Effect of Tropospheric Air density and dew point temperature on Radio (Electromagnetic) waves and Air radio wave refractivity

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Abstract: Signal strengths measurements were obtained half hourly for some hours and simultaneously, the atmospheric components: atmospheric temperature, atmospheric pressure, relative humidity and wind direction and speed were registered to erect the effects of air density and dew point temperature on radio signals (electromagnetic waves) as they travel through the atmosphere and air radio wave refractivity. The signal strength from Cross River State Broadcasting Co-operation Television (CRBC-TV), (4057'54.7"N, 8019'43.7"E) transmitted at 35mdB and 519.25 MHz (UHF) were measured using a Cable TV analyzer in a residence along Ettaabgor, Calabar, Nigeria (4057'31.7"N, 8020'49.7"E) using the digital Community – Access (Cable) Television (CATV) analyzer with 24 channels, spectrum 46 – 870 MHz, connected to a domestic receiver antenna of height 4.23 m. Results show that: on the condition that the wind speed and direction are the same or (0 mph NA), the radio signal strength is near negligibly directly proportional to the air density, mathematically Ss / ∂a1.3029 = K, where Ss is Signal Strength in dB, ∂a is Density of air Kg/m3 and K is constant; radio signal strength is slightly inversely proportional to the dew point temperature; irrespective of the wind speed direction, mathematically, Ss x Td0.761 = K at same wind speed and direction, where Ss is Signal Strength in dB, Td is Dew point temperature in 0C and K is the constant; also, the air radio wave refractivity is slightly directly proportional to the air density, not taking into cognizance the wind speed and direction, since the radio refractivity formula is not a function of wind, mathematically, NR / ∂a0.4443 = K where NR is Air radio wave refractivity in inHg20F1/2%1/3, ∂a is Density of air Kg/m3 and K is constant; finally, the atmospheric radio wave refractivity is slightly directly proportional to the dew point; irrespective of the wind speed direction, mathematically Ss / Td0.2662 where Ss is Signal Strength in dB, Td is Dew point temperature in 0C and K is the constant.

Keywords: Radio waves, Electromagnetic waves, Air radio wave refractivity, Air density, Dew point temperature, Troposphere, Signal strength.

1. Introduction

The density of air, (in Greek words: rho) is the mass per unit volume of the Earth's atmosphere. Air density, like air pressure, decreases with increasing altitude. It also changes with variation in temperature or humidity. At sea level and at 15 °C air has a density of approximately 1.225 kg/m^3 (0.001225 g/cm^3, 0.0023769 slug/ft^3, 0.0765 lbm/ft^3) according to ISA (International Standard Atmosphere) [1].

The air density is a property used in many branches of science as aeronautics; gravimetric analysis; the air-conditioning industry; atmospheric research and meteorology; the agricultural engineering in their modelling and tracking of Soil-Vegetation-Atmosphere-Transfer (SVAT) models; and the engineering community that deals with compressed air from industry utility, heating, dry and cooling process in industry like a cooling towers, vacuum and deep vacuum processes, high pressure processes, the gas and light oil combustion processes that power the turbine-powered airplanes, gas turbine-powered generators and heating furnaces, and air conditioning from deep mines to space capsules [1]. Also, the density of air property it is beginning to find application in Communication Engineering and Physics since radio waves in the atmosphere propagates through air.

The Earth's atmosphere is an extremely thin sheet of air extending from the surface of the Earth to the edge of space, about 60 miles above the surface of the Earth. If the Earth were the size of a basketball, a tightly held pillowcase would represent the thickness of the atmosphere. Gravity holds the atmosphere to the Earth's surface. Within the atmosphere, very complex chemical, thermodynamic, and fluid dynamics effects occur. The atmosphere is not uniform; fluid properties are constantly changing with time and place. This causes change in weather [2].

Variations in air properties extend upward from the surface of the Earth. The sun heats the surface of the Earth, and some of this heat goes into warming the air near the surface. The heated air is then diffused or convected up through the atmosphere. Thus the air temperature is highest near the surface and decreases as altitude increases. The pressure of the air can be related to the weight of the air over a given location. As we increase altitude through the atmosphere, there is some air below us and some air above us. But there is always less air above us than was present at a lower altitude. Therefore, air pressure decreases as we increase altitude. The air density depends on both the temperature and the pressure through the equation of state and also decreases with increasing altitude [2].

Depending on the measuring instruments, use, area of expertise and necessary rigor of the result different calculation criteria and sets of equations for the calculation

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of the density of air are used. This topic are some examples of calculations with the main variables involved, the amounts presented throughout these examples are properly referenced usual values, different values can be found in other references depending on the criteria used for the calculation . Furthermore we must pay attention to the fact that air is a mixture of gases and the calculation always simplify, to a greater or lesser extent, the properties of the mixture and the values for the composition according to the criteria of calculation [1].

The density of humid air varies with temperature and moisture content in the air. When the temperature increases: the higher molecular motion results in an expansion of the volume and decrease of density. The amount of water 357vapour in air will influence the density. Water 357vapour is a relatively light gas compared to diatomic Oxygen and diatomic Nitrogen – the dominant components in air. When the vapour content increase in moist air the amount of Oxygen and Nitrogen are decreased per unit volume and the density of the mix will also decrease since the mass is decreasing. Dry air is more dense that humid air [3]!

Atmospheric radio wave refraction or refractivity is the variation of radio waves from a straight path as it propagates through the atmosphere due to variation in the density of air as a function of altitude [4] [5]. Radio wave refractivity in the atmosphere is due to the velocity of radio waves through air decreasing with increasing density (or increasing index of refraction) [4] [6]. The afore-mentioned is true, since the index of atmospheric radio wave refraction or refractivity is the ratio of the speed of electromagnetic wave (in this case, radio wave) in free space to that of the radio wave in the atmosphere and the speed of the radio wave is a function of the density of the medium which it is travelling through.

Refractivity on the troposphere depends on the variations in space of the index of refractivity (n). Commonly, the index of refractivity decreases with increasing height. The index of refractivity governs the speed of propagation of an electromagnetic wave in a medium [5] [7] [8] [9].

If the air is gradually cooled while maintaining the moisture content constant, the relative humidity will rise until it reaches 100%. This temperature, at which the moisture content in the air will saturate the air, is called the dew point. If the air is cooled further, some of the moisture will condense [10].

Changes in the relative speed in which atomic and subatomic particles move is observed when particles are influenced by some environmental factors, i.e. gravity, air density, etc. This study asserts that a reduction of air density may be achieved by manipulating one or more of the three related parameters/factors: air pressure, temperature and humidity. Observations of a positive relationship between air densities, temperature, humidity and electromagnetic radiation explains that by changing air pressure and altering temperature and humidity in an area of three-dimension space, alteration of the oscillation frequency of radioactive particles in that area will result [11].

This research paper aims at erecting the effect of air density and dew point temperature on radio (electromagnetic) waves as they travel through the atmosphere and air radio wave refractivity by studying Ultra High Frequency - Television (UHF-TV) radio waves generated by the Cross River Broadcasting cooperation transmitter of height 50 m at 35mdB and 519.25 MHz. The experiment was carried out in the time course of the wet, with some road blocks like rain.

2. Methodology

The campaign was carried out in the Calabar metropolis in Cross River State, Nigeria. Signal strengths measurements were obtained half hourly for some hours and simultaneously, the atmospheric components: atmospheric temperature, atmospheric pressure, relative humidity and wind direction and speed were registered to erect the effects of air density and dew point temperature on radio signals (electromagnetic waves) as they travel through the atmosphere and air radio wave refractivity. The signal strength from Cross River State Broadcasting Co-operation Television (CRBC-TV), (4057'54.7"N, 8019'43.7"E) transmitted at 35mdB and 519.25 MHz (UHF) were measured using a Cable TV analyzer in a residence along Ettaabgor, Calabar, Nigeria (4057'31.7"N, 8020'49.7"E) using the digital Community – Access (Cable) Television (CATV) analyzer with 24 channels, spectrum 46 – 870 MHz, connected to a domestic receiver antenna of height 4.23 m.

To arrive at the actual effect of the air density and dew point temperature on radio signals (electromagnetic waves) as they travel through the atmosphere; the wind speed and direction was observed uniformly (that is at 0 NA mph) and non-uniformly.

To calculate the density of air as a function of altitude, one requires the following parameters. They are listed below, along with their values according to the International Standard Atmosphere, using the universal gas constant instead of the specific one. The altitude of Calabar is 57 m [12].

The air density as a function of altitude, air temperature, air pressure and relative humidity was computed thus:

$$\rho = (P/R \times 1/T) \times (1 - (0.378 \times Pv/P)) \text{ in Kg/m}^3 \quad (1)$$

Where: P_v = Pressure of water vapor i.e. partial pressure (Pascals)

P = Pressure at the altitude of 57 m

T = Temperature at the altitude of 57 m

But; $Pv = RH/100 \times Es$ (2)

Where RH = Relative humidity (%)

E_s = Saturation pressure of water vapour (Pa)

$$Es = C_0 \times \frac{10 C_1 T_C}{C_2 T_C} \text{ (Pascal)} \quad (3)$$

Where, $C_0 = 6.1078$

$C_1 = 7.5$

$C_2 = 237.3$

T_c = Ambient temperature (deg C)

$$T = T_0 - Lh \quad (4)$$

$$P = P_0\,(1 - ({}^{Lh}/{}_{T_0}))^{gM/RL} \qquad (5)$$

Where, P_0 = Ambient (Sea level) Pressure in Pa

T_0 = Ambient (Sea level) Temperature in deg K

g = Earth-surface gravitational acceleration = 9.80665 m/s^2

L = Temperature lapse rate = 0.0065 K/m

R = Universal gas constant = 8.31447 J/(mol·K)

M = Molar mass of dry air = 0.0289644 kg/mol

h = Altitude above sea level

Also: the Dew point air temperature (T_d) was computed using the formula below:

$$T_d = 243.12 \times H/(17.62 - H) \text{ in } {}^0C \qquad (6)$$

$$H = \{\log 10\,(RH) - 2.0\} \div \left\{\frac{(0.4343) + (17.62 \times T)}{(243.12 + T)}\right\} \qquad (7)$$

Where, RH = Relative Humidity

T = Absolute/Ambient Temperature in ^{0}C

Also: the air radio wave refractivity was computed using the Eqn. 1 below [13].

$$N = K \times P^2 \times \sqrt{T} \times \sqrt[8]{H} \qquad (8)$$

Where K = Constant = 0.01064097915

P = Atmospheric pressure in inHg

T = Atmospheric temperature in ^{0}F

H = Relative humidity in %

N = Radio refractivity

The above formulation has an accuracy of ± 5 in comparison with the existing International Telecommunication Union (ITU) expression for calculating Radio refractivity. The ITU expression may be used for all radio frequencies: for frequencies up to 100 GHz, the error is less than 0.5 % [14].

3. Results and Analysis

3.1 Results

Results from the data acquired are represented graphically below. To ascertain the true relationship between plotted parameters: some data were excerpted from the whole when bringing into cognizance the wind effect. Here, the wind as one of the major meteorological parameter that can also reduce the power density of radio signals was observed constant at (at 0 mps NA). Also, when not taking into account the wind effect, all the data acquired from the experiment was utilized: irrespective of the speed and direction.

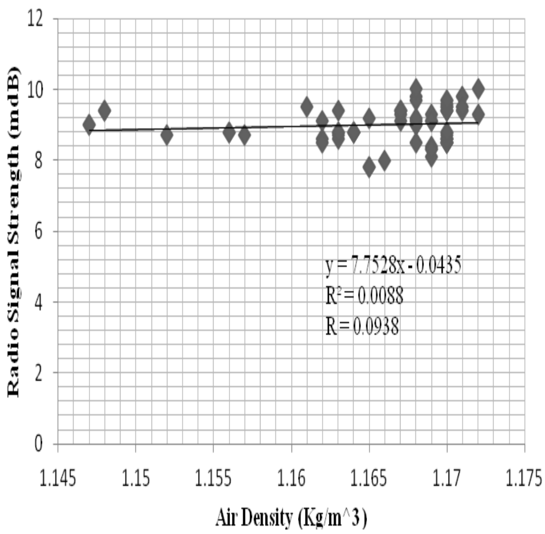

Figure 1: A graphical relationship between Radio signal strength and Air density without taking into cognizance the wind speed and direction

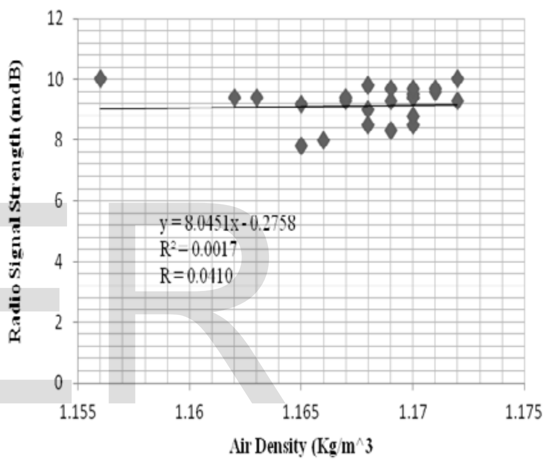

Figure 2: A graphical relationship between Radio signal strength and Air density taking into cognizance the wind speed and direction (Measurements at 0 mph NA)

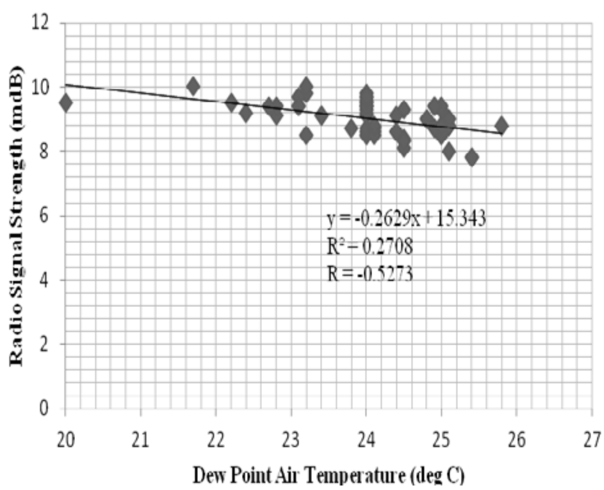

Figure 3: A graphical relationship between Radio signal strength and Dew point air temperature without taking into cognizance the wind speed and direction

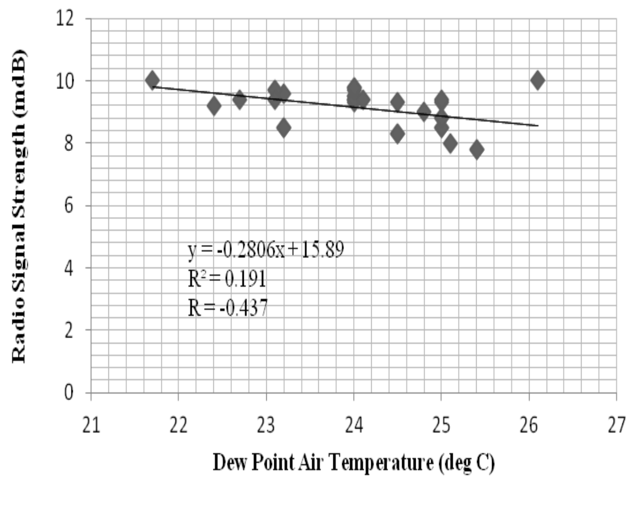

Figure 4: A graphical relationship between Radio signal strength and Dew point air temperature taking into cognizance the wind speed and direction (Measurements at 0 mph NA).

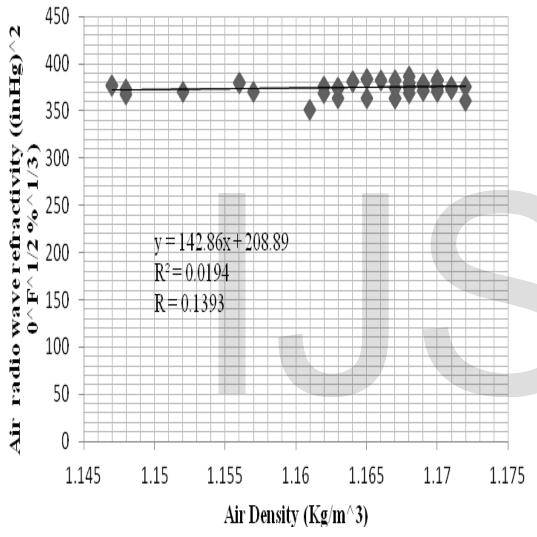

Figure 5: A graphical relationship between Air radio wave refractivity and Air density

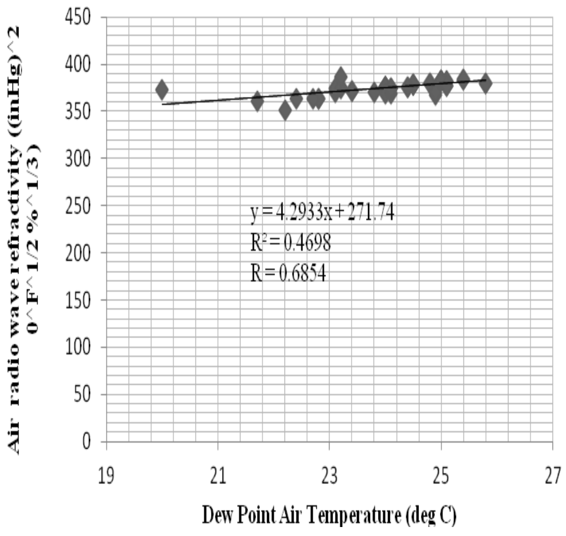

Figure 6: A graphical relationship between Atmospheric radio wave refractivity and Dew point air temperature

3.2 Analysis

Research has shown that wind speed and direction has a significant effect on radio waves as it propagates through the air in the troposphere [15]. Fig. 1 shows a graphical relationship between Radio signal strength and Air density without taking into cognizance the wind speed and direction. From the graph, the radio signal strength is very slightly directly proportional to the air density. The straight line equation from the line of best fit is: y = 7.7528x - 0.0435 and the correlation between radio signal strength and air density is 0.0938 to 4 decimal places.

Fig. 2 shows a graphical relationship between Radio signal strength and Air density taking into cognizance the wind speed and direction. It also indicates that, the radio signal strength is negligibly inversely proportional to the air density, taking into account the wind speed and direction at 0 mph NA. The straight line equation from the line of best fit is: y = 8.0451x - 0.2758 and the correlation between radio signal strength and air density is 0.0410 to 4 decimal places.

Figs. 1 and 2 also show that wind has some effect on radio (electromagnetic) wave propagation through the tropospheric air (at UHF). But, since both results differ very slightly i.e. when the wind speed and direction are brought to account and not: it indicates that the influence on the density of air as the radio (electromagnetic) wave propagates via the air in the troposphere; bringing to bear the wind speed and direction and not is nearly negligible, since the correlation between radio signal strength and air density under this condition is 0.04 and 0.09 sequentially to 2 decimal places.

However, this is a fact deduced from the results in Figs. 1 and 2. On the condition that the wind speed and direction are the same or (0 mph NA); the radio signal strength is near negligibly directly proportional to the air density. In other words, air density has a negligible effect on radio signals as they propagate the troposphere.

Figs. 3 and 4 show a graphical relationship between Radio signal strength and Dew point temperature without taking into cognizance the wind speed and direction and a graphical relationship between Radio signal strength and dew point temperature taking into cognizance the wind speed and direction (Measurements at 0 mph NA) respectively. Both graphical representations show that signal strength is inversely proportional to dew point. However the correlation between the radio signal strength and the dew point temperature when the wind effect was considered and not, differ and their correlations are -0.4370 and -0.5273 respectively with straight line equation models of: y = -0.2806x + 15.89 and y = -0.2629x + 15.343 in the stated order. Hence, radio signal strength is partially inversely proportional to the dew point; irrespective of the wind speed direction.

Figs. 5 shows a graphical relationship between air radio wave refractivity and air density. The straight line equation for the aforementioned parameters is: y = 142.86x + 208.89 and the correlations is: 0.1393. Here, the wind was not brought to account since, both the refractivity and air density formulas are not a function of wind. Even though research has shown that wind has a significant effect on refractivity as a radio signal propagates through the troposphere. There are cases of the same computed refractivity, but marked different radio signal strength on the condition of different wind directions.

Still in figs. 5, it is inferred that the air radio wave refractivity is slightly directly proportional to the air density. This counters science literatures that say dry air is denser than wet air. If the afore-statement is true, the straight line of best fit would have had a negative slope but not a positive one. But, researchers have shown that relative humidity degrades the strength of radio signal more than any of the meteorological parameters [16] [17] [18] [19]. Hence, the above line of best fit spells higher relative humidity is positively proportional to higher density.

Figs. 6 shows a graphical relationship between air radio wave refractivity and dew point temperature. The straight line equation is y = 4.2933x + 271.74 and the correlation is 0.6854.

Therefore, from Fig. 6 a verdict can be drawn that: the atmospheric radio wave refractivity is directly proportional to the dew point temperature.

4. Conclusion

Conclusively, these are the postulates from this research paper:

- On the condition that the wind speed and direction are the same or (0 mph NA); the radio signal strength is near negligibly directly proportional to the air density. In other words, air density has a negligible effect on radio signals as they propagate the troposphere. Mathematically; $S_s / \partial_a^{1.3029} = K$, where S_s is Signal Strength in dB, ∂_a is Density of air Kg/m^3 and K is the constant.
- Radio signal strength is slightly inversely proportional to the dew point temperature; irrespective of the wind speed direction. Mathematically; $S_s \times T_d^{0.761} = K$, where S_s is Signal Strength in dB, T_d is Dew point temperature in ^0C and K is the constant.
- The air radio wave refractivity is slightly directly proportional to the air density, not taking into cognizance the wind speed and direction, since the air radio refractivity formula is not a function of wind. None the less, studies have shown that the wind speed and direction has some significant effect on air radio wave refractivity [9]. Mathematically; $N_R / \partial_a^{0.4443} = K$, where N_R is Air radio wave refractivity in $inHg^{20}F^{1/2}\%^{1/3}$, ∂_a is Density of air Kg/m^3 and K is the constant.
- Also the air radio wave refractivity is slightly directly proportional to the dew point; irrespective of the wind speed direction. Mathematically; $S_s / T_d^{0.2662} = K$ where S_s is Signal Strength in dB, T_d is Dew point temperature in ^0C and K is the constant.

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Author's Profile

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