DATA ANALYTICS AND MACHINE LEARNING ON WEATHER IN SINGAPORE AND IMPACT ON SENSORS PERFORMANCE

INTRODUCTION

BACKGROUND

Many sensors used in electronic warfare (EW) rely on electromagnetic waves to receive and send signals. However, atmospheric aerosols caused by weather can attenuate radiofrequency on the EM spectrum, leading to affected performance of sensors and possibly inaccurate data.

IMPACT OF WEATHER ON EM WAVES & SENSORS

What is atmospheric attenuation?

- A reduction in the intensity of EM radiation in the Earth's atmosphere as a result of the absorption and scattering of the radiation, which occurs mostly due to the presence of hydrogen and oxygen molecules in the atmosphere.

Rain Fade

- absorption of microwave / radio signals by rainwater

Effect on sensors

- transmission quality of signal decreases
- signal might not be picked up by receivers

OBJECTIVE

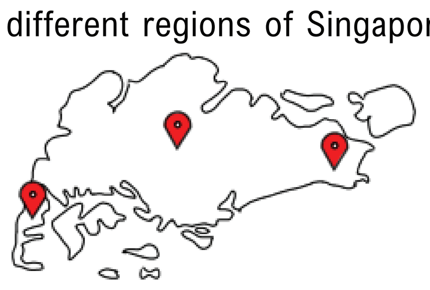
1. To analyse Singapore's weather and impact of weather on radiofrequency spectrum
2. Predict future rainfall amount using a Machine-Learning Model and its impact on sensors' performance

METHODOLOGY

1 DATA ANALYTICS OF PAST WEATHER

Weather trends across regions of Singapore

1. Obtain data sets of past weather from 3 different regions of Singapore to give an accurate overview of the weather in Singapore
   - Locations chosen:
     - Tuas South (West region)
     - Ang Mo Kio (Central)
     - Changi (East region)



2. Observe the variation in rainfall and determine which region is most suitable for sensors to be placed

Trends across historical data sets at Changi from 1983 to 2020

1. Obtain data sets of past weather from Changi from 1983 to 2020
2. Observe overall trends in annual rainfall and temperature and carry out further research on why these trends are present.
3. Use the dataset to calculate the average daily rainfall for each month and subsequently the attenuation a sensor would experience in that month to find out for which months sensors would have better performance.
   - Equation used:

$$L = kR^{\alpha} \cdot d_{eff}$$

- R = rate (mm/h)
- k = linear polarisation
- a = horizontal paths
- deff = effective propagation distance
- Assumptions:
  - Path elevation angle & polarisation tilt angles = 0
  - Daily rain rate lasted for 1 hour (convectional rain)
  - Effective propagation distance = 1km

2 MACHINE LEARNING MODEL

Logistic Regression & XGBoost

What the data set consists of:

- Year, Month, Day
- Daily Rainfall (mm)
- Mean Temperature (°C)
- Mean Wind Speed (km/h)

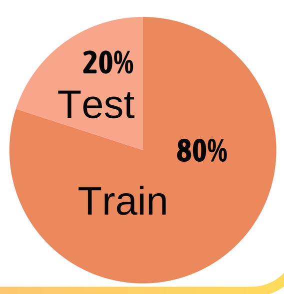
What the model aims to achieve:

- Predict if it rains and amount of rainfall to calculate the signal attenuation caused by rainfall on that particular day.

Rationale behind model choices:

- Logistic regression is a binary classification algorithm which suits our specific objective of predicting solely two outcomes—whether it will rain or not.
- XGBoost was chosen for its effectiveness in capturing non-linear trends, leveraging its boosting tree mechanism to iteratively refine predictive performance.

DATA SET SPLIT



CONCLUSION

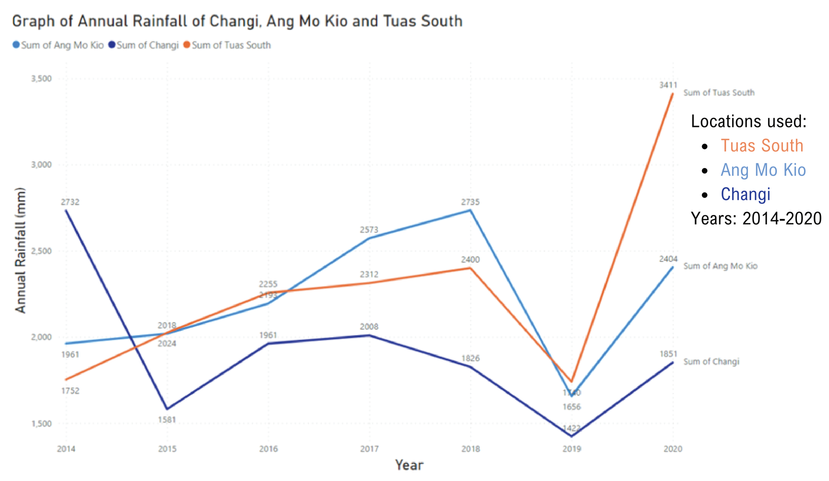
Our ML model is able to accurately forecast rainfall and RF attenuation. With more updated data, the model can be used to predict future rainfall with a higher accuracy.

Applications in defense:

- Sensors in island air defense — UAV, naval and air platforms
- Test transmitters can adjust transmission power considering RF attenuation, leading to a higher success rate in testing.
- Implement adaptive power management strategies for sensors, allowing them to dynamically adjust transmission power based on predicted rainfall attenuation. This ensures optimal performance under varying weather conditions.

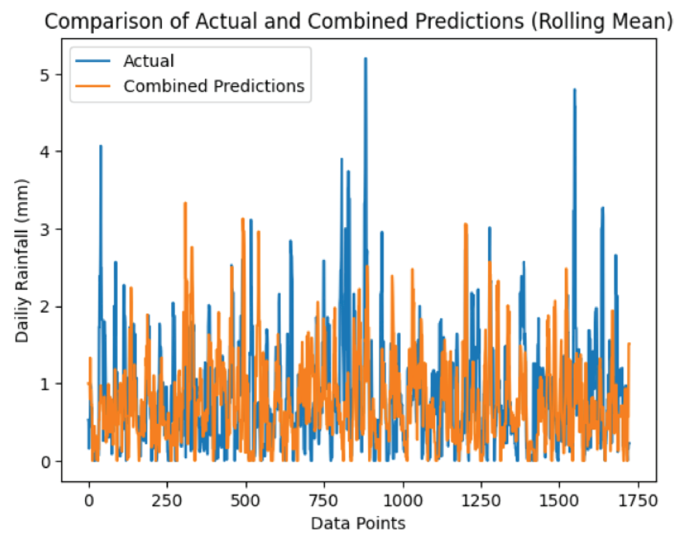
RESULTS & DISCUSSION

1 Weather trends across regions of Singapore



- There is a general increase in rainfall in all locations
- The east region generally has less rainfall than the west region
  - Due to the **rain shadow effect** from Bukit Timah Hill, the East side of Singapore experiences reduced rainfall.
  - East side of Singapore is less affected by rainfall and experiences less RF attenuation, hence is more suitable for the use of RF sensors.
- Install sensors in the North-west of Singapore instead of Tuas South to mitigate effects of rainfall on sensors.

2 Machine Learning Results



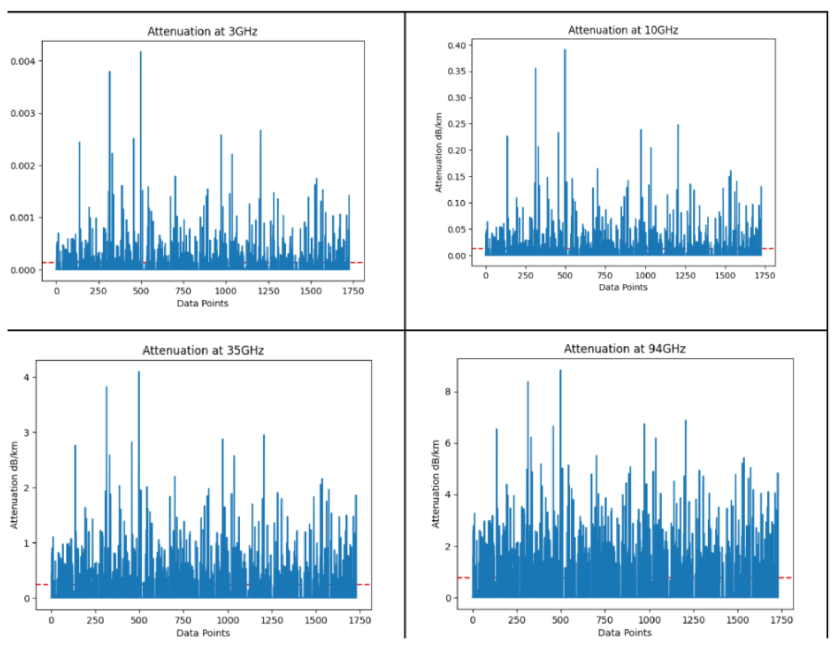
Root Mean Squared Error of combined model: 2.136mm

Accuracy of log: 0.7385

Root Mean Squared Error of XGBoost model: 2.120mm

- Our combined machine learning model integrates logistic regression and XGBoost.
  - Logistic regression predicts rain presence, outputting 0 for no rain and 1 for rain.
  - If both models predict less than 1mm rainfall the combined model outputs 0.
  - Otherwise, the combined model will output XGBoost prediction
- Reasoning for Combined Approach:
  - XGBoost struggles with predicting complete 0s
  - Logistic regression's binary nature complements XGBoost
  - Result: Complementary and accurate rainfall prediction model with an average deviation of 2.14mm in daily rainfall predictions from actual values.

Predicted signal attenuation using ML model



Observed trend of rainfall attenuation:

- The higher the frequency, the greater the rainfall attenuation.

Reason behind trend:

- Scattering Efficiency:
  - Higher-frequency raindrops efficiently scatter electromagnetic waves due to their size, absorbing more signal energy.
- Absorption by Water Molecules:
  - Higher-frequency signals are more susceptible to absorption by water molecules, contributing to significant signal attenuation.
- Shorter Interaction Distances:
  - Higher-frequency signals interact with raindrops over shorter distances, intensifying absorption and scattering effects, leading to greater attenuation.

Recommendation to overcome rainfall attenuation:

- Installing sensors of lower frequency so that it is less affected by rainfall attenuation.
- Use of satellite-based sensors, Synthetic Aperture Radar (SAR), as part of a suite of systems.

FUTURE WORK

- Use different variables such as haze and fog to form relationships with rainfall amount in our ML model
- Use data from different places of Singapore to predict RF attenuation of any location in Singapore

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