Effect of Aerosol Scattering Attenuation on Communication Links in Port Harcourt Airspace

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Abstract: - A novel technique called free space optics (FSO) enables data transmission via light propagation in free space. However free-space optical (FSO) communication is negatively impacted by atmospheric disturbances including dust and scintillations. The objectives of the work is to determine the monthly cumulative distribution of aerosol scattering attenuation for transmissions at 850 nm and 1550 nm wavelength and to calculate attenuation impact on signal strength in the study area airspace. In this work, meteorological data was collected for Port Harcourt, Nigeria, during a 10-year period (2011-2020) were statistically analyzed in order to assess the availability performance of FSO lines broadcasting at both 850 nm and 1550 nm. The visibility, temperature, relative humidity and sea level pressure were collected to determine the aerosol scattering attenuation on free space optical communication. The results show that in the month of June 850 nm starts at a higher attenuation value of 1.6 dB/m compared to 1550 nm, having an attenuation of 0.7 dB/m. From june to july there is a slight decrease of about 0.9 dB/m and 0.3 dB/m for 850 and 1550 wavelengths respectively in the year 2011. ATT (850) has a relatively stable period from July to December and again from February to April. In 2012. Both ATT (850) and ATT (1550) appear to show some seasonal variation, with higher attenuation in the colder months (November to March) and lower attenuation in the warmer months (April to October). During the study period, it was observed communication lines on the 850nm experienced higher values of attenuation. Deeper understanding of the connections between environmental parameters and signal attenuation was obtained through a further Minitab regression study. The ideal location for the installation of a free space optical communication link by communication engineers can also be determined using the study's findings.

Key-Words: - Free space optical communication, Attenuation, Scintillation. Aerosol Scattering, Meteorological data, Atmospheric disturbances

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1 Introduction

Optical wireless communication (OWC) is a growing field that includes a promising alternative to Radio Frequency (RF) technology which is known as FSO, in which light is utilized as a communication channel. Free Space Optics (FSO) systems utilize light waves for data transmission over short to medium distances through the atmosphere. However, their performance is significantly impacted by atmospheric phenomena like aerosol scattering attenuation. This framework explores the theoretical aspects of how aerosol scattering weakens the transmitted signal and degrades FSO system performance [1]. Scattering by aerosols deflects the signal in various directions, reducing its intensity at the receiver. This weakening can make it difficult to distinguish the signal from background noise, especially over longer distances [2]. Scattering can distort the signal waveform, affecting its clarity and leading to disruptions in communication quality. This can manifest as blurry images in video transmission or garbled audio in voice calls [3]. Severe aerosol scattering attenuation can significantly limit the distance a signal can travel before becoming unusable. This is a major concern for long-distance communication applications like satellite links [4].

Satellite communication is based on the transmission of signals via the atmosphere to and from satellites in orbit. Aerosol particles, such as dust, smoke, and industrial pollutants, scatter these signals, resulting in attenuation and lowering the quality and dependability of the communication link. According to studies, locations with high aerosol concentrations suffer from more signal loss. For example, [5] found that aerosols in urban and industrial areas could cause significant route losses in satellite communication networks. This conclusion is especially pertinent in Port Harcourt, where industrial pollutants are abundant. Microwave communication systems, which are commonly used for point-to-point communication, are also susceptible to aerosol scattering. Microwave signals, typically in the GHz frequency range, are particularly affected by atmospheric particles. According to [6], the presence of aerosols can cause considerable attenuation in microwave propagation, impacting the efficiency of these communication links. In Port Harcourt, the dense industrial activities and frequent air pollution episodes exacerbate this issue, leading to frequent disruptions and signal loss in microwave communication networks.

Optical communication, especially free-space optics (FSO), relies heavily on clear air conditions. Aerosol particles can scatter and absorb light, resulting in considerable attenuation of optical signals. [7] demonstrated that aerosol-induced scattering might significantly reduce the performance of FSO devices, particularly in urban locations with high pollution levels. Port Harcourt's airspace, which is characterized by considerable industrial pollutants, presents a significant difficulty for the deployment and maintenance of dependable optical communication systems. Comparative studies of different places reveal how aerosol scattering attenuation varies with geographical and environmental conditions. [8] examined the attenuation effects in industrial cities to those in less polluted places, discovering a significant difference in communication connection reliability due to changing aerosol concentrations. This comparative approach can help contextualize the situation in Port Harcourt, implying that comparable attenuation difficulties encountered in other industrial zones are likely to apply.

Port Harcourt, a bustling city in Nigeria, has a significant amount of industrial activity, especially in the oil and gas sector. This industrial concentration leads to increased aerosol emissions, which affect air quality and visibility. Aerosols, tiny particles suspended in the atmosphere, can scatter and absorb electromagnetic waves, thus impacting communication systems that rely on the transmission of these waves through the air [9]. Aerosol scattering is a critical factor affecting the performance of wireless communication links. Scattering occurs when electromagnetic waves encounter particles whose dimensions are comparable to the wavelength of the waves. This scattering can attenuate the signal, causing degradation in signal strength and quality. The extent of this attenuation depends on several factors, including the concentration, size distribution, and chemical composition of the aerosols [4,10].

Port Harcourt's atmosphere is often laden with aerosols from various sources, including vehicular emissions, industrial discharges, and natural sources such as dust and sea spray. The city's climate, characterized by high humidity and frequent precipitation, further complicates the behavior of aerosols. High humidity levels can cause hygroscopic growth of aerosol particles, increasing their size and scattering efficiency [10-11]. Previous studies have highlighted the detrimental effects of aerosol scattering on optical and radio frequency communication links, emphasizing the need for localized studies to understand the specific impacts in different environmental contexts [4,9]. Port Harcourt, known for its oil refineries and industrial activities, experiences frequent air pollution incidents. [11] studied the air quality in Port Harcourt and highlighted the high levels of particulate matter (PM10 and PM2.5) due to industrial emissions. These particulates can contribute to aerosol scattering, impacting communication links in the region.

Higher attenuation levels restrict the distance over which reliable communication can be achieved [12]. Laser Beam Propagation Through Random. This research is expected to provide critical insights into the impact of aerosol scattering on communication links at Port Harcourt International Airport. By quantifying the extent of signal attenuation and identifying effective mitigation strategies, the study will contribute to improving the reliability and resilience of communication systems in similar tropical and industrial environments. The findings will have practical implications for airport operations, enhancing safety and efficiency in aviation communication. In conclusion, understanding the effect of aerosol scattering attenuation on communication links is vital for maintaining robust communication infrastructure at Port Harcourt International Airport.

A thorough examination of the factors affecting aerosol scattering attenuation is necessary as technology develops and pushes the limits of communication and sensing applications. The objective of this study is to investigate the mechanisms underlying aerosol scattering attenuation in free space, measure the effects it has on signal quality, and suggest mitigating techniques to improve the resilience of communication systems in cloudy situations. This study aims to bridge the gap by examining the specific effects of aerosol scattering on communication links in Port Harcourt. By analyzing aerosol properties and their impact on signal attenuation, this research will provide crucial data to enhance the efficiency on communication systems in similar urban environments. The findings can inform strategies to enhance signal robustness against aerosol-induced disturbances, ensuring more reliable communication infrastructure in Port Harcourt and beyond [13].

For communication systems that depend on electromagnetic wave propagation, the growing concentration of aerosols in the atmosphere presents a serious difficulty in Port Harcourt, an area that is seeing tremendous industrial and urban growth. Reduced signal strength and quality due to aerosol scattering can result in increased mistake rates and decreased communication link reliability. The region's economic and social activities rely heavily on the aviation, sea, and terrestrial communication networks, therefore this is especially concerning. It is crucial to comprehend the magnitude and features of aerosol-induced signal attenuation in order to build resilient communication networks. This research aims to quantify the impact of aerosol scattering on communication links in Port Harcourt's airspace and to propose mitigation strategies to enhance signal resilience and reliability. Previous studies have highlighted the importance of addressing environmental factors in communication link design, but specific investigations into aerosol effects in this region are limited [12-13].

Gaining a thorough understanding of how different weather conditions, such as temperature, pressure, humidity, precipitation, and atmospheric gases, affect radio transmission. This study aims examine aerosol scattering attenuation, its consequences on communication lines, and possible mitigation strategies. The objectives for this research are to determine aerosol scattering attenuation for transmissions at 850 nm and 1550 nm wavelength in Port Harcourt Airspace. Also, to examining a statistical model of the regression analysis of the attenuation recorded using Mintab. And finally, to calculating the impact attenuation has on data transmission.

2 Research Methodology

Ten years (10) of daily data from (2011-2020) of visibility, temperature, sea level pressure, and relative humidity data were provided by visual crossing which is a company specializing in providing access to historical and forecast weather data. Visual crossing appears to have emerged in the late 2000s or early 2010s. Their focus from the beginning has been on creating a user-friendly platform for accessing weather data. The data analysis of atmospheric parameters was carried out using Microsoft excel and Minitab. Daily data was gathered from the Port Harcourt airport for the purpose of estimating the attenuation and its effects on the communication links and devices.

This study used the atmospheric parameters like visibility, relative humidity, temperature and sea level pressure acquired to determine the degree or impact of Fog-induced attenuation on communication links. Microsoft Excel is employed to organize and clean the dataset sourced from visual crossing, ensuring accuracy and consistency. The cleaned data is then analyzed using Minitab to perform regression analysis, identifying correlations between aerosol concentrations and communication link attenuation. Attenuation values are calculated using the Kim and Ijaz model, providing a robust framework for quantifying signal degradation due to aerosol scattering. Initial findings suggest a significant impact of high aerosol levels on communication quality, particularly during peak pollution periods. This study is crucial for improving the resilience of communication systems in aerosol-rich environments like Port Harcourt [14].

Considering the dependence of scattering on wavelength, FSO systems often operate in the near-infrared region (around 800nm to 1550nm) where scattering is less severe compared to shorter wavelengths. According to [14] p is given as:

$$\begin{cases} 1.6 & V > 50 \\ 1.3 & 6 < V < 50 \\ 0.16V + 0.34 & 1 < V < 6 \\ V - 0.5 & 0.5 < V < 1 \\ 0 & V < 0.5 \end{cases} \tag{1}$$

The regression analysis performed with variables such as temperature (TEMP), humidity (HUM), pressure (PRE), and visibility (VIS) yielded the following equation for attenuation at 850 nm (AER) and 1550 nm (AER):

$$\beta_{fog} = \frac{3.91}{V}\left(\frac{\lambda}{550}\right)^{-p} \quad (2)$$

3 Results and Discussion

This section presents the results and discussion of the analysis of meteorological parameters.

3.1 Monthly Variation of Attenuation over Study Area

The results of the specific attenuation calculated for the study area over the entire study period (2011-2020). Figures 1 to 9 present the comparison of the estimated specific attenuation for the two wavelengths over the study location in Port Harcourt. As shown in 2011, the results are as follows: in the month of June 850 nm starts at a higher attenuation value of 1.6 dB/m compared to 1550 nm, having an attenuation of 0.7 dB/m. From June to July there is a slight decrease of about 0.9 dB/m and 0.3 dB/m for 850 and 1550 wavelengths respectively. ATT (850) has a relatively stable period from July to December and again from February to April. In 2012. Both ATT (850) and ATT (1550) appear to show some seasonal variation, with higher attenuation in the colder months (November to March) and lower attenuation in the warmer months (April to October). In 2013, the ATT (850) values have continuously outperformed the ATT (1550) figures. This is to be expected since atmospheric scattering attenuation is larger at shorter wavelengths (850 nm) than at longer wavelengths (1550 nm). In the year 2014 based on data from Figure 1, the results show the attenuation at 850 nm generally fluctuates between approximately 0.7 and 1.1 dB/m and a noticeable peak is recorded in June, reaching about 1.1 dB/m, and another peak in May. The attenuation at 1550 nm is consistently lower than that at 850 nm, ranging between approximately 0.2 and 0.4 dB/m.

In Figure 2 (2015), the results show that at 850 nm the months from July to April show slight variations, generally maintaining around 1.0 to 1.1 dB/m of attenuation. And in 1550 nm the pattern is relatively flat throughout the year, with slight variations around 0.3 to 0.4 dB/m, until the sharp rise in May. As shown in 2016. The attenuation at 850 nm starts at around 2.0 dB/m in June, then sharply decreases to about 1.0 dB/m by July. After July, the attenuation fluctuates slightly, staying between approximately 1.0 and 1.2 dB/m until May, where it rises again to about 1.5 dB/m. The attenuation at 1550 nm starts at around 0.5 dB/m in June, decreases to about 0.2 dB/m by July, and then remains relatively stable, fluctuating between 0.2 and 0.4 dB/m throughout the year. There is a slight increase in May to about 0.5 dB/m.

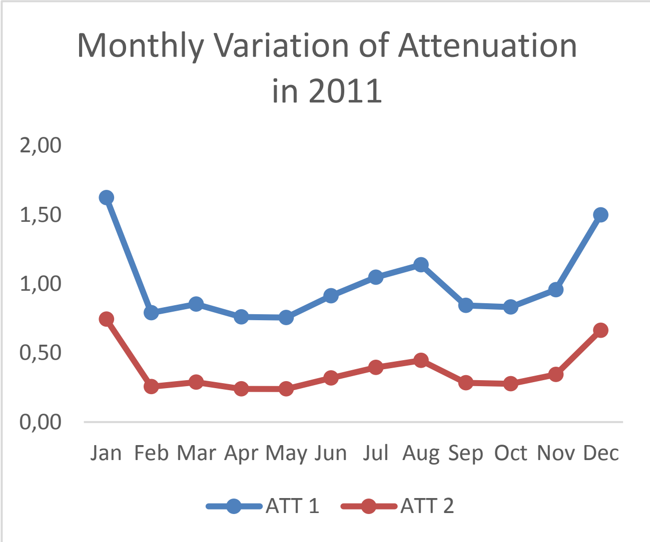

Fig. 1: Average evaluated Attenuation at 850 nm & 1550 nm for 2011

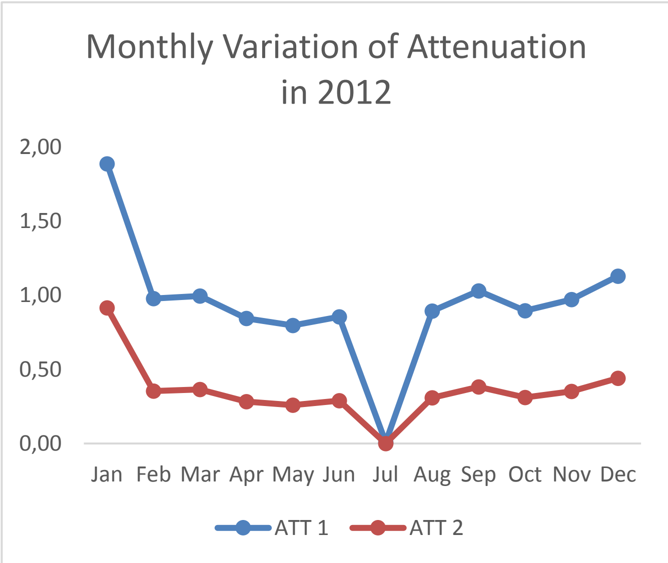

Fig. 2: Average evaluated Attenuation at 850 nm & 1550 nm for 2012

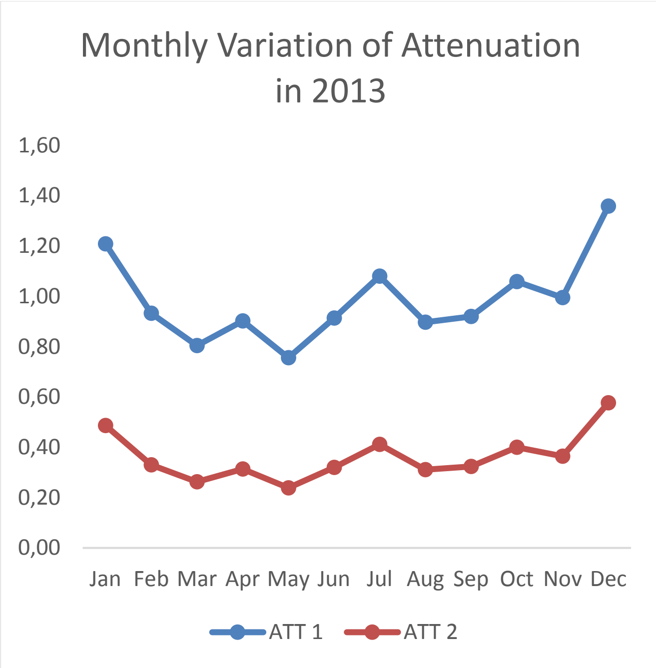

Fig. 3: Average evaluated Attenuation at 850 nm & 1550 nm for 2013

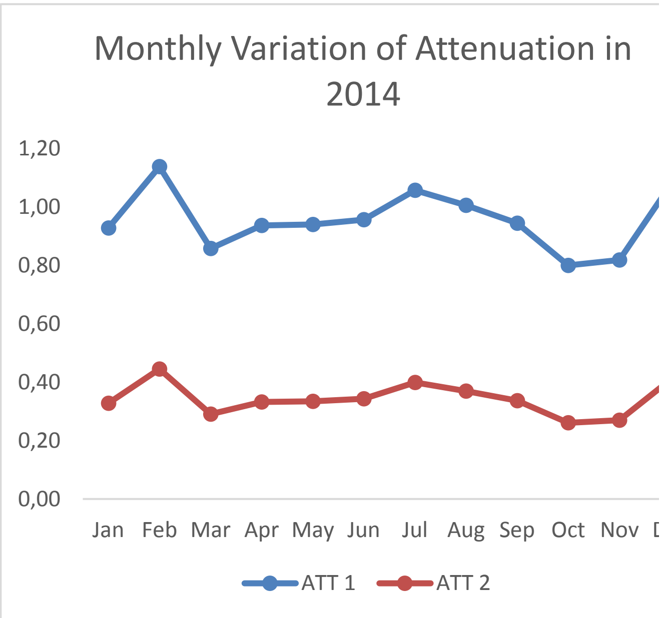

Fig. 4: Average evaluated Attenuation at 850 nm & 1550 nm for 2014

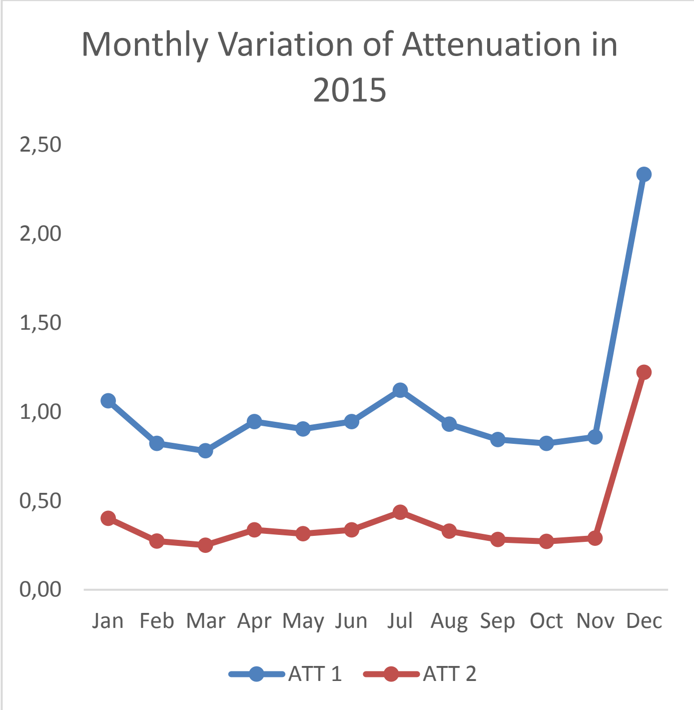

Fig. 5: Average evaluated Attenuation at 850 nm & 1550 nm for 2015

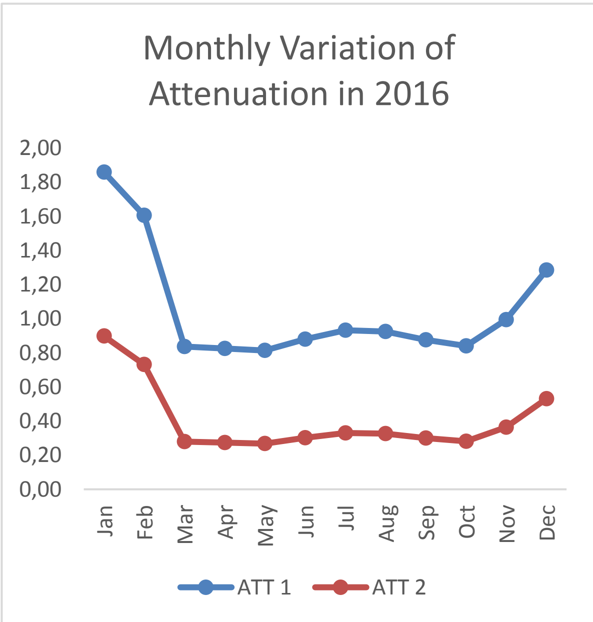

Fig. 6: Average evaluated Attenuation at 850 nm & 1550 nm for 2016

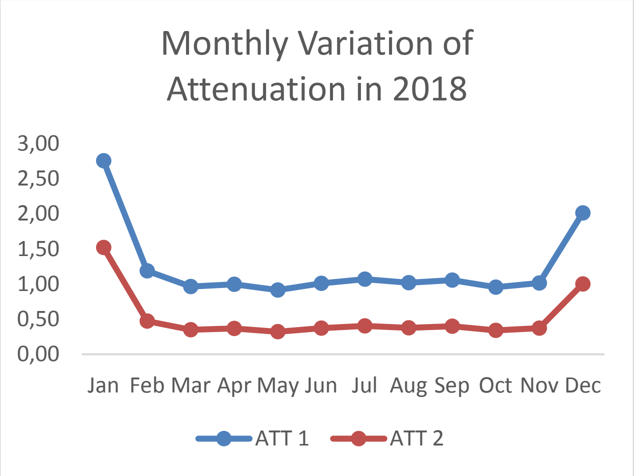

Fig. 7: Average evaluated Attenuation at 850 nm & 1550 nm for 2018

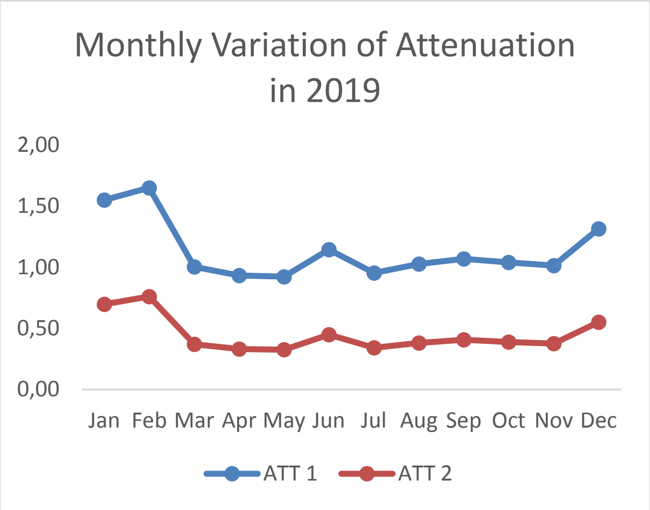

Fig. 8: Average evaluated Attenuation at 850 nm & 1550 nm for 2019

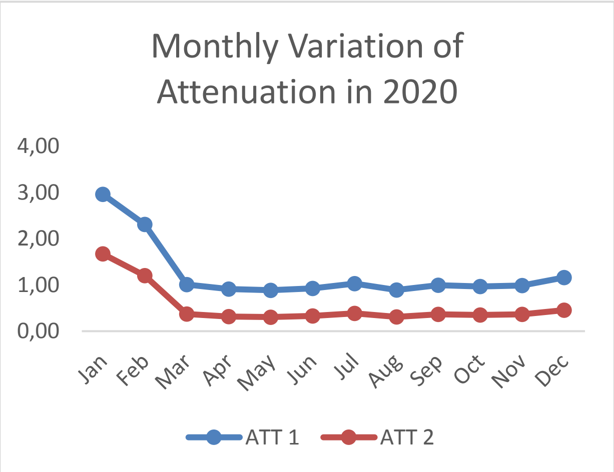

Fig. 9: Average evaluated Attenuation at 850 nm & 1550 nm for 2020

4.2 Regression Analysis for Aerosol Scattering Attenuation at 850 nm and 1550 nm

Table 1 revealed higher temperatures, higher humidity levels, and better vision are correlated with lower attenuation levels using 850 nm, as this equation below illustrates the negative association between these environmental parameters and attenuation. According to the temperature coefficient, attenuation reduces by around (-0.0903) for every degree Celsius that temperature rises. Similarly, higher humidity is correlated with decreased attenuation, according to the humidity's negative coefficient of (-0.03799). Visibility is the most important factor in influencing attenuation, having the biggest negative value (-0.08978). Attenuation likewise shows a minor reduction with an increasing sea level pressure, with a negative coefficient (-0.02745). As would be expected, poor visibility brought on by a high aerosol concentration dramatically increases attenuation. This result is consistent with the body of research that indicates visibility is a key factor in aerosol scattering attenuation. The regression model's high R-squared value of 62.52% indicates that a significant portion of the variability in attenuation can be explained by the environmental factors included in the model.

This equation for Attenuation calculated using 1550 nm emphasizes the negative association between these environmental parameters and attenuation, demonstrating that higher temperatures, higher humidity levels, and greater visibility correspond to lower attenuation levels. According to the temperature coefficient, for every one degree Celsius increase, attenuation reduces by roughly (-0.0706). Similarly, the negative coefficient for humidity (-0.02951) implies that higher humidity corresponds to lesser attenuation. Increased sea level pressure is likewise associated with a modest decrease in attenuation with a negative coefficient (-0.02154). Visibility, with the biggest negative value (-0.32751), is the most important factor in determining attenuation. poor visibility due to high concentration of aerosols significantly increases attenuation, as expected. This finding aligns with the existing literature, which consistently shows that visibility is a primary determinant of aerosol scattering attenuation. The regression model's high R-squared value of 56.77% indicates that a significant portion of the variability in attenuation can be explained by the environmental factors included in the model. This discussion delves into the findings of the regression analysis, the implications of these results, and how they align with or diverge from existing literature. Furthermore, we explore the practical applications of these findings in designing and optimizing communication systems under adverse weather conditions.

ATT 1 = 38.57 - 0.0903 Avg Temp - 0.03799 Humidity -0.02745 sea level pressure - 0.47385 visibility. (3)

Table 1: ATT 1 (850 nm) versus Avg Temp, Humidity, sea level pressure, visibility

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	38.57	8.82	4.37	0.000	
Avg Temp	-0.0903	0.0162	-5.58	0.000	1.75
Humidity	-0.03799	0.00302	-12.59	0.000	1.81
sea level pressure	-0.02745	0.00852	-3.22	0.001	1.41
visibility	-0.47385	0.00938	-50.53	0.000	1.51

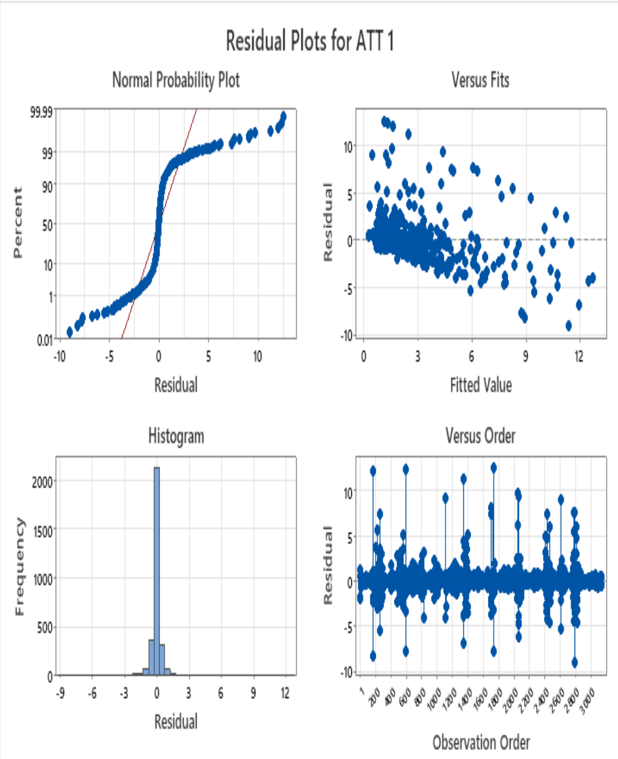

Fig. 10: Residual plot at 850 nm

ATT 2 = 29.44-0.0706 Avg Temp-0.02951 Humidity -0.02154 sea level pressure - 0.32751 visibility (4)

Table 2: ATT 1 (1500 nm) versus Avg Temp, Humidity, sea level pressure, visibility

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	29.44	7.00	4.20	0.000	
Av. Temp	-0.0706	0.0128	-5.50	0.000	1.75
Humidity	-0.02951	0.00240	-12.32	0.000	1.81
sea level pressure	-0.02154	0.00677	-3.18	0.001	1.41
visibility	-0.32751	0.00745	-43.98	0.000	1.51

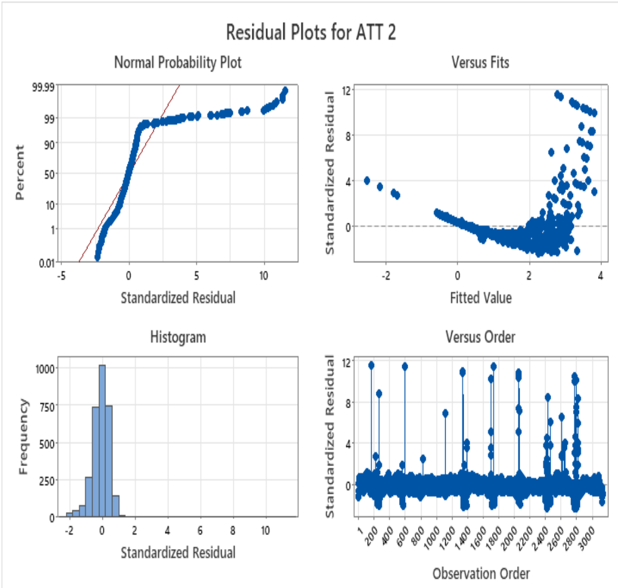

Fig. 11: Residual plot at 1550 nm

The analysis conducted on the data provided by visual crossing from 2011 to 2020 has yielded significant insights into the impact of aerosol scattering attenuation on communication links. This discussion delves into the findings of the regression analysis, the implications of these results, and how they align with or diverge from existing literature. Visibility, with the largest negative coefficient (-0.47385, -0.32751), plays the most critical role in determining attenuation. Poor visibility due to Aerosol Scattering significantly increases attenuation, as expected. This finding aligns with the existing literature, which consistently shows that visibility is a primary determinant of Aerosol Scattering attenuation, Poor visibility is a direct consequence of aerosol scattering attenuation. The more light gets scattered or absorbed by aerosols, the less light reaches our eyes or sensors, resulting in both reduced visibility and weakened signals for communication systems (radio waves, LiDAR).

Fresh insight on the parameters affecting aerosol scattering attenuation in communication lines has been made possible by the regression analysis. Three factors stood out as important predictors: temperature, humidity, and visibility, with visibility having the largest effect. These results can be used to optimize communication systems so that they continue to function well in inclement weather. Through comprehending and reducing the impact of aerosols (such as dust, smoke, mist, and fumes), we may create communication networks that are more dependable and resilient. The paper also identifies directions for future investigation, such as looking into other atmospheric variables and examining outliers in order to improve the predictive model. All things considered, this investigation adds to the continuous efforts to improve communication connection performance in the face of environmental difficulties, guaranteeing reliable and continuous data transfer.

4 Conclusion

Using visibility data from the past 10 years, the impact of aerosol scattering on terrestrial free space optical communication in Port Harcourt Airspace has been calculated. Kim and Ijaz model were used to calculate the attenuation caused by aerosol scattering and to uncover the effect it has on communication systems According to differences in visibility, attenuation decreases significantly, and the lowest attenuation occurs at 1550 nm wavelength, corresponding to 193 THz frequency. The study showed that aerosol scattering attenuation in communication linkages is highly influenced by environmental parameters such as temperature, humidity, and visibility. Visibility was found to be the most important feature in the regression analysis, with higher signal attenuation resulting from reduced visibility caused by aerosols. Though to a lesser extent, attenuation was also influenced by temperature and humidity. In the investigation, visibility turned out to be the most reliable indicator of signal attenuation. Regression analysis revealed a substantial inverse association, meaning that signal attenuation increased with decreasing visibility. This is because of a large amount of solid particles, which scatter and absorb electromagnetic waves, lowering the quality of the signal. For instance, it was found that, in comparison to times when visibility was greater, signal attenuation increased dramatically when visibility was less than one kilometer. This result is in line with previous research, which highlights the importance of visibility in assessing how much aerosol scattering affects signal propagation.

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