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Extreme Precipitation Trend Using Regional Climate Model from Multi-Source of Observational Data in Malaysia

Saiful Anuar Baharudin[1] and Arnis Asmat[1,2] *

[1] School of Chemistry and Environment, Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM) 40450, Shah Alam, Selangor, MALAYSIA.

[2] Climate Change and Carbon Footprint Research Group, Universiti Teknologi MARA (UiTM) 40450 Shah Alam, Selangor, MALAYSIA.

**Corresponding Author (Tel: +60192244222, Email: rnis_annis@uitm.edu.my)*

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Abstract

Having a better understanding of how extreme rainfall events change the future climate is vital due to its large impact on society. One of the factors that need to be considered is atmospheric temperature, where according to Clausius-Clapeyron relation, extreme rainfall is expected to increase at the rate of 7% per degree of warming. This paper investigates the trend of extreme rainfall by analysing observational data in Peninsular Malaysia and comparing it against regional climate models (RCM) simulations of historical climate. The study showed that RCM is driven by EC-EARTH generally performs better in simulating the trend of extreme rainfall with surface air temperature in Peninsular Malaysia compared to the model driven by IPSL-CM5A-LR. Furthermore, the study showed that extreme rainfall is decreasing with the increase of temperature at a large area across Peninsular Malaysia.

Disciplinary: Regional Climate, Climate Change, Atmospheric Thermodynamics, Hydrology (Extreme Rainfall).

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1 Introduction

Study on the change of precipitation under changing climate Is of interest due to its large impact on society. An increase in mean precipitation would lead to the increase of flood risk, whilst a decrease of it would lead to the increase of drought; causing damage and loss to the society. Flash flooding is associated with short-duration extreme rainfall (Kendon et al., 2018; Westra et al., 2014) and several studies emphasized the intensification of the events at sub-daily timescales (Kendon et al., 2018; Lenderink et al., 2011; Lenderink & van Meijgaard, 2010; Westra et al., 2014). Lacking observation data in Southeast Asia (Westra et al., 2014) means that climate research needs to rely on the regional climate model (RCM) to study historical climate and project future changes due to climate change. However, most RCMs tend to underestimate heavy precipitation when compared to historical data. This is reported by IPCC et al. (2013) where the majority of models underestimate extreme precipitation response to temperature, especially in the tropics. In studies of extreme precipitation in Europe by Drobinski et al. (2018), climate models systematically underestimate the 3-hourly precipitation. Cheong et al. (2018) found that extreme temperature and precipitation in Southeast Asia underestimate extreme climate, despite well-simulated trends and spatial variations of temperature extremes. However, a similar model has also overestimated the trends in precipitation extremes, especially in the western side of the region.

2 Literature Review

2.1 Precipitation-Temperature Scaling Technique

A variety of methods have been employed to compare extreme precipitation scaling calculated from gridded datasets to the in-situ observation data as a means to analyse spatial distributions of extreme precipitation scaling. The widely used method is a statistical analysis to determine regression corresponding to extreme precipitations of temperature rate changes.

2.1.1 Temperature Binning

Temperature binning is among the popular approaches adopted by many studies (Jones et al., 2010; Lenderink et al., 2011; Lenderink & van Meijgaard, 2010; Wasko & Sharma, 2014). This approach involves pairing precipitations data with the corresponding temperature which is then binned according to temperature into equal width or an equal number of samples (Wasko & Sharma, 2014). Precipitation quantiles of the bins are then analysed to estimate extreme precipitation scaling with temperature using exponential regression (Jones et al., 2010; Utsumi et al., 2011). Exponential regression assesses the paired parameters which relate precipitation, P, to the temperature change, ΔT, according to

$$P_2 = P_1(1+\alpha)^{\Delta T} \quad (1),$$

Exponential regression is applied to precipitation values where they first transformed logarithmically. The scaling coefficient represented by α is obtained from the slope derived from the exponential regression (Drobinski et al., 2018).

2.1.2 Quantile Regression

To overcome the limitation of the temperature binning approach, another approach that directly estimates the scaling coefficient is adopted which is by using quantile regression (Ali & Mishra, 2017; Molnar et al., 2015; Wasko & Sharma, 2014). Quantile regression follows the work of

Koenker and Bassett (1978) in which the paired parameters model the conditional quantiles of the parameters. The important feature of the approach is the model does not require prior data binning and it is unbiased with respect to sample size (Molnar et al., 2015) due to the fact that the regression model minimizes the absolute deviation of errors by penalizing under- and over-prediction (Wasko & Sharma, 2014). Quantile regression also offers many advantages over binning approach including the ability to introduce continuous variables as a covariate without the need for discretization and the ability to perform direct hypothesis testing to assess the significance level of the scaling obtained (Wasko & Sharma, 2014).

3 Method

3.1 Site Location

The study used rainfall and temperature data from weather stations in Peninsular Malaysia obtained from National Oceanic and Atmospheric Administration (NOAA) Global Historical Climate Network (GHCN). Daily precipitation and surface air temperature observations data, including Integrated Surface Database (ISD) which consists of hourly precipitation, surface air temperature and dewpoint temperature were collected from five selected stations. However, only 6-hourly and daily rainfall of ISD datasets were extracted due to their completeness. Figure 1 shows the location of five weather stations used in the analysis.

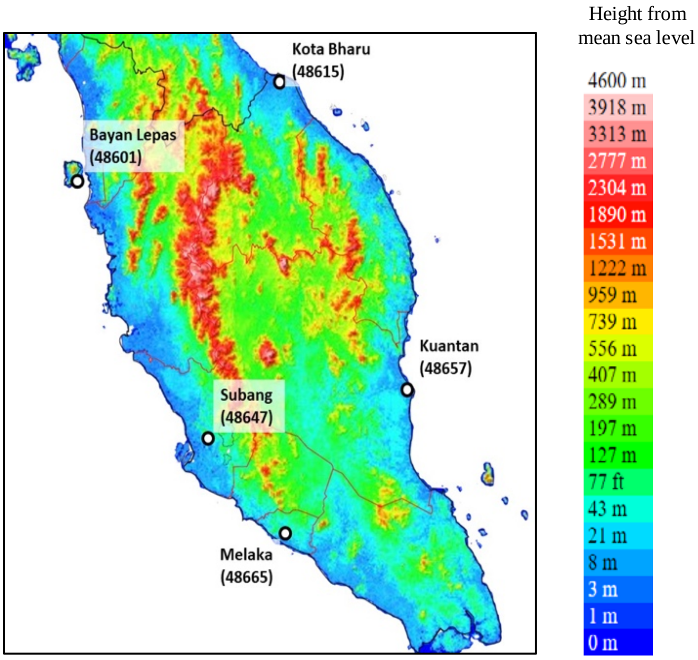

Figure 1: The topographic map of Peninsular Malaysia showing the location of the weather stations used in this study.

In addition to in-situ measurements from weather stations, publicly available SA-OBS dataset from the Southeast Asian Climate Assessment and Data (SACA&D) project (van den Besselaar et al., 2017) was used in this study. SA-OBS dataset is a blended SACA&D station series covering Southeast Asia from 1981 to 2015 at a daily time-step with a spatial resolution available at 0.25° and 0.50°. Version 1.0 of SA-OBS gridded data of four indices: daily mean temperature, TG; daily minimum temperature, TN; daily maximum temperature, TX; and daily precipitation sum, RR were compressed in NetCDF format. The elevation file used by the dataset was the Global 30 Arc-Second Elevation Data Set (GTOPO30), a global raster Digital Elevation Model (DEM) with a horizontal grid spacing of 30 arc seconds developed by the United States Geological Survey (USGS) (SACA&D, 2021).

RCM used in this study was part of the SEACLID/CORDEX project where two dynamically downscaled models were chosen: EC-EARTH and IPSL-CM5A-LR. Both RCMs were downscaled using RegCM4 configurations which covered a historical period of 1950-2006. The study focused on the period from 1981 to 2005 for comparison between the SA-OBS and RCM, as it was the only period that overlapped between the SA-OBS and RCM.

3.2 Methodology

Daily observations from GHCN and ISD, daily SA-OBS gridded datasets, and daily simulations of RCMs were used. This is to overcome the limitations with the SA-OBS gridded datasets which only provide daily gridded data. The occurrence of observational extreme precipitation at monthly and seasonal cycle was analysed at time *t*, *O(t)*, followed by Cortés Hernández et al. (2016) which can be expressed as

$$O(t) = \sum_{i=1}^{n} I[T(E_i), t] \quad (2),$$

where $T(E_i)$ is the time when E_i extreme precipitation occurred and *n* is the total number of precipitation events analysed at a certain temporal timescale (monthly or seasonal). *I* is the indicator function where

$$I[T(E_i), t] = \begin{cases} 1, & T(E_i) = t \\ 0, & otherwise \end{cases} \quad (3),$$

For comparison with SA-OBS gridded data and simulations from RCMs, precipitation, and temperature data were extracted at the nearest grid to the weather stations used in the stud. For each weather station used in the assessment, the closest grid to the weather stations is estimated using the following formula

$$closest\ grid = min\left[\sqrt{(lat_{obs} - lat_{grid})^2 + (lon_{obs} - lon_{grid})^2}\right] \quad (4),$$

where min is the minimum difference between the weather locations (*obs*) latitude, *lat*, and longitude, *lon*, and the grid (*grid*) *lon* and *lat*. The trend of extreme rainfall with surface air temperature from the SA-OBS gridded dataset and RCMs simulations was analysed by using quantile regression.

The true paired precipitation-temperature data is plotted where the quantile regression is applied into the precipitation depth equation (Wasko & Sharma, 2014),

$$ln\ P = \beta_0^q + \beta_1^q T \quad (5),$$

where $0 < q < 1$ is the quantile and β_0^q and β_1^q are the regression coefficient. The estimated trend of extreme precipitation with surface air temperature is determined from β_1^q term following Schroeer and Kirchengast (2018),

$$\alpha = \frac{\Delta P}{\Delta T} = 100\left(e^{\beta_1} - 1\right) \quad (6).$$

The trend determined from quantile regression is calculated to q = 0.99, corresponding to the upper 1% of precipitation depth from the precipitation distribution.

4 Result and Discussion

The first part of the analysis investigates whether RCMs are able to reproduce extreme occurrences when compared with observations. Both observations from GHCN and ISD were included for comparison on the agreeability between the two datasets. Figure 2 shows the number of extreme occurrences, O(t), against the month at 5 weather stations in Peninsular Malaysia for 1981-2005.

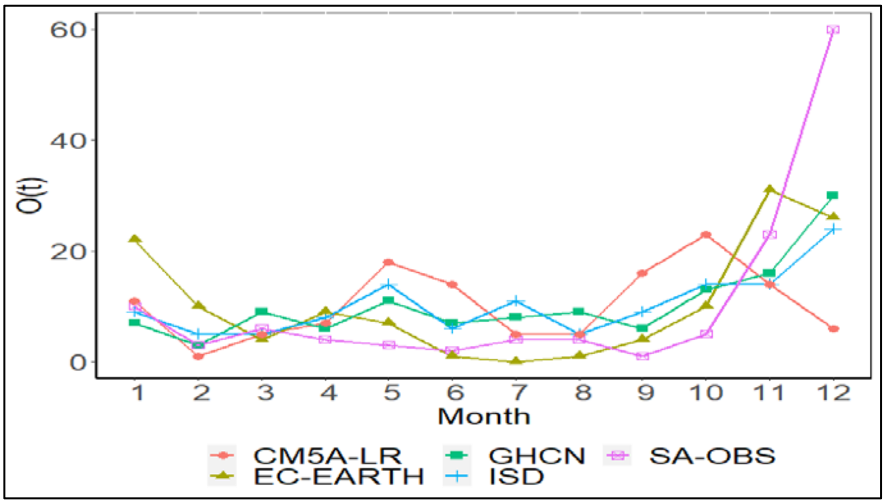

Figure 2: Monthly cycle of daily rainfall extreme in the observations: GHCN (green), ISD (blue), and SA-OBS (pink) and the simulations: EC-EARTH (brown) and CM5A-LR (red) for 5 weather stations across Peninsular Malaysia for the period of 1981-2005

Figure 2 observes that extreme occurrences were reasonably simulated by both RCMs to a certain degree where both GHCN and ISD data greatly corresponded to each other as expected. For RCM driven by EC-EARTH, the RCM was able to reproduce the extreme occurrence peak in December-January albeit ahead by a month. The RCM was also found to be overestimating the extreme occurrences for the first two months (January and February) while underestimating the extreme occurrences by as much as 75% from May (hence fails to simulate the extreme occurrences peak in May) until August. RCM driven by IPSL-CM5A-LR, on the other hand, was able to capture the extreme occurrences for the first 5 months (January to May) and simulate the extreme occurrences peak in May. However, after May, the response fluctuated. IPSL-CM5A-LR was unable to reproduce the extreme occurrence peak in December-January where the peak was observed in October which was ahead by two months.

Figure 3 shows the trend of extreme precipitation with surface air temperature from two simulations which were compared with the observations of GHCN and ISD as well as the SA-OBS gridded datasets. Results from the SA-OBS and simulation R1 and R2 suggested that the intensity of rainfall extremely approximately decreased with surface air temperature along the west and east coastline of Peninsular Malaysia, in contrast with the CC relation. In other parts of Peninsular Malaysia, the scaling varied among the three outputs observed.

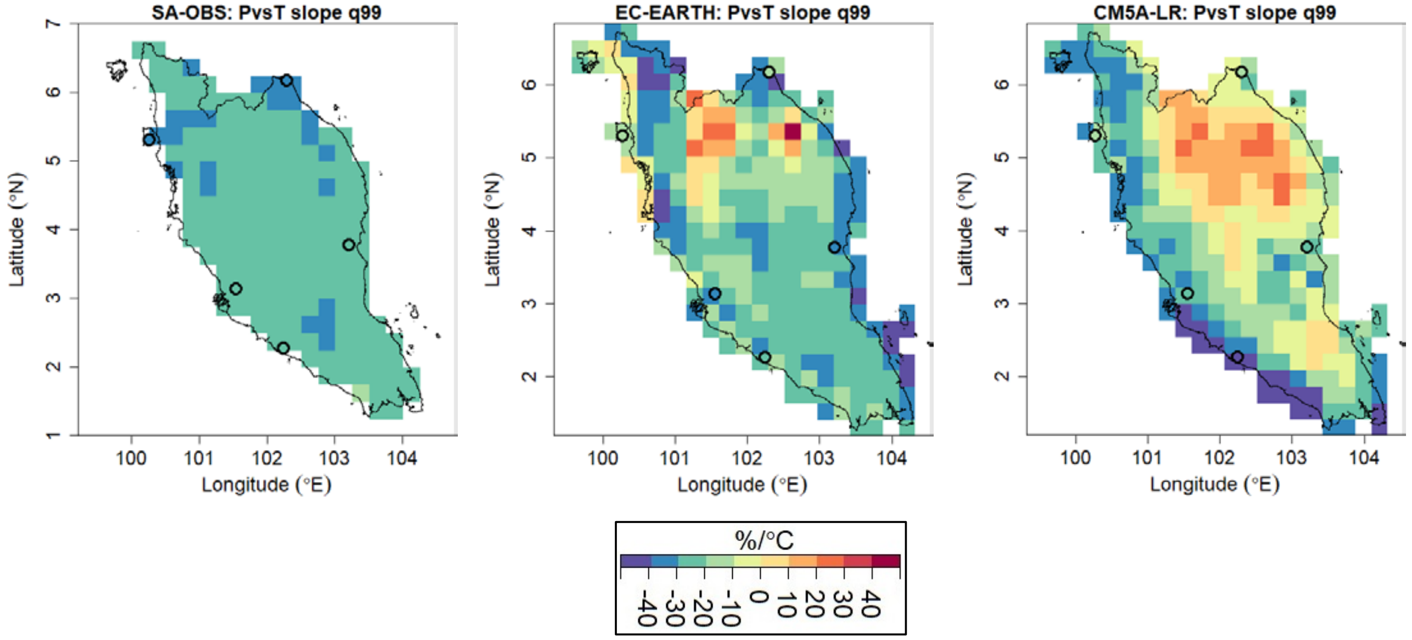

Figure 3: Slope of the 99th quantile regression daily rainfall intensity against mean surface temperature derived from SA-OBS dataset (left) at 0.25° resolution and from EC-EARTH (centre) and IPSL-CM5A-LR (right) simulations at 25 km resolution

In the northern part of Peninsular Malaysia, the trend was negative in the SA-OBS and over the majority of regions in RCM driven by EC-EARTH. Meanwhile, IPSL-CM5A-LR observed a positive trend over the region with a large percentage of the region having a larger intensity of extreme precipitation with surface air temperature than was expected from CC relation. Over the southern part of Peninsular Malaysia, the trend was negative in the SA-OBS and EC-EARTH driven RCM, while RCM driven by IPSL-CM5A-LR observed a positive trend at small parts of the region with the intensity of extreme precipitation and surface air temperature found to be greater than the expected CC relation.

EC-EARTH driven by RCM performed better than IPSl-CM5A-LR in simulating the trend of extreme precipitations with surface air temperature and the SA-OBS over a large area of Peninsular Malaysia. This means that RCM driven by EC-EARTH, to a large extend, was able to reproduce the expected changes in the water-holding capacity of the atmosphere associated with higher temperature.

Figure 3 shows that the trend of extreme rainfall with the surface area from the SA-OBS gridded dataset decreased throughout the whole of Peninsular Malaysia. The decreasing trend observed in This study implies that the intensity of rainfall decreases as the temperature increases, in contrast to Clausius-Clapeyron relation expectations. However, the negative trend observed here is not exclusive as shown by a previous study done on a global scale (Ali et al., 2018).

5 Conclusion

In this study, the performance of the regional climate model to simulate the trend of extreme rainfall in Peninsular Malaysia was investigated. Regional climate models driven by EC-EARTH and IPSL-CM5A-LR were compared against observational data from SA-OBS gridded dataset by comparing the trend of extreme rainfall with surface air temperature.

Despite spatial variability, RCM driven by EC-EARTH was found to perform better than IPSL-CM5A-LR in simulating the trend of extreme rainfall with surface air temperature when compared with the SA-OBS gridded datasets. The trend of extreme rainfall with surface air temperature decreases at a large area of Peninsular Malaysia as observed from SA-OBS gridded datasets. The decreasing trend observed in the study is in contrast to the expectations of Clausius-Clapeyron relation.

6 Availability of Data And Material

GHCN dataset is freely available from NCEI (http://doi.org/10.7289/V5D21VHZ).

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Saiful Anuar Baharudin is a Master's degree student at School of Chemistry and Environment, Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM), Malaysia. He received a Bachelor of Science degree with Honours in Physics from the University of Manchester, United Kingdom. His research area is Climate Change which focuses on extreme rainfall events.

Dr. Arnis Asmat is an Associate Professor at School of Chemistry and Environment, Faculty of Applied Sciences, Universiti Teknologi MARA (UiTM), Selangor, Malaysia. She got her PhD degree in Environmental Remote Sensing and Spatial Analysis from Southampton University of United Kingdom, Malaysia. Her research focuses on Environment, Atmospheric Aerosol, Air Quality, Extreme Weather, Climate Change and Carbon Footprint.