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REDUCED-TO-SEA-LEVEL REFRACTIVITY IN MINNA, CENTRAL NIGERIA

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Abstract

Knowledge of the temporal and spatial variations of surface refractivity N_s is important for good planning of terrestrial radio links over a region. Reduced-to-sea-level refractivity N_o removes elevation–dependence of N_s and enhances comparison and/or contouring of values for different stations. Earlier efforts in this regard in the Nigerian context could not explore diurnal trend due to lack of data. There is need to sustain the effort in the light of climate change and to establish the mean diurnal, seasonal and climatic trends in Nigeria. This paper highlights preliminary results of N_o obtained in Minna based on in-situ measurements of the relevant atmospheric parameters between 2008 and 2009.

Keywords: Reduced-to-Sea Level Refractivity, Air Temperature, Pressure and Vapour Pressure, Scale Height.

Introduction

Knowledge of the temporal and spatial variations of surface refractivity N_s is important for good planning of terrestrial radio links over a region. Reduced-to-sea-level refractivity N_o values remove elevation–dependence of N_s and enhance comparison and/or contouring of values for different stations. Earlier efforts in this regard [e.g. Owolabi and Williams (1970); Kolawole (1980)] must be sustained in the light of climate change and to establish the mean diurnal and seasonal trends in Nigeria.

The field strength of radio signals at VHF and higher frequency bands generally vary in the troposphere due to variations in the refractivity conditions of the air, which in turn depend on variations in temperature, pressure and water vapour pressure. These variations show climatic, seasonal and diurnal trends. In tropical continental climatic region (5^o-20^o latitude) N_o is much higher during the rainy season than during the dry season and has annual range of about 70-110 N-units (Ajayi, 1997; Kolawole and Owonubi, 1982). Refractivity variations are more pronounced in tropical climates and diurnal variations have been observed on VHF paths in tropical countries like Nigeria, Ghana and Kuwait (Owolabi and Williams, 1970; Oyedum and Gambo, 1994). Surface refractivity is also known to generally correlate well with the parameter dN representing the refractivity gradient in the first one kilometer of height above the Earth's surface (Hall, 1979), as well as in Nigeria (Adebanjo, 1977; Kolawole, 1981). More recently Falodun and Ajewole (2006) have reported considerable diurnal variations of refractive modulus at 100 m altitude in Nigeria.

Reduced-to-sea level refractivity N_o is given by (Bean and Dutton, 1968):

$$N_o = N_s \exp(h/H) \quad (1)$$

Where N_s= surface refractivity (N-units), h= station elevation (km) and H= scale height (km). The surface refractivity N_s is given by (Smith and Weintraub, 1953):

$$N = (77.6/T)(P + 4810e/T) \quad (2)$$

Where T= surface air temperature (K), P= surface air pressure (hPa) and e= water vapour partial pressure (hPa). The water vapour partial pressure is given by (Hall, 1979):

$$e = 6.11 exp\left[\frac{19.7t_D}{(t_D+273)}\right] \quad (3)$$

Where t_D=dew point temperature in ^oC. Studies show that the scale height has considerable seasonal and climatic variations (Kolawole, 1980; Oyedum, 2008)

Acquisition of Atmospheric Data

The data used for this study were collected with Davis instrument (Wireless Vantage Pro2 Plus) attached to a mast of the Nigerian Television Authority in Minna ($09^0$37'N; $06^0$32'E). The station elevation is about 249 m above sea level. The equipment has an Integrated Sensor Suite (ISS) which measures various atmospheric parameters such as temperature, pressure, relative humidity, dew point, etc and logs the values in a console kept within the NTA premises. The data is transmitted every 30 minutes from the ISS wireless transmitter to the radio frequency receiver attached to the console. Data logged in the console are downloaded into the computer routinely for analysis. Two Davis instruments are mounted on the NTA mast at surface level and at 100 m level, but only data from surface level is used for this report which covers the period January 2008 to December 2009.

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Data Analysis and Results

Equations 1, 2 and 3 were used to compute the following parameters:

- Mean hourly values of N_o
- Mean monthly values of N_o
- Mean monthly ranges of N_o

Aspects of the analysis were extended to the set of similar data obtained at Nsukka ($06^0$56'N; $07^0$23'E) in the southeastern part of Nigeria for comparison as well as to highlight the climatic tendency.

Results

Diurnal Trend

The mean hourly values of reduced-to-sea-level refractivity N_o shows a significant diurnal trend during dry season. Peak values occur in the night around 10-11 pm and thereafter decreases towards dawn, reaching minimum values after mid-day around 1-2 pm. This trend of mid-day minimum and midnight peak may be attributed to high sensitivity of refractivity to water vapour partial pressure. Increased surface moisture at night is due to lack of insolation and radiative cooling of the surface, while insolation in daytime causes some of the surface-based water vapour to be heated, expand and rise to higher altitudes thereby decreasing the surface moisture. The hourly N_o profile for the month of January which represents a typical dry season month in Nigeria is shown in Figure 1. Maximum value of N_o is about 309 N/km while the minimum is about 305 N/km. A similar diurnal trend is observed in Minna in September 2008 (Figure 2) and in September 2009 (Figure 3) as well as in September 2006 in Nsukka (Figure 4). However, the N_o values are higher in wet season, with minimum values between 373 and 374 while maximum values are between 376 and 378 in 2008; while in 2009 minimum and maximum values are respectively greater than 386 and 392. The higher wet season N_o values result from the generally higher moisture levels prevailing during the season. Figure 2 and Figure 3 show N_o values in Minna for the month of September which is a typical rainy season month in Nigeria. Values for Nsukka are considerably higher than those of Minna, which reflects the climatic difference, as greater surface moisture prevails at Nsukka.

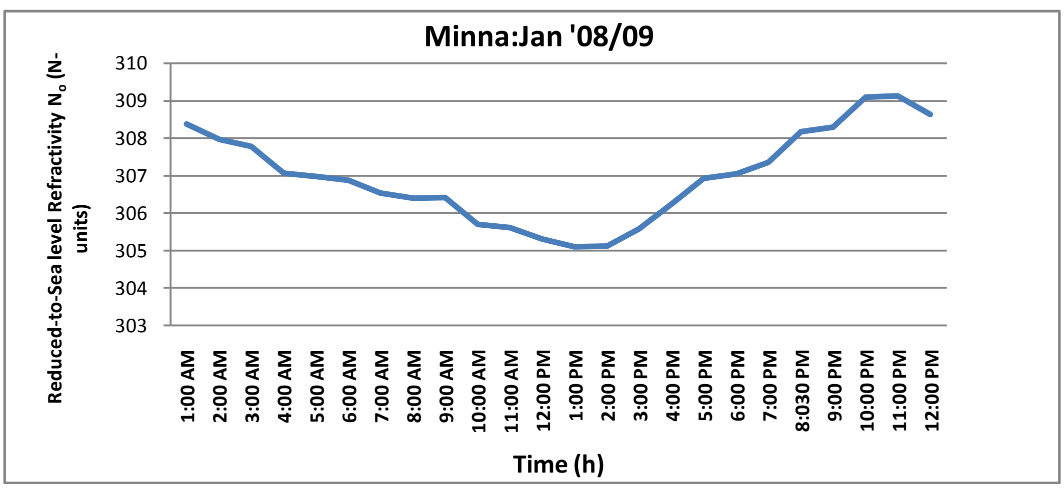

Fig. 1: Two-Year Mean Diurnal N_o in Minna for a Typical Dry Season Month

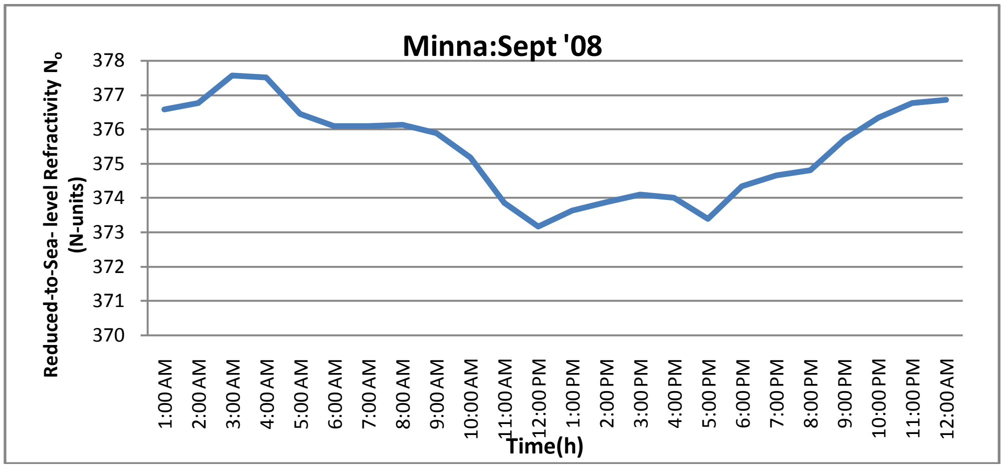

Fig. 2: Annual Mean Diurnal N_o in Minna for a Typical Wet Season Month

However, in September 2009 the wet season diurnal profile minimum values slightly shifted toward early evening, as well as higher values compared to the preceding year. This may be attributed to unusually heavy rains experienced in Minna in 2009 as a result of global warming and climate change. Consequently, the mean wet season diurnal trend of N_o in Minna during the period 2008-2009 (Figure 5) is significantly affected by the heavy rainfall in 2009; and further data collection is required to establish a more reliable wet season diurnal trend.

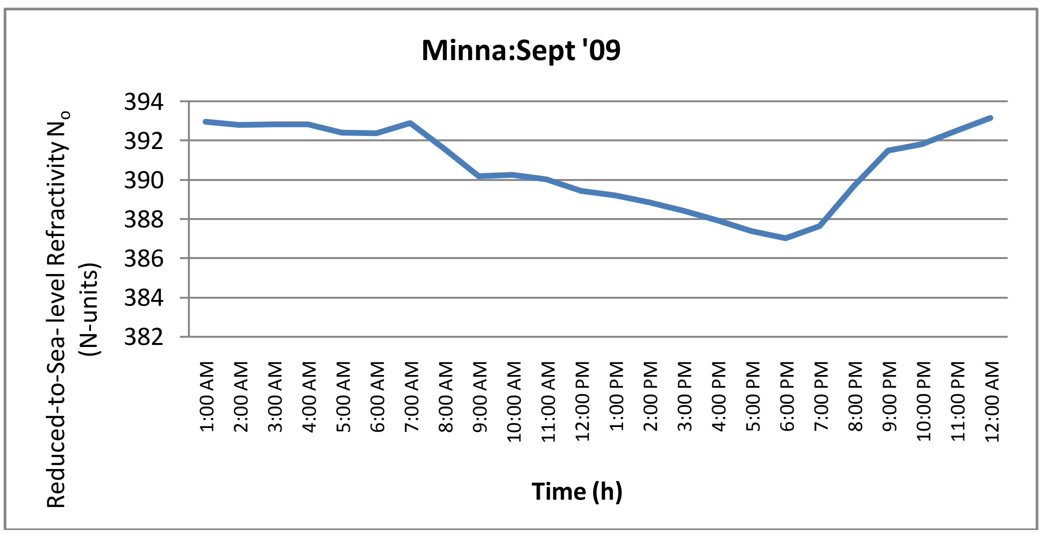

Fig. 3: Annual Mean Diurnal N_o in Minna for a Typical Wet Season Month

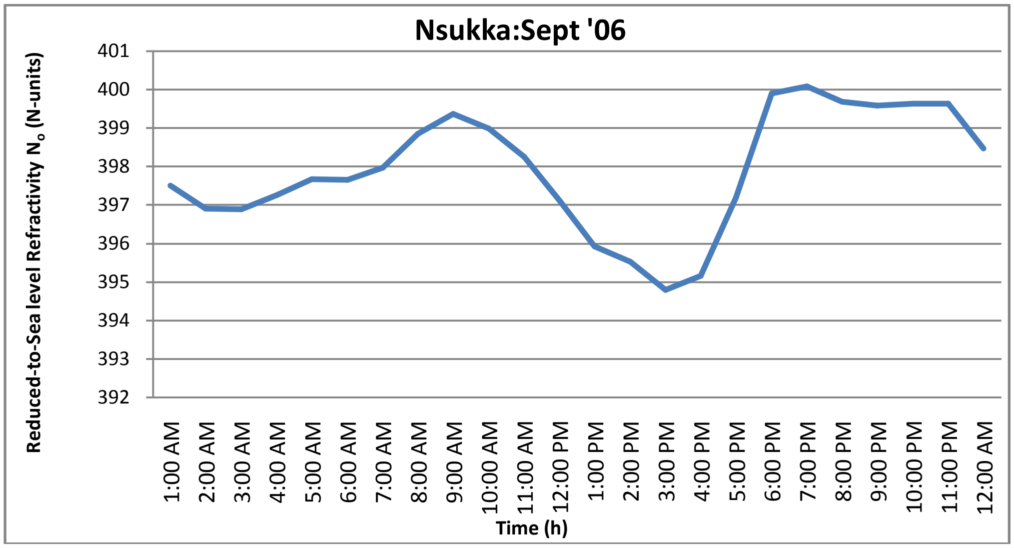

Fig. 4: Annual Mean Diurnal N_o in Nsukka for a Typical Wet Season Month

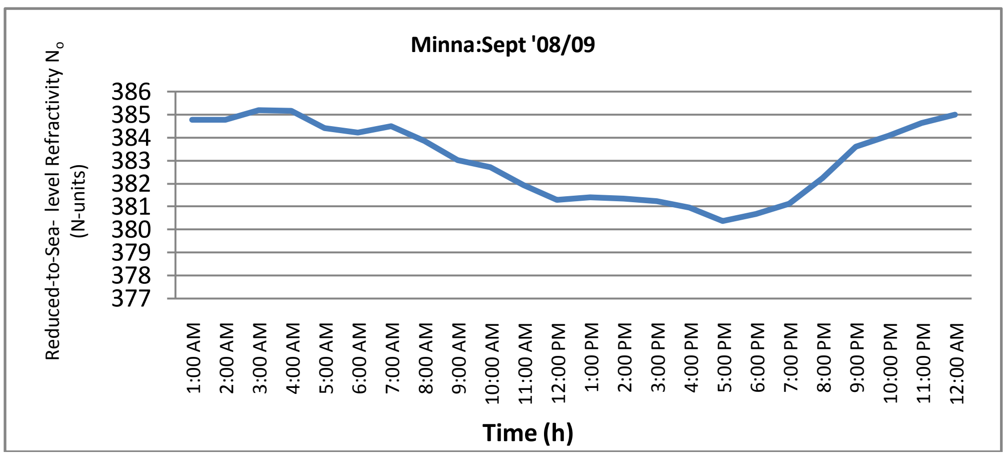

Fig.5: Two-Year Mean Diurnal N_o in Minna for a Typical Wet Season Month

Seasonal Trend and Variability of N_o

Monthly averages of N_o were also investigated to explore the seasonal trend and seasonal variability. The result shows a clear seasonal trend with higher N_o values in wet season and lower values in dry season (Fig. 6). Maximum values are slightly higher than 400 N-units during the wet season and slightly lower in the dry season, while the minimum values fall below 300 N-units during the season. Mean N_o values are between 300 and 400 N-units.

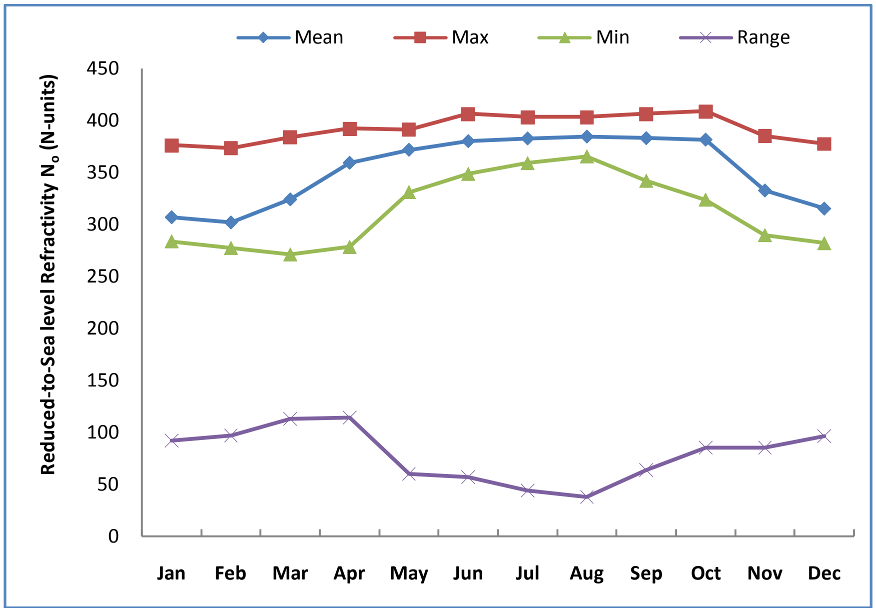

Fig. 6: Mean Monthly N_o in Minna

Maximum range (variability) of N_o occurs in dry season while minimum range occurs in wet season; least variability occurs in the month of August. Minimum annual range of 38 and maximum annual range of 114 are in agreement with 70- 110 for Tropical Continental Africa reported by Ajayi (1997). The observed seasonal trend is due to the yearly N-S migration of the Inter Tropical Discontinuity (ITD). The northward movement of the low pressure belt brings moisture from the Atlantic Ocean to the hinterland, reaching about 25^{o}N around September when the southward movement also begins. The southward migration brings dry, cold air (sometimes characterized by Harmattan dust haze from the Sahara Desert) and reaches its southern limits around about 4^{o}N in January. The observed seasonal profile of reduced-to-sea level refractivity in Minna is thus largely a reflection of the atmospheric moisture level in the lower troposphere in line with the N-S migration of the ITD.

Conclusion

Preliminary results based on in-situ measurement of 2-year atmospheric data show that surface refractivity has both diurnal and seasonal tendency. Although a clear dry season diurnal trend of N_o has appeared from the preliminary results, a more reliable trend in wet season is yet to emerge due to climate change effects, and additional data acquisition is required to obtain desired long-term results. The seasonal trend is also clear as well as the climatic tendency which is discernible from higher N_o values observed for Nsukka in southeastern Nigeria, compared to corresponding lower values in Minna in north-central Nigeria. The observed diurnal and seasonal variations of surface refractivity have important implications on radio propagation. Terrestrial relay links at VHF and higher frequency bands which abound in Nigeria may be particularly affected (Owolabi and Williams, 1970; Oyedum and Gambo, 1994).

Appreciation

This research has been made possible by contributions from certain individuals who have directly or indirectly enhanced the effort. However, the authors particularly wish to acknowledge and commend the erudite contributions of Professors I.E. Owolabi and L.B. Kolawole in this field of research in the Nigerian context. Recent inputs by Professors M.O. Ajewole and P.N. Okeke towards sustaining the efforts are also acknowledged and commended. It is our hope that the Nigerian Government will sooner than later renew Radiosonde acquisition of upper air data in Lagos, Minna and Kano to complement and sustain the current drive.

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