Journal of Atmospheric and Solar-Terrestrial Physics 133 (2015) 1–6

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

# Correlation between the sunspot number and tropospheric refractivity in a tropical environment

Najib Yusuf*, B.G. Ayantunji

*NASRDA'S Centre for Atmospheric Research (CAR), Kogi State University Campus, Anyigba. and NASRDA'S Department of Engineering and Space System, Obasanjo Space Centre, Abuja, Nigeria*

ARTICLE INFO

*Article history:*
Received 10 April 2015
Received in revised form
9 July 2015
Accepted 16 July 2015
Available online 20 July 2015

*Keywords:*
Sunspots
Radio refractivity
Variation
Troposphere and correlation coefficient

ABSTRACT

In this paper, a study of the tropospheric surface refractivity relationship with sunspots number variability on daily scale was carried out in a tropical region in Nigeria. The data was averaged to hourly mean from the initial five minutes update cycle and then to daily mean using spread sheet. The dependence of surface radio refractivity on sunspots number for the period considered in this work was established using linear regression coefficient and the results for Lagos and Anyigba are $R^2=0.019$, $R^2=0.004$, $R^2=0.010$, $R^2=0.000$ and $R^2=0.000$ for 2007, 2008, 2009, 2010 and 2011 and $R^2=0.089$, $R^2=0.027$ and $R^2=0.007$ for 2010, 2011 and 2012 respectively. However, when the spotless days were filtered the regression coefficient was obtained to be $R^2=0.145$, $R^2=0.01261$, $R^2=0.00001$, $R^2=0.0012$ and $R^2=0.062$ for 2007, 2008, 2009, 2010 and 2011 for Lagos and $R^2=0.1155$, $R^2=0.0261$ and $R^2=0.0071$ for 2010, 2011 and 2012 for Anyigba respectively. Meteorological data from 2007 to 2011 was employed for Lagos while meteorological data from 2010 to 2012 was employed for Anyigba. Sunspot data was also obtained from Royal Observatory of Belgium for the period under study. Results obtained show no correlation between Sunspot number and surface refractivity. The sunspot number data was filtered to remove noise due to spotless days. The result obtained after filtering did not show any significant difference.



## 1. Introduction

The study of the surface radio refractivity is necessary, especially in this part of the world, due to the fact that, radio wave propagation difficulty is common in this region, transmission properties in the troposphere cannot be modified; therefore the need for adequate understanding of the response of radio signals to variations in the tropospheric conditions is inevitable, most of the equipment used by the communication and broadcasting industries in Nigeria are not designed based on our local terrain data, the refractivity conditions of our environment are not fully understood. Therefore, the need to know the refractivity conditions of our immediate atmosphere that its dynamic nature plays a major role in our day-to-day communications became necessary. The effects of solar activity in the upper atmosphere particularly on ionospheric total electron content (TEC) has been an established fact but the effects of solar activity on the lower atmosphere particularly tropospheric parameters that determine the radio wave propagation in this medium has generated a controversy whether the effect is a direct or indirect effect. However, there is need to know if there is any other source of influence that affects radio wave propagation in the troposphere other than the known sources within the troposphere.

The objective of this work is to provide its contribution in addressing the tropospheric radiowave propagation response to solar activity specifically sunspots variability. Sunspot number characterizes the solar activity into solar maximum and solar minimum cycles.

Furthermore, the results from this research can be utilised by stakeholders in the communication and broadcasting industries to enhance their electronic gadgets functionality by designing future instruments using our own local terrain data to curb the communication difficulties from these areas of study.

Atmospheric refraction refers to the deviation of light or other electromagnetic wave from a straight line as it passes through the atmosphere due to the variation in air density as a function of altitude. The amount of atmospheric refraction is a function of temperature and pressure as well as humidity. Atmospheric refraction becomes more severe when the atmosphere is not homogenous, when there is turbulence in the air for example.

Refraction is described by Snell's law, which states that for a given pair of medium and a wave travelling with a single frequency, the ratio of the sines of the angle of incidence, $\theta_1$ and

* Correspondence to: Centre for Atmospheric Research (CAR) P. O. Box 380, Kogi State University Campus, Anyigba. Nigeria.
*E-mail address:* najibgal@yahoo.com (N. Yusuf).

http://dx.doi.org/10.1016/j.jastp.2015.07.012
1364-6826/

angle of refraction, $\theta_2$ is equivalent to the ratio of phase velocities ($\nu_1/\nu_2$) in the two medium, [or equivalently, to the opposite ratio of the indices of refraction ($n_2/\ n_1$)]:

$$\sin\ \theta_1/\sin\ \theta_2 = v_1/v_2 = n_2/n_1 \tag{1}$$

In general, the incident wave is partially refracted and partially reflected;

The troposphere is the lowest region in the earth's atmosphere which extends from the earth surface (or water) level up to about (17 km) high. The weather and clouds occur in the troposphere. In the troposphere, temperature generally decreases as altitude increases.

Radio wave propagation in the troposphere is essentially considered to be the propagation inside a non-ionised medium. This is the region where much meteorological phenomena such as wind and rain which depend on pressure, temperature and relative humidity of the air occur. In radio propagation study, the troposphere is considered as a dielectric medium. The variations of the refractive index of the troposphere are small but nonetheless play an important role in radio wave propagation.

The necessity of the knowledge of refractive index in our communications need not be over emphasised, thus, refractive index of the troposphere is an important factor in designing and predicting the performance of the terrestrial radio links. Refractive index variations of the atmosphere affect radio frequencies above 30 MHz, although these effects become significant only at frequencies greater than about 100 MHz especially in the lower atmosphere. The radio refractive index, $n$ of the troposphere deviates slightly from unity due to the polarisability of the constituent molecules by the incident electromagnetic field, and the quantum mechanical resonances at certain frequency bands. While molecular polarisability is independent of frequency up to millimetre waves, molecular resonance is totally frequency dependent, and the refractive index ($n$) tends to be dispersive above $\sim$50 GHz (Bean and Dutton, 1966).

Due to the minute difference between the value of refractive index in the troposphere (about 1.00003) and that of free space ($n$=1.0) it is more convenient to refer to variations in refractive index in terms of a new parameter called refractivity $N$ (Thayer, 1974), which is defined as:

$$N = n - 1 \times 10^{-6} \tag{2}$$

This is the excess over unity of the refractive index expressed in millionths. Thus, at the surface where $n$ = 1.000315, the value of $N$ is 315 N-unit (ITU-R P.453-10).

Previous work done on the same subject proved that refractivity value over Nigeria increases from about 270N-units north to about 390N-units in the south (Ayantunji and Okeke, 2011). Also cited by Igwe and Adimula (2009), the tropospheric radio wave propagation is to a very large extent influenced by the structure of the refractive index of the atmosphere (Willoughby, 1996).

Sunspots are regions of exceptionally intense magnetic field of several thousand gauss located in the two hemispheres of the sun. This distribution makes the sun to have complex distribution of magnetic fields. The distribution can be described as a complicated distribution of weak extensive unipolar regions and small areas of intense magnetic fields (sunspots) of opposite polarities (the bipolar regions).

The sunspot activity is a temporal event (almost periodical) having an approximately eleven years period. It is associated with strong ultraviolet radiation known to influence several terrestrial climatic parameters including the global average temperature (Lassen and Friis-Christensen, 1995).

Approximately, every 11 years the Sun moves through a period of fewer and smaller sunspots termed solar minimum, followed by a period of larger and more sunspots termed solar maximum (Smith and Marsden, 2003; Moeketsi, 2004).

The direct and indirect effects considered together point to a dominant role of solar activity in climate change (Weather parameters). Accordingly, many of the recent publications in the field of solar–terrestrial relationships range the Sun's contribution between 50% and 100% (Friis-Christensen and Lassen, 1991; Lau and Weng, 1995; Svensmark and Friis-Christensen, 1997; Cliver et al., 1998; Labitzke, 1999).

Rudolph Wolf devises a formula for the calculation of sunspot number in 1848:

$$S_n = k\ (10g + s) \tag{3}$$

(Wolf, 1877)

where $S_n$ is the sunspot number; $g$ is the number of sunspot groups on the solar disk; $s$ is the total number of individual spots in all the groups; and $k$ is a variable scaling factor (usually $<1$) that accounts for observing conditions and the type of telescope (binoculars, space telescopes, etc.). Scientists combine data from lots of observations each with its own $k$ factor to arrive at a daily value.

The scope of the study is constrained to Lagos and Anyigba. Lagos State South-West Nigeria is located at latitude 6° 27' N, longitude 5° 12' E and at an altitude of 7 m above sea level, chosen because of the nature of Lagos geographical characteristics of being a coastal, tropical monsoon, low altitude location and more so the existent of an Atlantic Ocean and North-Central Anyigba (Kogi State) located at latitude 7° 15' N, longitude 7° 11' E and an altitude of 420 m above the sea level was chosen because it is entirely different both in vegetation and geography from Lagos.

## 2. Methods

The first set of data for the sunspot numbers were obtained from the Solar Influence Data Centre, Royal Observatory Belgium, data catalogue at twenty-four hours interval local time. The daily variations of sunspot numbers for each year were considered.

The second sets of data were obtained from the Centre for Atmospheric Research, Anyigba. The fixed measuring method by an automatic weather station installed at ground/surface level at an average height of 3 m is employed in this study. In-situ measurement of meteorological parameters of temperature, humidity and pressure from each station were employed. The data were collected at the surface at Anyigba Kogi state, North-central Nigeria from July 2010 to December 2012 (i.e. 30 months), Lagos state, South-western Nigeria from October 2007 to July 2011 (i.e. 46 months). A total of seventy six (76) months data were used. The records cover 24 hours each day from 00 h to 2300 h local time at five minutes update cycle. The values of temperature in degree Celsius, humidity in percentage value and pressure in mbar is extracted from the data collected for the determination of tropospheric surface radio refractivity, $N$ using International Telecommunication Union, ITU, Model.

The daily variations $N$ were computed first by averaging the five minutes interval data into hourly values then into daily values for each of the station/locations considered.

The regression coefficient for the relationship of surface radio refractivity and sunspot number were presented. This is achieved after the data has been filtered to make sure that the data is in a good shape and agree with the literature. The daily variations of $N$ were considered.

Finally, the correlation analysis between the variations of daily sunspot numbers and the corresponding variations of daily surface