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# The influence of primary radio climatology parameters on radio refractive index over the African region: a 30-year satellite study

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# The influence of primary radio climatology parameters on radio refractive index over the African region: a 30-year satellite study

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**Abstract** In the lower part of the atmospheric boundary layer, structure of the radio refractive index plays a vital role when planning and designing microwave communication link. The effects of primary radio climatic parameters on radio wave propagation at UHF and microwave frequencies are crucial in studying radio refractive index. 1951 to 1980 satellite data has been used to investigate the mean values of both the primary radio climatic variables and surface radio refractive index over the Africa. The mean value of water vapor pressure, temperature and pressure ranges from 3-23 mbar, 284-302 K and 800-1000 mbar respectively across Africa. The high values of water vapor pressure around the Coastal and Rainforest reduce towards the Savanna and Steppe region (semi-arid). The mean variation value of surface refractivity over Africa ranges from 160 - 340 N-units. The refractivity values in larger part of the savanna range between 250 – 280 N-units.

**Index Terms**: Communication, Climatic parameter, Refractivity, Desert, Pressure

## 1. Introduction

The propagation of tropospheric radio waves is influenced by changes in the primary radio-climatic parameters, because each route between two points of radio communication, with the exception of satellite communication, passes through the troposphere. Troposphere is the layer in which weather occurs [1] and temperature is the main weather determinant factor among air masses [2]. The changes in weather that affect most of the terrestrial radio propagation take place in the troposphere. The quality of the propagated electromagnetic wave between a transmitter and receiver depends on the reliability of the microwave link [3]. The refractivity of the atmosphere affects the curvature of the ray path, provides insight into how radio waves fade through the troposphere [4] and it's accountable for different types of wave propagation phenomena, including ducting and scintillation [5]. The refractive index of the atmosphere is a function of different combinations of the primary radio-climatic parameters of the atmosphere (temperature, pressure, water vapor pressure or humidity). Certain combination may cause the radio signal to be heard far beyond targeted receiver while some combinations may attenuate the signal that it may or may not get to the desire distance [6]. The variation of these parameters with altitude contributes to changes in atmospheric density, which in turn induces differences in the velocity of electromagnetic waves in both vertical and horizontal directions, leading to changes in the direction of propagation or bending of waves as they travel through the atmosphere.

During the normal atmospheric condition, radio refractive index, n close to the Earth's surface is about unity (1.0003). Hence, is measured by a quantity known as radio refractivity, N which has the relationship with n as [7]

$$n = 1 + N \times 10^{-6} \tag{1}$$

Considering the atmospheric temperature T (K), Pressure P (hpa), water vapor pressure e (hpa), N can be computed by using [7]

$$N = 77.6 \frac{P}{T} + 3.75 \times 10^5 \frac{e}{T^2} \tag{2}$$

The water vapor pressure in term of relative humidity, RH (%) and air temperature, t (° C) can be determine by [8]

$$e = RH \times \frac{6.1121 \exp\ (\frac{17.502\,t}{t+240.97})}{100} \tag{3}$$

The investigation of the effect of primary radio climatology parameters on surface radio refractive index over Africa has been carried out to provide detailed variation of the parameters and refractivity across Africa. The data obtained in this study on surface radio refractivity will provide adequate information to radio engineers relevant to the design of communication systems across Africa

## 2. Materials and Methods

Thirty years (1951 – 1980) metrological reanalysis satellite data (Surface Pressure, Air temperature and Dew point temperature) on a grid of 0.25º x 0.25º were collected from the European Center for Medium-Range Weather Forecasts (ERA-Interim). The data was used to compute the refractivity using equation (2) and (3) while the relative humidity, RH (%) in term of dew point temperature was computed from the expression (4) [10].

$$RH = 100 \cdot \frac{\exp\left(\frac{17.625\,t}{243.04+t_d}\right)}{\exp\left(\frac{17.625\,t}{243.04+t}\right)} \tag{4}$$

where t and $t_d$ are ambient temperature and dew point temperature respectively in °C.

## 3. Results and Discussion

The monthly mean temperature values vary from region to region with in the range of 284 to 302 K across Africa (Figure 1). The Sahel region recorded the highest value (298 – 302 K) followed by the Savanna region while Mediterranean region recorded the lowest (284 K). This could be due to proximity of Sahel region to the equator where the solar heat is higher than that of the other regions meanwhile the Mediterranean region is a seaboard region that is far away from the equator hence resulting to the lowest temperature value. The Steppe region to the Southern part of Africa with an increase of its temperature value demonstrated the insignificant effect of climate change on temperature; it could likely be due to the proximity of the climate to continental tropical (cT) and maritime tropical (mT) air mass source regions.

The mean surface pressure value across the entire region in Africa (Figure 2) ranges from 800 – 1000 mbar. Latitudinal variability of the surface pressure value was observed to be high from equatorial region to the Northern part of African continent but low towards the Southern part. This is as a result of high surface temperature at the equator that reduces towards the north by convection and as the air temperature become colder it becomes denser, and falls resulting to high pressure area. Also the low pressure area is as a result of air that expands and rises when the air temperature gets warmer. The high pressure value (above 960 mbar) observed at the entire coastal region is as a result of the hot air on the ocean surface. In the Southern part Africa, the Savanna region, Steppe region, Kalahari Desert including the central of Madagascar recorded surface pressure variation that ranges from 800 to 930 mbar. This can be associated with cloud and precipitation of these locations.
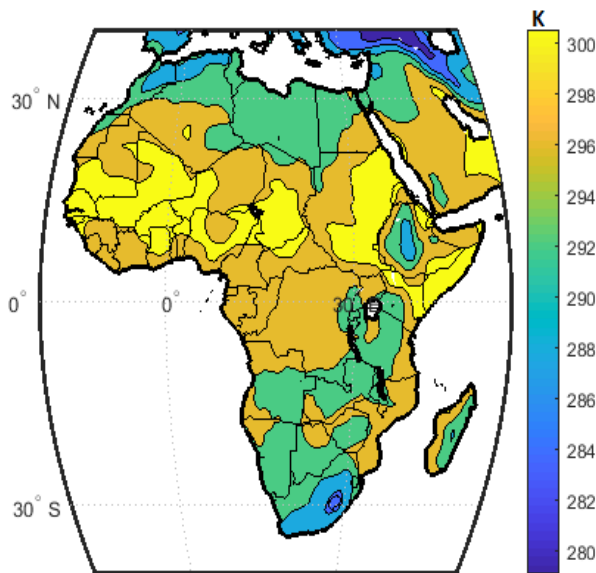
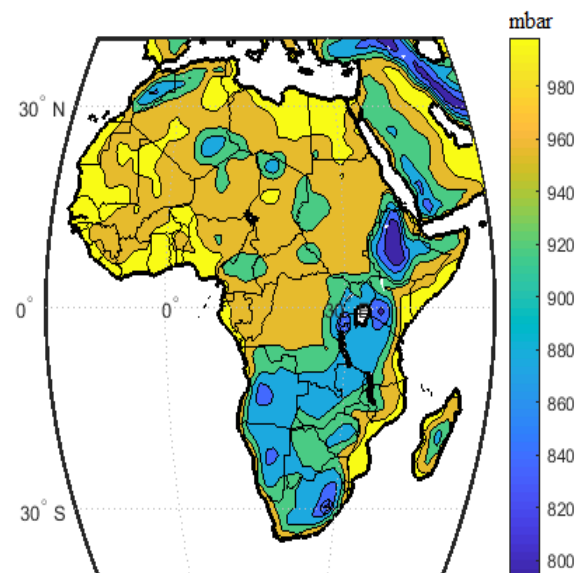Figure 1. Mean Value Distribution of Air Temperature over Africa.



Figure 2. Mean Value Distribution of Surface Pressure over Africa.

Mean value of water vapor pressure across Africa (Figure 3) ranges between 3 – 23 mbar and at Madagascar it is from 10 – 23 mbar. At Desert region and about 80% of the Steppe regions, the value vary between 3 – 9 mbar, at the Savanna region and about 20% of the Steppe region it is between 10 – 16 mbar meanwhile the entire Rainforest region and the coastal zone of the Western and Eastern part of Africa continent recorded the highest values which vary between 17 – 23 mbar. High values at these regions could be as a result high transpiration (128 – 153 cm) of the regions.

The mean value of Wet term, $N_{wet}$ of the refractivity, N (not shown) depict lowest variability value at the Desert regions (Sahara and Kalahari) which could be associated to the low humidity, little or no rainfall and dry air of the region, this is in agreement with [11].

The mean variation value of refractivity across Africa (Figure 4) ranges from 160 – 340 N–units. The highest mean values (300 N–units and above) were found in the Rainforest, entire coastal region and Madagascar which is due to the fact that large water vapor content, temperature including high precipitation are present in the atmosphere of the regions. The value gradually reduces radially outward making the Savanna region and the Kalahari Desert the second highest regions after rainforest with the value range of 245 – 280 N–units. This is due to the fact that, the precipitation of the regions is low. The relatively low range value of 210 – 240 N–units recorded in the Steppe region resulted from the fact that the potential evapotranspiration is higher than the precipitation in the region.

The variation pattern of the radio refractivity follows suite the pattern of its wet term which implies that the term contributes significantly to the variation of radio refractivity and demonstrates the relationship between $N_{wet}$ and the refractivity, and hence radio wave refraction, and the water content of the atmosphere. The pattern of surface radio refractivity at the equatorial and the tropical region could in addition be due to the fact that the moist monsoon air originating from the southern part of the continent and the dry tropical air from the northern part of the continent controls atmospheric circulation over the equatorial region and larger portion of the tropical continental region
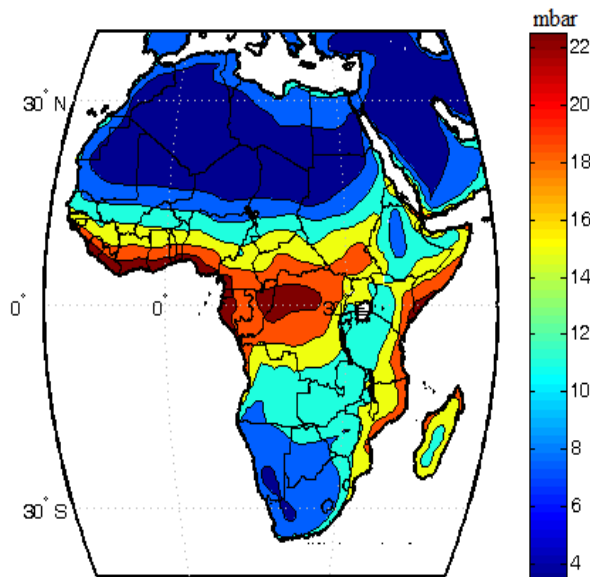
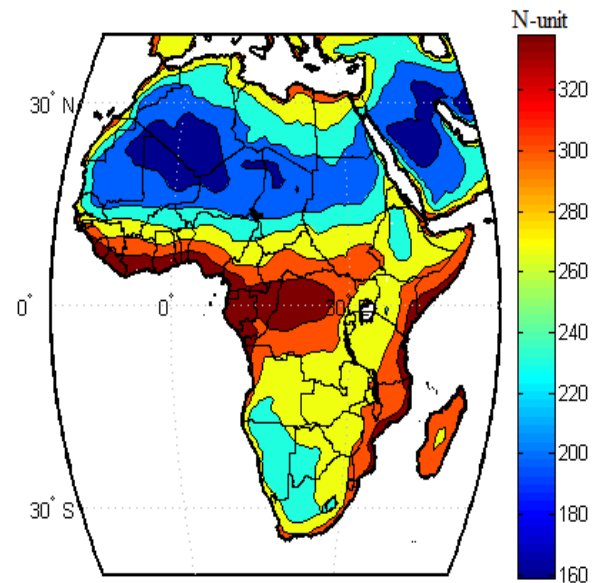Figure 3. Mean Value Distribution of Water Vapor Pressure over Africa.

Figure 4. Mean Value Distribution of Surface Radio Refractivity over Africa.

## 4. Conclusions

The results obtained shows that Temperature at the Desert regions ranges from 292 – 298 K but in the regions close to the ocean, the values are relatively small (< 294 K), which could be as a result of evaporation of water molecule from the surface of the water bodies. The high pressure value (above 960 mbar) observed at the entire coastal region is as a result of the hot air on the ocean surface. The high values of water vapor pressure around the Coastal and Rain-forest gradually reduces towards the Savanna and Steppe region (semi-arid) but become very low at the Desert. This is in agreement with several reports such as [4], [9].

Latitudinal variations of the surface radio refractivity which follows the pattern of its wet term at the north and southern part of Africa reduce radially outward from the tropical region to the northern region but high at the entire coastal region. The trend pattern of the $N_{wet}$ term is found to follow suite the pattern of water vapor pressure.

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