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Mathematical Relationships between Radio Refractivity and Its Meteorological Components with A New Linear Mathematical Equation to Determine Radio Refractivity

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Abstract

A concise review of radio refractivity has been captured. The relationships between radio refractivity and its meteorological components have been erected. Results from half hourly measurements for 48 hrs in the Calabar Metropolis, Nigeria have shown that: radio refractivity is directly proportional to the atmospheric temperature, atmospheric pressure and relative humidity: provided for any of the components, others, including wind speed and direction are observed constant. The correlations (r_ss) between radio refractivity and atmospheric temperature, atmospheric pressure and relative humidity were 0.99, 0.91 and 0.99 respectively. Also, a linear mathematical equation for calculating radio refractivity in all climatic regions has been established from the mathematical relationship between radio refractivity and its constituent meteorological composition. The accuracy of the mathematical formula is ± 5 %.

Keywords: *Radio refractivity, Meteorological components, Atmospheric temperature, Atmospheric pressure, Relative humidity, Wind speed and direction and Radio wave.*

1. Introduction

The atmosphere is an important channel in which radios are transmitted through [4] [8] [14]. Two principal spheres of the atmosphere provoke our curiosity from radio communications vantage point. These spheres are the ionosphere and the troposphere. The former is a sphere whose altitude stretches from around 60 km up to 700 km and cuts across the interface of the meteorological spheres [5]. Here, ions and free electrons are produced because the air becomes ionized. Radio signals are affected by the free electrons and ions at certain frequencies, typically those frequencies below 30 MHz and the latter is the sphere that is of meteorological concern with an altitude that transverses the region of 6 km and extends to about 10 km [5]. The troposphere controls and contains elements of the weather [7] [15] [16]. The components of refractivity are extracted from this sphere. The troposphere tends to have an impact on radio frequencies above 30MHz, but significantly helps in the conveyance of radios signals from the transmitter to the various segments of the globe where the receivers are positioned [1] [5].

The atmosphere will not be able to successfully perform the function of radio signal conveyance or transmission without refractivity [14]. Refractivity enables radios to bend back to the earth after striking an atmospheric channel with decreasing temperature of the troposphere, in other words, decreasing refractivity [1] [5]. None the less, radios may bump into a channel with an increase in temperature (known as a temperature inversion in scientific lexicon) in the troposphere instead of the normal decrease; the higher refractivity index of the atmosphere there will eventuate in the bending of the signal into space [13]. This is termed Tropospheric ducting. All frequencies of radio signals are affected by tropospheric ducting. Signals energized by means of this phenomenon usually propagate up to 1,300km [13]. However, there have been receptions of beyond 1,600km. Receptions of strong stable signals from 800+km away are commonplace when the refractivity of the atmosphere is considerably huge [13]. The air refractivity of the atmosphere performs a beneficial purpose in the radio communications applications that use tropospheric radio wave propagation [5]. The refractivity depends on the temperature, pressure and humidity of the atmosphere [5] [6].

Refraction on the troposphere depends on the variations in space of the index of refraction (n) [2] [9] [10] [11]. Commonly, the index of refraction decreases with increasing height. The index of refraction governs the speed of propagation of an electromagnetic wave (radio waves inclusive) in a medium [2] [10] [11].
The value of the index of refraction of air is very close to unity, commonly 1.0003 [2] [3] [11]. To make figures simplified, a new value is defined - the Refractivity [2] [11].

$$\text{Refractivity } N = (n - 1) \times 10^6 \qquad (1)$$

The refractive index of air and hence N depends mainly on the atmospheric pressure; P (millibars), atmospheric temperature; T (Kelvin) and partial pressure of water vapour; e_S (millibars) through the following relation [2] [11] [17].

$$N = 77.6\ P/T + 3.73 \times 10^5\ e_S/T^2 \qquad (2)$$

Where 77.6 P/T = Dry term and $3.73 \times 10^5\ e_s/T^2$ = Wet term.

As seen, the above equation is the sum of two terms in the: the 'dry term' and 'wet term'. The dry term is contributed by mainly dry gases such as Oxygen and Nitrogen and the wet term is governed by water vapour. This expression may be used for all radio frequencies: for frequencies up to 100 GHz, the error is less than 0.5 % [12]. The partial pressure of water vapour $e_{S;}$ which is a function of relative humidity H is given by the equation (3) below.

$$e_s = 0.01H \times 6.11 \exp [\ 17.26\ (T - 273.16) / (T - 35.87)] \qquad (3)$$

The focus of this research is converged on how to erect the relationship between radio refractivity and its dependent composition, so that a new linear equation will be drawn, to enable one calculate Radio refractivity easily.

2. Methodology

The meteorological components: atmospheric temperature and pressure, relative humidity and wind direction and speed were registered half hourly for 48 hrs from a residential area in the Calabar Metropolis, Cross River State, by employing the relevant meteorological measuring apparatuses. The radio refractivity was calculated using the Eq. (2) where the saturated vapour pressure of water e_s was obtained from the Eq. (3).

3. Results and Analysis

The following results were excerpted as shown in tables 1, 2 and 3 and the graphical relationships of the relevant parameters in the tables are captured in Figs. 1, 2 and 3 respectively. The relationship between radio refractivity and its constituent meteorological parameters: Relative humidity, Atmospheric temperature and Atmospheric pressure are discussed in each of the following subsections respectively.

3.1 Relationship between Radio refractivity and Relative humidity

Table 1: Measurement of relative humidity at constant atmospheric temperature and pressure with wind speed and direction and computed refractivity

Rel. Hum. (%)	**Atm. Temp (^{0}F)**	**Atm. Press. (inHg)**	**Wind (mph) N ✥**	**Radio Refrac. (N)**	**Time (hrs)**
94	77.0	29.91	0 NA	376	5:30
100	77.0	29.91	0 NA	383	13:00
89	77.0	29.91	0 NA	370	7:30
90	77.0	29.91	0 NA	371	0:30
82	77.0	29.91	0 NA	361	24:00

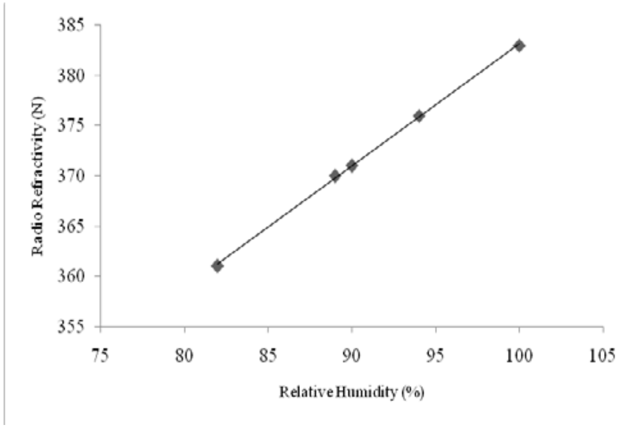

Fig. 1 Graphical relationship between refractivity (N) and relative humidity (%) at constant atmospheric temperature (of 77 ^{0}F) and pressure (of 29.91 inHg) with wind speed and direction (of 0 mph NA)

In Fig. 1, observing the atmospheric temperature and pressure constant, together with the wind speed and direction; the refractivity was directly proportional to the relative humidity, in other words, the higher the relative humidity, the higher the refractivity, provided that the atmospheric pressure and temperature, together with the wind speed and direction are observed constant. The correlation (r_s) between the refractivity and relative humidity is 0.99. It was mathematically discovered that, the refractivity is directly proportional to the cube root of relative humidity, on the condition that the other meteorological components are observed constant, that is: $N \infty \sqrt[3]{H}$. Where N is radio refractivity and H is relative humidity.

3.2 Relationship between Radio refractivity and Atmospheric temperature

Table 2: Measurement of atmospheric temperature at constant atmospheric pressure and relative humidity with wind speed and direction and computed refractivity

Atm. Temp (^{0}F)	Rel. Hum. (%)	Atm. Press. (inHg)	Wind (mph) N	Radio Refrac. (N)	Time (hrs)
77.0	94	29.94	0 NA	375	22:30
78.5	94	29.94	0 NA	380	8:00
78.0	94	29.94	0 NA	378	8:30
79.5	94	29.94	0 NA	384	11:30
79.0	94	29.94	0 NA	382	12:00

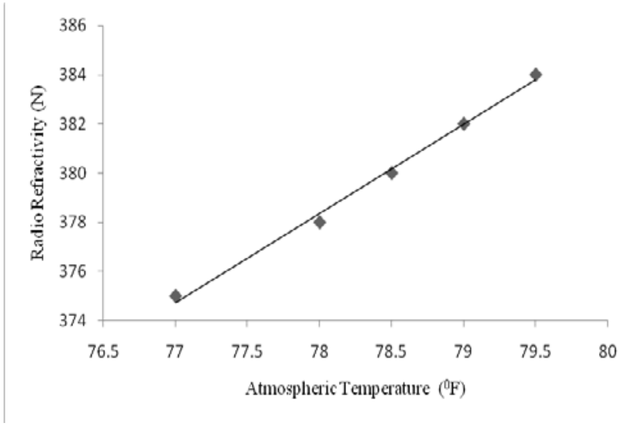

Fig. 2 Graphical relationship between refractivity (N) and atmospheric temperature (^{0}F) at constant atmospheric pressure (of 29.94 inHg) and relative humidity (of 94 %) with wind speed and direction (of 0 mph NA)

In Fig. 2, observing the atmospheric pressure, relative humidity and wind speed and direction constant; the refractivity was also directly proportional to the atmospheric temperature, hence, a rise in atmospheric temperature results in a rise in the refractivity, on the condition that, the atmospheric pressure, relative humidity and wind speed and direction are observed constant. The correlation (r_s) between refractivity and atmospheric temperature is 0.99. It was mathematically observed that, radio refractivity is directly proportional to the square root of atmospheric temperature (^{0}F), provided that the other meteorological components were observed constant, which is: $N \infty \sqrt{T}$. Where N is radio refractivity and T is atmospheric temperature.

3.3 Relationship between Radio refractivity and Atmospheric pressure

Table 3: Measurement of atmospheric pressure at constant atmospheric pressure and relative humidity with wind speed and direction and computed refractivity

Atm. Press. (inHg)	Atm. Temp (^{0}F)	Rel. Hum. (%)	Wind (mph) N	Radio Refrac. (N)	Time (hrs)
29.91	77.0	94	0 NA	375	22:30
29.94	77.0	94	0 NA	376	12:30
29.88	77.0	94	0 NA	375	24:00
29.85	77.0	94	0 NA	375	6:30
29.81	77.0	94	0 NA	374	5:30

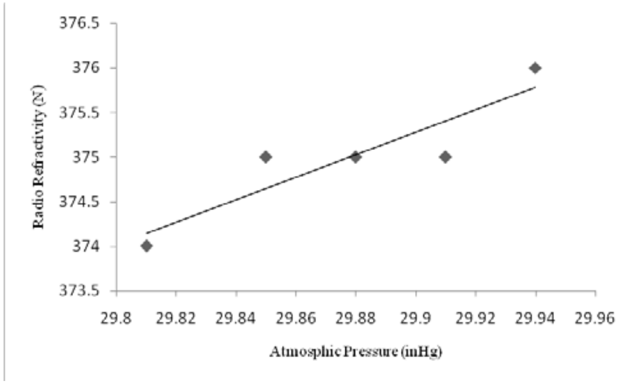

Fig. 3 Graphical relationship between refractivity (N) and atmospheric pressure (inHg) at constant atmospheric temperature (of 77 ^{0}F) and relative humidity (of 94 %) with wind speed and direction (of 0 mph NA)

In Fig. 3, observing the atmospheric temperature and relative humidity with the wind speed and direction constant; the refractivity was directly proportional to the atmospheric pressure, that is, an increase in atmospheric temperature eventuates in an increase in refractivity, provided that the atmospheric temperature and relative humidity with wind speed and direction are observed constant. The correlation (r_s) between refractivity and atmospheric pressure is 0.91. It was mathematically noticed that, radio refractivity is directly proportional to the square of atmospheric pressure (inHg), on the ground that the other meteorological composition were observed constant, that is: $N \infty P^2$. Where N is radio refractivity and P is atmospheric pressure.

4. Conclusions

In conclusion, the refractivity is directly proportional to the atmospheric temperature, atmospheric pressure, relative humidity provided that for any of the aforementioned parameters, the others including the wind speed and direction are observed constant.

Also from analysis, the mathematical equation was postulated, that is:

$$N = K \times P^2 \times \sqrt{T} \times \sqrt[3]{H}$$

Where K = Constant = 0.01064097915
P = Atmospheric pressure in inHg
T = Atmospheric temperature in ^{0}F
H = Relative humidity in %
N = Radio refractivity

It was observed that the accuracy was about ±5. The above formulation can be used in any climatic region.

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References

[1] "Atmospheric refraction", In Wikipedia, Retrieved 10th November, 2015, from http://en.wikipedia.org/wiki/Atmospheric_refraction, 2015.

[2] L. W. Barclay, M. P. M. Hall and M. T. Hewitt (Eds.), "Propagation of radio waves", IEEE., ISBN: 0 85296 8191, 1996.

[3] R. L. Freeman, "Radio system design for telecommunications", Hoboken-New Jersey: John Wiley & Sons Inc Pub, pp. 880, 2007.

[4] P. Ian (Ed.), "Radio signal path loss", In Radio-electronics, Retrieved 3rd April, 2015, from www.radio-electronics.com, 2015.

[5] P. Ian (Ed.), "Radio propagation and the atmosphere: Antennas and propagations", Retrieved 1st November, 2015, from Http://www.raadioelectronics.com/info/propagation/common/atmosphere.php, 2015.

[6] L. Jari& H. Isma, "Effect of temperature and humidity on radio signal strength in outdoor wireless sensor", Proceedings of the federated conference on computer science and information systems, 2015, Vol. 5, pp. 1247 – 1255.

[7] Y. S. Meng, Y. H. Lee & B. C. Ng, "The effects of tropical weather on radio wave propagation over foliage channel", IEEE transaction on vehicular technology, Vol. 58, No. 8, 2013, pp. 4023 – 4030.

[8] Rappaport, T. S. (1996). *Wireless communications*. New Jersey: Pearson Prentice Hall, 495 -502.

[9] S. S. John, "Introduction to RF propagation", New York: John Wiley and Sons, 2005.

[10] S. C. Liew, "Principles of remote sensing", Retrieved 14th January, 2015, from http://www.crisp.nus.edu.sg/-research/tutorial/em.htm.

[11] W. Mike. Refraction, Retrieved 10th November, 2015, from http://www.mike-wills.com/Tutorial/refraction.htm, 2015.

[12] Recommendation ITU-R, "The radio refractive index: its formula and refractivity data", Retrieved 10th November, 2015, from http://www.itu.int/rec/R-REC-P.453-9-200304, 2003.

[13] "Tropospheric propagation", In Wikipedia, Retrieved 5th April, 2015, from http://en.wikipedia.org/wiki/tropospheric_propagation, 2015.

[14] "The effects of the earth's atmosphere on radio waves", Introduction to wave propagation, Transmission lines and Antennas, Hwy - Port Richey: Integrated Publishing, Inc, Retrieved 5th April, 2015, from www.tpub.com/neets/book10/40c.htm, 2015.

[15] "Weather parameters", Retrieved 10th November, 2015, from cees.tamiu.edu/cees/weather/parameters.html, 2015.

[16] "Weather versus propagation", Introduction to wave propagation, Transmission lines, and Antennas, Retrieved November 5, 2015 from www.tpub.com/neets/book10/40c.htm, Port Richey-Hwy: Integrated publishing Inc, 2015.

[17] O. O. Yeeken & O. K. Michael, Signal strength dependence on atmospheric particulates, International Journal of electronics and communication engineering, Vol. 4, No. 3, 2011, pp. 283 – 286.

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