Anale. Seria Informatică. Vol. XVII fasc. 2 – 2019
Annals. Computer Science Series. 17th Tome 2nd Fasc. – 2019

ESTIMATION OF OPTIMAL ATMOSPHERIC CONDITION FOR WE-FM RADIO STATION, ABUJA

Jimoh Hamed [1], Ganiyu Agbaje [1], Olakunle Oladosu [1], Akoji Labija [2], Bisola Olaniyi [3]

[1] African Regional Centre for Space Science and Technology Education in English, Obafemi Awolowo University, Ile-Ife, Nigeria
[2] Naval Headquarters, Nigerian Navy, Abuja, Nigeria
[3] Engineering Space Systems, National Space Research and Development Agency, Obasanjo Space Centre, Abuja, Nigeria

Corresponding Author: Jimoh Hamed, hamedjimoh45@yahoo.com

ABSTRACT: This study evaluated the effect of atmospheric condition on radio network. Response Surface Methodology was used to develop a signal model in terms of atmospheric condition, analyse and optimize the effect of atmospheric temperature, pressure and relative humidity on signal of a WE-FM radio station based in Abuja. The result shows that atmospheric parameters such as temperature, pressure and relative humidity have inverse relationship with radio signal. The analysis of variance for the model formulated reveals that the atmospheric parameters have significant effect on signal strength. Also, the R – Squared value obtained implies that atmospheric condition have variability of 98.30% on the signal strength. The optimum signal strength of 54.0851 dBuV was obtained with the atmospheric condition of temperature 26.80^{0}C, pressure, 24.43inHg, and relative humidity of 78%. The model predicts signal strength with the accuracy of 84.71%. Hence, the approach is efficient for minimizing signal strength degradation in radio network.

KEYWORDS: Signal strength, Atmospheric condition, WE-FM Station, Frequency, Communication network**.**

1. INTRODUCTION

Atmosphere is a layer or set of layers of gases surrounding a planet or other material body that is held in place by the gravity of that body. The earth's atmosphere is rich in Nitrogen, oxygen and argon. These layers are the troposphere, stratosphere, mesosphere, thermosphere and Exosphere. The basis for this earth's atmospheric classification is the differences in temperature of the layers. In the troposphere and mesosphere, air temperature drops with altitude, while in the stratosphere and thermosphere it rises. The exosphere extends indefinitely into space [TAH14]. The Ionosphere is the layer of the earth's atmosphere that is ionized by solar and cosmic radiation, from about 60 Km to 1,000 Km altitude above the earth, a region that includes the thermosphere and parts of the mesosphere and exosphere. In this region, the electrical charged particles – ions and electrons – are large enough to affect the propagation of radio waves. As radio frequency signals propagate through the atmosphere, the signals degrade because of the absorption and scattering by the atmospheric particles. This degradation reduces the quality of the signal received [OO11].

Radio waves are type of electromagnetic radiation that transmitted in waves or particles at different wavelengths and frequencies. The broad range of wavelengths is called the electromagnetic spectrum. The spectrum is generally divided into seven regions in order of decreasing wavelength and increasing energy and frequency. The common designations are radio waves, microwaves, infrared, visible light, ultraviolet, X – rays and gamma rays [Luc15]. According to NASA, radio waves have the longest wavelengths in the EM spectrum, ranging from about 1mm to more than 100 Km. They also have the lowest frequencies, from about 3 KHz to 300 GHz. Performance impairments occur on C and KU – band satellite communication links because of severe tropospheric fading effects when the elevation angle of the ground station is very low (<50). Hence, this effect can be reducing by increasing the elevation angle. The elevation angle can be obtained once the latitude and longitude of earth stations are obtained by using either GPS or US Geological Survey Maps of the region as well as the longitude of the satellite from chart [KS99].

The four atmospheric parameters that govern the weather are the atmospheric temperature, pressure, humidity and wind speed and direction. Results of finding indicated that radio signal strength is inversely proportional to atmospheric temperature, pressure and humidity; provided that for any of the giving components, others were observed constant, including the wind speed and direction, since it has been erected that wind has a marked effect on radio signal [Ama16b]. However, there is little or no research work on optimal atmospheric value (s) for better signal strength to enhance communication network.

In signal processing, a high interest in improvement on communication signals is growing at geometric rate. It turns out to be a competitive solution since it enhances signal intensity propagation for better transmission [Blu05, Pri91]. This work provides an optimization approach for minimizing signal strength degradation in communication network. The factors affecting signal quality or degradation are natural phenomenon that posed a great threat to the communication companies [Ama16c, HOO17, Ama16a, LH15]. The study of atmospheric dynamics effect on signal strength is essential to develop a mathematical model for estimation of optimal atmospheric conditions to alleviate signal attenuation [A+17, Ama16b, Har18]. Hence, this research is highly imperative to make categorical recommendation for communication network providers on solution to various network problems.

Weather is the current state of the atmosphere at a specific location at any given point in time and is determined by factors such as temperature, pressure, humidity, solar radiation and wind [McC05, Ama16a, Har18]. These factors cause periodic changes in the Earth's air masses [Ama16a]. Whenever temperature, pressure, and humidity change, the weather also changes [Wil13, TAH14, BL05]. Changes in weather affects radio transmission signal [Car18, MN10, Pid06]. Because of the spatial distribution of refractive index at the lower portion of the atmosphere, radio signal is affected by weather at frequencies above 30 MHz [NU15]. Satellite communication at the Ku – band is affected by rain attenuation at frequencies above 10 GHz [H+15]. Rain drops absorb and scatter radio signal which result in the degradation of communication link [OO11]. Rain effects are dependent on temperature, rain rate, drop size distribution and drop shape [NU15, OO11]. Scattering occurs when signal interacts with atmospheric particles and as a result travels in a direction different from the original path of propagation. This effect is mostly noticed on TV set as interference. Sometimes, the received radio signal disappears or both the audio and video quality will be bad [HDN15].

Absorption on the other hand occurs when the radio signal impinges the rain droplets on its path of propagation and all the signals is converted to heat and absorbed by it [Wil13]. Empirically, signal strength is more affected during raining season than dry season. Hence, Television and Radio stations should be digitalized and measures should be taken to eliminate the effect of rain on signals [NU15]. In a clear sky condition, the signal strength improves because refractivity depends on the physical structure of the atmosphere. It means that changing the weather conditions can also lead to changes in radio wave propagation [Ama16a, Ama16b].

2. RESEARCH METHOD

2.1. Designed Data

The data adopted for the study is secondary and originally obtained by Ale, et al [A+17] at WE-FM radio station based in Abuja, Nigeria which operates at a frequency of 106.3MHz. The research was carried out on 29th September, 2017, between 5am and 9pm. The investigation was performed with the use of Community Access Television (CATV) signal level meter, Hygrometer and thermometer to measure the signal strength, the temperature, pressure and relative humidity respectively [A+17]. Also, relevant values of natural variables are obtained in a single replicate of 2^3 for the design (un-replicated factorial). The data and respective coded variables being used for the work are shown in the Table 1.

The values for $X_1, X_2,$ *and* X_3 in the coded variables columns in Table 1 were obtained using Equation 1, Equation 2, and Equation 3 respectively.

$$X_{i1} = \frac{\varepsilon_{i1} - \frac{[\max(\varepsilon_{i1}) + \min(\varepsilon_{i1})]}{2}}{\frac{[\max(\varepsilon_{i1}) - \min(\varepsilon_{i1})]}{2}} \qquad (1)$$

Where: $\max(\varepsilon_{i1}) = 30.80$
$\min(\varepsilon_{i1}) = 26.80$ and
ε_{i1} = corresponding value of temperature in column 1

Similarly,

$$X_{i2} = \frac{\varepsilon_{i2} - \frac{[\max(\varepsilon_{i2}) + \min(\varepsilon_{i2})]}{2}}{\frac{[\max(\varepsilon_{i2}) - \min(\varepsilon_{i2})]}{2}} \qquad (2)$$

Where: $\max(\varepsilon_{i2}) = 24.44$
$\min(\varepsilon_{i2}) = 24.38$ and
ε_{i2} = corresponding value of pressure in column 2

Also,

$$X_{i3} = \frac{\varepsilon_{i3} - \frac{[\max(\varepsilon_{i3}) + \min(\varepsilon_{i3})]}{2}}{\frac{[\max(\varepsilon_{i3}) - \min(\varepsilon_{i3})]}{2}} \qquad (3)$$

Where: $\max(\varepsilon_{i3}) = 78$
$\min(\varepsilon_{i3}) = 65$ and
ε_{i3} = corresponding value of relative humidity in column 3

Table 1: Measured natural variables obtained on 29 the September, 2017, between 5am and 9pm

S/No	**Natural variables**				**Coded variables**			**Response**
	ε_1 (^{0}C)	ε_2 $(inHg)$	ε_3 (%)	dBuV	X_1	X_2	X_3	Y
1.	**26.80**	**24.3800**	**65.0000**	47.1	-1	-1	-1	47.1
2.	27.86	24.3836	66.8850	44.6	-0.47	-0.88	-0.71	44.6
3.	28.14	24.3854	68.7700	44.5	-0.33	-0.82	-0.42	44.5
4.	28.26	24.3944	68.7700	42.9	-0.27	-0.52	-0.42	42.9
5.	28.30	24.4001	70.6550	42.7	-0.25	-0.33	-0.13	42.7
6.	28.38	24.4019	71.5650	42.8	-0.21	-0.27	0.01	42.8
7.	28.42	24.4037	72.1500	43.5	-0.19	-0.21	0.1	43.5
8.	28.50	24.4055	72.1500	42.4	-0.15	-0.15	0.1	42.4
9.	28.58	24.4091	72.5400	41.8	-0.11	-0.03	0.16	41.8
10.	28.66	24.4127	76.3100	43.6	-0.07	0.09	0.74	43.6
11.	28.78	24.4181	76.6350	43.5	-0.01	0.27	0.79	43.5
12.	28.82	24.4199	76.7000	43.0	0.01	0.33	0.8	43.0
13.	28.90	24.4199	76.8950	42.6	0.05	0.33	0.83	42.6
14.	29.20	24.4199	76.8950	42.5	0.2	0.33	0.83	42.5
15.	29.28	24.4217	76.9600	42.4	0.24	0.39	0.84	42.4
16.	29.38	24.4235	77.0250	42.2	0.29	0.45	0.85	42.2
17.	29.44	24.4325	77.0250	40.7	0.32	0.75	0.85	40.7
18.	29.78	24.4325	77.8050	40.8	0.49	0.75	0.97	40.8
19.	30.24	24.4346	77.8050	40.6	0.72	0.82	0.97	40.6
20.	**30.80**	**24.4400**	**78.0000**	40.3	1	1	1	40.3

2.2. Designed Model Development

Response Surface Methodology was adopted for the Optimization study. In approximating response function, the relationship below was established.

$$y = f(\varepsilon_1, \varepsilon_2, \varepsilon_3, \ldots \varepsilon_k) \qquad (4)$$

Where y represents the Response variable and $\varepsilon_1, \varepsilon_2, \varepsilon_3, \ldots \varepsilon_k$ (predictor variables or regressor) are called natural variables because they are expressed in terms of natural units of measurement such as degree Celsius, Pounds per Square Inches, or gram per litre.

In Response Surface Methodology, it is convenient to transform the natural variables to coded variables, $X_1, X_2, X_3, \ldots X_k$ which are usually defined to be dimensionless with mean zero and the same spread or standard deviation [HOO17, MMA09]. In terms of the coded variables, the true response function in Equation 1 is therefore written as thus;

$$y = f(X_1, X_2, X_3, \ldots X_k) \qquad (5)$$

In general, the first – order model used in Response Surface Methodology is given as

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k \qquad (6)$$

The model in Equation 6 is called multiple linear regression models with k regressor variables [R+09]. The parameters $\beta_j,\ j = 0,1,\ldots,k,$ are called the regression coefficients. Similarly, the second – order model used in Response Surface Methodology is given as thus;

$$y = \beta_0 + \sum_{j=1}^{k} \beta_j X_j + \sum_{j=1}^{k} \beta_{jj} X_j^2 + \sum_{i<j=2}^{k} \beta_{ij} X_i X_j \qquad (7)$$

To develop an empirical model relating signal strength and atmospheric parameters such as temperature, pressure and relative humidity, the first – order response surface model that might describe the relationship is given as thus;

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon \qquad (8)$$

Where y represents the signal strength, X_1 represents the temperature, X_2 represents the pressure, X_3 represents the relative humidity, and ε represents sources of variability not accounted for, such as measurement error, variations inherent in the system or process, or possibly unknown variables. ε is treated as statistical error. The β*'s* are sets of unknown parameters. To estimate the values of these parameters, data on the system under consideration were collected and linear regression adopted for its analysis.

2.3. Optimization Model for Signal Strength

An optimization problem was formulated to maximise signal strength subject to atmospheric parameters such as temperature, pressure, and relative humidity as given below:

$$\begin{aligned}&Maximise\ Y = f(X_I) \qquad (i = 1,2,3)\\ &Subject\ to:\\ &-1 \leq X_I \leq 1\end{aligned} \tag{9}$$

Where X_i coded variables are for temperature, pressure, and relative humidity (independent variables) and Y is response variable for signal strength.

3. RESULTS AND DISCUSSION

3.1. Performance Equation for Signal Strength

The analysis of the inputs coded values in MINITAB 18 yields coded coefficients shown in Table 2. The coefficient column shows the values of regression coefficients in Equation 10.

Table 2: Coded Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	40.754	0.425	95.91	0.000	
Temperature	-2.120	0.848	-2.50	0.031	32.39
Pressure	-6.87	2.27	-3.02	0.013	413.77
Relative Humidity	5.57	2.25	2.48	0.033	476.45
Temperature*Temperature	5.22	5.41	0.97	0.357	639.96
Pressure*Pressure	-2.72	5.12	-0.53	0.606	717.04
Relative Humidity*Relative Humidity	-2.47	3.17	-0.78	0.455	316.71
Temperature*Pressure	-3.2	10.0	-0.32	0.755	2282.71
Temperature*Relative Humidity	-1.46	3.49	-0.42	0.684	303.04
Pressure*Relative Humidity	7.58	7.43	1.02	0.332	1436.54

The Regression Expression in Un-coded Units obtained from Table 2 is therefore given as thus;

*Signal Strength = 40.754 - 2.120 * Temperature - 6.87 * Pressure + 5.57 * Relative Humidity + 5.22 * Temperature * Temperature - 2.72 * Pressure * Pressure - 2.47 * Relative Humidity * Relative Humidity - 3.2 * Temperature * Pressure - 1.46 * Temperature * Relative Humidity + 7.58 * Pressure * Relative Humidity*

Hence,

$$\beta_0 = 40.754,\ \beta_1 = -2.120,\ \beta_2 = -6.87,\ \beta_{11} = 5.22,\ \beta_3 = 5.57,\ \beta_{22} = -2.72,\ \beta_{33} = -2.47,\ \beta_{12} = -3.2,\ \beta_{13} = -1.46,\ \beta_{23} = 7.58$$

Therefore, from the expression, the fitted regression model equation is given as thus;

$$\breve{y} = 40.754 - 2.120X_1 - 6.87X_2 + 5.57X_3 + 5.22X_1^2 - 2.72X_2^2 - 2.47X_3^2 - 3.2X_1X_2 - 1.46X_1X_3 + 7.58X_2X_3 \tag{10}$$

3.2. Analysis of Variance (ANOVA)

The analysis of variance shows in Table 3 reveals that model terms with $p<0.05$ are significant. Hence, temperature, pressure, and relative humidity have significant effect on radio signal strength. However, values of $p > 0.10$ indicates the model terms are not significant. In the analysis, none of the interactions is significant at 0.05 levels. In addition, the difference in R – Squared and Adj. R – Squared obtained in the analysis respectively as 98.30% and 96.78% are not more than approximately 4%. The R – Squared value implies that atmospheric condition has variability of 98.30% on radio signal strength. The S value of 0.283784 which represents how far the data values fall from the fitted values indicated how well the model describes the radio signal strength. R – Sq (Pred) of 84.71% means that this model can predicts radio signal strength with the accuracy of 84.71%. Hence, the model describes signal strength appropriately.

Therefore, the atmospheric temperature and pressure have negative linear effect while relative humidity has positive linear effect on signal strength. Also, the temperature has positive quadratic effect while pressure and relative humidity have negative quadratic effects on signal strength. Although there are interactions effects in atmospheric parameters but they are not statistically significant on signal strength.

3.3. The relationship between Radio Signal Strength and Atmospheric Parameters

The study reveals that there is an inverse relationship between signal strength and atmospheric parameters. This relationship is depicted in Fig. 1

and 2. The Figures clearly indicated that as atmospheric parameters such as temperature, pressure, and relative humidity increases, signal strength decreases, and vice versa. Also, Fig. 3 shows the relationship between temperature, pressure, and relative humidity. It is evidently shown from the graphs that atmospheric parameters are directly proportionally related with each other.

3.4. Residual Analysis

The Residual plots shown in Fig. 3 are important because they helped to be ensured that assumptions are in line with conclusions. In the normal probability plot of the residual, there seems to be no significant deviation as all points virtually lie on the straight line. This verifies the assumption that the residuals are normally distributed. Residuals versus fits plot points fall randomly on both sides of 0, with no recognizable patterns in the points. This verifies the assumption that residuals are randomly distributed and have constant variance. The residual versus order plot shows that the residuals fall randomly around the centreline. This verifies the assumption that the residuals are independent from one another.

3.5. Normal Plot of the Standardized Effects

The Fig. 4 is the normal plot of the standardized effects. On this plot, the main factors such as temperature, pressure and relative humidity are statistically significant at 0.05 level. These points have a different colour and shape from the points for insignificant effects. Furthermore, relative humidity has a standardized effects. When relative humidity changes from low level to high level, the signal strength increases. On the other hand, temperature and pressure have negative standardized effects. When temperature and pressure increase, the signal strength decreases.

3.6. Pareto Chart of the Standardized Effects

The Pareto chart in Fig. 5 shows how factor or combination of factors are important. On the chart, pressure, temperature, and relative humidity cross the reference line at 2.228. Hence, these factors are statistically significant at 0.05 level. The Pareto displays the absolute value of the effect, so it can be determine which effect are larger, but it does not indicates which effect increases or decreases with the signal strength. The plot shows that pressure has the greatest effect on signal strength, followed by temperature and then relative humidity in that order.

3.7. Main and Interaction Effects

The Fig. 6 and 7 are the main and interaction effects plots respectively. Fig. 6 shows that the lines of the main effect of atmospheric factors (temperature, pressure, and relative humidity) are not horizontal or parallel to signal strength mean – axis. This implies that the signal strength mean is not the same across all factor levels. The interactions plots in Fig. 7 shows that interaction are less significant. The more nonparallel the lines are, the greater the strength of the interaction.

Table 3: Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	46.6922	5.18802	64.42	0.000
Linear	3	28.8625	9.62085	119.46	0.000
Temperature	1	0.5031	0.50311	6.25	0.031
Pressure	1	0.7348	0.73482	9.12	0.013
Relative Humidity	1	0.4935	0.49351	6.13	0.033
Square	3	0.2094	0.06981	0.87	0.490
Temperature*Temperature	1	0.0752	0.07523	0.93	0.357
Pressure*Pressure	1	0.0228	0.02277	0.28	0.606
Relative Humidity*Relative Humidity	1	0.0488	0.04875	0.61	0.455
2-Way Interaction	3	0.1157	0.03858	0.48	0.704
Temperature*Pressure	1	0.0083	0.00829	0.10	0.755
Temperature*Relative Humidity	1	0.0142	0.01416	0.18	0.684
Pressure*Relative Humidity	1	0.0838	0.08381	1.04	0.332
Error	10	0.8053	0.08053		
Total	19	47.4975			

Figure 1: Effect of Temperature, Pressure and Relative Humidity on signal strength

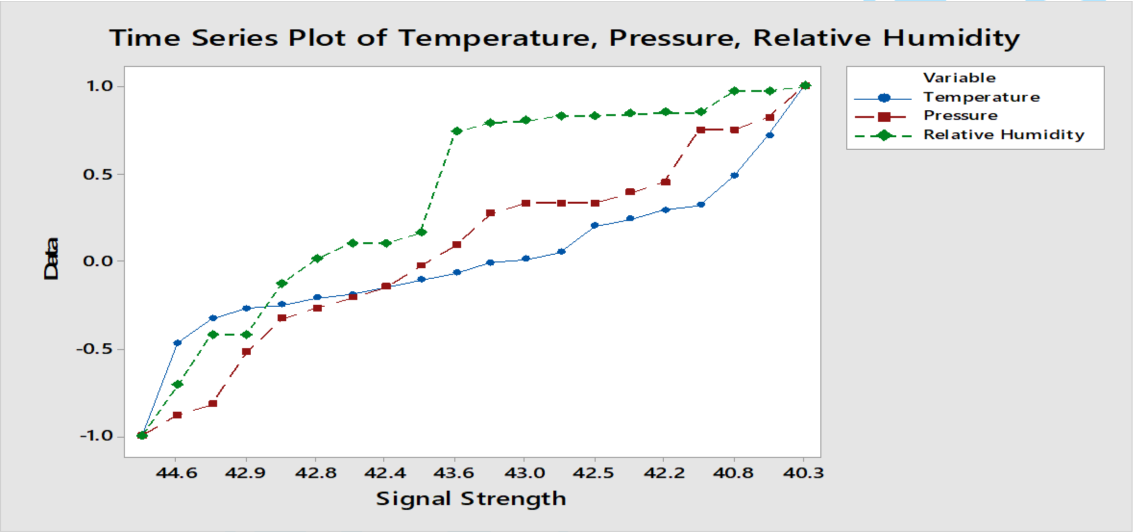

Figure 2: Time series plot of Temperature, Pressure, Relative Humidity versus signal Strength

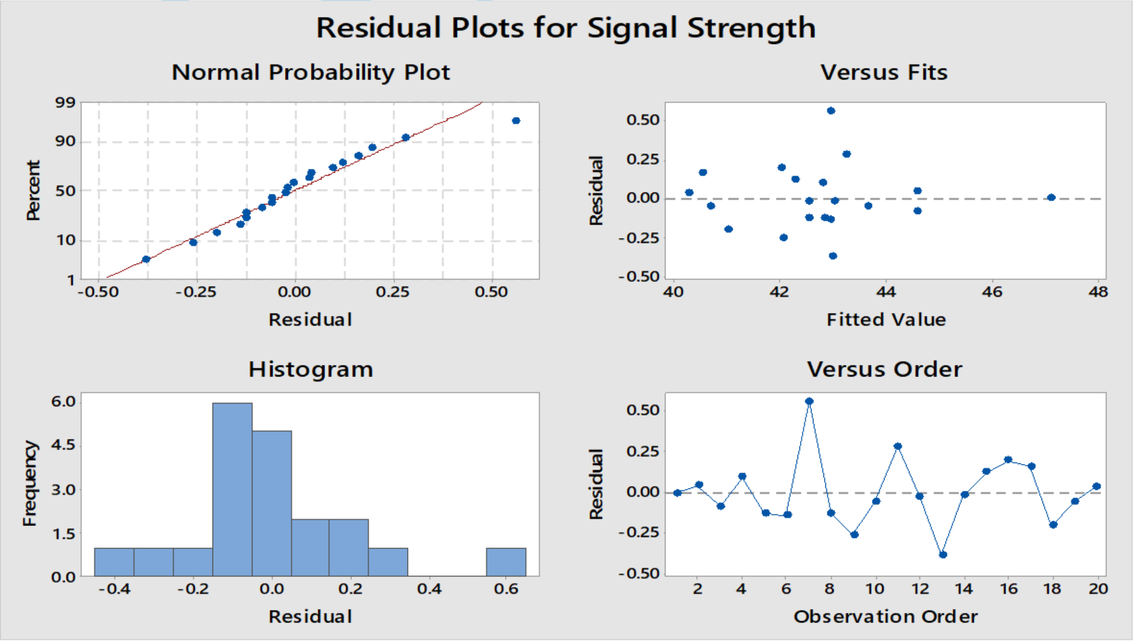

Figure 3: Residual Plots for Signal Strength

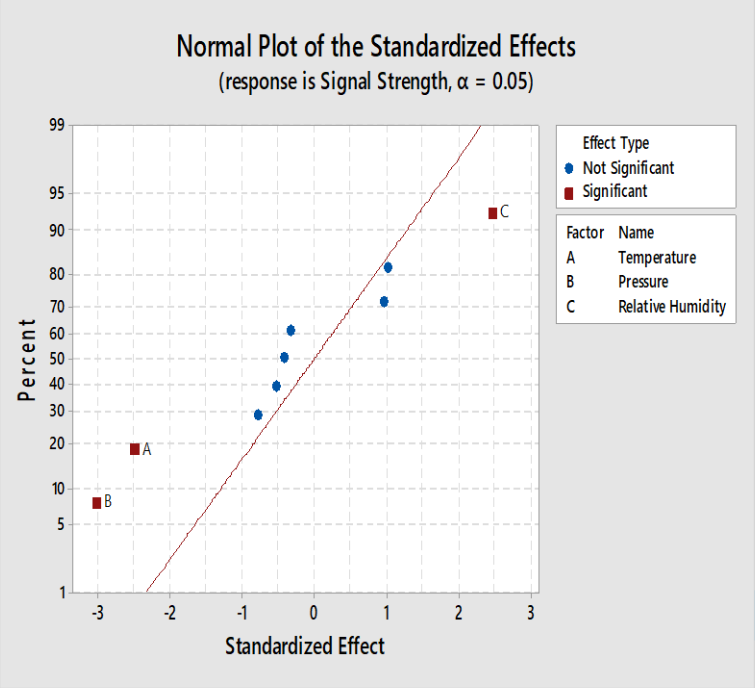

Figure 4: Normal Plot of the Standardized Effects

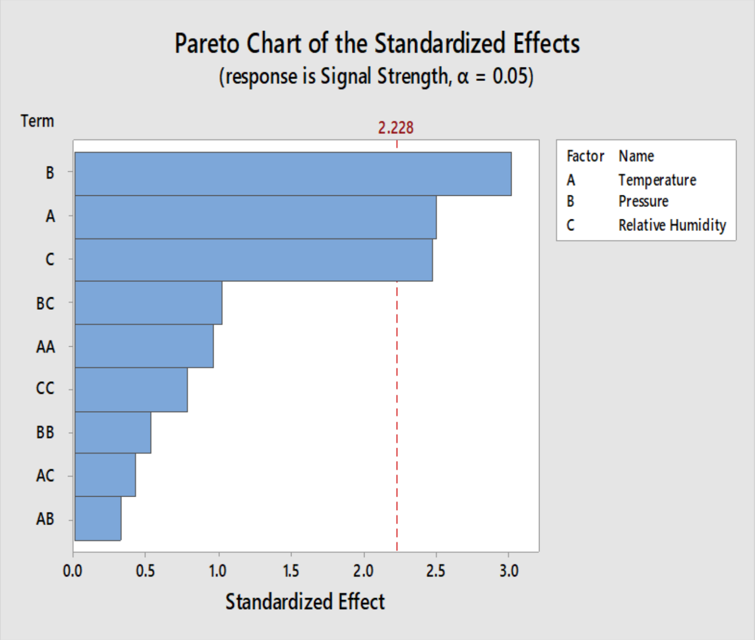

Figure 5: Pareto Chart of the Standardized effects

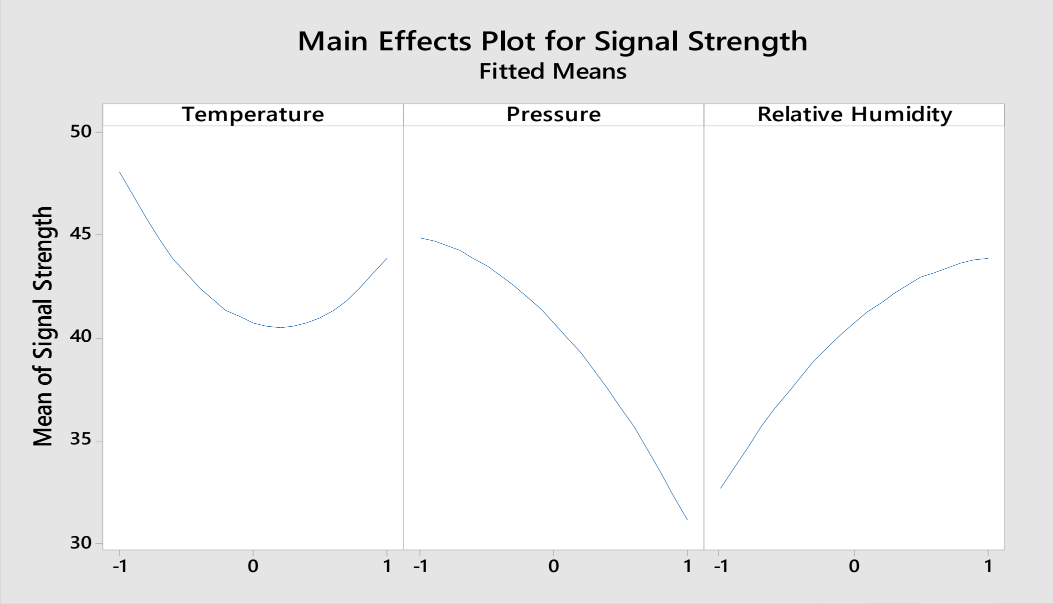

Figure 6: Main Effects for Signal Strength

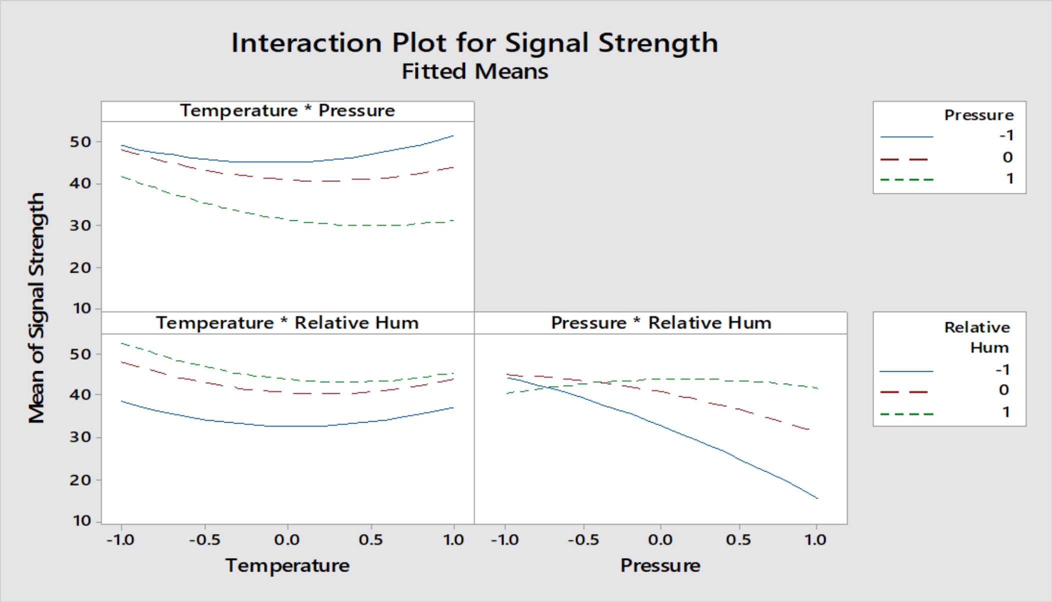

Figure 7: Interaction Effects for Signal Strength

3.8. Contour and Surface Plots

The contour and surface plots help to understand the relationship between the response and various factors. Fig. 8 and 9 show the surface plots whereas, Fig. 10 shows the contour plots. The effect of changes in the colour is to show the twist in the plane. The Fig. 8 and 9 show that curvature exists. Hence, there is evidence of interaction. It can be seen from the plots that the effect of temperature and pressure are proportional while Relative Humidity has no significant effect at low temperature values.

The Fig. 10 reveals that signal strength is not just affected by atmospheric parameters at any specific value, but at a range of values. This makes it necessary to identify optimum region where signal strength will be approximately maximum.

3.9. Optimization of Atmospheric Condition

The model developed was very important for indicating the direction in which to change variables in order to maximize signal strength subject to atmospheric parameters. The regression equation was optimized to estimate optimum atmospheric condition using MINITAB 18. This was depicted in Fig. 11. The optimum radio signal strength of 54.0851 dBuV was obtained with atmospheric conditions; temperature 26.80^{0}C, pressure, 24.43inHg, and relative humidity, 78%. The coded values (atmospheric parameters) fall within the experimental range. This implies that the variables considered are valid for model selected for the signal response.

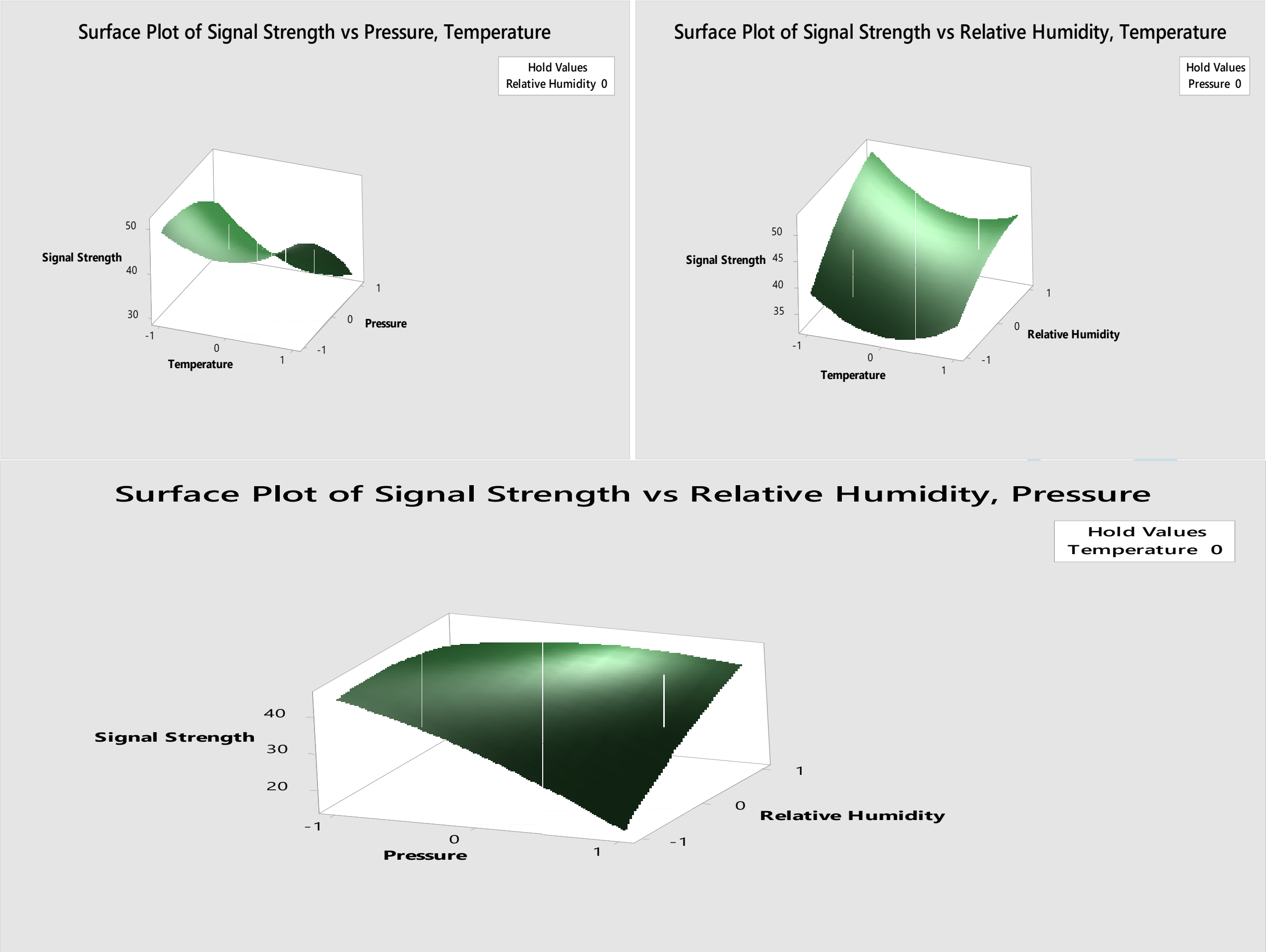

Figure 8: Surface plot of Signal Strength versus Temperature, Pressure, and Relative Humidity

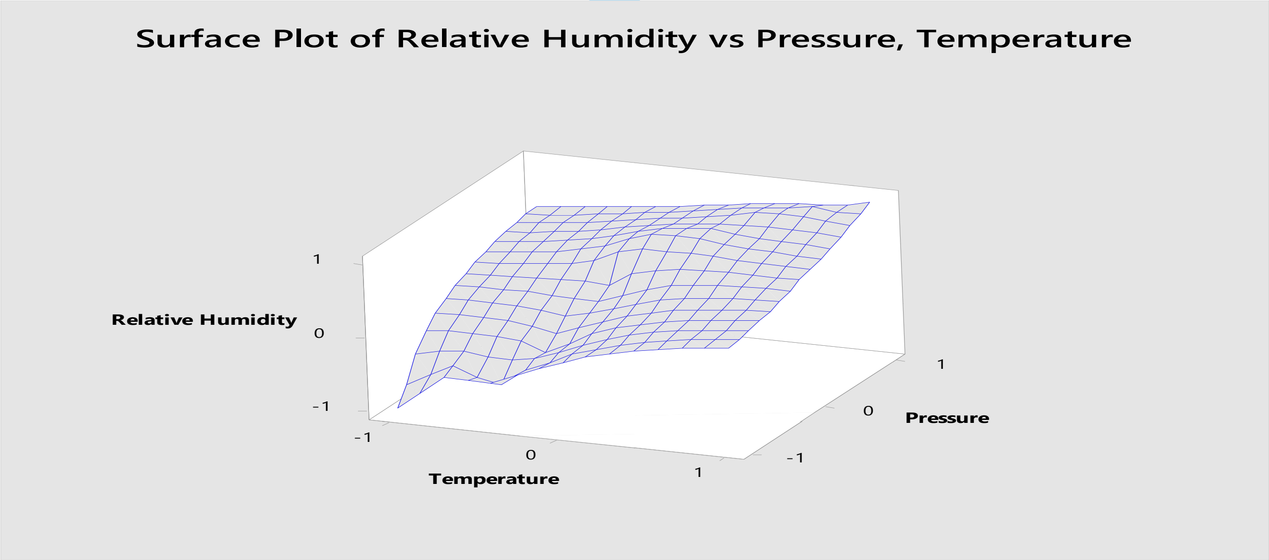

Figure 9: Surface plot of Temperature versus Pressure, Relative Humidity

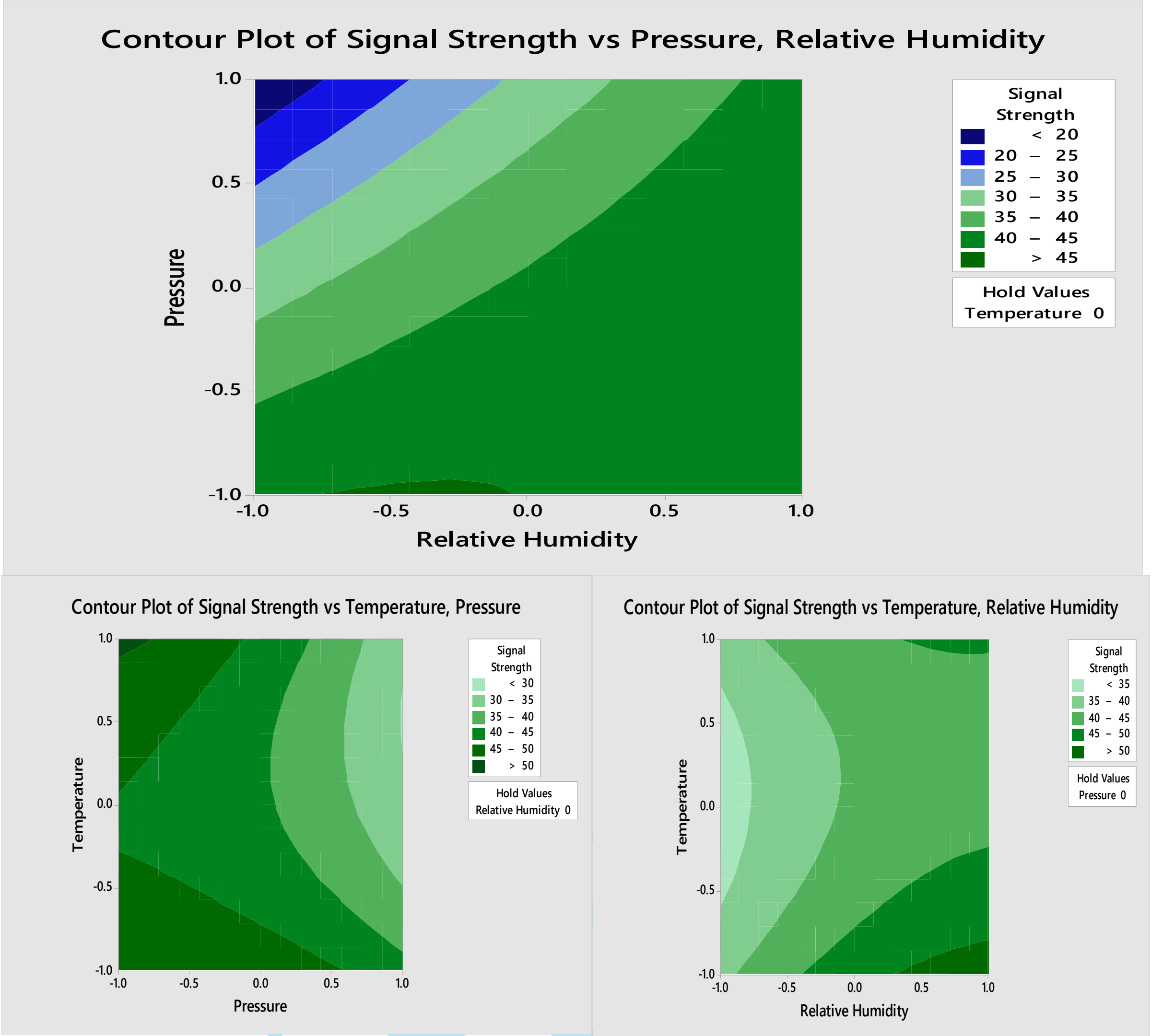

Figure 10: Contour plot of Signal Strength versus Temperature, Pressure, and Relative Humidity

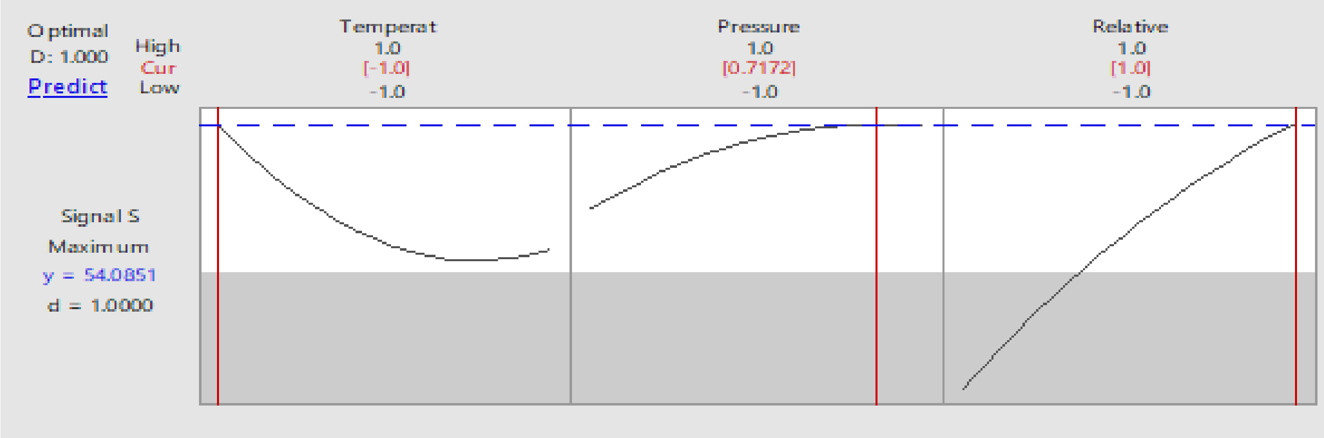

Figure 11: Optimization Plot

4. CONCLUSIONS

Response Surface Methodology was successfully applied for the determination of optimal radio signal strength using temperature, pressure, and relative humidity as the input predictor variables. Radio Signal Strength increases as Atmospheric parameters such as temperature, pressure and relative humidity decrease and vice versa. This means that these parameters have significant effect on radio signal strength. The model predictions were accurate and reliable to make generalizations for new observations beyond the sample data used for this experiment.

Hence, this research establishes an optimization approach to determine optimal atmospheric conditions for better communication signal intensity propagation. Also, the relationship between the atmospheric condition and signal strength was established.

5. ACKNOWLEDGEMENTS

The authors gratefully acknowledged all colleagues at Africa Regional Centre for Space Science and Technology Education - English (ARCSSTE-E), Obafemi Awolowo University, Ile-Ife, Nigeria involved in Space research and development for their moral support.

REFERENCES

[Ama16a] **Amajama J.** – *Impact of Weather Components on (UHF) Radio Signal*. International Journal of Engineering Research and General Science, Vol. 4 (3), pp. 481-482, 2016.

[Ama16b] **Amajama J.** – *Effect of Tropospheric Air density and dew point temperature on Radio (Electromagnetic) waves and Air radio wave refractivity*. International Journal of Scientific & Engineering Research, Vol.7 (6), pp. 356-360, 2016.

[Ama16c] **Amajama J.** – *Atmospheric Pressure bearing on (UHF) Radio Signal*. International Journal of Science Engineering and Technology. Vol. 5 (3). Retrieved from http://www.researchgate.net/publication/303882153_Atmospheric_Pressure_Bearing_on_UHF_Radio_Signal, pp. 131-133, 2016.

[A+17] **Ale F., Agboola A. O., Halidu D. I., Abdullahi A., Jegede J. O., Wysenyuy D. F., Ademu V.** – *Investigation of the influence of atmospheric temperature and relative humidity on FM Radio signal strength: A case study of WE FM Abuja*. International Journal of Scientific and Technology Research. Vol. 6 (11), pp. 70-73, 2017.

[Blu05] **Blum C.** – *Ant Colony Optimization: Introduction and recent trends*. Physics of Life Reviews, Vol. 2 (4), pp. 353-373, Retrieved from https://www.sciencedirect.com, 2005.

[Car18] **Carr R.** – *Simulated Annealing*. Math World – A Wolfram Web Resource, created by Eric W. Weisstein. Retrieved from http://mathworld.wolfram.com/SimulatedAnnealing.html, 2018.

[Har18] **Hardison K. P. L.** – *What are four controls of atmospheric temperature?* Retrieved from https://www.enotes.com/howework-help/discuss-detail-four-controls-atmospheric-418393, 2018.

[HDN15] **Harsh G., Devansh S., Nishant K.** – *Types of Signals*. International Journal of Innovative Research in Technology, Vol. 1 (12), pp. 1133-1135, 2015.

[HOO17] **Hamed J. O., Ogunleye O. O., Osheku C. A.** – *Optimal Design of a Composite Propellant Formulation using Response Surface Methodology*, Journal of Advances in Materials Science, Vol. 17, (1), p. 56, 2017.

[KS99] **Kim J. C., Schall D. E.** – *On the improvement of low elevation angle satellite communications impaired by tropospheric fading effects*. Atlantic City: IEEE, 1999.

[Luc15] **Lucas J.** – *What are Radio Waves?* Retrieved from https://amp.livescience.com/50399-radio-waves.html, 2015.

[LH15] **Luomala J., Hakala I.** – *Effects of Temperature and Humidity on Radio Signal Strength in Outdoor Wireless Sensor Networks*. Annals of Computer Science and Information Systems, Vol. 5. Kokkola, Finland: IEEE. Retrieved from http://urn.fi/URN:NBN:fi:jyu-201702141447, 2015.

[McC05] **McCall J.** – *Genetic algorithms for modelling and optimization*. Journal of Computational and Applied Mathematics, Vol. 184 (1), pp. 205-222. Retrieved from https://www.sciencedirect.com, 2005.

[MN10] **Mandeep J. S., Ng Y. Y.** – *Satellite Beacon Experiment for Studying Atmospheric dynamics*. Journal of Infrared, Millimeter and Terahertz waves, Vol. 31, pp. 988-994, 2010.

[MMA09] **Myers R. H., Montgomery D. C., Anderson-Cook C. M.** – *Response Surface Methodology: Process and Product Optimization using Designed Experiments*. Hoboken, New Jersey: John Wiley & Sons, Inc., Third Edition, 2009.

[NU15] **Nweke F. U., Ukwu C. N.** – *Weather Variation and its Effect on Transmission of Communication Signal*. International Journal of Scientific & Engineering Research, Vol.6 (6), pp. 643-645, 2015.

[OO11] **Odabi I. I., Olayinka A. S.** – *Absorption of Microwave Radio Frequency (RF) Signal by Atmospheric Rain*. Africa Journal of Science, technology and social science. Vol. 1 (1), pp. 24, 2011.

[Pid06] **Pidwirny M.** – *Atmospheric Pressure: Fundamentals of Physical Geography*. 2nd Edition. Retrieved from http://www.physicalgeography.net/fundamentals/7d.html, 2006.

[Pri91] **Priemer R.** – *Introductory Signal Processing*. Singapore: World Scientific Publishing Co. Pte. Ltd. Retrieved from https://books.google.com.ng/books?id, 1991.

[TAH14] **The American Heritage** – *Student Science Dictionary*. Boston, Massachusetts: Houghton Mufflin Harcourt. Second Edition. Retrieved from https://www.thefreedictionary.com/celestial+body+atmosphere, 2014.

[TE05] **Brown T. L., LeMay H. E.** – *The Rotronic Humidity Handbook*. New Jersey: Prentice Hall. Retrieved from http://hyperphysics.phy-astr.gsu.edu/hbase/, 2005.

[Wil13] **Williams J.** – *Weather weenies prefer dew point over relative humidity, and you should too!* Retrieved from https://www.washingtonpost.com/news/capital-weather-gang/wp/, 2013.