation statistics that match the recommended values. Furthermore, the two runs show the highest IOA values among all the runs, with a value of 0.90 for the 16 km run and 0.91 for the 8 km run. The two CNRM-CM5 runs in Clark both have MB and RMSE values that pass the benchmark, but have MAE and IOA values that do not.

Table 6: Evaluation results for the three cities outside Metro Manila. Values that do not match the recommended values are underlined.

ICBC	ds [km]	MB [°C]	MAE [°C]	RMSE [°C]	IOA
<i>Baguio</i>					
EIN15	16	<u>2.48</u>	<u>2.60</u>	3.08	<u>0.76</u>
EIN15	8	1.49	1.91	2.33	0.84
CNRM-CM5	16	<u>8.77</u>	<u>8.77</u>	<u>9.10</u>	<u>0.32</u>
CNRM-CM5	8	0.60	<u>2.05</u>	2.62	<u>0.79</u>
<i>Clark International Airport, Angeles</i>					
EIN15	16	-0.48	1.47	1.83	0.90
EIN15	8	-0.64	1.48	1.87	0.91
CNRM-CM5	16	0.41	<u>2.42</u>	2.84	<u>0.45</u>
CNRM-CM5	8	-1.98	<u>2.59</u>	3.13	<u>0.76</u>
<i>Cubi Point, Olongapo</i>					
EIN15	16	-1.52	1.80	2.16	0.85
EIN15	8	-0.55	1.55	1.95	<u>0.78</u>
CNRM-CM5	16	0.06	<u>2.18</u>	2.63	<u>0.44</u>
CNRM-CM5	8	-1.21	1.98	2.51	<u>0.67</u>

For Cubi Point, the two EIN15 runs both show good results among all the metrics, except for the IOA. The IOA value decreased as the horizontal resolution increased. This may be because Cubi Point is a bay area. The nearby water can play a part with the station's air temperature, which the simulation settings may not have accounted for. With the lower resolution, the interaction with water may have been negligible enough as to not affect settings, but the higher resolution gives more grid cells over water, which is perhaps why the accuracy worsened. The two CNRM-CM5 runs also show a low IOA, indicating inaccurate values for this station.

Out of the four runs, the run using EIN15 with 8 km resolution performs the best. The IOA values for each station, except Cubi Point, matches the recommended values of > 0.8 . This means that simulations using these settings are accurate for the places studied, and can be used for future research. One limitation of EIN15 is that it is not compatible for forecasts, only hindcasts. Studies of future trends will need to use another ICBC such as CNRM-CM5, which is a general climate model that does support forecasting.

It can be seen that in general, increasing the horizontal resolution of the simulation will show better performance statistics. One trade-off though in using a higher horizontal resolution is that it can slow down the time it takes for the simulation to finish, as the simulation needs more grid cells. Also, for a given horizontal resolution, the EIN15 run performed more accurately compared to the CNRM-CM5 run. This shows that runs using CNRM-CM5 need a higher horizontal resolution than EIN15 in order to perform accurately.

One limitation of this study is that it only studies one variable, namely: near-surface air temperature. It does not examine ground temperature or temperature at different elevations. It also does not examine other factors that may be relevant to the study of urban heat islands, such as humidity, wind speed, wind direction, or precipitation. Another limitation is that this study only examines the three-year period from 2015 to 2017. Future studies may choose to study these other variables or study longer timeframes.

There are many factors that can affect the findings. Firstly, the physics schemes used in this run are all the default schemes, with the exception of the Community Land Model version 4.5 being chosen over the default BATS1e. These runs do not use other models such as a lake model or a chemistry model, which may make the simulations more accurate and is an avenue

for future research. Next, simulations are compared to the weather station data from the ISD. Only six stations were considered in this study. The data will be as accurate as the instruments used to record the data. Lastly, the study only used one domain. Changing the size and location of the domain without tweaking other settings can change the accuracy of the simulation.

4. CONCLUSIONS

This study evaluated the performance of RegCM5 in simulating the near-surface air temperature in select cities of Luzon, Philippines: Angeles, Baguio, Manila, Olongapo, Pasay, and Quezon. Two ICBC datasets: EIN15 and CNRM-CM5, and two horizontal resolution settings: 16 km and 8 km, were investigated. The results show that using EIN15 with an 8 km resolution gives the best results in all cities except Olongapo. Hindcasts using these settings may suffice, though a higher horizontal resolution may be needed for more accuracy. For future research, possible avenues to explore are: incorporating other physics models, using a different domain, and using higher resolutions and longer time scales. These results may be used by city planners and local government officials to better study and implement ways to reduce heat in cities.

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