Climate Change and Its Effect on Temperature and Precipitation Trends: Case Study in Surabaya Using RegCM5*

Asyam Mulayyan Dary[1], Mas Agus Mardyanto[1**], Joni Hermana[1], and Chairul Imron[2]

***Abstract*—Climate change is increasingly driving extreme weather events, yet its regional impacts remain complex. This study employs the RegCM5 model, driven by ERA5 reanalysis data, to simulate high-resolution (5 km) climate dynamics in Surabaya, Indonesia from December 2018 to November 2023. Validated against gridded observational datasets and analyzed via Earth's energy balance, the results reveal a steady rise in both top-of-atmosphere and surface energy imbalances, corresponding with record-breaking increases in maximum and minimum temperatures by approximately 1.5°C and 1°C from 2020 to 2023. While monthly precipitation patterns were inconsistent, daily observations indicate a significant increase in high-intensity precipitation events. These findings offer critical insights into evolving regional climate impacts and inform local adaptation and mitigation strategies.**

I. INTRODUCTION

CLIMATE change impacts are becoming more frequent. In 2022, flood [1], [2] and drought [3], [4], [5] happen in the same year. These changes made them uncertain and become hard to mitigate and adapted to the problems [6], [7], [8]. Some studies revealed that climate change is impacting precipitation trends [9]. The changes are not only in precipitation, but it also alter the temperature trends. The temperature reached a record-breaking peak in 2023 [10], [11]. These changes in global scale do not necessarily mean all regions face the same thing, further regional studies are needed to determine the changes.

Surabaya is the second largest city in Indonesia, inhabited by 3 million people [12]. Brantas river flows through Surabaya and made Surabaya as the downstream of Brantas and a part of Brantas' Watershed. There was no recorded drought happening in Surabaya. Pluvial [13], coastal [14], and fluvial [15] floods happen frequently in Surabaya. Surabaya has experienced the highest observed rainfall at 159.3 mm/day in 2010 [16]. As for temperature, it has increased steadily since 1981 for minimum temperatures. While the maximum temperature decreased steadily, making the temperature variability decreased over years since 1981. Due to these changes, prediction tools are becoming more important to foresee the climate in the future.

Climate model is a mathematical model to simulate the earth's climate [17]. Global Climate Models (GCMs) are the general model of the entire earth's climate [18], which are used as the basis for Regional Climate Models (RCMs) [19]. One of the most used RCMs is RegCM, which is developed by ICTP [20]. Compared to GCMs, RCMs had more significant bias [21]. There are already several regional studies that utilize RCMs [22], [23], [24].

This study employs RegCM5 to simulate the regional climate of Surabaya, providing a fine-scale perspective of the regional impacts of global climate change. Gridded datasets observation used as model assessment and calibration. Thus, determining the climate change phenomenon and its impacts on temperatures and precipitation trends. The findings are expected to offer valuable insights for local policymakers and stakeholders, by improving climate change mitigation and adaptation. This research not only deepens the understanding of local climate dynamics but also contributes a replicable methodological framework for assessing climate change impacts in other vulnerable regions.

II. METHODS

This study utilized RegCM5, the latest version of RegCM [20]. The domain is 5 km cell resolution, with 60 cells longitude by 60 cells latitude. MOLOCH non-hydrodynamical core was used, with 18 vertical sigma levels and top of model at 30,000 km. Simulation period started from December 2018 until November 2023.

The GCM used in this study was ERA5 6-hour datasets at 0.25° horizontal resolution [25]. SST data is also from the same dataset. ESA-CCI soil moisture [26] was utilized to determine the initial soil moisture conditions.

The model was built under Windows Subsystem Linux (WSL) using Linux distribution. Model configuration is required before running the simulation. The scheme used in this study is shown on Table I, which is a mix from study by Wang [27] and Ngo-Duc [28]. There are five steps to run a simulation in RegCM5, which are in order: (1) terrain, (2) mksurf, (3) sst, (4) icbc, and (5) regcmmpi. Only the last step could be run in parallel, the other can only be run in series and required to be just once per scenario. All of required datasets can be found on ICTP database, except the finer resolution of ERA5 and ESA-CCI Soil Moisture. There are four output datasets, which are in NetCDF format: (1) ATM, (2) LAK, (3) RAD, and (4) SRF. In this study only radiation, temperatures, and precipitation was discussed. Thus, the needed output are only RAD and SRF. The output were hourly datasets, which then

A. M. Dary, M. A. Mardyanto and J. Hermana are with Department of Environmental Engineering, Institut Teknologi Sepuluh Nopember 60111

**Correspondent Author: marydanto@enviro.its.ac.id

C. Imron is with Department of Mathematics, Institut Teknologi Sepuluh Nopember

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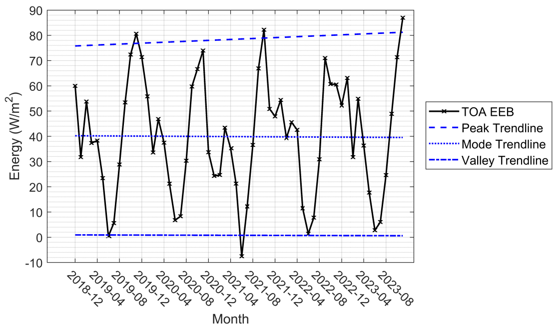

Fig. 1. Top-of-Atmosphere Monthly Energy Budget

be processed into monthly using Climate Data Operators [29] and NetCDF Operators [30].

TABLE I
SCHEMES USED IN THIS STUDY

Schemes	Configuration
Land Surface	CLM4.5
Planetary Boundary Layer	UW
Cumulus Convection	Tiedtke
Moisture	SUBEX
Ocean-Flux	Modified Zeng
Radiation	RRTM

Precipitation and temperatures bias were corrected using observed datasets from GPM IMERG NASA [31], [32] and TerraClimate [33] respectively. The bias-correction method used was quantile mapping, as it was the most suitable method for Indonesia [34].

Climate change phenomenon was determined using earth's energy balance (EEB) equation [35], shown below. Thus, needing TOA incident shortwave radiation (rsdt), TOA outgoing shortwave radiation (rsut), and TOA outgoing longwave radiation (rlut) for Top-of-Atmosphere (TOA) EEB. As for surface EEB the variables needed are surface downwelling shortwave radiation (rsds), surface upwelling shortwave radiation (rsus), surface downwelling longwave radiation (rlds), surface upwelling longwave radiation (rlus), sensible heat flux (hfss), and sensible latent heat flux (hfls).

$$\text{TOA EEB} = \text{rsdt} - (\text{rsut} + \text{rlut}) \tag{1}$$

$$\text{Surface EEB} = (\text{rsds} - \text{rsus}) + (\text{rlds} - \text{rlus}) - (\text{hfss} + \text{hfls}) \tag{2}$$

III. RESULTS AND DISCUSSION

A. Climate Change Phenomenon

One of the methods to determine climate change is by calculating the earth's energy budget. Shown on Figure 1, the trends of the TOA EEB have steadily increased each year. Both peak and median trendline show positive trends, while the valley trendline was relatively stagnant. The peak has increased around 15 W/m^2 in 2023 compared to 2020.

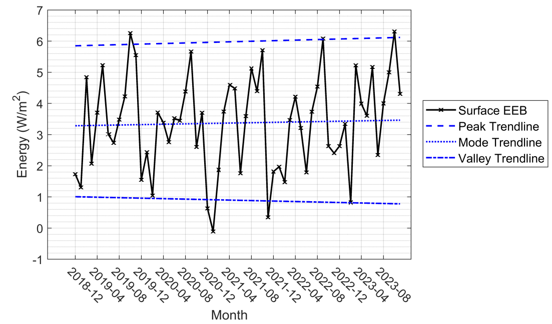

Fig. 2. Surface Monthly Energy Budget

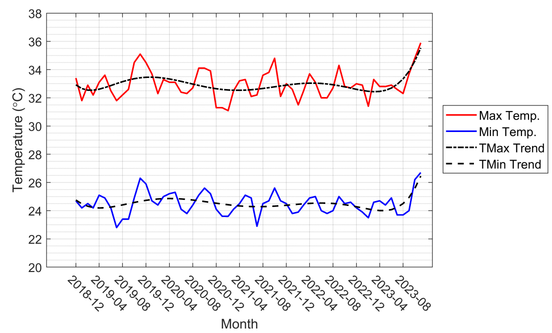

Fig. 3. Maximum and Minimum Temperature Trends

As for the surface EEB on Figure 2, the trendlines showed a similar result. But on the valley trendline, it has a slightly negative trend. The peak has increased around 0.5 W/m^2 in 2023 compared to 2020. The valley has also increased in 2023, around 1.5 W/m^2 compared to 2020.

B. Temperature Trends

The positive trendlines in the earth's energy budget translated into the increase in temperature trends on Figure 3. The temperatures had reached new peaks for both maximum and minimum temperatures. Maximum temperature has increased around 1.5°C in 2023 compared to 2020. The minimum temperature has also increased drastically, around 1°C in 2023 compared to 2020.

C. Precipitation Trends

Both EEB and temperatures trend had increased dramatically, but no same thing happened for precipitation. The trends of monthly precipitation were rather inconsistent displayed on Figure 4. It jumped to around 650 mm/month in 2022 but dropped to around 400 mm/month in 2023.

The daily precipitation trends show a different story, on Figure 5. The peak in 2023 was extreme, compared to the peak of every other year. The lowest peak was in 2020 at 53.2 mm/day, while the highest peak was in 2023 at 182.9 mm/day. Compared to the monthly trends, the daily precipitation follow similar patterns as the EEB and temperature trends.

D. Discussion

In 2020 there was a global phenomenon due to the COVID pandemic [36]. Because of the pandemic, global lockdown was

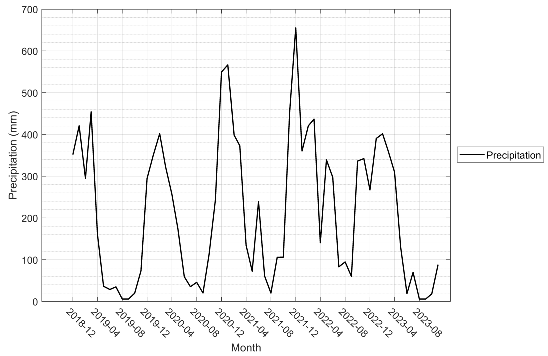

Fig. 4. Monthly Precipitation Trends

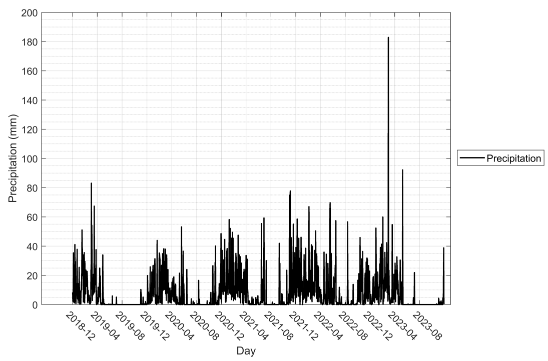

Fig. 5. Daily Precipitation Trends

applied to limit human activities [37]. This limitation resulted in the improvement of the climate conditions [38], [39]. But in 2023 the lockdown was lifted and human activities started to pace into the norms like back before the pandemic [40], [41]. In the same year, others major occurrences were also happening. There were two wars happening, in Russia [42] and in Palestine [43]. Some research showed that the wars impacted climate conditions and increased the GHGs in the atmosphere [44], [45], [46], [47]. Another reason was the trend in artificial intelligence (AI) [48], [49]. Studies suggested that AI required a huge amount of energy [50] and thus increased GHGs release into the atmosphere [51], [52].

Some studies revealed that in 2023, a record-breaking temperature occurred [10], [53]. Several researchers argued that the jump of temperature was due to the increase of human activities [11]. Study by Muller [54] revealed that there were different changes in precipitation regime. Based on this study findings it can be hypothesized that the precipitation regime in Surabaya changed, decrease in low intensity precipitation and increase in high intensity precipitation. This hypothesis is supported by the decrease in monthly trend and the increase in daily trend.

IV. CONCLUSION

In conclusion, this study revealed that the climate change in Surabaya has gotten worse in 2023 compared to the previous years. Showed by the increase of TOA and surface EEB in 2023, relative to 2020. The increase in EEB impacts on the temperature trends. It has reached a record-breaking temperature, both maximum and minimum temperatures. Temperatures are not the only impacted variable due to climate change. Precipitation was also affected. Monthly precipitation was relatively inconsistent, but extreme conditions were suggested from the daily precipitation trends. Further study is required to better picture the climate change effects. One can extend the simulation period, to compare a further year apart. These findings might shed light on the policymaker, to plan better mitigation and adaptation to climate change.

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