Rain Height and Satellite Interference over Malaysia from 1992 to 2022

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ABSTRACT

The impact of climate change on rainfall patterns poses significant challenges to satellite communication infrastructure. This study explores the dynamic relationship between changing climate conditions and

their effects on the reliability and efficiency of satellite communication systems. Utilizing an extensive dataset comprising satellite imagery and meteorological records, this study focuses on discerning the evolving rain height patterns in Malaysia. Rain height is one of the crucial parameters used to determine rain fade on satellite communications. The study employs a statistical methodology including predictive modeling using the regression method, to assess the correlation between climate change-induced alterations in rainfall and the resultant impact on rain height. Our findings reveal a strong correlation between climate change which is typically associated with the increase of global temperature (~ 0.5 °C - 1.5 °C) and rain height (~ 4 m increase per year) in Malaysia. Rain attenuation increases by approximately 0.03 dB per year with the increase of rain height and temperature. The research contributes by revising studies on climate change's effect on rain height with 30 years' worth of meteorological data collected from NOAA. In 2024, the rain height in Malaysia is predicted to be more than 5.4 km. Studies like this one contribute to the effective planning and deployment of satellite communication systems, especially at high-frequency ranges such as Ka and Ku bands, ensuring high-quality and stable communication systems while minimizing loss.

Keywords-rain height; climate change; satellite communications; rain fade; meteorological data

I. INTRODUCTION

Radio links operating at frequencies above 10 GHz frequently experience signal degradation caused by hydrometeor events, particularly in tropical regions where rain events are more intense. The severity of losses resulting from hydrometeor events can lead to links unavailability, causing system outages and significantly impacting the overall signal quality [1-4]. Hydrometeor events manifest in various forms, including rain, snow, clouds, and fog. Among these, rain is the most prevalent hydrometeor event affecting radio signals, especially in equatorial and tropical regions. The higher the operational frequency of radio links, the greater the loss due to rain [5-7]. Satellite communication operates within a high-frequency range, typically above 20 GHz, such as the Ka and Ku bands. This technology has become a crucial method for enhancing existing telecommunication infrastructure, including applications like 5G, UAVs, and other remote sensing applications. Consequently, maintaining the quality of satellite communication is imperative since high-frequency links are often susceptible to degradation caused by rain [8-10].

This research focuses on the measurement of rain height to assess the degree of attenuation due to precipitation across Malaysia. This study aims to find the correlation between climate change and rain height in Malaysia and deploy a simple AI prediction model of rain height for rain attenuation predictions in designing satellite communication systems. Authors in [11] stated that in the previous 50 years, most parts of the world have seen a notable increase in temperature, and global warming is most likely to continue for the rest of the century. It is widely acknowledged that climate change is a consequence of global warming. This fact has inspired this research to study the relationship between rain height and climate change. Rain attenuation components such as rain height, rain rate, altitude, and slant-path length must be accurately measured to estimate the rain attenuation of a location. In the case of satellite links, rain height is one of the most important factors [12, 13]. Severe attenuation typically occurs between ground stations and the rain height for earth-space satellite communications. The height at which raindrops with a diameter larger than 0.1 mm form is known as the rain height. It is the highest point in the rain area, measured from sea level, where precipitation starts to fall from supercooled melted ice [17-19]. The rain height h_r is 360 m above the Zero-Degree Isotherm (ZDI) height [14-16]. It is acceptable to expect the effective rain height and the ZDI height, coincide in certain places when the elevation of the earth's surface above sea level is negligible. However, it should be noted that there is a significant difference between the rain height and the ZDI height, for earth stations that are significantly higher than the sea level [20]. The ITU recommends the mean annual rain height, which is calculated by:

$$h_r = h_o + 0.36 \text{ km} \quad (1)$$

where h_o is the ZDI height above the mean sea level obtainable from ITU-R P.839-4 map [21].

The recent research works in analyzing the measurement of rain height to assess the degree of attenuation due to precipitation are reviewed in Table I.

TABLE I. COMPARISON OF THE RECENT CASE STUDIES

Ref.	Method of meteorological measurement	Sampling area	Integration time	Sampling time	Climate change study
[23]	Global Precipitation Mission (NASA)	Nigeria	1 hour	1997-2014	Yes
[24]	Radiosonde	China	1 hour	2005-2014	No
[24]	Radiosonde	Norway	1 hour	1980-2020	Yes
This work (2024)	Weather Satellite (NCEP/NCAR)	Malaysia	1 hour	1992-2022	Yes

Authors in [23] utilized data from the Global Precipitation Mission (GPM) to provide a comprehensive investigation of the variability of rain heights in Nigeria. The outcome shows a rising trend in rain height, with 4.92 km in the country's south and roughly 5.23 km in the north. The findings indicate that the rain height value recommended by ITU-R is underestimated. The case study in [24] proposed a new weighted mean annual rain height using the ratio of the mean monthly rainfall to the mean annual rainfall as the weight. Initially, data from multiple sites in China that have different rainfall climates are used for the analysis. The monthly zero-degree Celsius isotherm height for every station was determined from the radiosonde data collected between 2005 and 2014. Then, using the previously described techniques, the mean monthly rain heights, weighted mean annual rain height, and mean annual rain height were determined. Authors in [25] analyzed zero-degree height in

Norway region. This study utilized radiosonde data from the locations of Bjørnøya, Jan Mayen, and Ny Alesund and the ERA5 numerical weather data provided by the European Centre for Medium-Range Weather Forecasts. A trend analysis of surface temperatures for the radiosonde launch sites over the years 1980–2020 was presented. A clear pattern of increasing zero-degree height is also shown by the data analysis, which covers 40 years.

In this work, 30 years of data, from year 1992 to 2022, of temperature and altitude data from NCEP/NCAR were analyzed to investigate the correlation between rain height and climate change in Peninsular and East Malaysia. Further details on how the data was acquired are explained below.

II. METHODOLOGY

In this section, the flow of the method used in this study will be explained thoroughly, based on Figures 1 and 2. Rain height can be calculated based on temperature and geopotential height information, both can be extracted from NCEP/NCAR Reanalysis data from NOAA [25] which are publicly available and can be downloaded directly from NOAA's website. The raw downloaded data are in NetCDF file format, contains several parameters including temperature and height at 17 different pressure levels in our atmosphere, sampled every 6 hours and available globally. This study focuses on Peninsular and East, Malaysia. Therefore, the global available data were separated with MATLAB at Malaysia's latitude 4°12′14.40″ North, and longitude 109°10′15.60″ East [26]. The data does not provide ZDI directly, hence using the extracted temperature and altitude data, ZDI height was obtained using the linear interpolation method in MATLAB. Figure 1 shows how freezing level ZDI for rain height was calculated.

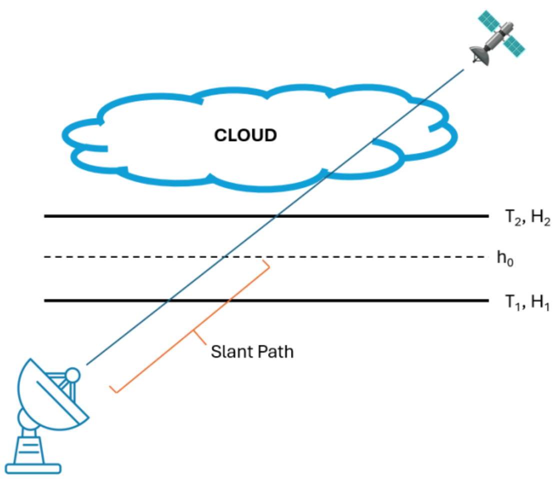

Fig. 1. Illustration of extracting ZDI from NCEP NCAR reanalysis data.

In Figure 1, h_0 is the ZDI height at 0 °C, T_2 and H_2 are the temperature and the geopotential height where the temperature is slightly lower than 0 °C, T_1, H_1 are the temperature and the geopotential height where the temperature is slightly higher than 0 °C. The rain height was calculated using (1) by adding h_0 of 0.36 km.

After the rain height was obtained, the ITU-R prediction method was applied to calculate the rain attenuation by using the rain height as the input parameter. For the climate change study, each year at 0.01% exceedance probability of rain fade was plotted, from 1992 to 2022. Exceedance probability is the probability of the percentage of rain rate being equal to or exceeded that level [27]. The calculation method for exceedance probability is:

$$P(\%) = \frac{CF\,(max) - CF}{CF\,(max)}\,(100\%) \qquad (2)$$

where $P(\%)$ is the exceedance probability, $CF(max)$ is the maximum cumulative frequency of the rain rate and CF is the range of all cumulative frequencies of the yearly rain rate. A regression model was then used to observe the trend. Using MATLAB, the rain height distribution graphs were plotted.

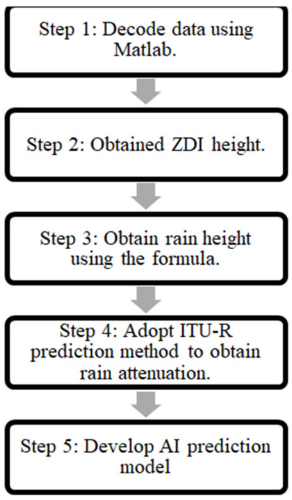

Fig. 2. Workflow of the followed methodology.

Finally, an AI prediction model of rain height was developed using Python with PyTorch in Google Colaboratory platform. Figure 3 visualizes the flow of the AI prediction model for the rain height. At first, necessary Python libraries were imported into PyTorch so that the program can recognize and run certain functions. PyTorch is an open-source machine learning library primarily developed by Facebook's AI Research Lab (FAIR [28, 29]. Then, the input data in CSV file form were uploaded and decoded. The decoded data need to be split up into two different sets (training set and validation set) before the normalization step.

After all the steps are done, the data training process can start. To validate the accuracy of the prediction, actual data from previous years will be compared with the predicted data. If they are not in accordance, the training process needs to be repeated by adjusting the training function. The flow will end when the predicted results are close to the actual results.

III. RESULTS AND DISCUSSION

A. Thirty-Year Average Rain Height in Malaysia

Figures 4 and 5 display the graphs of the average rain height in Peninsular and East Malaysia. They were plotted after the process of data extraction and analysis. A linear regression (in red line) is used to analyze the trend. Both graphs show a significant increase in average rain height in Malaysia from 1992 to 2022. There is an approximate 4 m increment in the rain height per year.

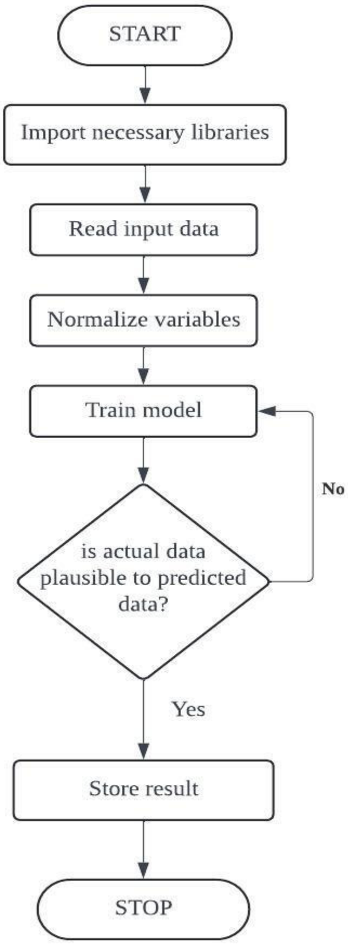

Fig. 3. Flowchart of the AI prediction model of average rain height.

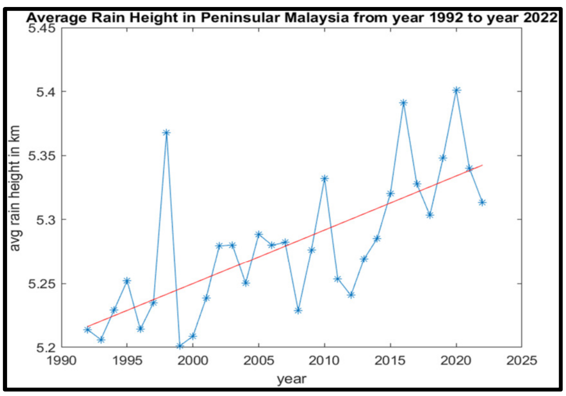

Fig. 4. Average rain height in Peninsular Malaysia from 1992 to 2022.

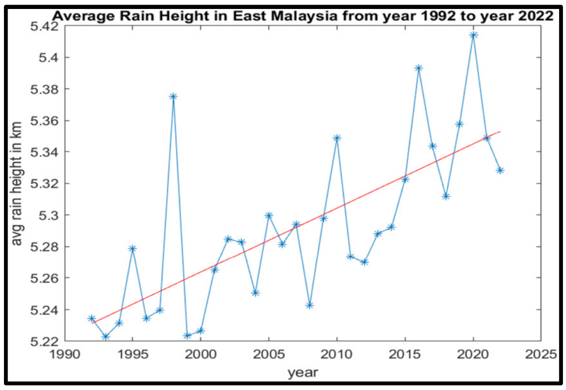

Fig. 5. Average rain height in Sabah and Sarawak from 1992 to 2022.

B. Correlation Graph between the Average Rain Height and Global Temperature

To study the effect of climate change on rain height in Malaysia, 30 years' worth of temperature and rain height data from NCEP/NCAR were plotted to find the correlation between them. The red-dotted linear regression line in Figures 6 and 7 shows the increasing trend of temperature in Malaysia. It means that there is a positive correlation between average rain height and global temperature in Malaysia.

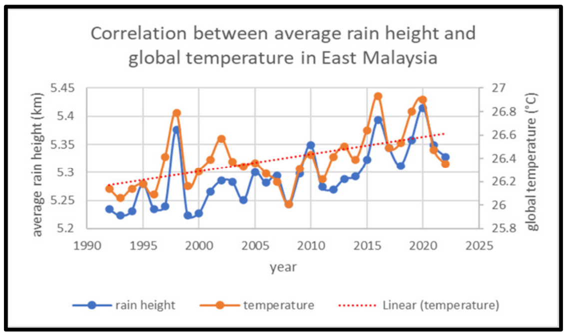

Fig. 6. Correlation between average rain height and global temperature in East Malaysia.

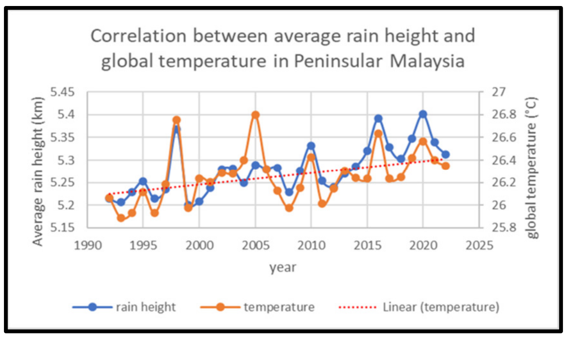

Fig. 7. Correlation between average rain height and global temperature in Peninsular Malaysia.

C. Rain Attenuation at 0.01% Exceedance in Malaysia over 30 Years

The rain attenuation results were obtained by adopting the ITU-R prediction model 618 (ITU-R P.618) for satellite communication with the input of rain height values obtained from reanalysis data. The link was simulated at 38 GHz with circular polarization. The aim for attenuation exceeded 0.01% of probability [30-32]. Figures 8 and 9 visualize the satellite rain fade at 0.01% exceedance in Peninsular and East Malaysia from 1992 to 2022. From the results, it is approximate 0.03 dB increase for the rain attenuation per year with the increase of rain height and temperature. This shows that the climate change gives a small impact on the rain attenuation exceedance in Malaysia.

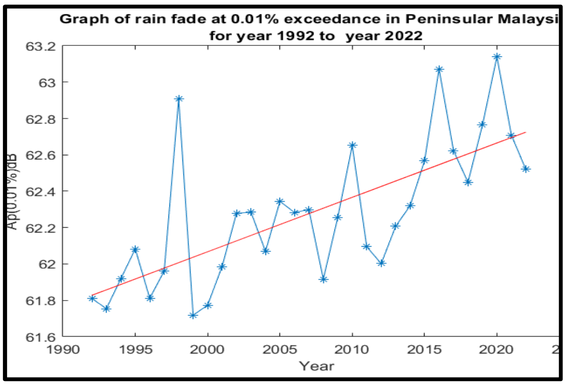

Fig. 8. The graph of rain fade at 0.01% exceedance in Peninsular Malaysia from 1992 to 2022.

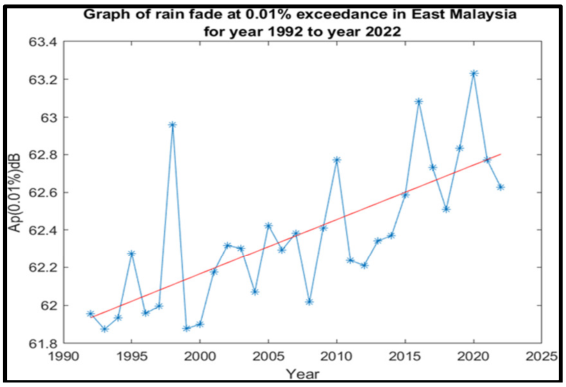

Fig. 9. The graph of rain fade at 0.01% exceedance in Peninsular Malaysia from 1992 to 2022.

D. Predicted Results for Rain Height in Malaysia from 2020 to 2024

The AI prediction for rain height in Malaysia was conducted after the analization process. The AI prediction model is essential for the preparation in future to make sure a constant signal availability. Figures 10 and 11 show the prediction of rain height in Malaysia from 2020 to 2024. Table II and III show the percentage error of the prediction. In this model, the Mean Square Error (MSE) of the prediction is equal to 0.0004. The prediction started from 2020 due to the accuracy checking for the AI prediction model. From Table II, the predicted average rain height in Peninsular Malaysia for the year 2021 is 5.347 km. The result has only 0.13% error compared to the actual result which is 5.34 km. Therefore, the predicted average rain height in Peninsular Malaysia for the year 2024 will be more than 5.4 km can be considered as reliable.

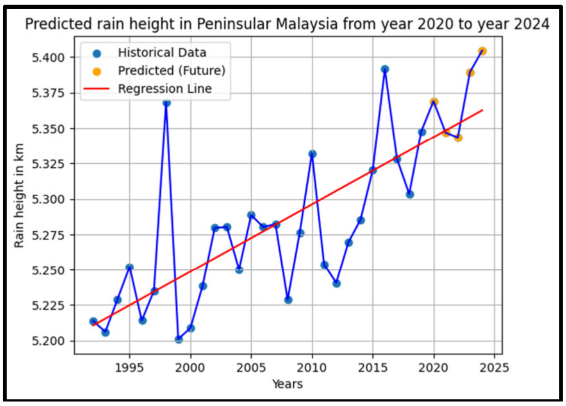

Fig. 10. Prediction for rain height in Peninsular Malaysia from 2020 to 2024.

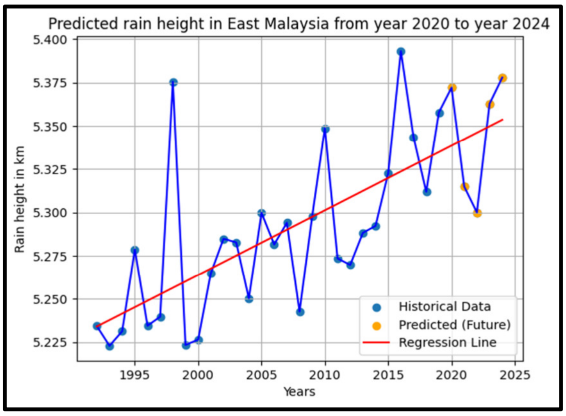

TABLE II. ERROR OF RAIN HEIGHT PREDICTION IN PENINSULAR MALAYSIA

Rain height			
Year	**Actual Results**	**Predicted Results**	**% error**
2020	5.401	5.369	0.59
2021	5.34	5.347	0.13
2022	5.313	5.343	0.56

TABLE III. ERROR OF RAIN HEIGHT PREDICTION IN EAST MALAYSIA

Rain height			
Year	**Actual Results**	**Predicted Results**	**% error**
2020	5.414	5.372	0.77
2021	5.349	5.315	0.63
2022	5.328	5.300	0.52

IV. CONCLUSION

In conclusion, the average rain height is proven to have an increasing trend along with the increase in temperature throughout the year. The results of the current research show a substantial relationship between climate change and rising global temperatures (~0.5 °C to 1.5 °C) and rain height (~4 m rise annually) in Malaysia. This will cause the slant path length of the satellite links to increase which results in more severe rain attenuation. As rain height and temperature rise, there is about 0.03 dB annual increase in rain attenuation.

An AI prediction model that achieved acceptable accuracy was successfully developed to forecast the rain height value associated with the effects of climate change in the future years. Malaysia is expected to have more than 5.4 km of rain height in 2024. The forecast rain height value can provide information for future design work of satellite-based communication systems and boost the performance of the systems.

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