Hybrid Radio Frequency/Free Space Optical (RF/FSO) Communication System

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Background

Rapid development of 6G and Applications in various fields such as AI and autonomous driving

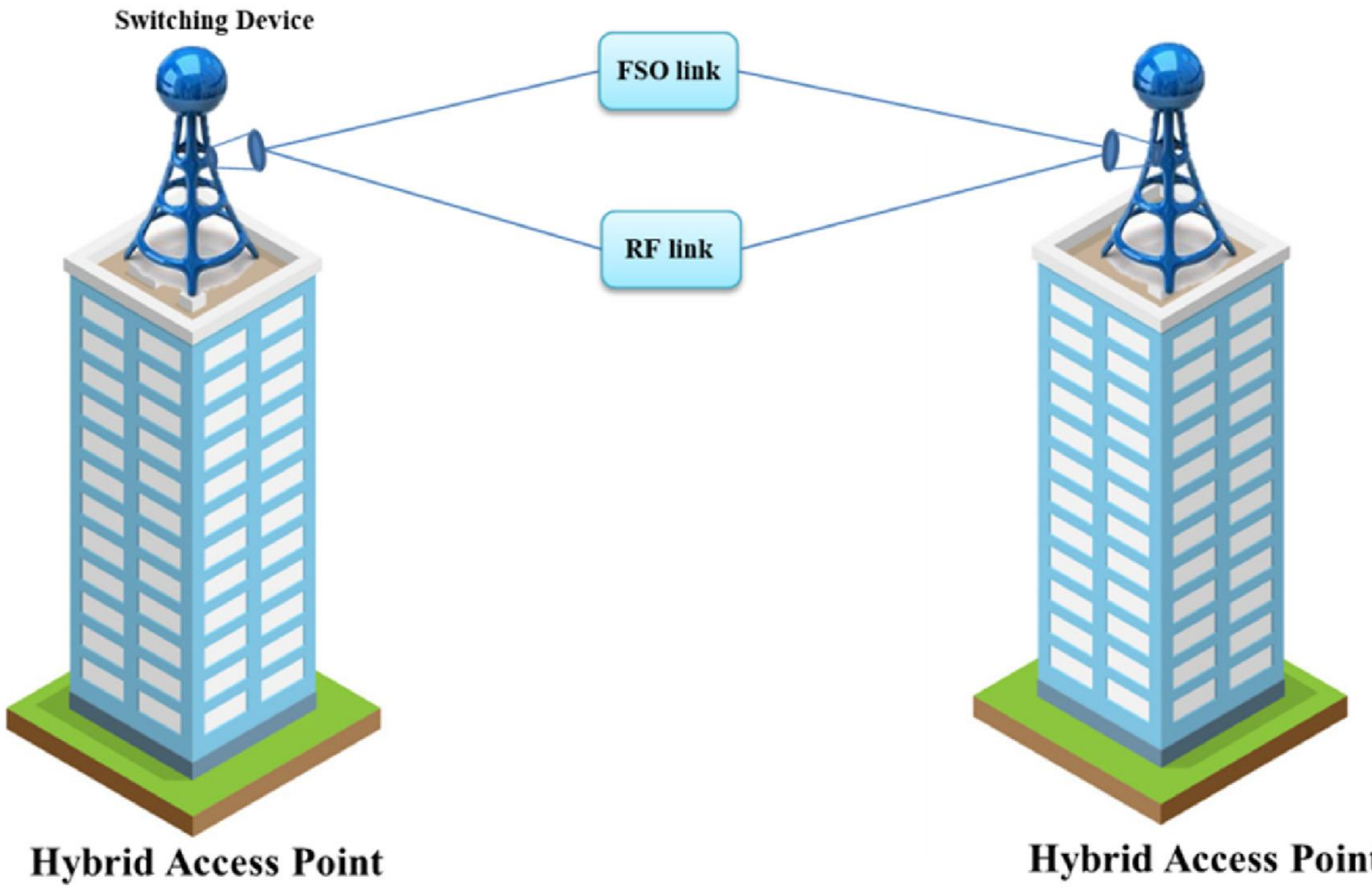
Demand for faster, ultra-low latency and higher link density

Hybrid Radio Frequency (RF) /Free Space Optical (FSO) Communication System has been developed as a promising solution

Radio Frequency (RF) communication is a commonly used data transmission method that utilises electromagnetic waves in the frequency range of 3 kilohertz(kHz) to 300 gigahertz(GHz).

Free Space Optical (FSO) communication is a technology that transmits data using infrared light through free space, providing high data rates without relying on the RF spectrum.

Hybrid RF/FSO Communication System



Syed Agha Hassnain Mohsan, Muhammad Asghar Khan, Hussain Amjad, Hybrid FSO/RF networks: A review of practical constraints, applications and challenges, *Optical Switching and Networking*, Volume 47, 2023, 100697, ISSN 1573-4277

Goals

1. Develop a reliable signal attenuation prediction model for a hybrid RF/FSO communication system under various weather conditions.

2. Preserve the correlation between RF and FSO attenuation to enhance model reliability in real-world scenarios.

Performance Metrics

$$RMSE = \sqrt{\frac{1}{N}\sum_{n=1}^{N}(y_n - \hat{y}_n)^2} \quad (1)$$

$$R^2 = 1 - \frac{\sum_{n=1}^{N}(y_n - \hat{y}_n)^2}{\sum_{n=1}^{N}(y_n - \bar{y}_n)^2} \quad (2)$$

Where:

- y_n : the measured RF or FSO attenuation (actual value) of the n-th sample.
- $\bar{y}_n$: the average value of y_n.
- $\hat{y}_n$: the model's predicted attenuation based on the predictor variables of the n-th sample.
- N: the total number of test samples.

Pearson Correlation Coefficient (PCC):

It measures the linear correlation between RF and FSO attenuations.
Range: [-1, 1]

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}}$$

Where:

x_i = values of the x-variable in a sample

$\bar{x}$ = mean of the values of the x-variable

y_i = values of the y-variable in a sample

$\bar{y}$ = mean of the values of the y-variable

RFLFSODataFull Dataset

The RFLFSODataFull dataset used in this study consists of approximately 91,000 records. These records are synthetic data based on real empirical data collected from hybrid RF/FSO systems operating in six cities worldwide. The dataset was provided by Dr. Siu Wai Ho and has already been cleaned.

Target variables	RF channel attenuation (dB)
	FSO channel attenuation (dB)

Features	SYNOP Code
	Frequency
	Distance
	Time
	Wind Direction
	Relative Humidity
	Temperature Difference
	Absolute Humidity, Absolute Humidity Max, Absolute Humidity Min
	Particulate, Particulate Max, Particulate Min
	Rain Intensity, Rain Intensity Max, Rain Intensity Min
	Temperature, Temperature Max, Temperature Min
	Visibility, Visibility Max, Visibility Min
	Wind Speed, Wind Speed Max, Wind Speed Min

Feature Selection

Removing redundant features by evaluating the RMSE and R^2 of the model.

Help reduce instability and overfitting, improving the model performance and generalisation.

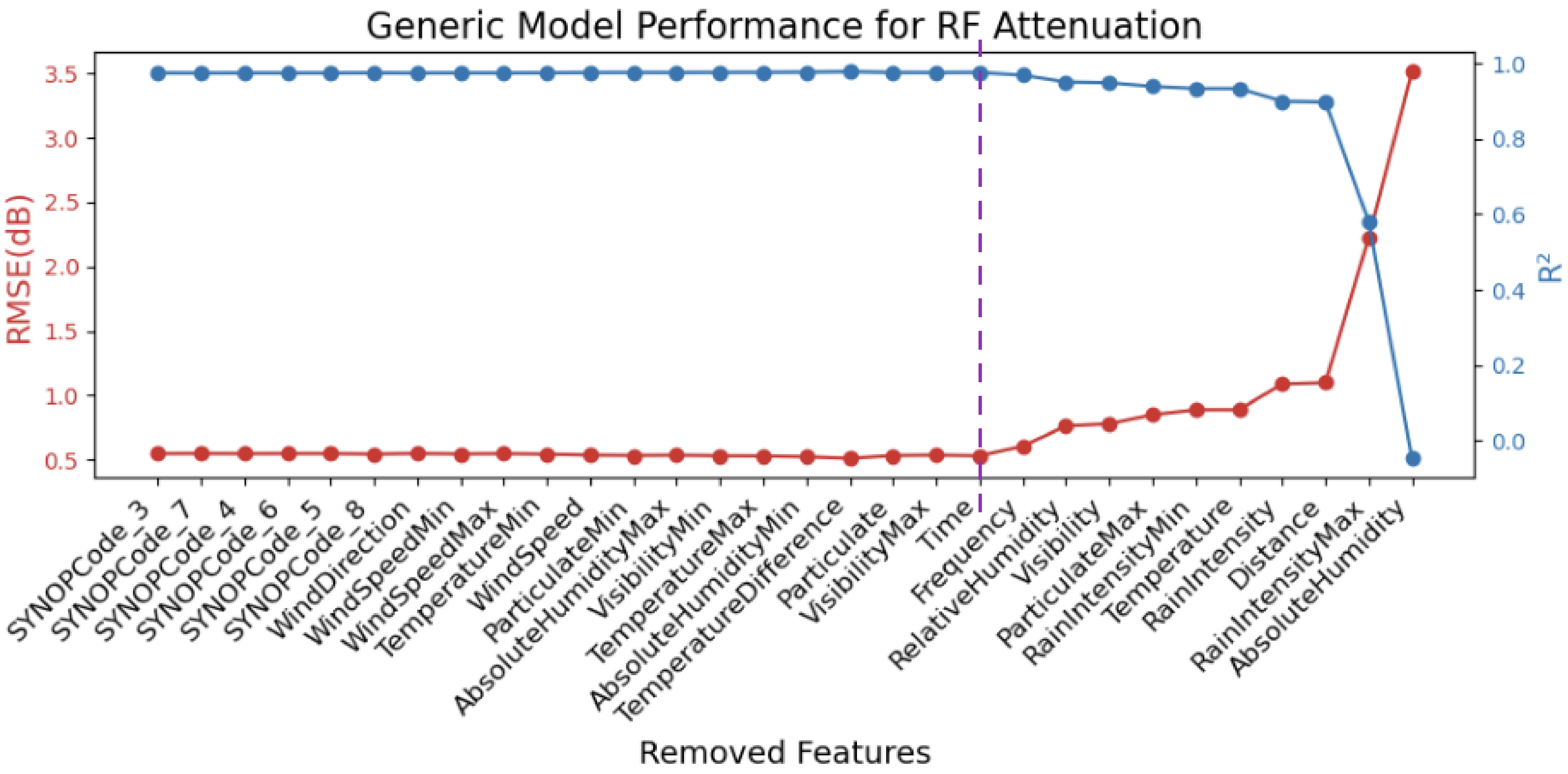
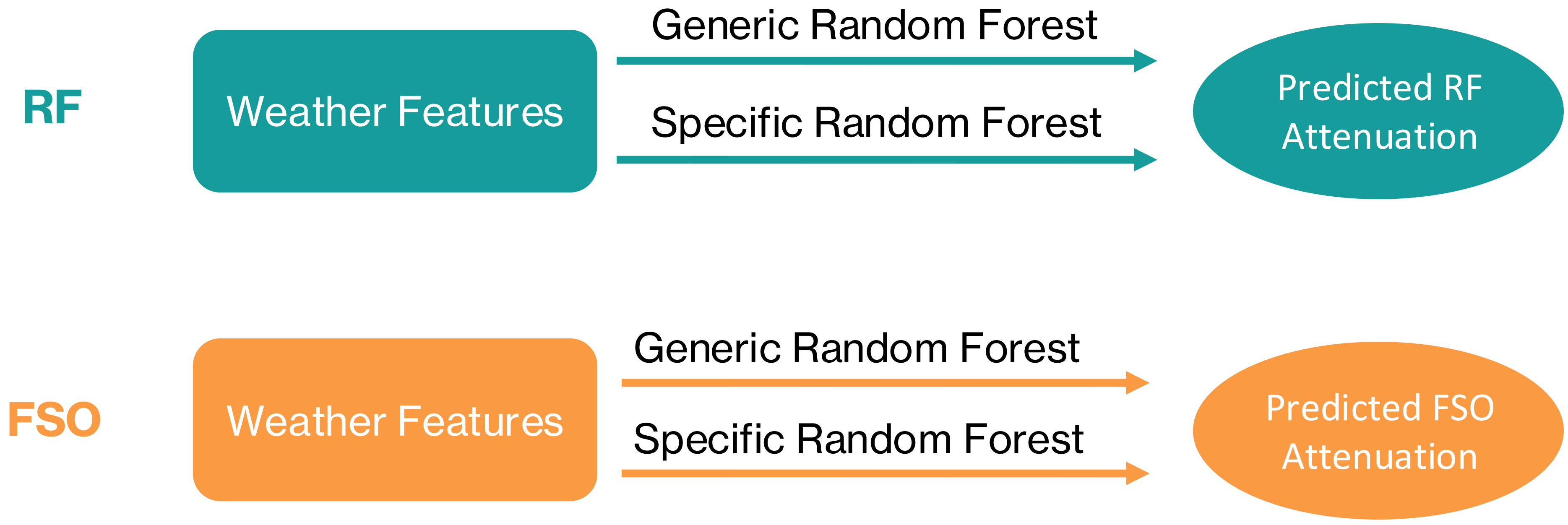


Figure 1. Generic Model Performance for RF Attenuation Prediction.

Models

- Method 1. Independent Model
- Method 2 & 3. Joint Model

Method 1. Independent Model



Method 1. Independent Model

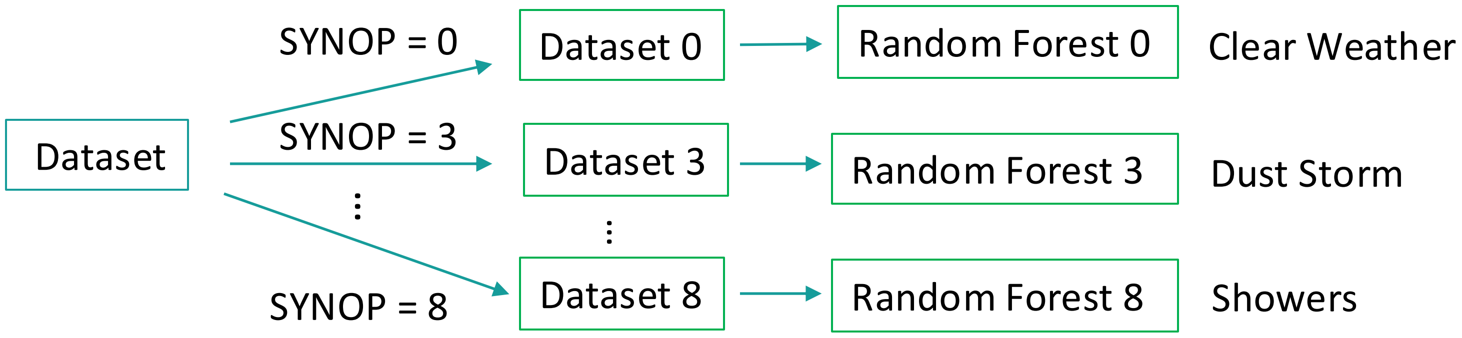
Generic Model vs. Specific Models

Generic Model :

- A single random forest model is trained using all available training data, treating the SYNOP code as a categorical variable.
- Test set data across all weather conditions can be evaluated using this model.

Specific Models :

- The training data is divided into seven subsets, each corresponding to a different weather condition. A separate random forest model is trained for each subset.
- Test set data is evaluated using the model corresponding to its respective weather condition.



Performance Comparison

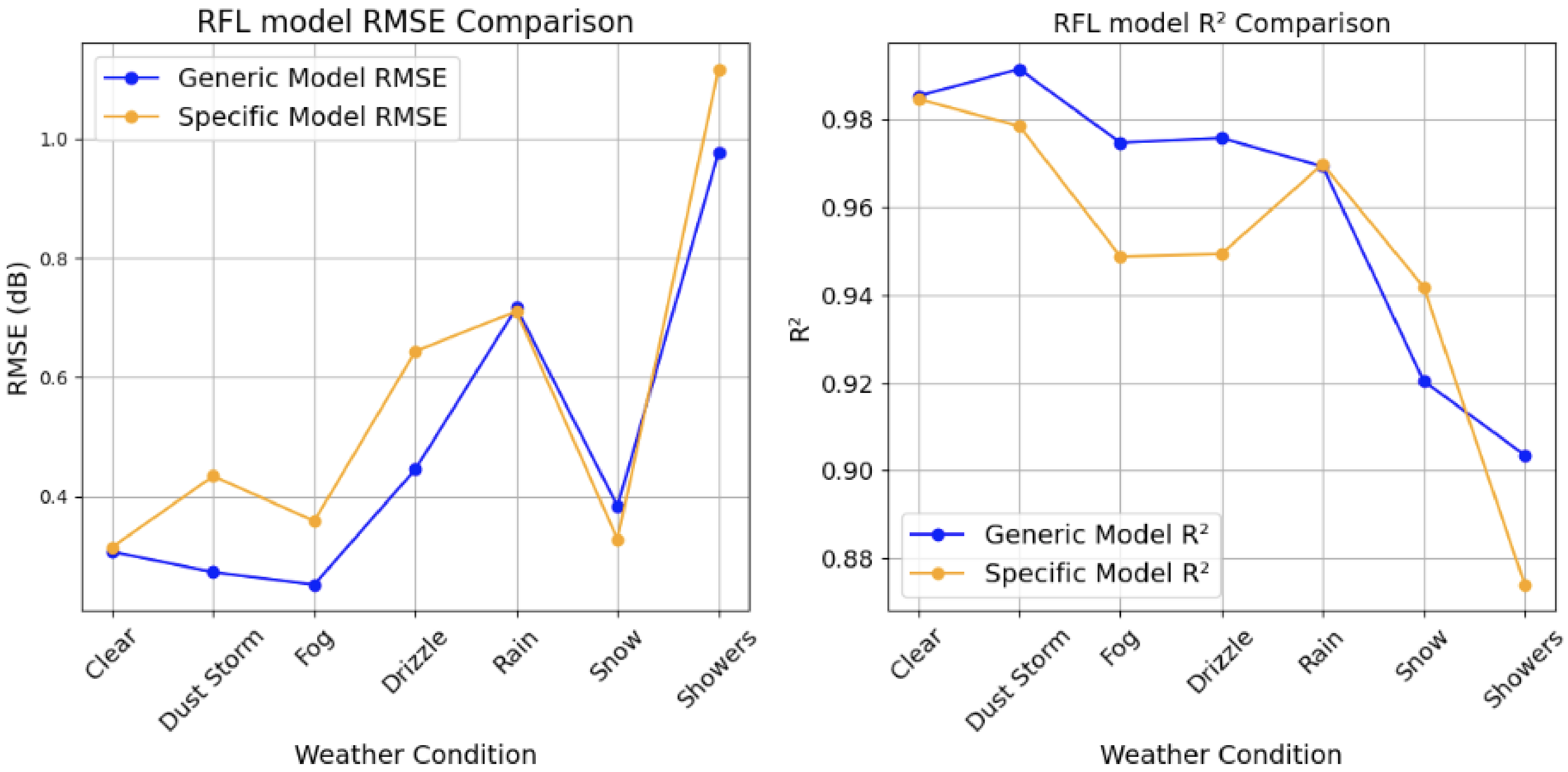


Figure 2: RF Model Metrics Comparison between Generic Model and Specific Model.

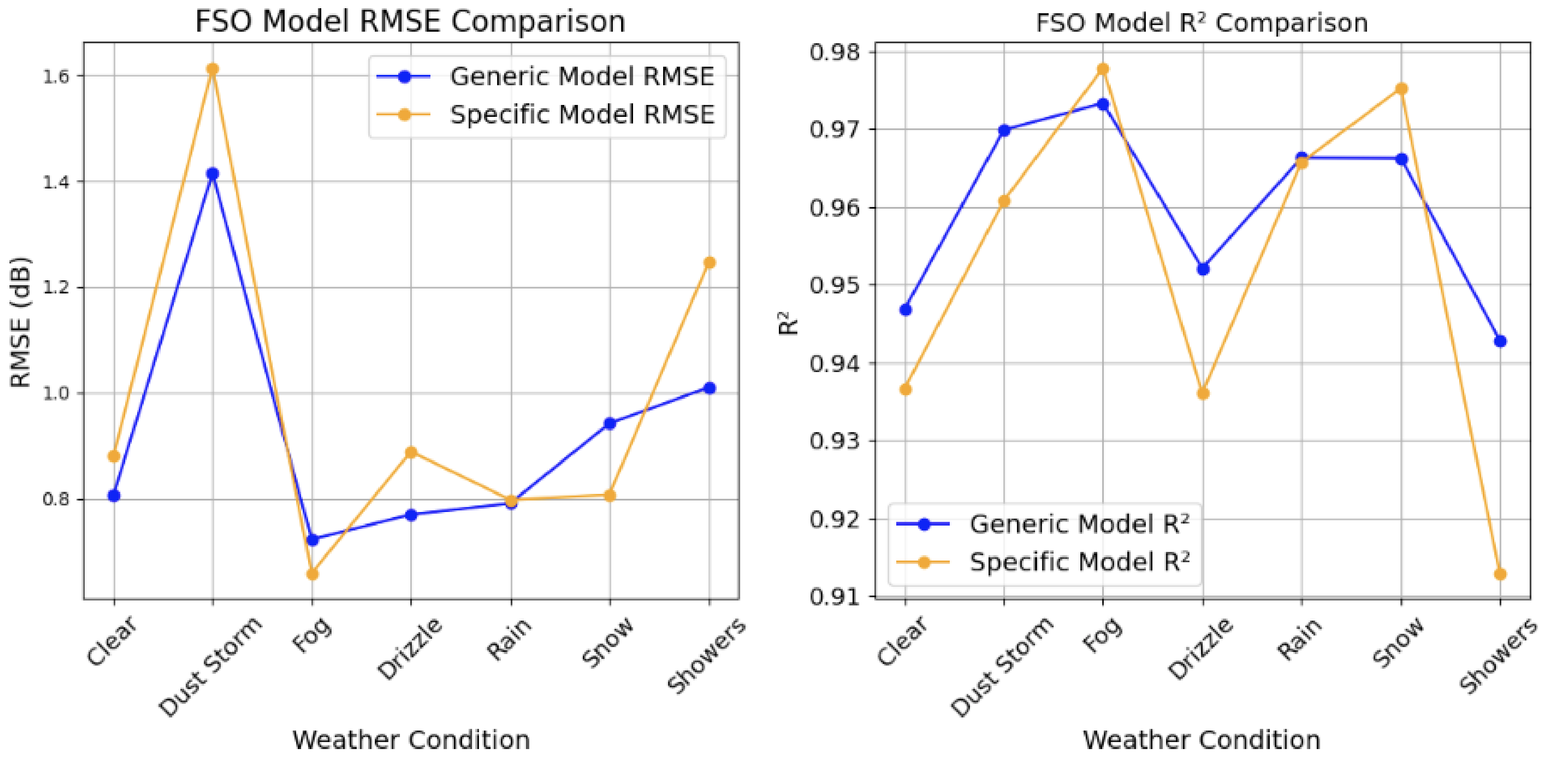
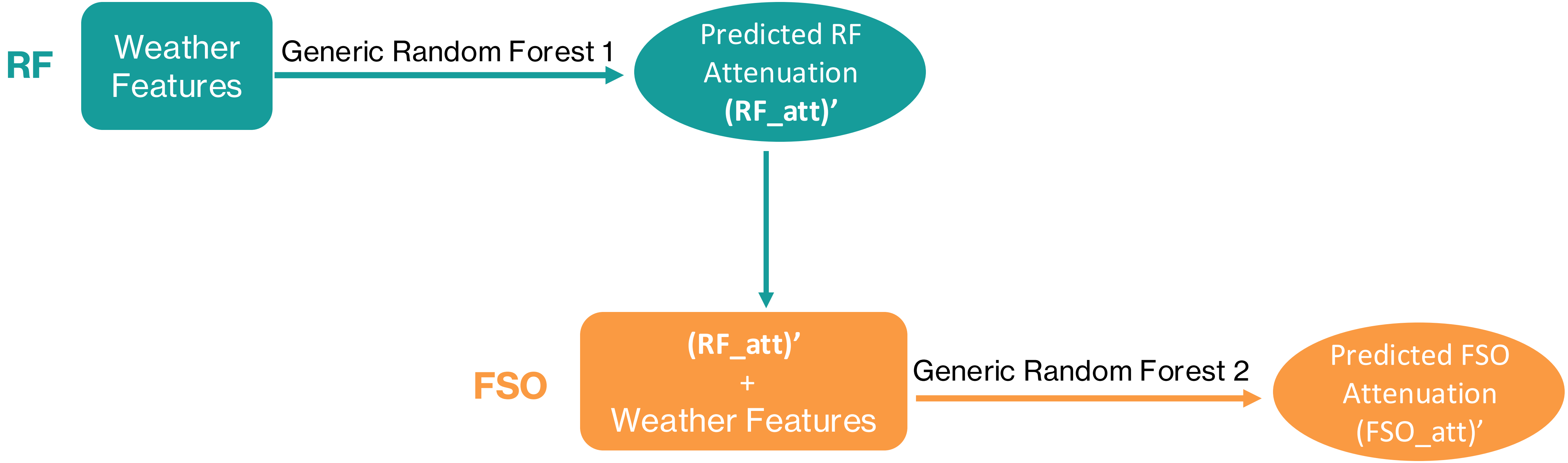


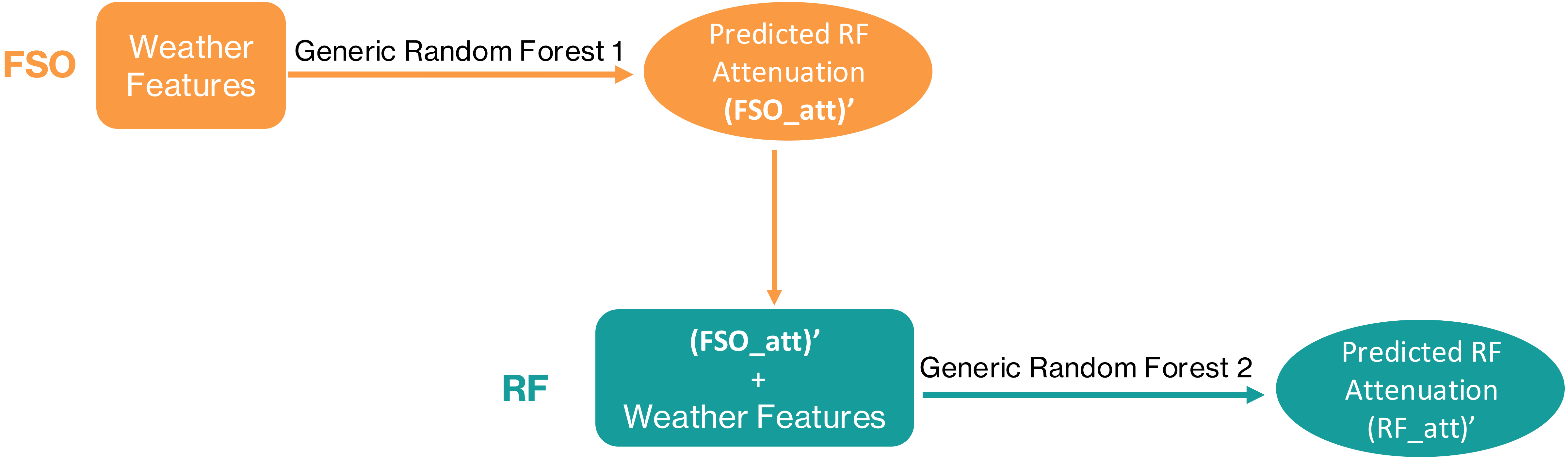
Figure 3: FSO Model Metrics Comparison between Generic Model and Specific Model.

Method 2. Joint Model



RF attenuation → FSO attenuation

Method 3. Joint Model



FSO attenuation → RF attenuation

Performance Comparison

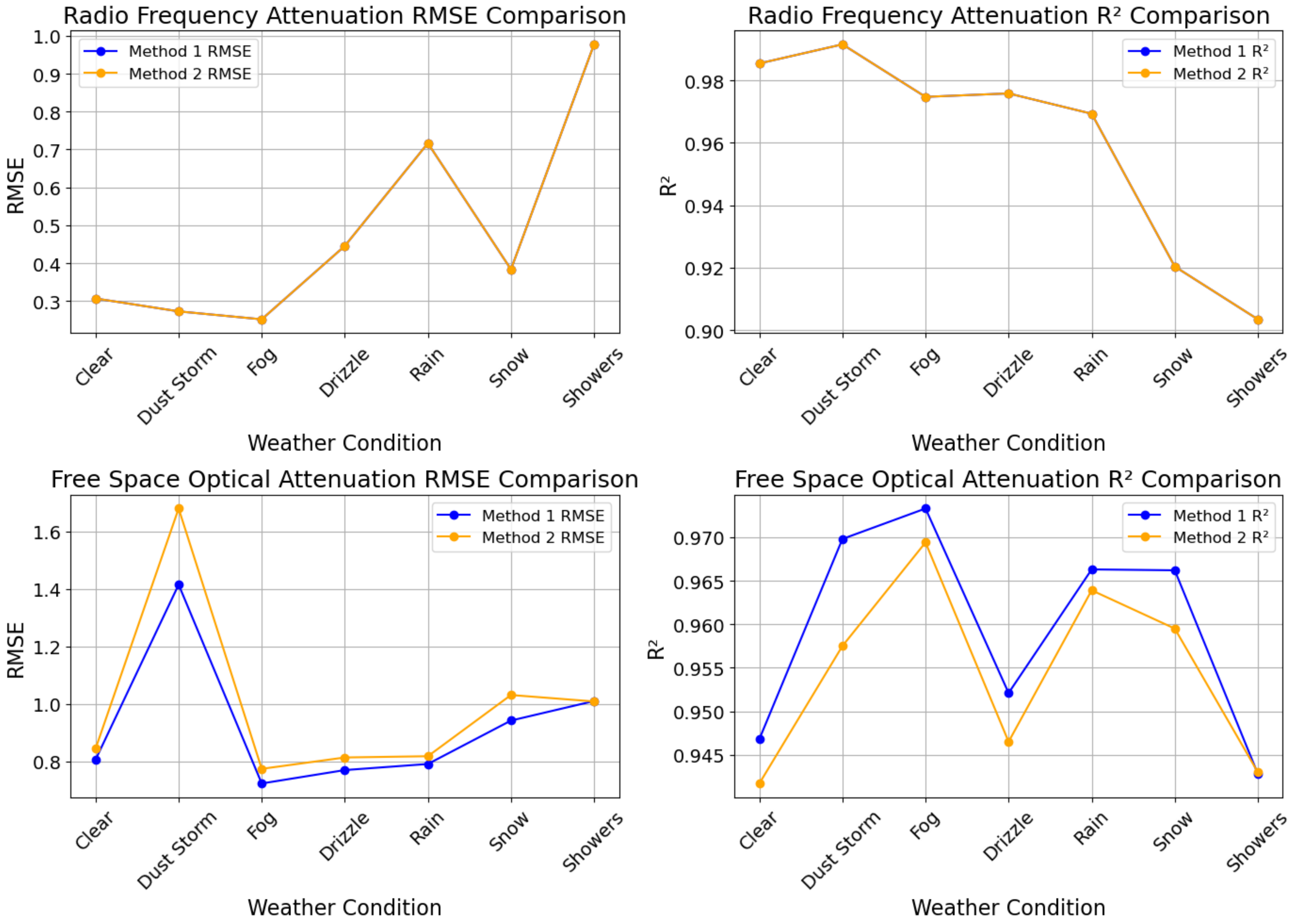


Figure 4: RMSE and R2 Comparison between Method 1 and Method 2.

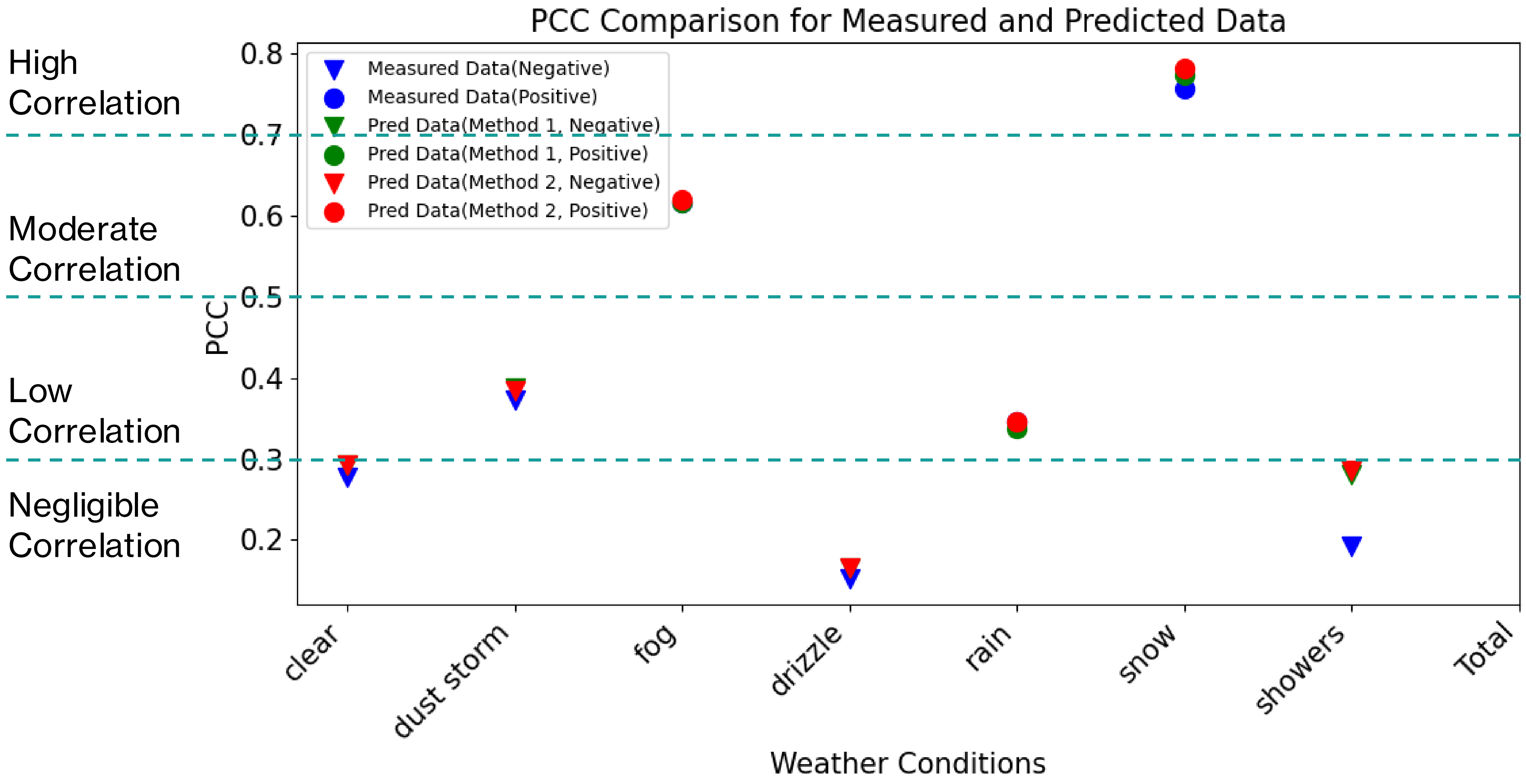


Figure 5: Pearson Correlation Coefficient Comparison between Method 1 and Method 2.

M. M. Mukaka, "A guide to appropriate use of correlation coefficient in medical research", Malawi medical journal, vol. 24, no. 3, pp. 69-71, 2012.

Considering the higher prediction accuracy and similar correlation preservation, independent models in Method 1 are selected as the best models.

Conclusion

Feature selection was applied to identify important features, and the random forest algorithm was used to develop prediction models for RF and FSO attenuation.

Due to their similar correlation preservation, the best model was determined based on prediction accuracy. The independent models in Method 1 were selected as the best, with RMSE values of 0.48 dB for RF attenuation and 0.81 dB for FSO attenuation, and R^2 values of 0.98 and 0.96, respectively.

Future work will focus on exploring Method 3 and incorporating Mutual Information (MI) to assess non-linear correlations.

Thank you !