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Influence of Air Temperature, Relative Humidity and Atmospheric Moisture on UHF Radio Propagation in South Western Nigeria

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Abstract: ***The influence of variable troposphere air temperature, relative humidity and atmospheric moisture on UHF radio network propagation in the tropical region of south western Nigeria has been comprehensively investigated using experimental, theoretical and statistical approaches. This was done by measuring UHF received signal strength (RSS) over the available frequency band of 900-960MHz and specifically at individual service providers operating frequency concurrently with the variable weather parameters. Data were evaluated using modified models and statistical methods. The results show significant influences of the three atmospheric parameters on UHF networks links within the region. Further evaluations reveal that relations between variations in air temperature (control factor) and the received signal strength (RSS) can be technically and instrumentally utilized for efficient link control in the region.***

Keywords: Air temperature, Relative humidity, Atmospheric moisture, UHF Radio propagation

1. Introduction

The reliance of many Nigeria UHF mobile communication network planners on the troposphere of tropical region of south western Nigeria that is predominated by variable air-temperature, relative humidity and atmospheric moisture for transmission of UHF signals without pre-evaluation and characterization of the region UHF path losses and attenuations due to the influence of the variable parameters is one of the reasons for poor network performances in terms of signal quality during transmissions and receptions in the region. In most cases some of the developed models obtained through data analysis from temperate region of the world are been used to developed link margins and link budgets in terms of the expected channel impairments during network planning and implementation in the tropical region because information or models on influence of weather parameters on UHF link in the region is not available. Air temperature, humid air and air moisture can combine in many ways to affects UHF propagation. The effects of some of the meteorological parameters like rain, wind, fog, wet snow and evaporating duct on higher microwave frequency bands have been a subject of active research in the last decade and some facts have been established by few researchers such as, [16], [4], [17], [13] and[10] while several models have been developed at higher frequency of operations as an important step to more reliable communications by [12], [15], [1], [2], [3], [8] and [5] but reports and models on the influence of air temperature, relative humidity and atmospheric moisture on UHF signal propagations from tropical climate like southwestern Nigeria predominated by variable weather parameters is relatively scarce in literature. The main goals the paper is to analysis and developed models on influence of the three weather parameters on UHF radio propagation and how it can be utilized for efficient link margins and link budgets in tropical rain forest regions.

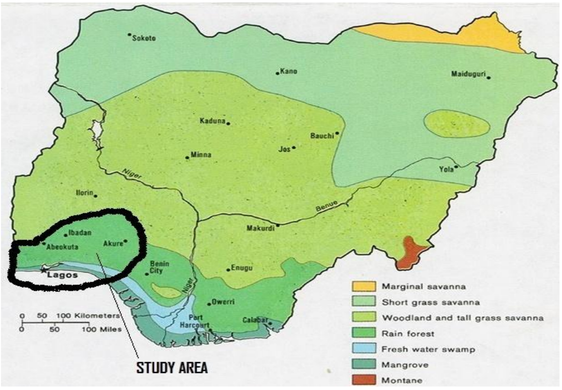

Figure 1: map of Nigeria showing study Area

2. Literature Survey

[18] studied the effects of radio waves propagation under sea at Pakistan coastal zones by transmitting VLF and ELF radio waves through certain depth of the sea and observed that the range and quality of transmission varies with water conditions in terms of salinity, temperature and density. [19] observed the influence of sea surface roughness on the electromagnetic wave propagation in the duct environment. [11] carried out a research on the effect of air-temperature on wireless sensor network from 25^{o}C to 45^{o}C using Telos-Class mote and observed that the performance efficiency of the wireless sensor reduces with increase in air-temperature; the effect was reported as hardware effect. [17] investigated the influence of sea breeze on microwave propagation over a line of – sight (LOS) link situated on the east of India and observed that atmospheric circulation due to the onset of sea breeze promotes the occurrence of water vapor around the propagation path, which brings about some distinct characteristic changes in the LOS link signal strength. [6] observed strong scintillation effects on Radio wave propagation through the solar corona at S, X and Ka bands when it passes through ionized region, the effect which degrades the communication link and at times results into complete outage.

3. Materials and Methods

A standard signal receiving instrumentation system was setup by connecting high gain UHF antenna of frequency band 900MHz to 960MHz with GSP 810 Spectrum Analyzer coupled with widow 98 computer systems as shown in plate1. This setup was permanently located in the vicinity of an automatic weather station for data acquisition. Variations in received signal strength at the chosen frequency band were periodically measured for fourteen months and synchronized with corresponding variations in weather parameters downloaded from the automatic weather station. Also, a locally constructed mobile signal strength measuring instrumentation system specifically designed for receiving and recoding variations in UHF signal strength concurrently with corresponding changes in weather parameters at the available mobile transmitting frequency was constructed to determine the influence of weather parameters on each of the available mobile network. Weather parameters data were also gathered from meteorological station within the selected locations for further evaluations.

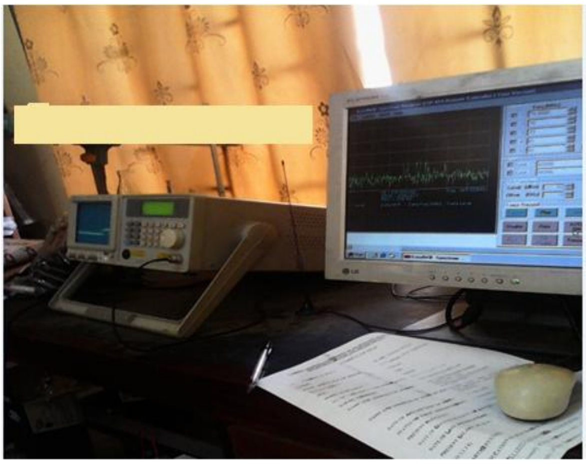

Plate 1A: Setup for data acquisition at frequency band of 900MHz - 960MHz

4. Estimation of UHF signal path loss and UHF Attenuation due to the influence of the measured weather parameters

Pathloss = (55.51-RSS) dBm [14] 1 RSS is the received signal strength measured in dBm. UHF specific attenuation due to liquid water density of the cloud was determined by formulating a temperature dependent model from the ITU-R model expressed as:

$$Y_c = k_C M \; [9] \qquad 2$$

Y_c is the specific attenuation of the cloud in dB/km, K_c is the specific attenuation coefficient of the cloud in (dB/km)/(kg/m^3), M is the liquid water density of the cloud in kg/m^3. Liquid water density of the cloud are made up of tiny water droplet controlled by air temperature, hence it cannot be fixed under normal atmospheric condition.

Hence, variations in liquid water density of the cloud (M) with corresponding changes in air temperature were deduced from the relation:

$$M = \left(\frac{\rho}{R_a T}\right)(1+x)/(1+\frac{xR_w}{R_a}) \qquad 3$$

$R_a = 286.9$ (Individual gas constant of air, J/kgK), $R_w = 461.5$ (Individual gas constant of water vapor, J/kgK), $x =$ Specific humidity or humidity ratio, $\rho =$ Pressure in the humid air (pa), $T =$ Absolute temperature in Kelvin. The value of M at all measured air temperature and pressure were determined using (3) and the results were used to calculate the specific attenuation due to liquid water density of the cloud of each of the selected locations. Cloud formation height was deduced from the relation:

$$Cloud\ base\ height = \frac{air\ temperature\ \ -dew\ point}{4.4} \times 100\ [7] \quad 4$$

The value of K_c in equation (2) was deduced from:

$$K_c = \frac{0.819f}{\epsilon''(1+\eta^2)}\ (\text{dB/Km})/\ (\text{kg/m}^3) \qquad 5$$

Where f is the frequency in MHz in this case

$$\eta = \frac{2+\epsilon'}{\epsilon''}\ 6$$

$$\text{Where } \eta = \frac{velocity\ \ of\ a\ signal\ \ in\ free\ space}{velocity\ \ of\ a\ signal\ \ in\ the\ medium}$$

$$\epsilon''(f) = \frac{f(\epsilon_o - \epsilon_1)}{f_p\left[1+\left(\frac{f}{f_p}\right)^2\right]} + \frac{f(\epsilon_1-\epsilon_2)}{f_s\left(\left[1+\left(\frac{f}{f_s}\right)^2\right]\right)} \qquad 7$$

$$\epsilon'(f) = \frac{(\epsilon_o - \epsilon_1)}{\left[1+\left(\frac{f}{f_p}\right)^2\right]} + \frac{(\epsilon_1-\epsilon_2)}{\left(\left[1+\left(\frac{f}{f_s}\right)^2\right]\right)} + \epsilon_2 \qquad 8$$

$$\epsilon_o = 77.6 + 103.3(\theta-1)\ \epsilon_1 = 5.48\,, \epsilon_2 = 3.51 \text{ and } \theta = {}^{300}/_{T}\ f_p = 20.09 - 142(\theta-1) + 294(\theta-1)^2\ 9$$

$$f_s = 590 - 1500(\theta - 1) \qquad 10$$

From equation 3.10, equation 3.9 can be deduced as

$$\epsilon_o = 77.6 + 103.3({}^{300}/_{T} - 1) \qquad 11$$

While equation 7 and 8 becomes

$$\epsilon''(f) = \frac{f(77.6+103.3({}^{300}/_{T}-1)-\epsilon_1)}{f_p\left[1+\left(\frac{f}{f_p}\right)^2\right]} + \frac{f(\epsilon_1-\epsilon_2)}{f_s\left(\left[1+\left(\frac{f}{f_s}\right)^2\right]\right)} \qquad 12$$

$$\epsilon'(f) = \frac{(77.6+103.3({}^{300}/_{T}-1)-\epsilon_1)}{\left[1+\left(\frac{f}{f_p}\right)^2\right]} + \frac{(\epsilon_1-\epsilon_2)}{\left(\left[1+\left(\frac{f}{f_s}\right)^2\right]\right)} + \epsilon_2 \qquad 13$$

For simplicity let

$$77.6 + 103.3({}^{300}/_{T} - 1) = \alpha,\ 1 + \left(\frac{f}{f_p}\right)^2 = \beta \text{ and}$$

$$1 + \left(\frac{f}{f_s}\right)^2 = \gamma$$

Hence, equation 3.5 becomes

$$\eta = \frac{2 + \frac{(\alpha)}{[\beta]} + \frac{(\epsilon_1-\epsilon_2)}{([\gamma])} + \epsilon_2}{\frac{f(\alpha)}{f_p[\beta]} + \frac{f(\epsilon_1-\epsilon_2)}{f_s([\gamma])}} \qquad 14$$

Therefore, equation 3.6 becomes

$$K_c = \frac{0.819f}{\frac{f(\alpha)}{f_p[\beta]} + \frac{f(\epsilon_1-\epsilon_2)}{f_s([\gamma])}\left(1 + \frac{2 + \frac{(\alpha)}{[\beta]} + \frac{(\epsilon_1-\epsilon_2)}{([\gamma])} + \epsilon_2}{\frac{f(\alpha)}{f_p[\beta]} + \frac{f(\epsilon_1-\epsilon_2)}{f_s([\gamma])}}\right)^2} \qquad 15$$

Hence, equation (3.2) which is the specific attenuation due to liquid water density of the cloud becomes

$$Y_c = \frac{0.819f}{\frac{f(\alpha)}{f_p[\beta]} + \frac{f(\epsilon_1-\epsilon_2)}{f_s([\gamma])}\left(1 + \frac{2 + \frac{(\alpha)}{[\beta]} + \frac{(\epsilon_1-\epsilon_2)}{([\gamma])} + \epsilon_2}{\frac{f(\alpha)}{f_p[\beta]} + \frac{f(\epsilon_1-\epsilon_2)}{f_s([\gamma])}}\right)^2} M \qquad 16$$

Remarks: The formulated model (equation 16) is analyzed numerically using Visual basic program compiler implemented with Matlab 7.8 version. The program interface was developed as shown in figure

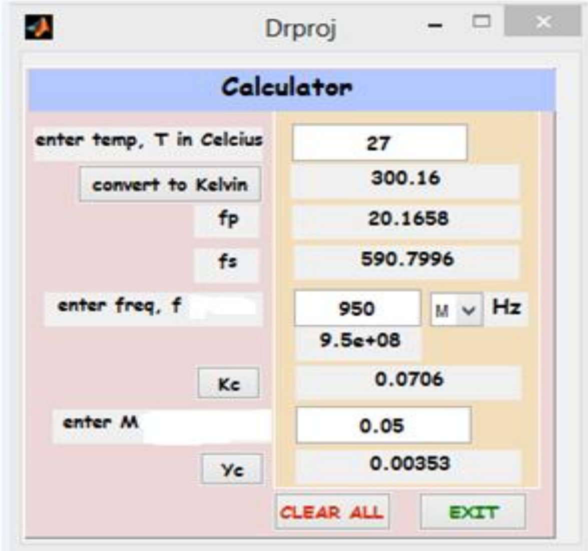

Figure 2: Developed user interface for determination of specific attenuation due to LWDC

5. Results and Discussions

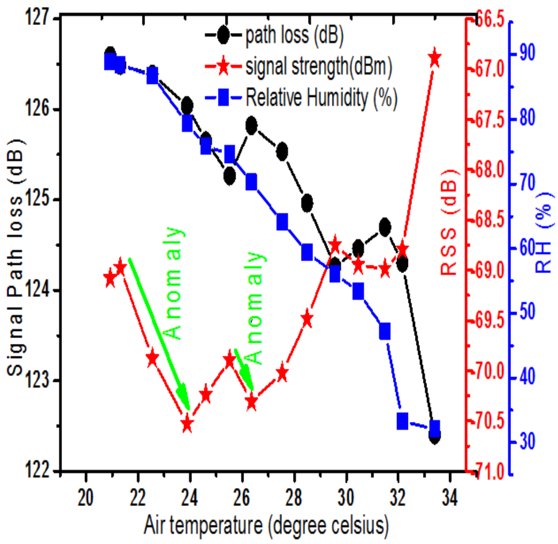

Figure 3: Received Signal Strength (RSS), Path loss, Air Temperature and Relative Humidity relations at UHF frequency band of 900MHz-960MHz

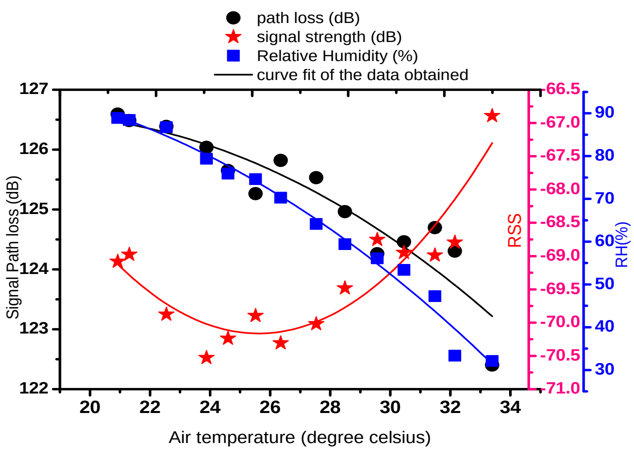

Figure 4: Graph showing curve fit of the relations obtained at the frequency band of 900-960MHz

The corresponding Models at frequency band of 900-960MHz are as shown in equation 17, 18 and 19:

$$\text{PL(dB)} = 122.07493 + 0.50341at^1 - 0.01405at^2 \quad (17)$$
$$\text{RH(\%)} = 66.61004 + 4.66151at^1 - 0.17115at^2 \quad (18)$$
$$\text{RSS} = -39.13971 - 2.4224at^1 - 0.04728at^2 \quad (19)$$

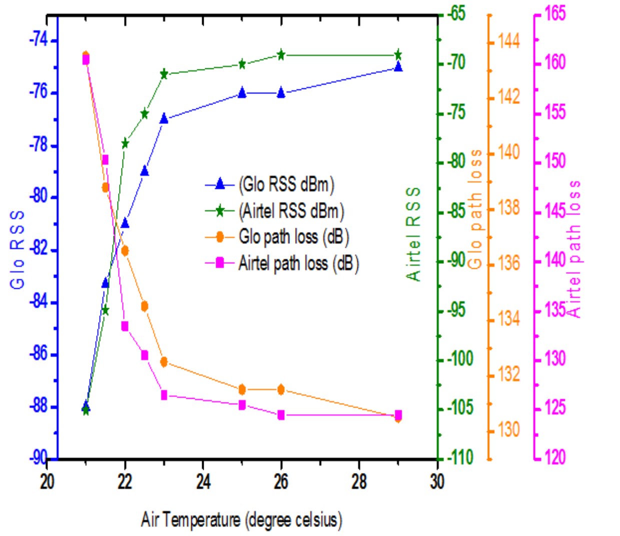

Figure 5: Available mobile network response to variations in air temperature

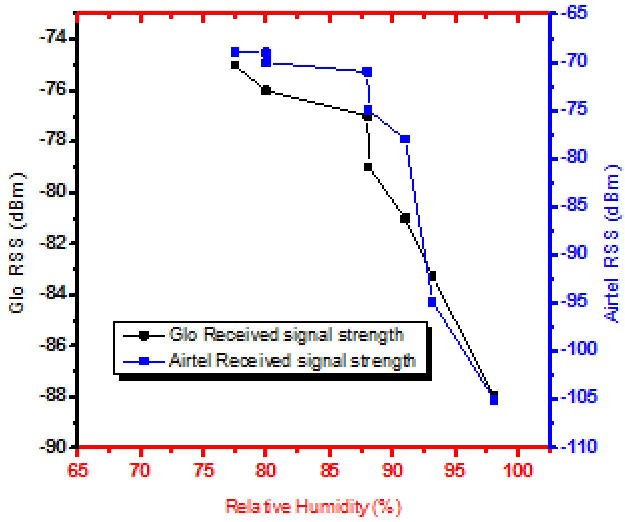

Figure 6: Available mobile network signals responses to variations in relative humidity.

Figure 7: Curve fit of the available mobile network signals responses to changes in relative humidity.

The curve fit Models of the available network signals are as shown in equation 20 and 21:

$$GLO\ RSS = -29.1686 - 0.57756RH \quad (20)$$
$$Airtel\ RSS = 62.51852 - 1.62663RH \quad (21)$$

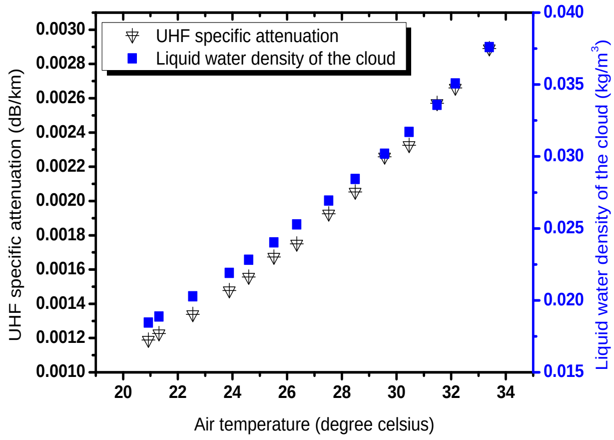

Figure 8: UHF specific attenuation due to liquid water density of the cloud relative to variations in air- temperature

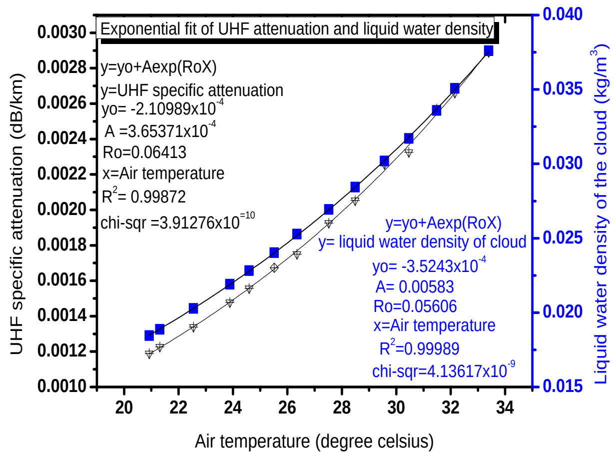

Figure 9: Exponential fit of UHF specific attenuation, LWDC and air temperature

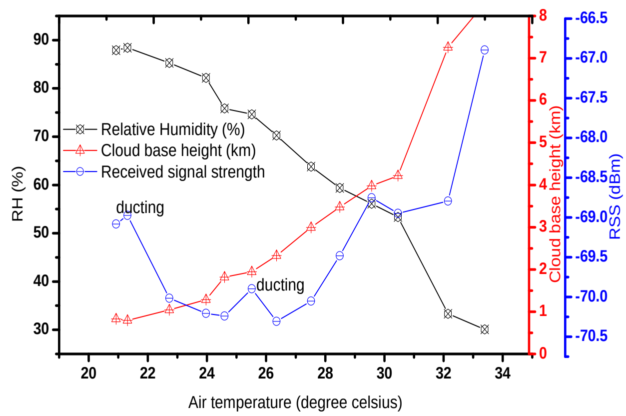

Figure10: Graph of relative humidity, cloud base height and received signal strength against air-temperature at the available GSM frequency.

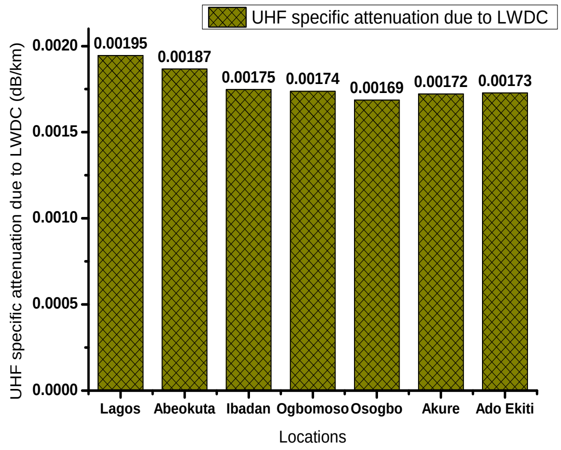

Figure11: Histogram of Annual average UHF specific attenuation due LWDC of the selected locations in year 2012

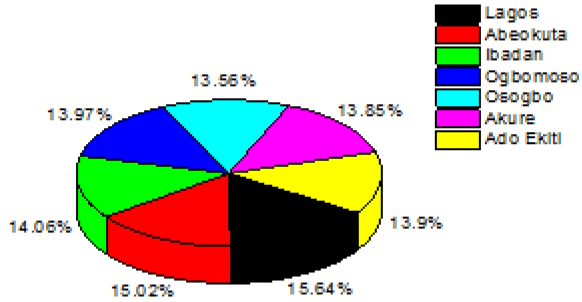

Figure12: Pie chart of Annual average UHF specific attenuation due to LWDC of the selected locations in year 2012

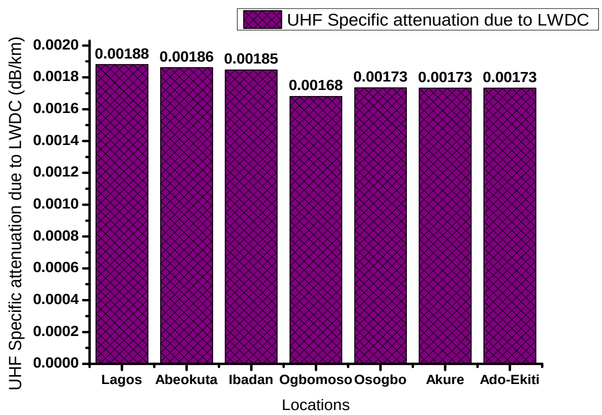

Figure13: Histogram of Annual average UHF specific attenuation due LWDC of the selected locations in year 2013.

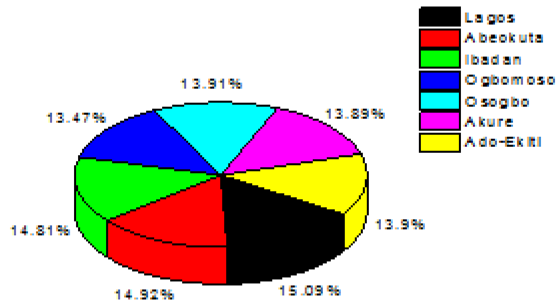

Figure 14: Pie chart of Annual average UHF specific attenuation due to LWDC of the selected locations in year 2013

Figure 3 shows the analysis of the measurement obtained at a frequency band of 900MHz-960MHz, the observation shows that as the air temperature increases, relative humidity decreases, hence a proportional decrease in UHF path loss while the received signal strength (RSS) shows a proportional increase. Figure 4 shows the curve fit and the corresponding models of the results obtained in figure 4, the fitted curve and the models shows high correlations and significant between the measured variable. Equation 17, 18 and 19 are the models obtained from the fitted curve. Figure 5 and Figure 6 show the responses of some of the Nigeria UHF mobile network signals to variations in the measure weather parameters. A harp increase in RSS was observed as the temperature rises while increase in relative humidity increases the signal path loss. Figure 7 represents the fitted curve of figure 5 and 6, equation 20 and 21 are the models obtained from the fitted curve. Figure8 shows a credible increase in LWDC and UHF specific attenuation (dB/km) relative to increase in tropospheric air temperature and figure 9 represent the corresponding models. Figure 10 shows that increasing air temperature increases the cloud base height and enhances the UHF RSS. It could be observed in figure 11, 12, 13 and 14 that UHF specific attenuation due to LWDC is location [latitude, Longitude] dependent and that Lagos has the highest average UHF attenuation of 0.0195(dB/km) and 0.018 (dB/km) which represent 15.64% and 15.09% of the average annual UHF specific attenuation due to LWDC in year 2012 and 2013 as a result of daily evaporation from the large body of water (Atlantic ocean)

6. Conclusion

All the results obtained show that air temperature, relative humidity and LWDC have significant influence on UHF signal propagation within the troposphere region of southwest Nigeria. The result can be used to develop efficient link margin and budget for the region rather than using existing link margin developed from temperate region data evaluation.

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